LSST DESC Science Roadmap

Version v1.4

Change Record

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LSST DESC Science Roadmap

Contents

1 Executive Summary

The Large Synoptic Survey Telescope (LSST) Dark Energy Science Collaboration (DESC) was established in June 2012 with the goal of developing and executing a high-level plan for the study of dark energy and associated fundamental physics of the Universe with LSST data. The LSST Project will create "prompt" (nightly alerts) and "data release" (annual catalog) data products that meet Project requirements, but will not perform science analyses with those datasets. The DESC is focused on undertaking a precise and timely analysis of the LSST Project data to optimally extract the dark sector science and create "user-generated" catalogs and analysis products for public release.

This document, the *Science Roadmap (SRM)*, lays out the mission-critical "operations" deliverables that must be completed in order for the collaboration to have its simulation, processing and analysis pipelines and infrastructure, and its team coordination, in place so as to successfully analyze the first year of LSST data for dark energy science. This includes work to build and validate a suite of collaboration-wide software to perform integrated cosmological analyses using LSST's key cosmological probes. This document also outlines the research needed to fully understand sources of systematic uncertainties in dark energy probes due to instrumental, physical and astrophysical effects, and to develop algorithms for use in the collaboration's data analysis.

The SRM is structured around the 12 working groups in the Collaboration: those focused on primary cosmological probes (weak and strong gravitational lensing, large scale structure [galaxy clustering and baryonic acoustic oscillations], galaxy clusters, and Type 1a supernovae) and those providing essential inputs to enable the primary probe analyses. For each, the SRM lays out a set of key research and development projects, and the activities they involve. The deliverables that make up the simulation, processing and analysis pipelines and related software infrastructure, are organized into key products which the working groups own.

The SRM focuses on the period prior to the LSST survey start, 2016-2022. An incremental, data challenge-driven approach is used to build the necessary analysis infrastructure and team coordination. Three Data Challenges (DC) of increasing scope and complexity, referred to as DC1, DC2, and DC3, will be used to test and validate the tools and software infrastructure that will be used to analyze the LSST survey data. DC3 will involve a collaboration-wide, fully-coordinated analysis of a dataset that has sufficient scale and complexity to ready the collaboration for the first year of LSST data. The data challenges will involve simulated datasets, to provide a controlled environment for testing systematic effects, and code validation. External precursor datasets, including LSST Project-selected verification datasets, and then LSST early commissioning and science verification data will also be used to test the DESC pipelines on real data.

The initial version (v1.0) of this SRM was developed from June through November 2015 through a collaboration-wide process based upon working group discussions and collective authorship of the sections. Since then, the SRM has been updated regularly and re-versioned approximately annually, as the working groups' plans have evolved under a "rolling wave" development model. Points of contact – individuals who played major roles in coordinating and authoring each section and can provide further details on SRM plans – are listed in Section 2.2.

Acronym Definitions

API	Application Programming Interface
BAO	Baryon Acoustic Oscillations
CI	Computing Infrastructure (one of the DESC computing working groups)
CL	Galaxy Clusters (one of the DESC analysis working groups)
CMB	Cosmic Microwave Background
ComCam	LSST Commissioning Camera
CPU	Central Processing Unit
CS	Cosmological Simulations (one of the DESC computing working groups)
DC	Data Challenge (see section 2 for details)
DDF	Deep-Drilling Field (deeper regions of observation within the LSST survey footprint)
DES	Dark Energy Survey
DESC	Dark Energy Science Collaboration
DESI	Dark Energy Spectroscopic Instrument
DM	LSST Project Data Management
DM Stack	The suite of LSST Project data processing software
DOE	U.S. Department of Energy
DP	Data Product
DR	Data Release (typically referring to LSST's data releases once the survey starts)
FY	U.S. federal financial year (e.g., FY18 started in October 2017)
HPC	High Performance Computing
HST	Hubble Space Telescope
IFU	Integral Field Unit
ISW	Integrated Sachs-Wolfe
JWST	James Webb Space Telescope
KP	Key Project (one of the main areas of work within a DESC working group)
LSS	Large Scale Structure (one of the DESC analysis working groups)
LSST	Large Synoptic Survey Telescope
MAF	Metrics Analysis Framework (containing tools to characterize the LSST survey and its scientific performance for various observational strategies)
NERSC	National Energy Research Scientific Computing Center
OSTF	Observing Strategy Task Force
PB	PetaByte

PC	Photometric Corrections (one of the DESC technical working groups)
PFS	Prime-Focus Spectrograph
PSF	Point-Spread Function
PZ	Photometric Redshifts (one of the DESC analysis working groups)
R&D	Research & Development, or basic research activities (as opposed to work on building infrastructure)
RQ	Requirements
SA or SAWG	Sensor Anomalies (one of the DESC technical working groups)
SED	Spectral Energy Distribution
SFH	Star-Formation History
SFR	Star-Formation Rate
SL	Strong Lensing (one of the DESC analysis working groups)
SN	Supernovae (one of the DESC analysis working groups)
SRD	Science Requirements Document (either for the LSST project or the DESC, depending on context)
SSim	Survey Simulations (one of the DESC computing working groups)
SV	Science Verification
SW	Software
SZ	Sunyaev-Zeldovich
TJP	Theory and Joint Probes (one of the DESC analysis working groups)
VA	Validation
WFD	Wide-Fast-Deep (a term used to describe the basic observational strategy of the main LSST survey)
WFIRST	Wide-Field Infrared Survey Telescope
WG	Working Group
WL	Weak Gravitational Lensing (one of the DESC analysis working groups)

2 Introduction

2.1 Overview of the Science Roadmap

The Dark Energy Science Collaboration: The Large Synoptic Survey Telescope (LSST) Dark Energy Science Collaboration (DESC) was established in June 2012 with the goal of developing and executing a high-level plan for the study of dark energy and associated fundamental physics of the Universe with LSST data. The DESC is separate from, but works closely with, the LSST Project. While the LSST Project is responsible for generating and processing the petabyte-scale imaging data to create science-ready catalogs (not to mention constructing LSST itself), the science analysis of these catalogs falls to the community. The DESC is one aspect of this community effort, focused principally on the use of LSST to study observable signatures of "dark sector" physics, including dark energy, dark matter, neutrinos, and signatures of inflation.

The Collaboration has grown significantly, with over 860 members (including 194 voting Full Members) as of January 2019, coming from 15 countries. The DESC's science activities are structured and overseen through its Governance Plan. Work is distributed across twelve working groups organized under Analysis, Computing and Simulation, and Technical Coordinators, who in turn report to the Spokesperson.

Five working groups each focus on a single cosmological probe: gravitational weak lensing (WL), large-scale structure (LSS), galaxy clusters (CL), strong lensing (SL), and Type Ia supernovae (SN). The Theory/Joint Probes (TJP) working group focuses on leveraging the complementarity of multiple cosmological probes, both those internal to LSST and from other experiments, to constrain dark sector theory and to mitigate systematics.

A second set of working groups aims to ensure that DESC can maximize the cosmological science extracted from LSST data: cosmological simulations (CS), survey simulations (SSim), characterization of LSST sensors and their anomalies (SA), photometric redshift estimation (PZ), photometric calibration (PC), and computing and infrastructure (CI) all play important roles. They provide critical interfaces to the LSST Project Hardware and Data Management (DM) development efforts, are responsible for the computing model and hardware infrastructure, and characterize important sources of systematic contamination.

Finally, there are three observing-oriented task forces that incorporate efforts from all DESC probes and several other working groups such as PZ: the Commissioning Task Force (CTF), Observing Strategy Task Force (OSTF), and the Follow-up Task Force (FTF). The first two of these provide an additional connection to the LSST Project.

The role of the Science Roadmap: The DESC produced a White Paper at its inception[1] that articulated the need for the Collaboration within the cosmological community and identified the high priority tasks it would tackle in its first three years. The progress achieved within that White Paper's framework has positioned the collaboration well to embark on the next stage of this journey: the path to science at LSST first light.

This document, the *Science Roadmap (SRM)*, presents the next step in the DESC's planning. The primary goals of the SRM are to outline the critical research and development activities needed to fully understand the various anticipated sources of systematic uncertainty in dark energy probes (due to both observational and astrophysical effects), incorporate these effects with the required fidelity in simulations at all levels, and build and validate (with simulations and real precursor data) the software pipelines and infrastructure for the key cosmological analyses using the first year of LSST data.

The primary audience for this document is the Collaboration members themselves: the SRM constitutes the primary technical planning document for Collaboration-wide science priorities and activities. It is intended to provide details of high-priority operations deliverables and research activities which members (existing or new) can sign up to contribute to, as well as presenting the broader context for those priorities. All of the DESC working groups have worked to identify the high-priority activities for their group to achieve SRM goals (q.v. below).

In April 2017 the LSST DESC's operations plan was reviewed by the US Department of Energy Office of High Energy Physics (OHEP), and subsequently became an operating experiment. The planned operations tasks include the development of mission-critical software and datasets; these key products are defined in Section 5 and Section 6 of this document, with a summary in Section 7. This deliverable list provides the majority of a quasi-work breakdown structure (WBS) for DESC operations, along with activities relating to the logistical support of the collaboration's interactions and its dataset production. This quasi-WBS allows us to assess the work needed to be done by specialist operations staff, along side the contributions needed from the wider collaboration. The organization of these operations specialists is described in the LSST DESC Operations Management Plan (OMP), while their various role descriptions and staffing levels (both actual and planned) are given in the LSST DESC Operations Prioritization Plan. (Note to reviewers: the OMP is the management section of the Experimental Operations Plan.) This detailed operations plan was reviewed by OHEP in May 2018.

The SRM is intended to be a living, evolving text. Versioned, publicly available releases of the Science Roadmap will be produced approximately annually following periodic review by the DESC Management Team and Working Group Conveners, with non-leadership review

[1] http://arxiv.org/abs/1211.0310

requests as needed. The SRM GitHub repository will allow dynamic SRM updates, on an ongoing basis, between formal versioned releases.

The Collaboration goals driving the SRM: The scale and complexity of the preparations ahead are substantial and will require:

- continued construction and validation of the collaboration simulation, (re-)processing, and analysis pipelines that will perform world-class cosmological analyses with the LSST data using the five main probes;
- characterization of instrumental, atmospheric, Galactic and extragalactic systematic contaminants to the level necessary to achieve the collaboration's dark sector science goals;
- implementation and utilization of a computing infrastructure that meets the DESC data re-processing requirements and efficiently interfaces with the prompt and data release products[2] from the Project;
- effective utilization of external datasets and incorporation of lessons learned from precursor surveys;
- determination of quantitative requirements on, and use of corollary data from, other facilities (e.g., spectroscopy, multi-wavelength data and complementary, concurrent photometric survey data), as highlighted in a recent NRC report (Elmegreen 2015); and
- the development of the capabilities and coordination of the DESC team, including the training of the next generation of DESC researchers and leaders.

Prioritization of these activities will be driven by our understanding of the key limiting systematic uncertainties that must be reduced/mitigated in order to achieve our scientific goals. The DESC's Science Requirements Document places requirements on our level of systematics control for elements of the analysis that are under our influence (beyond those that are already described by the LSST Project's SRD). How close we are to meeting those requirements will determine some elements of how the DESC's work is prioritized, and/or how it is carried out: are we close enough that we can expect incremental improvements of existing algorithms to be sufficient, or might totally new approaches be needed? The initial DESC SRD version includes

[2]Throughout the SRM, we will refer to the standard classification of LSST data product categories. The LSST alert production (AP) pipeline will perform "prompt" data processing, generating products continuously every observing night, including alerts to objects with changes in brightness or position. The LSST data release production (DRP) data products are those made available by LSST Project annually, including images and measurements of positions, fluxes, shapes and variability information. "User-generated" products are those created by the community to achieve their LSST science goals. See Ivezic et al. (2008) and LSST document LSE-163 for details.

requirements on several pipelines: SHEARMEASUREMENTPIPE (control of redshift-dependent weak lensing shear calibration), PZCALIBRATE (understanding of photometric redshift error distributions), WLNULLTEST (control of systematic biases in PSF models and understanding of stellar contamination), and several of the Photometric Corrections working group R&D plans and pipelines (control of several different issues that affect photometric calibration and its impact on supernova cosmology). Future versions of the SRM will include text highlighting key issues from the DESC SRD and commenting on how they affect the prioritization of work and evaluation of the relevant pipelines in more detail.

An incremental, data challenge-driven approach: To be ready for the first year of LSST data, we will incrementally build the necessary analysis infrastructure and team coordination. To this end, a central component of the SRM is a succession of three Data Challenges of increasing scope and complexity (referred to as DC1, DC2, and DC3). The Data Challenges are collaboration-centered activities that will use tailored simulated and real datasets to test and validate the tools and software infrastructure that will be used to analyze the LSST survey data. Activities in DC1 will be largely tailored to individual working groups' needs. DC2 will feature increased sophistication and more cross-working group analyses. By DC3, we intend to have progressed to a collaboration-wide, fully-coordinated data challenge, which will analyze data products with complexity close to what we would expect from the first year of LSST data.

We will use DC3 to prepare for our re-processing and analysis of the LSST data, first during commissioning and then during the survey. DESC will provide inputs into the design of commissioning surveys in response to solicitations from the Project, and then make full use of data from the LSST Commissioning Camera (ComCam) instrument, when available (scheduled for late 2020), as well as the LSST Science Validation (SV) data (from the full LSST Camera), to test DESC analysis pipelines and their interface to LSST DM products. By processing and analyzing DC3 mock data in advance of and in parallel with the ComCam data, we aim to get our pipelines set up and working at the appropriate scale to enable us to learn as much as possible from the SV commissioning data. More information on the Data Challenges and on Project Datasets is given in Section 6.1 and Section 6.2, respectively.

Each Data Challenge involves assessing, studying, and validating the required fidelity of survey simulation tools, producing the simulated data sets, and utilizing the datasets to validate codes and isolate specific systematic effects in a controlled environment. The goal of the increasing complexity of the data challenges is to test our ability to mitigate increasingly subtle systematics together as well as in isolation[3]. The goal of the increasing scope is two-fold: first, to check that our systematics floor is lowering appropriately towards where it needs to be in

[3]While the simulated datasets contain many effects together, it is often possible to isolate individual ones by using the truth tables and/or by carrying out systematic tests that are particularly sensitive to just a single effect.

order to handle the LSST data, which typically requires a substantial data volume; and second, to develop a workflow that involves running our pipelines (nearly) at LSST scale, as will be needed when there is real LSST data (FY23).

At that time, we anticipate that building systematic error budgets will still require some reprocessing of the LSST images, at the level of ~ 10 runs through $\sim 10\%$ of the dataset, even when running our analysis pipelines on the LSST release data for the main scientific results. Hence, in order to be prepared for LSST data both in terms of data volume and in terms of systematics control, the increase in both scope and complexity of the data challenges to something on the order of 10% of the first year LSST dataset is essential. Taking the multiple re-processings into account, we expect to need to be able to work with 300,000 visit images by the start of the survey at the start of FY2023. We aim to analyze the re-process and analyze the SV data in the same way as we will the Year 1 survey data: the goal of the data challenges is to realize a fully-functional re-processing and analysis system by the time of the SV data release, that can demonstrate performance at the appropriate scale such that we are ready for the Year 1 data.

While the DCs will be a driving component of the collaboration work, to be clear, they will not represent the full scope of work within the pre-commissioning period. DESC activities will also involve software development and theoretical research that does not wholly fall into the DC framework. They will also utilize the availability of precursor datasets as testbeds to develop, refine and validate the software and tools. In relation to this, we expect to fully leverage any LSST Project-processed external precursor datasets that the LSST Project makes available during the data challenge era. DESC re-processing of precursor datasets selected by the Project will help us make further early connections with the Project DM processing pipelines.

Figure 2.1.1 gives the DESC data challenge schedule, from the start of DC1 in FY16 through to the end of SV analysis in FY22.

Based on the experience gained in DC1, the schedule for DC2 and DC3 allows ample to learn from the previous era's results, with longer requirements (RQ) and analysis phases than in the first data challenge. The challenge datasets drive development of the analysis pipelines, providing a validation dataset against which the code can be continuously tested against. The data production phases in DC2 and DC3 are shorter than in DC1. This reflects the pathfinding work done in DC1, but it also captures the understanding that the DC2 and DC3 RQ phases are when the simulation and processing pipelines can be upgraded in parallel with the design work needed for the ensuing production phase. In DC3, the focus will be on SV data readiness. We note that the analyses of the ComCam and DC3 simulated data are likely to be carried out by different groups, with fairly different goals given the nature of those datasets. The ComCam

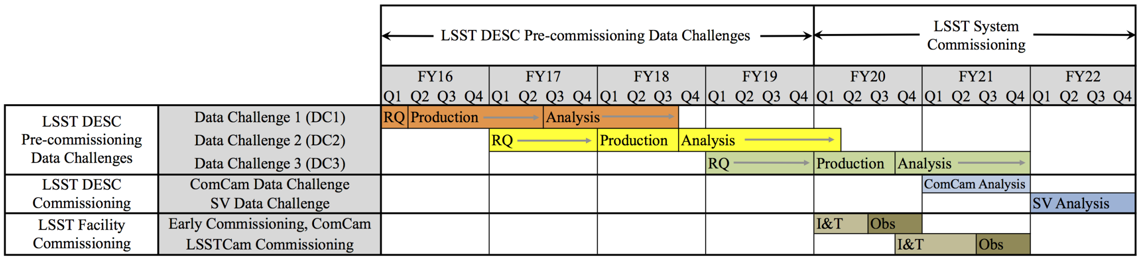

Figure 2.1.1: A timeline for key activities in DESC through US Fiscal Year 2022. Filled in sections represent work being completed by the end of that fiscal year quarter (e.g. work in Q3 would be completed by end of June). We are holding three simulated Data Challenges (DC1-DC3) to support the incremental creation and validation of the data analysis and simulation pipelines. The timeline shows projected timeframes for setting the simulation requirements, data production and data analysis in each challenge. While the DCs will be a driving component of the collaboration work, to be clear, they will not represent the full scope of work within the pre-commissioning period, which will also include some software development and theoretical research that does not fall into the DC framework. DESC activities will also utilize precursor datasets, as available, to develop, refine and validate the software and tools. Key examples of these will be data from the multi-stage commissioning activities, starting with ComCam data expected to be available in Fall 2020 through to the full instrument integration Science Validation (SV) survey data in Fall 2021.

analysis will inform the further evolution of the processing and analysis pipelines used on the DC3 data, and may lead to updates in our understanding of what is needed to prepare for SV data. The SV dataset will enable the first cosmology analysis by the DESC pipelines, and will lead to a well-tested suite of survey-ready simulation, processing and analysis tools.

Table 2.1.1 tabulates the milestones along the road to LSST DESC data readiness, laying out what we aim to have produced by the end of each of the data challenge phases shown in Figure 2.1.1.

The scope of the SRM: We emphasize that the set of key products and deliverables, key projects and activities described in the SRM is not meant to be an exhaustive list of all work to be carried out within each working group. Rather, the SRM is focused on those mission-critical activities *essential to develop, build and validate the pipelines and infrastructure to undertake the core DESC cosmological analyses*. We make a distinction between the research and development needed to design the DESC algorithms (some of which is speculative or aspirational by nature), and the construction work needed to implement them as production pipelines, execute them at appropriate scale with the necessary software infrastructure, and test them using chal-

Table 2.1.1: LSST DESC Milestones FY16–FY22.

Phase	Milestone	Completion Date
DC1 RQ	Specifications for the `Twinkles` pathfinder and `DC1 Phosim Deep` survey datasets.	12/31/15
DC1 Production	Prototype image simulation and processing pipelines. Initial internal data release.	03/31/17
DC1 Analysis	DC1 validation and analysis papers. Final internal data release.	06/30/18
DC2 RQ	Specifications for the `DC2` dataset. Upgraded image simulation pipeline.	09/30/17
DC2 Production	Image simulation pipeline validation. Validated DESC data release processing (DRP) pipeline. Initial internal data release.	06/30/18
DC2 Analysis	Final internal data release. Prototype analysis pipelines, with validation. DC2 validation and analysis papers. Public data release.	12/31/19
DC3 RQ	Specifications for the DC3 dataset(s). Upgraded and validated image simulation and DESC DRP pipelines. Catalog emulation pipeline.	09/30/19
DC3 Production	Initial internal data release.	06/30/20
DC3 Analysis	Final internal data release. SV-ready, validated analysis pipelines. DC3 validation and analysis papers. Public data release.	09/30/21
ComCam Analysis	ComCam-calibrated image simulation and DESC DRP pipelines. ComCam analysis papers.	09/30/21
SV Analysis	SV-calibrated image simulation, DESC DRP, and analysis pipelines. SV analysis papers.	09/30/22

lenge datasets. This construction work makes up the majority of the collaboration's operations activity in the period FY16–FY22.

The level of detail provided is intended to be sufficient to: **1)** coordinate and provide an integrated timeline for activities across the working groups and **2)** determine the scope of operations support (for both computing resources and personnel) needed to enable the DESC's science activities. A complete breakdown of activities to the task level is left to a more dynamic progress tracking system, based on the repositories used by the working groups for developing the tools and analyses, and the collaboration-wide "confluence" wiki. Detailed implementation plans for, and assignment of individual members to lead, specific collaboration activities are outside the scope of the SRM and fall under the purview of the working groups.

The SRM process: The first version of the SRM was developed from June through October 2015 through a collaboration-wide process based upon working group discussions and collective authorship of the science probe and enabling sections. Reviews of the initial document were conducted by independent working members, collaboration leadership, and more than a dozen red team reviewers.

Since then, the SRM has been maintained as a "living document," with working groups submitting change requests to be approved by their coordinators. A concerted effort to evolve the SRM further was undertaken in summer 2017, with the goal of accurately defining the working group projects for the DC2 era, based on their DC1 era experience.

A list of points of contact – those individuals who played major roles in coordinating and authoring each section and can provide further details on SRM plans – is provided in Section 2.2.

Organization of the SRM: this Section 2 provides an overview of the primary objectives and overall structure of the SRM. Section 3 contains descriptions of the key analysis steps involved in each of the individual cosmological probe analyses, and in the joint analysis. Section 4 describes how these analyses are enabled by the technical, computing and simulation activities of the other working groups. The simulation, processing and analysis software pipelines that will carry out this work are described in Section 5, organized into a set of "Key Products," each with a set of "Deliverables." Likewise, the challenge datasets that will be used to drive pipeline development and enable their validation are described in Section 6. The list of all the Key Products and Deliverables that the DESC needs to develop, operate and maintain is presented in Section 7. This operations-focused work will typically take place in the context of an investigation into the algorithms involved: these R&D "Key Projects" are laid out in Section 8, divided into constituent "Activities." This section is divided into subsections that outline the plans for the individual dark energy probe and analysis-enabling working groups, and is followed by a complete listing of all Key Projects and Activities. Finally, the appendix, Section 10, provides a summary of simulations nomenclature, and overviews of the anticipated timelines for relevant LSST Project hardware and DM development activities.

2.2 Points of Contact

For questions or enquiries about the sections of this version of the SRM, please contact the following people (the relevant working group conveners or coordinators).

Section	**Primary points of contact**
2 **Introduction**	Phil Marshall, Eric Gawiser
Analysis Coordinator	Rachel Mandelbaum
3.1 Weak Lensing	Chihway Chang, Tim Eifler
3.2 Large Scale Structure	David Alonso, Anže Slosar
3.3 Galaxy Clusters	Anja von der Linden, Eduardo Rozo, Adam Mantz
3.4 Strong Lensing	Danny Goldstein, Tom Collett
3.5 Supernova	Renée Hložek, Rahul Biswas
3.6 Theory & Joint Probes	Phil Bull, Jonathan Blazek
"Impacts of Blending" (CX1)	Patricia Burchat, David Kirkby
Computing and Technical Coordinators	Katrin Heitmann, Pierre Antilogus
5 Pipelines and Computing Infrastructure	Rachel Mandelbaum & Host WG PoCs
6 Datasets	Katrin Heitmann & Host WG PoCs
4.1 Cosmological Simulations	Eve Kovacs, Scott Daniel
4.2 Survey Simulations	Javier Sanchez, Chris Walter
4.3 Computing Infrastructure	Jim Chiang, Salman Habib
4.4 Sensor Anomalies	Pierre Astier, Andrei Nomerotski
4.5 Photometric Corrections	Eli Rykoff, Nicolas Regnault
4.6 Photometric Redshifts	Chris Morrison, Will Hartley
4.7 Observing Strategy	Michelle Lochner, Dan Scolnic
4.8 Commissioning	Chris Walter
4.9 Follow-up and Additional Datasets	Jeff Newman, Mark Sullivan
10 **Appendices**	
10.3 Simulations and Catalogs Nomenclature	Phil Marshall
10.4 LSST Project Hardware Testing Timeline	Steve Ritz
10.5 LSST Project DM Timeline	Wil O'Mullane

3 Key Science Analyses

The DESC is organized around five main probes of dark energy enabled by the LSST data:

1. Weak gravitational lensing (WL) – the deflection of light from distant sources due to the bending of space-time by baryonic and dark matter along the line of sight, which allows a measurement of the growth rate of cosmic structure (and therefore is also sensitive to dark energy).

2. Large-scale structure (LSS) – the large-scale power spectrum for the spatial distribution of matter as a function of redshift. This includes the Baryonic Acoustic Oscillations (BAO) measurement of the distance-redshift relation.

3. Type Ia Supernovae (SN) – luminosity distance as a function of redshift measured with Type Ia SN as standardizable candles.

4. Galaxy clusters (CL) – the spatial density, distribution, and masses of galaxy clusters as a function of redshift.

5. Strong gravitational lensing (SL) – the angular displacement, morphological distortion, and time delay for the multiple images of a source object due to a massive foreground object.

Both weak and strong lensing can also probe the evolution of cosmic geometry. This list includes the four techniques (WL, LSS, SN, CL) described in the 2006 Report of the Dark Energy Task Force (DETF). The goal of the DESC is not just to carry out these four analyses in isolation, but also to combine them; joint analysis is one goal of the Theory & Combined Probes working group (TJP), which also has the goal of addressing theoretical and statistical issues underlying the main probe analysis and cosmological constraints.

In this section we lay out the key steps that will be involved in each of these 5 individual probe analyses, and also in the joint inference, given LSST and supporting data. These descriptions motivate the design of the analysis pipelines defined in Section 5, and provide context for the research in Section 8.

3.1 Weak Lensing

The primary established method for constraining cosmological parameters with cosmic shear is via the angular two-point correlation function (or power spectrum) of shear in tomographic redshift bins. The Weak Lensing working group Key Projects for all three Data Challenges will focus on the steps required to accurately measure shear two-point statistics and to infer cosmological constraints given the these measurements.

With LSST, we will measure cosmic shear with statistical precision that demands a deeper understanding of potential systematic biases in galaxy shape measurements than has been achieved to date. In particular, we must achieve roughly two orders of magnitude improvement in shear calibration over published Stage II dark energy surveys. Therefore, the key to accurately measuring shear two-point statistics is understanding, correcting, or calibrating potential systematic biases. The necessary analytical, computational, simulation, and experimental studies are described primarily in these cross-linking and enabling-science Key Projects: "Impacts of Blending" (CX1) (Study the impacts of blending on all dark-energy probes for different algorithms in the science pipeline), "Survey geometry" (CX3) (Survey geometry), "Impact and Mitigation of Key Astrophysical Systematics" (CX5) (Impact and Mitigation of Key Astrophysical Systematics), "Cosmological Analysis Pipeline for LSST Precursor Data Sets" (CX6) (Cosmological Analysis Pipeline for LSST Precursor Data Sets), "Systematics Caused by the LSST Observing Strategy" (CX11) (Systematics Caused by the LSST Observing Strategy), "Using Deep Drilling Fields to Reduce Dark Energy Systematics" (CX12) (Using Deep Drilling Fields to Reduce Dark Energy Systematics), "Photometric Calibration Systematics" (CX13) (Photometric Calibration Systematics), "Brighter-Fatter effect" (SA1) (Brighter-Fatter effect), "Static sensor effects" (SA2) (Static sensor effects), "DC2 Requirements" (CS5) (Develop DC2 simulation requirements for the cosmological simulations and mock catalogs), "Extragalactic Catalogs for `DC2`" (CS7) (Development of mock catalogs for `DC2`), "`DC2` Production" (SSim4) (`DC2` Dataset Production), "`DC3 Mock Lightcone` Production" (SSim7) (`DC3 Mock Lightcone` Dataset Production). We are of course also highly reliant on the photometric redshift estimates, cf. Section 4.6. Also, many of the computing resources and infrastructure needs are discussed in Section 4.3.

The rest of the WL content of this SRM can be navigated from here, as follows:

- The simulation, processing and analysis pipeline and/or infrastructure components needed by the WL group are laid out as Products and Deliverables in Section 5.4.
- The challenge datasets that will provide a testing ground for those pipeline components are described in Section 6.
- The research and development projects hosted by the WL group, needed to design approaches and algorithms that can be coded into the pipeline components, are laid out in Key Projects and Activities in Section 8.1.
- The footer and header on each page provide hyperlinks to useful destinations: the back button on your PDF viewer should allow you to return from such a move.

- A summary of all WL Products and Projects (including pipelines and infrastructure, datasets and research and development) is given in the table below.

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

WL Products and Projects:

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

3.2 Large Scale Structure

Large-scale structure characterizes matter density fluctuations in the Universe through visible tracers including galaxies, galaxy clusters, and quasars. Galaxies are detected as individual objects in the LSST images, with photometric redshifts inferred from their colors and other properties. We will study cross-correlations between galaxies and other tracers of the cosmic structure to understand both cosmology and dark energy, as well as a wide-range of non-cosmological science cases, including characterizing the bias and redshift distribution of the tracers and their impact on galaxy formation models. These cross-correlations also offer the capability to detect and mitigate systematics (via e.g., null tests) and reduce the impact of sample variance on certain parameters through the multi-tracer effect.

This work will require a tight communication with several other working groups. We will work closely with the Weak Lensing and Clusters working groups with regards to the joint analysis pipelines with galaxy shapes and the cluster distribution. We will also coordinate with the Cosmological and Survey Simulations working groups, regarding the galaxy populations and sources of systematic uncertainty we need to simulate. Finally, our analysis pipeline will be developed in close communication with TJP in order to account for all relevant theoretical uncertainties, and to conform to the joint likelihood standards.

Looking forward to the era of LSST, we will have significant BAO measurements from DESI and PFS, which both concentrate on the northern sky. LSST will cover the southern hemisphere, therefore adding in volume for BAO measurements. Parts of the surveyed area covered by DESI and PFS will also be covered by LSST, adding in the possibility of cross-correlating the spectroscopic tracers with the photometric ones. This can in principle lead to significant science gain in determining the redshift distribution of galaxies, thus leading to much better constraints on the sum of neutrino masses, primordial non-gaussianities and BAO.

The primary deliverables from the LSS working group are measurements of the 2-point functions, in the form of auto- and cross-power spectra or correlation functions of tracer objects, and a likelihood evaluation scheme that can compute likelihoods of the observed data given basic cosmological parameters and a certain number of nuisance parameters. We expect to see significant correlations between the observed number density of sources and observing conditions, stellar densities, sky brightness, depth of the survey and additional systematics. Therefore, we will develop a pipeline that calculates the 2-point correlation functions of the sources along with their correlations with various systematics templates. We will project out the known systematics while developing machinery to find unknown systematics within the dataset. Our key project "Code for Measuring Power and Cross-power Spectra" (LSS2) is designed to develop this pipeline.

The development of this pipeline will be carried out with an eye towards the *3×2-point* pipeline, a joint endeavour of LSS and WL to obtain joint constraints from the galaxy-galaxy, galaxy-shear and shear-shear correlations. This pipeline will evolve towards a so-called *uber-pipeline*, incorporating also correlations of galaxy positions and shapes with the distribution of clusters, as well as the relevant cluster-cluster correlations.

In addition, we will develop LSS-specific catalogs, which will have finer separation into subsamples with differing requirements on purity, uniformity and photometric cleanliness that will allow us to probe correlations at scales ranging from from sub-Mpc to 1 Gpc. These catalogs will span the different science cases covered by LSS (e.g. BAO measurements or Halo Occupation Distribution analyses) and their equally different catalog-level requirements. Understanding the specific needs of LSS science is crucial in developing the correct catalogs (and randoms/masks). Therefore, we include a key project on catalog development and validation ("Determine LSS samples" (LSS1)).

The LSS working group will develop the likelihood function for input to the final LSST-DESC cosmological analysis framework. This requires including details of both the data and systematics and is part of "Cosmological constraints from LSS" (LSS3).

Precursor datasets will form an important part of testing our codes. We plan to work with public data releases from Hyper Suprime-Cam data (HSC, similar depth as LSST, but covering significantly smaller area), Dark Energy Survey data (comparable sky coverage, but significantly shallower) and low-redshift hacker catalogs (catalog constructed from multiple soruces, such as WISE, 2MASS, SuperCOSMOS, etc.) Each of these datasets will probe different aspects of our pipeline.

During DC1, we will utilize `DC1 Phosim Deep`, `HaloCat` and currently available photometric surveys to test, develop and validate our codes and to probe systematic effects in key projects "Systematics Caused by the LSST Observing Strategy" (CX11), "Code for Measuring Power and Cross-power Spectra" (LSS2), "Determine LSS samples" (LSS1) and "Cosmological constraints from LSS" (LSS3).

For DC2, we will use the `DC2` to continue our work on analysis code, using DC2 simulations and precursor datasets to test, develop, verify our codes on projects "Cosmological constraints from LSS" (LSS3), "Code for Measuring Power and Cross-power Spectra" (LSS2), "Determine LSS samples" (LSS1) and "Systematics Caused by the LSST Observing Strategy" (CX11). We will also use OpSim + MAF simulations to further probe systematic effects of the

LSST observing strategy in "Systematics Caused by the LSST Observing Strategy" (CX11), and a parallel set of catalog-level simulations of Deep Driling Fields to optimize the DDF observing strategy in "Using Deep Drilling Fields to Reduce Dark Energy Systematics" (CX12). Finally, during the DC3 phase we will use the `DC3 Mock Lightcone` and existing data to test, develop and validate our codes and to probe systematic effects, again in key projects "Code for Measuring Power and Cross-power Spectra" (LSS2), "Determine LSS samples" (LSS1) and "Cosmological constraints from LSS" (LSS3).

The rest of the LSS content of this SRM can be navigated from here, as follows:

- The simulation, processing and analysis pipeline and/or infrastructure components needed by the LSS group are laid out as Products and Deliverables in Section 5.5.
- The challenge datasets that will provide a testing ground for those pipeline components are described in Section 6.
- The research and development projects hosted by the LSS group, needed to design approaches and algorithms that can be coded into the pipeline components, are laid out in Key Projects and Activities in Section 8.2.
- The footer and header on each page provide hyperlinks to useful destinations: the back button on your PDF viewer should allow you to return from such a move.
- A summary of all LSS Products and Projects (including pipelines and infrastructure, datasets and research and development) is given in the table below.

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

LSS Products and Projects:

Activity: *"Observing strategy recommendations for large-scale structure"* 295

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

3.3 Galaxy Clusters

Measurements of the mass function of galaxy clusters (the number density as a function of mass and redshift) are sensitive to both the expansion history and growth of structure in the Universe. These measurements can provide powerful constraints on dark energy and fundamental physics, and critical distinguishing power between dark energy and modified gravity models for cosmic acceleration. Cosmological parameter inference from LSST cluster samples necessitates four key components:

1. **Accurate cosmological predictions:** Develop accurate emulators of the halo mass function, and the halo–mass and halo–halo correlation functions. Characterize robustness of these predictions to baryonic feedback (*"Develop Prediction Tools"*).
2. **Cluster Detection:** Develop and characterize one or more high-quality photometric cluster finders ("Cluster finding and catalog characterization" (CL1), *"Cluster redshifts (CLRedshift)"*,).
3. **Characterization of the Observable–Mass Relation:** Quantitative characterization of the probability $P(\lambda|M, z)$, where λ is the cluster observable. This is the most complex of the four components required for cluster cosmology, so we further break into three sub-components:

   (a) *Parametric Modeling:* Develop parametric models that adequately describe the relation between the survey mass proxy (e.g. cluster richness λ) and cluster mass, including the impact of cluster miscentering, halo triaxiality and projection effects. Parameterize how these effects impact the recovered weak lensing profiles of galaxy clusters.

   (b) *Absolute Mass Calibration:* Develop tools for analyzing the weak lensing profile of galaxy clusters for the purposes of determining the mean relation between cluster observable and cluster mass (*"Calibrating reduced shear with properly distorted galaxies (CLShear)"*,"Absolute mass calibration I" (CL2), "Absolute mass calibration II" (CL3),*"Cluster masses from weak-lensing shear maps (CLMassMod)"*).

   (c) *Shape and Scatter Calibration:* Utilize simulated and multi-wavelength cluster data sets to provide critical priors on the shape of the paramatric model, and the iscatter in cluster observable at fixed mass ("Relative Mass Calibration" (CL4)).

4. **Development of a Self-Consistent Likelihood Framework:** DESC will combine the above developments into a single cosmological-inference pipeline, and stress-test the pipeline by applying to simulated and existing cluster data sets, as well as early commissioning data ("Analysis of `DC3 Mock Lightcone` and pre-cursor data. CC/SV observing plan" (CL6)).

The rest of the CL content of this SRM can be navigated from here, as follows:

- The simulation, processing and analysis pipeline and/or infrastructure components needed by the CL group are laid out as Products and Deliverables in Section 5.6.
- The challenge datasets that will provide a testing ground for those pipeline components are described in Section 6.
- The research and development projects hosted by the CL group, needed to design approaches and algorithms that can be coded into the pipeline components, are laid out in Key Projects and Activities in Section 8.3.
- The footer and header on each page provide hyperlinks to useful destinations: the back button on your PDF viewer should allow you to return from such a move.
- A summary of all CL Products and Projects (including pipelines and infrastructure, datasets and research and development) is given in the table below.

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

CL Products and Projects:

Activity: *"On the use of the DDFs to reduce cluster mass systematics"*	293

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

3.4 Strong Lensing

The first strong lensing dark energy probe, time delay cosmography from lensed quasars and supernovae (e.g. Suyu et al. 2010, 2014; Bonvin et al. 2017), involves six key analysis steps. Each step is a stage in the SL analysis pipeline, and so has associated with it a piece of analysis software that will need to be built. The second probe, distance ratios from multiple source plane lenses ("compound lenses" that produce "double rings," see e.g. Collett & Auger 2014), require only four of the same time-delay analysis steps, but need a different discovery algorithm.

Because accurate time delay measurements require multi-year light curves, the first cosmology results from this probe will likely be produced around the third LSST data release (LSST DR3), or LSST DR2 for those systems that were monitored during science verification and/or the ComCam survey. This means that the lead time for the modeling of these lenses (SLMODELER) and cosmology analysis (SLCOSMO) development is long. In fact, the software to carry out both these analyses and the corresponding detailed analysis of followed-up compound lenses will be built by the H0LiCOW/STRIDES and DES Stage 2/3 teams outside (or partially outside) the DESC. In this Roadmap, we focus instead on the analysis of the LSST data, to prepare to find new lenses of each type in the ComCam data (SLFINDER), and begin monitoring the time-variable ones (SLMONITOR), inferring their time delays (SLTIMER) and characterizing all lens environments (SLENVCOUNTER and SLMASSMAPPER).

Finding lenses of all types will involve mining the DRP catalog and image store for lens candidates, with the number of targets large enough that it makes sense to write the SLFINDER using DM Stack libraries. Likewise, the SLMONITOR will also be user-generated software, that extends the MULTIFIT provided by LSST DM, as we may want and need to extract large numbers of accurate light curves to refine the candidate selection. (SLMONITOR is likely to be closely related to the code used by the SN group for extracting supernova lightcurves, also in very large numbers.) Time delay estimation can be done at LSST scale already (as shown by the first time delay challenge): the SLTIMER will be standalone DESC analysis code. Similarly, the environment characterisation codes will use DRP and user-generated products (field galaxy positions, photo-z's, stellar masses and so on) and will not need to be run at an LSST data center.

Focusing on the LSST data then, we can identify the following two key sources of systematic error and one logistical issue that we will need to address in order to be able to do accurate cosmography with strong gravitational lenses.

- **Time Delay Measurement.** In "Supernova and Strong Lens Light Curves" (CX2) we will use the DC1 `Twinkles` images to start testing the LSST blended object light curve extraction, continuing to develop and test against the DC2 `DC2` images in "Supernova and Strong Lens Light Curves" (CX10). Meanwhile, we will drive light curve analysis algorithm development in "SLTimer Development: The Second Time Delay Challenge" (SL1) (testing multi-filter light curves with realistic wide-fast-deep cadence) and "SLTimer Development: The Third Time Delay Challenge" (SL4) (using light curves extracted from the `DC2` images).
- **Lens Detection.** We expect that the LSST will produce thousands of gravitational lens candidates. Our current algorithms have not been tested under such a large volume. Therefore, there is a logistical concern about being able to handle and process the LSST data in an efficient and timely manner in order to to detect the lenses we need from the LSST images. In the DC1 era, algorithm development will proceed outside the DESC; at DC2 we will be ready to implement some of these algorithms for use on the LSST data, using the `DC2` data in "SLFinder: Target Selection in the `DC2` Survey" (SL2). We will prepare to run on the ComCam images using the `DC3 Mock ComCam Survey` data in "End-to-end test" (SL5).
- **Environment Characterization.** Algorithms for accounting for lens plane and line of sight structure are still being developed by the community, but in the DC2 era we will be ready to implement both types of method (based on number count statistics, or mass reconstruction using weak lensing data) in "Lens Environment Characterization" (SL3), using the `DC2` galaxy catalogs Analysis of the multi-cosmology `DC3 Mock ComCam Survey` galaxy catalogs in "End-to-end test" (SL5) will enable important high fidelity accuracy testing.

Beyond the LSST survey data, the SL probe will need both spectroscopic and high resolution imaging data to enable high precision time delay distance and compound lens distance ratio measurements. We anticipate following up several hundred systems with IFU observations on extremely large telescopes and/or JWST, and have begun a program of simulation work to prepare for these proposals. Lower fidelity spectroscopic information will also be important in constructing the lens samples (including the larger parent sample from which the follow-up targets are drawn), and also in charaterizing the lens environments. A cross-linking Key Project to explore the synergy with spectroscopic surveys like DESI will be explored in the next version of this Roadmap. In this version we focus on the LSST survey itself.

The rest of the SL content of this SRM can be navigated from here, as follows:

- The simulation, processing and analysis pipeline and/or infrastructure components needed by the SL group are laid out as Products and Deliverables in Section 5.7.
- The challenge datasets that will provide a testing ground for those pipeline components are described in Section 6.
- The research and development projects hosted by the SL group, needed to design approaches and algorithms that can be coded into the pipeline components, are laid out in Key Projects and Activities in Section 8.4.
- The footer and header on each page provide hyperlinks to useful destinations: the back button on your PDF viewer should allow you to return from such a move.
- A summary of all SL Products and Projects (including pipelines and infrastructure, datasets and research and development) is given in the table below.

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

SL Products and Projects:

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

3.5 Supernova

Supernovae were used to discover the accelerating expansion rate of the Universe and will continue to play an important role in constraining dark energy parameters with LSST. The basic approach remains the same: as standardizable candles, the calibrated apparent magnitudes of type Ia supernovae (SN Ia) constrain the expansion history of the Universe through their Hubble diagram, the relationship between (luminosity) distance and redshift, $d_L(z)$. The huge SN Ia sample from LSST will also enable novel, high-precision tests of the homogeneity and isotropy of dark energy, another check on the concordance ΛCDM cosmological model.

In the most straightforward approach, SN Ia cosmology from LSST will be conceptually similar to previous "rolling" surveys: LSST will both discover the SN Ia and provide multi-color light curves over a redshift range $0.1 < z <\sim 1.2$, from both the main survey and selected deep-drilling fields. LSST photometry of the SN Ia will be the input to light-curve fitting and distance-estimation models, resulting in the LSST SN Ia Hubble diagram for cosmological analysis.

The primary challenge is accuracy or controlling systematics in measurement and distance estimation compatible with the higher levels of precision stemming from the huge number of SN Ia expected: tens of thousands of SN Ia in the deep-drilling fields (observed exquisitely at high cadence; see "Using Deep Drilling Fields to Reduce Dark Energy Systematics" (CX12)), and hundreds of thousands of SN Ia in the main survey (for which optimizing the cadence to produce cosmologically-relevant SN Ia samples remains a key issue; see "Observing Strategy Optimization for SN Ia Cosmology" (SN3) and "Systematics Caused by the LSST Observing Strategy" (CX11)). This orders-of-magnitude increase in sample size from even the largest current surveys (e.g., DES will study ∼3,000 SN Ia) leads to several challenges beyond the scale of the simulations that are needed ("SUPERNOVAREALIZER Development" (SN1)).

- LSST SN Ia cosmology will quickly become systematics-limited and if systematic floors are not lowered, the statistical power of the huge LSST SN Ia sample and potential increase in the dark energy constraint figure-of-merit will be negated. Work is needed now to address these systematics, which include technical systematics (primarily the accurate calibration of SN Ia brightnesses over a wide redshift range; see "Required Precision" (PC1), "Supernova and Strong Lens Light Curves" (CX2), and "Supernova and Strong Lens Light Curves" (CX10)) and astrophysical systematics (including many effects that are subdominant to statistical and calibration uncertainties today, like redshift evolution in SN Ia progenitors and explosion mechanisms; accurate light-curve models, spectroscopic, and error models; subtle correlations with environment; accurate dust extinction models in the Milky Way, host galaxy, and potentially the intergalactic medium; effects from gravitational lensing; and selection biases). Many of these systematics can be checked by cross-calibrations along different directions by assuming cosmic isotropy. However, it may be that some of the most interesting analyses are those that check isotropy and homogeneity of the Universe. The work to address these systematic issues is begun in "Improved SN Ia Distances" (SN6) and "Galactic Extinction" (PC2).

- Current state-of-the-art SN Ia cosmology is based on spectroscopically-confirmed SN Ia, where there is no contamination from other core collapse or peculiar SNIa. In the recent years, SN cosmology analyses using photometric classification of supernovae have been published. These analyses used a sub-sample of spectroscopically followed up supernovae to perform photometric classification of supernovae with known redshifts, usually provided by later spectroscopic follow-up of host galaxies. It will not be feasible to obtain SN spectroscopy for any but a small fraction of LSST SN, and even obtaining spectroscopic redshifts of galaxy hosts later will be limited by resources. Both of these will require significant planning and preparation, and resources to manage such a program.

  Much development work is needed to allow photometric-only classification of SN that keeps the outlier fraction and bias in the SN Ia sample at a level small enough to be compatible with the systematic error goals. Photometric classification of SN is tied to redshifts; having spectroscopic redshifts for a large fraction of hosts of potential SN Ia will help the photometric classification. In addition, contextual information in the form of information from other surveys about the candidate object, and properties of host galaxies that correlate with the probability of hosting SN of different types will greatly improve the ability to do photometric cosmology on that subset of the LSST SN sample (e.g., Hlozek et al. 2012; Jones et al. 2017). Coordination within the WG is ongoing to combine ground-based spectroscopic surveys (e.g. 4MOST in Europe, DESI) which will provide just such spectroscopic redshift information for the host galaxies of some of the supernovae. Such coordination and planning for spectroscopic follow-up of the small sample of live supernovae is also ongoing with partners like TiDES using 4MOST as well as AAT. Ensuring that the cosmological sample produces unbiased constraints is one of the main challenges facing photometric cosmology with SNe. Selection of SN Ia because of amenable host properties (to give a good photometric or spectroscopic redshift, for example) may lead to a biased sample and biased cosmology; this needs detailed study. As such, work on cosmology from a photometric supernova sample will need to continue throughout the period up through the start of the LSST main survey, and is described below in "Cosmology from Photometric Supernova Samples DC2" (SN5), "Cosmology from Photometric Supernova Samples DC2" (SN5), and "Cosmology from

Photometric Supernova Samples DC3" (SN7).

- In order to trigger real time external observations (e.g., spectroscopy, photometry at other wavelengths, or higher cadence photometry) of LSST-discovered supernovae, the SN WG needs to maintain a program of early time classification of transient alerts combining that information with processed LSST data (from previous years) and external data. The result of such classification and the ensuing follow-up must be recorded to provide provenance of the selected sample, as lack of understanding of the sample selection may result in subtle biases in the cosmological analyses. This program may use information from suitable LSST community brokers, and studies in the SNWG are ongoing to determine the requirements for the combined output of brokers and DESC work for such classification, as well as infrastructure required to record the information on the selected sample. Studies are also underway to understand how to best use early time photometric data from LSST, and algorithms to provide the best classification. These issues will be studied in "DC2-era SN Pipeline Components" (SNPipe) in conjunction with "Cosmology from Photometric Supernova Samples DC2" (SN5) and "Cosmology from Photometric Supernova Samples DC3" (SN7). Aside from these methods, synergy with external satellite based surveys like WFIRST and Euclid are explored in "Observing Strategy Optimization for SN Ia Cosmology" (SN3). We also understand that, at least in the initial years, it will be important to complement the LSST supernova sample with appropriate low redshift samples from surveys like ZTF and Foundation Survey.

Of course there are many benefits from a huge sample. In particular systematic uncertainties may be better controlled by limiting the analysis to subsets of SN Ia that are restricted in some property (light-curve shape, color, host-galaxy characteristics, etc.) and by developing distance measures specific to these subgroups with potentially lower statistical and systematic uncertainties and thus more cosmological leverage. Analysis of current and forthcoming samples is important; for instance, we need to know sooner rather than later if external supplementary observations are needed to identify objects in these precise subsamples. All of the SN Key Projects will use SN Ia data from past and current surveys to develop and test methods. Furthermore, we recognize that these topics will typically require continuing efforts beyond the timescale of a single Data Challenge.

Within the DESC Data Challenge framework, the SN work will require simulated data sets of catalogs, images, and cadences specific to LSST. DC1 analyses specific to the SN science case include:

1. a validation of the simulation of supernova in simulated image series as generated by the main LSST and DESC catalog→image simulation tools (CatSim and PhoSim) – this

work will largely fall under the Twinkles effort ("Supernova and Strong Lens Light Curves" (CX2)) and its DC2 version;

2. simulated catalogs of supernova lightcurves to test photometric classification and redshift approaches for SNIa cosmology ("SUPERNOVAREALIZER Development" (SN1)).

The catalog-based simulations in DC1 assumes minimal errors in the difference imaging pipeline, and makes conservative assumptions about coadding of images. The DC2 analysis will be much more focused on image analysis (see e.g. the research items described in *"SN Light curves from processed DM difference images"*) and testing some of these assumptions in the difference imaging pipeline will rely on:

1. simulated plausible LSST cadences (OPSIM) to optimize observing strategy ("Observing Strategy Optimization for SN Ia Cosmology" (SN3));

2. incorporate mock galaxy photo-z catalog information along with the simulated SN lightcurve catalogs (*"$p(z)$ for simulated catalog objects"*).

In DC3, the SNWG will continue the work on increasingly realistic simulated SN data sets, often informed by updated information on supernova properties from DES and continuing nearby ($z < 0.1$) supernova surveys, as outlined in "Cosmology from Photometric Supernova Samples DC3" (SN7).

The rest of the SN content of this SRM can be navigated from here, as follows:

- The simulation, processing and analysis pipeline and/or infrastructure components needed by the SN group are laid out as Products and Deliverables in Section 5.8.
- The challenge datasets that will provide a testing ground for those pipeline components are described in Section 6.
- The research and development projects hosted by the SN group, needed to design approaches and algorithms that can be coded into the pipeline components, are laid out in Key Projects and Activities in Section 8.5.
- The footer and header on each page provide hyperlinks to useful destinations: the back button on your PDF viewer should allow you to return from such a move.
- A summary of all SN Products and Projects (including pipelines and infrastructure, datasets and research and development) is given in the table below.

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SN Products and Projects:

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

3.6 Theory & Joint Probes

The Theory and Joint Probes (TJP) working group is tasked with two distinct programs necessary to maximize the cosmological science yield from LSST data. First, TJP must deliver infrastructure for concrete joint probes analyses based on the current state of cosmology. Second, TJP must push the research frontier for theoretical models and phenomenology, which has to evolve with the state of the field and, in particular, in response to experimental results that will precede LSST over the next several years.

To develop the infrastructure for joint cosmological analyses, the TJP group will host key projects that culminate in cosmological likelihood analysis and software pipelines for joint probes analyses, TJPCosmo, including the necessary development of sophisticated joint probes covariance estimators TJPCov. Joint analyses of multiple cosmological probes require consistent modeling of observables as a function of all cosmological parameters of interest and all, potentially correlated, systematic uncertainties across all probes. Therefore, the joint analysis of all internal LSST cosmological probes represents a significant increase in both theoretical modeling capability and computational complexity compared to any single-probe analysis. The requirement of consistent parameterizations across all probes makes multi-probe analyses inherently less flexible than single probe analyses; consequently, the latter should be used initially to explore new parameterizations and the concomitant newly-opened regions of parameter space. To ensure that cosmological constraints from DESC are indeed complementary to CMB results and not affected by analysts' biases (such as confirmation bias), "Blinding Strategy for Cosmology Analysis" (CX8) will develop blind analysis strategies for TJPCosmo.

To provide the significant flexibility required to develop simultaneously both individual probe analysis techniques (tasks led by the probe-specific working groups) and joint probes cosmological analyses, the TJP group will provide a library of core cosmology routines (CCL) that individual working groups will use to write their probe-specific analysis modules and to explore the nuisance parameter spaces most relevant for each probe. Following the development of state-of-the-art single-probe analysis methods by the probe-specific groups ("Impact and Mitigation of Key Astrophysical Systematics" (CX5),"Cosmological Analysis Pipeline for LSST Precursor Data Sets" (CX6)), TJP will coordinate implementation of the most relevant systematic effects into a pipeline for the joint analysis of multiple probes self consistently. ("Integration of TJPCosmo into the CI Framework" (TJP5C)). By necessity, much of this work will be cross-linking, involving many of the DESC working groups. During DC3, TJP will validate TJPCosmo on mock catalogs, and test the multi-probe modeling framework under realistic conditions using precursor data sets ("Joint Cosmological Analysis with HSC/DES/KIDS Precursor Data" (TJP3)). Until TJPCosmo reaches the maturity required for precision forecasts, "Cosmology Forecasting Frameworks" (TJP1) will bridge the need for cosmological forecasts with quick turn around time based on pre-existing codes.

To advance cosmological theory and phenomenology in order to harvest the most benefit from LSST data, the TJP group will explore novel physics beyond dark energy including, but not limited to, primordial non-gaussianity, neutrino mass, modifications to the law of gravity on cosmological scales (non-GR gravity), and the nature of the dark matter as a part of key project "Physics Beyond wCDM with LSST" (TJP2). In this context, it is imperative to identify models for which consistent predictions for LSST core probes exist or models for which such definitive predictions could be developed. The TJP group will implement and develop techniques to produce predictions for core observables in these novel cosmological models and determine the models for which LSST data will yield informative constraints. This research program will deliver recommendations for the most promising models to be incorporated into the analysis infrastructure. TJP will develop implementations of these most promising models and integrate these implementations into the cosmological analysis software framework.

The TJP group will explore explore synergies with external data sets in "Synergies with External Data Sets" (TJP4) and identify high priority cross-correlations to mitigate parameter degeneracies. Based in these findings TJP will formulate a multi-data set research program beyond DC3 to maximize cross-calibration of system effects and to develop pipelines for key cross-correlations analyses.

The rest of the TJP content of this SRM can be navigated from here, as follows:

- The simulation, processing and analysis pipeline and/or infrastructure components needed by the TJP group are laid out as Products and Deliverables in Section 5.9.
- The challenge datasets that will provide a testing ground for those pipeline components are described in Section 6.
- The research and development projects hosted by the TJP group, needed to design approaches and algorithms that can be coded into the pipeline components, are laid out in Key Projects and Activities in Section 8.6.
- The footer and header on each page provide hyperlinks to useful destinations: the back button on your PDF viewer should allow you to return from such a move.
- A summary of all TJP Products and Projects (including pipelines and infrastructure, datasets and research and development) is given in the table below.

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TJP Products and Projects:

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

4 Enabling Analysis

The cosmological analyses laid out in the previous section rely on technical information about the LSST system, and in particular the details of the LSSTCam sensors and the photometric calibration schemes applied. They also all need accurate photometric redshifts, which must be computed from the LSST photometry provided. The analysis pipelines need well-understood and carefully controlled datasets to be developed against, which we either need to process from precursor data or generate with simulation tools. The DESC has 6 working groups and three task forces devoted to these "enabling" activities: in this section we give an overview of each group's program.

4.1 Cosmological Simulations

Cosmological simulations and mock catalogs derived from these simulations can enable a broad range of the data challenges and analyses described in Section 6 and Section 8. The required simulated datasets will come in a number of forms, e.g. dark matter halos, simulated observational catalogs, and inputs from which to simulate images. For each of these datasets there are a variety of levels of required fidelity. Increasing the fidelity along some dimensions is more straightforward than others and will need a detailed understanding of the interfaces, requirements, and a road-map of how fidelity should increase over time.

4.1.1 Input Simulations

Without significant work it does not seem possible to make a single input model of the Universe that would satisfy *all* precursor dark energy related studies. The dynamic range in sensitivity is simply too large. On the other hand, a set of targeted simulations, each with a different focus, could potentially be put together in different ways to serve many studies. Identification of this set of simulations is very important for moving forward. In particular, identifying deficiencies in the current state of the art and a path for fixing them will help to maintain a high level of productivity.

There currently exist a set of all-sky input catalogs developed for the LSST project and hosted at UW that serve as a baseline input simulation (see Connolly et al. (2010) for details). In this dataset, galaxies are populated from the Millennium dark matter simulations and mock catalogs (with some modifications to reproduce the observed density and redshift distributions of faint galaxies), stars are drawn from the GALFAST model (Jurić et al. 2008), and Solar System objects are a realization of the model by Grav et al. (2011). Limitations on these current models include: uncertainty in the stellar number counts at low Galactic latitude, differences between the model ellipticity distribution and observed ellipticity distributions of galaxies, a lack of realistic galaxy morphologies, and the small volume sampled by the simulated data.

How we will extend these baseline models to address the DC1 and DC2 requirements is described below. We have chosen to delay defining DC3 tasks in great detail because of the uncertainty in planning out that far. As we learn from DC1 and DC2, fleshing out DC3 requirements will become more tractable.

4.1.2 Framework and Planning

The key projects of the cosmological simulations group fall into six main categories.

A common definition of observable properties: Many of the key projects defined in Section 8 require that we can compare the properties of sources as measured from simulated images or images from precursor data (e.g. measures of size, shape, and flux) with the corresponding inputs from simulated catalogs. Many of these measures are sensitive to the amount of noise or the image quality present within the data. An initial objective for the cosmological simulations group is to define, in collaboration with the analysis working groups, a common set of definitions for the descriptions of the size and shapes of input sources, to characterize their dependence on noise and observing conditions, and to document these parameterizations.

Integrating cosmological simulations: As described in Section 6 there are broad ranges of input cosmological simulations and mock catalogs that will be required for the analysis and computing data challenges. Integrating these simulated data within a common framework that can be queried to generate simulated observations (catalogs and images) will enable end-to-end generation and processing of the simulated data. A non-trivial aspect of this effort will be the definition of a common schema and the formatting of the cosmological simulations and mock catalogs so that they can be ingested into the query framework developed for the LSST project simulations. This will be a collaboration with the Survey Simulations and the Computing and Infrastructure working groups.

Serving input simulations: The Computing and Infrastructure working group will be hosting a variety of catalogs that have been produced for multiple analysis tasks and data-challenge activities. The group will also provide a Generalized Catalog Reader (GCR) that reads each catalog and outputs the data in a unified format. This format will facilitate the comparison and validation of results from each catalog and can be ingested into the query framework described above.

Validation of the cosmological simulations and mock catalogs: A primary objective of the Cosmological Simulations working group will be the validation of the properties of the sources within the cosmological models and mock datasets against existing observational data.

This will require the definition of a common set of observational data (or the properties of these data) for use in the validation and an estimate of the uncertainties and selection biases within these observational datasets. This work needs to be done in order to produce simulations and associated catalogs with the required fidelity.

Prediction tools and covariances: Besides providing input simulations for the data challenges, we will also need to develop prediction tools for cosmological statistics, such as mass functions, power spectra etc. for different cosmologies at high accuracy. These will be used for extracting cosmological information from the simulated data sets and later also from observational data. Such prediction tools as well as estimates for covariances will be extracted from large simulation campaigns at good resolution, compared to the very high resolution cosmological simulations that will be used to generate high-fidelity input catalogs.

Hydrodynamical Simulations: High-fidelity simulations including gas physics and subgrid models pose a tremendous challenge for the cosmological simulation group. Nevertheless, they will play a very important role for understanding systematic effects in particular for cluster and weak lensing studies. Over the next few years, the fidelity of these simulations needs to be improved and we need to continue to develop strategies to mitigate baryonic effects on different probes.

In the process of planning data challenges and deliverables the effort to support fidelity and features should be considered realistically. We define the primary goals of the Cosmology Simulations working group below.

The rest of the CS content of this SRM can be navigated from here, as follows:

- The simulation, processing and analysis pipeline and/or infrastructure components needed by the CS group are laid out as Products and Deliverables in Section 5.2.
- The challenge datasets that will provide a testing ground for those pipeline components are described in Section 6.
- The research and development projects hosted by the CS group, needed to design approaches and algorithms that can be coded into the pipeline components, are laid out in Key Projects and Activities in Section 8.7.
- The footer and header on each page provide hyperlinks to useful destinations: the back button on your PDF viewer should allow you to return from such a move.
- A summary of all CS Products and Projects (including pipelines and infrastructure, datasets and research and development) is given in the table below.

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

CS Products and Projects:

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

4.2 Survey Simulations

The main goal of the Survey Simulation group (SSim) is to work with the analysis, computing and technical working groups to produce the simulated images needed for the various data challenges of the SRM. The DC data sets that will involve multiple groups are listed in Table 6.3.1 while image simulations required by individual working groups are listed in their respective sections, e.g., "Requirements on shear estimation" (WL1). The goal by the completion of DC3 will be to have produced data that closely resemble ComCam data in both volume and fidelity.

SSim will use Cosmological Simulations produced by the CS group as the *Input Catalogs*. The CS group will deliver the Generic Catalog Reader (GRC) together with the input catalogs. The GRC will provide CatSim with the access to the input catalogs and then CatSim returns *Instance Catalogs* with which the image simulations will be created.

The Photon Simulator (PhoSim) (Peterson et al. 2015) and imSim are packages developed by DESC members (and others) to produce high-fidelity synthetic LSST image data. PhoSim can produce realistic images that include the detailed photon physics of the atmosphere, telescope, and camera. It was originally conceived to provide *ab initio* simulations of LSST images (although it can now simulate images for other telescopes and cameras), and is actively used by the LSST Project systems engineering team to study the LSST optics. IMSIM builds on the GALSIM library (Rowe et al. 2015) and generates image data specific to the LSST site and instrument in a phenomenological approach. It is embedded in the official LSST simulation software environment, and thus also uses all of the same tools and databases used by the LSST project for planning and commissioning studies. We will use these two packages together to prepare ourselves for the first commissioning camera data.

The CI group will facilitate large-scale running of jobs along with the storage of their output. The images will be processed by LSST DM software (DM) as well as custom image processing software. The outputs will be analyzed by the analysis groups with their cosmological pipelines.

In addition to the main simulation goals, the SSim group plans to use other simulation tools that do not produce images, such as the the LSST *Metric Analysis Framework* (Jones et al. 2014) to help design the survey strategy. This group will also pursue the study of laboratory and observational data sets that can be used to assess the validity of the survey simulations.

The rest of the SSim content of this SRM can be navigated from here, as follows:

- The simulation, processing and analysis pipeline and/or infrastructure components needed by the SSim group are laid out as Products and Deliverables in Section 5.3.
- The challenge datasets that will provide a testing ground for those pipeline components are described in Section 6.
- The research and development projects hosted by the SSim group, needed to design approaches and algorithms that can be coded into the pipeline components, are laid out in Key Projects and Activities in Section 8.8.
- The footer and header on each page provide hyperlinks to useful destinations: the back button on your PDF viewer should allow you to return from such a move.
- A summary of all SSim Products and Projects (including pipelines and infrastructure, datasets and research and development) is given in the table below.

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

SSim Products and Projects:

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

4.3 Computing Infrastructure

The Computing Infrastructure (CI) group must provide several capabilities to the DESC: effective usage of the available computing resources, tools to run and manage large productions, a software environment for collaboration and external code to function in, and common tools needed by the various WGs. DESC must also have a distributed code development environment to allow the geographically dispersed DESC membership to work together on a common DESC code base.

Collaboration members will use simulation tools and the LSST Data Management Stack to produce simulated images and image processing data products (e.g., galaxy catalogs or shear measurements) that they will use to test their analysis codes. These codes will have multiple layers, starting, e.g., with computations of 2-point functions and propagating all the way to constraints on cosmological parameters. The overarching vision for the DESC computing environment is that scientists should find it easy to access the project tools, develop their own code, generate pipelines with modules written by others within the collaboration, incorporate external code (such as the HEALPix library and camb), and track results. This will enable the collaboration to identify the optimal algorithms, modules, and pipelines for different problems.

Building such an environment will be an iterative process through the Data Challenges as the WGs improve their understanding of requirements for simulations and datasets and for CPU cycles and storage, and as the tools themselves evolve from R&D explorations to collaboration standard tools. This process will inform the development of a framework meshing LSST Project tools, external code packages and custom-developed DESC code. The framework should also define API standards for DESC-written modules, both to define common properties of all modules as well as the interfaces for modules for which we might expect multiple candidate to be concurrently tested. As the Data Challenges progress in scale, we will also need capable workflow (executing chains or graphs of modules) and dataset tracking tools to run large-scale production runs with minimum FTE effort and track the provenance of the resulting datasets.

Project/DM tools will be key elements and we must explore, via the Data Challenges, our usage of them, especially for the reprocessing of the image data and potentially our own catalog instance (currently Qserv in the LSST Project plan). DC3 should provide a context for testing the scaling and interactions of the DESC and Project tools.

The rest of the CI content of this SRM can be navigated from here, as follows:

- The simulation, processing and analysis pipeline and/or infrastructure components needed by the CI group are laid out as Products and Deliverables in Section 5.1.
- The challenge datasets that will provide a testing ground for those pipeline components are described in Section 6.
- The research and development projects hosted by the CI group, needed to design approaches and algorithms that can be coded into the pipeline components, are laid out in Key Projects and Activities in Section 8.9.
- The footer and header on each page provide hyperlinks to useful destinations: the back button on your PDF viewer should allow you to return from such a move.
- A summary of all CI Products and Projects (including pipelines and infrastructure, datasets and research and development) is given in the table below.

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

CI Products and Projects:

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

4.4 Sensor Anomalies

The Sensor Anomaly Working Group (SAWG) is the only explicitly instrumental group within DESC, with a mandate to investigate features of the CCD sensors which are either novel or may particularly contribute to systematics in dark energy science. While the LSST Camera project is responsible for characterization of the camera, the project is most focused on ensuring that the instrument meets its previously-established science requirements. As detailed as these requirements are, they do not encompass all the issues of interest to the DESC; the role of the SAWG is to fill this gap.

LSST will employ thick, fully depleted CCDs with enhanced IR sensitivity. The CCD thickness, 100 μm, is considerably larger than the pixel size, 10×10 μm; as a result, deflections of photoelectrons by parasitic electric fields can make the mapping between sky coordinates and pixels non-trivial. The SAWG deals with these and other sensor effects, which broadly can be divided into two categories, dynamic and static, based on whether they depend on the source intensity or not. SAWG also studies the parameter space available for reliable operation of CCDs and readout electronics, as well as any trade-offs between these parameters and associated sensor anomalies.

In addition to laboratory measurements and on sky studies, SAWG activities include the validation of sensor effects in simulations, the development of signature removal algorithms for DM and the propagation of sensor effects into systematic uncertainties on the results of scientific analyses.

SAWG will need to generate multiple simulation datasets for DC1 and DC2 to perform planned PhoSim validation activities, as described below. The group will also produce recommendations to the analysis and simulation groups on the default sensor parameters to be used in DC2/DC3 simulations.

The rest of the SA content of this SRM can be navigated from here, as follows:

- The simulation, processing and analysis pipeline and/or infrastructure components needed by the SA group are laid out as Products and Deliverables in Section 5.10.
- The challenge datasets that will provide a testing ground for those pipeline components are described in Section 6.
- The research and development projects hosted by the SA group, needed to design approaches and algorithms that can be coded into the pipeline components, are laid out in Key Projects and Activities in Section 8.10.
- The footer and header on each page provide hyperlinks to useful destinations: the back button on your PDF viewer should allow you to return from such a move.
- A summary of all SA Products and Projects (including pipelines and infrastructure, datasets and research and development) is given in the table below.

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

SA Products and Projects:

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

4.5 Photometric Corrections

The Photometric Corrections (PC) working group helps to fill gaps between the responsibilities of the LSST project and the needs of the DESC for calibration. Examples include the mitigation of Galactic extinction, which is crucial for all DESC science but explicitly not part of DM's mandate, as well as more general work on photometric calibration systematics, which affect SN studies of dark energy directly and other probes via their impact on photometric redshifts. Photometric calibration uncertainties are an essential cross-cutting technical issue that impacts all aspects of DESC science.

The primary goal of efforts in this working group are to work with the LSST project team as well as the Sensor Anomalies WG to minimize and quantify systematic errors due to photometric calibration residuals arising from imperfect knowledge of instrumental throughput (“Required Precision” (PC1)), and Galactic extinction (“Galactic Extinction” (PC2)). We work in connection with science working groups to assess the impact of calibration uncertainties on specific cosmology probes (e.g. “Photometric Calibration Systematics” (CX13)). In addition, we aim to ensure clear documentation is maintained on how to map from calibrated magnitudes reported from the data release products to physical fluxes (“Model of the instrument response” (PC3)), as well as independently evaluate calibration systematics and make them available to DESC working groups in a synthetic and practical form. We will also coordinate forecasts for the LSST DM calibration strategies envisioned (“Survey Uniformity” (PC4), “Atmospheric extinction” (PC5)). Finally, we note that the flux calibration process ultimately relies on a primary flux reference, either a stellar object (DA white dwarf), or an artificial flux source, tied to the official NIST flux metrology chain. SN cosmological constraints are especially sensitive to the uncertainties affecting the primary reference spectrum. PCWG has initiated, in connection with the project team, an effort to compare the HST WD-flux scale (the state of the art, and the project baseline) with the NIST flux scale (“Physical flux calibration” (PC6)).

We emphasize that over the time period covered by this SRM there are many lessons to be learned from CFHT, Pan-STARRS, and from pre-LSST surveys currently in operation such as the Dark Energy Survey (DES) and the Subaru Strategic Program (SSP). Prior to first light, PCWG will participate in calibration related aspects of the reprocessing of these precursor datasets. During commissioning and science verification, PCWG will invest efforts in close connection with DM, to validate the calibration delivered by the alert production and data release pipelines.

Errors in photometry may be a function of sky position, wavelength, seeing, and time, and are affected by observing strategy as well as uncertainties in atmospheric and Galactic modeling. Photometric errors can result in systematic variations in photometric colors of galaxies; photometric redshifts; outlier fractions; and sample selection. All DESC science applications are affected by these systematic effects, including Baryon Acoustic Oscillations, Weak Lensing angular and redshift correlations, Cluster finding and correlation measurements, and type Ia supernovae.

Of considerable importance for DESC is the effect of Galactic extinction on galaxy magnitudes. While considerable attention is applied in the LSST SRD to the effects of the atmosphere, optics, and sensors, the effects of Galactic extinction are fully the responsibility of DESC and the other LSST Science Collaborations.

Another sector of activity for the PCWG comes from the fact that the LSST survey calibration requirements (1% in uniformity, and 0.5% in the relative flux scale) may be slightly worse than is needed for certain DESC science goals, particularly SN cosmology. It may be possible to exceed these goals at relatively low cost, besides additional work. For example, making use of Gaia data may make it possible to obtain $\sim 0.1\%$ in uniformity (at the top of the atmosphere). These goals are specific to DESC, and the PCWG proposes to explore non-disruptive ways to go beyond the official survey requirements, at little or no additional cost, and report back to the LSST project. Some of the techniques that are envisioned for calibrating the survey must be demonstrated. We list in this section several projects whose goal is to test techniques or pieces of LSST calibration hardware using real data (e.g. *"Atmospheric monitoring with an Auxiliary Telescope Demonstrator"*, *"Compare NIST and CALSPEC flux scales on O(10) objects"*). Most of these initiatives are of the responsibility of the LSST Project. At the request of these projects, individuals from the PCWG may get involved with these efforts.

We note that the production of calibrated magnitudes is ultimately under the responsibility of LSST DM. It involves algorithms and databases in the area of the alert production (AP) and data release production (DRP) pipelines. Regarding the instrument model that allows to interpret the calibrated magnitudes, ("Model of the instrument response" (PC3)), most of its ingredients will also be provided by the LSST project teams and their contractors: they come from acceptance tests and later, from commissioning and routine monitoring of the instrument by dedicated hardware.

The bulk of the deliverables in this working group are on DC3 timescales. Precisely how key systematics are incorporated into DC3 remains to be determined. For example, while the later data challenges will incorporate time-varying atmosphere into the simulations, it is as yet unclear how errors in the modeling of these systematics (from imperfect fits to atmospheric properties) will be incorporated into the final simulated photometry. We therefore expect plans for the PC working group to be a work in progress.

The rest of the PC content of this SRM can be navigated from here, as follows:

- The simulation, processing and analysis pipeline and/or infrastructure components needed by the PC group are laid out as Products and Deliverables in Section 5.11.
- The challenge datasets that will provide a testing ground for those pipeline components are described in Section 6.
- The research and development projects hosted by the PC group, needed to design approaches and algorithms that can be coded into the pipeline components, are laid out in Key Projects and Activities in Section 8.11.
- The footer and header on each page provide hyperlinks to useful destinations: the back button on your PDF viewer should allow you to return from such a move.

- A summary of all PC Products and Projects (including pipelines and infrastructure, datasets and research and development) is given in the table below.

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

PC Products and Projects:

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

4.6 Photometric Redshifts

Photometric redshift (photo-z) estimates will be a key requirement for almost all LSST dark energy probes. Each method of constraining dark energy depends on determining how observable quantities depend upon redshift; however, it will be infeasible to measure spectroscopic redshifts for the large samples of objects observed by LSST. Hence, we must infer redshift information from imaging alone.

We wish to minimize the uncertainties on photometric redshifts for individual objects in order to strengthen the constraints on cosmological parameters; these are the challenges of *measuring* photo-z's and *training* our algorithms with spectroscopic data. At the same time, we must also characterize the actual redshift distributions for samples with photometric redshift estimates; this is the problem of *calibrating* photo-z algorithms. For instance, the systematic error on inference of the Dark Energy equation of state w from weak lensing measurements is roughly five times the uncertainty in the actual mean redshift of photo-z-selected samples; calibration must reach an accuracy of $\sim 0.002(1+z)$. A summary of how photometric redshifts will be used for LSST is presented in LSST Science Collaboration et al. (2009); more details on the problems of photometric redshift training and calibration are presented in Newman et al. (2015).

In order to *measure* photo-z's for LSST samples accurately, a number of technical challenges must be addressed. Anything which causes differences between measured galaxy colors and their true colors will degrade photo-z estimates. For example, blending of galaxies with nearby objects, variations in photometric zero-points, miscorrected reddening by intervening dust, or unaccounted-for variations in filter throughputs or atmospheric absorption. We also must validate that the outputs of our photo-z codes are well characterized (e.g., redshift probability distributions should be well-behaved PDFs) and in formats that probes working groups can use.

The key challenge in *training* photometric redshift algorithms is systematic incompleteness in spectroscopic redshift samples. Many photo-z algorithms estimate redshift by comparing the observed broad band fluxes of an object to those of a representative training set, while others use spectroscopy to characterize the underlying spectral energy distributions of galaxies that may be used in inferring redshift. Any incompleteness in the training set will degrade photo-z estimates, as galaxies not represented in the spectroscopic sample will be mapped to incorrect regions of parameter space. The Photometric Redshift working group will develop a framework to optimize photo-z performance in the presence of such incompleteness, rather than relying on the assumption of complete characterization of the underlying galaxy distribution.

Given the high incompleteness of deep spectroscopic surveys, it is unlikely that our training sets of redshifts will be sufficient to achieve an accurate calibration of actual photo-z biases and uncertainties (or aggregate redshift distributions of LSST samples). Traditional assessment by comparing with spectroscopic samples can give a false measure of photo-z performance due to systematic biases in the populations that fail to yield secure redshifts. Instead, we expect to rely on cross-correlation methods for calibration (Newman et al. 2015). Key challenges for *calibration* are optimizing these methods in the presence of confounding effects such as dust extinction and lensing magnification and demonstrating that they will achieve the high accuracy needed for LSST.

In addition to developing methods of dealing with these challenges, the Photometric Redshift working group must develop the infrastructure needed for generating redshift estimates required by LSST DESC (whether point estimates, probability distribution functions, or samples from a PDF), optimizing those algorithms, and calibrating the results. We anticipate that in Data Challenge 2, the Photometric Redshift Working group will provide redshift probability distribution functions ($p(z)$'s) for all objects in the standard DC2 dataset, while in Data Challenge 3, the working group will provide joint PDFs for both redshift (z) and template type or other second parameters $p(z, \alpha)$, where α is e. g. Stellar Mass or star formation rate (SFR). Based on previous experience we do not expect significant challenges in terms of computing resources for DC1 and DC2; however, once photo-z algorithms are finalized we will need to work with the Computing Infrastructure group to scale up algorithms for a full scale production run of the PZ pipeline.

We first summarize the working group's activities for DC1 and DC2, and then describe the key projects planned for DC1, DC2, and DC3 in more detail.

DC1: For DC1 the PZ working group will focus on building simulation tools to enable more realistic tests of photometric redshift algorithms and on developing and testing the capability to calculate and disseminate redshift PDFs using current algorithms, as described in "Photo-z Testbed" (PZ1). For DC1, we will establish a framework for running multiple photo-z codes and storing the resultant PDFs (PZPDF).

A major focus will be the development of a data set with continuous SEDs and inclusion of strong emission lines (dataset `PZColor`). We will develop code (PZGalaxyGenerator) that takes input colors and physical parameters from lightcone mock catalogs, which may be systematically offset from those of observed galaxies, and generate a continuous range of SED templates that now add strong emission lines and other important physical effects. We will use this code to generate new a new photometric dataset, `PZColor`. This dataset will be a single catalog based sample to a depth i $\sim$ 27 with $\sim 10^6$ galaxies. We require realistic colors for the input catalog, as well as a size estimate for proper photometric error estimates. From `PZColor` we will create training, test, and validation sets for use with multiple photometric redshift codes and evaluate both their accuracy and the fidelity with which they generate properly-defined redshift probability distribution functions.

DC2: For DC2, the PZ group will calculate photometric redshifts for the Data Challenge set `DC2` for use by all working groups ("Photometric redshift infrastructure development" (PZ3)). It will undertake a variety of activities focused on the training ("Photo-z Testbed" (PZ1), "Develop infrastructure for spectroscopic redshift training sets" (PZ4)) and calibration ("Tests of photo-z cross-correlation calibration " (PZ2)) of photo-z's with spectroscopic data. The working group will also participate in cross-working-group activities to investigate the impact of blended objects on photo-z estimates (cf. "Impacts of Blending" (CX1)) and to explore the benefits of adding data at near-infrared wavelengths (cf. "Synergies with External Data Sets" (TJP4)).

Several mock datasets will need to be developed for DC2. We will extend `PZColor` to have realistic emulation of emission line fluxes and/or stellar mass and SFR estimates, allowing the modeling of spectroscopic incompleteness (dataset `PZIncomplete`). For realistic tests of cross-correlation calibration, we will require a mock dataset covering at least 3000 square degrees to i $\sim$ 25 which includes the effects of lensing magnification, complex and evolving galaxy bias, and realistic small-scale clustering (`PZCrossCorr`). Finally, for tests of methods of optimizing selection of spectroscopic training sets, we require a dataset with $\sim$ 100 several square degree patches on the sky to a depth i $\sim$ 25, including the effects of realistic variations in observing conditions and the incorporation of galaxies with as realistic as possible color, magnitude, stellar mass, metallicity, surface brightness, and emission line strength distributions (`PZSzTrain`).

Additional code development will also be required during DC2. In order to calibrate photo-z redshift distributions, a PZCalibrate pipeline will be developed, potentially using WLTwoPoint and/or LSSTwoPoint to compute correlation functions and/or power spectra rapidly. This code will be tested using the `PZCrossCorr` mock dataset. Similarly, we plan to develop a code to efficiently select targets for spectroscopic follow up campaigns, PZSpeczSelector, which will use dataset `PZSzTrain` for testing.

The rest of the PZ content of this SRM can be navigated from here, as follows:

- The simulation, processing and analysis pipeline and/or infrastructure components needed by the PZ group are laid out as Products and Deliverables in Section 5.12.
- The challenge datasets that will provide a testing ground for those pipeline components are described in Section 6.
- The research and development projects hosted by the PZ group, needed to design ap-

proaches and algorithms that can be coded into the pipeline components, are laid out in Key Projects and Activities in Section 8.12.

- The footer and header on each page provide hyperlinks to useful destinations: the back button on your PDF viewer should allow you to return from such a move.
- A summary of all PZ Products and Projects (including pipelines and infrastructure, datasets and research and development) is given in the table below.

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

PZ Products and Projects:

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

4.7 Observing Strategy

The LSST system was designed to enable a wide, fast and deep imaging survey that would support a wide range of science, and this was reflected in the baseline survey strategy released in 2016, `minion_1016` (LSST Science Collaboration et al. 2017). However, optimizing the LSST observing strategy for science is an activity that the LSST science community began in 2015 and will continue throughout the survey. The DESC will provide information to the LSST facility through the Community Observing Strategy Evaluation Paper (COSEP) and related white paper calls, following investigations of simulated observing strategies. This work is coordinated by the DESC's Observing Strategy Task Force (OSTF). In the pre-commissioning

DC2 and DC3 era, this work will largely involve research into the utility of various simulated observing strategies that have been produced outside the collaboration; this program may be extended to include development of simulation and analysis software for the collaboration's ongoing use.

OSTF Products and Projects:

OSTF Key Project (DC2): Response to the LSST Call for White Papers on Observing Strategy (OSTF)	294
Activity: *"Synthesized WFD observing strategy recommendations across all probes"*	296
Activity: *"Synthesized DDF observing strategy recommendations across all probes"*	297
Activity: *"Metrics summary for observing strategy across all probes"*	297

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

4.8 Commissioning

The LSST commissioning observations are designed to enable the LSST Project team to demonstrate that the system is producing data that meet the LSST science requirements. There is great potential for these observations to *also* enable the DESC to check its own analysis performance; small modifications to the detailed observing plans could bring great benefit to the DESC without impacting the Project's program. The DESC will provide information to the Project about the simulations and observations that would best enable the DESC to commission itself through a set of DESC research Notes, led by the collaboration's Commissioning Task Force (CTF).

CTF Products and Projects:

CTF Key Product (DC3): DESC Commissioning Efforts (CTF)	158
Deliverable: *"DESC technical note with suggested observing fields and tests"*	158

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

4.9 Follow-up and Additional Datasets

All of the DESC's cosmological probes either need or would benefit from the combination of the LSST survey data with additional data, either from complementary surveys or dedicated follow-up campaigns. Work is needed to set requirements for additional datasets, obtain access to those data (which may require white papers for large-scale needs; memoranda of understanding with outside projects; or observing proposals to obtain the data); and to develop tools for processing and analyzing the results. Much of this work should take place within individual working groups. However, coordination of effort that involves multiple working groups and the development of modes of working with outside groups that affect the collaboration broadly will be handled by the DESC's Follow-up Task Force (FTF).

FTF Products and Projects:

Legend: tabulated deliverables and activities are colored according to their status, as follows: done, defunct, active, planned, anticipated.

5 Pipelines and Computing Infrastructure

In this section we describe all of the mission critical software that we will need to build, in order to be able to analyze the commissioning data in the same way as we would the survey data. The pipelines described here should enable us to carry out the key analysis steps defined in Section 3, while the datasets in Section 6 should be sufficient to support the development, validation and system testing of the pipelines. We note that some pipeline components – the analysis tools – already exist as external code, leaving just the "plumbing" needing to be done by the DESC. For these cases, we find the building work laid out as "computing infrastructure" deliverables. The pipeline stages that need to be built are laid out in a series of "pipeline diagrams." Each pipeline constitutes a Key Product, while each stage to be built is a Deliverable.

Each pipeline Deliverable should include a verification analysis that answers the question, "did we build what we said we would build?" presented as a research Note or journal paper (or part of one). Each Key Product should include a validation analysis describing a system test that answers the question, "is what we built fit for purpose?" also presented as a research Note or journal paper. The collaboration needs to understand its own tools, and pipeline builders need to be recognized for their efforts. These Notes and papers are therefore extremely important.

The software Key Products are (currently) largely organized by cosmological probe (or, roughly equivalently, working group), an initial choice made to preserve continuity with previous versions of the SRM (in which pipeline Deliverables were embedded in the R&D Key Projects). This organization may be revisited as construction proceeds and the design of the pipelines evolves, and so we employ a numbering-free system for labeling (and referring to) the Deliverables and products below. (We therefore anticipate the titles of these items evolving to become more like names over time.) For a summary table of all software Key Product and Deliverables, see Section 7.

NB: in the text below, deliverables and activities are presented with color coding determined by their status, as follows: "done" deliverables have hyperlinks like this, "defunct" deliverables have hyperlinks like this, "active" deliverables have hyperlinks like this, "planned" deliverables have hyperlinks like this, and "anticipated" deliverables have hyperlinks like this.

5.1 Computing Infrastructure

The DESC simulation, processing and analysis pipelines have some needs in common, to enable them to be run efficiently at the required scale on the computing resources we have access to. In this Section we collect together these common pieces of mission-critical "computing infrastructure."

CI Key Product (DC2): The Initial Elements of a Software Framework (CI2)
Host WG: CI
Objective: Large collaborations need a standard environment for their code to be developed and operated in and workflow tools to facilitate running their software at a variety of scales. DESC will exploit the broad expertise within the collaboration to reduce the tendency to reinvent the wheel so that the WGs can concentrate on the content of their code rather than on the infrastructure surrounding it. Standard interfaces will define how code modules interact with each other and with the data, and will thus dictate how the DESC code is structured and how external packages will be configured and executed to be used by the DESC code. Powerful workflow tools will facilitate the submission of large jobs and will enable groups to track results.

Given the constraints of DESC member efforts, deviations from Project/DM standards should be considered carefully; we should concentrate on those elements unique to our needs and reuse what we can.

Deliverable: *Software Framework Implementation (DC2 SW)*

Host WG: CI *Started:* 10/01/16 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :
Objective: The framework will include definitions of software interfaces (APIs) as well as interfaces to data services. External tools like OpSim, CatSim, PhoSim, and the Data Management pipeline will be considered in an integrated fashion with the DESC code.

Deliverable: *Distributed Code Development Environment (DC2 SW)*

Host WG: CI *Started:* 10/01/16 *Originally due:* 02/28/18
Status: done *Completed:* 02/28/18
URL : https://confluence.slac.stanford.edu/display/LSSTDESC/NERSC+Software+Installations; https://github.com/LSSTDESC
Objective: The DESC software development environment should have tools and policies in place to facilitate efficient distributed development. Recommendations for a distributed code repository (such as GitHub), C++/python build tools, policies for code package management,

and continuous integration tools will be made, with consideration of the applicability of existing or planned LSST DM development tools.

Deliverable: *Workflow & Data Management Tools (DC2 SW)*

Host WG: CI *Started:* 10/01/16 *Originally due:* 02/28/18
Status: done *Completed:* 02/28/18
URL : https://confluence.slac.stanford.edu/display/LSSTDESC/DESC+Workflow+Management+System+Evaluation
Objective: DESC simulations and data processing will require tools to manage and track large numbers of batch jobs and data files. Existing workflow management systems – such as Pegasus, Parsl, or Airflow – should be evaluated, and a recommendation for a final candidate made, keeping in mind the need to be able to operate with the LSST DM Project tools.

CI Key Product (DC1 & DC2): Targeted Frameworks for Use by the Analysis Working Groups (CI3)
Host WG: CI
Objective: For DC1, we found that the best path forward to attain the ultimate objective of a framework used by all members of DESC was to *work with analysis teams on several Key Projects, enabling them to work together*. CI and the relevant analysis group produced mini-frameworks for each of these smaller projects. Although these smaller interactions did not produce all of the elements that will eventually be required, they gave important feedback as to which ideas work and which do not. They will therefore feed into the Key Projects in DC2.

Deliverable: *A framework for Twinkles light curve generation (DC1 SW)*

Host WG: CI *Started:* 10/01/15 *Originally due:* 06/30/16
Status: done *Completed:* 06/30/16
URL : https://github.com/LSSTDESC/Monitor/tree/master/python/desc/monitor
Objective: SNIa and time delay lenses need to be detected in catalog space (using the outputs of the DM stack deblender, object aggregator, and MULTIFIT) and classified in pixel space (either in a "SuperFit", or some other user-generated tool). Light curves must be extracted for both, so that time domain model parameters (stretch, time delay) can be inferred. These commonalities suggest that the development of the software instrumentation needed to detect and measure both types of system can be carried out using the same test dataset, the `Twinkles` survey. For DC1, the SN and SL groups have defined the cross-linked Key Project "Supernova

and Strong Lens Light Curves" (CX2) to assemble analysis pipelines (SUPERNOVAMONITOR and SLMONITOR) to extract the light curves of supernovae and strong lenses.

The production of the `Twinkles` images, and their "standard" pipeline processing using the LSST DM stack, can be used to drive the development of several aspects of DESC computing infrastructure at DC1. The design should be able to scale to DC2 requirements. The construction of a Twinkles image and catalog mock dataset (see "`Twinkles`" (SL7)) will involve building DESC CI group expertise in operating CATSIM, PHOSIM, and the DM stack at scale, using resources identified in "Estimate Resource Needs and Recommend the Host for DESC Computing Resources" (CI1), and will provide a valuable testing ground for (at least) the deblender, image differencing and forced photometry DM DRP algorithms.

Deliverable: *A Framework for TJP (DC1 RQ)*

Host WG: CI *Started:* 10/01/15 *Originally due:* 06/30/16
Status: defunct
URL :

Objective: CI and TJP will produce guidelines for the development of TJPCOSMO, which will provide a key set of metrics for systematics. This will be an excellent test case for the larger software framework. The framework will define standard APIs so that different members of the collaboration can work on different aspects of the same problems, will include an environment where code can be checked in, and will provide access to relevant (pseudo-) data sets.

CI Key Product (DC1 & DC2): Distributed Code Development Environment (CI4)

Host WG: CI
Objective: Implement policies describing best practices in code development and management in order to maximize the productivity of the geographically dispersed team. These policies should cover code repository and organization, issue tracking tools, software standards and code review processes, and testing policies and usage of continuous integration services.

Deliverable: *An initial development environment (DC1 SW)*

Host WG: CI *Started:* 10/01/15 *Originally due:* 01/31/16
Status: done *Completed:* 01/31/16
URL :

Objective: The development environment will start with a distributed repository. Standards will be developed for organization of code and packages in the repository, so that each WG will use a similar directory structure when developing their software.

Deliverable: *Software coding standards and code review policies (DC2 SW)*

Host WG: CI *Started:* 10/01/16 *Originally due:* 02/28/18
Status: done *Completed:* 02/28/18
URL : https://docs.google.com/document/d/1v54bVQI2NejK2UqACDnGXj1t6IGFgY3Uc1R7iV2uLpY/edit

Objective: Software coding standards and code review policies will be developed.

Prerequisites: "Targeted Frameworks for Use by the Analysis Working Groups" (CI3)

CI Key Product (DC2): Common Pipeline Infrastructure (CI12)
Host WG: CI
Objective: For DC2, the collaboration is writing a number of pipelines for generating simulated images, for image processing, and for science analyses. Since these tasks will entail a variety of software packages, some of which have interfaces and usage patterns inherited from other contexts, it will be essential to define a common set of software abstractions to define the interfaces between the pipeline components for both the software and data product elements. Having standard interfaces will enable the use of existing workflow and data management tools that have been used by other large projects for running their analysis and data processing pipelines. Such abstraction layers will also help decouple the particular choice of workflow and data management system from the DESC software, so that alternative technologies can be more easily used in the future.

Deliverable: *Pipeline Software Interfaces and Abstractions (DC2 SW)*

Host WG: CI *Started:* 10/01/16 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: This will include a set of tools to help the WGs design their pipelines (e.g., DAG drawing tools and utilities to help convert the design-level descriptions to actual code). It will also comprise a set of base classes that define the interfaces between the underlying simulation and analysis software and the workflow and data management systems, as well as data format specifications so that information such as metadata can be easily associated with the main data content. These latter software abstractions will provide a context in which the inputs and outputs to any processing software will be well-defined so that standard workflow software can manage the execution of the DESC pipelines in a correct and consistent manner.

CI Key Product (DC3): Common Pipeline Infrastructure for DC3 and SV (SV-CPI)

Host WG: CI

Deliverable: *SV-Ready Pipeline Software Interfaces and Abstractions (DC3 SW)*

Host WG: CI *Started:* 10/01/18 *Originally due:* 10/01/21
Status: anticipated *Anticipated:* 10/01/21
URL :

Objective: Upgraded pipeline interfaces to support DC3, ComCam and SV simulation, processing and analysis.

CI Key Product (DC1): `DC1 Phosim Deep` Workflow and Data Management Configuration (CI8)
Host WG: CI
Objective: Simulations will involve large amounts of computing time, on the scale of hundreds of thousands of jobs and the resulting datasets will need to be tracked. Workflow and dataset tracking/provenance tools are needed to provide full visibility into the resulting dataset and to minimize the FTE effort needed to produce it. Workflow tools with capable web UIs have proven essential to allow easy access to job logs, etc., rollback of failed jobs and monitoring of progress. Logical file catalogs provide virtual filesystems with the added benefit of metadata to permit identifying which files in datasets are needed for different analyses. These tools will need to leverage the computing resources available to the collaboration that were identified in the Key Project "Estimate Resource Needs and Recommend the Host for DESC Computing Resources" (CI1). The largest DC1 datasets identified are for the PhoSim Deep dataset. Note that projected datasets for DC2 are not significantly larger than for DC1 and so should be able to be accommodated by a similar system.

Deliverable: *Tracking Tools for DC1* PhoSim *Datasets (DC1 SW)*

Host WG: CI *Started:* 10/01/15 *Originally due:* 01/31/16
Status: done *Completed:* 01/31/16
URL : https://confluence.slac.stanford.edu/display/~dragon/DC1+PhoSim+28and+dmtcp29+Task

Objective: The `DC1 Phosim Deep` dataset is estimated to require some 4M CPU-hrs to execute. The workflow tools must make this as efficient a process as possible, while tracking the outputs of the simulations, running on computing resources available to the collaboration.
Approach: Work with the Survey Simulations WG to configure the early workflow and dataset management tools to run the simulation.

CI Key Product (DC2): DC2 Workflow and Data Management Configuration (CI10)

Host WG: CI
Objective: DC2 is expected to be a moderately large simulation and could tax the sites where the code will be run. Careful optimization will be needed to reduce failure rates to low levels. Additionally, the workflow and catalog tools must scale to handle the dataset volume and not suffer in performance. Data access tools will need to provide for efficient transfer from the host sites to collaborators' institutes.

Deliverable: *Workflow and Dataset Tracking Tools for DC2 (DC2 SW)*

Host WG: CI *Started:* 10/01/16 *Originally due:* 06/30/18
Status: defunct
URL :
Objective: The `DC2` dataset is estimated to be some 30x larger than for DC1. The workflow tools must scale effectively to minimize the FTE effort needed to run the processing and maximize use of the computing resources.

CI Key Product (DC3): DC3 Workflow and Data Management Configuration (CI14)

Host WG: CI
Objective: The `DC3 Mock Lightcone` and `DC3 Mock ComCam Survey` datasets have the potential to be very large simulations, and could significantly tax the sites where the sim-

ulation and processing pipelines will be run. Careful optimization will be needed to reduce failure rates to low levels. Additionally, the workflow and catalog tools must scale to handle potentially millions of datasets and not suffer in performance. Data access tools will need to provide for efficient transfer from the host sites to collaborators' institutes.

Current estimates indicate challenging dataset sizes, and will have to be studied for feasibility. This project will need to respond as best as possible to that determination.

Deliverable: *Workflow and Dataset Tracking Tools for DC3 (DC3 SW)*

Host WG: CI *Started:* 10/01/18 *Originally due:* 06/30/20
Status: planned *Expected:* 06/30/20
URL :

Objective: The `DC3 Mock Lightcone` and `DC3 Mock ComCam Survey` datasets could be significantly larger than DC1 and DC2. The workflow tools must scale effectively to minimize the FTE effort needed to run the processing and maximize use of the computing resources.

CI Key Product (SV): SV-Era Workflow and Data Management Configuration (CI17)

Host WG: CI
Objective: Based on the DC3 experience, we will upgrade the DRP workflow and configuration for the SV data.

Deliverable: *Workflow and Dataset Tracking Tools for SV (DC3 SW)*

Host WG: CI *Started:* 07/01/20 *Originally due:* 10/01/21
Status: anticipated *Anticipated:* 10/01/21
URL :

Objective: The workflow tools must be able to cope with the variety of reprocessings that we want to do on the SV data, and also the idiosyncracies of real data at high throughput.

5.2 Cosmological Simulation Infrastructure

CS Key Product (DC2): DESCQA2 Validation Framework (CS10)
Host WG: CS
Objective: This project follows on from the DC1 R&D project, CS3, DESCQA, which developed a framework suitable for testing and validating a wide variety of synthetic sky catalogs against observational or other validation data. DESCQA2 expands this framework to include light-cone catalogs and to incorporate additional tests that will be developed in collaboration with the analysis working groups.

Deliverable: *DESCQA validation framework with full functionality (DC2 SW)*

Host WG: CS *Started:* 10/01/16 *Originally due:* 06/30/18
Status: done *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/descqa
Objective: The DESCQA2 framework will operate on any available catalog and automatically run a suite of tests to check the properties of each catalog against observational or other data as deemed appropriate by the analysis working groups.

CS Key Product (DC2): Generic Catalog Reader (GCR) (CS11)
Host WG: CS
Objective: The Generic Catalog Reader (GCR) is a tool to facilitate the comparison of different sky catalogs by providing the interface to convert an arbitrary input catalog to a uniform output schema with known units. The GCR was developed as part of the DESCQA framework and the DC1 R&D project, CS3, but it now also exists as a stand-alone product that can be used by any aanalysis WG wishing to compare a number of different catalogs within the same analysis module.

Deliverable: *GCR interface available for all Sky Catalogs (DC2 SW)*

Host WG: CS *Started:* 10/01/16 *Originally due:* 01/31/18
Status: done *Completed:* 01/31/18
URL : https://github.com/LSSTDESC/gcr-catalogs
Objective: The GCR will be available for use with any sky catalog, including DC2 extragalactic object catalogs, special-purpose catalogs and CatSim instance catalogs.

CS Key Product (DC3): Advanced Tooling for Working with Cosmological Simulation Outputs (CS15)
Host WG: CS
Objective: In the DC3 era, we expect to need to upgrade the various tools we have for manipulating and transforming cosmological simulation outputs: this Key Product defines that suite of tools.

Deliverable: *DC3 Upgrade to GCR Interface (DC3 SW)*

Host WG: CS *Started:* 10/01/18 *Originally due:* 06/30/20
Status: anticipated *Anticipated:* 06/30/20
URL :
Objective: We anticipate needing to upgrade the GCR interface to cope with the various DC3 input catalogs, DRP output catalogs and analysis pipeline intermediates.

Deliverable: *DC3 Upgrade to DESCQA (DC3 SW)*

Host WG: CS *Started:* 10/01/18 *Originally due:* 06/30/20
Status: anticipated *Anticipated:* 06/30/20
URL :
Objective: We anticipate needing to upgrade DESCQA for DC3.

Deliverable: *DC3-Era Galaxy Model (DC3 SW)*

Host WG: CS *Started:* 10/01/18 *Originally due:* 06/30/20
Status: anticipated *Anticipated:* 06/30/20
URL :
Objective: We anticipate needing to write software to support the DC3-era extragalactic catalog generation.

5.3 Survey Simulation and Image Processing Pipelines

As well as an extragalactic catalog (Section 5.2), the ingredients needed to simulate an LSST dataset are a galactic catalog (of Milky Way stars), and a visit list (e.g. from an OpSim cadence simulation). From these, we can follow one of two paths. Either we a) simulate the LSST survey and produce mock LSST images, and then process them using the LSST DM stack software to make a mock LSST catalog, or we b) emulate an LSST catalog directly. We refer to "simulation" and "processing" as the separate, sequential steps in path a), because the processing pipeline is the same code we would run on real LSST images in order to probe for systematics. The second path, "emulation" is currently an R&D activity (Section 8.8). In this section we describe the components of the image simulation and processing pipelines, starting with the tools needed for image simulation.

SSim Key Product (DC3 & ComCam): IMSIM Development (imSim1)

Host WG: SSim

Objective: We describe current development efforts on IMSIM, a GalSim based Large Synoptic Survey Telescope (LSST) image simulation package used in the DESC. IMSIM development work is a wide ranging effort across the DESC and LSST project focused on improvements to fidelity, realism and performance. IMSIM development is focused both on creating simulated data to be used both for large (such as the data challenges) and small scale studies, and also for use in analysis during our data taking period. IMSIM development is managed by the IMSIM development team.

Deliverable: *Improve IMSIM performance (DC2 SW & DC3 SW & ComCam SW)*

Host WG: SSim *Started:* 01/01/18 *Originally due:* 01/01/21
Status: active *Expected:* 09/30/21
URL : https://github.com/LSSTDESC/imSim

Objective: Increasing run speeds and decreasing memory usage of IMSIM and underlying tools will allow us to scale up the area and depth of our large data challenges. Coupled with new features, these changes could also allow us to build detailed IMSIM simulations which include the control systems of the telescope. The goal would be to quickly simulate extended observing periods with time correlations. This work focuses on file formats, code restructuring, leveraging advanced computer architecture features etc.

Deliverable: *Add major features to IMSIM (DC2 SW & DC3 SW & ComCam SW)*

Host WG: SSim *Started:* 01/01/18 *Originally due:* 01/01/21
Status: active *Expected:* 09/30/21
URL : https://github.com/LSSTDESC/imSim

Objective: A major strength of IMSIM is the flexibility of having multiple algorithms and approaches for most important features. The user can easily select a full physics model for calculations such as the atmospheric PSF, or if not needed for a particular run, can choose parameterized models for increased speed instead. Crucially, the parameterized models can be tuned with the full models. Some pieces of the simulation, most notably the treatment of the telescope optics, are missing a full detailed simulation. This task will deliver new major functionality such as a full optical ray-tracer in IMSIM and the interfaces to the software packages it relies on.

Deliverable: *Increase the realism of* IMSIM *(DC3 SW & ComCam SW)*

Host WG: SSim *Started:* 01/01/18 *Originally due:* 01/01/21
Status: active *Expected:* 09/30/21
URL : https://github.com/LSSTDESC/imSim

Objective: This task encompasses work which make the IMSIM output more realistic. Increased realism will result both in a better test of the DESC and LSST pipelines and also eventually make the output more useful for analysis during the period of data taking. Work on this deliverable includes increases in fidelity to the sky model including variability, realistic morphology of astronomical sources, other galactic sources of light, important optical effects in the telescope including diffraction and ghosting, more realistic CCD sensor response etc. Some of this work is dependent on the addition of major features as outlined above.

SSim Key Product (DC1): DC1 Survey Simulation Tools (SSim1)
Host WG: SSim
Objective: Design the necessary software tools for production of the DC1 datasets and validate the fidelity of the output. This work will be done in collaboration with the analysis working groups and the computing infrastructure groups. Specifically, enable the production of the `Twinkles` and `DC1 Phosim Deep` DC1 datasets used by multiple working groups, and coordinate with teams developing simulation tools within individual working groups, such as the LSST images using millions of galaxy postage stamps produced by GALSIM in the Key Project "Requirements on shear estimation" (WL1).

The DC1 data challenges will predominantly rely on existing tools. `Twinkles` will use PHOSIM. However, the SL and SN groups also require oversampled and time dependent SN and lenses in the produced images for `Twinkles` which is currently not possible. The SSim group will work with the Twinkles Task Force and the LSST Project simulation team to implement the needed features in the production of the PHOSIM instance catalogs.

Deliverable: *Survey Simulation Tools for DC1 (DC1 SW)*

5: Pipelines and Computing Infrastructure - Survey Simulation and Image Processing Pipelines

Host WG: SSim *Started:* 10/01/15 *Originally due:* 01/01/16
Status: done *Completed:* 01/01/16
URL : https://github.com/LSSTDESC/SSim_DC1

Objective: To create a complete set of validation tests and a suite of survey simulation tools that meet the requirements for the DC1 datasets `Twinkles` and `DC1 Phosim Deep`. The emphasis is studying the capabilities of the tools, their interfaces, and the necessary infrastructure.

Prerequisites: All analysis working group DC1 requirements (DC1 RQ): Deliverable *"`Twinkles` CS, SS and DM Stack Requirements"*, R&D Activity *"Dither patterns for `DC1 Phosim Deep` simulations"*

Approach: First, collate requirements from the analysis working groups into a single, integrated image requirements document for each of the `Twinkles` and `DC1 Phosim Deep` datasets. Next, study the user and deveoper interfaces to check whether the implemented capabilities are sufficient to meet the analysis requirements of the working groups for DC1. Then extend the CATSIM framework to return multiple strongly lensed galaxies. In the `Twinkles` dataset the SL group requires multiple sources to be returned for each lensed object. Finally, validate the simulation tool fidelity. The goal will be to demonstrate sufficiency according to the requirements of DC1 set by the analysis working groups. Methods of validation should be specified.

Deliverable: *An LSST module in* GALSIM *(DC1 SW)*

Host WG: WL *Started:* 10/01/15 *Originally due:* 06/30/16
Status: defunct
URL :

Objective: As the first step in building WLIMSIM, construct an LSST-specific GALSIM module, including optics and (short-exposure) atmosphere PSFs, sensor response models adapted from SAWG models, key features of the sensor focal plane array layout, and image contributions from the 'spider' and vignetting. This module will be used for the WL DC1 data set generation in the R&D Activity *"Create WL DC1 simulated datasets"*. The LSST-specific features should be as simple as possible to yield useful forecasts and calibration of galaxy shear systematic errors.

Prerequisites: Deliverables *"Validation of the BF effect in simulations"*, *"Validation of static effects in* PHOSIM*"*

SSim Key Product (DC2): DC2 Survey Simulation Tools (SSim3)
Host WG: SSim

Objective: Design the necessary tools and validate the tools for the DC2 datasets, in collaboration with the analysis working groups and the Computing Infrastructure group. Enable the production of the DC2 datasets used by multiple working groups, and coordinate with teams developing simulation tools within individual working groups, such as the WL PSF modeling software *"Identify and characterize PSF systematic uncertainties"*. The DC2 data challenges will emphasize increased fidelity and sophistication along with an increase in simulated volume. DC2 will for the first time emphasize unification of data challenges across working groups. Time dependent sources, which in the past were included in the Twinkles framework, will now also be included in the DC2 dataset. Additionally, a field oversampled in time dependent sources will be embedded in the main data set. In coordination with the Project, the simulation framework will also be updated to allow more realistic time-dependent SEDs for SN and lensed sources, and lensed SN will for the first time be considered.

Deliverable: *Survey Simulation Tools for DC2 (DC2 SW)*

Host WG: SSim *Started:* 10/01/16 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: To create a complete set of validation tests and a suite of survey simulation tools that meet the requirements of the DC2 dataset. The analysis working groups will be requested to finalize a list of DC2 requirements for proposed analysis and validation projects and finally agree upon needed improvements and extensions to be implemented in our simulation tools. After the resulting code is initially validated, a limited test run will be produced and the analysis working groups will then use this data to validate that all effects were properly included.

Prerequisites: All analysis working group DC2 requirements (DC2 RQ): Deliverables *"DC2 Specifications"*, *"DC2 Time Domain Requirements"*, *"DC2 Time Domain Requirements"*, *"DC2 Time Domain Requirements"*, *"Optimal catalog splits into samples (TXSELECTOR)"*

Approach: The approach here is similar to DC1, starting with collecting requirements and studying user and developer interfaces. The validation work is more elaborate than in DC1 and will use 1) real data (laboratory or from other telescopes), 2) other test codes, 3) simplified analytic calculations, or 4) basic sanity check-type simulations. The goal will be to demonstrate sufficiency according to the DC2 requirements set by the analysis groups. Methods of validation should be specified.

Deliverable: *Validation of static effects in PHOSIM (DC2 VA)*

5: Pipelines and Computing Infrastructure - Survey Simulation and Image Processing Pipelines

Host WG: SA *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Perform necessary studies to validate the static effects in PhoSim code.

Deliverable: *Validation of the BF effect in simulations (DC2 VA)*

Host WG: SA *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: The BF effect implementation in PhoSim is based on an electrostatic model where the electric field is dependent on the charge stored in CCD wells. The implementation details need to be validated with respect to the data and adjusted if needed. This may require iterations with the PhoSim team, and should result in validated BF simulation software.

CI Key Product (DC2): DC2 DM DRP Processing Pipeline and Data Service (CI11)

Host WG: CI
Objective: The DC2 dataset should provide an intermediate scale test of survey conditions: we must demonstrate that we can reprocess significant amounts of survey data and execute DESC analysis pipelines on that data. This Key Product is the DESC's replica of the LSST DM data release production (DRP) pipeline, and a system for storing and serving the catalog data to the collaboration. This software addresses image processing at scale, and enabling final analysis of the resulting data. The processed data would need to be in standard catalog form, and by the current DM plan, accessed via a Qserv database server.

Deliverable: *A DESC-modified DM DRP Reprocessing Pipeline (DC2 SW)*

Host WG: CI *Started:* 10/01/16 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: DESC must replicate the LSST Project DM data release production (DRP) pipeline technology, such that the algorithms can be investigated and potentially replaced.

Deliverable: *Replica of the DM Catalog Technology (DC2 SW)*

5: Pipelines and Computing Infrastructure - Survey Simulation and Image Processing Pipelines

Host WG: CI *Started:* 10/01/16 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: DESC must replicate the Project/DM catalog technology to capture and serve its reprocessings of survey data.

CI Key Product (DC2): Enhanced Twinkles Framework to Handle DC2-level Requirements (CI7)
Host WG: CI
Objective: At DC2, the Twinkles program will also support the development of user-generated "SuperFit" algorithms, built against the MULTIFIT API to handle time-variable point sources and mixed point source / extended source models for optimal light curve extraction (see the Key Project "Supernova and Strong Lens Light Curves" (CX10)). Twinkles will provide an end-to-end testbed to prototype the software framework and develop the infrastructure to support distributed code development. The Twinkles images will be absorbed into `DC2`, and will extend `Twinkles` with additional DM algorithms, like deblending, photometry and multi-fit algorithms.

The CI-hosted R&D Activity in Key Project "Supernova and Strong Lens Light Curves" (CX2) is *"`Twinkles` SN and SL Light Curves"*: production of the light curves using the software assembled by the analysis WGs. That deliverable will depend on this one. We will develop the framework for running the monitoring pipelines in parallel with the development of that code (R&D Activities *"SUPERNOVAMONITOR 1.0"* and *"SLMONITOR 1.0"*), and then use the framework to carry out the calculations in a scaleable way.

Deliverable: *Pipeline for Extracting DC2 Light Curves (DC2 SW)*

Host WG: CI *Started:* 10/01/16 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: The Deliverable *"A framework for Twinkles light curve generation"* will be extended to include the additional pipeline elements needed for `DC2`.

Deliverable: *Workflow to execute the Light Curve Extraction pipeline. (DC2 SW)*

Host WG: CI *Started:* 10/01/16 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18

URL:

Objective: The Deliverable *"A framework for Twinkles light curve generation"* will be extended to include the additional pipeline elements needed for `DC2` and must extend the workflow definitions to allow running the full pipeline.

SSim Key Product (DC3): DC3 Survey Simulation Tools (SSim5)
Host WG: SSim
Objective: Design the necessary tools and validate the tools for the DC3 datasets, in collaboration with the analysis working groups and the CI group. Enable the production of the `DC3 Mock Lightcone` and `DC3 Mock ComCam Survey` DC3 datasets used by multiple working groups, and coordinate with teams developing simulation tools within individual working groups, such as the WL shear calibration simulation effort, "Simulations for shear catalog testing" (WL7). These datasets will be an order of magnitude larger than the previous DC simulations and will need to be run on large scale dedicated resources. The output will be processed by the LSST image pipeline which will require deblending, multi-epoch photometry, multi-epoch fitting, and PSF estimation algorithms.

The `DC3 Mock Lightcone` dataset, a 3000 sq degree, $ugrizy$ filter simulated survey produced from new cosmological simulations is primarily for use of the LSS and TJP groups. It will be used by Key Projects "Physics Beyond wCDM with LSST" (TJP2), "Determine LSS samples" (LSS1), "Code for Measuring Power and Cross-power Spectra" (LSS2), "Cosmological constraints from LSS" (LSS3), and "Systematics Caused by the LSST Observing Strategy" (CX11).

The `DC3 Mock ComCam Survey`, is a 6 month Wide-Fast-Deep, six filter simulated commissioning camera survey simulating a single 9 sensor raft observing approximately 1000 square degrees of the sky. The output will be used in Key Projects "Physics Beyond wCDM with LSST" (TJP2), "Code for Measuring Power and Cross-power Spectra" (LSS2), "Cosmological constraints from LSS" (LSS3), "Systematics Caused by the LSST Observing Strategy" (CX11), and "Simulations for shear catalog testing" (WL7).

The SSim group will work with CI to ensure the necessary infrastructure is in place for the simulation pipelines to run efficiently in the chosen computer data center environment as specified in the Key Product "DC3 Workflow and Data Management Configuration" (CI14).

Deliverable: *Survey Simulation Tools for DC3 (DC3 SW)*

5: Pipelines and Computing Infrastructure - Survey Simulation and Image Processing Pipelines

Host WG: SSim *Started:* 10/01/18 *Originally due:* 10/01/19
Status: planned *Expected:* 10/01/19
URL :

Objective: To create a complete set of validation tests and a suite of survey simulation tools that meet the requirements for the DC3 datasets `DC3 Mock Lightcone` and `DC3 Mock ComCam Survey`.

Prerequisites: All analysis working group DC3 requirements (DC3 RQ): Deliverables and R&D Activities *"Requirements on DC3 simulated datasets"*, *"CL Requirements for `DC3 Mock Lightcone`"*, *"`TDC3` Requirements"*, *"SL Requirements for DC3"*, *"LSS Observing strategy for `DC3 Mock Lightcone`"*, *"WL Observing strategy for `DC3 Mock ComCam Survey`"*

Approach: The approach for DC3 is again similar to the approach for DC1 and DC2, starting with listing requirements, studying user and developer interfaces, and carrying out a comprehensive validation study.

CI Key Product (DC3): Upgraded DM DRP Processing Pipeline and Data Service (CI15)

Host WG: CI
Objective: The DC3 datasets should provide a 30%-scale test of survey conditions (Section 6.3): we must demonstrate that we can reprocess significant amounts of survey data and execute DESC analysis pipelines on that data. Ideally the use case is development of DESC algorithms that would be fed back to the Project for inclusion in their subsequent reprocessings. This software addresses reprocessing at scale, using candidate DESC-modified DRP algorithms, running DESC analysis algorithms on the reprocessed data and enabling final analysis of the resulting data. The processed data and analysis pipeline output would need to be in standard catalog form, and by the current DM plan, accessed via a Qserv database server.

Deliverable: *Upgraded DESC DM DRP Reprocessing Pipeline (DC3 SW)*

Host WG: CI *Started:* 10/01/18 *Originally due:* 06/30/20
Status: active *Expected:* 06/30/20
URL :

Objective: For DC2, DESC replicated the LSST Project DM data release production (DRP) pipeline technology, such that its algorithms can be investigated and potentially replaced. For DC3 this pipeline will need to be upgraded to keep pace with the DM team's development.

Deliverable: *Upgraded Replica of the DM Catalog Technology (DC3 SW)*

Host WG: CI *Started:* 10/01/18 *Originally due:* 06/30/20
Status: planned *Expected:* 06/30/20
URL :

Objective: DESC must upgrade its replica of the Project/DM catalog technology to continue capturing its reprocessings of survey data.

CI Key Product (ComCam): SV-Ready DRP Processing Pipeline and Data Service (SV-DRP)
Host WG: CI
Objective: We will use the ComCam dataset to prepare a data release production pipeline and hosting service that is ready to go on the SV data.

Deliverable: *SV-Ready DESC DRP Pipeline (ComCam SW)*

Host WG: CI *Started:* 10/01/19 *Originally due:* 09/30/21
Status: anticipated *Anticipated:* 09/30/21
URL :

Objective: For SV the DESC's DRP pipeline will need to be upgraded to keep pace with the DM team's development, and be able to reproduce exactly the ComCam and SV catalogs released by the Project.

Deliverable: *SV-Ready Replica of LSST Science Platform (ComCam SW)*

Host WG: CI *Started:* 10/01/19 *Originally due:* 09/30/21
Status: anticipated *Anticipated:* 09/30/21
URL :

Objective: DESC must implement a replica of the Project's Science Platform to host its reprocessings of the SV data, including the infrastructure needed in the replication, eg a qserv instance.

5.4 Weak Lensing Pipeline

In this section, we focus on the development of pipelines to go from input images to accurate two-point statistics and cosmology derived from them. The WL and LSS working groups are collaboratively building a pipeline for joint analysis of these probes to the point of summary statistics. A schematic of that pipeline, TXPIPE, is shown in Figure 5.4.1. The rest of the analysis, in particular the likelihood analysis that goes from summary statistics to cosmological parameters, will take place within TJPCOSMO. In practice, the "images to catalogs" and "catalogs to cosmology" parts of the pipeline are developed in separate stages. The high-level development path is as follows:

- **DC1 era**: development of "catalogs to cosmology" pipeline for shear-shear correlations within WL group (and parallel LSS clustering development within LSS group).
- **DC2 era**: development of "images to catalogs" shear pipeline and extension of "catalogs to cosmology" pipeline to include additional two-point correlations (galaxy-shear and galaxy-galaxy), so as to have a complete TXPIPE implementation that covers the WL and LSS analyses; development of systematics models for modeling and marginalization purposes.
- **DC3 era**: further development of systematics models and algorithms in TXPIPE to ensure it meets DESC requirements for systematics control. The deliverables for this era are most uncertain, since the DC2 pipeline development and validation will inform our priorities for DC3.
- **SV era**: application of TXPIPE to the SV data, including adaptation of the code to real data. Possible extension of the framework to support additional advanced algorithms.

Documentation of the plans at a higher level of detail, and more finely-grained timelines, will be included in more transient documents (DESC Notes and GitHub issues). All major pipeline activities will be documented in one of the above ways.

WL Key Product (DC1): Weak Lensing Pipeline (WLPIPE)
Host WG: WL
Objective: Build the prototype weak lensing pipeline WLPIPE WL pipeline analysis stages. WLPIPE constitutes a well-defined subset of the analysis process that will eventually be carried out by DC2-era software TXPIPE (Figure 5.4.1), in two respects: it does not include the "images to catalogs" part of the process, and it only covers shear-shear correlations, not the full 3×2-point analysis (with galaxy-shear and galaxy-galaxy correlations included).

Deliverable: *Pipeline for WL Cosmology Constraints from a Shear Catalog (DC1 SW)*

Host WG: WL *Started:* 10/01/15 *Originally due:* 06/30/18
Status: done *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/WLPipe

Objective: The goal of this deliverable is to produce a prototype of the "catalogs to cosmology" pipeline, which should be able to take catalogs with shear estimates that have already been calibrated, and photometric redshift estimates, and produce cosmological parameter constraints from shear-shear correlations.
Prerequisites:

Deliverable: WLPIPE *Validation (DC1 VA)*

Host WG: WL *Started:* 10/01/15 *Originally due:* 06/30/18
Status: done *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/WLPipe

Objective: WLPIPE validation is carried out through analysis of catalogs from precursor survey, in addition to internal cross-checks. A cross-survey cosmic shear comparison paper should result from this process.
Prerequisites: Deliverable *"Pipeline for WL Cosmology Constraints from a Shear Catalog"*

Deliverable: *Workflow management system applied to DC1 WL workflow* WLPIPE *(DC2 SW)*

Host WG: WL *Started:* 10/01/16 *Originally due:* 06/30/18
Status: done *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/WLPipe/tree/master/parsl_wlpipe

Objective: In collaboration with the CI working group, evaluate and use a workflow management system to coordinate the flow of data within WLPIPE, impose the dependencies of each step on previous steps, and provide a coherent structure for the overall pipelines. This should include the ability to submit jobs on HPC facilities.
Prerequisites: Deliverable *"Pipeline for WL Cosmology Constraints from a Shear Catalog"*

Deliverable: *Extension of* WLPIPE *to 3x2-point analysis (DC2 SW)*

Host WG: WL *Started:* 10/01/17 *Originally due:* 07/01/18
Status: done *Completed:* 07/01/18
URL : https://github.com/LSSTDESC/WLPipe

Objective: Extend the WLPIPE framework to include the full 3x2-point analysis, i.e., shear-shear, shear-galaxy, galaxy-galaxy correlations.

Prerequisites: Deliverables *"Pipeline for WL Cosmology Constraints from a Shear Catalog"*, *"Workflow management system applied to DC1 WL workflow* WLPIPE*"*

WL Key Product (DC2): Weak Lensing and Large-Scale Structure Pipeline (TXPIPE-DC2)
Host WG: WL
Objective: Build the more complete WL pipeline illustrated in Figure 5.4.1. Note that the analysis stage called "PZEstimationPipe" is provided by PZ, while "TXSysMapMaker" and "TXRandoms" are provided by LSS. These stages are not listed below, since this subsection is specifically for WL infrastructure activities. For the analysis stages listed below, some will have contributions from multiple groups, but WL is leading or coordinating the effort.

Deliverable: *Pipeline tools that connect to workflow management system (*CECI*) (DC2 SW)*

Host WG: WL *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL : https://github.com/LSSTDESC/ceci
Objective: After exploration of workflow management tools in general, develop a lightweight framework (CECI) for using our adopted DC2-era WMS (Parsl) to easily run DESC pipelines.
Prerequisites: Deliverables *"Pipeline for WL Cosmology Constraints from a Shear Catalog"*, *"Workflow management system applied to DC1 WL workflow* WLPIPE*"*

Deliverable: *Pipeline for Producing a Shear Catalog (*SHEARMEASUREMENTPIPE*) (DC2 SW)*

Host WG: WL *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL : https://github.com/EiffL/metacal-pipeline
Objective: Using as many DM tools as possible, put together an end-to-end pipeline (the analysis stage in Figure 5.4.1 called SHEARMEASUREMENTPIPE) to process a set of images and produce a shear catalog. The catalog should include estimators of the shear, size, S/N, and a covariance matrix of these quantities, along with ancillary information such as the mean PSF size and shape used for the analysis, the list of positions on the focal plane that were used, etc.. Note that not all methods produce a useful shape estimate on each object – certain hierarchical methods, for example, generate the ensemble shear estimation from a set of quantities of the galaxy sample. Currently the default shear estimation algorithm adopted is MetaCalibration (Metacal, Sheldon 2014), with the Bayesian Fourier domain (BFD, Bernstein & Armstrong

2014) method being a second proposed algorithm. In addition, some thought will be required to see how hierarchical methods that do not even do this can fit into this framework.
Prerequisites: Deliverables *"Implemented and Validated Correction Algorithm for the BF Effect"*, *"Validation of correction algorithms for static effects"*, *"Pipeline tools that connect to workflow management system (CECI)"*

Deliverable: *Source selector and tomographic binning definition software (TXSELECTOR) (DC2 SW)*

Host WG: WL *Started:* 07/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL : https://github.com/LSSTDESC/TXPipe/blob/master/txpipe/selector.py

Objective: Develop the TXSELECTOR analysis stage (see Figure 5.4.1), which selects sources to use and divides them into tomographic bins for WL and LSS analysis.
Prerequisites: Deliverable *"Pipeline for WL Cosmology Constraints from a Shear Catalog"*

Deliverable: *Source summarizer analysis stage (SOURCESUMMARIZER) (DC2 SW)*

Host WG: WL *Started:* 07/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Develop the SOURCESUMMARIZER analysis stage (see Figure 5.4.1), which computes ensemble summary statistics for the tomographic bins (e.g., number densities, shape noise). These values will be input to the covariance calculation in *"Covariances for the joint WL+LSS analysis (TXCOV)"*.
Prerequisites: Deliverable *"Pipeline for WL Cosmology Constraints from a Shear Catalog"*

Deliverable: *Software for two-point statistics (TXTWOPOINT) (DC2 SW)*

Host WG: WL *Started:* 07/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL : https://github.com/LSSTDESC/TXPipe/blob/master/txpipe/twopoint.py

Objective: Develop the TXTWOPOINT analysis stage (see Figure 5.4.1) that can efficiently calculate the relevant two-point statistics given a catalog, building on relevant pre-existing software. Note that unlike the two-point correlation analysis stage in DC1 software WLPIPE, TXTWOPOINT should generalize beyond shear-shear correlations to other relevant two-point correlations, such as shear-galaxy and galaxy-galaxy correlations. The null tests of the Deliverable *"Null test pipeline (WLNULLTEST)"* should be applied to these statistics. In practice, there will be a configuration- and Fourier-space version of this analysis stage.

Prerequisites: Deliverable *"Software for characterizing mask as a function of pixelization using DM tools"*; overlap with Deliverable *"Power-spectrum estimation code (TXTwoPoint)"*, *"Pipeline for WL Cosmology Constraints from a Shear Catalog"*, *"Extension of WLPipe to 3x2-point analysis"*

Deliverable: *Covariances for the joint WL+LSS analysis (TXCov) (DC2 SW)*

Host WG: WL *Started:* 07/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Develop the TXCov analysis stage (see Figure 5.4.1), which estimates quick covariances for the pipeline using simple methods or serves as an interface to the TJPCov framework. The likelihood analysis will use TJPCov, but for some purposes (like null tests and sanity checks) having a simple covariance estimator in the pipeline at an earlier stage is necessary.
Prerequisites:

Deliverable: *Summary statistic collector (TXSummaryStatistic) (DC2 SW)*

Host WG: WL *Started:* 07/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Develop the TXSummaryStatistic analysis stage (see Figure 5.4.1), which aggregates information in a form to be ingested by TJPCosmo.
Prerequisites:

Deliverable: *Validation of TXPipe (DC2 VA)*

Host WG: WL *Started:* 03/31/19 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Once the DC2 prototype of TXPipe is put together, it should be validated using precursor survey datasets and DC2 simulations.
Prerequisites: Deliverables *"Pipeline tools that connect to workflow management system (ceci)"*, *"Pipeline for Producing a Shear Catalog (shearMeasurementPipe)"*, *"Source selector and tomographic binning definition software (TXSelector)"*, *"Source summarizer analysis stage (SourceSummarizer)"*, *"Software for two-point statistics (TXTwoPoint)"*, *"Covariances for the joint WL+LSS analysis (TXCov)"*, *"Summary statistic collector (TXSummaryStatistic)"*

WL Key Product (DC2): Weak Lensing Mass Maps and Map-Based Statistics (WLMassMap-DC2)

Host WG: WL
Objective: Build a pipeline that generates weak lensing mass maps and evaluates certain map-based statistics. This pipeline will reuse components of TXPipe (e.g. ceci, TXSelector, SourceSummarizer) whenever possible.
Prerequisites:

Deliverable: *Pipeline to generate weak lensing mass maps (DC2 SW)*

Host WG: WL *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL : https://github.com/LSSTDESC/WLMassMap

Objective: A Pipeline that takes in a shear catalog and generates weak lensing convergence maps as well as a number of map-based statistics.
Prerequisites: Deliverable *"Pipeline tools that connect to workflow management system (ceci)"*, *"Pipeline for Producing a Shear Catalog (shearMeasurementPipe)"*, *"Source selector and tomographic binning definition software (TXSelector)"*, *"Source summarizer analysis stage (SourceSummarizer)"*, *"Software for two-point statistics (TXTwoPoint)"*

WL Key Product (DC2): WL Systematic Uncertainty Characterization Framework (WL2)

Host WG: WL
Objective: Develop a framework for handling systematic errors, including both errors in the shear catalog, and theoretical systematics (e.g., intrinsic alignments, baryonic mass), including (where appropriate) developing models of the systematics to be used within this framework and a process for marginalizing over them. The software developed here will be used as a separate stage to validate outputs of the shear measurement pipeline from TXPipe, and/or as inputs to the TJPCosmo likelihood modeling framework.
Prerequisites:

Deliverable: *Null test pipeline (WLNullTest) (DC2 SW)*

Host WG: WL *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: Set up a pipeline, WLNULLTEST, that can run a set of lensing-related null tests on catalog-level data, including one a variety of one-point and two-point statistics. Examples of one-point statistics include shear vs PSF shape, star-galaxy correlations, mean shear vs. galaxy properties, B-mode, consistency of shear correlation functions and systematics when dividing by observational conditions and galaxy properties, etc.. Examples of two-point statistics include tests that $\xi_{\pm}$ are not different when splitting on airmass, PSF size, PSF shape, etc.. See e.g., Jarvis et al. 2015 and Becker et al. 2015; Zuntz et al. 2018 for a list of these null tests. *Note: At least for DC2, this Deliverable is distinct from the two-point estimators* LSSTWOPOINT *(Deliverable "Power-spectrum estimation code (*TXTWOPOINT*)") because of the need to develop shear E/B mode correlation estimators on a short timescale.* This pipeline will be extended in DC3 to include null tests for higher-order statistics.
Prerequisites: Deliverable *"Software for two-point statistics (*TXTWOPOINT*)"*, *"Pipeline to generate weak lensing mass maps"*, *"Software for characterizing mask as a function of pixelization using DM tools"*

Deliverable: *Identify and characterize PSF systematic uncertainties (DC2 SW)*

Host WG: WL *Started:* 07/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Here we separate PSF-related systematic uncertainties from other sources of systematics for its unique role in shear estimation. PSF systematics here is categorized to include atmosphere, optics, and sensor image transfer functions, including chromatic effects at each stage. This deliverable provide models of their impact in shear correlation measurements. This is connected to the PSF modeling and interpolation framework to be used by the shear estimation analysis stage (c.f. Deliverable *"Pipeline for Producing a Shear Catalog (*SHEARMEASUREMENTPIPE*)"*). Work is needed within the DESC on evaluation of the new algorithm in comparison with other state-of-the-art methods such as PIFF, in comparison with our requirements for WL science. The development and testing of models for PSF systematics will use DC2 simulations and simulation codes for sensor systematics including POISSON_CCD[4]. Validate the systematics model effectiveness with the null test pipeline from the Deliverable *"Null test pipeline (*WLNULLTEST*)"*.
Prerequisites: Deliverables *"Validation of the BF effect in simulations"*, *"Validation of static*

[4]https://github.com/craiglagegit/Poisson_CCD

effects in PHOSIM*"*, *"Null test pipeline (*WLNULLTEST*)"*

Deliverable: *Identify and characterize non-PSF systematic uncertainties (DC2 SW)*

Host WG: WL *Started:* 07/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Provide computational implementations of models for how observational systematics that we want to marginalize over impact the WL observables (shear-shear and galaxy-shear correlations), plus priors on the parameters of those models in the TJPCOSMO pipeline (we do not expect all WL-specific systematics to be available in TJPCOSMO without this Deliverable). Validate the systematics model effectiveness with the null test pipeline from the Deliverable *"Null test pipeline (*WLNULLTEST*)"*. The systematics to be considered here include star/galaxy separation, blending, impact of unresolved sources, shear calibration errors, photo-z errors, and depth variation across the survey area.
Prerequisites: Deliverables and Activities *"Null test pipeline (*WLNULLTEST*)"*, *"$p(z)$ for DC1 Galaxies"*, *"Software to quantify impacts of blending"*, *"Models of residual observational systematic effects on observables"*

WL Key Product (DC3): Updated Weak Lensing and Large-Scale Structure Pipeline (TXPIPE-DC3)
Host WG: WL
Objective: Further upgrade the combined WL+LSS pipeline illustrated in Figure 5.4.1 as needed for future analyses, aimed at reaching the level of systematics control needed for LSST. This key project includes some work that was deliberately deferred to a later stage in pipeline development, and will be updated later based on lessons learned during DC2 about additional functionality that is needed to meet the DESC science requirements.

Deliverable: *Improved shear pipeline (DC3 SW)*

Host WG: WL *Started:* 03/31/19 *Originally due:* 07/01/20
Status: planned *Expected:* 07/01/20
URL :

Objective: Make necessary improvements to the shear measurement pipeline to handle the larger data volume and additional realism of the DC3 simulated data and any data from precursor datasets that is used to test the pipeline. In addition to the shear estimates, the pipeline

should also be producing accurate size estimates of the galaxies for use in magnification measurements (along with corresponding null tests).
Prerequisites: Deliverables and Activities *"Pipeline for Producing a Shear Catalog (*SHEARMEASUREMENTPIPE*)"*, *"Develop shear catalog selection criteria"*, *"Identify and characterize PSF systematic uncertainties"*

Deliverable: *Proper handling of chromatic effects (DC3 SW)*

Host WG: WL *Started:* 03/31/19 *Originally due:* 07/01/20
Status: planned *Expected:* 07/01/20
URL :

Objective: Include in the shear estimation pipeline proper handling and testing of chromatic effects in the data. This involves estimating the appropriate PSF to use for each galaxy based on its SED and the wavelength dependence of the PSF. There should also be a number of new null tests being run to test for systematics related to chromaticity.
Prerequisites: Deliverables and Activities *"Null test pipeline (*WLNULLTEST*)"*, *"Identify and characterize PSF systematic uncertainties"*, *"Shear Deblending in DC2 cluster fields"*, *"Validation of the BF effect in simulations"*, *"Implemented and Validated Correction Algorithm for the BF Effect"*, *"Validation of static effects in* PHOSIM*"*, *"Validation of correction algorithms for static effects"*

Deliverable: *Proper handling of neighbors (DC3 SW)*

Host WG: WL *Started:* 03/31/19 *Originally due:* 07/01/20
Status: planned *Expected:* 07/01/20
URL :

Objective: Make sure the shear measurement pipeline is properly handling blended objects and neighbors. The code for doing this should have been developed as part of Key Project "Impacts of Blending" (CX1). The WL-specific task within this Key Project is to develop null tests to confirm that there are not significant artifacts in the shear catalog due to blending or close neighbors. In particular, this includes two regimes: bright nearby objects that affect the local background level (both amplitude and slope) and fainter objects that are very close to the object being measured for which deblending techniques are required for accurate shear measurements.
Prerequisites: Deliverables and Activities *"Null test pipeline (*WLNULLTEST*)"*, *"Identify and characterize PSF systematic uncertainties"*, *"Identify and characterize non-PSF systematic uncertainties"*, *"Shear Deblending in DC2 cluster fields"*, *"Software to calibrate deblender residuals with extra data"*, *"Results from DC2 DDF catalog simulations"*

Deliverable: *Pipeline for magnification (*WLMAGPIPE*) (DC3 SW)*

Host WG: WL *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: Develop a pipeline, WLMAGPIPE, that can produce accurate lensing magnification estimates as an additional WL probe.
Prerequisites: Deliverables and Activities *"Improved shear pipeline"*, *"Results from* `DC1 Phosim Deep`*"*, *"LSS Observing strategy for* `DC3 Mock Lightcone`*"*; overlap with *"Results from* `DC3 Mock Lightcone`*"*

Deliverable: *Pipeline for validating shear calibration (DC3 SW)*

Host WG: WL *Started:* 03/31/19 *Originally due:* 07/01/20
Status: planned *Expected:* 07/01/20
URL :

Objective: Work with LSST DM and the computing working groups to set up a software pipeline that can automatically test the shear catalogs. This will likely tie closely to the pipeline produced by Key Project "Images to shear catalog I" (WL3).
Prerequisites: *"Generate and test shear catalog"*.

WL Key Product (SV): Applied Weak Lensing and Large-Scale Structure Pipeline (TXPIPE-SV)
Host WG: WL
Objective: Adapt the combined WL+LSS pipeline to SV data, incorporating lessons learned during the DC3 era (including ComCam testing). Extend the pipeline to support alternative advanced algorithms.

Deliverable: *At-scale* TXPIPE *Application (SV SW)*

Host WG: WL *Started:* 07/01/20 *Originally due:* 09/30/22
Status: anticipated *Anticipated:* 09/30/22
URL :

Objective: Adapt the TXPIPE code to the real SV data, to run at scale and without error.
Prerequisites:

Deliverable: TXPIPE *SV Extensions (SV SW)*

Host WG: WL *Started:* 07/01/20 *Originally due:* 09/30/22
Status: anticipated *Anticipated:* 09/30/22
URL :
Objective: Extend the TXPIPE pipeline to support additional advanced algorithms.
Prerequisites:

5.5 Large Scale Structure Pipeline

The focus of this subsection is development of a pipeline for large-scale structure analysis. The WL and LSS working groups are collaboratively building a pipeline for joint analysis of these probes to the point of summary statistics. A schematic of that pipeline, TXPIPE, is shown in Figure 5.4.1. The rest of the analysis, in particular the likelihood analysis that goes from summary statistics to cosmological parameters, will take place within TJPCOSMO. The high-level development path is as follows:

- **DC1 era**: development of LSS-only pipeline within the LSS working group, largely independent of other working groups.
- **DC2 era**: development of TXPIPE jointly with the WL working group and other relevant groups such as PZ, so as to have a complete TXPIPE implementation that covers the WL and LSS analyses; development of systematics models for modeling and marginalization purposes.
- **DC3 era**: further development of systematics models and algorithms in TXPIPE to ensure it meets DESC requirements for systematics control. The deliverables for this era are most uncertain, since the DC2 pipeline development and validation will inform our priorities for DC3.
- **SV era**: application of TXPIPE to the SV data, including adaptation of the code to real data. Possible extension of the framework to support additional advanced algorithms.

Documentation of the plans at a higher level of detail, and more finely-grained timelines, will be included in more transient documents (DESC Notes and GitHub issues). All major pipeline activities will be documented in one of the above ways.

LSS Key Product (DC1): DC1 LSS Pipeline (LSS-DC1)
Host WG: LSS
Objective: Build the LSS pipeline for DC1 analysis.

Deliverable: *Software for storing correlation function and covariance information (SACC) (DC1 SW)*

Host WG: LSS *Started:* 10/01/15 *Originally due:* 04/01/17
Status: done *Completed:* 04/01/17
URL : https://github.com/LSSTDESC/sacc
Objective: Build software for storing and transferring information about two-point correlations and their covariances.
Prerequisites:

Deliverable: *Two-point preliminary studies (DC1 SW)*

Host WG: LSS *Started:* 04/01/17 *Originally due:* 06/30/18
Status: done *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/2pt_validation
Objective: Explore optimal techniques to estimate reliable two-point functions: Exploratory study of existing (and non-existing) methods for two-point estimation for large-area datasets in the presence of systematic uncertainties. Optimality should be evaluated in terms of computational speed, robustness against systematics, simplicity and error bar size.
Prerequisites: Deliverable *"Temporary survey coverage tools"*

Deliverable: *Validation tests of DC1-era LSS pipeline on simulations (DC1 VA)*

Host WG: LSS *Started:* 04/01/17 *Originally due:* 06/30/18
Status: done *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/LSS_DC1_paper
Objective: Apply DC1-era LSS tools to DC1 simulations to validate them and develop understanding of future needs.
Prerequisites: Deliverable *"Software for storing correlation function and covariance information (SACC)"*, Deliverable *"Temporary survey coverage tools"*, Deliverable *"Two-point preliminary studies"*

Deliverable: *Validation tests of DC1-era LSS pipeline on precursor datasets (DC1 VA)*

Host WG: LSS *Started:* 04/01/17 *Originally due:* 06/30/18
Status: done *Completed:* 06/30/18

URL : https://github.com/LSSTDESC/HyperSupremeStructure-HSC-LSS

Objective: Apply DC1-era LSS tools to the HSC survey dataset to validate them and develop understanding of future needs.

Prerequisites: Deliverable *"Software for storing correlation function and covariance information (SACC)"*, Deliverable *"Temporary survey coverage tools"*, Deliverable *"Two-point preliminary studies"*

LSS Key Product (DC2): LSS Pipeline Components of TXPIPE (LSS4/TXPIPE)

Host WG: LSS

Objective: Build the LSS-specific pipeline pieces of the Key Project "Weak Lensing and Large-Scale Structure Pipeline" (TXPIPE-DC2) and illustrated in Figure 5.4.1. In some cases, this involves building a Fourier-space version of analysis stages for which the WL group is building configuration-space versions, hence the analysis stage appears in multiple sections.

Deliverable: *Power-spectrum estimation code (TXTWOPOINT) (DC2 SW)*

Host WG: LSS *Started:* 10/01/17 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL : https://github.com/DESC/NaMaster

Objective: Measure power spectra for any number of spin-0 and spin-2 projected quantities.

The main Deliverable of this effort is a well-written and documented code (a Fourier-space version of TXTWOPOINT, a module in TXPIPE) that can compress positions of billions of objects, their shear estimates, their photo-z estimates and their window function into a 2-point function measurement in either Fourier or configuration space, using the information gathered in the Deliverable *"Two-point preliminary studies"*. This code can marginalize over systematic templates and provides uncertainty estimates based on several different methods. It should also be possible to use this code for null tests (e.g. correlation with known systematics), which will be necessary at any validation stage.

Prerequisites: Deliverable *"Two-point preliminary studies"*

Deliverable: *Two-point storage framework (DC2 SW)*

Host WG: LSS *Started:* 10/01/17 *Originally due:* 07/01/18
Status: active *Expected:* 07/01/18
URL : https://github.com/LSSTDESC/sacc

Objective: Optimized file format for two-point statistics and covariances

Development of self-contained and well documented file format able to store a large number of generic two-point statistics between pairs of tracers, as well as all of the information needed to perform a science analysis of them, including spins, tracer types, binning schemes, units, window functions, and covariance matrices.

Ideally, the format should be extended to also accommodate 1-point measurements (e.g. cluster number counts), possibly linked to the two-point functions of the same samples.
Prerequisites: Deliverable *"Software for storing correlation function and covariance information (SACC)"*

Deliverable: *Optimal catalog splits into samples (*TXSELECTOR*) (DC2 SW)*

Host WG: LSS *Started:* 10/01/17 *Originally due:* 12/31/19
Status: planned *Expected:* 12/31/19
URL :

Objective: Study optimal methods for sample separation

It is not a priori clear what the optimal way of dividing a given photometric sample into subsamples is in order to preserve the maximum amount of cosmological information. Optimality here can be defined in different terms, e.g. signal-to-noise maximization, robustness against known systematics or minimum variance of final parameters. This Deliverable will explore different possibilities based on true observables (fluxes), derived quantities (photo-z properties) or physical properties of the galaxy population. It will result in creation of a version of the TXSELECTOR analysis stage in TXPIPE.

Deliverable: *Basic LSS likelihood module (*LSSCOSMO*) contribution to* TJPCOSMO *(DC2 SW)*

Host WG: LSS *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL : https://github.com/LSSTDESC/LSSLike

Objective: Develop likelihood code with realistic nuisance parameters

Develop a likelihood code able to transform a set of measured two-point statistics (stored in the format of the Deliverable *"Two-point storage framework"*) into constraints on cosmological and basic nuisance parameters (e.g. bias parameters, photo-z systematics), making use of CCL. This will involve interfacing with TJP to make sure the LSS theory needs are met (e.g. in terms of bias parametrizations or clustering models) and potentially also with WL and PZ.

Deliverable: *Validation tests of DC2-era LSS pipeline on simulations (DC2 VA)*

Host WG: LSS *Started:* 07/01/18 *Originally due:* 12/31/19
Status: planned *Expected:* 12/31/19
URL :

Objective: Apply DC2-era LSS tools, as implemented in TXPIPE and TJPCOSMO, to DC2 simulations to validate them.
Prerequisites: Deliverable *"Two-point storage framework"*, Deliverable *"Power-spectrum estimation code (*TXTWOPOINT*)"*, Deliverable *"Basic LSS likelihood module (*LSSCOSMO*) contribution to* TJPCOSMO*"*

Deliverable: *Validation tests of DC2-era LSS pipeline on precursor datasets (DC2 VA)*

Host WG: LSS *Started:* 07/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL : https://github.com/LSSTDESC/HyperSupremeStructure-HSC-LSS

Objective: Apply DC2-era LSS tools, as implemented in TXPIPE and TJPCOSMO, to existing precursor datasets. This is a continuation of the analysis of the HSC DR1 data *"Validation tests of DC1-era LSS pipeline on precursor datasets"* as well as other precursor data (DES and KiDS) to probe different ranges of data volume and scales.
Prerequisites: Deliverable *"Two-point storage framework"*, Deliverable *"Power-spectrum estimation code (*TXTWOPOINT*)"*, Deliverable *"Basic LSS likelihood module (*LSSCOSMO*) contribution to* TJPCOSMO*"*

LSS Key Product (DC1 & DC2): Survey geometry (CX3)
Host WG: LSS
Objective: Several of the analysis Working Groups will need a *mask* in order to extract cosmological results from catalogs. While different groups have different needs, the following type of functionality should generically be supported: identifying regions in which galaxies could not be observed even if present, such as those near bright stars; quantifying position-dependent information about survey depth and number density (which goes beyond a binary yes/no and requires floating point numbers such as limiting magnitudes in various bands to be tracked). The dependence of the mask on depth and SED may also not be trivial, since dust extinction may differentially obscure galaxies with different SEDs. Since there will be multiple definitions of magnitude and each of these applies in different bands, there will be a large variety of masks produced and used by the analysis WGs.

The Large Scale Structure WG will produce accurate clustering statistics of galaxies only if the expected number of galaxies in the absence of clustering in every pixel is known. The covariance matrix on estimates of shear statistics that will be produced and used by the WL WG will be informed by the number density of galaxies as a function of redshift used in each pixel, a number that relies on the mask. The richness of galaxy clusters will require a mask that uses multiple bands and has particular angular requirements. Photometric redshifts cut across many of the WG's, and these too will require a wide variety of masks. Even photometric redshift algorithms based solely on colors require depth masks in different bands to ensure completeness; those that use clustering information are even more heavily dependent on accurate masks.

Beyond these masks aimed at the *signal*, the collaboration will produce maps of systematics, and these too rely on having a robust framework to map survey geometry. Various observational quantities that might be relevant for masking and more generally for null tests, such as the mean and median seeing, sky noise, and airmass, should be stored in a pixelized format similar to that used for the mask.

LSST DM plans to produce tools for some of the above; among the first part of this task is to more fully investigate what they will produce and when, to enable the DESC to use as much of their infrastructure as possible. This key project is hosted by LSS but requires input from other working groups.

Deliverable: *Temporary survey coverage tools (DC1 SW)*

Host WG: LSS *Started:* 10/01/15 *Originally due:* 06/30/18
Status: defunct
URL : https://github.com/LSSTDESC/LSS_utils

Objective: Since DM tools for quantifying survey geometry are not available during DC1, the LSS group must port over pre-existing tools for use during DC1 and the start of DC2. A variety of tools are under consideration for this purpose.
Prerequisites: None

Deliverable: *Survey mask use cases (DC2 RQ)*

Host WG: LSS *Started:* 07/01/18 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: In order to further understand our needs and to properly convey them to LSST DM, it will be helpful to collect a set of use cases for survey geometry tools, including their requirements with respect to flexibility in the range of scales represented, speed, etc. The results of this survey should be discussed within the collaboration and with DM.

Prerequisites: None

Deliverable: *Software for characterizing mask as a function of pixelization using DM tools (DC2 SW)*

Host WG: CI *Started:* 03/31/19 *Originally due:* 12/31/19
Status: planned *Expected:* 12/31/19
URL :

Objective: Once DM tools for characterizing survey geometry in place, the LSS working group will provide software that uses those tools to carry out a reasonable subset of the identified use cases, ranging from binary in/out to 2D and 3D floating-point maps.
Prerequisites: Deliverable *"Survey mask use cases"*

Deliverable: *Random points software (TXRANDOMS) for TXPIPE (DC2 DP)*

Host WG: LSS *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: The combined WL+LSS pipeline TXPIPE needs a module to generate random points using the tools developed as part of *"Software for characterizing mask as a function of pixelization using DM tools"*. Since these tools may take some time to develop, preliminary work will take place using in-house software based on the LSS work carried out as part of *"Validation tests of DC2-era LSS pipeline on precursor datasets"*.
Prerequisites: Deliverable *"Software for characterizing mask as a function of pixelization using DM tools"*

Deliverable: *Maps of systematics: TXSYSMAPMAKER for TXPIPE (DC2 DP)*

Host WG: LSS *Started:* 07/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Apply the mask framework from the Deliverable *"Software for characterizing mask as a function of pixelization using DM tools"* to make maps of systematics (seeing, PSF asymmetry, airmass, sky noise, dust extinction, stellar density, survey depth) for the DC2 dataset. The resulting software will serve as the TXSYSMAPMAKER analysis stage in TXPIPE. Since the mask framework may take some time to develop, preliminary work will take place using in-house software based on the LSS work carried out as part of *"Validation tests of DC2-era LSS pipeline on precursor datasets"*. These maps will be shared with all working groups and used as templates for systematics searches including null tests.

Prerequisites: Deliverables *"Software for characterizing mask as a function of pixelization using DM tools"*,*"DC2 Simulated Images"*

LSS Key Product (DC3): Improved LSS Pipeline Components (TXPIPE-LSS)
Host WG: LSS
Objective: Further upgrade the LSS-specific pipeline components illustrated in Figure 5.4.1 as needed for future analyses, aimed at reaching systematics control and improved statistical precision. This key project includes some work that was deliberately deferred to a later stage in pipeline development, and will be updated later based on lessons learned during DC2 about additional functionality that is needed to meet the DESC science requirements.

Deliverable: *Joint pipeline with CMB data (DC3 SW)*

Host WG: LSS *Started:* 03/31/19 *Originally due:* 06/30/20
Status: planned *Expected:* 06/30/20
URL :

Objective: Extend DC2-era LSS analysis pipeline (e.g. *"Power-spectrum estimation code (TXTWOPOINT)"* and *"Two-point storage framework"*) to include the joint analysis of LSS data with external CMB data, with a particular emphasis on secondary anisotropies (lensing, SZ and ISW). Validate the new tools making use of simulations and precursor LSS and CMB data.
Prerequisites: Deliverables *"Power-spectrum estimation code (TXTWOPOINT)"* and *"Two-point storage framework"*

Deliverable: *Optimal deblending for LSS (DC3 SW)*

Host WG: LSS *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: Study optimal methods for deblending of sources at weaker SNR Blending of sources will be a major issue for LSST LSS analysis. It is clear that deblending of sources for use in WL will have more stringent requirements than for sources than only need to separate fluxes to be used as point tracers. We will study if sources that are rejected for use for shear can be salvaged for use as point tracers and if probabilistic catalog can be used for better systematic control and smaller statistical errors. These will eventually become part of TXPIPE.

Prerequisites: Deliverables *"Shear Deblending in DC2 cluster fields"*, *"Software to calibrate deblender residuals with extra data"*

5.6 Clusters Pipeline

The focus of this subsection is development of a pipeline for cosmological analysis with galaxy clusters. The galaxy clusters (CL) working group has two parallel analysis pathways: a fully stacked analysis pathway that includes cluster 1- and 2-point statistics, and a pathway that involves individual cluster shear profiles. While both can rely on similar inputs to the data analysis and similar analysis stages, the likelihood analysis for the two approaches is rather different. The high-level development path is as follows:

- **DC1 era**: pre-DC2 work has focused on development of CLMassMod, a package for fitting weak lensing profiles. CLMassMod.
- **DC2 era**: development of the cluster-specific parts of the stacked analysis pipeline, which will rely on TXPipe and the WL shear calibration pipeline; and development of the likelihood analysis for that analysis pathway within TJPCosmo. Continued development of tools to validate WL mass estimates on simulations CLMassMod.
- **DC3 era**: further development of the stacked analysis pipeline; integration of algorithms for the individual cluster analysis pathway (based on work in precursor surveys) into TJPCosmo.
- **SV era**: integration of the CL pipeline and adaptation to the real SV data. Possible extension of the framework to support additional advanced algorithms.

Documentation of the plans at a higher level of detail, and more finely-grained timelines, will be included in more transient documents (DESC Notes and GitHub issues). All major pipeline activities will be documented in one of the above ways.

A diagram exemplifying the required information flow is given in Figure 5.6.1. Deliverables will include the development of codes that enable a complete and general modeling of multi-wavelength cluster scaling relations, and the extension of the code to handle very large data sets without loss of efficiency or information. As opportunities arise, the code will be applied to real data to determine state-of-the-art cosmological constraints (see Key Product "CL Cosmology Likelihood Module CLCosmo" (CL5)). We expect this pipeline design to evolve as the collaboration iterates towards an efficient multi-probe analysis design.

CL Key Product (DC2 & DC3): CL Pipeline Components for use with TXPIPE (CL7)

Host WG: CL
Objective: Build the CL-specific pipeline pieces in Figure 5.6.1.

Deliverable: *Cluster Finder (CLFINDER) (DC2 SW)*

Host WG: CL *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :
Objective: RedMaPPer is currently the most robust, well-tested optical cluster finder, and will be (at least one of) the primary algorithm(s) to identify clusters from LSST data. While much of its further development is currently being performed outside the DESC (as part of the Dark Energy Survey), the findings of this Key Project will be used to further refine the algorithm. The goal of this deliverable is to produce a version of RedMaPPer that has been ported to python for use within DESC.
Prerequisites: Activities and Deliverables *"Projection Effects and miscentering of redMaPPer clusters (CLOPTCAT)"*,*"Cluster redshifts (CLREDSHIFT)"*,*"$p(z)$ for DC1 Galaxies"*,`HaloCat`

Deliverable: *Cluster Finder (CLFINDER) Validation (DC2 VA)*

Host WG: CL *Started:* 07/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :
Objective: To validate RedMaPPer for DESC, we require simulated galaxy catalogs including accurate galaxy colors/clustering in all LSST bands (DC2 extragalactic and image simulations). Where deemed useful to compare the impact of assumptions made in cluster finding, a comparison with other cluster finders that meet similarly high standards as RedMaPPer in terms of completeness and purity may be carried out.
Prerequisites: Activities and Deliverables *"Projection Effects and miscentering of redMaPPer clusters (CLOPTCAT)"*,*"Cluster redshifts (CLREDSHIFT)"*,*"$p(z)$ for DC1 Galaxies"*,`HaloCat`, *"Cluster Finder (CLFINDER)"*

Deliverable: *Cluster Finder Updates (CLFINDER) (DC3 SW)*

Host WG: CL *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21

URL :

Objective: The goal of this deliverable is to produce a version of the cluster finding algorithm that is updated to address issues identified during DC2 analysis and/or as a result of work in precursor surveys, to ensure the cluster finding algorithm meets our needs for LSST.
Prerequisites: Deliverables *"Cluster Finder (CLFINDER)"*, *"Cluster Finder (CLFINDER) Validation"*

Deliverable: *Validation of Cluster Finder Updates (CLFINDER) (DC3 SW)*

Host WG: CL *Started:* 07/01/20 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: DC3-era updates of CLFINDER should be validated with DC3-era simulations and/or precursor datasets.
Prerequisites: Deliverables *"Cluster Finder (CLFINDER)"*, *"Cluster Finder (CLFINDER) Validation"*, *"Cluster Finder Updates (CLFINDER)"*

Deliverable: *Shear calibration in the cluster regime (DC3 SW)*

Host WG: CL *Started:* 07/01/20 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: The goal of this deliverable is to update the shear calibration routines in TXPIPE to include shear calibration in the cluster lensing regime.
Prerequisites:

Deliverable: *Photo-z estimates in cluster fields (DC3 SW)*

Host WG: CL *Started:* 07/01/20 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: The goal of this deliverable is to update the photo-z routines in TXPIPE, PZPDF, and PZCALIBRATE to include training data specific to cluster fields.
Prerequisites:

CL Key Product (DC1 & DC2): CL Cosmology Likelihood Module CLCOSMO (CL5)

Host WG: CL
Objective: Build an efficient and self-consistent likelihood calculator for cluster data. This will ultimately be used within the multi-probe cosmology analysis code being developed by the TJP group, and we will work closely with TJP on this project. An initial likelihood code already exists, but it will need to be refined and expanded continuously over the course of the data challenge period. We plan in parallel (again in collaboration with TJP) to provide a faster Fisher matrix calculator suitable for cluster data, for use in forecasting applications (Key Project "Cosmology Forecasting Frameworks" (TJP1)); however, the Fisher matrix code is not part of this Key Project.

Deliverable: *DC1-era CL Likelihood Code (DC1 SW)*

Host WG: CL *Started:* 10/01/15 *Originally due:* 06/30/18
Status: defunct
URL :
Objective: Preparation for the final LSST likelihood code will require work all the way up to the beginning of the LSST survey. This Deliverable covers development needed on the DC1 timescale. Halo mass function emulator was developed externally to DESC, while CLMASSMOD is in active development within DESC.
Prerequisites: R&D Activity *"Develop Prediction Tools"*, data models and associated uncertainties for cluster observables from Key Projects "Cluster finding and catalog characterization" (CL1), "Absolute mass calibration I" (CL2), "Relative Mass Calibration" (CL4).

Deliverable: *DC2-era CL Likelihood Code (DC2 SW)*

Host WG: CL *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :
Objective: This Deliverable covers continuing development of the code on the DC2 timescale. Existing code will be extended to incorporate a fully general cluster scaling relation model, which will be necessary to optimally extract information from clusters with data at multiple wavelengths. To keep the calculations tractable, this will likely require the use of different algorithms than the current codes use, and we will work closely with the computing group at this stage to maximize the efficiency of the resulting code. As part of this process, additional cluster probes (such as clustering) which the forecasting projects indicate are worthwhile will be implemented. Apply the code to contemporaneous data, including masses and mass proxies

measured in R&D Activities *"Apply refined results to existing cluster lensing data (CLAbsMass)"*, *"Low-scatter mass proxies from Chandra data"* and *"Low-scatter mass proxies from XMM-Newton data"*, implementing the blinding strategies identified in R&D Activity *"Blind analysis strategies for individual probe analyses"*.
Prerequisites: Mass and bias functions for cosmologies of interest, plus self-consistent estimates of systematic uncertainties spanning halo finding, cluster centering and baryonic physics prescription (R&D Activity *"Develop Prediction Tools"*, Deliverable *"Cosmological Emulator Integration"*); data models and the associated uncertainties for cluster observables from Key Projects "Cluster finding and catalog characterization" (CL1), "Absolute mass calibration I" (CL2), "Absolute mass calibration II" (CL3), "Relative Mass Calibration" (CL4)). Blinding strategy from R&D Activity *"Blind analysis strategies for individual probe analyses"*.

Deliverable: *Validation of DC2-era CL Likelihood Code (DC2 VA)*

Host WG: CL *Started:* 07/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :
Objective: This deliverable covers work to validate the DC2-era clusters likelihood code using DC2 simulations.
Prerequisites: Deliverable *"DC2-era CL Likelihood Code"*

Deliverable: *DC3-era CL Likelihood code (DC3 SW)*

Host WG: CL *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :
Objective: This Deliverable covers continuing development of the code on the DC3 timescale. Final development of the likelihood code will focus on extending it to handle stage 4 (i.e. very large) cluster catalogs without loss of efficiency or information. This includes investigating the effects of binning for surveys where a only small fraction of clusters have information beyond the basic survey observables. Apply to contemporaneous data, including comprehensive lensing mass analysis from Key Project "Analysis of `DC3 Mock Lightcone` and pre-cursor data. CC/SV observing plan" (CL6) and low-scatter mass proxies from R&D Activities *"Low-scatter mass proxies from Chandra data"* and *"Low-scatter mass proxies from XMM-Newton data"*, implementing the blinding strategies identified in R&D Activity *"Blind analysis strategies for individual probe analyses"*.
Prerequisites: Mass and bias functions for cosmologies of interest, plus self-consistent estimates of systematic uncertainties spanning halo finding, cluster centering and baryonic physics

prescription (Activities and Deliverables *"Develop Prediction Tools"*, *"Cosmological Emulator Integration"*, *"Simulations for covariance studies"*); data models and the associated uncertainties for cluster observables from Key Projects "Cluster finding and catalog characterization" (CL1), "Absolute mass calibration I" (CL2), "Absolute mass calibration II" (CL3), "Relative Mass Calibration" (CL4), "Analysis of `DC3 Mock Lightcone` and pre-cursor data. CC/SV observing plan" (CL6)). Blinding strategy from R&D Activity *"Blind analysis strategies for individual probe analyses"*.

CL Key Product (SV): CL Pipeline Integration and Adaptation to the SV Data (CLIA)

Host WG: CL
Objective: Integrate the CL-specific pipeline in Figure 5.6.1 with the other DESC pipelines, and adapt it to run at scale on the real SV data.

Deliverable: *Integrated CL Pipeline (SV SW)*

Host WG: CL *Started:* 07/01/20 *Originally due:* 09/30/22
Status: anticipated *Anticipated:* 09/30/22
URL :

Objective: Fully integrated CL pipeline, for application to SV data.

5.7 Strong Lensing Pipeline

The focus of this subsection is development of a pipeline for cosmological analysis with strong lenses. Figure 5.7.1 shows the SL workflow diagram.

Documentation of the plans at a higher level of detail, and more finely-grained timelines, will be included in more transient documents (DESC Notes and GitHub issues). All major pipeline activities will be documented in one of the above ways.

SL Key Product (DC1 & DC2 & DC3): SL Pipeline Components (SL6)
Host WG: SL
Objective: Build the SL-specific pipeline pieces illustrated in Figure 5.7.1.

Deliverable: SLMonitor *(DC1 SW)*

Host WG: SL *Started:* 10/01/15 *Originally due:* 06/30/18
Status: done *Completed:* 06/30/18
URL :
Objective: Extract light curves for all time-variable lens candidates. Completed by Deliverable *"A framework for Twinkles light curve generation"*.
Prerequisites: Deliverable *"A framework for Twinkles light curve generation"*

Deliverable: SLModeler *(DC1 SW)*

Host WG: SL *Started:* 10/01/15 *Originally due:* 06/30/18
Status: defunct
URL :
Objective: Construct models of lenses from high resolution imaging. Has been implemented in surveys prior to DESC.
Prerequisites: None

Deliverable: SLFinder *Lens Candidate Extractor (DC2 SW)*

Host WG: SL *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :
Objective: Develop lens candidate extraction algorithms and build prototype code, based on community pixel-leveling modeling experience to date, that can operate on the `DC2` cutout images. The Einstein Ring extraction code should be able to work on sets of postage stamps centered on either lensed supernova or compound lens targets; the variable lens extractor should be able to work on sets of postage stamps centered on either lensed quasar or lensed supernova targets.
Prerequisites: None

Deliverable: SLEnvCounter *(DC2 SW)*

Host WG: SL *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :
Objective: Build prototype code, based on community experience of estimating weak lensing effects from weighted galaxy number density to date, that can operate on the `DC2`.
Prerequisites: Deliverable *"`DC2` Time Domain Requirements"*

Deliverable: SLMassMapper *(DC2 SW)*

Host WG: SL *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Build prototype code, based on community line of sight mass reconstruction experience to date, that can operate on the `DC2`.
Prerequisites: Deliverable *"`DC2` Time Domain Requirements"*

Deliverable: *Validation of DC2-era pipeline components (DC2 VA)*

Host WG: SL *Started:* 07/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Validate DC2-era pipeline components using DC2 simulations.
Prerequisites: Deliverables "SLFinder *Target Selection Code*", "SLFinder *Lens Candidate Extractor*", "SLEnvCounter", "SLMassMapper"

Deliverable: SLTimer *(DC3 SW)*

Host WG: SL *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: Develop algorithms for time delay inference and build prototype code, based on community time delay estimation experience to date. This code will be able to operate on the `TDC3` light curves, and enter the third Time Delay Challenge. Test on the `TDC2` light curves.
Prerequisites: R&D Activity *"`TDC3` Simulated Light Curves"*

Deliverable: SLCosmo *(DC3 SW)*

Host WG: SL *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: Implement cosmological parameter inference code for SL, including realistic lens samples, time delay measurements, and environment characterisation, and a hierarchical model for the lens population. This will make use of the TJP cosmological likelihood library developed in the Deliverable *"Single-probe likelihood for Strong Lensing"*, and also depend on the lens environment investigation in R&D Activity *"SL Environment Characterization and Assessment"*.

Prerequisites: Deliverable *"Single-probe likelihood for Strong Lensing"*, R&D Activity *"SL Environment Characterization and Assessment"*

Deliverable: *Validation of DC3-era pipeline components (DC3 VA)*

Host WG: SL *Started:* 07/01/20 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :
Objective: Validate DC3-era pipeline components using DC3 simulations.
Prerequisites: Deliverables *"SLTIMER"*, *"SLCOSMO"*

SL Key Product (SV): SL Pipeline Integration and Adaptation to the SV Data (SLIA)

Host WG: SL
Objective: Integrate the SL-specific pipeline with the other DESC pipelines, and adapt it to run at scale on the real SV data.

Deliverable: *Integrated SL Pipeline (SV SW)*

Host WG: SL *Started:* 07/01/20 *Originally due:* 09/30/22
Status: anticipated *Anticipated:* 09/30/22
URL :
Objective: Fully integrated SL pipeline, for application to SV data.

5.8 Supernova Pipeline

The focus of this subsection is development of a pipeline for cosmological analysis with supernovae. The high-level development path is as follows:

- **DC1 era**: The DC1 era focused on building up template libraries for different populations of supernovae and transients, developing classification algorithms and frameworks, developing catalog and image simulation software and initiating image-level pipeline analyses through efforts like the `Twinkles` challenge.
- **DC2 era**: There are three parallel DC2 activities: work on the image-level characterization (classification etc.) pipeline, development of the SN emulation pipeline, and development of likelihood analysis routines within TJPCOSMO.

- **DC3 era**: This will focus on expanding the SN likelihood frameworks to take account of classification probabilities, redshift uncertainty and light-curve parameters, and integrating these more complicated frameworks into TJPCosmo, following the prescriptions developed in DC2. It will include comprehensive follow-up procedure planning for both transient and host redshift follow-up.
- **SV era**: integration of the SN pipeline and adaptation to the real SV data. Possible extension of the framework to support additional advanced algorithms.

The software that needs to be built is summarized in Figure 5.8.1 and Figure 5.8.2.

Documentation of the plans at a higher level of detail, and more finely-grained timelines, will be included in more transient documents (DESC Notes and GitHub issues). All major pipeline activities will be documented in one of the above ways.

SN Key Product (DC1): DC1-era codes for simulating SN at Cadences from OpSim (SN-OpSim)
Host WG: SN

Deliverable: *SN simulation software integrated with OpSim (DC1 SW)*

Host WG: SN *Started:* 10/01/15 *Originally due:* 07/01/18
Status: done *Completed:* 07/01/18
URL : https://github.com/rbiswas4/OpSimSummary

Objective: Based on "SupernovaRealizer Development" (SN1), code up components to enable integrating with LSST Project-supplied data products like OpSim outputs, and produce catalog and image simulations of supernovae.

SN Key Product (DC1): DC1-era SN Pipeline Components (SupernovaType)
Host WG: SN
Objective: Build the DC1-era pipeline components from Figure 5.8.1 and Figure 5.8.2.

Deliverable: *Classification Code: SupernovaType (DC1 SW)*

Host WG: SN *Started:* 10/01/15 *Originally due:* 07/01/18
Status: done *Completed:* 07/01/18

URL : https://github.com/LSSTDESC/snmachine

Objective: The main Deliverable is SUPERNOVATYPE code to run a variety of classification algorithms. Development of SUPERNOVAREALIZER will involve development and testing of competing algorithms and approaches to photometric classification in SUPERNOVATYPE.

Prerequisites: Catalog of simulated SN from difference images from SUPERNOVAREALIZER (from "SUPERNOVAREALIZER Development" (SN1)). In addition, an estimate of the selection function of the survey ("Cosmology from Photometric Supernova Samples DC2" (SN5)).

SN Key Product (DC2): DC2-era SN Pipeline Components (SNPipe)
Host WG: SN
Objective: Build the DC2-era pipeline components from Figure 5.8.1 and Figure 5.8.2.

Deliverable: *SN Analysis Pipeline (DC2 SW)*

Host WG: SN *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: A software interface between the different analysis tools of the SNWG. This will be developed after studying the interfacing in different sets of codes required in an analysis pipeline and streamline them. This involves surveying members of the SNWG for their expected inputs and outputs, and agreeing on some common formats of (e.g.) light curve files, and creating a link between the various analysis nodes from images to cosmology. The "glue" between the various parallel blocks will be developed and optimized with input from the CI WG.

Prerequisites: Catalog of early-time SN sources, from a simulated difference image light curve with SUPERNOVAREALIZER, from Key Project "SUPERNOVAREALIZER Development" (SN1), plus a Photo-z Point estimate database.

Deliverable: *SN Light fitting code (DC2 SW)*

Host WG: SN *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL : https://github.com/rbiswas4/AnalyzeSN

Objective: The light curve fitting formalism specified here will produce posterior distributions (or summaries thereof) of SN light curve model parameters from the light curves and the photo-z pdf database. As shown in Figure Figure 5.8.1, this fitter differs from the light curve fititng codes developed in DC1 in that they will include information on the photo-z of the host. Preliminary R&D work in exploring such a light curve fitting code has started in the working group

Prerequisites: Photo-z database, and the light curve catalog from "SUPERNOVAREALIZER Development" (SN1).

Deliverable: *SN selection function to produce a SN catalog for classification (DC2 SW)*

Host WG: SN *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19

URL : https://github.com/lsstdesc/SN_Catalog_Simulations/

Objective: The SN selection function/code will take as input the catalog of early sources and the catalog of general SN sources and build a final catalog of sources for classification, based on defined data quality cuts.

Prerequisites: Early SN catalog, full SN catalog from the above deliverables.

Deliverable: *SN summaries code (DC2 SW)*

Host WG: SN *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19

URL : https://github.com/aimalz/proclam

Objective: The SN Summaries code will take as input the SN catalog, and classification output and compute various figures of merit in the classification, discovery, LC quality and cosmological uncertainty space. These metrics will be used to constrain different cadence scenarios.

Prerequisites: Early SN catalog, full SN catalog the above deliverables, classification output.

Deliverable: *Multi-type transient simulations (DC2 SW)*

Host WG: SN *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19

URL : http://plasticcblog.wordpress.com/

Objective: In order to test classification algorithms, simulations of LSST-type surveys containing multiple types of transients will be produced, to test classification algorithms like "Cosmology from Photometric Supernova Samples DC2" (SN5) and others.

Prerequisites: The "SUPERNOVAREALIZER Development" (SN1) code, updated to contain more models and updated LSST-like cadence.

Deliverable: *Photometric classification (DC2 SW)*

Host WG: SN *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL : https://github.com/aimalz/proclam

Objective: Using the updated simulations mentioned above, multiple classification schemas will be tested based on DC2-era simulations with multiple transients and updated cadence and simulation volume.
Prerequisites: The *"Multi-type transient simulations"* suite of simulations.

Deliverable: *SN Light curves from processed DM difference images (DC2 RQ)*

Host WG: SN *Started:* 07/01/18 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: Building on work done as part of `Twinkles`, and to ensure a reliable catalog of light curves can be produced for analysis, work at the image level DC2 will focus on building a difference image pipeline, SNPIPEvi, from the DM image data base. Source detection on difference images that result from the DM pipeline. These are defined through the subtraction of a science image from a single visit and templates (which may be compiled from several visits). It will be easier to detect dimmer SN from multiple science images: the simplest strategy could be co-adding/stacking science images in the same band within short time periods, that are less than the time scale of a SN light curve change, and then performing the difference image with the template.

The work to determine how these calculations will be performed is both an essential pipeline requirement for the SNWG, and also an active area of R&D. In particular, the detection of objects from multiple visits is not included in the current DM pipeline, so this will be developed within the SNWG. Tests will need to be run on the pipeline to test for precision and accuracy of photometry on difference images and forced photometry light curves.
Prerequisites: DC2 simulations

Deliverable: *SN Analysis Pipeline Validation (DC2 VA)*

Host WG: SN *Started:* 07/01/18 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: Validate the catalog pipeline through tests based on the Summaries code *"SN summaries code"*, possibly collaborating with people building the DESCQA framework.

Deliverable: *Detection Efficiency of SN (DC2 VA)*

Host WG: SN *Started:* 07/01/18 *Originally due:* 03/31/19
Status: planned *Expected:* 03/31/19
URL : https://stanford.io/2vuSfLk

Objective: Using the *"SN Light curves from processed DM difference images"*, calculate the efficiency of detection of SN from single epochs under different observing conditions and astrophysical backgrounds. This will also be part of the validation of *"SN Light curves from processed DM difference images"*.
Prerequisites: The DC2 image simulations, DIA processing of the DC2 simulations using *"SN Light curves from processed DM difference images"* in the uDDF region.

Deliverable: *Discrepancy Modelling for SN light Curves (DC2 VA)*

Host WG: SN *Started:* 07/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL : https://stanford.io/2Hx2iEE

Objective: Study the performance of the image processing pipeline in terms of comparing catalog expectations with the forced photometry applied on difference images as part of the DIA processing pipeline *"SN Light curves from processed DM difference images"*.

Deliverable: *Validating Surface Brightness of Host Galaxy (DC2 VA)*

Host WG: SN *Started:* 07/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL : https://stanford.io/2HJ7ouZ

Objective: Validate the values of local surface brightness of host galaxies as determined from the parameters measured in the emulated DRP catalogs obtained from DC2 processing against the truth values from the DC2 cosmo simulations.
Prerequisites: The DC2 image simulations and DRP processing of them in the main survey region.

SN Key Product (DC3): DC3-era SN Pipeline Components (SNType)
Host WG: SN
Objective: Build the DC3-era pipeline components from Figure 5.8.1 and Figure 5.8.2.

Deliverable: *DC3-era SN Analysis Pipeline updates (DC3 VA)*

Host WG: SN *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: The deliverable will be the components of the difference imaging pipeline, including providing catalog of supernovae based on difference images and modelling.
Prerequisites: DC3 image simulations, *"SN Light curves from processed DM difference images"*, *"SN Light curves from processed DM difference images"*

Deliverable: *Verification of the difference imaging pipeline on DC3 data (DC3 VA)*

Host WG: SN *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: The deliverable will validate the difference imaging pipeline based on DC3 simulations and precursor datasets
Prerequisites: DC3 image simulations, *"DC3-era SN Analysis Pipeline updates"*

Deliverable: *Code for photometric supernova cosmology (DC3 SW)*

Host WG: SN *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: Software tools for photometric sample, including SUPERNOVATYPE and SUPERNOVADISTANCE, ready to be applied to LSST data, using blinded analysis strategy, if feasible.
Prerequisites: R&D Activities *"Application to SN Typing and redshift estimation"*, *"SUPERNOVADISTANCE Code: Light-curve and distance fitters for SN Ia"*, *"Blind analysis strategies for individual probe analyses"*

Deliverable: *Verification of photometric supernova code in different scenarios (DC3 VA)*

Host WG: SN *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: Validate codes on precursor datasets and DC3 era simulations

Deliverable: *DC3-era SN summaries code (DC3 SW)*

Host WG: SN *Started:* 10/01/18 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :

Objective: The SN Summaries code be updated from the DC2 implementation, but will include additional ancillary information such as information on nearest neighbours and host properties. The code will take as input the SN catalog, and classification output and compute various figures of merit in the classification, discovery, LC quality and cosmological uncertainty space. These metrics will be used to constrain different cadence scenarios
Prerequisites: Early SN catalog, full SN catalog from the above deliverables, classification output, ancillary products from DC2 simulations.

Deliverable: *SN summaries code validation on DC3 simulations (DC3 SW)*

Host WG: SN *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: The full SN summary pipeline will be tested on simulations.

SN Key Product (SV): SN Pipeline Integration and Adaptation to the SV Data (SNIA)

Host WG: SN
Objective: Integrate the SN-specific pipeline in Figure 5.6.1 with the other DESC pipelines, and adapt it to run at scale on the real SV data.

Deliverable: *Integrated SN Pipeline (SV SW)*

Host WG: SN *Started:* 07/01/20 *Originally due:* 09/30/22
Status: anticipated *Anticipated:* 09/30/22
URL :

Objective: Fully integrated SN pipeline, for application to SV data.

SN Key Product (DC3): DESC Broker (SN)
Host WG: SN

Objective: Develop a broker for DESC by providing components additional to with the SN and SL working groups, based on the research and development in Key Project "DESC Broker Investigation and Development" (CX14). This cross working group project is hosted by the SNWG.

Deliverable: *SLWG Broker Requirements (DC2 RQ)*

Host WG: SL *Started:* 10/01/17 *Originally due:* 07/01/18
Status: active *Expected:* 07/01/18
URL : https://github.com/LSSTDESC/DESCNote_TransientBroker

Objective: Determine SLWG requirements for an LSST broker, provided the research efforts in Key Project "DESC Broker Investigation and Development" (CX14) suggest a DESC-specific one is needed. The WG will use the broker to identify strongly lensed supernovae.
Prerequisites: None

Deliverable: *Broker Sandbox (DC3 SW)*

Host WG: SN *Started:* 03/31/19 *Originally due:* 06/30/20
Status: planned *Expected:* 06/30/20
URL : This work will proceed with the research and development cross working group project Key Project "DESC Broker" (SN). This broker would be to interface Community Brokers with DESC studies, to understand the pros and cons of each broker environment.
Prerequisites: *"DESC Broker Requirements for SN"*, *"DESC Broker Requirements for SL"*, *"DESC Broker Tests"*, PLASTICC models, community broker interaction

Deliverable: *Early SN classification system (DC3 SW)*

Host WG: SN *Started:* 03/31/19 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL : https://github.com/LSSTDESC/DESCNote_TransientBroker

Objective: The early classification code specified in Figure 5.8.1, will provide classification of sources using a few points in the light curve. Developing this classification system will depend on the output of the LSST broker. This work will be done in tandem with the research and development project Key Project "DESC Broker Investigation and Development" (CX14)

Deliverable: SLFINDER *Target Selection Code (DC3 SW)*

Host WG: SL *Started:* 10/01/17 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21

URL :

Objective: Develop target selection algorithms and build prototype code,based on community catalog querying and machine learning experience to date, that can operate on the `DC2` object catalogs (and possibly alerts), and return lists of lens targets. Part of this Deliverable will involve arc and ring target selection, as the first step in compound lens target selection. For lensed supernova detection the Deliverable will need to include the ability to interact with LSST agents to rapidly identify possible lensed transients as a trigger for followup.
Prerequisites: *"SLWG Broker Requirements"*

Deliverable: *Verification of the DESC SN broker infrastructure on DC3 simulations (DC3 VA)*

Host WG: SN *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: Validate *"Early SN classification system"* with DC3 simulations and precursor datasets
Prerequisites: *"Early SN classification system"*, precursor data, Classification Algorithms, interfaced community brokers.

5.9 Theory & Joint Probes Pipeline

The focus of this subsection is development of pipelines for the TJP working group. There are three such pipelines: the Core Cosmology Library (CCL), TJPCOV (for covariance matrix estimation), and TJPCOSMO (for individual and joint probe likelihood analysis). The core of this effort is TJPCOSMO, which will integrate theoretical predictions from CCL, the covariances generated by TJPCOV, and a consistent set of models for systematics effects. The high-level development path is as follows:

- **DC1 era**: Focus on CCL development.
- **DC2 era**: Continued CCL development; initial construction of the TJPCOSMO framework; beginning of TJPCOV and joint systematics modules.
- **DC3 era**: Maturation of TJPCOSMO and full integration of TJPCOV and joint systematics modules. Integration of TJPCOSMO into the CI infrastructure.
- **SV era**: Adaptation of the TJP code to the real SV data. Possible extension of the framework to support additional advanced algorithms.

Documentation of the plans at a higher level of detail, and more finely-grained timelines, will be included in more transient documents (DESC Notes and GitHub issues). All major pipeline activities will be documented in one of the above ways.

The TJP analysis pipeline TJPCosmo is summarized in Figure 5.9.1, with CCL illustrated in more detail in Figure 5.9.2.

TJP Key Product (DC1 & DC2): Core Cosmology Library (TJP5A)
Host WG: TJP

Objective: The Core Cosmology Library (CCL) is a general-purpose, accuracy-validated library to make standardized predictions for cosmological observables. It is one of the core components of the TJPCosmo likelihood pipeline, and a required dependency for systematics modules. The main purpose of this key product is to provide a uniform method of computing cosmological quantities and observables that can be used by all pipeline software, with the aim of guaranteeing consistency and accuracy of predictions. As such, CCL will be held to a particularly high standard of code validation, and to be capable of calculating all cosmological quantities needed by other analysis working groups (to the greatest extent possible).

Deliverable: *Cosmology library prototypes (DC1 SW)*

Host WG: TJP *Started:* 10/01/15 *Originally due:* 03/31/16
Status: defunct
URL :

Objective: Draft preliminary computing environment for cosmology analyses. Provide function prototypes for core cosmology library to inform early pipeline development efforts.
Prerequisites: "The Initial Elements of a Software Framework" (CI2)

Deliverable: *Cosmological Emulator Integration (DC2 SW)*

Host WG: TJP *Started:* 10/01/16 *Originally due:* 02/28/18
Status: defunct
URL :

Objective: Integrate state-of-the-art emulators for non linear power spectrum, halo mass function, bias modeling in CCL, which will be incorporated into TJPCosmo (see the Deliverable *"Cosmological analysis pipeline for LSST precursor data"*). This deliverable is superseded by *"Enhanced cosmological observable predictions"*.

Deliverable: *Basic cosmological observable predictions (DC1 SW)*

Host WG: TJP *Started:* 10/01/15 *Originally due:* 06/30/18
Status: done *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/CCL/releases/tag/0.2

Objective: Develop and validate a core cosmology library to compute basic observables for cosmological models with dark energy parameterized by w0 and wa ($w_0 w_a$CDM models). The library will include the basic building blocks that are needed for single-probe predictions. Modules in this version of the library will include, but not be limited to: redshift distributions, cosmological distance measures, the growth rate and growth factor, linear as well as non-linear power spectra, and lensing weight functions. This deliverable also satisfies Deliverable *"Develop Prediction Tools"*.
Prerequisites: Deliverable *"Cosmology library prototypes"*

Deliverable: *Enhanced cosmological observable predictions (DC2 SW)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 07/01/18
Status: done *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/CCL/releases/tag/v0.9

Objective: Extend the core cosmology library to make more realistic predictions for the quantities needed by single-probe likelihoods. This includes adding the ability to calculate angular correlation functions and the halo mass function and halo bias; integrating available emulators for the non-linear matter power spectrum; and implementing baryonic effects and massive neutrino models. This version of the library should be accompanied by extensive documentation and validation tests, and a publication describing it. (This deliverable is considered complete with the availability of the CCL paper.)
Prerequisites: Deliverable *"Basic cosmological observable predictions"*

Deliverable: *Fast and accurate correlation function predictions (DC2 SW)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL : https://github.com/LSSTDESC/CCL

Objective: Extend the core cosmology library to include accurate correlation function predictions, using state-of-the-art tools such as fast perturbation theory approaches (e.g. FAST-PT) for galaxy clustering and intrinsic alignments, and new power spectrum emulators. A more complete implementation of all relevant cross-correlations between large-scale structure observables and other cosmological probes should also be included, to prepare for joint probes

analyses.
Prerequisites: *"Enhanced cosmological observable predictions"*

Deliverable: *Cosmological model extensions beyond wCDM (DC3 SW)*

Host WG: TJP *Started:* 10/01/18 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL : https://github.com/LSSTDESC/CCL
Objective: Extend the range of cosmological models supported by CCL to include beyond-wCDM models, based on the results of *"Models Beyond wCDM Testable with LSST Analyses"*. This will mostly be focused on providing linear theory predictions for beyond-wCDM models, but may also include basic quasi-linear/non-linear predictions using emulators (see Deliverable *"Cosmological Simulations with Novel Physics"*). This deliverable is co-dependent on *"TJPCosmo: Software to Perform Cosmological Analyses of Novel Physics"*.
Prerequisites: *"Models Beyond wCDM Testable with LSST Analyses"*, *"Enhanced cosmological observable predictions"*

TJP Key Product (DC2 & DC3): Systematics Models for Joint Analyses (CX5)
Host WG: TJP
Objective: While the importance of astrophysical and instrumental systematic effects has long been recognized for individual probes, their impact on joint analyses remains something of an unknown. The TJPCosmo joint probes analysis will produce significantly tighter cosmological constraints than any individual tracer, and so it seems likely that the relative importance of systematic effects will be correspondingly greater. Systematic effects may be probe-specific however, potentially making it easier to separate them out in a joint probe analysis. In response to these considerations, this Key Product will deliver a consistent, integrated package of multi-probe systematics models, implemented as modules within the TJPCosmo library. These will be used for exploratory work during the DC2 era, and then developed into a mature systematics package within TJPCosmo ready for analyses with LSST precursor datasets following DC3. While individual probe working groups are expected to provide the base systematics models and code to feed into this work, it will be the responsibility of TJP to ensure consistency between the models, and to curate them in the event that multiple competing models are available.

Deliverable: *Software modules for astrophysical systematics (DC2 SW)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: To produce software modules for astrophysical systematics and incorporate them into existing software infrastructure, particularly TJPCosmo. Develop software modules that implement mitigation schemes for intrinsic alignments, galaxy bias (including assembly bias), and baryonic effects. These modules should interface with TJPCosmo and CCL. Note that the (assembly) bias mitigation modules should include cluster cosmology capabilities.

As part of this deliverable, the interactions of photometric redshifts and photometric redshift uncertainties with each of the primary LSST cosmology probes should also be quantified. Validation of these modules in the context of cosmological analyses is part of the Deliverable *"Cosmological analysis pipeline for LSST precursor data"*.
Prerequisites: *"Galaxy Intrinsic Alignments"*, *"Galaxy Bias and Assembly Bias"*, *"Baryonic Effects"*

Deliverable: *Workflow for testing accuracy of systematics mitigation (DC2 SW)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 03/31/19
Status: planned *Expected:* 03/31/19
URL :

Objective: Set up an easy-to-use software pipeline to analyze input data vectors containing sophisticated systematics models (or simulation results) with the TJPCosmo baseline model. This software will enable everyone to quantify the impact of different systematic effects on cosmological parameters for well-defined LSST-like single/joint probe analyses.

Due to the timeline, this workflow will be developed simultaneously with the individual probe systematics modules in Deliverable *"Software modules for astrophysical systematics"*. Initial development may therefore happen outside of the TJPCosmo framework that will ultimately host the systematics modules (e.g. from the point that Deliverable *"Preliminary joint probes likelihood pipeline"* becomes available). Where possible, new code will be written to allow integration of the systematics modules into CCL or TJPCosmo however.
Prerequisites: *"Software modules for astrophysical systematics"*

Deliverable: *Consistency of systematics modeling across all probes (DC3 SW)*

Host WG: TJP *Started:* 03/31/19 *Originally due:* 07/01/20
Status: planned *Expected:* 07/01/20
URL :

Objective: TJPCOSMO requires systematics classes developed by a single probe WG to include methods that can also calculate the impact of the systematic on all cross-correlations included in the joint likelihood analysis. This Deliverable will implement a factory method in TJPCOSMO that checks consistency of the systematics model choices across all probes included in a joint analysis, and provide guidelines for the integration of new systematics classes into TJPCOSMO.
Prerequisites: *"Software modules for astrophysical systematics"*

Deliverable: *Incorporate spatial variations into joint systematics models (DC3 SW)*

Host WG: TJP *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: Update and expand the joint systematics model employed in Deliverable *"Preliminary joint probes likelihood pipeline"* to incorporate systematics models with spatial variations, based on Key Project "Systematics Caused by the LSST Observing Strategy" (CX11).

Prerequisites: "Systematics Caused by the LSST Observing Strategy" (CX11), *"Preliminary joint probes likelihood pipeline"*, "Post-DC1 Requirements of the Software and Computing Environment" (CI5)

TJP Key Product (DC2 & DC3): TJPCOV: Covariance Matrices for Joint Analyses (CX7)

Host WG: TJP

At the core of the likelihood pipeline developed in TJPCOSMO is a set of appropriate multi-probe covariance matrices that can accurately account for correlations in the cosmological signals measured by the individual probes. The covariance matrices required are unprecedented in size and complexity, and it is likely that new methods will need to be developed to keep the computational cost of generating them in check, whilst also meeting accuracy requirements (to avoid biasing cosmological parameter estimates). In the first instance, simple placeholder covariances can be delivered to allow TJPCOSMO development to proceed and initial proof-of-concept joint probes analysis to begin. By the time of DC3, more sophisticated covariance estimation solutions will need to be in place, along with an understanding of the computational complexity of covariance estimation for the DESC Y1 analysis. Since this Key Product is likely to have the largest computational burden of any component of the analysis pipeline, it should be considered a high priority for cross-working-group development.

Deliverable: *Gaussian covariances for* TJPCOSMO *(DC2 SW)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: Develop basic covariance estimators for the single-probe LSS and WL likelihoods, using Gaussian assumptions. These may be implemented using analytic methods (e.g. CosmoLike), fast N-body simulations, or existing collections of mock catalogs. The Gaussian covariances will be used as placeholders to develop covariance-related infrastructure in TJPCOSMO, and for initial testing and validation of the TJPCOSMO likelihood pipeline during DC2.

Deliverable: *Improved covariance estimators for single- and joint-probe analyses (DC2 SW)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: Develop and implement novel covariance estimators which combine mock survey realizations and theory templates (e.g. using shrinkage techniques). Test and refine the estimators for single-probe, 2-point statistic covariances before proceeding to joint covariance estimation.

Large-scale structure and weak lensing 2-point statistics will serve as pilot projects for more comprehensive joint covariance estimation that takes advantage of the availability of suitable number of mock catalogs on the timescale of DC2 and yields useful scientific results that may be exploited by the LSS and WL working groups as well as other science collaborations.
Prerequisites: *"Workflow for testing accuracy of systematics mitigation"*, *"Parameterization of the Extragalactic Catalogs for DC2 and DC3"*, *"Simulations for covariance studies"*, *"Gaussian covariances for* TJPCOSMO*"*
Approach: Implement and test shrinkage estimator on LSS mock catalogs in Key Project "Simulation for Covariance Studies" (CS8). Extend shrinkage covariance estimator to WL, and test performance on WL mock catalogs available within the collaboration.

Deliverable: *Numerical routines for fast covariance estimation (DC3 SW)*

Host WG: TJP *Started:* 07/01/18 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :

Objective: Implement optimized numerical routines to enable fast covariance estimation. The

most useful covariance estimation methods studied in Deliverable *"Improved covariance estimators for single- and joint-probe analyses"* need to be optimized to reduce their computational cost before they are integrated into the TJPCosmo pipeline. The target performance of these methods should be defined with respect to Deliverable *"CI Framework Requirements for Joint Analysis Pipelines"*.
Prerequisites: *"CI Framework Requirements for Joint Analysis Pipelines"*, *"Improved covariance estimators for single- and joint-probe analyses"*.

Deliverable: *Consistent joint probe covariances (DC3 SW)*

Host WG: TJP *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: Build a joint covariance matrix suitable for a 5x2pt (WL, LSS, and GC) joint probe analysis that satisfies pre-determined accuracy requirements. This will extend the covariance estimation methods developed in *"Improved covariance estimators for single- and joint-probe analyses"* as appropriate, and may build off sets of simulations developed as part of Key Project "Simulation for Covariance Studies" (CS8), developed during DC2. The emphasis will be placed on building a covariance matrix that is sufficiently accurate (in terms of minimizing bias on recovered cosmological parameters) while maintaining a high level of theoretical consistency between probes. The impact of systematic effects on the covariance must be consistently included.
Prerequisites: *"Improved covariance estimators for single- and joint-probe analyses"*, *"Simulations for covariance studies"*.

TJP Key Product (DC2 & DC3): TJPCosmo: Likelihood Pipeline for Joint Analyses (TJP5B)
Host WG: TJP
Objective: The joint analysis of correlated cosmological probes as planned by DESC is an emerging line of research, and there exist only limited previous results to inform the joint probes analysis software pipeline development. In this Key Project, TJP will lead the development of a preliminary pipeline for the joint cosmological analysis of the primary cosmological probes.

The study will identify modeling complexities due to, for example, unprecedented demand on precision and systematic uncertainties that are correlated across probes, and determine requirements on computing frameworks for such analyses. In close collaboration with CI, TJP will provide a library of core cosmology routines, which individual probe working groups will use to develop preliminary single-probe likelihood modules. These single-probe likelihood modules should incorporate the key systematic uncertainties, liberally using place holder routines if models/parameterizations will be determined at later times, so that TJP can identify cross-correlations and work with the individual working groups to develop consistent parameterizations. TJP will then curate and package a consistent combination of single-probe likelihoods and systematic models as joint probes analysis pipeline.

Individual probe working groups are encouraged to develop more detailed modeling for their probe-specific cosmology analysis pipeline within TJPCosmo, but TJP cannot guarantee that all such modifications will be consistent with, or supported by the Joint Probes pipeline.

Deliverable: *Single-probe likelihood for Weak Lensing (DC2 SW)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: Develop and document (preliminary) single-probe likelihood for weak lensing, built on CCL routines. This can initially be a 'straw-man' likelihood, making liberal use of placeholder routines for systematic effects if models/parameterizations are to be determined at later times. This has a higher priority than other single-probe likelihoods, as it is needed for preliminary work on 3x2pt statistics in TJPCosmo.
Prerequisites: .

Deliverable: *Single-probe likelihood for Large-Scale Structure (DC2 SW)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: Develop and document (preliminary) single-probe likelihood for large-scale structure/galaxy clustering, built on CCL routines. This can initially be a 'straw-man' likelihood, making liberal use of placeholder routines for systematic effects if models/parameterizations are to be determined at later times. This has a higher priority than other single-probe likelihoods, as it is needed for preliminary work on 3x2pt statistics in TJPCosmo. See also "Cosmological constraints from LSS" (LSS3).

Deliverable: *Single-probe likelihood for Galaxy Clusters (DC2 SW)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 12/31/19
Status: planned *Expected:* 12/31/19
URL :

Objective: Develop and document (preliminary) single-probe likelihood for galaxy clusters, built on CCL routines. This can initially be a 'straw-man' likelihood, making liberal use of placeholder routines for systematic effects if models/parameterizations are to be determined at later times. This has a lower priority than the WL and LSS likelihoods, as it is not needed for preliminary work on 3x2pt statistics in TJPCosmo.
Prerequisites: *"DC2-era CL Likelihood Code"*

Deliverable: *Single-probe likelihood for Supernovae (DC2 SW)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 12/31/19
Status: planned *Expected:* 12/31/19
URL :

Objective: Single-probe likelihood for SN. Develop and document (preliminary) single-probe likelihood for supernovae, built on CCL routines. This can initially be a 'straw-man' likelihood, making liberal use of placeholder routines for systematic effects if models/parameterizations are to be determined at later times. This has a lower priority than the WL and LSS likelihoods, as it is not needed for preliminary work on 3x2pt statistics in TJPCosmo.
Prerequisites: *"Cosmological Constraint Covariance Matrix"*

Deliverable: *Single-probe likelihood for Strong Lensing (DC2 SW)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 06/30/20
Status: planned *Expected:* 06/30/20
URL :

Objective: Develop and document (preliminary) single-probe likelihood for strong lensing, built on CCL routines. This can initially be a 'straw-man' likelihood, making liberal use of placeholder routines for systematic effects if models/parameterizations are to be determined at later times. This has a lower priority than the WL and LSS likelihoods, as it is not needed for preliminary work on 3x2pt statistics in TJPCosmo.
Prerequisites: "SLCosmo"

Deliverable: *Validation of single-probe likelihoods on* `DC2` *(DC2 VA)*

Host WG: TJP *Started:* 07/01/18 *Originally due:* 12/31/19
Status: planned *Expected:* 12/31/19

URL :

Objective: Validate all available single-probe likelihoods by applying them to DC2 mock light-cone data and checking for biases and other issues. This phase of testing will most likely use the Gaussian covariances from Deliverable *"Gaussian covariances for* TJPCOSMO*"*, and should incorporate any systematic effect modules that are already available as a result of Deliverable *"Software modules for astrophysical systematics"*. If the single probe likelihoods are already sufficiently well-integrated into TJPCOSMO this will be used to run the validation tests; otherwise, the systematics testing workflow from Deliverable *"Workflow for testing accuracy of systematics mitigation"* may be used instead. The expectation is that, at minimum, the WL and LSS likelihoods will be ready for validation testing; the GC and SN likelihoods should be ready; and the SL likelihood is unlikely to be ready.

Prerequisites: *"Single-probe likelihood for Weak Lensing"*, *"Single-probe likelihood for Large-Scale Structure"*, *"Single-probe likelihood for Galaxy Clusters"*, *"Single-probe likelihood for Supernovae"*, *"Single-probe likelihood for Supernovae"*, *"Gaussian covariances for* TJPCOSMO*"*, *"Workflow for testing accuracy of systematics mitigation"*

Deliverable: *Preliminary joint probes likelihood pipeline (DC2 SW)*

Host WG: TJP *Started:* 07/01/18 *Originally due:* 12/31/19
Status: planned *Expected:* 12/31/19
URL :

Objective: Develop preliminary likelihood module for joint probes data vectors, including placeholder modules for forthcoming development. Integrate joint likelihood modules from individual probe likelihoods and identify cross-correlations of systematic effects, starting from the single-probe systematics models from Deliverable *"Software modules for astrophysical systematics"*. The main focus of this deliverable is to get preliminary 3x2pt (WL and LSS) joint analysis capabilities up and running.

Prerequisites: *"Single-probe likelihood for Weak Lensing"*, *"Single-probe likelihood for Large-Scale Structure"*, *"Gaussian covariances for* TJPCOSMO*"*, *"Software modules for astrophysical systematics"*

Deliverable: *Forecasting module in likelihood pipeline (DC2 SW)*

Host WG: TJP *Started:* 07/01/18 *Originally due:* 12/31/19
Status: planned *Expected:* 12/31/19
URL :

Objective: Develop forecasting capabilities, including Fisher matrix and MCMC methods, built within the TJPCOSMO framework. Perform single- and joint-probe forecasts consistent with

the state-of-the-art analysis pipeline, update requirements in the SRD, and forecast the performance of cosmological analyses, systematics mitigation, and constraints on novel physics. Once available, this Deliverable will replace the separate TJPFORECAST tools.
Prerequisites: *"Single-probe likelihood for Weak Lensing"*, *"Single-probe likelihood for Large-Scale Structure"*, *"Gaussian covariances for* TJPCOSMO*"*, *"Software modules for astrophysical systematics"*

Deliverable: COSMOPARAMS*: Common exchange format for cosmological parameter sets (DC2 SW)*

Host WG: TJP *Started:* 07/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Develop a common data format for exchanging sets of cosmological parameters between different codes. This should include a standard interchange file format that can be used to pass around sets of parameters, as well as in-memory data formats that can be shared between codes. Methods should be provided for validating and comparing sets of parameters to ensure consistency with the standard format. The primary goal of this deliverable is to ensure that sets of cosmological (and nuisance) parameters can be passed between various DESC codes in a robust and unambiguous way, and that default values for parameters etc. are consistent between codes. In the first instance, the COSMOPARAMS standard will be implemented by CCL, TJPCOSMO, and TJPCOV, and should ultimately be supported by any DESC code that needs to interact with any of these codes.

Deliverable: *Modules for data compression and alternative inference methods (DC3 SW)*

Host WG: TJP *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: This deliverable is for improved data compression and alternative inference methods that will ease the process of inferring cosmological parameters from high-dimensional data vectors while marginalizing over many nuisance parameters.
Prerequisites: Key Project "Advanced cosmological parameter inference methods" (CX7)

Deliverable: *Cosmological analysis pipeline for LSST precursor data (DC3 SW)*

Host WG: TJP *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: Produce and disseminate a complete software pipeline that can be used to perform cosmological analyses using core cosmology probes operating at the precision of LSST precursor data sets. This pipeline will include software to predict core observables, mitigation of systematic errors (developed in the Deliverable *"Preliminary joint probes likelihood pipeline"*), and infer cosmological parameters, all sufficiently well developed and integrated to address forthcoming large data sets. This effort is a refinement and further development of Deliverable *"Preliminary joint probes likelihood pipeline"*, and is intended to provide a focus for the integration and finalization of TJPCOSMO components required to enable an end-to-end joint probes analysis with real data. No systematic effect or covariance placeholders should remain in the 'standard' run-mode of TJPCOSMO pipeline at this point.
Prerequisites: Deliverables *"Preliminary joint probes likelihood pipeline"*, *"Consistency of systematics modeling across all probes"*, *"Consistent joint probe covariances"*

TJP Key Product (DC3): Integration of TJPCOSMO into the CI Framework (TJP5C)

Host WG: TJP
Objective: Implement detailed cosmological likelihood analysis pipeline for joint probes analyses. This project upgrades Key Product "TJPCOSMO: Likelihood Pipeline for Joint Analyses" (TJP5B) to the requirements of DC3 analyses, by incorporating refined systematics modeling and mitigation techniques developed by individual working groups during DC2 and integrating the likelihood pipeline into the CI framework developed in Key Project "Post-DC1 Requirements of the Software and Computing Environment" (CI5). Developments in Key Project "Post-DC1 Requirements of the Software and Computing Environment" (CI5) compared to the Deliverable *"Cosmology library prototypes"*, which served as the basis for Key Project "TJPCOSMO: Likelihood Pipeline for Joint Analyses" (TJP5B), may require major software development. Hence the application of the final pipeline produced in this Key Project to DC3 mock catalogs and precursor data sets will likely be postponed to ComCam Phase.
Prerequisites: "TJPCOSMO: Likelihood Pipeline for Joint Analyses" (TJP5B),"Post-DC1 Requirements of the Software and Computing Environment" (CI5),*"Blind analysis strategies for joint probe analyses."*,"WL Systematic Uncertainty Characterization Framework" (WL2), *"Field test of likelihood module"*,*"Cluster masses from shear maps, with baryons (CLMASSMOD)"*,*"Photometric SN Cosmology Forecast"*

Deliverable: *CI Framework Requirements for Joint Analysis Pipelines (DC2 RQ)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 07/01/18
Status: active *Expected:* 07/01/18
URL :

Objective: Identify conceptual and computational bottle necks in the individual and joint probes likelihoods developed in the Deliverable *"Preliminary joint probes likelihood pipeline"*. Present these findings to the CI group, and discuss potential updates to the CI framework.
Prerequisites: *"Preliminary joint probes likelihood pipeline"*

Deliverable: TJPCosmo *pipeline integration and validation (DC3 VA)*

Host WG: TJP *Started:* 03/31/19 *Originally due:* 07/01/20
Status: planned *Expected:* 07/01/20
URL :

Objective: Integrate the TJPCosmo joint probe likelihood pipeline into the CI framework. This will take the essentially complete TJPCosmo library from *"Cosmological analysis pipeline for LSST precursor data"*, finalize the integration of any remaining systematics models or covariance modules, and begin integration testing and basic validation tests, including simple test runs of single- and joint-probes likelihoods.
Prerequisites: *"Cosmological analysis pipeline for LSST precursor data"*

Deliverable: *Apply* TJPCosmo *joint likelihood pipeline to* `DC3 Mock Lightcone` *(DC3 DP)*

Host WG: TJP *Started:* 07/01/20 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: Perform end-to-end validation tests of the complete TJPCosmo joint likelihood pipeline on `DC3 Mock Lightcone`.
Prerequisites: "TJPCosmo *pipeline integration and validation"*

TJP Key Product (SV): TJP Pipeline Adaptation to the SV Data (TJP-SV)
Host WG: TJP
Objective: Adapt the TJP pipeline on the real SV data, extending it to include more advanced algorithms as needed.

Deliverable: *Extended TJP Pipeline (SV SW)*

Host WG: TJP *Started:* 07/01/20 *Originally due:* 09/30/22
Status: anticipated *Anticipated:* 09/30/22
URL :

Objective: Adapted and extended TJP pipeline, for application to SV data.

5.10 Sensor Anomalies Pipeline

SA Key Product (DC1 & DC2 & DC3): Sensor Anomalies Pipeline Components (SA5)

Host WG: SA
Objective: Build the SA-specific pipeline pieces.

Deliverable: *Implemented and Validated Correction Algorithm for the BF Effect (DC2 SW)*

Host WG: SA *Started:* 10/01/16 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: The final step on the BF effect is to develop and validate BF signature removal algorithm(s).The optimal BF signature removal that will be implemented in DM will be validated by SAWG.

Deliverable: *Validation of correction algorithms for static effects (DC2 VA)*

Host WG: SA *Started:* 10/01/16 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: The signature removal of the static sensor effects will be implemented in DM. The implementation will need to be validated.

Deliverable: *Studies of sensor systematics with ComCam (DC3 VA)*

Host WG: SA *Started:* 10/01/18 *Originally due:* 12/31/20
Status: active *Expected:* 12/31/20
URL :

Objective: This work includes the sensor studies, validation of the signature removal algorithms and propagation of the residual systematics in to the science observables in ComCam data.

SA Key Product (SV): Integrated SA Pipeline, Adapted to SV Data (SA-SV)
Host WG: SA
Objective: Fully integrated sensor anomaly testing and correction pipeline, for application to the SV data.

Deliverable: *Integrated SA Pipeline (SV SW)*

Host WG: SA *Started:* 07/01/20 *Originally due:* 09/30/22
Status: anticipated *Anticipated:* 09/30/22
URL :
Objective: Fully integrated end-to-end pipeline for testing for sensor anomalies, enabling custom corrections, and quantifying their impact and uncertainty.
Prerequisites:

5.11 Photometric Corrections Pipeline

PC Key Product (DC1 & DC2 & DC3): Photometric Correction Pipeline Components (PC7)
Host WG: PC
Objective: Build the PC-specific pipeline pieces.

Deliverable: *Analytical Models for PC Biases (DC1 SW)*

Host WG: PC *Started:* 10/01/15 *Originally due:* 12/31/17
Status: defunct
URL :
Objective: This software Deliverable describes the development of analytical models to describe the scale and magnitude of various biases. This includes, but is not limited to, typical

seeing variations and atmospheric transmission variations with time (and space, depending on observing strategy); extinction mis-corrections; raft-to-raft photometric residuals on degree scales; varying response variations as determined from SA WG.

Deliverable: *PC Bias on Individual Probes (DC2 SW)*

Host WG: PC *Started:* 10/01/16 *Originally due:* 12/31/17
Status: active *Expected:* 12/31/17
URL :

Objective: A software module that is used to determine the impact on parameters measured by individual cosmological probes (e.g., SN Ia distance moduli; cluster redshifts; BAO scale). This makes use of the bias models software Deliverable in the previous task. A more detailed description of the effect of such biases on a particular probe for the case of is given in "Photometric Calibration Systematics" (CX13), similar analysis is needed for photo-zs and perhaps other WGs.

Deliverable: *PC Observing Strategy Metrics (DC2 SW)*

Host WG: PC *Started:* 10/01/16 *Originally due:* 12/31/17
Status: active *Expected:* 12/31/17
URL :

Objective: This Deliverable is a set of software tools that will analyze the performance of a given observing strategy which holds promise to detect, mask, and reduce systematics. At the same time, recommendations to the observing strategy will be made based on these results.

PC Key Product (SV): Integrated PC Pipeline, Adapted to SV Data (PC-SV)
Host WG: PC
Objective: Fully integrated photometric corrections pipeline for application to the SV data.

Deliverable: *Integrated PC Pipeline (SV SW)*

Host WG: PC *Started:* 07/01/20 *Originally due:* 09/30/22
Status: anticipated *Anticipated:* 09/30/22
URL :

Objective: Fully integrated end-to-end pipeline for carrying out photometric corrections and

quantifying their impact and uncertainty.
Prerequisites:

5.12 Photometric Redshifts Pipeline

The focus of this subsection is development of pipelines for the PZ working group. There are three such pipelines: PZPDF (Figure 5.12.1), for development of 2D $p(z, \alpha)$; PZCALIBRATE (Figure 5.12.2), for calibration of ensemble $N(z)$ for tomographic redshift samples used in e.g. TXPIPE; and `PZIncomplete` (Figure 5.12.3), for estimation of the impact of spectroscopic training sample incompleteness. The high-level development path is as follows:

- **DC1 era**: Beginnings of PZPDF, focusing just on $p(z)$ (1D PDFs).
- **DC2 era**: PZCALIBRATE, `PZIncomplete`
- **DC3 era**: PZPDF including the 2D version.
- **SV era**: integration of the PZ pipeline and adaptation to the real SV data. Possible extension of the framework to support additional advanced algorithms, and external data.

Documentation of the plans at a higher level of detail, and more finely-grained timelines, will be included in more transient documents (DESC Notes and GitHub issues). All major pipeline activities will be documented in one of the above ways.

PZ Key Product (DC1 & DC2 & DC3): Photometric Redshifts Pipeline PZPDF (PZ5)

Host WG: PZ
Objective: Build PZPDF (Figure 5.12.1). The metrics are developed during DC1 and applied to external photo-z codes; the parts of the pipeline relevant to 1D $p(z)$ are developed during DC2; and the parts of the pipeline relevant to 2D $p(z)$ are developed during DC3.

Deliverable: *Metrics pipeline for evaluation and comparison of photometric redshift codes (DC1 SW)*

Host WG: PZ *Started:* 10/01/15 *Originally due:* 06/30/18
Status: done *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/PZDC1paper/tree/master

Objective: The deliverable is a set of scripts to calculate standard metrics related to photometric redshift accuracy (bias, scatter, outlier rates) given a sample with known redshifts.
Prerequisites:

Deliverable: *Validation of metrics pipeline (DC1 VA)*

Host WG: PZ *Started:* 10/01/15 *Originally due:* 06/30/18
Status: done *Completed:* 06/30/18
URL : https://confluence.slac.stanford.edu/pages/viewpage.action?pageId=238561496
Objective: The deliverable is a paper that shows the application of the metric scripts to a set of external photo-z codes applied to the DC1 extragalactic simulations. These serve both to validate the metric scripts and establish a baseline for photo-z performance.
Prerequisites: Deliverable *"Metrics pipeline for evaluation and comparison of photometric redshift codes"*

Deliverable: *ComputePrior analysis stage for* PZPDF *(DC2 SW)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL : https://github.com/LSSTDESC/pz_pdf
Objective: The deliverable is the analysis stage to compute priors for PZPDF.
Prerequisites:

Deliverable: *One-dimensional $p(z)$ routines (PZMainAlgorithms) for* PZPDF *(DC2 SW)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL : https://github.com/LSSTDESC/pz_pdf
Objective: The deliverable is the analysis stage that calls external or internal photo-z codes to compute 1D $p(z)$, PZMainAlgorithms.
Prerequisites: Deliverable *"ComputePrior analysis stage for* PZPDF*"*

Deliverable: *CombineResults for one-dimensional $p(z)$ for* PZPDF *(DC2 SW)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL : https://github.com/LSSTDESC/pz_pdf

Objective: This deliverable combines $p(z)$ results across algorithms for a given set of inputs.
Prerequisites: Deliverable *"One-dimensional $p(z)$ routines (PZMainAlgorithms) for* PZPDF*"*

Deliverable: *PZStorage1D for one-dimensional $p(z)$ for* PZPDF *(DC2 SW)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL : https://github.com/LSSTDESC/pz_pdf

Objective: This analysis stage uses the chosen algorithms for storage of 1D $p(z)$ to store the results.
Prerequisites: Deliverable *"CombineResults for one-dimensional $p(z)$ for* PZPDF*"*

Deliverable: *$p(z)$ for DC2 using* PZPDF *(DC2 DP)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 03/31/19
Status: planned *Expected:* 03/31/19
URL :

Objective: Using the previously-developed pipeline tools, produce $p(z)$ to serve to the analysis WGs for their DC2 analysis.
Prerequisites: Deliverable *"PZStorage1D for one-dimensional $p(z)$ for* PZPDF*"*

Deliverable: *Validation of $p(z)$ for DC2 using* PZPDF *(DC2 VA)*

Host WG: PZ *Started:* 07/01/18 *Originally due:* 12/31/19
Status: planned *Expected:* 12/31/19
URL :

Objective: This deliverable is for validation of the DC2 photometric redshifts.
Prerequisites: Deliverables *"Metrics pipeline for evaluation and comparison of photometric redshift codes"* and *"$p(z)$ for DC2 using* PZPDF*"*

Deliverable: *Needs assessment for two-dimensional $p(z, \alpha)$ for* PZPDF *(DC3 RQ)*

Host WG: PZ *Started:* 07/01/18 *Originally due:* 09/30/19
Status: planned *Expected:* 09/30/19
URL :

Objective: Assess working group needs for 2D $p(z, \alpha)$, including a set of concrete use cases.
Prerequisites:

Deliverable: *Accounting for spectroscopic incompleteness in* PZPDF *(DC3 SW)*

Host WG: PZ *Started:* 03/31/19 *Originally due:* 07/01/20
Status: planned *Expected:* 07/01/20
URL :

Objective: Use outcome of study of spectroscopic incompleteness to update PZPDF as needed.
Prerequisites: `PZIncomplete` and Deliverable *"Validation of $p(z)$ for DC2 using* PZPDF*"*

Deliverable: *Two-dimensional $p(z, \alpha)$ implementation for* PZPDF *(DC3 SW)*

Host WG: PZ *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL : https://github.com/LSSTDESC/pz_pdf

Objective: Produce $p(z, \alpha)$ meeting the needs from Deliverable *"Needs assessment for two-dimensional $p(z, \alpha)$ for* PZPDF*"*.
Prerequisites: Deliverable *"Needs assessment for two-dimensional $p(z, \alpha)$ for* PZPDF*"*

Deliverable: *Validation of $p(z, \alpha)$ for* PZPDF *on DC3 (DC3 VA)*

Host WG: PZ *Started:* 07/01/20 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: Validate the $p(z, \alpha)$.
Prerequisites: Deliverables *"Needs assessment for two-dimensional $p(z, \alpha)$ for* PZPDF*"*, *"Two-dimensional $p(z, \alpha)$ implementation for* PZPDF*"*

PZ Key Product (DC2 & DC3): Photometric Redshifts Pipeline PZCALIBRATE (PZCALIBRATE)
Host WG: PZ
Objective: Build PZCALIBRATE (Figure 5.12.2). This pipeline will include the infrastructure necessary for calibrating photometric redshifts using cross-correlations, including compensation for non-linear galaxy bias evolution, weak-lensing magnification, and other systematic effects. The pipeline PZCALIBRATE will be used to calibrate the redshift distributions of tomographic bins defined by analysis working groups. The code may take advantage of LSS or WL software such as TXPIPE for fast 2-point correlation function calculations, so no deliverable is listed for the TwoPointCode analysis stage. Similarly, it will use working group

definitions for tomographic binning, so the WGTomographicSelector deliverable is about interfacing with other working groups rather than building something new.

Deliverable: *WGTomographicSelector for* PZCALIBRATE *(DC2 SW)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: Interface with WL and LSS tomographic binning selectors to ensure a connection between their pipelines and PZCALIBRATE.
Prerequisites: Deliverable *"Source selector and tomographic binning definition software (*TXSELECTOR*)"*

Deliverable: *PZBiasEvolutionEstimator for* PZCALIBRATE *(DC2 SW)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: Software for modeling the redshift-dependent galaxy bias for the clustering redshift analysis in PZCALIBRATE.
Prerequisites:

Deliverable: *MagnificationCorrection for* PZCALIBRATE *(DC2 SW)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL : https://github.com/LSSTDESC/pz_calibrate

Objective: Software for modeling the impact of magnification on galaxy correlation functions for the clustering redshift analysis in PZCALIBRATE.
Prerequisites:

Deliverable: *PZClusterz for* PZCALIBRATE *(DC2 SW)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL : https://github.com/LSSTDESC/pz_calibrate

Objective: This is the core clustering redshift analysis module that combines the observed clustering results with models for galaxy bias and magnification to infer the $N(z)$.

Prerequisites: Deliverables *"WGTomographicSelector for* PZCALIBRATE*"*, *"PZBiasEvolutionEstimator for* PZCALIBRATE*"*, *"MagnificationCorrection for* PZCALIBRATE*"*, *"Software for two-point statistics (*TXTWOPOINT*)"*

Deliverable: *Interface with WL and LSS for* PZCALIBRATE *(DC2 SW)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL : https://github.com/LSSTDESC/pz_calibrate
Objective: Some infrastructure work may be needed to interface at various stages with the WL and LSS pipeline TXPIPE, including at the tomographic binning stage and the delivery of $N(z)$ in some form. This deliverable is for that infrastructure work.
Prerequisites: Deliverables *"WGTomographicSelector for* PZCALIBRATE*"*, *"PZBiasEvolutionEstimator for* PZCALIBRATE*"*, *"MagnificationCorrection for* PZCALIBRATE*"*, *"PZClusterz for* PZCALIBRATE*"*

Deliverable: PZCALIBRATE *validation on DC2 simulations (DC2 VA)*

Host WG: PZ *Started:* 07/01/18 *Originally due:* 12/31/19
Status: planned *Expected:* 12/31/19
URL :
Objective: Exercise, validate, and update PZCALIBRATE on the DC2 simulations.
Prerequisites: Deliverables *"WGTomographicSelector for* PZCALIBRATE*"*, *"PZBiasEvolutionEstimator for* PZCALIBRATE*"*, *"MagnificationCorrection for* PZCALIBRATE*"*, *"PZClusterz for* PZCALIBRATE*"*, *"Interface with WL and LSS for* PZCALIBRATE*"*

Deliverable: *DC3-era* PZCALIBRATE *updates (DC3 SW)*

Host WG: PZ *Started:* 03/31/19 *Originally due:* 07/01/20
Status: planned *Expected:* 07/01/20
URL : https://github.com/LSSTDESC/pz_calibrate
Objective: Carry out DC3-era updates to PZCALIBRATE, with details to be determined based on the results of DC2 analysis
Prerequisites: Deliverable "PZCALIBRATE *validation on DC2 simulations"*

Deliverable: *DC3-era* PZCALIBRATE *validation (DC3 VA)*

Host WG: PZ *Started:* 03/31/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21

URL :

Objective: Exercise, validate, and update PZCALIBRATE on the DC3 simulations.
Prerequisites: Deliverable *"DC3-era* PZCALIBRATE *updates"*

PZ Key Product (DC2): Photometric Redshifts Pipeline `PZIncomplete` (`PZIncomplete`)

Host WG: PZ
Objective: Build `PZIncomplete` (Figure 5.12.3). This pipeline will be used to study the impact of incompleteness in spectroscopic training samples on the resulting photometric redshifts, resulting in improvements to PZPDF and a better understanding of expected photometric redshift performance

Deliverable: *MakeSpectra (DC2 SW)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL : https://github.com/LSSTDESC/pz_incomplete
Objective: Software to produce templates for galaxies based on a template library, without emission lines.
Prerequisites:

Deliverable: *AddEmissionLines (DC2 SW)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 05/31/19
URL : https://github.com/LSSTDESC/pz_incomplete
Objective: Software to add emission lines based on continuum spectra.
Prerequisites: Deliverable *"MakeSpectra"*

Deliverable: *PZGalaxyGenerator (DC2 SW)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 07/31/19
URL : https://github.com/LSSTDESC/pz_incomplete
Objective: Software to estimate spectroscopic incompleteness and rate of wrongly assigned

redshifts given the previous ingredients.
Prerequisites: Deliverables *"MakeSpectra"*, *"AddEmissionLines"*

Deliverable: *Validation and testing of `PZIncomplete` using DC2 simulations (DC2 VA)*

Host WG: PZ *Started:* 07/01/18 *Originally due:* 12/31/19
Status: planned *Expected:* 12/31/19
URL :

Objective: Validate `PZIncomplete` using the DC2 simulations, resulting in lessons that can feed into PZPDF development.
Prerequisites: DC2 simulations and deliverables *"MakeSpectra"*, *"AddEmissionLines"*, *"PZ-GalaxyGenerator"*.

PZ Key Product (SV): Integrated PZ Pipeline, Adapted to SV Data (PZ-SV)
Host WG: PZ
Objective: Fully integrated PZ pipeline for application to the SV data.

Deliverable: *Integrated PZ Pipeline (SV SW)*

Host WG: PZ *Started:* 07/01/20 *Originally due:* 09/30/22
Status: anticipated *Anticipated:* 09/30/22
URL :

Objective: Fully integrated end-to-end pipeline for producing DESC photometric redshifts.
Prerequisites:

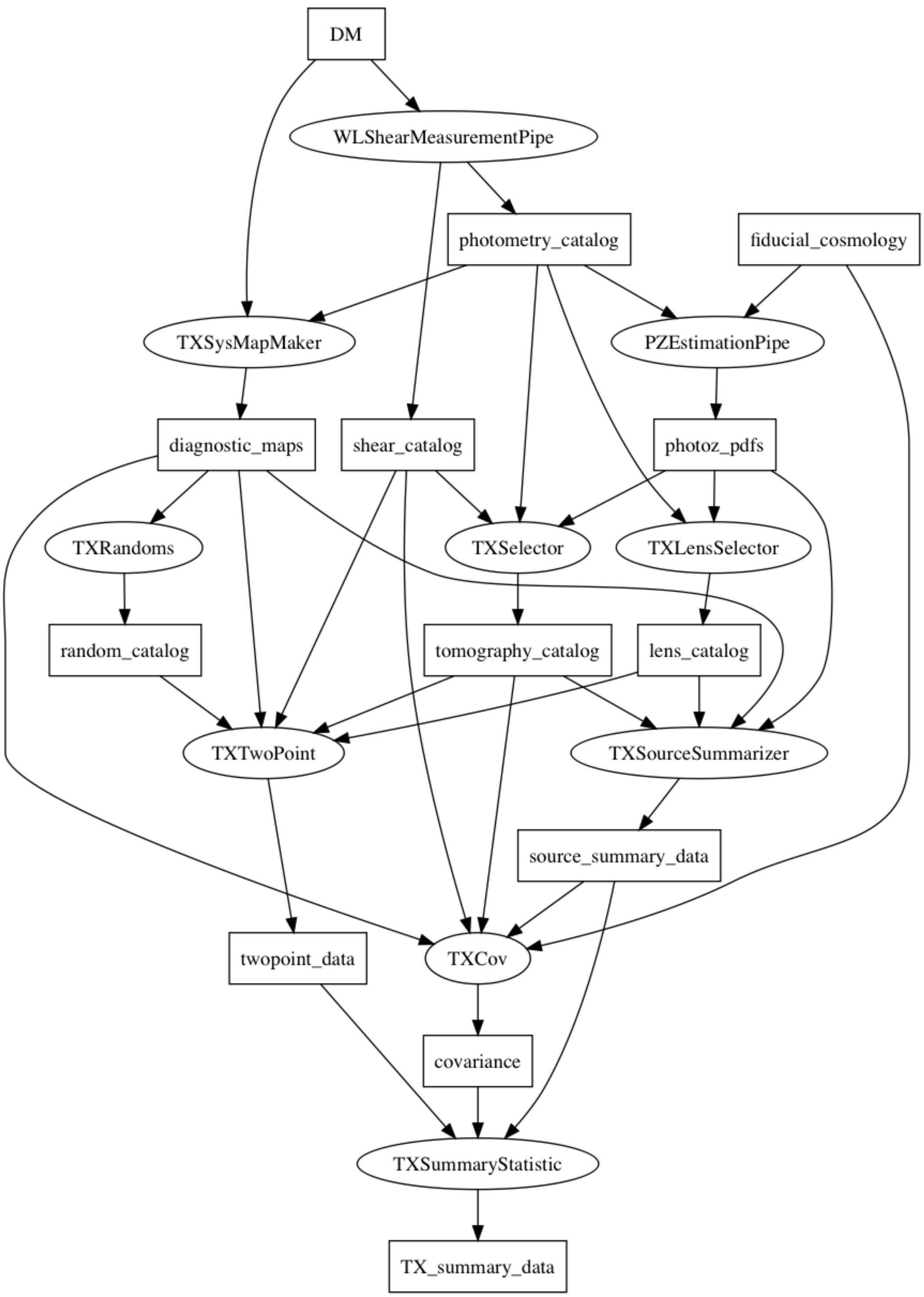

Figure 5.4.1: A schematic of the joint WL + LSS pipeline (TXPIPE), where ovals indicate analysis stages and rectangles indicate data that gets passed around.

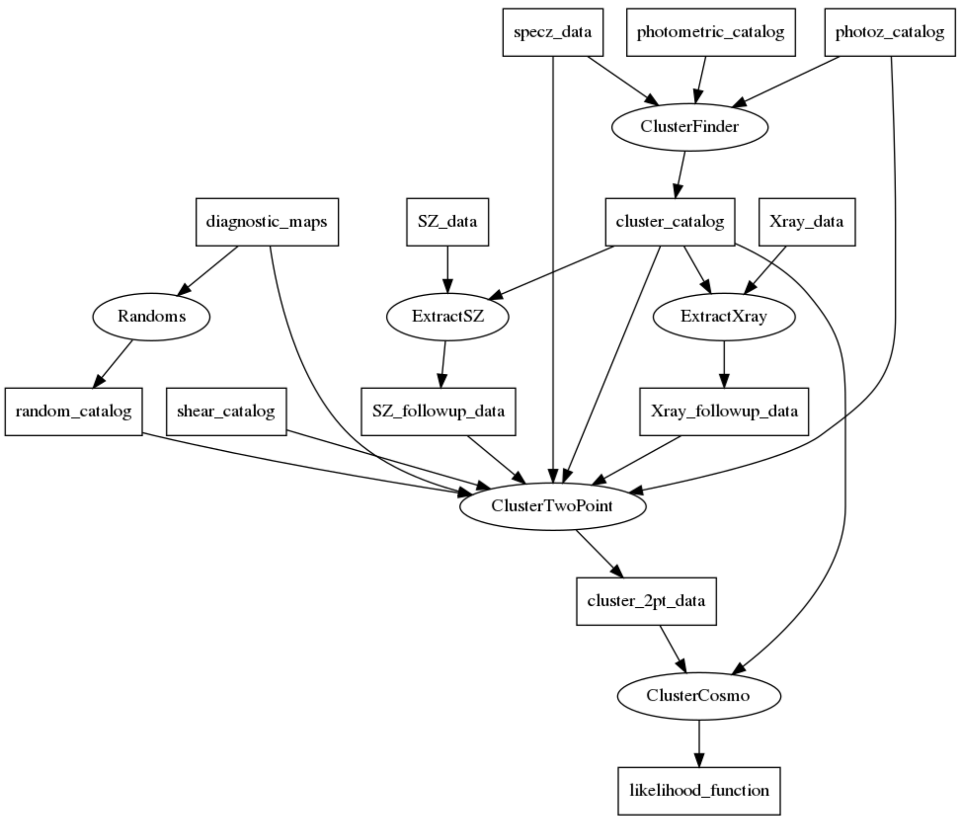

Figure 5.6.1: Pipeline diagram illustrating the components of cluster count cosmology inference. In practice, the analysis will use TXPIPE (Figure 5.4.1) with the addition of some cluster-specific components.

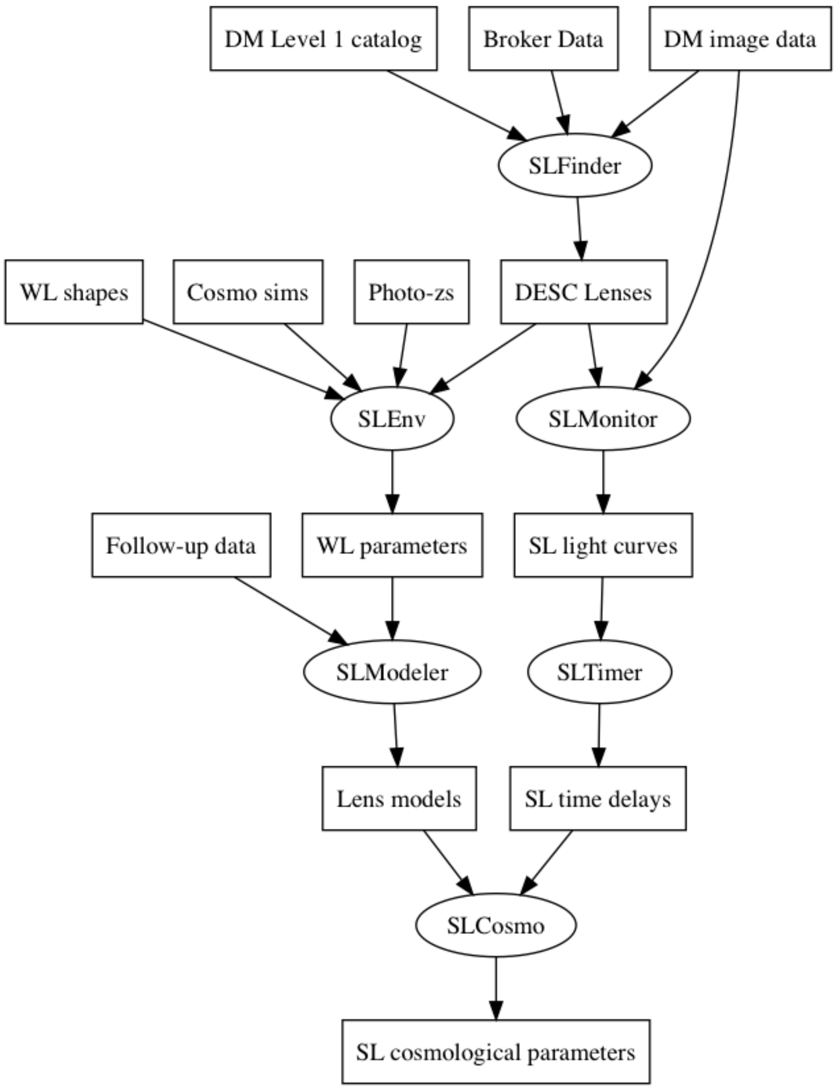

Figure 5.7.1: Graphical representation of the SL workflow.

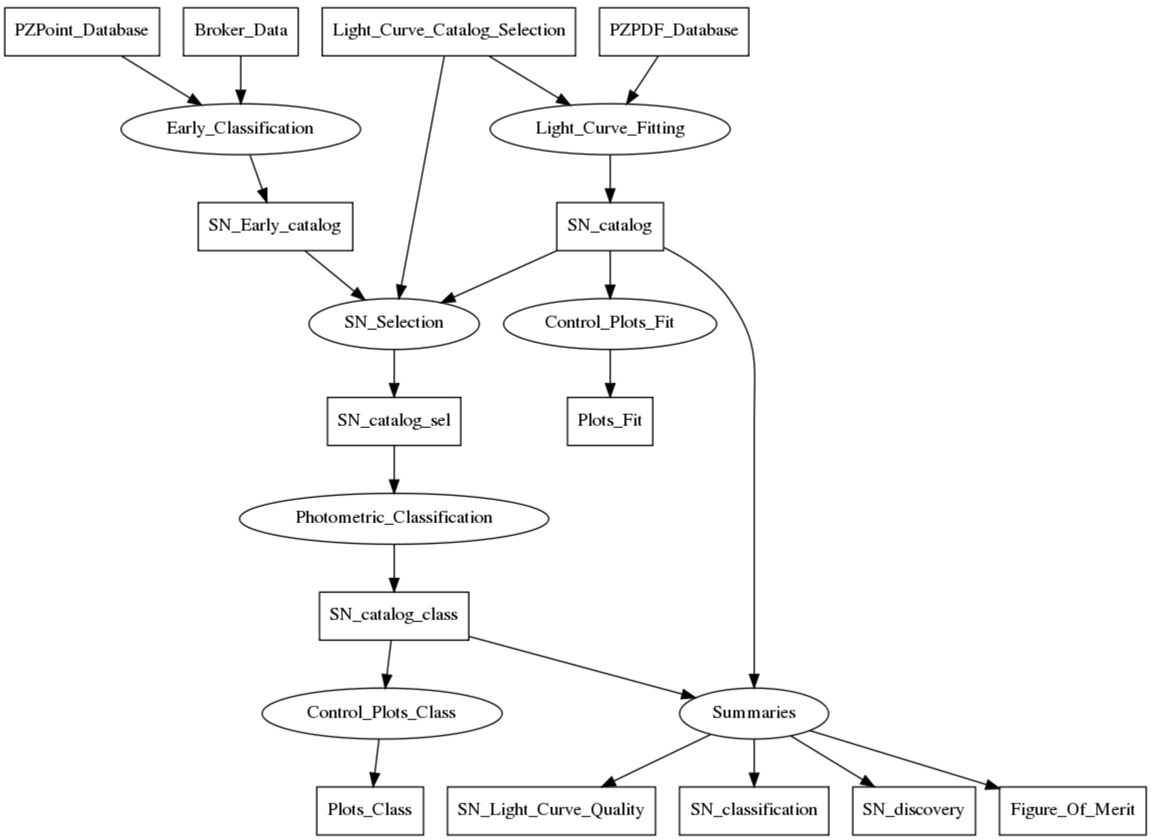

Figure 5.8.1: Pipeline diagram illustrating the components of the SN analysis pipeline at the catalog level.

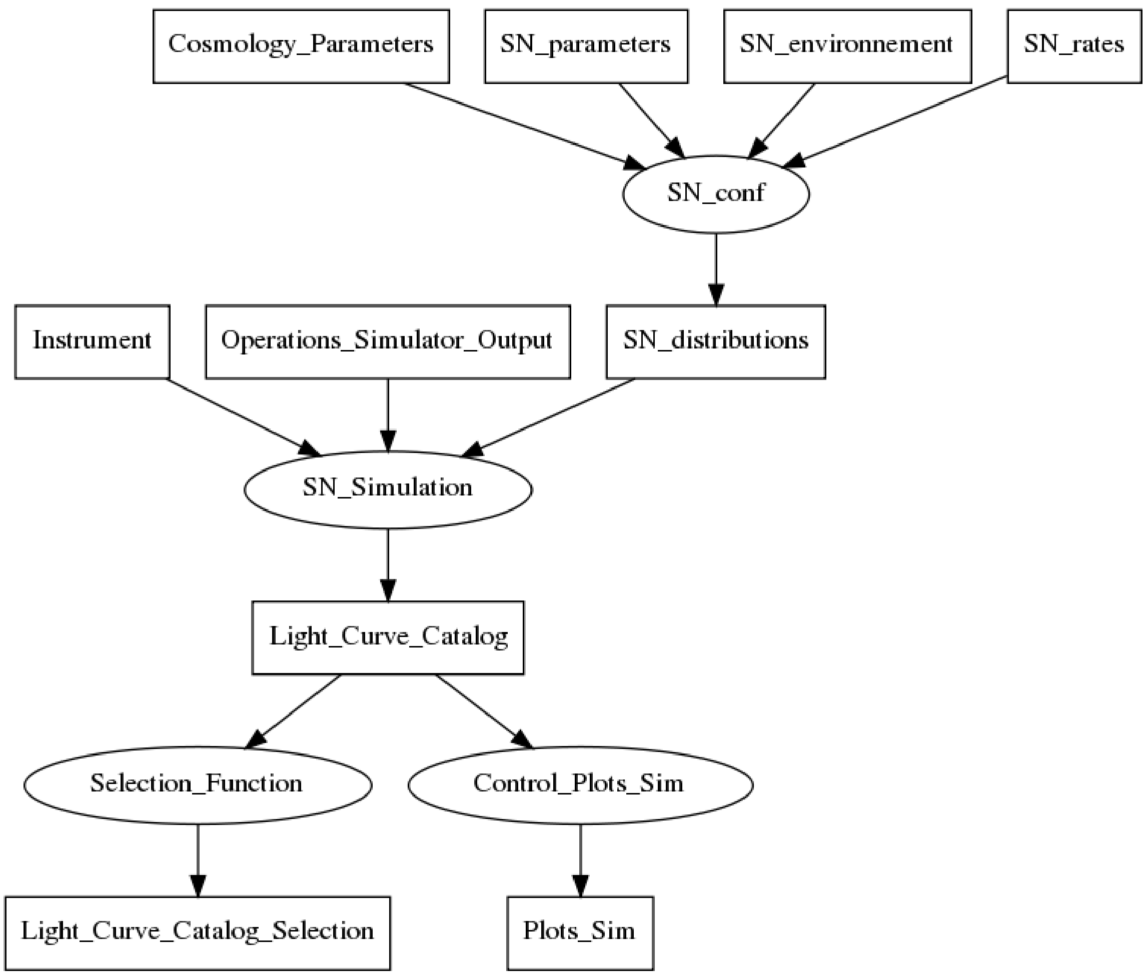

Figure 5.8.2: Pipeline diagram illustrating the components of the SN emulation pipeline at the catalog level.

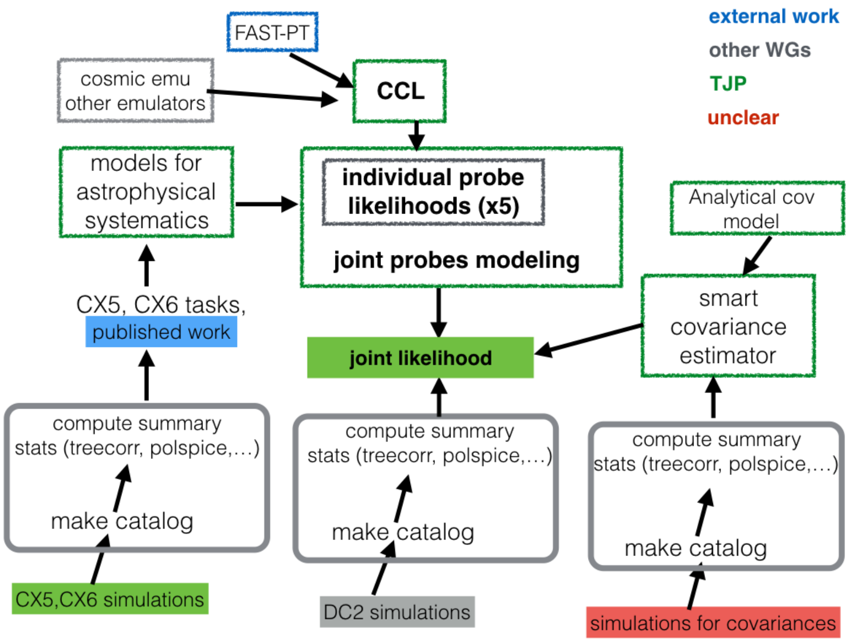

Figure 5.9.1: Pipeline diagram illustrating the components of TJPCosmo pipeline.

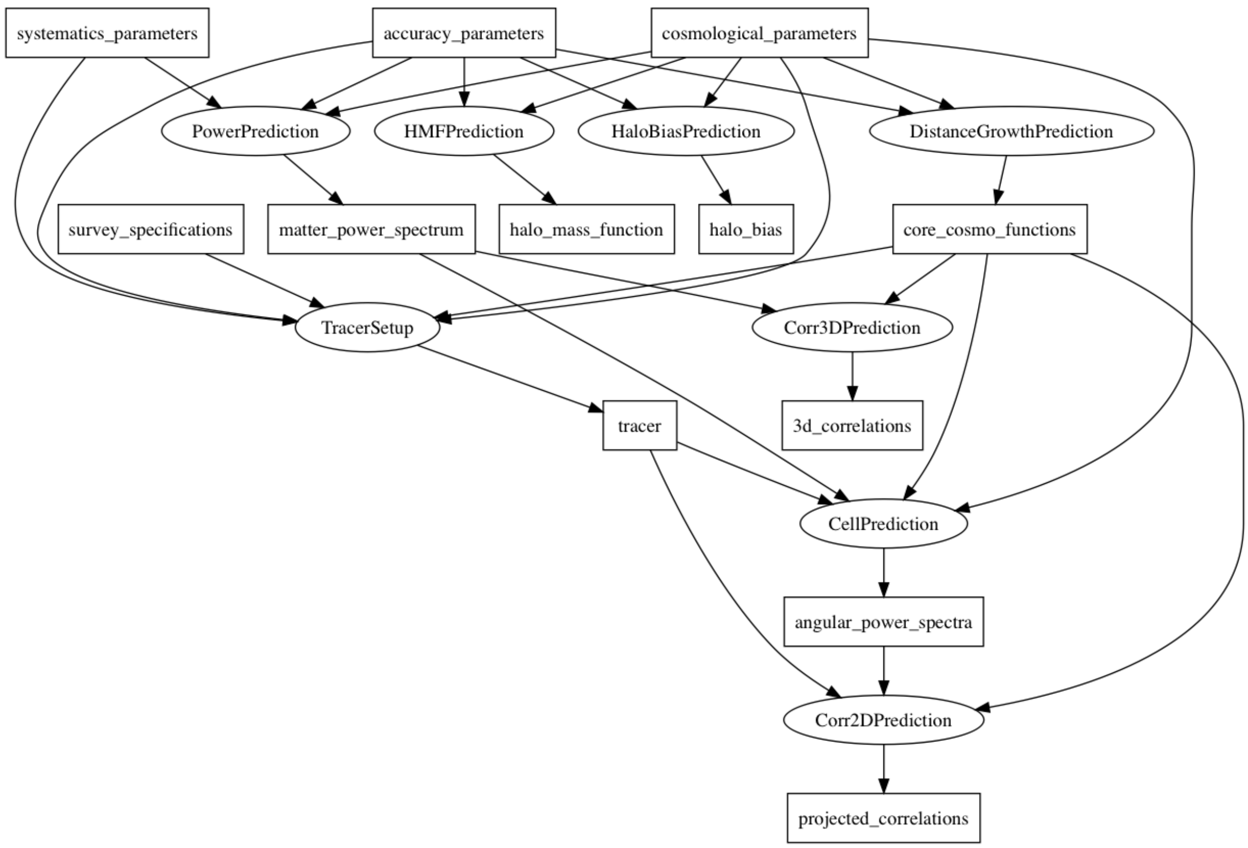

Figure 5.9.2: Zoom-in to the CCL module of the TJPCosmo pipeline.

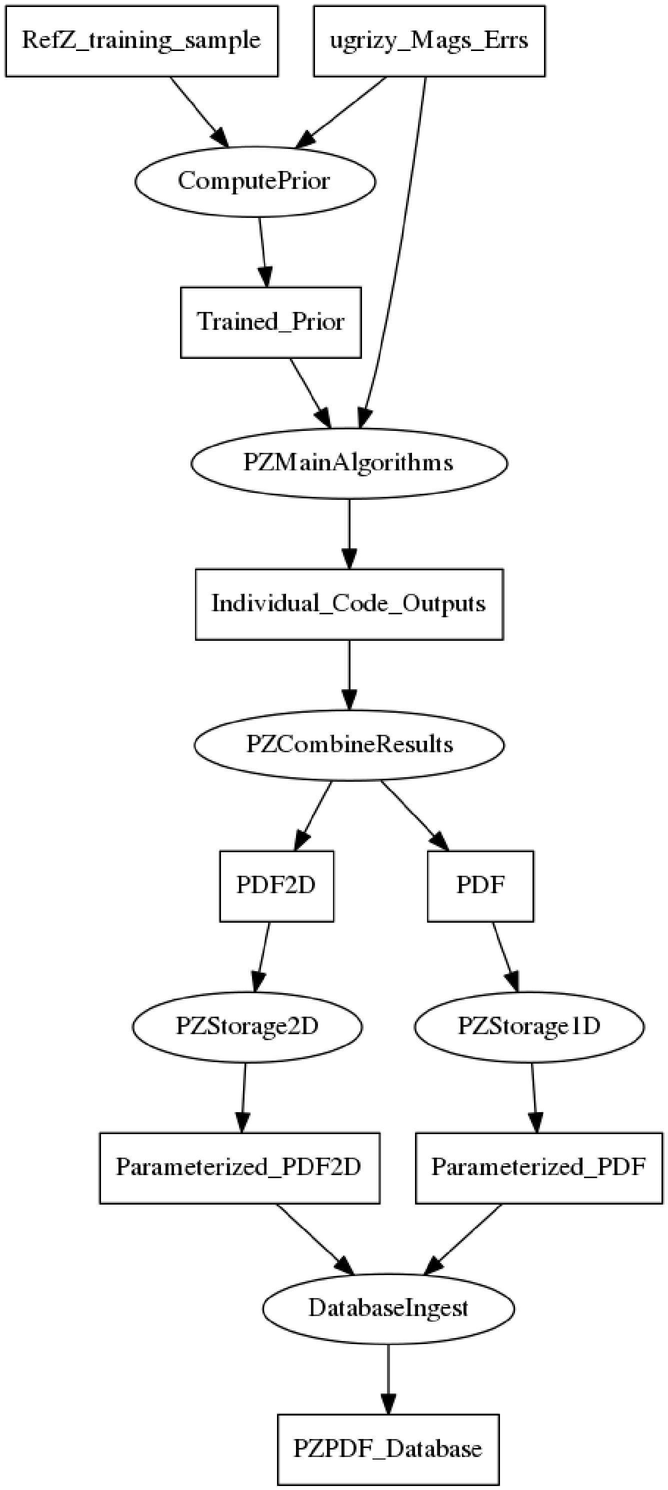

Figure 5.12.1: Pipeline diagram illustrating the components of the PZPDF workflow.

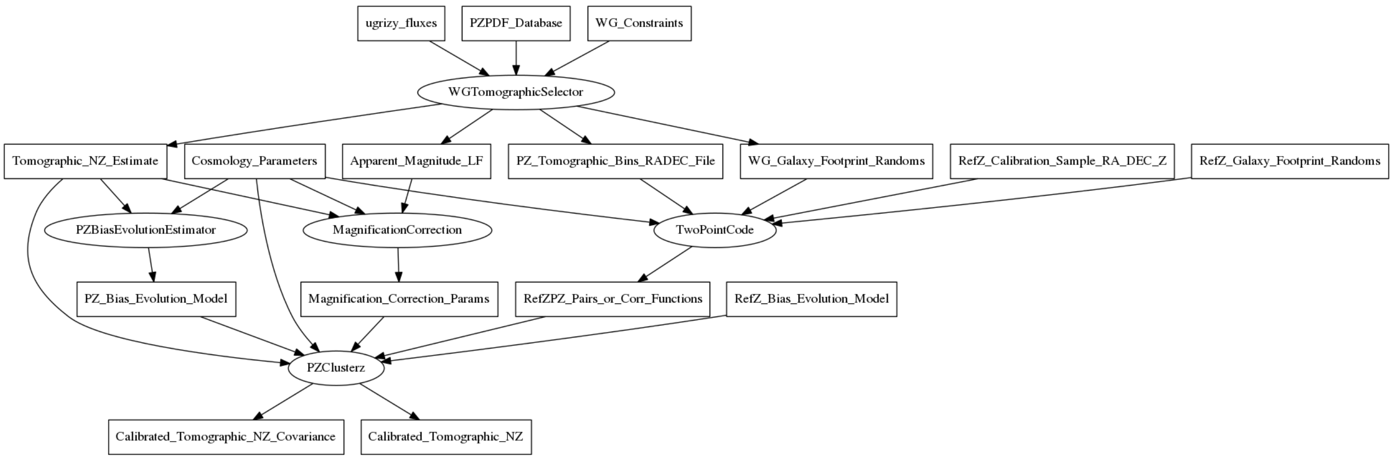

Figure 5.12.2: Pipeline diagram illustrating the components of the PZCALIBRATE workflow.

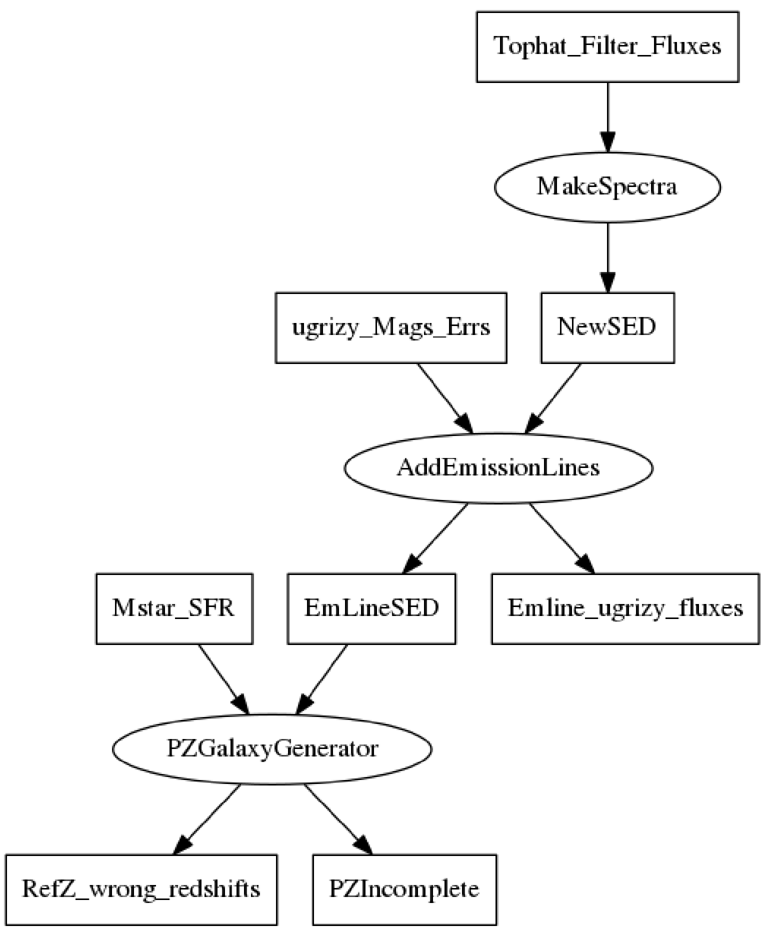

Figure 5.12.3: Pipeline diagram illustrating the components of the `PZIncomplete` workflow.

6 Datasets

In this section we explain in more detail what we mean by "data challenge," and show how the three that we have defined relate to various precursor datasets being prepared by the LSST Project. We then define as set of challenge datasets that meet the requirements of the working group R&D projects, and then divide them up into Key Products and Deliverables to be built as part of the collaboration's operations activity.

6.1 DESC Data Challenges

In this Roadmap (and in the collaboration more generally) we use the term "data challenge" to refer to the use of simulated or real data (at either image or catalog level) to develope and validate one or more components of the DESC software pipelines or associated infrastructure. Examples of data challenges include: quantifying the effects of systematics and the ability of pipeline tools to remove them; testing the performance of an algorithm when scaling up to data of increased size and/or complexity; determining the ability of the pipeline to recover an input cosmology; and demonstrating the successful operation of a pipeline at the required scale. The key common feature of all of these data challenges is that they involve the use of large, LSST-like datasets to address one or more well-defined and critical questions for LSST DESC in a controlled environment. These challenges are typically captured in some of the Activities in the R&D section Section 8. A critical requirement for the success of the data challenge Activities that use simulations is the validation, at each stage, of the fidelity of the simulated data, to ensure that they meet the requirements for each of the Activities that depend on them.

Economy of scale leads us to define a small number of "challenge datasets," and organize their assembly and analysis into discrete timeframes, leading to the concept of there being, in DESC, three discrete data challenge "eras." These can be seen in the schedule shown in Figure 2.1.1.

We summarize the expectations for each data challenge (DC) era as follows:

- DC1: Given the relatively short time-scale for development and completion, this will be a challenge in which working groups identify questions for which the necessary simulation and analysis infrastructure is essentially in place or easily put in place by 2016. Different working groups may have different priorities for what sorts of simulations or data sets would be most useful for DC1, depending upon the questions they choose to focus on first and their existing capabilities. Hence, challenge datasets may serve multiple working groups in some cases, but this will not always be true.

- DC2: The challenges in this era will focus primarily on a set of simulated catalog and image products of the form we expect from the Project but with partial fidelity and smaller scale; these should serve as a testbed for as many working groups as possible. DC2 challenges will include greater complexity in both simulation design and science questions than those from DC1. While there may be some opportunity to test cross-probe data combination, this will be of secondary priority compared to pushing forward with the primary probe data analysis pipeline development.

- DC3: this should be a collaboration-wide data challenge, in the sense of having common images and catalogs across the working groups and cross-linking analyses. The aim is to use LSST data release pipeline-reduced data products from simulations and/or precursor datasets to test analysis methods at the scale of that anticipated for the LSST commissioning Science Verification (SV) data, and develop the infrastructure to be ready for the first year of LSST data. The main aim is to finalize and validate the data analysis pipeline for the primary cosmological probes (including photo-z determination, etc.), in order to demonstrate that we can produce data-limited analyses of the ComCam and SV data. Cross-probe data combinations will also be investigated in this challenge.

Details of the expected simulations for each DC era are provided in Section 6.3 and Table 6.3.1 below.

6.2 LSST Project Datasets

DESC also intends to make full use of opportunities to analyze real datasets produced by the LSST Project to complement the analysis of simulated data challenge datasets:

- *Project-reprocessed external precursor data:* The Project is anticipating processing a number of precursor datasets, having characteristics ranging from a few square degrees at LSST depth to shallower but wide surveys, as "verification datasets."

  As of March 2018, the timelines for and expected products from these datasets are still being finalized. The SRM will be updated to incorporate their use, to build and validate interfaces with LSST Project DM software and to perform tests of the DESC analysis pipeline that are complementary to those done via simulated data. One important use of these precursor image sets will be in exercising the DESC's replica of the DM data release production pipeline: we need to be able to reproduce the LSST catalogs in order to then probe the systematic errors in them.

- *The Commissioning Camera (ComCam):* ComCam is a single-raft camera that will be installed on the LSST telescope in advance of the full science instrument. It is planned to have 6 filters ($ugrizy$), 9 CCDs, and cover $0.7 \times 0.7 \sim 0.5$ sq.deg per image. The primary objectives of ComCam are early system integration and testing. More details may be found in the LSST Commissioning Plan, LSE-79.

It is very likely that early commissioning will produce data that DESC could profitably analyze and learn from. The LSST Commissioning Plan includes three short (~ 4 night) observing campaigns surveys taken with the ComCam to test the DM pipeline. To test the system's Key Performance Metrics, we expect a non-contiguous area of some 10 square degrees to be imaged 25 times in each of 6 filters, reaching a depth of about 26 magnitudes in r, plus a second set that goes to 10-year depth in ri only, to test the full-depth Key Performance Metrics (e.g., ellipticity residuals). For the system's 20-year depth test, we expect an area of 5 square degrees to be imaged in all filters to a depth of about $r \approx 28$.

Data is expected to be made available to the science collaborations within a few months of data taking, albeit with a lower level of support than is expected for survey operations. The DESC will coordinate with the Project on this.

- *Science Verification:* The full LSSTCam/telescope/DM system is scheduled for 7 months of integration and testing through the first half of 2021. This would be followed by 5 months of Science Verification, again including short observing campaigns (totalling 3 months on the sky) to characterize performance relative to LSST System Requirements and to test operations readiness using the initial survey cadence.

  The LSST Commissioning Plan includes a "Wide Area" survey, imaging 1600 square degrees at 15 epochs in each of 6 filters over about 40 nights. It also includes a 10-year depth survey, covering 300 square degrees with 825 visits per field over the full filter set, also over about 40 nights. Together, these data will comprise some 40,000 visit images.

  It is anticipated that the Project will seek external input on this Science Verification survey design. The DESC will actively seek opportunities to engage with the Project on this as early as possible. Again, the SV data is expected to be available for science collaboration use within a few months of data-taking.

By design, the analysis of DC3 will conclude at the time when Science Verification data will become available. We will then use the DESC processing and analysis pipelines developed through the DCs to analyze the SV data, and in doing so scale them up to be able to operate on the initial LSST survey data.

More details on timelines for Project Hardware and DM development and testing are given in Section 10.4 and Section 10.5 respectively.

CTF Key Product (DC3): DESC Commissioning Efforts (CTF)
Host WG: CTF
Objective: We describe a set of activities undertaken by DESC members to support the LSST commissioning effort.

Deliverable: *DESC technical note with suggested observing fields and tests (DC3 RQ)*

Host WG: CTF *Started:* 01/07/2018 *Originally due:* 01/07/2019
Status: active *Expected:* 01/7/2019
URL : https://github.com/LSSTDESC/LSST-Commissioning
Objective: The DESC collaboration will suggest a set of survey fields and science validation tests which can be used by the commissioning team during both the ComCam and LSST Camera commissioning periods. These fields and tests will cover a range of times of year and will supply important test data to evaluate LSST performance metrics beyond those specified in the LSST project documents. The DESC can use this data to evaluate the system performance for metrics which are relevant to dark energy science.

This work will be undertaking by a large cross-section of the analysis and technical groups in the DESC including the Weak Lensing, Large Scale Structure, Galaxy Cluster, Supernovae, and Strong Lensing groups. The outcome of the work will be a DESC technical note to be delivered to the LSST project.

6.3 DESC Dataset Properties

Based on the descriptions of the Activities in Section 8, their data requirements can be addressed by a small number of common datasets. In the DC2 and DC3 eras, these common datasets will require substantial computational resources together with the development of an end-to-end framework that can both generate and process simulated data. In this section we describe the common datasets and their production, list the host working groups responsible for the dataset delivery, identify the working groups who will use the datasets, and list the Key Projects and tasks that the datasets will support.

As specified in Table 6.3.1 there are four cross-working group datasets that comprise cosmology simulations, simulated mock "extragalactic" catalogs, simulated images, and catalogs derived from the processing of the simulated images through the DM pipelines. These cross-working group simulated datasets, `Twinkles`, `DC2`, `DC3 Mock ComCam Survey`, and `DC3 Mock Lightcone` address the needs and requirements of most of the data sets described in Section 8. Two further datasets for DC1, `HaloCat` and `DC1 Phosim Deep`, are defined to supplement the data challenges. `HaloCat` is related to structure formation investigations and `DC1 Phosim Deep` to image processing. Finally, we define and include in the table the precursor datasets introduced above.

We anticipate that while each challenge dataset is defined as a single dataset, different working groups will use subsets of the data (e.g. the cosmology simulations, the extragalactic catalogs, the simulated images and so on), depending on their objectives.

Table 6.3.1: DC dataset properties.

Era	WGs	Name	Input	Catalog Area	Cadence[a]	Image Area	Bands	Depth	Scale
DC1	CL/LSS	HaloCat	N-body		N/A	N/A	N/A	N/A	N/A
DC1	SL/SN	Twinkles	CatSim (T)[b]	100 sq arcmin	DDF 10 yr	100 sq arcmin	$ugrizy$	$r = 27.5$	0.1k
DC1	LSS/WL	DC1 Phosim Deep	CatSim	80 sq deg	WFD 10 yr	80 sq deg	r	$r = 28.0$	6k[e]
DC2	SL/WL/LSS CWG/CL/PZ TJP/SN	DC2	CatSim (T, N)[c]	5000 sq deg	WFD 10 yr	300 sq deg	$ugrizy$	$r = 27.5$	30k
DC2	WL/LSS CL/TJP	DC2 HSC Public Release 1	*HSC* survey	c. 100 sq deg	*HSC*	100 sq deg	$grizy$	$r = 26.4$	N/A
DC3	SL/WL/LSS CL/PZ/TJP CWG	DC3 Mock Lightcone	CatSim (NN)[c]	18000 sq deg[d]	WFD 10 yr	$\leq$ 1000 sq deg[f]	$ugrizy$	$r = 27.5$	$\leq$100k
DC3	SL/WL/LSS	DC3 Mock ComCam Survey	CatSim (NN)[c]	20 sq deg	ComCam[g]	10, 5 sq deg	$ugrizy$	$r \approx \{26, 28\}$	1k

Notes: The relevant "scale" of a dataset is the number of visit images *processed* (since the DESC's program during the survey is based on reprocessing subsets of the LSST images to probe for systematics). The scale of re-processing the LSST Year 1 dataset 10 times (in 2023) will be 300k, while re-processing the LSST Science Verification data (in 2022) 3 times will be about 120k.

[a] Refers to the observing plan in the OpSim databases. DDF = "Deep Drilling Field," WFD = "Wide-Fast-Deep."

[b] The (T) refers to Twinkles modifications to CatSim. Time dependent SEDs and spatially oversampled images will be made available.

[c] (N) refers to a new cosmological model input. (NN) refers to multiple input cosmological models.

[d] The size and resolution of the input cosmological simulation will be defined based on the results from DC2 and the catalog will be generated from a set of realizations rather than a single volume to reduce computational costs.

[e] The DC1 Phosim Deep sky and bandpass coverage leads to 2000 visit images, but three copies of the image set were made to exercise the simulation tools.

[f] The DC3 Mock Lightcone dataset is not yet designed, and may not cover a contiguous area; more likely it will be a set of smaller sky patches, sampling different cosmologies and/or DM processing configurations. How much imaging area is required will depend on the analysis pipeline development needs, but we can use the scaling argument limit to place an upper limit of 100k visit images, which is the appropriate scale for SV readiness.

[g] ComCam observation plans are still in the design phase. Key Performance Metric testing is expected to need 10 sq deg in $ugrizy$ with 25 epochs per filter. The 20-year depth test is expected to be carried out over 5 sq deg.

Table 6.3.1 shows the datasets that have been requested by the analysis working groups. In the table, the dataset name is shown along with the requested parameters of each data set. The exact simulation tools used will depend on the requirements defined by the analysis working groups and the results of the validation tests. For the datasets requested by the SN and SL groups the Survey Simulation group working with the Twinkles team (Key Project "Supernova and Strong Lens Light Curves" (CX2)) will need to assure the proper modifications are in place to produce the over-sampled time dependent sources needed for SN and SL analysis. In the case of later datasets CatSim will integrate new (and possibly multiple) cosmological models. The observing strategy used to define the inputs to the image simulations, i.e. the pointings on the sky, will be as simulated by OpSim. In some cases, analysis groups will use idealized or e-image files which contain the truth information before electronics simulation, effectively acting as if perfect instrument signature removal (ISR) has been applied.

The dataset entries within Table 6.3.1 represent the simulated images and derived DM catalogs together with associated input and metadata including: the N-body cubes, halo catalogs, mock extragalactic catalogs of galaxies, associated lightcones, models for representing variability, and derived quantities such as shear measurements. For DC1 the cosmological models will be a canonical ΛCDM model. For DC3 the cosmological models will be extended based on the requirements defined in the R&D Activity *"Cosmological Simulations with Novel Physics"*.

The design of the `DC3 Mock Lightcone` image simulation will be informed by the analysis of `DC2`, and the needs of the analysis pipeline development. Readiness for SV places an upper limit on the required scale of the DC3 image set. The "scale" column of Table 6.3.1 shows how many LSST visit image processings are involved in each dataset, which increases as DESC's computational capabilities ramp up. Re-processing 10% of the LSST Year 1 dataset 10 times (in 2023) corresponds to a scale of 300,000 processed visit images. Re-processing the LSST Science Verification data once (in 2022) would involve about 40,000 visit images, so doing 7 re-processings would get us up to Year 1 scale. Following this logic, a sensible upper limit for the scale of `DC3 Mock Lightcone` is 100,000 visit images, the geometric mean of the scale of `DC2` (30,000) and LSST Year 1. In practice, we can plan on using both the processing of DC3 and the re-processing of the SV data to get us up to Year 1 scale, such that the DC3 can be scoped at somewhere between DC2 and SV.

The CPU time cost of the simulation scales (roughly) with the area of sky simulated, while the storage cost scales (roughly) with the number of visit images processed. We have a few avenues for reducing the scope of DC3 while still meeting our science goals within a fixed amount of computing time. First, the outcome of Key Project "Emulation of LSST Catalog Data" (SSim8) may enable us to emulate at least some catalog-level data products at a fidelity that enables tests of our pipelines without image simulations (see the Deliverable *"`DC3`*

`Mock Lightcone` *Emulated DM Catalog"*). Second, if image simulation proves too computationally expensive, we could, instead, consider remaining at DC2 scale in terms of mock sky area covered (300 sq deg for 10 years, or 3000 sq deg for 1 year), and re-processing these DC3 images 3-4 times with different settings in DM designed to enable tests of our sensitivity to algorithmic choices. Alternative options with varying levels of computational expense and complexity, meeting different scientific needs, could include reprocessing of precursor datasets on their own or with synthetic galaxies injected (Balrog or SynPipe methodology). It is possible that the DC3 dataset that jointly meets the needs of different working groups is actually a combination of several of the above options. Balancing the computing costs with the needs of the analysis pipeline development will bound the detailed DC3 design, to be made during the DC3 RQ phase (Figure 2.1.1).

6.4 DESC Dataset Requirements

The detailed design of each challenge dataset must be primarily determined by the analysis groups who will be using it. To this end, we collect the requirements of all the groups in the following deliverables.

NB: in the text below, deliverables and activities are presented with color coding determined by their status, as follows: "done" deliverables have hyperlinks like this, "defunct" deliverables have hyperlinks like this, "active" deliverables have hyperlinks like this, "planned" deliverables have hyperlinks like this, and "anticipated" deliverables have hyperlinks like this.

CS Key Product (DC1): DC1 Requirements (CS12)
Host WG: CS
Objective: We describe the DC1 requirements from a range of working groups. Since DC1 is a collection of smaller simulation projects, these requirements have to be fullfilled by a range of different simulations.

Deliverable: `HaloCat` *Requirements (DC1 RQ)*

Host WG: CS *Started:* 10/01/15 *Originally due:* 12/31/15
Status: defunct
URL:
Objective: The delivery of a document listing the DC1 tasks that can be accomplished from

large, gravity-only simulations and describing the requirements from the analysis WGs for the HaloCat dataset

Deliverable: *CL Requirements for HaloCat (DC1 RQ)*

Host WG: CL *Started:* 10/01/15 *Originally due:* 12/31/15
Status: defunct
URL :
Objective: To provide the Cosmological Simulations group with requirements for HaloCat, including considerations relating to halo definitions and centering methods that should enable the best match to observational data possible. We note that the cluster work requires HaloCat to provide self-consistent determinations of halo masses, halo centers and shear maps.
Prerequisites:

Deliverable: *PZ Requirements for and development of DC1 simulations (DC1 RQ)*

Host WG: PZ *Started:* 10/01/15 *Originally due:* 06/30/16
Status: done *Completed:* 06/30/16
URL : https://github.com/LSSTDESC/PZDC1paper/tree/pz_metrics
Objective: For DC1, we will need to generate (with PZGalaxyGenerator) a catalog of simulated galaxy colors based on a extragalactic catalog with realistic galaxy SEDs; photo-z algorithms can then be run on this catalog. Work on PZGalaxyGenerator will continue into DC2.
Prerequisites: preliminary data used in researching/defining Activities for the Key Project "Research and define all relevant measurements for cosmological simulations" (CS1)

Deliverable: *Twinkles CS, SS and DM Stack Requirements (DC1 RQ)*

Host WG: SL *Started:* 10/01/15 *Originally due:* 03/31/17
Status: done *Completed:* 03/31/17
URL :
Objective: Provide minimum and/or desired science requirements for the simulated or precursor data to be used in DC1 to develop and test the initial SN and SL monitoring codes. Key tasks will involve setting the cosmological simulations (CS) and survey simulations (SS) requirements, as well as our requirements for the DM stack software (i.e. the deblender, image differencer and forced photometer) and DESC computing infrastructure, based on the tests that we need to do. These tests must first be specified, in terms of a set of quantitative performance metrics. Due to the pilot nature of the Twinkles project, many of these requirements will

emerge as R&D proceeds.
Prerequisites: None

CS Key Product (DC2): DC2 Requirements (CS5)
Host WG: CS
Objective: Here we list the DC2 requirements, from the simulation as well as analysis point of view. While, for DC1 these are relatively straightforward, requirements on the DC2 and DC3 simulations will be more challenging. This Key Product will define the DC2 requirements, and inform the process for collecting the DC3 requirements. The requirements should be collected in a DESC Note that describes the DC2 plan, and which later becomes part of the the planned DC2 survey and catalog papers.

Deliverable: *CS Requirements for DC2 (DC2 RQ)*

Host WG: CS *Started:* 10/01/16 *Originally due:* 09/30/17
Status: done *Completed:* 9/30/17
URL : https://github.com/LSSTDESC/DC2_Repo/blob/master/Documents/README.md

Objective: The different data challenges have a range of requirements for the extragalactic catalogs. For example the depth of, the area covered by, and magnitude of the galaxies in the catalog dictates the simulation volume as well as force and mass resolution required. In addition, different methods for generating mock galaxy catalogs have different requirements on resolution. In all cases, the process will certainly be iterative. A document that maps the second data challenge into detailed simulation requirements with regard to simulation methodology, cosmological physics, fidelity, volume, mass resolution, and properties of the mock catalogs.
Prerequisites: Deliverables *"DC2 Time Domain Requirements"*, *"DC2 Time Domain Requirements"*, *"DC2 Time Domain Requirements"*, *"$p(z)$ for DC1 Galaxies"*, *"DC2 Specifications"*,

Deliverable: *Methods beyond brute-force cosmological simulations (DC2 RQ)*

Host WG: CS *Started:* 10/01/16 *Originally due:* 12/31/17
Status: defunct
URL :
Objective: For different DCs, different methods of enhancing resolution in the simulations can be employed, e.g. for clusters it could be re-simulation techniques, or merger trees that serve

as input for semi-analytic models could be enhanced in resolution by approximate methods.
Prerequisites: Already available simulations at different resolutions.

Deliverable: *DC2 Time Domain Requirements (DC2 RQ)*

Host WG: SL *Started:* 10/01/16 *Originally due:* 09/30/17
Status: done *Completed:* 09/30/17
URL : https://github.com/LSSTDESC/DC2_Repo/blob/master/Documents/README.md

Objective: Provide minimum and/or desired requirements for the time domain part of the DC2 survey, in order to drive development of SLFINDER target selection, SUPERNOVAMONITOR and SLMONITOR light curve extraction, and catalog level SL and SN emulation. In the process, best-estimate lens-finding requirements for the LSST DRP data and LSST DM software, could be made, for completeness. We will have a good idea of what the time domain parts of DC2 will need to look like based on the Twinkles experience.
Prerequisites: None

Deliverable: *PZ Requirements for Incompleteness (DC2 RQ)*

Host WG: PZ *Started:* 10/01/16 *Originally due:* 12/31/17
Status: done *Completed:* 12/31/17
URL : https://github.com/LSSTDESC/DC2-production/pull/152
Objective: Using results of PZ2, determine what further ingredients are needed in DC2 photo-z-specific simulations for realistic tests of the impact of SED bias and incompleteness on photo-z analyses. We need Stellar Mass, SFR, SFH, and metallicity in order to construct incompleteness models, we will examine what level of detail is needed for DC2 incompleteness models.
Prerequisites: Deliverable *"$p(z)$ for DC1 Galaxies"*

Deliverable: *PZ Requirements for Cross-correlation Method (DC2 RQ)*

Host WG: PZ *Started:* 10/01/16 *Originally due:* 12/31/17
Status: done *Completed:* 12/31/17
URL : https://github.com/LSSTDESC/DC2-production/pull/152
Objective: Set requirements for simulations of cross-correlation method and assess whether they may be included in the standard DC2 simulation.

Deliverable: *DC2 Specifications (DC2 RQ)*

Host WG: SSim *Started:* 10/01/16 *Originally due:* 04/30/18
Status: done *Completed:* 4/30/18
URL : https://github.com/LSSTDESC/DC2_Repo/blob/master/Documents/README.md

Objective: Refine the area, depth, input catalog, selection of systematic effects, and properties of simulated systematics for the DC2 data set for the Key Product "DC2 Production" (SSim4). Refinements should be made based on the results of DC1 Deliverables in TJPFORECAST, IMSIM, and WLNULLTEST.
Prerequisites: Activity *"Assess the DM stack shape measurement code"*, Deliverables *"Null test pipeline (WLNULLTEST)"*, *"Validation of the BF effect in simulations"*, *"Validation of static effects in PHOSIM"*; overlap with Deliverables *"Identify and characterize PSF systematic uncertainties"*, *"Identify and characterize non-PSF systematic uncertainties"*, *"Survey Simulation Tools for DC2"*

Deliverable: *WL Requirements on the depth of the DC2 and DC3 extragalactic catalogs (DC2 RQ)*

Host WG: WL *Started:* 10/01/16 *Originally due:* 12/31/16
Status: active *Expected:* 12/31/16
URL :

Objective: Hoekstra et al. (2015) found that they needed to include galaxies down to 1.5 magnitudes fainter than their detection limit in order not to bias their shear calibration. This result may be dependent on the shear algorithm used. They used a moments-based method, and it is unclear how this translates to other shear estimation algorithms. We need to know how faint the input catalogs need to go for DC2 and DC3 simulations.
Prerequisites: R&D Activity *"Software to quantify impacts of blending"*

CS Key Product (DC3): DC3 Requirements (CS13)
Host WG: CS
Objective: As for DC2, we list the DC3 requirements from the simulation as well as analysis point of view. The requirements should be addressed in the DESC Note that describes the DC3 plan and can later become part of the the planned DC2 survey and catalog papers.

Deliverable: *Requirements on DC3 simulated datasets (DC3 RQ)*

Host WG: SSim *Started:* 10/01/18 *Originally due:* 09/30/19
Status: active *Expected:* 09/30/19

URL :

Objective: Set the WL DC3 requirements on the input galaxy catalog (correlated morphologies, sizes, colors, limiting magnitudes), PSF contributions from the atmosphere, optics, and sensor effects (including chromaticity), clustering of input sources, and cosmological models to enable DC3 Deliverable targets.

The level of photo-z systematics should be considered here. If the photo-z errors are irreducible beyond some level, it may lessen the required accuracy of the shear estimation.
Prerequisites: Deliverables *"Identify and characterize PSF systematic uncertainties"*, *"Identify and characterize non-PSF systematic uncertainties"*, *"DC2 Specifications"*, *"Implemented and Validated Correction Algorithm for the BF Effect"*, *"Validation of correction algorithms for static effects"*; overlap with *"Survey Simulation Tools for DC3"*

Deliverable: *CL Requirements for* `DC3 Mock Lightcone` *(DC3 RQ)*

Host WG: CL *Started:* 10/01/18 *Originally due:* 09/30/19
Status: active *Expected:* 09/30/19
URL :

Objective: On the basis of the results from the DC1 and DC2 Key Projects, determine the optimum cosmological simulation strategy for DC3. Utilize CLFORECAST to assess whether more precise mass functions are required in order to exploit LSST commissioning/SV data. If so, request as a DC3 Deliverable from CS. Use the results of Key Projects "Absolute mass calibration I" (CL2) and "Absolute mass calibration II" (CL3) to determine how best to populate `DC3 Mock Lightcone` with galaxies, and re-utilize and extend the DC2 hydro re-simulations. The output will inform the cluster information in `DC3 Mock Lightcone` simulations.

Deliverable: *SL Requirements for DC3 (DC3 RQ)*

Host WG: SL *Started:* 10/01/18 *Originally due:* 09/30/19
Status: active *Expected:* 09/30/19
URL :

Objective: Provide minimum and/or desired requirements for the `DC3 Mock ComCam Survey` and `DC3 Mock Lightcone` datasets such that all the SL analysis codes can be tested for science readiness. The most important one here will probably be the high density of lenses (and lens-like non-lenses) required.
Prerequisites: None

Deliverable: *LSS Observing strategy for* `DC3 Mock Lightcone` *(DC3 RQ)*

Host WG: LSS *Started:* 10/01/18 *Originally due:* 09/30/19
Status: active *Expected:* 09/30/19
URL :
Objective: In consultation with SSim WG, combine previous Deliverable with cadences recommended by SN and SL WGs to specify dither pattern and filter cadence to be implemented in six-filter Deep-Wide PHOSIM +DM simulations in DC3.
Prerequisites: R&D Activities *"Optimized LSST observing strategy"* and *"Observing Strategy Recommendations"*

Deliverable: *WL Observing strategy for* `DC3 Mock ComCam Survey` *(DC3 RQ)*

Host WG: WL *Started:* 10/01/18 *Originally due:* 09/30/19
Status: active *Expected:* 09/30/19
URL :
Objective: We will develop an observing strategy that can be used on ComCam to validate our findings for optimal survey strategies. Here it will be tested on the `DC3 Mock ComCam Survey` simulations.
Prerequisites: LSS-CWG-OS-3

6.5 DESC Dataset Production

Dataset production can be usefully seen as a three-step process:

1. **Extragalactic catalog production**, in which a noise-free mock galaxy catalog is produced from an N-body cosmological simulation halo catalog "painted" with observable galaxies via some prescription.

2. **Image simulation**, in which simulated LSST images are produced from "instance catalogs" derived from the extragalactic catalog combined with a visit list, typically provided from an LSST schedule simulation tool such as OPSIM.

3. **Image processing**, in which the simulated LSST images are passed through the LSST DM pipelines, resulting in tables of Object, Source, DIASource etc. measurements.

Steps 2 and 3 can be circumvented by *emulating* the LSST DM catalogs from an extragalactic catalog and a visit list, directly.

In this Section we outline the Key Products in each data challenge era that will result from each of these dataset production steps. We organize these products chronologically, first by challenge era, and then within each era.

NB: in the text below, deliverables and activities are presented with color coding determined by their status, as follows: "done" deliverables have hyperlinks like this, "defunct" deliverables have hyperlinks like this, "active" deliverables have hyperlinks like this, "planned" deliverables have hyperlinks like this, and "anticipated" deliverables have hyperlinks like this.

CS Key Product (DC1): `HaloCat` Dataset Production (CS14)
Host WG: CS
Objective: The `HaloCat` dataset will be based on dark-matter-only simulations. According to current requirements from CL and LSS, ~2-4 Gpc cube volumes should be sufficient. For the CL working group, we will use cluster catalogs from the Outer Rim simulation, a $(4.225\text{Gpc})^3$ volume, to deliver cluster shear maps. For LSS we will continue using one of the Mira-Titan Universe simulations (2.1Gpc^3 volume, described in Heitmann et al. 2015). This simulation has been populated with galaxies using an HOD. We will additionally use the Buzzard galaxy catalog based on a lightcone derived from 1–4 Gpc^3 simulations, populated with a different galaxy prescription including LSST colors. This data set can be used for CL and LSS DC1 tasks. Galaxy and halo catalogs for both simulations are available to the collaboration at NERSC.

This dataset supports the Activities and Deliverables: *"Cluster masses from weak-lensing shear maps (*CLMASSMOD*)"*, *"Two-point preliminary studies"*.

Deliverable: *`HaloCat` Test catalogs for LSS measurement codes (DC1 DP)*

Host WG: CS *Started:* 01/01/16 *Originally due:* 03/31/17
Status: defunct
URL :

Objective: Deliver large volume test catalogs based on, e.g. Halo Occupancy Distribution (HOD) modeling, that can be used by the LSS working group to test out algorithms and code for power spectrum and cross-power spectrum measurements. This will enable work described in the Deliverable *"Two-point preliminary studies"*.

SL Key Product (DC1): `Twinkles` (SL7)
Host WG: SL
Objective: The `Twinkles` simulation is designed to address the objectives of the cross-working group Key Project "Supernova and Strong Lens Light Curves" (CX2) through a small

(on the scale of a single CCD) image simulation of strong lenses and supernovae. The functionality to generate the simulated catalogs and images is already in place using the CatSim and PhoSim simulation tools. The depth of the input catalog need only be such that the visit images yield the expected detected Sources; no analysis is planned on the faintest Objects found in the coadds. The images will be processed by the LSST DM pipelines, requiring the existence of deblending and single epoch photometry algorithms. The volume and computational resources required are minimal (<1 TB of data and 1000 CPU hrs) but the production of these data will require the development of a prototype end-to-end simulation and image processing framework. The development of this framework is addressed in the Deliverable *"A framework for Twinkles light curve generation"* and the validation of the input data in the Key Product "DC1 Survey Simulation Tools" (SSim1).

This dataset supports the R&D Activities and Deliverables: *"`Twinkles` CS, SS and DM Stack Requirements"*, *"SupernovaMonitor 1.0"*, *"SLMonitor 1.0"*, *"`Twinkles` SN and SL Light Curves"*, *"SupernovaMonitor 2.0"*, *"SLMonitor 2.0"*

Deliverable: *`Twinkles` Images and DM Catalogs (DC1 DP)*

Host WG: SSim *Started:* 01/01/16 *Originally due:* 04/01/17
Status: done *Completed:* 04/01/17
URL : https://github.com/LSSTDESC/Twinkles/tree/Run3-phoSim-v2
Prerequisites: None
Objective: A 100 sq arcmin dataset composed of 10 years of simulated catalogs, the resulting $ugrizy$ PhoSim images (simulated using a Deep Drilling Field cadence) and the catalogs of emulated DM DRP object measurements. The dataset will be generated via a prototype end-to-end framework for the simulation and processing of LSST-like images, the Deliverable *"A framework for Twinkles light curve generation"*.

SSim Key Product (DC1): `DC1 Phosim Deep` (SSim2)
Host WG: SSim
Objective: The `DC1 Phosim Deep` simulation is a general imaging dataset defined to address image processing and analysis of temporal or coadded data. Functionality to generate the simulated catalogs and images is in place and the catalogs used as input to the images will be those derived from the current CatSim datasets. The volume of data and computational resources required to generate this dataset is <50 TB of data and 4M CPU hrs.

This dataset supports the following R&D Activity: *"Results from `DC1 Phosim Deep`"*

Deliverable: *`DC1 Phosim Deep` Images (DC1 DP)*

Host WG: SSim *Started:* 01/01/16 *Originally due:* 03/31/17
Status: done *Completed:* 03/31/17
URL : https://github.com/LSSTDESC/SSim_DC1

Objective: Several 80 sq deg datasets composed of 10 years of observations in the r passband (simulated using a main survey (WFD) cadence).
Prerequisites: R&D Activity *"Dither patterns for `DC1 Phosim Deep` simulations"*, Deliverable *"Survey Simulation Tools for DC1"*
Approach: Design DC1 simulations cover hundreds of visits in a single filter (r) over multiple overlapping LSST fields-of-view (FOVs). At least 4 FOVs are needed in order to trace the angular separations of "triple points" at the intersections of the hexagonal lattice used to tile the sky. Several versions of this simulation will be run with (and without) translational and rotational dithers performed at each visit. Simulation inputs must include realistic, coupled LSS and weak lensing shear. It is understood that DM will not yet correct for BFF and static sensor effects, so most of our simulations will not include these effects. We will however run unditheded and fully-dithered versions that include these effects. The production run to generate `DC1 Phosim Deep` input catalogs and simulated images will be carried out at NERSC and the resulting data will be hosted at NERSC.

Deliverable: *$p(z)$ for DC1 Galaxies (DC1 DP)*

Host WG: PZ *Started:* 01/01/16 *Originally due:* 10/31/17
Status: done *Completed:* 10/31/17
URL : https://github.com/aimalz/qp/tree/issue/54/paper/docs/desc-0000-qp-photo-z_approximation

Objective: We will generate a catalog of redshift probability distributions based on the DC1 extragalactic catalog for working groups to use as input for cosmological error propagation. An important component of this work will be determining the storage format for the redshift estimates, and assuring that the format is compatible with the needs of other working groups. As a comparative review of probability distribution accuracy for current production codes is valuable to the community this will be written up as a journal article.
Prerequisites: Deliverable *"PZ Requirements for and development of DC1 simulations"*

CS Key Product (DC2): Extragalactic Catalogs for DC2 (CS7)
Host WG: CS
Objective: The DC2 and DC3 data sets will require the development of new extragalactic catalogs that express the shear, color-morphology correlations, morphology-density correlations, and complex morphologies. Part of this process will be deciding on the most appropriate prescription for predicting the galaxy properties for the various mock catalogs.

Deliverable: *Parameterization of the Extragalactic Catalogs for DC2 and DC3 (DC2 SW)*

Host WG: CS *Started:* 10/01/16 *Originally due:* 04/30/18
Status: done *Completed:* 04/30/18
URL : https://github.com/LSSTDESC/cosmodc2
Objective: Develop the tools and the validation of the various prescriptions for generating extragalactic catalogs including appropriate colors, sizes, morphologies and correlations with density (based on the requirements defined in DC1).
Prerequisites: Deliverable *"DC2 Specifications"*, R&D Activity *"Documentation and validation of all tools that deliver input catalogs"*

Deliverable: *Validation of the DC2 Extragalactic Catalogs (DC2 VA)*

Host WG: CS *Started:* 10/01/16 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL : https://github.com/LSSTDESC/descqa
Objective: Once the extragalactic catalogs have been generated, there will be a validation phase that will use the validation framework (R&D Activity *"A validation framework for the input catalog distributions."*) to compare observational and simulated data. Additional tests will need to be incorporated as the catalog needs become better understood. This will rewqure input from the analysis working groups.
Prerequisites: R&D Activity *"A validation framework for the input catalog distributions."*

Deliverable: *HaloCat Cluster shear maps (DC2 DP)*

Host WG: CS *Started:* 10/01/17 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :
Objective: A set of cluster shear maps extracted from a large N-body simulation that also serves for predictions of the halo mass function for tasks specified in the R&D Activity *"Cluster masses from weak-lensing shear maps (CLMassMod)"*.

Deliverable: *Extragalactic Catalogs for the* `DC2` *Simulation (DC2 DP)*

Host WG: CS *Started:* 10/01/17 *Originally due:* 06/30/18
Status: done *Completed:* 06/30/18
URL : https://confluence.slac.stanford.edu/display/LSSTDESC/ProtoDC2+and+CosmoDC2+Information

Objective: Based on the requirements for `DC2` and the most effective prescription for generating extragalactic catalogs, generate the cosmological simulations and mock catalogs required for `DC2`. Shears will be derived by ray-tracing through the dark matter halo distribution.
Prerequisites: Deliverable *"Compilation of precursor survey data to test the shear pipeline"*

SSim Key Product (DC2): `DC2` Production (SSim4)
Host WG: SSim
Objective: The `DC2` dataset is the first cross-working group simulated dataset that includes both LSS and WL in the input data and simulated images. The `DC2` images will be processed by the LSST DM pipelines, requiring the existence of deblending, multi-epoch photometry, and PSF estimation algorithms. production of these data will use the end-to-end simulation and image processing framework described in the Key Product "Targeted Frameworks for Use by the Analysis Working Groups" (CI3).

For time domain cosmography, a fraction of the `DC2` survey area will contain supernovae and strong lens systems: the `DC2` dataset will extend `Twinkles` to greater levels of realism, both in the physics inputs but also the image processing and object detection and measurement. The astrophysical inputs will utilize temporally evolving supernova spectral energy distributions (see the Deliverable *"Survey Simulation Tools for DC2"*), and also a wider range of time-variable "backgrounds" (to enable experiments in transient and variable classification). Lensed supernovae will also be included, as will microlensing effects in all lenses. The DM MultiFit algorithm may become available during the DC2 era; the `DC2` images should enable user-generated "scene modeling" to be investigated.

This image dataset supports the following static sky R&D Activities: *"Generate and test shear catalog"*, *"Field test of likelihood module"*, *"Field test of two-point software"*, *"Field test of sampling methods"*, *"Cluster shears from DC2 simulations"*, *"SL Environment Characterization and Assessment"*, *"WL Recommendations for LSST observing strategy"*, *"$p(z)$ for simulated catalog objects"*, *"Galaxy Measurement Emulation Methods in DC2"*.

It also supports the following time domain Activities and Deliverables: "SLFinder *Target Selection Code"*, "SLFinder *Lens Candidate Extractor"*, *"*`DC2` *(DC2)* SLFinder *Target*

Catalogs and Assessment", *"DC2* SLFINDER *Candidate Samples and Assessment"*, *"TDC3 Simulated Light Curves"*, *"DC2 SN and SL Light Curves"*, *"Emulation of Lensed Quasar Measurements in DC2"*.

Deliverable: *DC2 Simulated Images (DC2 DP)*

Host WG: SSim *Started:* 10/01/17 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: Define the detailed specifications for a 300 sq degree simulated imaging survey in the $ugrizy$ passbands. Cadence will be WFD with possible extensions, plus a small "ultra deep drilling field" region designed to support time domain studies.
Approach: We will generate instance catalogs based on the extragalactic catalog produced in Deliverable *"Extragalactic Catalogs for the DC2 Simulation"*. We will then produce simulated images, and host them, at NERSC.
Prerequisites: Deliverables *"Survey Simulation Tools for DC2"* and *"Extragalactic Catalogs for the DC2 Simulation"*, and all the analysis working group DC2 requirements (DC2 RQ) Deliverables: *"DC2 Specifications"*, *"DC2 Time Domain Requirements"*, *"DC2 Time Domain Requirements"*, *"DC2 Time Domain Requirements"*

Deliverable: *DC2 DM DRP Catalogs (DC2 DP)*

Host WG: CI *Started:* 10/01/17 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: Run the DESC's DM data release production (DRP) pipeline on the DC2 simulated images to make DM DRP catalogs (including Object, Source, DIASource etc. tables), and serve them to the collaboration.
Approach: We will run the pipeline built as Deliverable *"A DESC-modified DM DRP Reprocessing Pipeline"*, first at CC-IN2P3 and then later at NERSC.
Prerequisites: Deliverables *"DC2 Simulated Images"*, *"A DESC-modified DM DRP Reprocessing Pipeline"*, *"Workflow and Dataset Tracking Tools for DC2"*, and *"Replica of the DM Catalog Technology"*.

SSim Key Product (DC3): DC3 Mock Lightcone Production (SSim7)
Host WG: SSim

Objective: The DC3 Mock Lightcone dataset will comprise a catalog-level simulation covering approximately 18,000 sq degrees (the LSST main survey volume) and an image simulation of a fraction of this area. The requirements for the size and resolution of the input cosmological simulations will be defined based on the analysis of the DC2 dataset and the experience gained during its production. The catalog and images will be based on new simulations with at least two cosmologies (including a non-ΛCDM cosmology) and several realizations each to cover the large area in a computationally feasible way. Simulated extragalactic catalogs will include realistic morphologies and a validated morphology-density relation. Simulated image data will be processed by the LSST DM pipelines, requiring the existence of deblending, multi-epoch photometry, multifit, and PSF estimation algorithms. production of these data will be through the end-to-end simulation and image processing framework described in Key Product "DC3 Workflow and Data Management Configuration" (CI14).

This dataset supports the R&D Activities and Deliverables: *"Generate and test shear catalog"*, *"Field test of likelihood module"*, *"Analyze DC3 Mock Lightcone"*, *"Results from DC3 Mock Lightcone"*, *"Joint Probes Analysis of DC3 Mock Lightcone"*

Deliverable: *DC3 Mock Lightcone Simulated Images (DC3 DP)*

Host WG: SSim *Started:* 10/01/19 *Originally due:* 06/30/20
Status: planned *Expected:* 06/30/20
URL :

Objective: Define the specifications for the DC3 Mock Lightcone image simulations, and then generate these simulated images according to those specifications.
Prerequisites: Deliverables *"DC2 Simulated Images"* and *"Survey Simulation Tools for DC3"*, plus all analysis working group DC3 requirements (DC3 RQ): Deliverables *"Requirements on DC3 simulated datasets"*, *"CL Requirements for DC3 Mock Lightcone"*, *"SL Requirements for DC3"*, *"LSS Observing strategy for DC3 Mock Lightcone"*, *"WL Observing strategy for DC3 Mock ComCam Survey"*, and R&D Activity *"TDC3 Requirements"*.

Deliverable: *DC3 Mock Lightcone DM DRP Catalogs (DC3 DP)*

Host WG: CI *Started:* 10/01/19 *Originally due:* 06/30/20
Status: planned *Expected:* 06/30/20
URL :

Objective: Run the DESC's DM data release production (DRP) pipeline on the DC3 Mock Lightcone simulated images to make DM DRP catalogs (including Object, Source, DIASource etc. tables), and serve them to the collaboration.

Approach: We will run the upgraded DC3-era DM DRP pipeline built as Key Product "Upgraded DM DRP Processing Pipeline and Data Service" (CI15).
Prerequisites: Deliverables *"`DC3 Mock Lightcone` Simulated Images"*, *"Upgraded DESC DM DRP Reprocessing Pipeline"*, *"Workflow and Dataset Tracking Tools for DC3"*, and *"Upgraded Replica of the DM Catalog Technology"*.

Deliverable: *`DC3 Mock Lightcone` Emulated DM Catalog (DC3 DP)*

Host WG: SSim *Started:* 10/01/19 *Originally due:* 06/30/20
Status: planned *Expected:* 06/30/20
URL :

Objective: Define the specifications for the `DC3 Mock Lightcone` catalog-level simulations, and then generate these emulated DM catalogs according to those specifications.
Prerequisites: Deliverable *"`DC2` Simulated Images"*, R&D Activities *"Galaxy Measurement Emulation Methods in DC2"* and *"Emulation of Lensed Quasar Measurements in DC2"*.

SSim Key Product (DC3): `DC3 Mock ComCam Survey` Production (SSim6)
Host WG: SSim
Objective: The `DC3 Mock ComCam Survey` dataset will consist of a simulation of the expected ComCam survey(s). The definition of these ComCam survey(s) has not been completed but is expected to comprise a single LSST raft with a 6 month observing window, and some 1000 sq degrees of sky coverage. The extragalactic catalog for this simulated survey will be based on large volume simulations with at least two cosmological models (including a non-ΛCDM cosmology) as defined in the Key Product "`DC3 Mock Lightcone` Production" (SSim7). Extragalactic catalogs derived from these cosmological simulations will include realistic morphologies and a validated morphology-density relation.

Data will be processed by the LSST DM pipelines, requiring the existence of deblending, multi-epoch photometry, multifit, and PSF estimation algorithms. production of these data will use the end-to-end simulation and image processing framework described in Key Product "DC2 Workflow and Data Management Configuration" (CI10).

This dataset supports the Key Projects, Activities and Deliverables: "Physics Beyond wCDM with LSST" (TJP2), *"Lens Candidates"*, *"Time Delays"*, *"Lens Environments"*, *"WL Observing strategy for `DC3 Mock ComCam Survey`"*, *"Results from `DC3 Mock ComCam Survey`"*

Deliverable: *`DC3 Mock ComCam Survey` Simulated Images (DC3 DP)*

Host WG: SSim *Started:* 10/01/19 *Originally due:* 06/30/20
Status: planned *Expected:* 06/30/20
URL :

Objective: Define the specifications for the `DC3 Mock ComCam Survey` image simulations, and then generate these simulated images according to those specifications.
Prerequisites: Deliverables *"`DC2` Simulated Images"* and *"Survey Simulation Tools for DC3"*, plus all analysis working group DC3 requirements (DC3 RQ): Deliverables *"Requirements on DC3 simulated datasets"*, *"CL Requirements for `DC3 Mock Lightcone`"*, *"SL Requirements for DC3"*, *"LSS Observing strategy for `DC3 Mock Lightcone`"*, *"WL Observing strategy for `DC3 Mock ComCam Survey`"*, and R&D Activity *"`TDC3` Requirements"*.

Deliverable: *`DC3 Mock ComCam Survey` DM DRP Catalogs (DC3 DP)*

Host WG: CI *Started:* 10/01/19 *Originally due:* 06/30/20
Status: planned *Expected:* 06/30/20
URL :

Objective: Run the DESC's DM data release production (DRP) pipeline on the `DC3 Mock ComCam Survey` simulated images to make DM DRP catalogs (including Object, Source, DIASource etc. tables), and serve them to the collaboration.
Approach: We will run the upgraded DC3-era DM DRP pipeline built as Key Product "Upgraded DM DRP Processing Pipeline and Data Service" (CI15).
Prerequisites: Deliverables *"`DC3 Mock ComCam Survey` Simulated Images"*, *"Upgraded DESC DM DRP Reprocessing Pipeline"*, *"Workflow and Dataset Tracking Tools for DC3"*, and *"Upgraded Replica of the DM Catalog Technology"*.

WL Key Product (DC2): WL Precursor Dataset Production (WL10)
Host WG: WL
Objective: Obtain or re-process precursor data for use by various Working Groups.

Deliverable: *Compilation of precursor survey data to test the shear pipeline (DC2 DP)*

Host WG: WL *Started:* 10/01/16 *Originally due:* 06/30/17
Status: active *Expected:* 12/31/19
URL :

Objective: The simulated data to be produced for DC2 has the advantage that the true shear field can be known. However, real data is useful in that it includes all the actual systematic effects from the telescope, sensors, atmosphere, etc. In particular, while the true signal is not known, shear estimates from the real data should pass all relevant null tests. We will need to determine which real data sets are appropriate to use as test beds for our code, and possibly repackage the data into the format needed. Where possible, we will take advantage of processing done by DM as part of their own validation exercises, rather than re-processing within the DESC.
Prerequisites: R&D Activity *"Assess the DM stack shape measurement code"*, Deliverable *"Null test pipeline (WLNULLTEST)"*.

CI Key Product (DC2): Re-processed `DC2 HSC Public Release 1` (CI16)
Host WG: CI
Objective: The Subaru Hyper-SuprimeCam (*HSC*) survey public release 1 provides an interesting precursor dataset for a number of DESC research projects. Those that involve DESC *re-processing* of the *HSC* images would, wneh defined, depend on this re-processed image Key Product. We can anticipate at least two Deliverables: one for WL from Erin Sheldon's shape measurement investigation, and one for CL from Dominique Boutigny's reprocessing at IN2P3, both of which would need defining. There should then be associated Deliverables in Section 5 describing the necessary extension of the DESC DM processing pipeline.

CI Key Product (SV): The DESC-reprocessed ComCam Dataset (DESC-ComCam)

Host WG: CI
Objective: We anticipate re-processing the ComCam dataset several times, to test our ability to cope with real images, and reproduce the Facility release data.

Deliverable: *DESC-Reprocessed ComCam DRP Catalogs (ComCam DP)*

Host WG: CI *Started:* 10/01/20 *Originally due:* 09/30/21
Status: anticipated *Anticipated:* 09/30/21
URL :
Objective: Re-process the ComCam images using the DESC DRP pipeline, and verify that it

reproduces the key cosmological summary statistics derived from the Facility data release.
Prerequisites:

Deliverable: *DESC-Processed Alternative ComCam DRP Catalogs (ComCam DP)*

Host WG: CI *Started:* 10/01/20 *Originally due:* 09/30/21
Status: anticipated *Anticipated:* 09/30/21
URL :

Objective: We will produce alternative DRP catalogs for the ComCam dataset, probing the systematic effects due to various configurations and algorithm choices.
Prerequisites:

CI Key Product (SV): The DESC-reprocessed SV Dataset (DESC-SV)
Host WG: CI
Objective: The DESC's MO in survey operations is to re-process $\sim 10\%$ of the available LSST imaging ~ 10 times. As described in Section 6.3 above, we anticipate re-processing the SV dataset several times, as part of a scaling up process to reach readiness for the Year 1 survey dataset.

Deliverable: *DESC-Reprocessed SV DRP Catalogs (SV DP)*

Host WG: CI *Started:* 10/01/21 *Originally due:* 09/30/22
Status: anticipated *Anticipated:* 09/30/22
URL :

Objective: Re-process the SV images using the DESC DRP pipeline, and verify that it reproduces the key cosmological summary statistics derived from the Facility data release.
Prerequisites:

Deliverable: *DESC-Processed Alternative SV DRP Catalogs (SV DP)*

Host WG: CI *Started:* 10/01/21 *Originally due:* 09/30/22
Status: anticipated *Anticipated:* 09/30/22
URL :

Objective: We will produce alternative DRP catalogs for subsets of the SV dataset, probing the systematic effects due to various configurations and algorithm choices.
Prerequisites:

6.6 DESC Follow-up Datasets

In many cases DESC analyses will incorporate data from telescopes other than LSST. In this subsection we describe activities needed to ensure that collaboration members have access to the data products needed to pursue their work. The work defined in this subsection is primarily coordinated by the Follow-up Task Force (FTF).

FTF Key Product (DC2): Coordinate production of white papers and proposals for non-LSST datasets (FTF1)
Host WG: FTF

Deliverable: *Response to the Astro2020 Decadal Survey Call for Science White Papers (DC2 DP)*

Host WG: FTF *Started:* 10/1/18 *Originally due:* 02/22/19
Status: active *Expected:* 02/22/19
URL :

Objective: Datasets needed to make optimal use of LSST data may not be feasible to obtain without new capabilities being implemented or new observational programs being carried out. The Follow-up Task Force (FTF) will help to coordinate cross-collaboration white papers and proposals as necessary to help ensure these data may be obtained. As an example the DESC has an opportunity to provide input to the Astro2020 Decadal Survey through the call for science white papers due in January 2019. It would be valuable to submit white papers which lay out the science case for any large-scale datasets we are likely to need that would not be feasible with currently available resources. Cross-working-group white papers would fall under the umbrella of FTF. In many cases this may require quantification of the science gains from additional data, which may lead to separate publications. This activity (led by the FTF) covers all primary probe working groups, as well as the photometric redshifts group.

FTF Key Product (DC3): Develop Inter-Collaboration Agreements (ICAs) with External Projects (FTF2)
Host WG: FTF

Deliverable: *Completion of First Inter-Collaboration Agreement (DC3 DP)*

Host WG: FTF *Started:* 1/1/19 *Originally due:* 01/1/20
Status: active *Expected:* 01/1/20
URL :

Objective: In many cases, data which will be vital for pursuing DESC science will be proprietary to other collaborations. In such situations, it will be necessary to negotiate mutually beneficial arrangements that allow the best science to be pursued. The Follow-up Task Force (FTF) will act as a clearinghouse which helps to connect the DESC working groups with external collaborations and, by putting into place concrete examples, will develop the format and requirements for inter-collaboration agreements between DESC and other collaborations that ensure necessary data access, and facilitate the development of at least one signed ICA. The 4MOST/TiDES project is one example of a possible partner in such an ICA. This activity (led by the FTF) involves all primary probe working groups, as well as the photometric redshifts group. Our aim is to enable the first completed ICA to be in place by the beginning of 2020.

FTF Key Product (DC3): Develop Policies for Internal Data-Sharing (FTF3)
Host WG: FTF
Objective: There will be many cases in which subsets of a DESC working group have proprietary access to data which may not be broadly shared. In such cases, we will need to have policies and procedures in place which allow the working groups to pursue cosmological measurements efficiently without breaking the restrictions placed upon non-LSST datasets. The Follow-up Task Force (FTF) will work with working group leadership to develop broadly-applicable policies that serve this need. Such policies will be central to the inter-collaboration agreements (ICAs) that the DESC will enter into with external collaborations. As per the DESC External Collaborator Policy, such agreements should be negotiated by the Spokesperson, and ratified by the Collaboration Council. The role of the FTF will be to facilitate the collaboration's discussion of relevant data-sharing needs, and synthesize those discussions for inclusion in an ICA. This activity involves all primary probe working groups, as well as the photometric redshifts group. Our aim is to have the first draft of a data-sharing policy for discussion completed by Fall 2019.

Deliverable: *Draft data-sharing policy (DC3 DP)*

Host WG: FTF *Started:* 1/1/19 *Originally due:* 09/01/2019
Status: active *Expected:* 09/01/2019
URL :

Objective: The FTF will develop a draft data-sharing policy for an initial example case, to be included as a key part of an inter-collaboration agreement with an external group.

7 Pipeline, Infrastructure and Dataset Deliverables

The deliverables of the previous two sections constitute all the mission-critical pipeline and infrastructure software, and accompanying test data, that we need to develop, operate and maintain in order to be ready to analyze commissioning data. This short section simply lists all of these Key Products, and their Deliverables, so as to provide an overview of these operations tasks. NB: in the text below, deliverables and activities are presented with color coding determined by their status, as follows: "done" deliverables have hyperlinks like this, "defunct" deliverables have hyperlinks like this, "active" deliverables have hyperlinks like this, "planned" deliverables have hyperlinks like this, and "anticipated" deliverables have hyperlinks like this.

Pipelines and Computing Infrastructure

CI Key Product (DC2): The Initial Elements of a Software Framework (CI2)

Deliverable: *Software Framework Implementation* 06/30/18

Deliverable: *Distributed Code Development Environment* 02/28/18

Deliverable: *Workflow & Data Management Tools* 02/28/18

CI Key Product (DC1 & DC2): Targeted Frameworks for Use by the Analysis Working Groups (CI3)

Deliverable: *A framework for Twinkles light curve generation* 06/30/16

Deliverable: *A Framework for TJP* 06/30/16

CI Key Product (DC1 & DC2): Distributed Code Development Environment (CI4)

Deliverable: *An initial development environment* 01/31/16

Deliverable: *Software coding standards and code review policies* 02/28/18

CI Key Product (DC2): Common Pipeline Infrastructure (CI12)

Deliverable: *Pipeline Software Interfaces and Abstractions* 06/30/18

CI Key Product (DC3): Common Pipeline Infrastructure for DC3 and SV (SV-CPI)

Deliverable: *SV-Ready Pipeline Software Interfaces and Abstractions* 10/01/21

CI Key Product (DC1): `DC1 Phosim Deep` Workflow and Data Management Configuration (CI8)

Deliverable: *Tracking Tools for DC1* PHOSIM *Datasets* 01/31/16

CI Key Product (DC2): DC2 Workflow and Data Management Configuration (CI10)

Deliverable: *Workflow and Dataset Tracking Tools for DC2* 06/30/18

CI Key Product (DC3): DC3 Workflow and Data Management Configuration (CI14)

Deliverable: *Workflow and Dataset Tracking Tools for DC3* 06/30/20

CI Key Product (SV): SV-Era Workflow and Data Management Configuration (CI17)

Deliverable: *Workflow and Dataset Tracking Tools for SV* 10/01/21

CS Key Product (DC2): DESCQA2 Validation Framework (CS10)

Deliverable: *DESCQA validation framework with full functionality* 06/30/18

CS Key Product (DC2): Generic Catalog Reader (GCR) (CS11)

Deliverable: *GCR interface available for all Sky Catalogs* 01/31/18

CS Key Product (DC3): Advanced Tooling for Working with Cosmological Simulation Outputs (CS15)

Deliverable: *DC3 Upgrade to GCR Interface* 06/30/20

Deliverable: *DC3 Upgrade to DESCQA* 06/30/20

Deliverable: *DC3-Era Galaxy Model* 06/30/20

SSim Key Product (DC3 & ComCam): IMSIM Development (imSim1)

Deliverable: *Improve* IMSIM *performance* 01/01/21

Deliverable: *Add major features to* IMSIM 01/01/21

Deliverable: *Increase the realism of* IMSIM 01/01/21

SSim Key Product (DC1): DC1 Survey Simulation Tools (SSim1)

Deliverable: *Survey Simulation Tools for DC1* 01/01/16

Deliverable: *An LSST module in* GALSIM 06/30/16

SSim Key Product (DC2): DC2 Survey Simulation Tools (SSim3)

Deliverable: *Survey Simulation Tools for DC2* 06/30/18

Deliverable: *Validation of static effects in* PHOSIM 12/31/19

Deliverable: *Validation of the BF effect in simulations* 12/31/19

CI Key Product (DC2): DC2 DM DRP Processing Pipeline and Data Service (CI11)

Deliverable: *A DESC-modified DM DRP Reprocessing Pipeline* 06/30/18

Deliverable: *Replica of the DM Catalog Technology* 06/30/18

CI Key Product (DC2): Enhanced Twinkles Framework to Handle DC2-level Requirements (CI7)

Deliverable: *Pipeline for Extracting DC2 Light Curves* 06/30/18

Deliverable: *Workflow to execute the Light Curve Extraction pipeline.* 06/30/18

SSim Key Product (DC3): DC3 Survey Simulation Tools (SSim5)

Deliverable: *Survey Simulation Tools for DC3* 10/01/19

CI Key Product (DC3): Upgraded DM DRP Processing Pipeline and Data Service (CI15)

Deliverable: *Upgraded DESC DM DRP Reprocessing Pipeline* 06/30/20

Deliverable: *Upgraded Replica of the DM Catalog Technology* 06/30/20

CI Key Product (ComCam): SV-Ready DRP Processing Pipeline and Data Service (SV-DRP)

Deliverable: *SV-Ready DESC DRP Pipeline* 09/30/21

Deliverable: *SV-Ready Replica of LSST Science Platform* 09/30/21

WL Key Product (DC1): Weak Lensing Pipeline (WLPIPE)

Deliverable: *Pipeline for WL Cosmology Constraints from a Shear Catalog* 06/30/18

Deliverable: WLPIPE *Validation* 06/30/18

Deliverable: *Workflow management system applied to DC1 WL workflow* WLPIPE 06/30/18

Deliverable: *Extension of* WLPIPE *to 3x2-point analysis* 07/01/18

WL Key Product (DC2): Weak Lensing and Large-Scale Structure Pipeline (TXPIPE-DC2)

Deliverable: *Pipeline tools that connect to workflow management system (*CECI*)* 03/31/19

Deliverable: *Pipeline for Producing a Shear Catalog (*SHEARMEASUREMENTPIPE*)* 12/31/19

Deliverable: *Source selector and tomographic binning definition software (*TXSELECTOR*)* 12/31/19

Deliverable: *Source summarizer analysis stage (*SOURCESUMMARIZER*)* 12/31/19

Deliverable: *Software for two-point statistics (*TXTWOPOINT*)* 12/31/19

Deliverable: *Covariances for the joint WL+LSS analysis (*TXCOV*)* 12/31/19

Deliverable: *Summary statistic collector (*TXSUMMARYSTATISTIC*)* 12/31/19

Deliverable: *Validation of* TXPIPE 12/31/19

WL Key Product (DC2): Weak Lensing Mass Maps and Map-Based Statistics (WLMASSMAP-DC2)

Deliverable: *Pipeline to generate weak lensing mass maps* 03/31/19

WL Key Product (DC2): WL Systematic Uncertainty Characterization Framework (WL2)

Deliverable: *Null test pipeline (*WLNULLTEST*)* 03/31/19

Deliverable: *Identify and characterize PSF systematic uncertainties* 12/31/19

Deliverable: *Identify and characterize non-PSF systematic uncertainties* 12/31/19

WL Key Product (DC3): Updated Weak Lensing and Large-Scale Structure Pipeline (TXPIPE-DC3)

Deliverable: *Improved shear pipeline* 07/01/20

Deliverable: *Proper handling of chromatic effects* 07/01/20

Deliverable: *Proper handling of neighbors* 07/01/20

Deliverable: *Pipeline for magnification (*WLMAGPIPE*)* 09/30/21

Deliverable: *Pipeline for validating shear calibration* 07/01/20

WL Key Product (SV): Applied Weak Lensing and Large-Scale Structure Pipeline (TXPIPE-SV)

Deliverable: *At-scale* TXPIPE *Application* 09/30/22

Deliverable: TXPIPE *SV Extensions* 09/30/22

LSS Key Product (DC1): DC1 LSS Pipeline (LSS-DC1)

Deliverable: *Software for storing correlation function and covariance information (SACC)* 04/01/17

Deliverable: *Two-point preliminary studies* 06/30/18

Deliverable: *Validation tests of DC1-era LSS pipeline on simulations* 06/30/18

Deliverable: *Validation tests of DC1-era LSS pipeline on precursor datasets* 06/30/18

LSS Key Product (DC2): LSS Pipeline Components of TXPIPE (LSS4/TXPIPE)

Deliverable: *Power-spectrum estimation code (*TXTWOPOINT*)*	06/30/18
Deliverable: *Two-point storage framework*	07/01/18
Deliverable: *Optimal catalog splits into samples (*TXSELECTOR*)*	12/31/19
Deliverable: *Basic LSS likelihood module (*LSSCOSMO*) contribution to* TJPCOSMO	12/31/19
Deliverable: *Validation tests of DC2-era LSS pipeline on simulations*	12/31/19
Deliverable: *Validation tests of DC2-era LSS pipeline on precursor datasets*	12/31/19

LSS Key Product (DC1 & DC2): Survey geometry (CX3)

Deliverable: *Temporary survey coverage tools*	06/30/18
Deliverable: *Survey mask use cases*	03/31/19
Deliverable: *Software for characterizing mask as a function of pixelization using DM tools*	12/31/19
Deliverable: *Random points software (*TXRANDOMS*) for* TXPIPE	03/31/19
Deliverable: *Maps of systematics:* TXSYSMAPMAKER *for* TXPIPE	12/31/19

LSS Key Product (DC3): Improved LSS Pipeline Components (TXPIPE-LSS)

Deliverable: *Joint pipeline with CMB data*	06/30/20
Deliverable: *Optimal deblending for LSS*	09/30/21

CL Key Product (DC2 & DC3): CL Pipeline Components for use with TXPIPE (CL7)

Deliverable: *Cluster Finder (*CLFINDER*)*	12/31/19
Deliverable: *Cluster Finder (*CLFINDER*) Validation*	12/31/19
Deliverable: *Cluster Finder Updates (*CLFINDER*)*	09/30/21
Deliverable: *Validation of Cluster Finder Updates (*CLFINDER*)*	09/30/21
Deliverable: *Shear calibration in the cluster regime*	09/30/21
Deliverable: *Photo-z estimates in cluster fields*	09/30/21

CL Key Product (DC1 & DC2): CL Cosmology Likelihood Module CLCOSMO (CL5)

Deliverable: *DC1-era CL Likelihood Code*	06/30/18
Deliverable: *DC2-era CL Likelihood Code*	12/31/19
Deliverable: *Validation of DC2-era CL Likelihood Code*	12/31/19
Deliverable: *DC3-era CL Likelihood code*	09/30/21

CL Key Product (SV): CL Pipeline Integration and Adaptation to the SV Data (CLIA)

Deliverable: *Integrated CL Pipeline* 09/30/22

SL Key Product (DC1 & DC2 & DC3): SL Pipeline Components (SL6)

Deliverable: SLMONITOR 06/30/18

Deliverable: SLMODELER 06/30/18

Deliverable: SLFINDER *Lens Candidate Extractor* 12/31/19

Deliverable: SLENVCOUNTER 12/31/19

Deliverable: SLMASSMAPPER 12/31/19

Deliverable: *Validation of DC2-era pipeline components* 12/31/19

Deliverable: SLTIMER 09/30/21

Deliverable: SLCOSMO 09/30/21

Deliverable: *Validation of DC3-era pipeline components* 09/30/21

SL Key Product (SV): SL Pipeline Integration and Adaptation to the SV Data (SLIA)

Deliverable: *Integrated SL Pipeline* 09/30/22

SN Key Product (DC1): DC1-era codes for simulating SN at Cadences from OpSim (SN-OpSim)

Deliverable: *SN simulation software integrated with OpSim* 07/01/18

SN Key Product (DC1): DC1-era SN Pipeline Components (SUPERNOVATYPE)

Deliverable: *Classification Code:* SUPERNOVATYPE 07/01/18

SN Key Product (DC2): DC2-era SN Pipeline Components (SNPipe)

Deliverable: *SN Analysis Pipeline* 03/31/19

Deliverable: *SN Light fitting code* 12/31/19

Deliverable: *SN selection function to produce a SN catalog for classification* 12/31/19

Deliverable: *SN summaries code* 03/31/19

Deliverable: *Multi-type transient simulations* 03/31/19

Deliverable: *Photometric classification* 12/31/19

Deliverable: *SN Light curves from processed DM difference images* 03/31/19

Deliverable: *SN Analysis Pipeline Validation* 03/31/19

Deliverable: *Detection Efficiency of SN* 03/31/19

Deliverable: *Discrepancy Modelling for SN light Curves* 12/31/19

Deliverable: *Validating Surface Brightness of Host Galaxy* 12/31/19

SN Key Product (DC3): DC3-era SN Pipeline Components (SNType)

Deliverable: *DC3-era SN Analysis Pipeline updates* 09/30/21

Deliverable: *Verification of the difference imaging pipeline on DC3 data* 09/30/21

Deliverable: *Code for photometric supernova cosmology* 09/30/21

Deliverable: *Verification of photometric supernova code in different scenarios* 09/30/21

Deliverable: *DC3-era SN summaries code* 09/30/21

Deliverable: *SN summaries code validation on DC3 simulations* 09/30/21

SN Key Product (SV): SN Pipeline Integration and Adaptation to the SV Data (SNIA)

Deliverable: *Integrated SN Pipeline* 09/30/22

SN Key Product (DC3): DESC Broker (SN)

Deliverable: *SLWG Broker Requirements* 07/01/18

Deliverable: *Broker Sandbox* 06/30/20

Deliverable: *Early SN classification system* 09/30/21

Deliverable: SLFINDER *Target Selection Code* 09/30/21

Deliverable: *Verification of the DESC SN broker infrastructure on DC3 simulations* 09/30/21

TJP Key Product (DC1 & DC2): Core Cosmology Library (TJP5A)

Deliverable: *Cosmology library prototypes* 03/31/16

Deliverable: *Cosmological Emulator Integration* 02/28/18

Deliverable: *Basic cosmological observable predictions* 06/30/18

Deliverable: *Enhanced cosmological observable predictions* 07/01/18

Deliverable: *Fast and accurate correlation function predictions* 03/31/19

Deliverable: *Cosmological model extensions beyond* w*CDM* 09/30/21

TJP Key Product (DC2 & DC3): Systematics Models for Joint Analyses (CX5)

Deliverable: *Software modules for astrophysical systematics* 03/31/19

Deliverable: *Workflow for testing accuracy of systematics mitigation* 03/31/19

Deliverable: *Consistency of systematics modeling across all probes* 07/01/20

Deliverable: *Incorporate spatial variations into joint systematics models* 09/30/21

TJP Key Product (DC2 & DC3): TJPCOV: Covariance Matrices for Joint Analyses (CX7)

Deliverable: *Gaussian covariances for* TJPCOSMO 03/31/19

Deliverable: *Improved covariance estimators for single- and joint-probe analyses* 03/31/19

Deliverable: *Numerical routines for fast covariance estimation* 09/30/21

Deliverable: *Consistent joint probe covariances* 09/30/21

TJP Key Product (DC2 & DC3): TJPCOSMO: Likelihood Pipeline for Joint Analyses (TJP5B)

Deliverable: *Single-probe likelihood for Weak Lensing* 03/31/19

Deliverable: *Single-probe likelihood for Large-Scale Structure* 03/31/19

Deliverable: *Single-probe likelihood for Galaxy Clusters* 12/31/19

Deliverable: *Single-probe likelihood for Supernovae* 12/31/19

Deliverable: *Single-probe likelihood for Strong Lensing* 06/30/20

Deliverable: *Validation of single-probe likelihoods on* `DC2` 12/31/19

Deliverable: *Preliminary joint probes likelihood pipeline* 12/31/19

Deliverable: *Forecasting module in likelihood pipeline* 12/31/19

Deliverable: COSMOPARAMS*: Common exchange format for cosmological parameter sets* 12/31/19

Deliverable: *Modules for data compression and alternative inference methods* 09/30/21

Deliverable: *Cosmological analysis pipeline for LSST precursor data* 09/30/21

TJP Key Product (DC3): Integration of TJPCOSMO into the CI Framework (TJP5C)

Deliverable: *CI Framework Requirements for Joint Analysis Pipelines* 07/01/18

Deliverable: TJPCOSMO *pipeline integration and validation* 07/01/20

Deliverable: *Apply* TJPCOSMO *joint likelihood pipeline to* `DC3 Mock Lightcone` 09/30/21

TJP Key Product (SV): TJP Pipeline Adaptation to the SV Data (TJP-SV)

Deliverable: *Extended TJP Pipeline* 09/30/22

SA Key Product (DC1 & DC2 & DC3): Sensor Anomalies Pipeline Components (SA5)

Deliverable: *Implemented and Validated Correction Algorithm for the BF Effect* 06/30/18

Deliverable: *Validation of correction algorithms for static effects* 06/30/18

Deliverable: *Studies of sensor systematics with ComCam* 12/31/20

SA Key Product (SV): Integrated SA Pipeline, Adapted to SV Data (SA-SV)

Deliverable: *Integrated SA Pipeline* 09/30/22

PC Key Product (DC1 & DC2 & DC3): Photometric Correction Pipeline Components (PC7)

Deliverable: *Analytical Models for PC Biases* 12/31/17

Deliverable: *PC Bias on Individual Probes* 12/31/17

Deliverable: *PC Observing Strategy Metrics* 12/31/17

PC Key Product (SV): Integrated PC Pipeline, Adapted to SV Data (PC-SV)

Deliverable: *Integrated PC Pipeline* 09/30/22

PZ Key Product (DC1 & DC2 & DC3): Photometric Redshifts Pipeline PZPDF (PZ5)

Deliverable: *Metrics pipeline for evaluation and comparison of photometric redshift codes* 06/30/18

Deliverable: *Validation of metrics pipeline* 06/30/18

Deliverable: *ComputePrior analysis stage for* PZPDF 03/31/19

Deliverable: *One-dimensional $p(z)$ routines (PZMainAlgorithms) for* PZPDF 03/31/19

Deliverable: *CombineResults for one-dimensional $p(z)$ for* PZPDF 03/31/19

Deliverable: *PZStorage1D for one-dimensional $p(z)$ for* PZPDF 03/31/19

Deliverable: *$p(z)$ for DC2 using* PZPDF 03/31/19

Deliverable: *Validation of $p(z)$ for DC2 using* PZPDF 12/31/19

Deliverable: *Needs assessment for two-dimensional $p(z, \alpha)$ for* PZPDF 09/30/19

Deliverable: *Accounting for spectroscopic incompleteness in* PZPDF 07/01/20

Deliverable: *Two-dimensional $p(z, \alpha)$ implementation for* PZPDF 09/30/21

Deliverable: *Validation of $p(z, \alpha)$ for* PZPDF *on DC3* 09/30/21

PZ Key Product (DC2 & DC3): Photometric Redshifts Pipeline PZCALIBRATE (PZCALIBRATE)

Deliverable: *WGTomographicSelector for* PZCALIBRATE 03/31/19

Deliverable: *PZBiasEvolutionEstimator for* PZCALIBRATE 03/31/19

Deliverable: *MagnificationCorrection for* PZCALIBRATE 03/31/19

Deliverable: *PZClusterz for* PZCALIBRATE 03/31/19

Deliverable: *Interface with WL and LSS for* PZCALIBRATE 03/31/19

Deliverable: PZCALIBRATE *validation on DC2 simulations* 12/31/19

Deliverable: *DC3-era* PZCALIBRATE *updates* 07/01/20

Deliverable: *DC3-era* PZCALIBRATE *validation* 09/30/21

PZ Key Product (DC2): Photometric Redshifts Pipeline `PZIncomplete` (`PZIncomplete`)

Deliverable: *MakeSpectra* 03/31/19

Deliverable: *AddEmissionLines* 03/31/19

Deliverable: *PZGalaxyGenerator* 03/31/19

Deliverable: *Validation and testing of `PZIncomplete` using DC2 simulations* 12/31/19

PZ Key Product (SV): Integrated PZ Pipeline, Adapted to SV Data (PZ-SV)

Deliverable: *Integrated PZ Pipeline* 09/30/22

Datasets

CTF Key Product (DC3): DESC Commissioning Efforts (CTF)

Deliverable: *DESC technical note with suggested observing fields and tests* 01/07/2019

CS Key Product (DC1): DC1 Requirements (CS12)

Deliverable: *`HaloCat` Requirements* 12/31/15

Deliverable: *CL Requirements for `HaloCat`* 12/31/15

Deliverable: *PZ Requirements for and development of DC1 simulations* 06/30/16

Deliverable: *`Twinkles` CS, SS and DM Stack Requirements* 03/31/17

CS Key Product (DC2): DC2 Requirements (CS5)

Deliverable: *CS Requirements for DC2* 09/30/17

Deliverable: *Methods beyond brute-force cosmological simulations* 12/31/17

Deliverable: *`DC2` Time Domain Requirements* 09/30/17

Deliverable: *PZ Requirements for Incompleteness* 12/31/17

Deliverable: *PZ Requirements for Cross-correlation Method* 12/31/17

Deliverable: *`DC2` Specifications* 04/30/18

Deliverable: *WL Requirements on the depth of the DC2 and DC3 extragalactic catalogs* 12/31/16

CS Key Product (DC3): DC3 Requirements (CS13)

Deliverable: *Requirements on DC3 simulated datasets* 09/30/19

Deliverable: *CL Requirements for* `DC3 Mock Lightcone` 09/30/19

Deliverable: *SL Requirements for DC3* 09/30/19

Deliverable: *LSS Observing strategy for* `DC3 Mock Lightcone` 09/30/19

Deliverable: *WL Observing strategy for* `DC3 Mock ComCam Survey` 09/30/19

CS Key Product (DC1): `HaloCat` Dataset Production (CS14)

Deliverable: `HaloCat` *Test catalogs for LSS measurement codes* 03/31/17

SL Key Product (DC1): `Twinkles` (SL7)

Deliverable: `Twinkles` *Images and DM Catalogs* 04/01/17

SSim Key Product (DC1): `DC1 Phosim Deep` (SSim2)

Deliverable: `DC1 Phosim Deep` *Images* 03/31/17

Deliverable: $p(z)$ *for DC1 Galaxies* 10/31/17

CS Key Product (DC2): Extragalactic Catalogs for `DC2` (CS7)

Deliverable: *Parameterization of the Extragalactic Catalogs for DC2 and DC3* 04/30/18

Deliverable: *Validation of the* `DC2` *Extragalactic Catalogs* 06/30/18

Deliverable: `HaloCat` *Cluster shear maps* 06/30/18

Deliverable: *Extragalactic Catalogs for the* `DC2` *Simulation* 06/30/18

SSim Key Product (DC2): `DC2` Production (SSim4)

Deliverable: `DC2` *Simulated Images* 06/30/18

Deliverable: `DC2` *DM DRP Catalogs* 06/30/18

SSim Key Product (DC3): `DC3 Mock Lightcone` Production (SSim7)

Deliverable: `DC3 Mock Lightcone` *Simulated Images* 06/30/20

Deliverable: `DC3 Mock Lightcone` *DM DRP Catalogs* 06/30/20

Deliverable: `DC3 Mock Lightcone` *Emulated DM Catalog* 06/30/20

SSim Key Product (DC3): `DC3 Mock ComCam Survey` Production (SSim6)

Deliverable: `DC3 Mock ComCam Survey` *Simulated Images* 06/30/20

Deliverable: `DC3 Mock ComCam Survey` *DM DRP Catalogs* 06/30/20

WL Key Product (DC2): WL Precursor Dataset Production (WL10)

Deliverable: *Compilation of precursor survey data to test the shear pipeline* 06/30/17

CI Key Product (DC2): Re-processed `DC2 HSC Public Release 1` (CI16)

CI Key Product (SV): The DESC-reprocessed ComCam Dataset (DESC-ComCam)

Deliverable: *DESC-Reprocessed ComCam DRP Catalogs* 09/30/21

Deliverable: *DESC-Processed Alternative ComCam DRP Catalogs* 09/30/21

CI Key Product (SV): The DESC-reprocessed SV Dataset (DESC-SV)

Deliverable: *DESC-Reprocessed SV DRP Catalogs* 09/30/22

Deliverable: *DESC-Processed Alternative SV DRP Catalogs* 09/30/22

FTF Key Product (DC2): Coordinate production of white papers and proposals for non-LSST datasets (FTF1)

Deliverable: *Response to the Astro2020 Decadal Survey Call for Science White Papers* 02/22/19

FTF Key Product (DC3): Develop Inter-Collaboration Agreements (ICAs) with External Projects (FTF2)

Deliverable: *Completion of First Inter-Collaboration Agreement* 01/1/20

FTF Key Product (DC3): Develop Policies for Internal Data-Sharing (FTF3)

Deliverable: *Draft data-sharing policy* 09/01/2019

8 Research and Development

In this section we describe the high priority research investigations for the working groups, both individually Section 8.1–8.12 and in collaboration (Section 8.13). Each working group's subsection has a uniform hierarchical structure, as follows:

- **Key Projects:** Each significant analysis and/or study that will be performed or primarily led by the group may constitute a *Key Project* (e.g.,"Requirements on shear estimation" (WL1)). Each Key Project has a short summary providing an overview of its primary aims.
- **Activities:** Each Key Project will have multiple *Activities* (e.g., R&D Activity *"Software for determining WL requirements"*). In general, a research Activity will involve the production of a requirements document (RQ), dataset (DP), piece of software (SW), or validation test/suite (VA), that must be developed as part of this work and delivered to the Collaboration. A typical Activity will likely correspond to a year or less of full-time equivalent (FTE) effort. Typically, an Activity should result in a journal paper or LSST DESC Research Note to ensure that individuals doing work receive appropriate credit. Each Activity will be described with the same structure: an explanation of its *Objective*, a list of all *Prerequisites*, and in some cases some more detail about how the work will be approached.

To summarize, sets of Key Projects and associated Activities with deadlines are provided for the full period up to commissioning.

NB: in the text below, deliverables and activities are presented with color coding determined by their status, as follows: "done" deliverables have hyperlinks like this, "defunct" deliverables have hyperlinks like this, "active" deliverables have hyperlinks like this, "planned" deliverables have hyperlinks like this, and "anticipated" deliverables have hyperlinks like this.

8.1 Weak Lensing R&D Projects

We separate the analysis steps into two parts: (1) measuring lensing shears from galaxy CCD images, including shear systematics correction and suppression, and (2) constraining cosmological parameters given a galaxy shear catalog. These two parts of the analysis also delineate two Key Projects for each of the three Data Challenges described below. The Key Projects for each Data Challenge are distinguished by increasing analysis complexity and precision and accuracy requirements.

The first Key Project for each Data Challenge will address many of the same issues targeted by the community galaxy shape measurement challenges (e.g., GREAT08, GREAT10, GREAT3). These issues include point spread function (PSF) fitting and interpolation, galaxy sample selection, shape measurement algorithms, calibration of additive shear biases, suppression of multiplicative shear biases, and shear systematics tests.

The second Key Project for each Data Challenge will focus on interpretation of a galaxy catalog with shear measurements (as will be produced by the LSST Data Management DRP analysis framework) in the context of a cosmological model. Issues to be addressed include selection of galaxies in photometric redshift bins, estimators for the shear two-point correlation functions (2PCF), derived two-point statistics or in some cases direct estimators of alternate two-point statistics such as the power spectrum, models for systematic errors in these statistics, likelihood function specification for them, sample covariance models, and cosmological parameter inference via likelihood function evaluations and cosmological model comparisons.

WL Key Project (DC1 & DC2): Requirements on shear estimation (WL1)
Host WG: WL
Objective: Develop a software pipeline that can be used to derive a rigorous set of requirements for both LSST DM outputs and our own analysis steps, along with a suite of null tests to verify that these requirements are met.

For DC1, we will use small-scale simulated datasets (e.g., from GalSim) and/or real data to do the preparatory steps needed to carry out a cosmological weak lensing analysis. Part of the motivation for this choice to not do a traditional data challenge is that some aspects of the analysis on the DM side (e.g., shear estimates) are not quite ready for us to use in any kind of realistic analysis, and there is substantial software to develop for the step from catalogs to science.

Note that this Key Project will not focus much on blending issues; these are the subject of a parallel effort in the Key Project "Impacts of Blending" (CX1), especially R&D Activities *"Software to quantify impacts of blending"* and *"Requirements on DM deblender from cosmic shear"*, which will happen on a similar timescale. However, at no point in this Key Project should blending issues be "designed out" of the code. By the DC2 time frame, we will need to merge these two parallel tracks into a single pipeline and suite of null tests.

Activity: *Software for determining WL requirements (DC1 SW)*

Host WG: WL *Started:* 10/01/15 *Originally due:* 03/16
Status: defunct
URL :

Objective: Construct a framework for placing requirements on WL systematics in a self-consistent way using the TJPFORECAST code. This mostly involves propagating various potential systematic errors up to the final cosmological constraints using the forecasting framework from R&D Activity *"Forecasting Software"* along with the software organization in the Deliverable *"A Framework for TJP"*.

The canonical cosmological WL analysis is assumed to be cosmic shear plus galaxy-shear cross-correlations plus galaxy clustering, in order to better marginalize over various systematics, both theoretical and astrophysical. At this point, the full joint analysis framework will not be complete, but an initial best effort should be made to at least combine these three statistics for the purpose of the requirements, which may be further refined in the future (cf. R&D Activities *"Cosmological constraints"* and *"Cosmological constraints"*).
Prerequisites: R&D Activity *"Forecasting Software"*; overlaps with Deliverable *"A Framework for TJP"*

Activity: *Create WL DC1 simulated datasets (DC1 DP)*

Host WG: WL *Started:* 01/01/16 *Originally due:* 09/16
Status: defunct
URL :

Objective: Simulate the small-scale datasets (e.g. galaxy 'postage stamps') as well as real data for DC1. The specific features, fidelity, and volume of the simulations will be designed to meet the needs of R&D Activity *"Assess the DM stack shape measurement code"*. They will be small, targeted simulations to assess each of the requirements therein. We do not anticipate that any of these simulations will require an inordinate amount of computing resources.
Prerequisites: Deliverables *"An LSST module in* GALSIM*"*, *"Validation of the BF effect in simulations"*, *"Validation of static effects in* PHOSIM*"*.

Activity: *Assess the DM stack shape measurement code (DC2 DA)*

Host WG: WL *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Use the TJPFORECAST framework from R&D Activity *"Software for determining WL requirements"* to set requirements in a self-consistent way on the various stages in the measurement of shapes, including astrometry, PSF measurement, sensor effects, and additive and multiplicative calibrations. This will use the DC simulations, and require close connection to LSST DM. It is a progressive task, and different steps within it will become possible only when the relevant code is written.

The required tolerances on the shear biases will be informed by joint probes forecasts from TJP (largely produced outside this Roadmap timeline) that in some cases relax the shear calibration requirements over what might be derived using shear statistics alone for cosmological parameter inferences. In particular, we are interested in shear calibration requirements when combining tomographic shear two-point correlations with galaxy angular cross-correlations, 2D BAO, and CMB constraints.

Prerequisites: R&D Activities *"Software for determining WL requirements"*, *"Forecasting Software"*, *"Science metrics and accuracy requirements for BF effect"*, *"Science metrics and accuracy requirements for static effects"*, *"Requirements on DM deblender from cosmic shear"*

WL Key Project (DC2): Images to shear catalog I (WL3)
Host WG: WL
Objective: Develop, in cooperation with LSST DM, a complete pipeline for going from images to a shear catalog, including running a complete suite of null tests on the catalog to check for various systematic errors. This will be used to analyze the DC2 images and carry out those null tests.

DC2 involves analysis of the DESC-wide `DC2` data set from Key Product "`DC2` Production" (SSim4) consisting of an area of order 100 deg^2 of PhoSim and/or imSim imaging data with an input galaxy catalog from CatSim. The input catalog will have a limiting depth 2 magnitudes below the LSST Gold Sample (to accurately predict the shear calibration biases from unresolved sources) and include cosmological clustering and lensing information from an N-body simulation light cone with ray-tracing (enabling test of shear-clustering cross-correlations and clustering related systematics and selection effects).

For DC2, we completely separate the "pixels to catalog" and "catalog to science" steps of the analysis, with a Key Project focusing on each one. To better understand the shear inference process and biases, we may choose to replace the cosmologically generated shear in the `DC2` light cone with simpler, more phenomenological shear and magnification models (e.g., Gaussian distributed over the sky with an input power spectrum).

Activity: *Develop shear catalog selection criteria (DC2 SW)*

Host WG: WL *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Determine the appropriate selection criteria to apply such that the final shear catalog is adequately free of systematic errors. In particular, the galaxy selection itself should try to avoid or minimize selection biases from measurement failures, neighbors, cuts on S/N and size, etc. This also includes biases from the weighting scheme, which is a form of selection that is not just a binary 0 or 1.
Prerequisites: Deliverables *"Pipeline for Producing a Shear Catalog (SHEARMEASUREMENTPIPE)"* and *"Null test pipeline (WLNULLTEST)"*, overlap with R&D Activity *"Code for generating LSS catalogs"*

Activity: *Generate and test shear catalog (DC2 DP)*

Host WG: WL *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Apply the WLSHEARPIPE software from the Deliverable *"Pipeline for Producing a Shear Catalog (SHEARMEASUREMENTPIPE)"* and R&D Activity *"Develop shear catalog selection criteria"* to create a per-object shear catalog as well as per-field probabilistic shear inferences, to which the null test pipeline (cf. Deliverable *"Null test pipeline (WLNULLTEST)"*) will be applied. This is expected to be an iterative process, since the initial application of the null tests will likely not pass all the tests.
Prerequisites: Deliverables and R&D Activities *"Null test pipeline (WLNULLTEST)"*, *"Pipeline for Producing a Shear Catalog (SHEARMEASUREMENTPIPE)"*, *"Develop shear catalog selection criteria"*, *"Software to calibrate deblender residuals with extra data"*, *"DC2 Simulated Images"*

WL Key Project (DC2): Shear and LSS catalogs to science statistics I (WL4)
Host WG: WL
Objective: Develop software powered by TXPIPE to produce science (particularly cosmology constraints) from a shear catalog and redshift catalog (both here taken to be pristine - the CATSIM truth table rather than the output of Key Project "Images to shear catalog I" (WL3)). The full pipeline contains three principal components. First, TXTWOPOINT will produce relevant two-point statistics from the catalogs, including shear-shear correlations, tangential shear

around LRGs, and possibly the galaxy clustering as well. The 2PCF contains all the two-point shear information, but this may be more appropriately packaged into derived quantities such as the power spectrum, COSEBIs, aperture mass statistics, rings statistics, etc. We will also consider direct estimators of these alternate statistics, such as direct power spectrum estimators. Second, the code to computer the covariance matrix of these statistics will be part of TJPCov. Finally, TJPCosmo (see the Deliverable *"Identify and characterize non-PSF systematic uncertainties"*), will use the outputs of these to constrain cosmology, including marginalizing over or otherwise accounting for systematics, etc.

Activity: *Software for blinding the shear catalogs (DC2 SW)*

Host WG: WL *Started:* 10/01/16 *Originally due:* 07/01/18
Status: active *Expected:* 07/01/18
URL :

Objective: Develop an appropriate method for blinding a shear catalog that preserves the nullity of all null tests, including cosmological tests, but which hides the true cosmology until the analysis is complete.
Prerequisites: R&D Activity *"Blind analysis strategies for individual probe analyses"*

Activity: *Models of residual observational systematic effects on observables (DC2 SW)*

Host WG: WL *Started:* 10/01/16 *Originally due:* 07/01/18
Status: active *Expected:* 07/01/18
URL :

Objective: Develop good models for the impact of residual observational systematics on WL and LSS observables. Residual errors in astrometry, PSF determination, deblending, and star-galaxy separation will all cause errors in the weak lensing correlation function or other observables. This task is to determine reasonable models (informed by precursor surveys and simulations) of these effects.
Prerequisites:

Activity: *Cosmological constraints (DC2 DP)*

Host WG: WL *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Apply the TXTwoPoint and TJPCov pipelines from the Deliverable *"Software* *for two-point statistics (*TXTWOPOINT*)"* and R&D Activity *"Preliminary Covariance Matrices for Cosmological Analyses"* together and feed them into the WLCOSMO software developed in the Key Product "WL Systematic Uncertainty Characterization Framework" (WL2) to produce cosmological constraints from the mock catalog. This project will be in tandem with the R&D Activity *"Cross-correlation tests of tomographic bins"* to choose effective photo-z binning for tomographic shear measurements and to propagate photo-z uncertainties to the cosmological parameter inferences.

Prerequisites: Deliverables and R&D Activities *"Identify and characterize PSF systematic uncertainties"*, *"Identify and characterize non-PSF systematic uncertainties"*, *"Software for two-point statistics (*TXTWOPOINT*)"*, *"Preliminary Covariance Matrices for Cosmological Analyses"*,*"$p(z)$ for simulated catalog objects"*; synchronous with *"Cross-correlation tests of tomographic bins"*

WL Key Project (DC3): Images to shear catalogs II (WL5)

Host WG: WL

Objective: Further develop the pipeline from the DC2 Key Project "Images to shear catalog I" (WL3), with added rigor and more area for the simulated data. It would ideally involve analysis of order 1000 deg.^{2} of simulated data or real data from e.g., DES or HSC. Depending on the outcome of previous work, we will have to decide whether it is more valuable to have simulated data with the appropriately large number of exposures that LSST will have, or real data with fewer exposures but potentially more realistic image artifacts, or some combination of both. The area need not be contiguous; e.g. 10×100 deg^2 is acceptable. The simulation should preferably include accurate shear and convergence in all LSST-observed bands.

Activity: *Generate and test shear catalog (DC3 DP)*

Host WG: WL *Started:* 10/01/19 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :

Objective: Apply the WLSHEARPIPE enhancements from Deliverables *"Improved shear pipeline"* and *"Proper handling of chromatic effects"* to create shear catalogs, to which the WLNULLTEST null test pipeline from the Deliverable *"Null test pipeline (*WLNULLTEST*)"* will be applied (along with any new tests that have been added from the Deliverables *"Proper handling of chromatic effects"* and *"Proper handling of neighbors"*). Here we anticipate more than one shear catalog (e.g. Metacal and BFD) to provide cross-check for robustness of the

shear estimate algorithm.
Prerequisites: Deliverables *"Null test pipeline (*WLNULLTEST*)"*, *"Improved shear pipeline"*, *"Proper handling of chromatic effects"*, *"Proper handling of neighbors"*, and *"DC2 Simulated Images"*

WL Key Project (DC3): Shear catalogs to science statistics II (WL6)
Host WG: WL
Objective: Improve on the pipeline developed in DC2 to include a more realistic treatment of potential systematic errors. In particular, we will run the pipeline on the output catalog of Key Project "Images to shear catalogs II" (WL5). We will use the photo-z outputs from the R&D Activity *"$p(z)$ for simulated catalog objects"* for the redshifts in the catalog (rather than the 'truth' as in DC2).

Activity: *Develop pipeline for non-Gaussian statistics (DC3 SW)*

Host WG: WL *Started:* 10/01/18 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :
Objective: Develop a pipeline, WLNPOINT, to include additional shear statistics to be used for improving cosmology constraints. These will include non-Gaussian statistics such as shear peaks, moments of the convergence field, and probabilistic mass maps. The null tests of the Deliverable *"Null test pipeline (*WLNULLTEST*)"* should be extended to include these n-point statistics. Task Force work in the DC1 and DC2 timeframe on WL1n-point and WL2n-point are key analysis steps for the successful execution of this Activity.
Prerequisites: Deliverables and R&D Activities *"Software for two-point statistics (*TXTWOPOINT*)"*, *"Studies of Alternative Parameter Inference Methods"*, *"Null test pipeline (*WLNULLTEST*)"*, *"Pipeline to generate weak lensing mass maps"*

Activity: *Extended shear correlation functions (DC3 SW)*

Host WG: WL *Started:* 10/01/18 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :
Objective: Extend the WLNPOINT and WLNULLTEST pipelines to include additional shear statistics to be used for improving cosmology constraints. These will include the three-point correlation function or bispectrum, and 3D correlated lensing inferences.

Prerequisites: Deliverables and R&D Activities *"Software for two-point statistics (TXTwoPoint)"*, *"Studies of Alternative Parameter Inference Methods"*, *"$p(z)$ for simulated catalog objects"*

Activity: *Cosmological constraints (DC3 DP)*

Host WG: WL *Started:* 10/01/19 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :

Objective: Apply the TXTwoPoint, WLMagPipe, WLNullTest, WLNPoint, TJPCov, and WLCosmo pipelines to the weak lensing catalog from the Key Project "Images to shear catalogs II" (WL5) to produce cosmological constraints from the mock catalog.
Prerequisites: Deliverables and R&D Activities *"Generate and test shear catalog"*, *"$p(z)$ for simulated catalog objects"*, and Key Project "Blinding Strategy for Cosmology Analysis" (CX8)

WL Key Project (DC3): Simulations for shear catalog testing (WL7)
Host WG: WL
Objective: We require a set of simulations to test our understanding and control of shear calibration (multiplicative-type systematics rather than additive ones) as a function of tomographic redshift bin. These will typically require a larger volume than will be used for any of the data challenges, and may be reanalyzed many times as the shear estimation algorithms are developed and updated. The data itself may be simpler in structure than the ones used for DC2 and DC3: for instance, it may be appropriate to use postage stamps, and it may not need to include the full litany of detector and telescope artifacts. These simulations are designed to test, rather than calibrate the DM pipeline; calibration simulations are the purview of DM.

8.2 Large Scale Structure R&D Projects

The LSS analysis is separated into 3 steps: (1) Collect a homogeneous sample of galaxies from the raw data and optimally sub-sample (in e.g. color) to extract the maximum amount of information in later steps. (2) Compute the summary statistics that will constitute our data vector when extracting cosmological parameters. In the first instance, these will be two-point statistics in Fourier or configuration space, but this may be extended in the future to higher-order observables. (3) Modelling the data vector, including systematic uncertainties, and extracting constraints on cosmological parameters. Below we define one Key Project for each of these steps, with Activities described within them for each of the three data challenges.

LSS Key Project (DC1, DC2 and DC3): Determine LSS samples (LSS1)
Host WG: LSS
Objective: Develop method for the LSS catalog generation code LSSCATALOG to produce vetted LSS samples and their completeness function.

The main Activity of this effort is methodology to split the total LSST catalog into sub-samples based on their redshift, redshift errors, redshift robustness and various astrophysical properties such as biases.

Activity: *Code for generating LSS catalogs (DC1 and DC2 SW)*

Host WG: LSS *Started:* 10/01/15 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Provide code to generate LSS catalogs.

Using the information gathered during construction of the Deliverable *"Optimal catalog splits into samples (*TXSELECTOR*)"*, write software to implement sample selection and produce galaxy catalogs that can be directly ingested by the two-point function code developed in the Deliverable *"Power-spectrum estimation code (*TXTWOPOINT*)"*. Note that the Deliverable *"Optimal catalog splits into samples (*TXSELECTOR*)"* need not have finished for work on this deliverable to begin.

Each catalog should therefore store a set of objects (and their main observable and derived properties) divided into sub-samples, the redshift distribution of these sub-samples, depth variations and potentially a set of relevant systematic templates.

Activity: *Sampling and data compression (DC2 and DC3 SW)*

Host WG: LSS *Started:* 03/31/19 *Originally due:* 07/01/20
Status: planned *Expected:* 07/01/20
URL :

Objective: Develop methods to devise optimal sampling strategies that concentrate as much information as possible into a small dataset. This should be understood, with some level of generality, as both the binning of summary statistics (correlation functions, power spectra) and

the binning of the full galaxy population in the space of observed properties (colors, magnitudes, morphology etc.). This should be done in tight communication with the pipeline sibling of this deliverable: *"Optimal catalog splits into samples (*TXSELECTOR*)"*.
Prerequisites: R&D Activity *"Code for generating LSS catalogs"*

Activity: *Field test of sampling methods (DC3 VA)*

Host WG: LSS *Started:* 10/01/18 *Originally due:* 07/01/20
Status: planned *Expected:* 07/01/20
URL :

Objective: Validate sampling methods and catalog code. Use data from precursor datasets (HSC DR1, DES Y1, KiDS) and existing DC2 and DC3 simulated data to quantify the performance of the sampling techniques developed for the Deliverable *"Optimal catalog splits into samples (*TXSELECTOR*)"* and to validate the catalog code developed in R&D Activity *"Code for generating LSS catalogs"* in a real-world setting.
Prerequisites: R&D Activity *"Code for generating LSS catalogs"*

LSS Key Project (DC1, DC2 and DC3): Code for Measuring Power and Cross-power Spectra (LSS2)
Host WG: LSS
Objective: An efficient and generic code (LSSTWOPOINT) that measures auto and cross-correlation power spectra between different tracers of the matter distribution.

Activity: *Fast mock creation code (DC1 SW)*

Host WG: LSS *Started:* 10/01/15 *Originally due:* 02/18
Status: active *Expected:* 02/18
URL : https://github.com/damonge/CoLoRe

Objective: Create large mock datasets in large numbers

The main Activity of this effort involves writing and documenting code that can create large test datasets with toy systematic imprints to test the power spectrum code. The code should be able to generate a large number ($O(1000)$) of LSST-sized datasets containing the main cosmological probes associated with two-point-based likelihoods (galaxy clustering, cosmic shear) as well as, ideally, relevant external datasets (e.g. CMB lensing, ISW).
Prerequisites: LSSCATALOG

Activity: *Field test of two-point software (DC3 SW)*

Host WG: LSS *Started:* 10/01/18 *Originally due:* 07/01/20
Status: active *Expected:* 07/01/20
URL :

Objective: Validate two-point software in real-world scenarios

Make use of precursor datasets (HSC DR1, DES Y1, KiDS) and simulated data from DC2 and DC3 to quantify the performance of LSSTWOPOINT, developed in the Deliverable *"Power-spectrum estimation code (*TXTWOPOINT*)"*, in a realistic setting ("performance" should be understood here in the same terms described in the Deliverable *"Two-point preliminary studies"*). The same data should be used to validate the two-point storage framework developed in the Deliverable *"Two-point storage framework"*. Work on this Activity should start during DC1 and DC2 using existing simulated and real data.
Prerequisites: Deliverables *"Power-spectrum estimation code (*TXTWOPOINT*)"*, *"Two-point preliminary studies"*, and *"Two-point storage framework"*

Activity: *Higher-order correlations (DC3 SW)*

Host WG: LSS *Started:* 10/01/18 *Originally due:* 06/30/20
Status: planned *Expected:* 06/30/20
URL :

Objective: Extract higher-order correlators in Fourier or configuration space.

Develop algorithms to estimate ≥ 3-point correlators of the galaxy distribution efficiently and extend *"Power-spectrum estimation code (*TXTWOPOINT*)"* to deal with these estimators. Explore the possibility of using other non-Gaussian statistics to constrain cosmology.
Prerequisites: Deliverable *"Power-spectrum estimation code (*TXTWOPOINT*)"*, R&D Activity *"Fast mock creation code"*

LSS Key Project (DC1, DC2 & DC3): Cosmological constraints from LSS (LSS3)
Host WG: LSS
Objective: A code (LSSCOSMO), part of TJPCOSMO, that is able to interpret measured clustering properties within standard theories of clustering of biased tracers on weakly non-linear scales.

Galaxies are local, but highly non-linear tracers of structure. To fully exploit the reach of LSST it is necessary to understand the precise way in which they cluster on finite, weakly non-linear scales. The purpose of this module is to develop and validate code that can produce meaningful χ^2 values. This work will use the infrastructure provided by the TJP group but will develop LSS-specific pieces.

Activity: *Robust modelling of galaxy clustering (DC2 VA)*

Host WG: LSS *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Determine main sources of astrophysical systematics

Through a thorough model-comparison project making use of cosmological simulations, determine the relevant sources of astrophysical systematics (e.g. non-linear, non-local, non-deterministic bias, baryonic effects etc.) that need to be modeled in order to obtain unbiased cosmological constraints from LSS, as well as the most reliable ways to model them and the conservative range of scales where this can be done. This work is carried out in tight communication with the TJP and CS groups.

Activity: *Modeling photo-z systematics (DC2 VA)*

Host WG: LSS *Started:* 10/01/16 *Originally due:* 12/31/19
Status: planned *Expected:* 12/31/19
URL :

Objective: Determine main effects of photo-z uncertainties

Following the same logic of R&D Activity *"Robust modelling of galaxy clustering"*, determine the most relevant effects of photo-z systematic uncertainties and the most reliable ways to model them.

Activity: *Field test of likelihood module (DC3 VA)*

Host WG: LSS *Started:* 10/01/18 *Originally due:* 07/01/20
Status: planned *Expected:* 07/01/20
URL :

Objective: Update and validate likelihood module

Implement the systematics models found in the R&D Activities *"Robust modelling of galaxy clustering"* and *"Modeling photo-z systematics"* into the first version of LSSCOSMO developed in the Deliverable *"Basic LSS likelihood module (LSSCOSMO) contribution to TJP-COSMO"*. Validate code on DC simulations and existing precursor data (HSC DR1, DES Y1,

KiDS) during DC1, 2 and 3.
Prerequisites: LSSCosmo, Deliverable *"Basic LSS likelihood module (LSSCosmo) contribution to TJPCosmo"*, and R&D Activities *"Robust modelling of galaxy clustering"* and *"Modeling photo-z systematics"*

8.3 Clusters R&D Projects

Research and development for the CL analysis is focused on three broad areas: cluster finding (Key Project "Cluster finding and catalog characterization" (CL1)), cluster mass calibration, both absolute (Key Projects "Absolute mass calibration I" (CL2), "Absolute mass calibration II" (CL3)) and relative ("Relative Mass Calibration" (CL4)), and preparing for the analysis of the data challenge and commissioning data (Key Project "Analysis of `DC3 Mock Lightcone` and pre-cursor data. CC/SV observing plan" (CL6)).

CL Key Project (DC1 & DC2): Cluster finding and catalog characterization (CL1)

Host WG: CL
Objective: Continued development and simulation-based characterization of the performance of the redMaPPer cluster finding algorithm, particularly with regards to: photometric redshift accuracy and precision, cluster centering, and the impact of halo triaxiality and projection effects. The focus on the redMaPPer code is due to its well-demonstrated performance (e.g., Rozo et al. 2015) in several datasets. As other cluster finders manage to achieve comparable performance, these activities will extend to these new cluster finders.

Activity: *Projection Effects and miscentering of redMaPPer clusters (CLOptCat) (DC1 SW,VA)*

Host WG: CL *Started:* 10/15 *Originally due:* 03/18
Status: active *Expected:* 03/18
URL :
Objective: The impact of projection effects and cluster miscentering will be quantitatively characterized both by studying redMaPPer outputs on simulated data sets, and through the use of multi-wavelength cluster data, particularly X-ray and SZ. This twin approach is necessary to empirically validate the conclusions from simulations via multi-wavelength analyses, while simultaneously verifying the assumptions inherent to the empirical multi-wavelength tests.
Prerequisites:

Activity: *Cluster redshifts (CLREDSHIFT) (DC2 SW,VA)*

Host WG: CL *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 07/01/18
URL :

Objective: Characterize cluster photometric redshift performance, and deliver a tool to estimate cluster photometric redshifts for galaxy clusters selected at other wavelengths. Identify the redshift range over which these photometric redshift estimates are robust.
Prerequisites: `HaloCat`

CL Key Project (DC1): Absolute mass calibration I (CL2)
Host WG: CL
Objective: Weak gravitational lensing is currently the best method for calibrating clusters masses, but requires the use of numerical simulations to understand the systematic uncertainties associated with the use of parameterized mass models, and to calibrate shear measurements in the cluster regime. Spectroscopic redshift measurements are also required for cluster fields to help distinguish foreground from background galaxies.

Activity: *Cluster masses from weak-lensing shear maps (CLMASSMOD) (DC1 SW+RQ)*

Host WG: CL *Started:* 10/01/15 *Originally due:* 03/17
Status: active *Expected:* 03/17
URL :
Objective: Utilize shear maps derived from existing dark-matter only simulations to quantify the bias and scatter of weak lensing mass estimators as a function of cluster mass, redshift, cosmology, and mis-centering. This should be quantified for individual cluster mass estimates, hierarchical mass estimates of cluster ensembles, as well as stacked lensing analyses.
Prerequisites: `HaloCat`

Activity: *Calibrating reduced shear with properly distorted galaxies (CLSHEAR) (DC1 SW)*

Host WG: CL *Started:* 10/01/15 *Originally due:* 07/01/18
Status: active *Expected:* 12/31/19
URL :
Objective: We will calibrate the shear response of the weak lensing shear estimators to large $\gamma > 0.05$ shears. The results from this work will enable use of high shear regions of galaxy

clusters, and determine the range of radial scales that can be utilized for mass calibration. This work will be carried out in collaboration with the weak lensing group, and be incorporated into the WL-developed pipelines (described in WL Key Projects "Requirements on shear estimation" (WL1), "Images to shear catalog I" (WL3), and "Images to shear catalogs II" (WL5).
Prerequisites: Images generated as part of the ARCLETS project by 01/16

Activity: *Shear Profile Bias in Simplified Clusters (CLSHEAR) (DC1 DP,RQ)*

Host WG: CL *Started:* 10/15 *Originally due:* 12/16
Status: done *Completed:* 12/16
URL :

Objective: Produce images of galaxy cluster fields using analytic cluster models and the full distortion code. This will allow us to isolate the shear algorithm's ability to extract cluster profiles and determine the level of bias in both the radial profile and absolute mass calibration. These images will also serve as input to the cluster contribution to the cross-working group Key Project on deblending (R&D Activity *"Measure the impact of blends on cluster shear profiles"*). Related to this task is the compilation of fidelity requirements for the DC2 cluster simulations. We will use the same DM software tools to compile fidelity requirements for DC2 cluster simulations in R&D Activity *"Calibrating reduced shear with properly distorted galaxies (CLSHEAR)"*.
Prerequisites: Images generated as part of the ARCLETS project by 01/16

Activity: *Gather spec-z training sets for cluster lensing (CLSMURFS) (DC1 DP)*

Host WG: CL *Started:* 01/01/16 *Originally due:* 06/17
Status: active *Expected:* 12/31/19
URL :

Objective: Quantify residual contamination by cluster galaxies in weak lensing source catalogs, and the performance of photometric redshift estimates in cluster fields. Due to the relative paucity of complete spectroscopic follow-up of cluster fields, this task requires submitting observing proposals to acquire spectroscopy of cluster field, and analysis of the resulting data.

Activity: *Cluster masses from existing cluster observations (CLABSMASS) (DC1 DP)*

Host WG: CL *Started:* 01/01/16 *Originally due:* 06/17
Status: active *Expected:* 12/31/19
URL :

Objective: Stress-test LSST DESC cluster mass calibration pipeline on existing, high-quality imaging in 5-6 bands to verify the validity and feasibility of the DESC mass calibration pipeline in real-world scenarios. This activity complements testing of the pipeline in simulated data sets.
Prerequisites: R&D Activities *"Cluster masses from weak-lensing shear maps (*CLMASSMOD*)"*,*"Calibrating reduced shear with properly distorted galaxies (*CLSHEAR*)"*

CL Key Project (DC3): Absolute mass calibration II (CL3)
Host WG: CL
Objective: Improve mass calibration pipeline developed in "Absolute mass calibration I" (CL2) and "Requirements on shear estimation" (WL1). Key improvements are development of methods robust to baryonic physics, further refinement of the shear measurement capabilities in the cluster regimes, and empirical tests of the performance of photo-z algorithms in cluster fields. We will also assess the CL WG requirements for DC3 simulations.

Activity: *Cluster masses from shear maps, with baryons (*CLMASSMOD*) (DC2 SW)*

Host WG: CL *Started:* 10/01/16 *Originally due:* 12/18
Status: active *Expected:* 12/18
URL :
Objective: Develop a flexible framework to estimate cluster weak lensing masses, given a variety of models and data / simulation formats in a self-consistent manner. The application to simulations will be used to quantify the bias and scatter. Parts of the framework will be integrated into the pipeline. On the same timeline, expand the work to include simulations with baryons.
Prerequisites: R&D Activities *"Cluster masses from weak-lensing shear maps (*CLMASSMOD*)"*; *"Shear Profile Bias in Simplified Clusters (*CLSHEAR*)"*; *"Calibrating reduced shear with properly distorted galaxies (*CLSHEAR*)"*; halo centers plus shear maps from simulations; simulated optical, X-ray and SZ images (R&D Activity *"Simulations for covariance studies"*)

Activity: *ARCLETS2.0: shear normalization for realistic clusters (DC2 SW,VA)*

Host WG: CL *Started:* 10/01/16 *Originally due:* 12/18
Status: active *Expected:* 12/18
URL :

Objective: Characterize recovered weak lensing profiles in realistic LSST simulations. This builds on the R&D Activity *"Shear Profile Bias in Simplified Clusters (CLSHEAR)"*, but includes realistic effects of galaxy colors, unresolved (and undetected) galaxies, galaxy clustering and morphology-density relations, as well as instrumental and atmospheric effects.
Prerequisites: R&D Activities *"Shear Profile Bias in Simplified Clusters (CLSHEAR)"* and *"Calibrating reduced shear with properly distorted galaxies (CLSHEAR)"*, Key Projects "Impacts of Blending" (CX1) and "Requirements on shear estimation" (WL1), Deliverables *"Pipeline for Producing a Shear Catalog (SHEARMEASUREMENTPIPE)"* and *"Validation of the BF effect in simulations"*,

Activity: *Cluster shears from DC2 simulations (DC2 DP,VA)*

Host WG: CL *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL:

Objective: Validate algorithms developed in R&D Activity *"Calibrating reduced shear with properly distorted galaxies (CLSHEAR)"* by measuring shear profile of galaxy clusters at a variety of redshifts in the DC2 simulation.
Prerequisites: R&D Activities *"Calibrating reduced shear with properly distorted galaxies (CLSHEAR)"*,*"Shear Profile Bias in Simplified Clusters (CLSHEAR)"*; Key Project "Impacts of Blending" (CX1); production of the DC2 simulations

Activity: *Evaluate $p(z)$ algorithms with spec-zs in cluster fields (CLSMURFS) (DC2 VA)*

Host WG: CL *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 09/30/21
URL:

Objective: Continuation of the R&D Activity *"Gather spec-z training sets for cluster lensing (CLSMURFS)"* to evaluate the performance of photo-z estimates in cluster fields, testing DESC $p(z)$ algorithms (PZPDF, where available, or similar precursor codes) on spectroscopic training data gathered in DC1 and DC2.

Activity: *Apply refined results to existing cluster lensing data (CLABSMASS) (DC2 DP)*

Host WG: CL *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL:

Objective: We will use the results of the R&D Activities *"Cluster masses from shear maps,*

with baryons (CLMassMod)", "ARCLETS2.0: shear normalization for realistic clusters" and *"Evaluate $p(z)$ algorithms with spec-zs in cluster fields (CLSmurfs)"* to further improve mass measurements from available "LSST-like" cluster weak-lensing datasets (both currently existing and gathered in the R&D Activity *"Cluster masses from existing cluster observations (CLAbsMass)"*). On this timescale, we will also look towards converting our data processing pipelines to DM stack.
Prerequisites: R&D Activities *"Cluster masses from existing cluster observations (CLAbsMass)","Cluster masses from shear maps, with baryons (CLMassMod)","ARCLETS2.0: shear normalization for realistic clusters","Evaluate $p(z)$ algorithms with spec-zs in cluster fields (CLSmurfs)"*

CL Key Project (DC2): Relative Mass Calibration (CL4)
Host WG: CL
Objective: Determine the form of photometric scaling relations to enable LSST cluster cosmology though simulations and multi-wavelength cluster data.

Activity: *Low-scatter mass proxies from Chandra data (DC2 DP)*

Host WG: CL *Started:* 10/01/17 *Originally due:* 12/16
Status: active *Expected:* 12/16
URL :
Objective: Low-scatter mass proxies will be extracted from available archival Chandra X-ray data for clusters in state-of-the-art cosmological catalogs. The primary output will be a catalog of low-scatter mass proxy measurements for these clusters.
Prerequisites: None

Activity: *Low-scatter mass proxies from XMM-Newton data (DC2 DP)*

Host WG: CL *Started:* 10/01/17 *Originally due:* 12/17
Status: active *Expected:* 12/17
URL :
Objective: Low-scatter mass proxies will be extracted from available archival XMM-Newton data for clusters in state-of-the-art cosmological catalogs. The primary output will be a catalog of low-scatter mass proxy measurements for these clusters.
Prerequisites: None

Activity: *Measuring the mass-observable scaling relations (DC2 DP)*

Host WG: CL *Started:* 10/01/17 *Originally due:* 12/18
Status: active *Expected:* 12/18
URL :

Objective: Using the low-scatter X-ray mass proxy measurements described in the R&D Activities *"Low-scatter mass proxies from Chandra data"* and *"Low-scatter mass proxies from XMM-Newton data"* above, and utilizing the absolute mass calibration measurements from R&D Activity *"Apply refined results to existing cluster lensing data (*CLAbsMass*)"* and the likelihood code described in the Key Product "CL Cosmology Likelihood Module CLCosmo" (CL5), we will self consistently determine the forms and covariance of the scaling relations linking cluster survey observable(s) and mass.
Prerequisites: X-ray measurements from R&D Activities *"Low-scatter mass proxies from Chandra data"*, *"Low-scatter mass proxies from XMM-Newton data"*; weak lensing measurements from the R&D Activity *"Apply refined results to existing cluster lensing data (*CLAbsMass*)"*; CLCosmo; external cluster catalogs (CLPanCat).

Activity: *A strategy for precise relative mass calibration with LSST (DC2 RQ)*

Host WG: CL *Started:* 10/01/16 *Originally due:* 12/18
Status: active *Expected:* 12/18
URL :

Objective: By the time of LSST commissioning, an array of powerful, new, multi-wavelength observing facilities and data should be available that will be highly complementary with LSST for cluster science. At mm wavelengths, the SPT3G and AdvACT surveys will be nearing completion and preparatory work for CMB-S4 will be well underway. At X-ray wavelengths, the eROSITA satellite, scheduled for launch in 2017, should have its survey underway and would be expected to have announced an AO for targeted observations. In the longer term, the ATHENA observatory (launching in 2028) will provide the capability to efficiently gather X-ray data for LSST clusters at high redshifts. We will identify a strategy to utilize these resources to obtain the best possible relative cluster mass calibration and cluster centering information for LSST. We will assess the effort needed to extend the extraction of X-ray mass proxy and centering measurements to eROSITA data and develop a plan for an eROSITA follow-up observation program.
Prerequisites: None

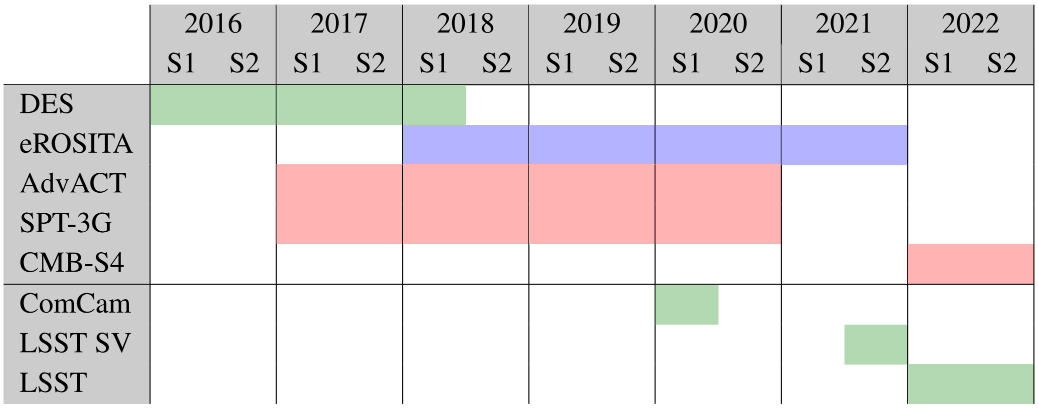

Figure 8.3.1: Projected timeline for data acquisition by large-area cluster surveys (stages 3 and 4), as well as the planned ComCam and LSST Science Validation observations, through the first year of the LSST survey. Surveys are color-coded according to wavelength coverage: optical in green (DES, ComCam/LSST), X-ray in blue (eROSITA), and millimeter in red (AdvACT, SPT-3G, CMB-S4).

CL Key Project (DC3): Analysis of `DC3 Mock Lightcone` and pre-cursor data. CC/SV observing plan (CL6)

Host WG: CL

Objective: In preparation for DC3, the CL working group will determine what updated simulations will be needed to be ready for ComCam/SV data. The bulk this Key Project will then involve applying all developed algorithms to both `DC3 Mock Lightcone` and pre-cursor datasets (both large survey data re-processed by the LSST Project, and deep pointed observations of massive clusters). These analyses will be used to test and validate the cluster finding and mass measurement algorithms, and to extract weak-lensing mass estimates from current data. Deep, pointed pre-cursor observations of cluster fields, reaching comparable depth to LSST and using similar filters, but also adding additional information through e.g. HST imaging, NIR imaging or spectroscopy, can be used to stress-test critical aspects of the LSST pipeline in these crowded extra-galactic fields. This includes testing the performance of deblending algorithms, shear estimates, and photometric redshifts. The results obtained from this Key Project will be used to report on the performance of the DM Stack, WL shear estimates, photo-z's, deblending, as well as the cluster-specific algorithms developed in the CL working group. In addition, in conjunction with cluster samples from Stage 3 cluster surveys (see Figure 8.3.1), ComCam will hold the potential to make a significant and immediate impact on cosmological constraints by providing weak lensing measurements for clusters. With a cadenced observing plan, these fields could also provide useful testbeds for both strong lensing and supernovae variability searches (including the potential for discovering strongly lensed supernovae). We will quantify the potential impact of a ComCam cluster observing campaign (or SV observations, alternatively), and provide an optimized target list.

Activity: *ComCam and/or SV cluster target list (DC3 DP)*

Host WG: CL *Started:* 10/01/19 *Originally due:* 03/19
Status: active *Expected:* 03/19
URL :

Objective: We will use the Fisher matrix code developed for cluster counts to identify the optimal redshift and mass range for weak lensing follow-up with ComCam or the LSST camera during SV. In conjunction with stage 3 catalogs that will exist from SPT-3G, Advanced ACT and eROSITA, we will provide a target list that will optimize the immediate impact of such observations for cosmology, which is likely to be substantial.
Prerequisites: Absolute mass calibration from Key Projects "Absolute mass calibration I" (CL2) and "Absolute mass calibration II" (CL3), relative mass calibration from Key Project "Relative Mass Calibration" (CL4), Fisher matrix code (CLForecast), external cluster catalogs (CLPanCat).

Activity: *Analyze* `DC3 Mock Lightcone` *(DC3 DP+VA)*

Host WG: CL *Started:* 10/01/18 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :

Objective: We will apply all developed algorithms to the `DC3 Mock Lightcone`. In addition to measuring cluster masses, `DC3 Mock Lightcone` will serve as testbed for cluster identification, and allow to determine covariance of lensing mass with optical (richness), SZ and X-ray signals for the resimulated clusters.
Prerequisites: CLFinder, CLRedshift, CLMassMod, CLShear, CLSmurfs, CLAbsMass

Activity: *Cluster-finding on Project re-processed survey data (DC3 DP+VA)*

Host WG: CL *Started:* 10/01/18 *Originally due:* 03/20
Status: active *Expected:* 03/20
URL :

Objective: We will test the LSST cluster-finder on precursor survey data re-processed by the LSST Project. We will validate cluster candidates using available multiwavelength catalogs

and spectroscopic follow-up, and provide feedback to DM, WL, and photo-z WGs, and revise CLFINDER, as necessary.
Prerequisites: Project-reprocessed survey datasets. CLFINDER

Activity: *Cluster masses from Project re-processed survey data (DC3 DP+VA)*

Host WG: CL *Started:* 10/01/18 *Originally due:* 03/20
Status: active *Expected:* 03/20
URL :
Objective: We will use the DESC algorithms to process project reprocessed "LSST-like" survey data sets to extract cluster masses. Survey data sets that may be available at the time include CFHTLS, DES, and HSC. The results will be used to provide feedback to DM and relevant DESC groups.
Prerequisites: R&D Activities *"Cluster masses from existing cluster observations (CLABSMASS)"* and *"Apply refined results to existing cluster lensing data (CLABSMASS)"*, CLMASSMOD, CLSHEAR, CLSMURFS, CLABSMASS

Activity: *Masses from other data processed with the DM stack (DC3 DP+VA)*

Host WG: CL *Started:* 10/01/18 *Originally due:* 03/20
Status: active *Expected:* 03/20
URL :
Objective: We will use DM stack and the DESC algorithms to process other available "LSST-like" cluster weak-lensing datasets. Examples include data from SuprimeCam, CHFT and DECam.
Prerequisites: R&D Activities *"Cluster masses from existing cluster observations (CLABSMASS)"* and *"Apply refined results to existing cluster lensing data (CLABSMASS)"*, CLMASSMOD, CLSHEAR, CLSMURFS, CLABSMASS

8.4 Strong Lensing R&D Projects

The R&D Key Projects in strong lensing are primarily about algorithm development, for lensed quasar detection (Key Project "SLFINDER: Target Selection in the DC2 Survey" (SL2)), time delay estimation (Key Projects "SLTIMER Development: The Second Time Delay Challenge" (SL1) and "SLTIMER Development: The Third Time Delay Challenge" (SL4)), and lens environment characterization (Key Project "Lens Environment Characterization" (SL3)). There is also a need to demonstrate the SL pipeline on realistic simulated data: this is Key Project "End-to-end test" (SL5).

SL Key Project (DC2): SLTIMER Development: The Second Time Delay Challenge (SL1)

Host WG: SL

Objective: A critical component required for the strong lensing probe is an unbiased and precise measurement of the differences in light travel times for the various images in a lensed quasar system, i.e., the time delays. We need to do this for ∼1000 quasar lens systems. A first time delay challenge has been conducted, but with simplified inputs. The second time delay challenge, named provisionally "TDC2" by its community, will incorporate (1) information about the gravitational potential of the primary lensing galaxy and (2) realistic multiband light curves.

Activity: *TDC2 Requirements (DC2 RQ)*

Host WG: SL *Started:* 10/01/16 *Originally due:* 09/30/17
Status: active *Expected:* 09/30/17
URL :

Objective: Provide minimum and/or desired requirements for the simulated data to be used in TDC2.
Prerequisites: None

Activity: *TDC2 Multi-filter Light Curve Generator (DC2 SW)*

Host WG: SL *Started:* 10/01/16 *Originally due:* 10/01/17
Status: active *Expected:* 10/01/17
URL :

Objective: Write software to generate the multi-filter simulated light curves defined in the TDC2 requirements document (R&D Activity *"TDC2 Requirements"*).
Prerequisites: R&D Activity *"TDC2 Requirements"*

Activity: *TDC2 Simulated Light Curves (DC2 DP)*

Host WG: SL *Started:* 10/01/17 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: Create simulated data set to meet requirements for TDC2 using TDC2 light curve generator.

Prerequisites: R&D Activities *"TDC2 Requirements"*, *"TDC2 Multi-filter Light Curve Generator"*

Activity: *TDC2 Community-inferred Time Delays (DC2 VA)*

Host WG: SL *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Run the time delay challenge using data set created in the R&D Activity *"TDC2 Simulated Light Curves"*, collect and analyze the resulting submissions.
Prerequisites: R&D Activity *"TDC2 Simulated Light Curves"*

Activity: *TDC2 SL-Optimized LSST Main Survey Observing Strategy (DC2 VA)*

Host WG: SL *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Use the time delays determined in the R&D Activity *"TDC2 Community-inferred Time Delays"* to compute diagnostic metrics and a strong lensing Figure-of-Merit using the MAF framework, and use it to test various available LSST Observing Strategies ("cadences"), as defined by the Project's OpSim database outputs. This work will provide input into the DC2 R&D Activity *"Optimized LSST observing strategy"* of Key Project "Systematics Caused by the LSST Observing Strategy" (CX11).
Prerequisites: R&D Activity *"TDC2 Community-inferred Time Delays"*

SL Key Project (DC2): SLFinder: Target Selection in the DC2 Survey (SL2)
Host WG: SL

Objective: We need to find $\sim 10^4$ bright lensed quasars and supernovae, and hundreds of multiple source plane lenses. The final SLFinder is very likely to be user-generated software, taking in catalogs and postage stamp images and producing a catalog of lens candidates, each with an initial model.

The first stage of this pipeline will involve selecting "targets" from the LSST DM DRP*catalogs* (object, source or diffsource); the second stage will then be extracting "candidates" from the cutout images, using gravitational lens model information to make the classification.

Selecting lensed quasar, lensed supernova and compound lens targets will involve subtly different strategies. Detecting lensed quasar targets will rely on cataloged object component colors, morphologies and time variability. Both lensed supernova target selection and compound lens target selection will need colors and morphologies to select likely arcs and rings around massive lens galaxies. In the supernova case, some alert and object variability characteristics will be invaluable.

With the multi-filter, multi-epoch second-round `DC2` simulated dataset, we will extend current state of the art lens detection techniques and test them on 1) the deblended object and diffsource catalogs (produced in color by the LSST DM stack software), and 2) postage stamp images of the targets. The production of this dataset is described in the Deliverable *"DC2 Simulated Images"*.

Activity: *DC2 (DC2) SLFinder Target Catalogs and Assessment (DC2 VA)*

Host WG: SL *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Use the SLFinder Target Selectors to make target catalogs from the available `DC2` and `DC2 Real Data`, and assess their completeness.
Prerequisites: Deliverables *"SLFinder Target Selection Code"* and *"DC2 Simulated Images"*

Activity: *DC2 SLFinder Candidate Samples and Assessment (DC2 VA)*

Host WG: SL *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Use SLFinder Candidate Extractor to make candidate samples from the available `DC2` and `DC2 Real Data`, and assess their completeness.
Prerequisites: R&D Activity *"DC2 (DC2) SLFinder Target Catalogs and Assessment"*, Deliverable *"SLFinder Lens Candidate Extractor"*

SL Key Project (DC2): Lens Environment Characterization (SL3)
Host WG: SL
Objective: For precision cosmographic measurements using gravitational lenses, the line-of-sight weak lensing effects must be well constrained in order for us to avoid bias in the time

delay distances (and hence cosmological parameters) arising from the selection of the sample. This Key Project will test a number of approaches already being developed by the SL community on simulated lines of sight, with the aim of quantifying the residual systematic error after modeling the lens (and line of sight) density environments. We assume the existence of a " DC2" that spans a range of different cosmological models, and contains galaxies whose observed properties include photometric redshifts, stellar masses, and lensed shapes (as well as more basic positional, photometric and structural/morphological measurements).

Activity: *SL Environment Characterization and Assessment (DC2 VA)*

Host WG: SL *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :
Objective: Run SLEnvCounter and SLMassMapper on DC2 to estimate weak lensing effects at a large sample of mock strong lens positions (to be defined), analyze and compare results.
Prerequisites: Deliverables "SLEnvCounter", and "SLMassMapper"

SL Key Project (DC3): SLTimer Development: The Third Time Delay Challenge (SL4)

Host WG: SL

Objective: As for TDC2, this project has the aim of producing unbiased and high-precision time delay measurements. However, in this case the input light curves will capture the statistical properties of light curves extracted from the images of the DC2 DC2 Key Project. At DC2, the SLMonitor code will advanced to a point where it should be able to provide good approximations to the "final photometry" we expect to be able to perform (using scene modeling algorithms implemented against the user-generated MultiFit API). These light curve fluxes will come with some measure of the correlations in their uncertainties, and it is these that we want to use in the development and testing of the SLTimer time delay measurement code.

Activity: *TDC3 Requirements (DC3 RQ)*

Host WG: SL *Started:* 10/01/18 *Originally due:* 09/30/19
Status: active *Expected:* 09/30/19
URL :
Objective: Provide minimum and/or desired requirements for the simulated data to be used

in TDC3: how should we make use of the DC2 light curves when developing and testing the SLTIMER?
Prerequisites: None

Activity: *TDC3 Simulated Light Curves (DC3 DP)*

Host WG: SL *Started:* 10/01/19 *Originally due:* 06/30/20
Status: active *Expected:* 06/30/20
URL :
Objective: Slice and dice the SLMONITOR DC2 light curves from the R&D Activity *"DC2 SN and SL Light Curves"* to create the set of simulated light curves to be used in TDC3 (as defined in the TDC3 requirements document.
Prerequisites: R&D Activities *"TDC3 Requirements"*, *"DC2 SN and SL Light Curves"*

Activity: *TDC3 Community-inferred Time Delays (DC3 VA)*

Host WG: SL *Started:* 10/01/18 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :
Objective: Run the time delay challenge using data set created in the R&D Activity *"TDC3 Simulated Light Curves"*, collect and analyze the resulting submissions.
Prerequisites: R&D Activity *"TDC3 Simulated Light Curves"*

SL Key Project (DC3): End-to-end test (SL5)
Host WG: SL
Objective: Our aim here is a full SL analysis to test the SLFINDER, SLMONITOR, SLTIMER and SLENVCOUNTER/SLMASSMAPPER analysis code. We will likely focus on the mooted DC3 Mock ComCam Survey dataset, where realistic images containing realistic sources are generated and analyzed with a DM Stack pipeline close to that planned to be used by the project on the Real ComCam data. As in DC2, we would want to include some over-density of multiply-imaged quasars, supernovae and compound lenses. The larger DC3 Mock Lightcone dataset, designed with the large-scale probes in mind, may be useful for additional lens environment work, but the DC3 Mock ComCam Survey dataset will probably be sufficient for our work at this stage.

Activity: *Lens Candidates (DC3 VA)*

Host WG: SL *Started:* 10/01/18 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :

Objective: Run SLFINDER on the `DC3 Mock ComCam Survey`, producing a sample of lens candidates. Assess its completeness.
Prerequisites: Deliverables *"SLFINDER Target Selection Code"*, *"SLFINDER Lens Candidate Extractor"*, and *"`DC3 Mock ComCam Survey` Simulated Images"*

Activity: *Time Delays (DC3 VA)*

Host WG: SL *Started:* 10/01/18 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :

Objective: Run SLMONITOR and SLTIMER on the `DC3 Mock ComCam Survey` lens candidates. Assess the accuracy of the time delays.
Prerequisites: Deliverables *"SLTIMER"* and *"`DC3 Mock ComCam Survey` Simulated Images"*

Activity: *Lens Environments (DC3 VA)*

Host WG: SL *Started:* 10/01/18 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :

Objective: Run SLENVCOUNTER and SLMASSMAPPER on the fields around the `DC3 Mock ComCam Survey` lens candidates. Assess the accuracy of the inferred environmental weak lensing effects. These codes will make use of the photo-zss and stellar masses produced in the R&D Activity *"Improved $p(z, \alpha)$ catalog"*.
Prerequisites: Deliverables *"SLENVCOUNTER"*, *"SLMASSMAPPER"*, and *"`DC3 Mock ComCam Survey` Simulated Images"*, R&D Activity *"Improved $p(z, \alpha)$ catalog"*

Activity: *SL Cosmological Parameter Accuracy (DC3 VA)*

Host WG: SL *Started:* 10/01/18 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :

Objective: Investigate the residual systematic errors in the cosmological parameters from a realistic sample of LSST time delay lenses based on the results of the DC3 End-to-End test (and making reasonable assumptions about lens model accuracy). This investigation will use

the implementation of SLCosmo from the Deliverable *"SLCosmo"*.
Prerequisites: R&D Activities *"Lens Candidates"*, *"Time Delays"*, and *"Lens Environments"*, and Deliverable *"SLCosmo"*

8.5 Supernova R&D Projects

The primary activity of the supernova cosmology working group is the inference of dark energy parameters using the luminosity distances of Type Ia supernovae, as described in Section 3.5. This will then be integrated to the Theory and Joint Probes framework to self-consistently include all systematic effects in the full SN posterior. As such, one can think of the main project of the SNWG as computing the SN posterior, and then integrating it into the larger TJP context.

There are several steps required in this main goal of computing and testing the ability to perform dark energy inference. These tasks form part of the main analysis pipeline, but require additional research and development.

- Determining the optimal cadence of the survey. This is essential for both the high redshift (DDF) and low redshift (WFD) surveys. This is part of the early research and development for the SN DESC efforts, but also forms part of the required pipeline tasks explored in R&D Activities *"Observing Strategy Recommendations"* and *"Application to SN Typing and redshift estimation"*.

- Determining the difference image requirements. An important requirement for supernova cosmology is the sample selection of supernovae, and since they are detected through difference images, understanding the precision and accuracy of the procedure used in LSST is essential for the SNWG. Such investigations are planned on image simulations of DC2, while they also need to be performed while reprocessing available data (eg. SNLS, HSC, DES) using the LSST image processing pipeline. Such investigations will give us an understanding the templates required for good difference imaging and the time needed to obtain them. This task also forms part of the early R&D for the SN DESC efforts in optimising the DDF fields during the telescope commissioning. While difference imaging will be mostly performed by the data management group of LSST, it is possible that efficient supernova detection will require difference imaging to be performed differently, for example on coadded science images, in the DDF (see the Deliverable *"SN Analysis Pipeline"*) will be extremely useful in generating much of this R&D for the SNWG for studying difference images.

- Classifying transients early. Classifying potential SN candidates for spectroscopic follow-up is an increasingly important task, and the SNWG is devoting R&D efforts to ensuring that this early classification is possible within the DESC and by interacting with the official LSST brokers, included in the deliverable *"Early SN classification system"*. The SNWG is also devoting considerable effort to understanding the zoo of relevant transients through the effort in *"Multi-type transient simulations"*in order to help in such classifications. Because such classifications may benefit greatly from contextual information of the spatial environment of the candidate, investigations are recommended and planned to study if such information (eg. local surface brightness of host galaxies) is available in LSST catalog products on the basis of DC2, and reprocessed data. Finally, a pipeline implementing the best early classification algorithms, and software infrastructure to record the results for subsequent analyses is part of a DC3 pipeline building effort (*"Early SN classification system"*).

- Obtaining follow-up observations of a subset of supernovae. In concert with ground-based telescopes, the research and development for this task is to determine a spectroscopic follow up procedure, and to address questions like whether there will be photometric follow up of a selected number of SN to boost their cadence and to help with classification, and whether or not to follow up SN in the IR. Such procedures will also take into account and inform the requirements on early classification proecdure of transients. This will also guide choices in cross survey optimization with other teams. This forms part of the Key Project "Cosmology from Photometric Supernova Samples DC2" (SN5).

- Extracting a light curve from the photometric data. Supernovae usually occur in regions where there is background galactic light. In the field of supernova cosmology, the gold standard for extracting the light curve (usually called Scene Modelling Photometry) utilizes mutiple images at different times to efficiently deblend the time varying SN light from the static galactic light. While the task of extracting and storing forced photometered transient light curves is a task that falls largely to the data management group, but it is essential for early R&D to be done by the SN group to test the extraction efficiency through both reprocessing other data (e.g. SNLS, ZTF, DES data) using the LSST software pipeline and through data challenges like the DC2/DC3 challenges and study its impact on cosmology. The pipeline deliverables in the DC2 era, *"SN selection function to produce a SN catalog for classification"* and *"SN summaries code"*, will be useful in carrying out such investigations and inform the SNWG on the needs and requirements for developing further software to performing accurate extraction of light curves.

- Refining supernova light curve models. In order to ensure accurate cosmological constraints, improvements are required to light curve models (e.g. SALT2k2 for Type Ia supernovae), including better understanding of the rest-frame u-band, the secondary maximum, measures of model uncertainty, environmental information (e.g. the analog of the Tripp ansatz), extending the model into the near-IR. For the core-collapse models the R&D extends to ensuring complete models over a range of different objects, and developing robust spectrophotometric models to capture the behaviour of a range of core-collapse objects. This R&D is actually required for the Key Project "SUPERNOVAREALIZER Development" (SN1).

- Determining the true rates of SN within galaxies. This R&D work centers around determining the correlations between the SN properties and their host galaxies, building on such analyses performed in other surveys. This will build part of the frameworks in the Key Project "SUPERNOVAREALIZER Development" (SN1).
- Determining accurate photo-z determination of SNIa and their hosts. This R&D effort must continue in parallel with the tasks defined in Section 8.12.
- Cosmological inference with SN light curves. This R&D effort continues over simulated SN light curves in DC1 and computed difference images in DC2 (Key Project "Cosmology from Photometric Supernova Samples DC2" (SN5)), and includes light curve modeling, classification uncertainties, calibration and selection effects as described in the items above.

In addition to these Key Projects that are required for the main supernova science driver, there are additional items of R&D that form part of the ancillary SN science case, but that remain vital to investigate in parallel.

- Detecting Dwarf galaxies. The research and development for this project is to determine the correct cadence to allow for good detection and possibly redshift determination of dwarf galaxies through detection of supernova within them. This should be largely dependent on the rates of SN in dwarfs and the rate of interlopers.
- Using supernovae to test for cosmological isotropy. This is a science case that is novel to LSST with its large footprint. The R&D here is to test if the cadence strategy is optimal for this science case. This forms part of the Key Project "Novel Science with the Wide Field Survey" (SN4) efforts.
- Using supernovae to probe peculiar velocity. Using SNIa as bright objects within galaxies that are moving in gravitational potentials, these supernovae can allow us to trace the galaxies themselves, and therefore measure large-scale features in the distribution of

large scale structure. This is novel as no survey prior to LSST has the sky area to perform such tests with SNe. The R&D here is to determine if the current LSST cadence will allow distance modulus uncertainties that are sufficiently small to enable this science, and if the photo-z errors are sufficient for this science. This is again part of the Key Project "Novel Science with the Wide Field Survey" (SN4) efforts.

- Weak lensing of supernovae. This R&D effort is to understand the deviations from the standard candle luminosity relation due to supernova lensing. This will be something one is able to test in Key Project "Cosmology from Photometric Supernova Samples DC2" (SN5).

- Strong lensing of supernovae. This large and ongoing R&D effort is described in Key Projects "Supernova and Strong Lens Light Curves" (CX2), "Supernova and Strong Lens Light Curves" (CX10) and "SLFINDER: Target Selection in the DC2 Survey" (SL2), and is also relevant for the "Novel Science with the Wide Field Survey" (SN4) Key Project, as described below.

SN Key Project (DC1): SUPERNOVAREALIZER Development (SN1)
Host WG: SN

Objective: A pressing need for much SN analysis work (for instance, cadence optimization, statistical/systematic error budget, photometric classification tests) is the ability to simulate the LSST SN Ia sample with fidelity, given different choices of survey strategy, in both the main survey and deep-drilling fields. The SUPERNOVAREALIZER effort is under active development to address this need[5]. The goal is to take a particular LSST survey description (from the output of OPSIM), including cadence, exposure time, sky coverage, filters, image quality, and sky transparency, and output a realistic catalog of supernova light curves (with accurate photometric uncertainties and including non-Ia SN and potentially other transients that could confuse algorithms attempting to identify SN Ia) with an appropriate distribution of SN types, redshifts, sky location, and host-galaxy properties.

These catalog-level (CATSIM) outputs, in particular those from R&D Activities *"Simulated SN Catalog"* and *"Simulated SN Light Curves"*, will go "downstream" to an analysis pipeline (leading to cosmological parameter constraints). This will allow, for example, a study of the effect of different choices of cadence or other survey design parameters on dark energy con-

[5] https://github.com/DarkEnergyScienceCollaboration/SNRealizer

straints. These will also go "upstream" to the PHOSIM pipeline, allowing realistic SN light curves to be added at the image level.

In particular, SUPERNOVAREALIZER will be used to inject supernovae into the input catalogs for the Twinkles project (e.g., Key Projects "Supernova and Strong Lens Light Curves" (CX2) and "SLFINDER: Target Selection in the DC2 Survey" (SL2)).

Activity: *Improved SN template library (DC1 SW)*

Host WG: SN *Started:* 10/01/15 *Originally due:* 06/16
Status: done *Completed:* 06/16
URL :

Objective: While good, parameterized libraries of SN Ia templates (SEDs and synthetic photometry as a function of time since explosion) are in hand, the non-Ia template library is limited and should be improved. This is especially important for photometric classification work. This project involves developing the spectral models and templates, updating the ansatz for evaluating the intrinsic SNIa brightness and linking this to brightness estimates and systematics in SN cosmology.

Prerequisites: None

Activity: *Simulated SN Catalog (DC1 DP)*

Host WG: SN *Started:* 01/01/16 *Originally due:* 09/16
Status: done *Completed:* 09/16
URL :

Objective: Create a catalog with SN distributions with SN type, redshift, location on the sky, host galaxy info. To produce this catalog, we will need accurate rates of SN (Ia and non-Ia) as function of these parameters as input to catalog generation. These rates will come from currently available plus continued observational improvements in these num bers from ongiong nearby ($z < 0.1$) and higher-redshift surveys ($0.1 < z < 1$). In addition we will develop a model of the parameters of SNIa and non-Ia as a function of host galaxy properties and location. Finally we will develop the the Discrepancy/ Error Model of light curves built out of forced photometry of simulated transients detected using difference imaging in the LSST DM pipeline using Twinkles 1.3 data and update the resuls using DC2 data. Among other quantities this will calculate efficiency of detecting transients in a variety of situations (PSF/galaxy background light) as a function of true signal to noise, and the biases in photometry performed on the difference images.

Prerequisites: None

Activity: *Simulated SN Light Curves (DC1 DP)*

Host WG: SN *Started:* 01/01/16 *Originally due:* 12/16
Status: done *Completed:* 12/16
URL :

Objective: Simulate light curves of all SN in observed filters with photometry including weather, image quality variations, etc. and accurate estimates of photometric uncertainties (including systematics and correlations, if possible). This Activity involves integrating SUPERNOVAREALIZER with OPSIM output to connect image quality and transparency data with system throughput to produce realistic light curves. This will enable a reasonable first-guess error model for photometric uncertainties and covariance across filters/time/position, including noise from template subtraction. This will be expanded in DC2 to a more sophisticated systematics covariance matrix.

Prerequisites: R&D Activities *"Improved SN template library"* and *"Simulated SN Catalog"*

SN Key Project (DC2): Observing Strategy Optimization for SN Ia Cosmology (SN3)

Host WG: SN
Objective: The LSST main-survey and deep-drilling-field observing strategy (cadence, filters, etc.) has a direct consequence on the constraining power of LSST SN Ia cosmology on dark energy parameters and tests of dark energy isotropy. For example, the nominal "universal" cadence for the main survey produces SN Ia light curves of too low quality to be useful. Switching to a rolling cadence and/or including large dithers in pointings could produce a huge increase in the number of cosmologically useful SN Ia. This project aims to analyze and optimize LSST observing strategy for SN Ia cosmology, based on the output of the SUPERNOVAREALIZER (Key Project "SUPERNOVAREALIZER Development" (SN1)), of the SUPERNOVATYPE photometric classifier (Key Project "Cosmology from Photometric Supernova Samples DC2" (SN5)) and current or improved light-curve fitters/distance estimators. This Key Project overlaps with Key Project "Systematics Caused by the LSST Observing Strategy" (CX11) and "Using Deep Drilling Fields to Reduce Dark Energy Systematics" (CX12).

Activity: *Metrics code to evaluate and optimize observing strategy (DC2 SW)*

Host WG: SN *Started:* 10/01/16 *Originally due:* 09/17
Status: active *Expected:* 09/17
URL :

Objective: SUPERNOVACADENCE code to develop appropriate metrics (e.g., DE uncertainties) for arbitrary observing strategy; and analysis code to optimize observing strategy (using, e.g., ROC curves and AUC scores). This needs to be run on a wide range of OPSIM outputs with varying cadences, dither patterns, etc.

Prerequisites: R&D Activities *"Simulated SN Catalog"*, *"Simulated SN Light Curves"*, and *"Cosmological Constraint Covariance Matrix"*, and Deliverable *"Classification Code: SUPERNOVATYPE"*.

SN Key Project (DC2): Novel Science with the Wide Field Survey (SN4)
Host WG: SN
Objective: The LSST Wide Fast Deep Survey will be the first survey to potentially enable six band supernovae observations over an area of the sky as large as 18000 square degrees, where supernovae might be studied in the low redshift range to about a redshift of ~ 0.5. While the number of supernovae exploding in such a large volume and time range could be used to aid cosmological inferences, the unprecendented spatial coverage could enable certain novel analyses. Examples of such analyses are (a) Study of isotropy of the universe at low redshifts (b) cosmology and local bulk flows from peculiar velocities of supernovae.

The weak lensing magnification of SNe c) will be a new cosmological probe for LSST. Predictions by Scovacricchi et al. (2017) suggest the LSST SN-galaxy cross-correlation function could be accurately measured on scales up to 30 arc minutes, with an integrated S/N > 100. Such cross-correlation functions, combined with the measurement of the skewness and kurtosis of the SN magnitude distribution (see Macauley et al. 2016), would provide powerful constraints on parameters for the growth of structure (σ_8), independent of cosmic shear and galaxy clustering measurements, as well as providing a unique measurement of the small-scale dark matter power spectrum. Moreover, measurements of the LSST SN magnifications could be used to calibrate multiplicative errors in the LSST cosmic shear measurements (Zhang 2015). Finally, the detection of (d) Strong Lensing of supernovae (which is under investigation within the DC2 as Key Project "Supernova and Strong Lens Light Curves" (CX10)), the (e) detection faint galaxies such as dwarfs using novae and supernovae will provide rich and exciting new avenues for research, while (f) consistency studies based on the relationship of luminosity and angular diameter distances in conjunction with large scale structure/cluster working groups will allow cross-checks of cosmology with the same experiment configurations.

Activity: *Isotropy science white paper. (DC2 RQ)*

Host WG: SN *Started:* 10/01/16 *Originally due:* 06/18
Status: active *Expected:* 06/18
URL :

Objective: The Isotropy White paper will evaluate the requirement of cadence and resources for selected projects. For the projects that are found to generate interest, build forecasting tools to study the cadence and other computational requirements and merge results with SUPERNOVACADENCE. This will be a WG effort across various subgroups.

Activity: *Observing Strategy Recommendations (DC2 RQ)*

Host WG: SN *Started:* 10/01/16 *Originally due:* 12/17
Status: active *Expected:* 12/17
URL :

Objective: Observing strategy recommendations to optimize SN Ia DE constraints, over both the DDF and the WFD survey configurations. Begin interfacing with other probes on observing strategy. Get limits to SN Ia-optimized strategy and provide input to the R&D Activity *"Optimized LSST observing strategy"*. This has resulted in a Task Force across working groups to more fully test a range of observing strategies particularly for the WFD survey

Prerequisites: R&D Activity *"Metrics code to evaluate and optimize observing strategy"*

SN Key Project (DC2): Cosmology from Photometric Supernova Samples DC2 (SN5)

Host WG: SN
Objective: Continued development of SUPERNOVATYPE and methods to estimate cosmological parameters from photometrically classified SN Ia, including objects with host spectroscopic redshifts, host photometric redshifts (Section 8.12), or just SN photometry for classification and redshift. Test SUPERNOVATYPE codes on surveys with host-galaxy redshifts (like 4MOST). Apply SUPERNOVATYPE to LSST-simulated samples (including currently at hand and those produced by the Key Project "SUPERNOVAREALIZER Development" (SN1)) as well as real samples (PanSTARRS, SDSS, DES etc.).

Activity: *Application of* SUPERNOVATYPE *(DC2 VA)*

Host WG: SN *Started:* 10/01/15 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Study of classification system and SUPERNOVATYPE impact on cosmological constraints, by applying SUPERNOVATYPE code to complete light curves of simulated and real data sets (SDSS, SNLS, DES). Compare against spectroscopically confirmed samples and explore effects on cosmological parameter constraints.

Prerequisites: Deliverable *"Classification Code: SUPERNOVATYPE"*

Activity: *Cosmological Constraint Systematics Covariance Matrix (DC2 VA)*

Host WG: SN *Started:* 10/01/16 *Originally due:* 6/18
Status: done *Completed:* 6/18
URL :

Objective: A full simulation of the systematic error budget for the photometric SN pipeline will be explored, and the dependence of the cosmology on the systematic errors like calibration uncertainty and intrinsic scatter uncertainty will be explored at the catalogue level with DC1 data and at the image level with DC2. This involves accumulating a list of expected systematic uncertainties with brief analysis of 'current' and 'optimistic' estimates of their magnitudes for LSST SN analysis. After these systematics are collected, they are propagated into a global covariance, and then the cosmological fits will be run with covariance matrices of single systematic uncertainties to estimate a systematic error budget. Finally, a list of suggestions will be made for the survey strategy to mitigate large uncertainties in error budget.

Activity: *Cosmological Constraint Covariance Matrix (DC2 DP)*

Host WG: SN *Started:* 10/01/17 *Originally due:* 6/17
Status: active *Expected:* 6/17
URL :

Objective: Covariance matrices for cosmological constraints from LSST SN suitable for combination with other LSST probes. This should be compiled each for using SN cosmological information from: (a) photometric sample only; and (b) photometric sample plus spectroscopic training sample. This item is moved down in timeline as it relies on assumptions made about the structure of the final data product and likelihood. Once produced, it will be tested against publicly available real data sets (SDSS, SNLS, DES).
Prerequisites: R&D Activities *"Simulated SN Catalog"* and *"Simulated SN Light Curves"*

Activity: *Application to SN Typing and redshift estimation (DC2 SW)*

Host WG: SN *Started:* 10/01/16 *Originally due:* 06/18
Status: active *Expected:* 12/31/19

URL :

Objective: Application of updated SUPERNOVATYPE (with code release) to typing and redshift estimation of LSST photometric SN, including comparison of different methodologies (analytic vs. template-based) and their application to simulated and real data sets.

Prerequisites: Deliverables *"SN selection function to produce a SN catalog for classification"* and *"SN summaries code"*, R&D Activity *"Application of SUPERNOVATYPE"*.

Activity: *Photometric SN Cosmology Forecast (DC2 VA)*

Host WG: SN *Started:* 10/01/16 *Originally due:* 12/18
Status: active *Expected:* 12/31/19
URL :

Objective: Derive updated cosmological forecasts for LSST photometric SN. We will use optimized results of observing strategy for main survey and deep-drilling fields to generate simulated LSST photometric data sets, and apply photometric cosmology covariance matrix and SUPERNOVATYPE tools to estimate cosmological parameter constraints from simulated LSST photometric SN sample.

Prerequisites: R&D Activities *"Observing Strategy Recommendations"*, *"Cosmological Constraint Covariance Matrix"*, and *"Application to SN Typing and redshift estimation"*

Activity: *Spectroscopic Follow-Up Resources: Selection and Resources Needed (DC2 RQ)*

Host WG: SN *Started:* 10/01/16 *Originally due:* 12/18
Status: active *Expected:* 12/18
URL :

Objective: DESC Note with a list of different spectroscopic resources, with capabilities and comments on potential availability

Activity: *Follow-up plans with specific resources (DC2 RQ)*

Host WG: SN *Started:* 10/01/16 *Originally due:* 12/18
Status: active *Expected:* 12/18
URL :

Objective: DESC Note, upgradable to a paper investigating potential follow-up plans with particular facilitiesactive

Activity: *Spectroscopic Follow-Up Plan: Target Selection and Resources Needed (DC2 RQ)*

Host WG: SN *Started:* 10/01/16 *Originally due:* 12/18
Status: active *Expected:* 12/18
URL :

Objective: Study how spectroscopic resources should be optimally allocated to best inform/train photometric classification and how these needs overlap with a program designed for cosmology with only a spectroscopically classified sample with appropriate help from the broader data science community. Engage wider SN community to develop spectroscopic followup plan to meet these needs.

Prerequisites: R&D Activities *"Observing Strategy Recommendations"*, *"Cosmological Constraint Covariance Matrix"*, and *"Application to SN Typing and redshift estimation"*

SN Key Project (DC3): Improved SN Ia Distances (SN6)
Host WG: SN
Objective: Develop SUPERNOVADISTANCE software. Current SN Ia light-curve fitters and distance estimators are missing astrophysical effects that will be critical for high-precision SN Ia cosmology from the LSST sample, including correlation with host-galaxy properties, velocity-based corrections, light-curve/color error models, dust extinction corrections, lensing corrections, etc. Work is needed to develop updated models.

Activity: SUPERNOVADISTANCE *Code: Light-curve and distance fitters for SN Ia (DC3 SW)*

Host WG: SN *Started:* 10/01/18 *Originally due:* 06/18
Status: active *Expected:* 06/18
URL :

Objective: Software tools (SUPERNOVADISTANCE) that can be run on all SN candidates to provide best distances including systematic uncertainties.

Activity: *SN Distance Estimation Sufficient for LSST Year 1 SN Cosmology (DC3 VA)*

Host WG: SN *Started:* 10/01/18 *Originally due:* 03/19
Status: active *Expected:* 03/19
URL :

Objective: Even the LSST Year 1 SN Ia sample will surpass previous surveys and provide new cosmological constraints; the distance estimation techniques in SUPERNOVADISTANCE need to be sufficiently developed to make good use of this sample, with low-enough systematic uncertainties.

Prerequisites: R&D Activity *"SUPERNOVADISTANCE Code: Light-curve and distance fitters for SN Ia"*

SN Key Project (DC3): Cosmology from Photometric Supernova Samples DC3 (SN7)

Host WG: SN
Objective: Further develop SUPERNOVATYPE and tools for cosmology from photometric sample, in preparation for LSST 1st year data. Of particular importance at this stage is to develop tools that are optimized on a few photometric epochs for early-time classification (to trigger external followup), as opposed to cosmological versions of SUPERNOVATYPE that will have the whole light curve as input.

Activity: *Photometric SN cosmology workflow and chosen method(s) (DC3 RQ)*

Host WG: SN *Started:* 10/01/18 *Originally due:* 12/19
Status: active *Expected:* 12/19
URL :
Objective: Describe chosen method(s) for photometric supernova cosmology and comparing results with spectroscopic only data vs. spectroscopic and photometric, with applications to simulated and real data sets (SDSS, SNLS, DES).
Prerequisites:

8.6 Theory & Joint Probes R&D Projects

In addition to providing the pipeline and infrastructure deliverables described above, TJP is responsible for a number of R&D Activities that will explore the cosmological and astrophysical models that can be probed with LSST. These tasks include:

- Identify novel and interesting models
- Make or identify existing theoretical predictions for both new and baseline models on DESC observables
- Develop code to implement these predictions
- Develop forecasting tools and modify existing forecasting tools for DESC forecasts, including the DESC Science Requirements Document (DESC SRD)

- Perform forecasts on baseline and extended model constraints
- Perform simulations and create mock catalogues with new cosmological and astrophysical effects
- Test DESC capabilities to successfully constrain/mitigate these effects
- Test methods by performing analyses on precursor data sets

TJP Key Project (DC1): Cosmology Forecasting Frameworks (TJP1)
Host WG: TJP
Objective: To develop prediction codes and forecast tools for joint analyses of cosmological probes internal to LSST, and LSST probes in conjunction with external data sets. To explore LSST sensitivity to cosmological models by predicting the constraining power of different measurements within LSST, and LSST in combination with external data sets. To estimate the impact of systematic errors on cosmological science goals and to determine requirements for the control of systematic errors that can serve to guide further work within both the Theory and Joint Probes Working Group as well as the probe-specific working groups. To provide guidance on optimal combinations of cosmological probes and external data sets. These tools will be used to establish goals for future analyses and guide the development of TJPCosmo.

In order to deliver forecasts on short time scales, this project initially draws on pre-existing codes and software may be developed outside computing framework concurrently developed in the Key Product "The Initial Elements of a Software Framework" (CI2). This initial timeframe includes the forecasts used in formulating the DESC Science Requirements Document (DESC SRD). As forecast needs arise in other working groups, these working groups should discuss their modeling requirements and desired timelines with TJP. As the CI code framework matures, forecasting tools will be included in the TJPCosmo pipeline, which will naturally absorb TJPForecast and allow state-of-the-art forecasts that most closely correspond to the eventual DESC analyses.

Activity: *Forecasting Software (DC2 SW)*

Host WG: TJP *Started*: 10/01/16 *Originally due*: 12/31/19
Status: done *Completed*: 08/31/18
URL: https://doi.org/10.5281/zenodo.1409816
Objective: To provide fast and user-friendly Fisher Matrix-based forecasting software and

MCMC-based parameter inference software for studying the constraining power of LSST and the influence of systematic errors on dark energy science. In order to achieve the fast turnaround time required of this Key Project, the TJPFORECAST software will be developed, in part, from pre-existing software outside of the computing framework developed in the Key Project "The Initial Elements of a Software Framework" (CI2). This initial forecasting software will thus be independent of the likelihood pipeline. This deliverable is now considered complete, since CosmoLike and CCL provide all of the required capabilities. DESC has made publicly available the forecasting software used to produce the DESC SRD. TJP will maintain an advisory role in the use of existing tools. As TJPCOSMO becomes functional, it will include forecasting tools which will replace the initial TJPFORECAST codes.
Prerequisites: None

Activity: *Forecasts for Probe-specific Cosmological Constraints (DC1 DP)*

Host WG: TJP *Started:* 01/01/16 *Originally due:* 10/01/19
Status: done *Completed:* 09/18
URL : https://doi.org/10.5281/zenodo.1409816
Objective: To provide high-precision forecasts for cosmological constraints based upon up-to-date knowledge of expected LSST performance and data quality. To utilize updated forecasts to establish specific goals for dark energy constraints from LSST that will be used to assess control of systematics. This includes the DESC Science Requirements Document (DESC SRD) and subsequent updates. To provide an estimate of the impact of theoretical systematic errors (e.g., intrinsic alignments, baryonic effects, galaxy bias, photometric redshift distributions) on core science. To provide a prioritized list of systematic error challenges. This deliverable is considered complete, as a completed version of the DESC SRD is now available.
Prerequisites: R&D Activity *"Forecasting Software"*, coordinate with Deliverables *"Basic LSS likelihood module (LSSCOSMO) contribution to TJPCOSMO"* and *"$p(z)$ for DC1 Galaxies"*.

TJP Key Project (DC2 & DC3): Physics Beyond wCDM with LSST (TJP2)
Host WG: TJP
Objective: To identify novel physics beyond dark energy including, but not limited to, primordial non-gaussianity, neutrino mass, deviations from General Relativity on cosmological scales, and the properties of the dark matter for which consistent predictions for Joint Probes observables exist and for which forthcoming LSST data may provide informative constraints. To develop the theoretical models and preliminary software tools needed to perform a cosmo-

logical analysis aimed at constraining or identifying these novel physics.

Activity: *Models Beyond wCDM Testable with LSST Analyses (DC2 DP)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 07/01/18
Status: active *Expected:* 07/01/18
URL :

Objective: To identify phenomenological models that are well motivated and informative for answering questions of fundamental physics. To determine the models for which simulations and other consistent theoretical predictions for LSST core observables are available or can be developed without significant ambiguity. To identify phenomenological parameterizations of novel physics that capture distinct imprints of the new physics on cosmological observables. To identify parameterizations of novel physics that lend themselves to being constrained using LSST observables.
Prerequisites: R&D Activity *"Forecasting Software"*

Activity: *Cosmological Simulations with Novel Physics (DC3 DP)*

Host WG: TJP *Started:* 10/01/19 *Originally due:* 06/30/20
Status: active *Expected:* 06/30/20
URL :

Objective: To perform and analyze a set of cosmological simulations of structure growth in models with novel physics beyond dark energy, possibly including non-gaussianity, significant neutrino mass, non-GR gravity, and non-CDM dark matter. To provide raw simulation snap shots and summary statistics level data products to the DESC collaboration. To use simulations results to inform the development of analysis techniques that can be used to constrain these novel physics, e.g. by developing power spectrum emulators.

These simulations will be exploratory and focus on the imprints of new physics that have not been previously explored as part of the simulation effort within the CS working group. The TJP and CS groups will coordinate to ensure the simulations are undertaken in the most efficient way. The interplay between new physics and observational systematics will be considered during ComCam phase by producing and analyzing detailed mock catalogs for the most promising theoretical models (if necessary).
Prerequisites: R&D Activities *"Models Beyond wCDM Testable with LSST Analyses"* and *"Develop Prediction Tools"*

Activity: TJPCosmo*: Software to Perform Cosmological Analyses of Novel Physics (DC3 SW)*

Host WG: TJP *Started:* 10/01/18 *Originally due:* 06/30/20
Status: active *Expected:* 06/30/20
URL :

Objective: To develop the methods necessary to measure statistics that are sensitive to novel physics beyond dark energy, e.g. using clustering probes on ultra-large scales, or combinations of lensing and clustering such as E_{G}. Implement software tools to measure necessary statistics and to incorporate these statistics into cosmological analyses of LSST data.
Prerequisites: R&D Activities *"Models Beyond wCDM Testable with LSST Analyses"* and *"Cosmological Simulations with Novel Physics"*

Activity: *Forecasts for LSST Constraints on Novel Physics Beyond wCDM (DC3 DP)*

Host WG: TJP *Started:* 10/01/18 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :

Objective: To present estimates of the reach of LSST data and LSST data in concert with other data sets to constrain novel physics beyond wCDM. To provide guidance for optimizing constraints on novel physics beyond wCDM, in particular by exploiting ultra-large-scale statistics. To estimate the role of systematic errors in constraints on novel physics beyond wCDM and on ultra-large scales. These forecasts will provide guidance to all working groups for further development of constraints on novel physics.
Prerequisites: R&D Activities *"Models Beyond wCDM Testable with LSST Analyses"*, *"Cosmological Simulations with Novel Physics"*, and *"TJPCosmo: Software to Perform Cosmological Analyses of Novel Physics"*

TJP Key Project (DC2 & DC3): Advanced cosmological parameter inference methods (CX7)
Host WG: TJP
Objective: Existing methods for inferring cosmological parameters may not scale well to the dimensionality of the data vectors for LSST, especially when considering the need to marginalize over potentially of order 100 nuisance parameters. The goal of this key project is to consider alternate methodology that may improve the efficiency and stability of the cosmological parameter inference process.

Activity: *Data compression methods (DC2 DP)*

Host WG: TJP *Started:* 03/31/19 *Originally due:* 06/30/20
Status: planned *Expected:* 06/30/20
URL :

Objective: Data compression can ease the cosmological parameter inference process by reducing the dimensionality of the data vectors that go into the inference process. This activity is for investigation of the suitability of various proposed data compression methods for LSST dark energy analysis.

Activity: *Alternatives to Gaussian likelihood inference methods (DC3 DP)*

Host WG: TJP *Started:* 10/01/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: Likelihood analysis methods that go beyond the simple Gaussian likelihood assumption have been proposed in the literature and/or that do not rely on accurate covariance estimation have been proposed in the literature. This activity is for investigation of the suitability of various proposed alternative inference methods for LSST dark energy analysis.

TJP Key Project (DC3): Joint Cosmological Analysis with HSC/DES/KIDS Precursor Data (TJP3)
Host WG: TJP
Objective: To perform a test of the individual and multi-probe modeling framework developed in TJPCosmo under realistic conditions using summary statistics of real, complex data, including real systematics.

Activity: *Joint Probes Analysis of* `DC3 Mock Lightcone` *(DC3 DP)*

Host WG: TJP *Started:* 10/01/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: To test the multi-probe cosmological analysis software framework TJPCosmo being developed for LSST cosmological analyses, including systematic effects modules, by analyzing `DC3 Mock Lightcone` at the summary statistics level.
Prerequisites: R&D Activities *"Forecasting Software"* and *"Preliminary Covariance Matrices for Cosmological Analyses"*, summary statistics computed by individual WGs (WL-

ShearPipe,LSSTwopoint,SupernovaType,CLFinder, CLRedshift, CLMassMod, CLShear, CLSmurfs, CLAbsMass)

Activity: *Cosmological Constraints from LSST Precursor Data Sets (DC3 DP)*

Host WG: TJP *Started:* 10/01/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: To use the multi-probe cosmological analysis software framework TJPCosmo being developed for LSST cosmological analyses to analyze precursor data in order to update cosmological constraints, test the LSST DESC cosmological analysis software in analyzing complex and realistic data, and to identify shortcomings in the LSST DESC cosmological analysis software pipeline. This effort will operate primarily at the level of summary statistics and make use of published summary statistics constructed by the collaborations providing the precursor data.
Prerequisites: R&D Activities *"Forecasting Software"*, *"Preliminary Covariance Matrices for Cosmological Analyses"*, and *"Joint Probes Analysis of `DC3 Mock Lightcone`"*, data reduction and summary statistics computed by individual probe WGs(WLShearPipe, LSSTwopoint,SupernovaType,CLFinder, CLRedshift, CLMassMod, CLShear, CLSmurfs, CLAbsMass)

TJP Key Project (DC3): Synergies with External Data Sets (TJP4)
Host WG: TJP
Objective: To explore synergies between LSST and external data sets including, but not limited to, overlapping spectroscopic (DESI, Euclid, PFS, WFIRST), space-based imaging (Euclid, WFIRST), CMB (advanced ACTPol, CMB S4), radio (SKA), and infrared (WISE) experiments. To determine the degree to which incorporation of external data sets and cross-correlations between LSST and external data sets increases the demands on systematic error control. To assess the degree to which improved photometric redshift performance from the addition of near-infrared bands (Euclid, WFIRST) improves systematic error control and cosmological constraints. To explore using joint analyses of numerous data sets to mitigate parameter degeneracies and open new avenues to constrain physics of the Universe.

Activity: *Calibration of Key Systematics with External Data Sets (DC3 RQ)*

Host WG: TJP *Started:* 10/01/18 *Originally due:* 07/01/20
Status: active *Expected:* 07/01/20
URL :
Objective: Parametrized phenomenological models for astrophysical effects that may limit cosmological analyses exist. The parameters of these models may be calibrated using sufficient data enabling the removal of biases in cosmological parameters that would have been induced by the systematic. TJP aims to determine the key astrophysical systematic effects limiting LSST internal dark energy constraints and identify optimal cross-correlations with external data sets to improve the parameterizations and priors on parameters describing these systematics. In this way, the significant data available from external data sets can be leveraged to enhance greatly the constraining power of LSST data.
Prerequisites: R&D Activity *"Forecasting Software"*

Activity: *Gravity Tests Combining LSST and External Data Sets (DC3 RQ)*

Host WG: TJP *Started:* 10/01/18 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :
Objective: To identify promising combinations of observables for tests of gravity on cosmological scales and determine required analysis tools (to be developed during ComCam phase).
Prerequisites: R&D Activities *"Forecasting Software"* and *"TJPCosmo: Software to Perform Cosmological Analyses of Novel Physics"*

Activity: *Requirements for joint simulations of LSST and external probes (DC3 RQ)*

Host WG: TJP *Started:* 10/01/18 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :
Objective: To forecast possibilities of joint analyses with external data sets to provide novel constraints on gravity on large scales. To provide recommendations for simulations and mock data sets needed to analyze LSST probes in conjunction with external probes.
Prerequisites: R&D Activities *"Calibration of Key Systematics with External Data Sets"* and *"Gravity Tests Combining LSST and External Data Sets"*

8.7 Cosmological Simulations R&D Projects

The Cosmological Simulations WG has a wide range of responsibilities including the production of validated synthetic sky catalogs suitable for a wide variety of tasks such as testing of analysis and data-management pipelines and image simulations, the development of fast and accurate prediction tools for cosmological inference, the evaluation of covariances and the estimation of systematic effects due to baryonic physics predicted from hydrodynamical simulations. Here we describe the R&D projects that have been completed to date and the current and proposed projects that will be necessary in order to achieve the above goals. These projects have been conceived to break down the tasks into a series of manageable steps and to elucidate the key characteristics of the envisaged solutions for each problem. For example, in outlining the projects associated with the production and validation of synthetic catalogs, it is important to recognize that the catalogs are generated by multiple providers and that a unified interface will be necessary to test the catalogs on an equal footing. It is also important to bear in mind that as data sets become larger and validation tests become more complex and more varied, it will be crucial to have an automated procedure for testing and examining the catalogs. The catalogs associated with time-domain observations present additional challenges. The projects associated with DC1 have been completed successfully and have been integrated into the infrastructure and pipelines for DC2. The projects for the development of prediction tools and covariance estimation are proceeding and it is anticipated that the results of these projects will be incorporated into the infrastructure for DC3. Finally, R&D work on hydrodynamical simulations is progressing more slowly and will continue into the DC3 era.

CS Key Project (DC1): Research and define all relevant measurements for cosmological simulations (CS1)
Host WG: CS
Objective: There are many ways of defining the measured parameters associated with cosmological sources. This situation is made worse by the fact that the mapping between simulated sources and measured observables is not always straightforward. For example, galaxy size, as measured in noisy data, depends on the relative contributions from the bulge, disk, and nucleus, the signal-to-noise of the data, and the image quality. This project is to define the required observables for the data challenges and analysis Key Projects, and to provide mappings between input catalog values and observed measurements. These definitions should be common across DESC and the LSST project.

Activity: *Identify relevant galaxy properties (DC1 RQ)*

Host WG: CS *Started:* 10/01/15 *Originally due:* 12/15
Status: done *Completed:* 04/18
URL : https://github.com/LSSTDESC/gcr-catalogs/blob/master/GCRCatalogs/SCHEMA.md

Objective: Define the common observational properties that will need to be controlled and validated (e.g. size, shape, flux, and light profile.) Units, where applicable, should also be determined.
Prerequisites: None.

Activity: *Document measurement definitions (DC1 RQ)*

Host WG: CS *Started:* 10/01/15 *Originally due:* 09/16
Status: done *Completed:* 04/18
URL : https://github.com/LSSTDESC/gcr-catalogs/blob/master/GCRCatalogs/SCHEMA.md

Objective: Create a document containing the definitions of all important galaxy parameters. This document should also contain mappings from noiseless catalog parameters to noisy measured values where reasonable to do so.
Prerequisites: R&D Activity *"Identify relevant galaxy properties"*

CS Key Project (DC1): Produce a system for mapping and ingesting simulation data (CS2)
Host WG: CS
Objective: For any cosmological simulation produced for the data challenges, there will need to be a mechanism for translating simulated properties to the schema expected by CATSIM. This project will provide both the functional piece to ingest data into a public database as well as the mapping between simulated parameters and the expected CATSIM schema.

Activity: *Define the schema required for input catalogs (DC1 RQ)*

Host WG: CS *Started:* 10/01/15 *Originally due:* 12/16
Status: done *Completed:* 04/18
URL : https://github.com/LSSTDESC/gcr-catalogs/blob/master/GCRCatalogs/SCHEMA.md

Objective: There currently exists a schema for all components needed by CATSIM for generating simulated observed catalogs as well as inputs to both PHOSIM and GALSIM. This schema should be reviewed to make sure it is both compact (i.e. to maximize the orthogonality between different parameters) and sufficient for all potential simulated catalogs.
Prerequisites: None

Activity: *Provide mappings from simulated parameters to schema fields (DC1 RQ)*

Host WG: CS *Started:* 10/01/15 *Originally due:* 06/17
Status: done *Completed:* 06/17
URL : https://github.com/LSSTDESC/gcr-catalogs/blob/master/GCRCatalogs/SCHEMA.md

Objective: The cosmological simulations must be turned into catalogs that can be readily converted to the CATSIM schema via a suitable interface. The GCR, described above, will be used as an input to this interface, which will thus provide a conversion between the catalog unified format and the CATSIM schema. The interface will include a combination of prescriptions for predicting galaxy properties, fitting (for example SEDs), and mapping from one observable parameterization to another in order to satisfy the schema of the input catalogs. This should come with a document describing the operations as well as code written against the LSST project APIs for doing the conversions.
Prerequisites: R&D Activity *"Define the schema required for input catalogs"*

CS Key Project (DC1): Validation of input catalogs (CS3)
Host WG: CS
Objective: A key aspect of providing input catalogs is the ability to validate their properties and determine if they are appropriate for the analysis to which they will be applied. Different methods of input catalog generation need to be explored and validated against observational data. Here, the term input catalog is used in a broad sense, from galaxy catalogs, to shear catalogs, to single simulation objects for e.g. strong lensing.

Activity: *A document listing observation sets for validation (DC1 RQ)*

Host WG: CS *Started:* 10/01/15 *Originally due:* 06/17
Status: defunct
URL :
Objective: In particular for the galaxy input catalogs, a set of observations and their biases and selection effects needs to be assembled for use in validating the simulated catalogs.
Prerequisites: None

Activity: *Validation protocol for input catalogs (DC1 VA)*

Host WG: CS *Started:* 10/01/15 *Originally due:* 06/17
Status: done *Completed:* 06/17
URL : https://github.com/LSSTDESC/sims_GCRCatSimInterface
Objective: A standard protocol should be developed to test the catalogs. This protocol will rely on using the GCR to render the native catalog format into the unified format that is used by the validation framework.
Prerequisites: A first catalog, already available.

Activity: *A validation framework for the input catalog distributions. (DC1 VA)*

Host WG: CS *Started:* 10/01/15 *Originally due:* 06/17
Status: done *Completed:* 06/17
URL : https://portal.nersc.gov/project/lsst/descqa/v1/
Objective: A framework for visualizing and comparing simulated and observed distributions of catalog properties will be developed. This framework should be capable of reading a wide variety of catalogs and observational data sets, make comparisons and summaries, and provide a convenient way for framework users to inspect and compare results. Any code written to accomplish this will be version controlled.

Activity: *Documentation and validation of all tools that deliver input catalogs (DC1 SW)*

Host WG: CS *Started:* 10/01/15 *Originally due:* 12/17
Status: active *Expected:* 12/17
URL :
Objective: This task is, in particular, aimed at the non-galaxy catalogs and concerns e.g. shear catalogs, strong lensing images etc.
Prerequisites: None

Activity: *Validate input catalog properties. (DC1 VA)*

Host WG: CS *Started:* 10/01/15 *Originally due:* 12/17
Status: active *Expected:* 12/17
URL :
Objective: Mapping the cosmological simulations to a set of observables is a complicated process. The result of this effort will be a document outlining the validation process and results of the validation to ensure the mapping produces realistic distributions of galaxy properties. A specific example is to check that the assignment of SEDs to the galaxy components produces realistic color distributions as a function of redshift. This will require iterating with the other

working groups to define the appropriate set of validation metrics.
Prerequisites: R&D Activity *"A document listing observation sets for validation"*

CS Key Project (DC1): Validate the input catalogs for `Twinkles` (CS4)
Host WG: CS
Objective: It is likely that the current input catalogs are sufficient to support the Twinkles 1.0 project. Twinkles is made unique from other datasets in that higher than realistic densities of variable sources will be injected into otherwise realistic populations of sources. The mechanism for doing this injection is the responsibility of the CatSim group, but the input variability models will likely come from this group with input from others.

Activity: *Verify that existing input catalogs are sufficient (DC1 RQ)*

Host WG: CS *Started:* 10/01/15 *Originally due:* 09/16
Status: done *Completed:* 09/16
URL :
Objective: There exists a comprehensive model of the universe in the current CatSim database. There are, of course, some limitations (e.g. simple galaxy profiles). This task will document that the Twinkles 1.0 requirements are met.
Prerequisites: Deliverable *"`Twinkles` CS, SS and DM Stack Requirements"*

Activity: *Verify that existing input variability models are sufficient (DC1 RQ)*

Host WG: CS *Started:* 10/01/15 *Originally due:* 09/16
Status: done *Completed:* 09/16
URL :
Objective: Variability in `Twinkles` includes strong lensing and supernovae. Variability models within CatSim can support the complexity required by these sources but will require extending to incorporate a diverse set of light curves. The Twinkles team will provide their own models to augment CatSim but these custom models will need to be supported by the CatSim API.
Prerequisites: Deliverable *"`Twinkles` CS, SS and DM Stack Requirements"*

CS Key Project (DC1): Generating prediction tools across cosmologies (CS6)

Host WG: CS

Objective: In order to carry out a cosmological analysis for any of the major dark energy probes, high-accuracy prediction tools need to be available. These prediction tools are required to cover a wide range of cosmologies and, in order to be useful for likelihood analysis, need to run very fast. The required accuracy can only be obtained from high-resolution simulations. To obtain the required speed, we will build a set of prediction tools based upon a set of high-fidelity simulations. The accuracy of the prediction tools will increase over time by adding more simulations. Working together with the analysis working groups, accuracy requirements – including the length scales these requirements need to be fulfilled – will be determined and the set of prediction tools for the different tasks will be defined. A first set of prediction tools will be developed during DC1, following the outline given in Heitmann et al. (2015). These prediction tools will then be refined over the course of DC1-DC3.

Activity: *Develop Prediction Tools (DC1 SW)*

Host WG: CS *Started:* 10/01/15 *Originally due:* 09/16
Status: active *Expected:* 01/20
URL :

Objective: Deliver tools for accurately predicting the mass function, the matter, halo, and halo–matter power spectrum/correlation functions, the concentration-mass relation, and the galaxy correlation function. Allowable parameter space should include massive neutrinos and a dynamical dark energy equation of state.

Activity: *Assemble requirements for DC2 and DC3 (DC1 RQ)*

Host WG: CS *Started:* 10/01/15 *Originally due:* 12/16
Status: active *Expected:* 12/16
URL :

Objective: Create a document containing the requirements for DC2 and DC3 with regard to prediction tools. The document will include: the list of statistics for which predictions are needed, the required accuracy of the predictions, a specification of the valid range of cosmology model space and scales, and the systematic effects that should be included. As an example, it is already known that the clusters WG will need mass function prediction to better than 5%.

CS Key Project (DC2 & DC3): Simulation for Covariance Studies (CS8)

Host WG: CS

Objective: Generate a large set of large simulations that can be used to verify new approaches developed by the TJP group to tackle covariance estimates. (A major simplifying point is that when testing and verifying models for covariances, one does not need to run simulations at the scale of the target survey.) The task will focus on LSS relevant covariance questions to start with since the simulation requirements are less stringent than for weak lensing and approximate methods can be more easily tested.

Activity: *Simulations for covariance studies (DC2 DP)*

Host WG: CS *Started:* 10/01/17 *Originally due:* 06/17
Status: planned *Expected:* 06/17
URL :
Objective: Set of large simulations and related mock catalogs for large scale structure investigations and covariances.

CS Key Project (DC2 & DC3): Hydrodynamics simulations (CS9)
Host WG: CS

Objective: For several of the probes, baryonic effects are significant since small scales are targeted. For example, intrinsic alignment studies in weak lensing will need information extracted from simulations including baryonic physics. Cluster mass functions are another example. In order to make use of these simulations, very focused studies to test the sensitivity of quantities on simulation parameters will be carried out in conjunction with the working groups. An example from the clusters working group is a study on how resolution and feedback models impact bias in the centering algorithms used to fit mass models.

While hydrodynamic simulations have made great progress in the last few years, more work is needed. Subgrid models need to be improved and validated. This Key Project is intentionally left relatively under-defined as it will necessarily progress as the validation and other interactions with the collaboration evolve.

Another important aspect of this work is that significant computational resources will be required to generate a set of hydrodynamics simulations in volumes relevant for weak lensing, cluster physics, and strong lensing. Specifics about this task will be defined during the coming years and depent on available codes as well as progress in modeling approaches.

Activity: *Document Requirements (DC2 RQ)*

Host WG: CS *Started:* 10/01/16 *Originally due:* 12/17
Status: active *Expected:* 12/17
URL :

Objective: Develop document that outlines the requirements for hydrodynamical simulations for different dark energy probes. This document needs to describe the required accuracy as well as required statistics. It also needs to provide an analysis of different approaches (e.g. resimulation) to determine the needed simulation campaign.

Activity: *Produce Shear Maps (DC2 DP)*

Host WG: CS *Started:* 10/01/17 *Originally due:* 12/17
Status: active *Expected:* 12/17
URL :

Objective: Some working groups, e.g., the Cluster WG, need shear maps associated with the hydrodynamic simulations. The tools exist to do the ray tracing for these shear maps, but once produced, they need to be tested to make sure the resolution of the shear maps is sufficient for the various customers.

Activity: *Validation (DC2 VA)*

Host WG: CS *Started:* 10/01/16 *Originally due:* 12/17
Status: active *Expected:* 12/17
URL :

Objective: First investigations and validation of subgrid models. Build upon work already done both within the collaboration and in the community as a whole.

Activity: *Simulations (DC3 DP)*

Host WG: CS *Started:* 10/01/19 *Originally due:* 12/18
Status: active *Expected:* 12/18
URL :

Objective: Deliver a set of simulations for large volume studies

8.8 Survey Simulations R&D Projects

Research and development work in survey simulation falls into two categories: 1) improved techniques for end-to-end simulation of LSST data (e.g. upgrades or alternatives to existing scheduling or image simulation tools), and 2) techniques to emulate LSST catalog data from cadence, galactic, and extragalctic catalogs directly, without recourse to image simulation.

SSim Key Project (DC2,DC3): Emulation of LSST Catalog Data (SSim8)
Host WG: SSim
Objective: Image simulations are computationally expensive to make; meanwhile, many of the DESC's systematic errors only become apparent when working with the full survey area. In this Key Project we will develop and test approaches to emulating LSST DM catalogs without generating image simulations, using the DC2 simulations as a training dataset.

Activity: *Galaxy Measurement Emulation Methods in DC2 (DC2 SW)*

Host WG: SSim *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :
Objective: The goal of this Activity is to explore several DM catalog emulation methods using the DC2 simulations as a training set, with a goal of investigating the following questions: what types of effects can/cannot be emulated, enabling which science cases? How much training data is needed? What is the best approach for handling the fact that emulation of output quantities is not a 1:1 problem due to effects like blending and masking? Are different approaches needed for emulating catalog-level data for transient vs. static objects? Can we reduce the area of image simulations in DC3 using one of the approaches explored here?
Prerequisites: Deliverable *"DC2 Simulated Images"*

Activity: *Emulation of Lensed Quasar Measurements in DC2 (DC2 SW)*

Host WG: SL *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :
Objective: Investigate the emulation of Source, Object, DIASource and DIAObject properties directly, by "realizing" model lenses and testing their properties against the DM catalogs in DC2. The goals are to be able to emulate large-volume catalog-level lens simulations, to enable catalog-level lens finder training, and to enable a model-based interpretation of the LSST catalogs, for use in lens finding and light curve extraction.
Prerequisites: Deliverable *"DC2 Simulated Images"*

8.9 Computing Infrastructure R&D Projects

The CI R&D Key Projects relate to investigating resource needs (Key Project "Estimate Resource Needs and Recommend the Host for DESC Computing Resources" (CI1)) and the needed functionality of the developer environment (Key Project "Post-DC1 Requirements of the Software and Computing Environment" (CI5)), and determining how to adapt to HPC machines (Key Project "Port DESC Codes to NERSC architecture" (CI9)).

CI Key Project (DC1): Estimate Resource Needs and Recommend the Host for DESC Computing Resources (CI1)
Host WG: CI
Objective: It is crucial to identify the computational resources that DESC members will use to carry out the Key Projects specified in this document and the even broader spectrum of work when data taking begins. There are several issues here: where to run the wide variety of jobs, where to store data, how much CPU time is needed, and how much storage is required. The first two of these issues might be plausibly resolved while the collaboration is continuing to improve its estimates of the last two. A committee representing both the analysis and computing communities will be set up to study the first two issues, producing a written report within the next few months. The estimates for disk space and CPU time will be refined continually over the next three years and recorded in an easily accessible location, where all DESC members can view and update them.

Activity: *Estimate CPU and disk space requirements (DC1 RQ)*

Host WG: CI *Started:* 10/01/15 *Originally due:* 12/15
Status: defunct
URL :
Objective: DESC made an initial estimate in 2014 of CPU and storage needs to provide DOE with an Operations budget estimate. The largest need was to be able to reprocess a year's worth of survey data, which by DM estimates would require some 45k then-cores and 5 PB of storage. There were no real needs identified for the period between 2014 and the Science Survey; the SRM is filling in that void. We need to update the needs model to reflect current understanding. It should include costs involved with replicating the Project/DM catalog tools.

Activity: *Recommend the Computing Resource Host (DC1 RQ)*

Host WG: CI *Started:* 10/01/15 *Originally due:* 1/16
Status: done *Completed:* 1/16
URL : https://github.com/LSSTDESC/ComputingModel/blob/pdfs/ci1.pdf

Objective: There are several options available to DESC which must be evaluated for being the primary host for DESC resources. These include NERSC, a DOE Lab, a non-US institute and clouds. Presumably the totality of DESC resources will come from a combination of these sources. This may include soliciting proposals from candidate sites to help make the comparison.

CI Key Project (DC2): Post-DC1 Requirements of the Software and Computing Environment (CI5)
Host WG: CI
Objective: With the aid of the experience gained in building the Key Product "Targeted Frameworks for Use by the Analysis Working Groups" (CI3), a committee comprised of members of the science and computing WG's will refine the requirements for the software framework.

Activity: *Updated Requirements for a DESC Software Framework (DC2 RQ)*

Host WG: CI *Started:* 10/01/16 *Originally due:* 08/18
Status: active *Expected:* 08/18
URL :

Objective: This document will build upon the initial one produced in the Key Product "The Initial Elements of a Software Framework" (CI2). It will be based on lessons learned from the early pathfinders and address how pipelines are assembled from components and how they interact with input and output data. The resulting report will form the basis for construction of the DESC software framework.
Prerequisites: "Targeted Frameworks for Use by the Analysis Working Groups" (CI3),"The Initial Elements of a Software Framework" (CI2)
Approach: This work will be incremental based on pipelines and workflows developed in DC1. At present, a report is not foreseen.

CI Key Project (DC2): Port DESC Codes to NERSC architecture (CI9)
Host WG: CI

Objective: The HPC environment at NERSC evolves with time. For DC2, the primary target will be the KNL partition. We need to port codes to it to run efficiently.

Activity: *Port codes to NERSC architecture (DC2 SW)*

Host WG: CI *Started:* 10/01/16 *Originally due:* 01/18
Status: active *Expected:* 01/18
URL :

Objective: KNL is the likely target architecture at NERSC for DC2 and DC3.

8.10 Sensor Anomalies R&D Projects

The sensor anomaly working group is committed to developing detailed understanding of the sensor-induced image distortions in order to correct them at the level required for the DESC science. The R&D work vitally relies on the data acquired on CCD test benches devoted to detailed studies of LSST sensors. SAWG closely coordinates its activities with the LSST Project, and the Camera team and SAWG audience have a very large overlap.

The biggest challenge for SAWG is the efficient understanding and parametrization of the so-called Brighter-Fatter effect, namely that bright point sources exhibit bugger images than faint point sources. It is now widely accepted that this effect is caused by forces induced by accumulated charges in the CCD on forthcoming ones, but details of these forces depend on the electrostatic of the sensor which has to be constrained from a variety of measurements and also from available information from the vendors. The precursor surveys (DES and HSC) currently rely on a correction method with poorly known limitations and a considerable residual, 10 % of the effect, may remain after correction. One important need of SAWG, in collaboration with analysis working groups is to estimate how well the effect should be corrected, in particular for shear measurements, and point source photometry. The core goal is obviously to improve over the currently available correction method, through a precise electrostatic modelling of sensors and improved measurements of dynamic distortions

Sensors are also subject to static distortions, which are more straightforward to understand and correct. SAWG is committed to assessing the measurements of these static distortions and the proposed correction methods. In this arena, precursor surveys have developed approaches that could be applied in LSST.

CCDs are sensitive to tiny details of their operation mode, and SAWG participates, in strong coordination with the Project to optimizing the operation conditions of the sensor in order to mitigate or eliminate undesirable sensor behaviors, e.g. deferred charge or gain variations.

SA Key Project (DC2): Brighter-Fatter effect (SA1)
Host WG: SA

Objective: This KP is devoted to the development of quantitative understanding of the Brighter-Fatter (BF) effect and validation of its simulation and correction algorithms. The BF effect, or dependence of the PSF on the source intensity, is one of the most challenging sensor effects to characterize and mitigate. While the qualitative understanding of the effect is quite advanced, we are just starting to develop models which promise to provide quantitative agreement with the data and which support adequate correction algorithms. The plan is to conclude this Key Project prior to the end of DC2 and have a final set of results and publications for the Precision Astronomy with Fully Depleted CCDs (PACCD) 2018 workshop.

Activity: *Detailed electrostatic sensor model (DC2 SW/DP)*

Host WG: SA *Started:* 10/01/16 *Originally due:* 12/17
Status: active *Expected:* 12/17
URL :

Objective: Understand physics of the BF effect, develop the software CCD electrostatic model that is able to predict the main observables to the required precision; compare sensor modeling to the data.

Activity: *Science metrics and accuracy requirements for BF effect (DC2 RQ)*

Host WG: SA *Started:* 10/01/16 *Originally due:* 6/18
Status: active *Expected:* 6/18
URL :

Objective: The importance of BF effect should be evaluated using metrics that would allow comparison to other contributions to the systematic uncertainties. We will engage analysis and simulation groups to determine these metrics. Ultimately, we will determine the required fidelity necessary in the BF effect corrections for stars to be useable for PSF characterization.

Activity: *Publish results on BF (DC2 NA)*

Host WG: SA *Started:* 10/01/16 *Originally due:* 12/01/18
Status: active *Expected:* 12/01/18
URL :

Objective: Publish the key results on the BF effect obtained in SAWG

SA Key Project (DC2): Static sensor effects (SA2)
Host WG: SA

Objective: This KP focuses on the characterization of all known static effects and their verification in simulations and in the corresponding correction algorithms. The static effects due to the built-in electric fields in silicon or actual pixel size variations and some other sensor effects are possible sources of astometric bias and PSF distortion. They are more straightforward to map out and to correct than the BF effect, but at the same time are more pervasive and more dependent on the sensor fabrication process and could be different for the two sensor brands. The static effects include tree-rings, edge roll-off, actual pixel size variations, other static sensor features in UV and IR. The plan is to conclude this Key Project prior to the end of DC2 and have a final set of results and publications for the Precision Astronomy with Fully Depleted CCDs (PACCD) 2018 workshop.

Activity: *Characterization of static displacement bias using multiple techniques (DC2 DP)*

Host WG: SA *Started:* 10/01/17 *Originally due:* 06/18
Status: active *Expected:* 06/18
URL :

Objective: The static sensor effects can be characterized using a variety of techniques, which include the flat fields; fringe and spot projectors; and x-rays.

Activity: *Science metrics and accuracy requirements for static effects (DC2 RQ)*

Host WG: SA *Started:* 10/01/16 *Originally due:* 06/18
Status: active *Expected:* 06/18
URL :

Objective: The importance of sensor effects should be evaluated using metrics, which would allow comparison to other contributions to the systematic uncertainties. This task is similar to the corresponding task in the BF section (Deliverable *"Validation of the BF effect in simulations"*) and again will lead to a requirement on the fidelity on our understanding of sensor static effects.

Activity: *Publish results on the static electrostatic effects (DC2 NA)*

Host WG: SA *Started:* 10/01/16 *Originally due:* 12/01/18
Status: active *Expected:* 12/01/18
URL :

SA Key Project (DC2): Collection and reduction of astronomical data with LSST sensors (SA3)

Host WG: SA

Objective: Astronomical data could provide important complementary information on astrometric and photometric precision achievable with the LSST sensors; these studies also could be used to evaluate the atmospheric contributions to the PSF, exposure time dependence, brighter-fatter and other sensor effects using real astronomical sources. Some of these studies cannot be done in the lab environment. This KP will be aligned and coordinated as much as possible with the Camera Project, Calibration and DM teams, though most of the work will be done within SAWG.

The initial measurements have been performed in 2016 with a single sensor camera (MonoCam) at the US Naval Observatory Flagstaff Station (NOFS). The next step in this direction would be to use the ComCam data for the sensor studies, validation of the signature removal algorithms and propagation of the residual systematics in to the science observables. An example of promising science that could be done with limited observation time would be the studies of weak lensing by massive clusters and groups of galaxies. Full scope of this KP will need to be discussed with interested analysis groups.

Activity: *Astronomical data taken with MonoCam at NOFS. (DC1 DP)*

Host WG: SA *Started:* 01/01/16 *Originally due:* 06/16
Status: active *Expected:* 06/16
URL :

Objective: Prepare a minimal camera configuration and take data.

Activity: *Analysis of MonoCam data (DC1 DP)*

Host WG: SA *Started:* 01/01/16 *Originally due:* 09/17
Status: active *Expected:* 09/17
URL :

Objective: Perform analysis of the reduced MonoCam data, publish the results.

SA Key Project (DC2): Studies of the CCD parameter space (SA4)

Host WG: SA

Objective: CCD operation is controlled by complex sequences of serial and parallel clocks and several other signals/voltages. Their exact timing and amplitude during exposure and readout are critical for the correct functionality, for example to avoid tearing (disruptions in dark images, caused by accumulation of holes along the channel stops in the sensor) and image persistence (appearance of bright objects from an exposure in consequent exposures). They also affect the sensor properties in more subtle ways, causing trade-offs between various characteristics, for example readout time, crosstalk, noise, CTE (charge transfer efficiency) etc.; and the configurations could be optimized for improved performance. Operational parameter space and trade-offs require dedicated studies, which were done in the first pass by the Project but have not been completed. This work will be done in close cooperation with the Project, taking on arising tasks related to the sensor performance and helping it during the raft production period in 2016-2019.

Activity: *Characterization of tearing and persistence (DC2 SW)*

Host WG: SA *Started:* 10/01/16 *Originally due:* 12/18
Status: active *Expected:* 12/18
URL :

Objective: Tearing and persistence are important modes of CCD malfunctioning which we hope to never see in the LSST images. They depend on details of the CCD timing sequence and clock levels.

Activity: *Optimization of noise, crosstalk and power consumption. (DC2 VA)*

Host WG: SA *Started:* 10/01/16 *Originally due:* 12/17
Status: active *Expected:* 12/17
URL :

Objective: These parameters depend on the CCD readout rate and relative timing of control signals. There will be trade-offs to consider: a lower readout rate results in lower crosstalk and noise, but on the other hand the readout time is increased.

Activity: *Optimization of CTE, trapping and other parameters. (DC2 VA)*

Host WG: SA *Started:* 10/01/16 *Originally due:* 12/18
Status: active *Expected:* 12/18
URL :

Objective: These parameters could depend on the CCD timing sequences, on the clock voltages, temperature and other things.

8.11 Photometric Corrections R&D Projects

PCWG activites are at the interface between the Project and the DESC analysis working groups. Our goals are threefold: (1) we seek to build, in collaboration with the analysis groups, quantitative estimates of how the photometric calibration error budget impacts each individual cosmological probe; (2) we derive from such studies DESC-specific calibration requirements; (3) we assess, in collaboration with the Project, the photometric calibration error bugdet that can be expected given the instrument performance, observation strategy (cadence) and calibration strategy.

Photometric calibration uncertainties impact each cosmological probe in a different way. In collaboration with the analysis working groups, PC members carry out lightweight simulations that emulate the cosmological analysis strategies. These simulations are at catalog (flux) level, in order to generate quickly entire survey realizations. They are specifically designed to propagate the calibration uncertainties in an efficient and realistic way.

An example is the work currently carried out in collaboration with the SN working group: a pipeline is being developed, that takes as an input a cadence and a calibration covariance matrix, emulates the crucial steps of a modern SN analysis, notably the training of the empirical light curve model, and derives a figure-of-merit that includes the calibration systematics. We find that realizing the full potential of the SN survey requires a flux calibration at the level of 1-2 mmag. These "DESC-specific" requirements are well beyond the current requirements of the survey.

On the other hand, we find that fitting the SN empirical light curve model together with the Hubble diagram reduces significantly the impact of uncertainties on the telescope passband determination. This is a concrete example of how the final impact of calibration depends on specific details of the cosmology analyses, and will change as the analysis techniques are refined.

Photometric calibration may also impact LSS probes through the photometric redshifts. One such project is to assess the impact of calibration on the determination of galaxy photometric redshifts. In this case, we do not expect flux uncertainties to have a similarly strong impact on the accuracy of photometric redshifts and on the probes that depend on them. On the other hand, unaccounted for non-uniformities of the passband determinations can generate spatially correlated errors on the photometric redshift determinations at specific angular scales.

Finally, PC members carry out specific R&D hardware projects. An example is the development of holographic grisms for the Auxiliary Telescope, in order to improve the spectral resolution of the spectra that are going to be used to constrain the instantaneous atmospheric transmission. Another example is the DICE R&D project, whose goal is to compare directly the HST white dwarf flux scale with the instrumental definition of the optical watt maintained at NIST, at the level of $\sim 0.1\%$ required for the SN Hubble diagram.

PC Key Project (DC1 & DC2): Required Precision (PC1)
Host WG: PC
Objective: This KP concerns the development of a quantitative assessment of the photometric precision (vs. sky position, wavelength, seeing, and time, including time-of-night, season, moon phase, and other astronomical variations) which is required by DESC analyses. Prioritization will be made based on the reduction in sensitivity from joint-probe cosmological analysis (via TJP).

Activity: *Cosmology Bias (DC3 SW)*

Host WG: PC *Started:* 10/01/18 *Originally due:* 12/18
Status: active *Expected:* 12/18
URL :

Objective: New software will be developed to ensure that known photometric biases are incorporated into simulated photometry, including modifications to catalog-level flux estimates. This will enable WGs to understand via simulations the cosmology bias arising from shear errors which are correlated with seeing, photo-z residual bias, and sample selection bias.

PC Key Project (DC1 & DC2): Galactic Extinction (PC2)
Host WG: PC
Objective: This KP concerns the effect of Galactic extinction due to Milky Way dust. Current data show that assumptions of a constant dust law using currently available dust emission maps from far infrared satellite observations are incorrect.

Activity: *Required Precision (DC1 RQ)*

Host WG: PC *Started:* 10/01/15 *Originally due:* 12/18
Status: active *Expected:* 12/18
URL :

Objective: Quantify the precision of reddening corrections required by DESC on various spatial scales to ensure that uncertainties here do not dominate the error budgets of various probes. This will result in a set of DESC requirements, which will be discussed with the Project team.

Activity: *Quantify Galactic Extinction Residuals (DC1 DP)*

Host WG: PC *Started:* 01/01/16 *Originally due:* 12/18
Status: active *Expected:* 12/18
URL :

Objective: Using existing multi-wavelength data, including stellar colors, IR observations, and CMB observations, quantify what is known about the variations and uncertainties in the reddening corrections.

Activity: *Improve Galactic extinction modeling. (DC2 SW)*

Host WG: PC *Started:* 10/01/16 *Originally due:* 12/19
Status: active *Expected:* 12/19
URL :

Objective: With existing and planned multi-wavelength and high precision photometric data, improve Galactic extinction modeling to reduce residuals below our required precision on both small and large scales. The final output will be a set of software and associated data products.

PC Key Project (DC3): Model of the instrument response (PC3)
Host WG: PC

Objective: An accurate model of the instrument response is one of the key ingredients of every calibration process. It is what allows to physically interpret the calibrated natural magnitudes of the objects themselves. Such a model is used every time one has to compare the magnitudes of LSST objects with their prediction from some spectral model. Notable examples are the determination of photometric redshifts and the measurement of SNe Ia luminosity distances.

The LSST instrument response is intrinsically time variable. On the long time scales, one must account for the ageing of the optical components and the mirror re-aluminizations; on the short time scales, there is the variability of the atmosphere. The instrument response may also vary as a function of the focal plane position, depending on the flat-fielding strategy implemented by the level-1 pipeline and on the spatial uniformity of the filters.

To keep the model simple, one generally chooses to *uniformize* the calibrated magnitudes: most of the response variability is corrected for when building the calibrated magnitudes (level-1 and level-2), so that they do not depend, at first order, on time or position on the sky or focal plane (see the Key Project “Survey Uniformity” (PC4)).

It is not possible to map out all the variability, while keeping a natural magnitude system. For example, variations in the shape of the atmospheric extinction results, in some bands in percent-level color-dependent variations. We concentrate here on producing and maintaining the average instrument model. Atmospheric effects are the subject of Key Project “Atmospheric extinction” (PC5). Also, one must note that there is always a certain degree of arbitrariness in choosing what to incorporate in the reported measurements or in the instrument model. The PCWG group will maintain a liaison with the LSST DM team and properly document and track the choices that are made, at the intention of the other DESC working groups.

The PCWG will work in collaboration with the LSST project teams, in particular DM and the Sensor Anomalies Working Group, to produce, document and maintain this model of the instrument response.

This model will include up-to-date determinations of the instrument transmission and QE curves. It will also document, for the DESC community, the calibration procedures implemented in DM.

PC Key Project (DC3): Survey Uniformity (PC4)
Host WG: PC

Objective: The goal of the survey uniformization procedures is to build from all the measurements available, averaged natural magnitudes expressed in a system which is essentially independent of the object position on the sky. This means that the level-1 and level-2 pipelines are able to map out, at first order, the position dependent effects (e.g. seasonal variations of the observing conditions).

Again, the calibration process cannot absorb the entirety of the position dependent effects and present uniform magnitudes at the catalog-level. There remain effects, such as the night-to-night variations of the atmospheric transmission, which cannot be corrected for, while keeping a natural magnitude system. These effects may be sizeable enough in the redder bands. They have to be incorporated into the instrument model used to interpret the calibrated magnitudes provided by the level-2 software.

The goal of this Key Project is to compare the uniformizations methods that are envisioned for LSST, discuss our findings with the LSST Project team who is ultimately responsible for implementing a uniformization strategy in the level-2 pipeline, and help assessing the systematics that affect the uniformized magnitudes.

Activity: *Compare uniformization methods envisioned for LSST (DC2 RQ)*

Host WG: PC *Started:* 10/01/16 *Originally due:* 6/18
Status: active *Expected:* 6/18
URL :

Objective: As of today, three methods are envisioned to ensure that the survey magnitudes are uniform. (1) First, there are the now classical "Übercal-like" methods, pioneered by SDSS (Padmanabhan et al. 2008), and used with success in the PanSTARRS (Schlafly et al. 2012) and DES surveys. These methods rely on the fact that each part of the sky is observed many times, with a carefully chosen dithering strategy which allows one to solve simultaneously for the object magnitudes and exposure (relative) zero-points. These methods have been shown to deliver sub-percent precision on large surveys such as PanSTARSS. (2) Second, there is the so-called "forward calibration method" being tested within the DES survey. This method consists in complementing an Übercal-like strategy with a-priori knowledge of the atmospheric transmission obtained from an auxiliary telescope and/or directly from the magnitudes variations of the observed objects – which span a large color range. (3) Finally, one may use an external catalog to rigidify the system. As an example, the ESA/GAIA satellite (Perryman et al. 2001) will release in 2018 a all-sky catalog, comprising low-resolution spectroscopy (the BP and RP channels, which correspond to the LSST gri- and z-bands) for the billion of objects of magnitude $G < 20$ (Jordi et al. 2010). The uniformity of the GAIA BP/RP channels is expected to better than 0.1%.

Which of this method is best suited for LSST is uncertain at the moment. A safe bet is to develop forecasts for each strategy, make sure that LSST will be able to deliver on its own the required sub-percent uniformity, and use GAIA as a bonus to get to 0.1% or better.

Activity: *Position-dependent systematics (DC2 VA)*

Host WG: PC *Started:* 10/01/16 *Originally due:* 2019
Status: active *Expected:* 2019
URL :

Objective: Help to establish the systematic uncertainty affecting the uniformized magnitudes, given what is implemented in the level-2 pipeline. We envision this as a typical activity during ComCam observations.

PC Key Project (DC3): Atmospheric extinction (PC5)

Host WG: PC

Objective: The goal of this KP is to evaluate how the variability of the atmospheric extinction affects the calibrated magnitudes and their interpretation as physical fluxes.

Activity: *Effective Atmospheric Extinction Models (DC2 SW)*

Host WG: PC *Started:* 10/01/16 *Originally due:* 6/18
Status: active *Expected:* 6/18
URL :

Objective: Provide the DESC with an effective extinction model, incorporating the effect of all major contaminants in a parametrized form. This model will be used as a common base for the forecasts.

Activity: *Atmospheric monitoring with an Auxiliary Telescope Demonstrator (DC2 VA)*

Host WG: PC *Started:* 10/01/16 *Originally due:* 12/2018
Status: active *Expected:* 12/2018
URL :

Objective: The goal is to demonstrate in real scale, that it is possible to extract real time estimates of the atmospheric extinction with the hardware that is envisioned for LSST – i.e. low-res, slitless spectroscopy as what will be obtained from the LSST auxiliary telescope, and possibly some complementary wide-angle IR data.

PC Key Project (DC3): Physical flux calibration (PC6)

Host WG: PC

Objective: The goal of this KP is to explore how the uniformized fluxes can be mapped to physical units, – up to a global gray scale, which is unimportant for cosmology. This process involves using a fundamental metrology standard, which may be either a stellar object or a laboratory standard, such as a photodiode calibrated at NIST.

At the moment, the only proven technique relies on direct – or indirect – observations of DA white dwarfs whose SED can be predicted from stellar atmosphere models (e.g. the CALSPEC library). The technique may be improved using lab metrology standards, and there are plans to switch to a NIST-based flux metrology chain. Considerable work remains to be done, to prove that one may indeed transport the calibration of a photodiode to the sky with a sub-percent accuracy.

It is interesting to note that such a measurement is much easier to perform using small aperture telescopes. As a consequence, it can be done early in the project's life, before the camera is available. If successful, one will be able to build a dense network of NIST-calibrated stars, simply by transporting this calibration to the GAIA catalog. All of this can be done well before LSST first light. For redundancy, it is however essential to equip LSST with the dedicated calibration hardware currently envisioned, and to make sure that the survey can perform its own calibration using this hardware.

The PCWG will work, in collaboration with the LSST team, on demonstrator projects, to transport the NIST flux scale on the sky, and directly compare the NIST- and WD-based calibration. PCWG members will also maintain a connection with the DM team, in order to clarify and document how the calibration solutions will be propagated into the DM products, and updated as more calibration observations become available.

Activity: *Compare NIST and CALSPEC flux scales on O(10) objects (DC2 DP)*

Host WG: PC *Started:* 10/01/17 *Originally due:* 12/2018
Status: active *Expected:* 12/2018
URL :

Objective: One will use smaller, NIST-calibrated telescopes to observe CALSPEC standards. The goal is to compare directly the NIST and CALSPEC flux scale. The targeted accuracy is of the order 0.1%.

Activity: *How DM will propagate and update the photometric calibration solutions (DC3 SW)*

Host WG: PC *Started:* 10/01/18 *Originally due:* 2019
Status: active *Expected:* 2019
URL :

Objective: How the calibration solutions are propagated into the survey products is ultimately under the responsibility of DM. It is however essential for DESC scientists to understand how DM handles the calibration. PCWG has established a link with DM to discuss this, and will document the procedure for the DESC community.

PC Key Project (DC3): Closing the loop with AuxTel (PC7)

Host WG: PC

Objective: The Auxiliary Telescope (AuxTel) commissioned in 2019 is expected to be the first live test-case of a full LSST integrated analysis. This Key Project describes how DESC will interleave efforts with the Project integration of AuxTel in order to characterize the accuracy of the full calibration loop.

The full calibration loop can be separated in three distinct tasks: the measurement of the telescope transmission, the measurement of the atmospheric transmission, and the calibration of a flux standard. For LSST telescope, the first point will be covered by the Colimated Beam Projector and relates to PC3, the second by the AuxTel spectroscopy as described in PC5, and the third by the StarDICE experiment as described in PC6.

While the delivery of the full LSST calibration loop is of the responsibility of DM, our goal here is to have a first experience of the sub-systems integration, and characterize the end-to-end accuracy of the procedure. This is to be considered as a DESC participation to the commissioning effort.

The different activities of this Key Project interact strongly with other Key Projects, since they are in many case their first manifestation integrated into the LSST system.

Activity: *CBP demonstration (DC3 DP)*

Host WG: PC *Started:* 10/01/18 *Originally due:* 2020
Status: active *Expected:* 2020
URL :

Objective: The Colimated Beam Projector is currently being built in Tucson and will be delivered by the Project for the LSST telescope. This activity aims at demonstrating and caracterizing the on-site telescope transmission measurement using the traveling CBP of Harvard, first on the StarDICE telescope, and second on the AuxTel telescope in Chile.

Deliverables: traveling CBP demonstration on StarDICE (end 2019). Traveling CBP transmission measurement of AuxTel 2020.

Activity: *Slitless spectro-photometry and atmospheric transmission measurement (DC3 SW)*

Host WG: PC *Started:* 10/01/18 *Originally due:* 2020
Status: active *Expected:* 2020
URL :

Objective: This activity aims at characterizing the AuxTel spectrograph and the atmospheric transmission measurements delivered. The final delivery of the atmospheric transmission parameter is one of the DM deliverables: the goal here is to get a first experience of the integrated data-taking process. This activity also aims at characterizing the systematics and accuracy of the atmospheric transmission provided by the AuxTel spectrograph, as well as the possible use of ancillary data to increase the constraints on the atmospheric transmission delivered.

Deliverables: Slitless spectro-photometry characterization 2019 Ancillary data direct prediction of atmospheric transmission characterization 2019. Forward modeling of atmospheric transmission on slitless spectra characterization 2020

Activity: *Photometric calibration of AuxTel data (DC3 SW)*

Host WG: PC *Started:* 10/01/18 *Originally due:* 2021
Status: active *Expected:* 2021
URL :

Objective: This activity aims at bringing together the instrument transmission measurement, the atmospheric transmission measurement, the flux standard provided by StarDICE and the photometric extraction of AuxTel imaging data and characterize the photometric calibration provided by DM in this fully integrated system.

Deliverable Forward model photometric calibration of AuxTel imaging data caracterization.

8.12 Photometric Redshifts R&D Projects

After initial tests of baseline code performance in DC1, there are two major challenges faced by the Photometric Redshifts working group: first, estimating the effects of incomplete training data, and the impact of said incompleteness on resultant photometric redshift probability distribution functions. Second, implementing the spatial cross-correlation based calibration procedure. The cross-correlation based calibration will be used to correct systematics in both the single galaxy probability density functions, as well as the tomographic N(z) distributions that will be used by analysis working groups in their cosmology analysis. In addition to these two major challenges, determining a method for storing the resultant photo-z information in a compact manner for bivariate PDFs remains an open issue.

The first step in estimating the impact of training set incompleteness is developing a realistic model for spectroscopic failure modes using simulated data. An important necessary ingredient is a realistic model of emission line strengths. Once an incomplete training set is created, it will be necessary to re-test current generation photo-z codes and examine the failure modes, and then attempt to develop mitigation strategies. The incompleteness model will also provide a potential method to prioritize spectroscopic follow up in future telescope proposals.

Spatial correlation based calibration (aka “clustering-z”) also relies on a calibration set of spectroscopic redshifts. While results with this method have proven extremely promising, they have not been tested in the sub-percent level regime needed by DESC. One of the largest challenges is testing that we can correctly account for the impact of clustering bias evolution in the galaxy population. To test this, we model the calibration sets that we expect to be available in the LSST era (e. g. DESI) in simulations, with known bias evolution, and estimate how well we can recover the distributions. The clustering-z calibration operates on ensemble distributions rather than individual objects. As stated above, we must coordinate with the relevant working groups on how galaxies are assigned to tomographic bins and how different selections affect the resultant N(z) distributions.

Below we describe the Key Projects that are necessary for each of the three data challenges.

PZ Key Project (DC1 & DC2): Photo-z Testbed (PZ1)
Host WG: PZ $p(z)$ and Incompleteness
Objective: We need the capability to create mock data with a realistic, continuous range of SEDs and emulation of spectroscopic incompleteness to enable tests of $p(z)$ accuracy, investigation of methods of dealing with incompleteness, and realistic estimates of photo-z error distributions. The colors (and associated SEDs) output by cosmological simulations codes may not span the expected color space of the working group’s SED models, and may be missing important features, such as strong emission lines. To correct for these potential differences, we will develop PZGalaxyGenerator, a code to take input simulated galaxies and output improved galaxy colors from a continuous distribution of SEDs that form a well controlled testbed dataset (`PZColor`). We will also construct a dataset with modeled incompleteness and presence of some incorrect redshifts in the spectroscopically confirmed dataset (`PZIncomplete`). If simulations are not far enough along, some work may use testbed observations with spectroscopic redshifts.
For DC1, this Key Project should enable a paper testing accuracy of $p(z)$ reconstruction from existing photo-z codes, exploring to what degree existing codes return actual, well-calibrated *probability distributions* for the redshift of an object (as other WGs generally assume they will have). For DC2, it should result in a paper assessing methods of dealing with spectroscopic incompleteness (excision of regions of color space (Masters et al. 2015), etc.). Tests of photometric redshift methods cannot be done with blinded photometric simulations as expected for standard DC2/DC3 datasets.

Activity: *Requirements for spec-z training sets (DC2 RQ)*

Host WG: PZ *Started:* 10/01/16 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: We will generate a catalog of simulated incomplete spectroscopic training sets (`PZIncomplete`) from the mock catalogs and test the impact on the accuracy of the resultant trained photo-z distributions using multiple algorithms. The simulations will be validated with existing spectroscopic testbeds, such as DEEP2 Matthews et al. (2013). The results will be used to set requirements for spectroscopic training sets. We will also examine which spatially varying systematics (depth, Galactic foreground, etc...) can be included in the DC2 simulations to give a more realistic picture of expected photometry in LSST.

PZ Key Project (DC2 & DC3): Tests of photo-z cross-correlation calibration (PZ2)

Host WG: PZ

Objective: Test the calibration plan for photometric redshifts using the cross-correlation method, using simulations with both realistically complicated and non-linear bias evolution and lensing magnification (dataset `PZCrossCorr`), and/or large sets of real data with measured spectroscopic redshifts. If area covered by DC2 simulations are limited, this may need to be done in DC3.

Activity: *Core cross-correlation code development (DC2 SW)*

Host WG: PZ *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Write and test the core code functionality for calibrating photometric redshifts using cross-correlations, PZCALIBRATE, in the presence of nonlinear biasing, color-dependent photo-z errors in dataset `PZCrossCorr`, as well as a method of selecting a mock set of spectroscopic objects that will match expected samples (e. g. DESI). This may entail use of the LSSTWOPOINT code for fast 2 point correlation function calculations.

Activity: *Cross-correlation tests of tomographic bins (DC2 DP)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Sample selection and choice of tomographic photometric redshift bins will have a large impact on certain science cases. We will coordinate with the Weak Lensing working group to examine the distributions that result from tomographic bin selection using PZCALIBRATE and, potentially, to optimize the choice in tomographic bin selection
Prerequisites: Development of `PZCrossCorr` code, R&D Activity *"Core cross-correlation code development"*

Activity: *Explore additional systematics of the cross-correlation calibration (DC3 SW)*

Host WG: PZ *Started:* 10/01/18 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :

Objective: Extend the cross-correlation calibration analysis to include assessment of methods in the presence of spatially varying systematics (e. g. correlated Galactic dust absorption, variations in depth, psf, and weather conditions) as well as lensing magnification.
Prerequisites: Development of `PZCrossCorr` dataset that includes bias evolution, dust, and magnification effects

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PZ Key Project (DC2 & DC3): Photometric redshift infrastructure development (PZ3)

Host WG: PZ

Objective: The photometric redshift working group will need to provide photo-z PDF estimates via PZPDF for the cross-collaboration data challenges DC2 (`DC2`) and DC3 (`DC3 Mock Lightcone`). This will provide the opportunity to work with the cosmological probe working groups to optimize methods for photo-z estimation and database storage.

Activity: *$p(z)$ for simulated catalog objects (DC2 DP)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: The photo-z working group will use PZPDF to generate a catalog of redshift prob-

ability distributions based on the DC2 catalog for working groups to use as input for cosmological measurements.
Prerequisites: Deliverable *"PZ Requirements for Incompleteness"*

Activity: *Improved $p(z, \alpha)$ catalog (DC3 DP)*

Host WG: PZ *Started:* 10/01/19 *Originally due:* 06/30/20
Status: active *Expected:* 06/30/20
URL :

Objective: The photo-z working group will use PZPDF to generate joint probability distributions for redshift and a small selection of the most important secondary parameters (e.g., stellar mass or specific star formation rate/restframe color) that are important for specific working groups to incorporate into their cosmological analyses. We note that some of these distributions may be difficult to calibrate, given a limited amount of training data. Another component of this work that will be addressed is deciding on a compact storage format for the bivariate probability distributions that captures the relevant information and is useable by the working groups.

PZ Key Project (DC2 & DC3): Develop infrastructure for spectroscopic redshift training sets (PZ4)
Host WG: PZ

Objective: It is estimated that highly secure redshifts for $\sim 30,000$ objects spanning the full range of galaxy types and apparent magnitudes, spread over multiple widely separated areas on the sky (to minimize sample variance), are needed in order to train and calibrate photometric redshift algorithms using traditional techniques (see Newman et al. (2015) for details). However, it is very likely that spectroscopic training sets for photo-z training will be incomplete, as some objects do not yield a secure redshift even after many hours of observation on 10m class telescopes. We must estimate why these failures arise, develop strategies to optimally select spec-z samples for targeting, and begin planning to obtain these samples. A list of current and planned samples is described in Newman et al. (2015), which will be updated as new surveys and instruments come online. We will test target selection algorithms on dataset `PZSzTrain`. If a highly complete and highly secure set of spectroscopic redshifts can be obtained for those training sets (at least within subsets of color space), they may also provide a calibration of DESC photo-z's. The spectroscopic training and calibration set needs for LSST overlap those of other current and upcoming surveys (e. g. DES, *WFIRST*, and *Euclid*). Coordinating with these groups will be key to maximizing the telescope resources necessary for obtaining these spectroscopic samples. We will continue to build contacts with leaders of the teams conducting either imaging surveys with overlapping needs or large, deep spectroscopic surveys that can contribute to photo-z training samples. Where helpful, DESC will offer support for and advice on proposals for spectroscopy; we will also work to develop strategies to maximize the synergies for LSST photo-z training of samples which are primarily being obtained for non-DESC purposes (e.g., from the Sumire survey to be conducted with Subaru/PFS).

Activity: *Spec-z sample target selection algorithm (DC2 SW)*

Host WG: PZ *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: We will develop target selection algorithms (PZSPECZSELECTOR) that efficiently sample the underlying galaxy distribution and account for potential failures. We will test the resultant algorithms on real data (e. g. DEEP2) where available.

Activity: *First spec-z sample training redshifts (DC3 DP)*

Host WG: PZ *Started:* 10/01/19 *Originally due:* 07/01/20
Status: active *Expected:* 07/01/20
URL :

Objective: New instruments (including VLT/MOONS and Subaru/PFS) will provide an order of magnitude improvement in the efficiency of obtaining highly-secure redshifts for faint galaxies on a timescale comparable to ComCam. We will work to begin obtaining the necessary spectroscopy with these instruments once available.
Prerequisites: R&D Activities *"Requirements for spec-z training sets"* and *"Spec-z sample target selection algorithm"*

8.13 Cross Working Group R&D Projects

In this section, we describe those Key Projects which involve the close collaboration of multiple working groups. In many cases, many working groups are facing common systematics or the need for pipeline development activities that require diverse computing, technical and analytic expertise not found in a single working group or a single institution.

Each Key Project is assigned a single host working group which is responsible for tracking its progress. Individual activities may belong to other working groups, however.

WL Key Project (DC1, DC2, & DC3): Impacts of Blending (CX1)
Host WG: WL

Objective: Two or more objects are described as "blended" if their images overlap enough that each object's properties cannot be accurately measured independently. The current DM science pipeline addresses the challenges presented by blended objects in three step: (i) object *detection,* which includes identification of above-threshold regions and approximate positions of objects within them; (ii) construction of individual object images or models in which a portion of the flux in each pixel is assigned to each blended object (*deblender*); and (iii) measurement of position, shape, flux, etc., for the deblended object. Detection and deblending can be an iterative process, and deblending and measurement could be done simultaneously.

The current LSST DM deblender is derived from the single-band SDSS deblender and has been used in all Hyper Suprime-Cam releases to date, but is known to be inadequate for LSST depths. A new multi-band deblender, called Scarlet[6], is being integrated in DM and evaluated. The Multi-object Fitting deblender[7] (MOF), first developed within the DES, is also being used for comparisons. Given the challenges in dealing with blended objects, LSST DM welcomes research, development, and testing of new and existing algorithms.

Early goals of the CX1 Key Project include establishing quantitative metrics for the impacts of blending and measuring the baseline performance of existing algorithms to compare to established requirements (e.g., on shear biases). In addition, missing requirements will be established (e.g., impacts of blending on photometric redshifts). An additional goal of this project is to explore and test new algorithms for detection, deblending, and/or measurement of blended objects, including machine-learning approaches that leverage recent advances in "deep learning". In support of these goals, CX1 activities include design and implementation of tools for training and testing algorithms, and the coordination and curation of real data sets (ground and space) and simulations, including injection of simulated objects into real data.

Some studies of performance metrics will involve working with pixel-level simulations or data. For detection algorithms these metrics could describe whether blended objects are accurately recognized as blends, unrecognized as blends, iteratively recognized as blends, shredded into multiple objects, etc. The metrics for deblending and measurement algorithms will include the accuracy of shape measurements and photometry for blended objects.

Impacts of detection failures on higher level quantities, such as photo-z estimates or 2-point correlation functions, could be studied with pixel-level datasets, or with catalog-level

[6]https://github.com/fred3m/scarlet
[7]https://github.com/esheldon/mof

simulations (with no pixel simulation) if accurate surrogates for detection and deblending performance can be identified based on only catalog-level quantities.

In September 2017, the DESC leadership established a Blending Task Force (BTF) with a set of near term goals.[8] The BTF provides a communication channel and the sharing of relevant expertise across the many WGs touched by blending challenges, and between the DESC and LSST DM. Most of the activities described below involve more than one DESC WG and are coordinated within the BTF. A few activities are focused within a particular WG (e.g., CL) but benefit from feedback from the broader community engaged in the BTF. In addition to regular BTF meetings (with recorded presentations[9]), the BTF engages in organizing workshops that involve experts in LSST DM and members of other LSST science collaborations who have relevant expertise.

While this key project is hosted by WL, like the BTF, it provides a home for any DESC WG activity with a focus on the impacts of blending.

Activity: *Software to quantify impacts of blending (DC1 SW)*

Host WG: WL *Started:* 10/01/15 *Originally due:* 09/16
Status: done *Completed:* 09/16
URL : https://weaklensingdeblending.readthedocs.io

Objective: Develop pixel-level simulations (based on GALSIM) and tools that can be used to study the impacts of blending as functions of the number of blended images, amount of image overlap, SNR, relative fluxes, relative galaxy types, and relative colors/SEDs. Allow option for user-specified object parameters and for using input galaxy and star catalogs (e.g., CATSIM). Include the option of comparing images with blending off and blending on for the same set of objects. Provide tools for computing galaxy parameter estimation covariances and pixel-noise bias based on Fisher formalism, for isolated and blended objects. Include capacity to simulate LSST and other surveys (zero points, pixel scale, throughput for each band, etc.), for different exposure times, for validation of forecasts with existing measurements (e.g., CFHT, DES, HSC).

Activity: *Quantify impacts of blending on parameter estimation covariances and pixel-noise (DC1 SW)*

Host WG: WL *Started:* 09/16 *Originally due:* 10/18
Status: active *Expected:* 12/18
URL :

[8] https://confluence.slac.stanford.edu/display/LSSTDESC/Blending+Task+Force
[9] https://confluence.slac.stanford.edu/display/LSSTDESC/BTF+Meetings+and+Resources

Objective: Use simulations and tools developed in R&D Activity "Software tools to quantify impacts of blending" to forecast the increase in galaxy parameter covariances due to blending and subsequent decrease in effective number density of galaxies ($N_{\rm eff}$), for optimal parameter estimation (Fisher forecasts). Quantify impact of stars on $N_{\rm eff}$ for varying stellar density. Compare predicted values of $N_{\rm eff}$ for existing surveys to measured values in the literature. Quantify change in pixel-noise bias for shape measurements with blending off and on, and correponding increase in shear bias, due to increased correlations between parameters.
Prerequisites: R&D Activity *"Software to quantify impacts of blending"*

Activity: *Measure the impact of blends on cluster shear profiles (DC1 DP)*

Host WG: CL *Started:* 01/01/16 *Originally due:* 10/16
Status: done *Completed:* 10/18
URL :

Objective: Generate cluster-scale distorted fields with and without blending from cluster galaxies and with and without contributions from unresolved sources. Measure the bias both in the ideal (perfect photometry) case and using the DC1-era version of the DM deblender. In parallel, use real observations of clusters with both HST and LSST-depth ground-based data to measure blend fractions and effect on measured shears. The products will be an estimate of the level of mass and mass profile bias associated with blends in clusters and requirements for deblending correction for the next-generation DM deblender.
Prerequisites: R&D Activity *"Shear Profile Bias in Simplified Clusters (CLSHEAR)"*

Activity: *Design and implement a blending testing framework (DC2 DP)*

Host WG: WL *Started:* 07/18 *Originally due:* 03/19
Status: active *Expected:* 09/19
URL : https://github.com/LSSTDESC/BlendingToolKit

Objective: Design and implementation of a framework for running existing (DM) and new (Scarlet and MOF) pipeline algorithms on prepared images and truth catalogs, and analysis of the results. The framework will perform detection, deblending and measurement on blended and unblended objects, and produce a common set of documented outputs for measuring performance.

Activity: *Generate custom simulations and perform blending tests (DC2 DP)*

Host WG: WL *Started:* 07/18 *Originally due:* 09/19
Status: active *Expected:* 09/19

URL :

Objective: Custom simulations of simple configurations of a few galaxies with a low-dimensional parameter space are needed for controlled parametric studies, building intuition and debugging. This activity is to prepare an input catalog and simulated LSST images for a standard suite of parameter variations, then establish baselines for the detection, deblending and measurement performance of the current DM algorithms, Scarlet and MOF.
Prerequisites: R&D Activity *"Design and implement a blending testing framework"*

Activity: *Use space data for blending tests (DC2 DP)*

Host WG: WL *Started:* 10/01/17 *Originally due:* 06/19
Status: active *Expected:* 06/19
URL :

Objective: Custom simulations that use space data as "truth" are needed to test algorithms with realistic data. This activity is to define the fields to use, prepare and document catalogs matched to available ground data, especially HSC, then establish baselines for the detection, deblending and measurement performance of the current DM algorithms, Scarlet and MOF. There is a limited amount of space data available in (area $\times$ depth $\times$ bands) so this approach will need to be combined with *"Inject known sources into real data for blending tests"*.

Activity: *Inject known sources into real data for blending tests (DC2 DP)*

Host WG: WL *Started:* 10/01/17 *Originally due:* 09/19
Status: active *Expected:* 03/20
URL :

Objective: Custom simulations with known sources (from simulation or space data) injected into real data (primarily HSC) offer the most detailed characterization of the impacts of blending, and have been successfully used by DES (Balrog) and HSC (SynPipe). The DM team are planning to implement an injection pipeline based on SynPipe. This activity is to document and test a standard configuration of this pipeline, then establish baselines for the detection, deblending and measurement performance of the current DM algorithms, Scarlet and MOF.

Activity: *Explore new algorithms for blended objects (DC2 DP)*

Host WG: WL *Started:* 10/01/17 *Originally due:* 06/20
Status: active *Expected:* 06/20
URL :

Objective: Explore new algorithms for detection, deblending, and/or measurement of blended objects, including machine-learning approaches that leverage recent advances in "deep learning".

Activity: *Shear Deblending in DC2 cluster fields (DC2 DP)*

Host WG: CL *Started:* 10/01/17 *Originally due:* 06/19
Status: active *Expected:* 06/19
URL :

Objective: Measure deblending in the DC2 images corresponding to galaxy clusters using a color-based deblender (such as SCARLET) to test whether color information can help identify blends and correct the measured shear (and photo-z) signal. We will also use the raytraced distortion fields around the clusters to test the dependence of the shear error from the deblending on the linear shear in the DC2 simulations. Results from this study will inform the development of the Clusters DC3 pipeline.
Prerequisites: R&D Activity *"Measure the impact of blends on cluster shear profiles"*

Activity: *Software to calibrate deblender residuals with extra data (DC2 SW)*

Host WG: WL *Started:* 10/01/16 *Originally due:* 09/19
Status: active *Expected:* 09/19
URL :

Objective: Deeper and higher resolution imaging can help to identify blends and calibrate blend shear and photo-z measurements. We will use simulations to quantify the improvements from LSST deep-drilling fields (DDFs) and expected space-based imaging that will overlap with the LSST footprint (e.g., Euclid, WFIRST). These data will provide information about the systematic errors still remaining after the LSST deblender has been applied. This will feed into the systematic error model to be marginalized over.

Simulated catalogs of the DDFs will be created in the R&D Activity *"Catalogs for DC2 Deep Drilling Field simulations "*, with catalog-level forecasts of blending from the R&D Activity *"Results from DC2 DDF catalog simulations"*. This Activity involves simulating images given the input catalogs to test the image-level shear systematics. It is expected that sufficient PSF and detector noise image simulation information for WFIRST will be available in GalSim from ongoing work outside of DESC.
Prerequisites: R&D Activities *"Software to quantify impacts of blending"*, *"Catalogs for DC2 Deep Drilling Field simulations "*, and *"Results from DC2 DDF catalog simulations"*

Activity: *Assessment of impact of blending on Photo-z (DC2 DP)*

Host WG: PZ *Started:* 10/01/17 *Originally due:* 07/01/20
Status: active *Expected:* TBD
URL :

Objective: Write a document describing the effects of blending on photo-z's and a summary of plans for mitigating these effects. This work may be extended to incorporate foreground, atmosphere, filter variations, and detector effects.

Activity: *Requirements on DM deblender from cosmic shear (DC1 RQ)*

Host WG: WL *Started:* 10/01/15 *Originally due:* TBD
Status: active *Expected:* TBD
URL :

Objective: Use the tools developed in R&D Activity *"Software to quantify impacts of blending"* to set requirements[10] on blended source identification, rejection, and processing to achieve shear measurements that can be calibrated effectively. This will focus mostly on the kinds of blends that can be identified in the image (i.e. not unrecognized blends), since these are the objects that the DM deblender will try to correct. The predicted fraction of unrecognized blends for the LSST Gold Sample is 7%. This deliverable should validate or update this prediction based on DM deblender performance.

SL Key Project (DC1): Supernova and Strong Lens Light Curves (CX2)
Host WG: SL Initial Extraction

Objective: We need to extract light curves from pixelated images containing complex objects — blended supernovae and hosts, and blended lens galaxies and AGN images — with high accuracy, including characterization of the correlated photometric uncertainties between the measured component fluxes.

Initially, we need to understand the frame subtraction (image differencing) and forced photometry capabilities of the DRP DM stack, by assembling a simple "monitoring" pipeline out of existing stack components. The primary output of this MONITOR code is a an LSST light curve, ready for further analysis with packages such as SNCOSMO. The single object version of this pipeline would constitute an initial SUPERNOVAMONITOR code; the initial SLMONITOR would involve an extension to capture multiple highly blended point sources. The baseline

[10] Note that while DESC cannot technically set requirements on LSST DM, the DM team have asked for our input on this. These are technically suggested requirements that we will send to them. LSST DM can then choose to accept these requirements or not.

DM light curves produced by these codes *may* enable SN and SL measurements with sufficient accuracy: this Key Project is about testing whether or not they do, or are likely to.

(If higher fidelity light curves are indeed required, we might anticipate developing either or both of SUPERNOVAMONITOR and SLMONITOR in the Key Project "Supernova and Strong Lens Light Curves" (CX10) to include an advanced component that is user-generated software, working on a sequence of postage stamp images and producing a "final photometry" light curve data product that captures the information we need to carry out accurate SN and SL time series modeling.)

The primary scientific goal of the "Twinkles" project is to test our ability to extract light curves that enable measurements of accuracy sufficient for Dark Energy studies, and in doing so, provide an "error model" for the LSST Level 2 light curve data. Such an error model will find applications in a) defining the likelihood function needed in cosmological light curve modeling, and b) generating high-volume catalog level simulations for a range of forecasting investigations (including observing strategy work).

The basic concept is to simulate a tiny patch of sky (10–100 arcmin^2) that is overloaded with unphysically high densities of supernovae and time delay lenses, but has been observed by LSST with realistic survey strategy and observing conditions. This will enable us to investigate the DM algorithms' performance on these key objects, with minimal image processing overhead. A Task Force to design, build and analyze such datasets has been formed, and includes members of the SN, SL, SSim and CI working groups. The group's work is organized at the Twinkles GitHub repository.

For the first-round `Twinkles` simulated dataset we will build initial versions of the emulated DM Level 2 pipeline and DESC monitoring code out of existing LSST DM Stack components, and use them to assess the performance of the stack-deblended and stack-forced photometry, for cosmological light curve extraction.

In fact, this Key Project can be thought of as the parent project for `Twinkles`. A number of other Key Projects are tied to this one, as follows:

"Supernova and Strong Lens Light Curves" (CX2) (hosted by SL, with SN support): develops science analysis, while

"DC1 Survey Simulation Tools" (SSim1): enables the building (and validation) of DC1.

"`Twinkles`" (SL7) (hosted by SL, managed by SS): actually produces `Twinkles`, using the

"Targeted Frameworks for Use by the Analysis Working Groups" (CI3): targeted framework for use by analysis groups.

Activity: SUPERNOVAMONITOR *1.0 (DC1 SW)*

Host WG: SN *Started:* 10/01/15 *Originally due:* 04/01/17
Status: active *Expected:* 04/01/17
URL :

Objective: Assemble prototype DM Stack monitoring (frame subtraction and forced photometry) pipeline, that can operate on the `Twinkles` images. Produce test SN light-curves from the `Twinkles` validation images (a by-product of the Deliverable *"Survey Simulation Tools for DC1"*). Check for photometric issues in images/subtractions, such as the following:

- Does brightness of recovered simulated source match input catalog brightness to within Poisson uncertainty?
- Does (measured flux / reported uncertainty) have mean of 0 and sigma of 1 for blank regions on (a) images; (b) subtracted images.
- Does the (measured flux / reported uncertainty) for a static point source behave correctly?
- Does the (measured flux / reported uncertainty) for a variable point source behave correctly?
- Does the recovery efficiency as a function of background brightness of sky and astrophysical sources make sense?

Answers to these questions will form the basis of the "error model" we seek.
Prerequisites: Deliverables *"`Twinkles` CS, SS and DM Stack Requirements"* and *"Survey Simulation Tools for DC1"*

Activity: SLMONITOR *1.0 (DC1 SW)*

Host WG: SL *Started:* 10/01/15 *Originally due:* 04/01/17
Status: active *Expected:* 04/01/17
URL :

Objective: Extend (or sub-class) SUPERNOVAMONITOR 1.0 into SLMONITOR 1.0, a code to produce multi-object light-curves suitable for time delay lens analysis. Produce test SL light-curves from the early `Twinkles` images (a by-product of the Deliverable *"Survey Simulation Tools for DC1"*).
Prerequisites: Deliverables *"Survey Simulation Tools for DC1"* and *"`Twinkles` CS, SS and DM Stack Requirements"*, R&D Activity *"SUPERNOVAMONITOR 1.0"*

Activity: *`Twinkles` SN and SL Light Curves (DC1 DP)*

Host WG: CI *Started:* 01/01/16 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: Use SUPERNOVAMONITOR 1.0 and SLMONITOR 1.0 to extract light curves from the `Twinkles` production data (Deliverable *"`Twinkles` Images and DM Catalogs"*), and assess their quality. Since this involves executing code, it makes sense for the CI group to oversee this Activity (even if the work is carried out by SL and SN WG members). The pipelines will run in the targeted framework built by the CI group in the Deliverable *"A framework for Twinkles light curve generation"*.
Prerequisites: Deliverables *"`Twinkles` CS, SS and DM Stack Requirements"*, *"`Twinkles` Images and DM Catalogs"*, and *"A framework for Twinkles light curve generation"*, R&D Activities "SUPERNOVAMONITOR *1.0*" and "SLMONITOR *1.0*",

Activity: *`DC2` Light Curve Extraction Requirements (DC2 VA)*

Host WG: SL *Started:* 10/01/16 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: Use the results of the R&D Activity *"`Twinkles` SN and SL Light Curves"* to provide minimum and/or desired requirements for the version 2 SUPERNOVAMONITOR and SLMONITOR software. (These will be run on the `DC2` (DC2) dataset.)
Prerequisites: R&D Activity *"`Twinkles` SN and SL Light Curves"*

TJP Key Project (DC1 & DC2): Impact and Mitigation of Key Astrophysical Systematics (CX5)
Host WG: TJP
Objective: This is a collaborative effort between the TJP and CS working groups, to conduct detailed studies quantifying the impact of key astrophysical effects and systematic errors on cosmological analyses. The aims of this project are to implement and test mitigation strategies proposed to remove, calibrate, and/or mitigate astrophysical systematics on mock data derived from cosmological simulations where available/applicable.
Approach: Because the understanding of requirements and generation of data products are closely related, we treat each primary astrophysical systematic as a hybrid Activity (*"Galaxy*

Intrinsic Alignments"–*"Baryonic Effects"*). The approach for each R&D Activity will follow the same outline:

- Estimate the scales on which the systematic is important (wavenumber and multipole) and estimate the contribution to the dark energy error budget expected prior to mitigation.
- Produce mock galaxy catalogs, as part of a collaboration between TJP and CS, based on N-body simulations (informed by baryonic/galaxy formation simulations and/or analytic prescriptions) that include the systematic, and incorporate these catalogs into the existing R&D Activity *"A validation framework for the input catalog distributions."* validation framework. See the R&D Activities *"Mock catalogs with DC2 level astrophysics"* and *"A validation framework for the input catalog distributions."*.
- Produce summary statistics (e.g., power spectra, correlation functions) from these mock catalogs for use in analysis tests and incorporate these into the validation framework developed in R&D Activity *"A validation framework for the input catalog distributions."*.
- Study existing and forthcoming baryonic/galaxy formation simulations in order to better understand the effect and inform methods to account for it in cosmological analyses.
- Specify, as far as possible, items needed in halo catalogs from current/future N-body simulations in order to build phenomenological models that include the effect (e.g., halo shapes, halo formation histories, and any other relevant halo properties).

Activity: *Galaxy Intrinsic Alignments (DC1/2 RQ/DP)*

Host WG: TJP *Started:* 10/01/16 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: To develop an understanding of the impact of intrinsic alignments as an astrophysical systematic in cosmological analyses of LSST-like lensing data and to develop mock data sets that include intrinsic alignments.

Activity: *Galaxy Bias and Assembly Bias (DC1/2 RQ/DP)*

Host WG: TJP *Started:* 10/01/16 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: To develop an understanding of the potential role of galaxy bias and assembly bias as astrophysical systematics in single- and combined-probe cosmological analyses of LSST-like data, including determining the minimum scale available in WL and LSS analyses and potential impact on meeting requirements in DESC SRD. To develop mock data sets that include assembly bias.

Activity: *Baryonic Effects (DC1/2 RQ/DP)*

Host WG: TJP *Started:* 10/01/16 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: To develop an understanding of baryonic effects on cosmological analyses of forthcoming data and to implement and test strategies to mitigate these systematic effects. Note that this Activity does not include the production of new, DESC-specific, mock catalogs with baryonic effects. It does include the production of relevant summary statistics.

TJP Key Project (DC2): Cosmological Analysis Pipeline for LSST Precursor Data Sets (CX6)

Host WG: TJP
Objective: Develop a software analysis pipeline that can be used to perform cosmological analyses using summary statistics as available from LSST precursor data sets such as DES/HSC/KiDS.

Activity: *Mock catalogs with DC2 level astrophysics (DC2 DP)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: Incorporate mock catalogs with astrophysical systematics (and the associated summary statistics) into the validation framework (R&D Activity *"A validation framework for the input catalog distributions."*) to be used for testing analysis pipeline and mitigation. The R&D for the this Activity as well as the production of the mocks has been merged into R&D Activities *"Galaxy Intrinsic Alignments"*, *"Galaxy Bias and Assembly Bias"*, and *"Baryonic Effects"*.

TJP Key Project (DC2): Improved Multi-Probe Data Covariances (CX7)
Host WG: TJP

Objective: Producing reliable confidence regions on cosmological parameters from LSST data requires sophisticated covariance modeling capabilities for complex combinations of LSST data and combinations of LSST data with external data. This Key Project aims to initiate this modeling and develop preliminary covariance matrices for the optimal data combinations identified through the DC1 Key Projects.

Activity: *Preliminary Covariance Matrices for Cosmological Analyses (DC2 DP)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 07/01/18
Status: active *Expected:* 07/01/18
URL :

Objective: To develop approximate, computationally-efficient methods for generating covariances for individual (R&D Activities *"Robust modelling of galaxy clustering"*, *"Modeling photo-z systematics"*, and *"Cosmological constraints"*) and joint probes cosmological analyses and to provide preliminary covariances for the data combinations identified during DC1.
Prerequisites: R&D Activity *"Forecasting Software"*

Activity: *Requirements for Tolerable Uncertainty in Covariances (DC2 RQ)*

Host WG: TJP *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: To estimate the precision with which the covariance matrices of the observables for the cosmological probes must be determined in order to render uncertainty in the covariance matrix a negligible contribution to the error budget on dark energy parameters. This information will be provided to each working group and will inform cosmological simulations performed by the CosmoSims (CS) working group to produce covariances for ComCam, LSST year1, and subsequent data analyses.
Approach: Quantify (analytically and/or through simulated likelihood analyses) the influence of uncertainty in the covariance model on the inferred posterior distributions of cosmological parameters for both individual and joint probes analyses. Establish requirements on covariance precision for both single-probe and LSST-internal joint probes analyses.
Prerequisites: R&D Activities *"Forecasting Software"* and ,*"Preliminary Covariance Matrices for Cosmological Analyses"*

Activity: *Studies of Alternative Parameter Inference Methods (DC2 DP)*

Host WG: TJP *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: To explore efficacy and efficiency of parameter inference methods including Approximate Bayesian Computation (ABC) that may alleviate precision requirements on covariances for individual probes and for simple joint probes analyses. To provide necessary guidance and prescriptions (for example parameter choices) for implementing parameter inference methods and applying them in cosmological analyses such as those that will be undertaken with LSST data.
Prerequisites: None

TJP Key Project (DC2): Blinding Strategy for Cosmology Analysis (CX8)
Host WG: TJP
Objective: Cosmological constraints from LSST will physically be complementary to CMB results. Performing a blinded cosmology analysis will prevent experiments' biases (e.g., confirmation bias) and upkeep this complementarity.

Activity: *Blind analysis strategies for individual probe analyses (DC2 SW)*

Host WG: TJP *Started:* 10/01/16 *Originally due:* 03/31/19
Status: active *Expected:* 03/31/19
URL :

Objective: Blind analysis strategies for different types of measurements and analyses are commonly used in other fields, such as medicine, and particle physics. These can serve as a starting point to identify viable blind analysis strategies for individual probe analyses.
Approach: Determine applicability of existing blinding strategies for individual probe analyses. Implement suitable blinding procedure in individual probe likelihood pipelines.

Activity: *Blind analysis strategies for joint probe analyses. (DC2 SW)*

Host WG: TJP *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Prerequisites: CX-DC2-Blind-SW1
Objective: Synthesize blind analysis strategies for individual probes into a blind analysis concept for joint probes. One of the outstanding questions is how we can test the consistency

of individual probes before unblinding the joint analysis. Lessons from Stage-III experiments should also be considered.

SL Key Project (DC2): Supernova and Strong Lens Light Curves (CX10)
Host WG: SL   Final Photometry

Objective: We anticipate the need to build on the Key Project "Supernova and Strong Lens Light Curves" (CX2) and investigate, and potentially start building, software to carry out either enhanced frame subtraction and forced photometry, or potentially alternatively "scene modeling," for our supernova and strong lens light curve final photometry.

Investigation of the scene modeling approach could usefully proceed by developing the SUPERNOVAMONITOR and SLMONITOR code started in the Key Project "Supernova and Strong Lens Light Curves" (CX2) to include an advanced "SuperFit" component. Tuning the image differencing approach would proceed in similar fashion. Both algorithms would be implemented as user-generated software, built against the LSST DM Stack user-generated "MULTIFIT" API. This extended code would take as input a sequence of postage stamp images (as opposed to the DRP catalog measurements used in the Key Project "Supernova and Strong Lens Light Curves" (CX2)), and produce light curves with accurate fluxes, and some measure of their covariance. The product of this KP will be a paper describing our code, and its performance compared to the forced photometry baseline.

As in the Key Project "Supernova and Strong Lens Light Curves" (CX2), this Key Project can be thought of as the parent project for the time domain parts of DC2. A number of other Key Projects and Products are tied to this one, as follows:

"Supernova and Strong Lens Light Curves" (CX10) (hosted by SL, with SN support): develops science analysis, while the Key Product

"DC2 Survey Simulation Tools" (SSim3): enables the building (and validation) of DC2 (including the time domain parts), using the

"Enhanced Twinkles Framework to Handle DC2-level Requirements" (CI7): enhanced targeted framework key Product for use by analysis groups.

Activity: SUPERNOVAMONITOR *2.0 (DC2 SW)*

Host WG: SN   *Started:* 10/01/16   *Originally due:* 12/31/19
Status: active   *Expected:* 12/31/19

URL :

Objective: Develop enhanced frame subtraction and/or scene modeling algorithms and build prototype user-generated code, that can operate on the old `Twinkles` images and produce simple lightcurves. Test on the old `Twinkles` images (Deliverable *"`Twinkles` Images and DM Catalogs"*). Assess promise of each approach. Make sure photometric tests defined for initial forced photometry (R&D Activity "SUPERNOVAMONITOR *1.0"*) are also passed for final photometry, but now also including full information about photometric covariance (in time, across filters, and across spatial position on the sky).
Prerequisites: Deliverables *"`DC2` Time Domain Requirements"* and *"`Twinkles` Images and DM Catalogs"*, R&D Activity "SUPERNOVAMONITOR *1.0"*

Activity: SLMONITOR *2.0 (DC2 SW)*

Host WG: SL *Started:* 10/01/16 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Extend (or sub-class) SUPERNOVAMONITOR 2.0 into SLMONITOR 2.0, a user-generated code to produce multi-object lightcurves suitable for time delay lens analysis. Test on the old `Twinkles` images. Assess promise of each algorithm.
Prerequisites: Deliverables *"`DC2` Time Domain Requirements"* and *"`Twinkles` Images and DM Catalogs"*, R&D Activity "SUPERNOVAMONITOR *2.0"*

Activity: *`DC2` SN and SL Light Curves (DC2 DP)*

Host WG: CI *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Use SUPERNOVAMONITOR 2.0 and SLMONITOR 2.0 to extract light curves from the `DC2` images (Deliverable *"`DC2` Simulated Images"*), and assess their quality. Since this involves executing code, it makes sense for the CI group to oversee this Activity (even if the work is carried out by SL and SN WG members). The pipelines will run in the enhanced framework built by the CI group as Key Product "Enhanced Twinkles Framework to Handle DC2-level Requirements" (CI7).
Prerequisites: Deliverables *"`DC2` Time Domain Requirements"*, *"`DC2` Simulated Images"*, *"Pipeline for Extracting DC2 Light Curves"*, and *"Workflow to execute the Light Curve Extraction pipeline."*, R&D Activities "SUPERNOVAMONITOR *2.0"* and "SLMONITOR *2.0"*

Activity: *Light Curve Extraction Performance (DC3 VA)*

Host WG: SL *Started:* 10/01/18 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Use the results of R&D Activity *"DC2 SN and SL Light Curves"* to provide minimum and/or desired requirements for future versions of SUPERNOVAMONITOR and SLMONITOR software, which will be run on the DC3 or ComCam datasets (see e.g. R&D Activity *"Time Delays"*).
Prerequisites: R&D Activity *"DC2 SN and SL Light Curves"*

LSS Key Project (DC1, DC2 & DC3): Systematics Caused by the LSST Observing Strategy (CX11)
Host WG: LSS
Objective: The goal is to test the influence of favored dither pattern and cadence choices on systematics in survey depth, magnitude zeropoints and PSF generated by field overlaps, chip gaps, the brighter-fatter feature (BFF), and static sensor effects (edge roll-off, tree rings, midline shifts, pixel size variations). The systematics to be addressed are artificial galaxy clustering (LSS) and artificial WL shear and cosmic magnification signals. This program will require PHOSIM simulations, followed by DM analysis, of many visits to multiple contiguous pointings in a single filter, which we need for DC1. During DC2, we will apply the results to a final round of full-sky OPSIM +MAF optimization of dither pattern and timescale, and DC3 will utilize updated PHOSIM +DM capabilities and six-filter simulations to verify that the adopted observing strategy produces sub-dominant dark energy systematics.

Activity: *Dither patterns for DC1 Phosim Deep simulations (DC1 RQ)*

Host WG: LSS *Started:* 10/01/15 *Originally due:* 12/15
Status: active *Expected:* 12/15
URL :

Objective: The goal is to utilize the high fidelity of PHOSIM to illuminate systematics imprinted by the detailed detector response that cannot be revealed by Operations Simulations, even with HEALPIX sampling in the Metrics Analysis Framework (MAF), and to create templates for these systematics. A sky area of several contiguous FOVs is needed to reveal print-through of residual systematics in survey depth, magnitude zeropoints and PSF on scales crucial for LSS-BAO, WL shear, and cosmic magnification.

Approach: Translational dithers will be performed at each visit following a random pattern of amplitude as large as the FOV radius; random rotational dithers will be performed at each filter change. A comparison simulation without dithering will be created to assess the impact of dithering.
Prerequisites: Overlaps with R&D Activity *"WL studies of LSST observing strategy"*

Activity: *WL studies of LSST observing strategy (DC1 DP)*

Host WG: WL *Started:* 01/01/16 *Originally due:* 03/16
Status: active *Expected:* 03/16
URL :

Objective: Determine how different choices with respect to the LSST observing strategy affect WL systematics. Mostly, this will probably involve choices of the dithering pattern of multiple observations of each point on the sky, as well as the distribution of camera rotation angles. The time between successive observations of a particular galaxy may also be relevant. ComCam observations are covered in the LSST Operations proposal due mid-2016, so rapid feedback to the Project is needed on that timescale.
Prerequisites: R&D Activity *"Software for determining WL requirements"*

Activity: *Results from `DC1 Phosim Deep` (DC1 DP)*

Host WG: LSS *Started:* 01/01/16 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: Analyze `DC1 Phosim Deep` simulations with and without translational and rotational dither patterns, with results reduced and calibrated through the DM pipeline. The undithered simulation will maximize most systematics, which can then be turned into templates and looked for at residual levels in the dithered simulations. The latter will also be searched for any new systematics introduced by dithering.
Prerequisites: Deliverable *"`DC1 Phosim Deep` Images"*

Activity: *WL Recommendations for LSST observing strategy (DC2 DP)*

Host WG: WL *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Make recommendations for how to optimize the strategy for best WL results, including the distribution of camera rotation angles, translational dither pattern, and time between

successive observations. For DC2, simulations are desired that cover 50 FOVs with 100 visits each, including all known sensor systematics, with pseudo-random x / y / θ dithers with multiple θ dither weight functions and with DM first order corrections for sensor effects performed; it is believed that `DC2` fits these requirements (including the realistic atmosphere PSF variations from the simulated WFD cadence).
Approach: We will also investigate survey strategy choices using OpSim to determine how various choices affect WL shear systematics, and produce a WL optimization function that the telescope scheduler can include in its overall optimization for determining where to observe next. *Note: This should not require much if any image generation. Rather, systematics can be inferred from specific realized catalogs generated by* OpSim*; the goal is to find survey strategy choices that minimize the resulting overall systematics on things like* ξ_+.
Prerequisites: R&D Activity *"WL studies of LSST observing strategy"*, Deliverable *"`DC2` Simulated Images"*

Activity: *Optimized LSST observing strategy (DC2 DP)*

Host WG: LSS *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: We will perform full-sky OpSim +MAF analysis to test improved patterns of translational and rotational dithers on various timescales, motivated by DC1 results that identify which aspects are most crucial for systematics on ∼FOV scales. Variations in survey depth can be modelled via a window function, but uncertainties in this window function must also be estimated and propagated into cosmological parameter estimation. We seek an optimal observing strategy, including filter cadences and scheduler optimization using weather and DQA inputs and site monitoring requirements. The time-coverage cadence has significant potential impact on the power of SN and SL cosmology; this impact will be explored as part of this key project.
Prerequisites: R&D Activities *"Results from `DC1 Phosim Deep`"*, *"WL Recommendations for LSST observing strategy"*, *"Metrics code to evaluate and optimize observing strategy"*, and *"`TDC2` SL-Optimized LSST Main Survey Observing Strategy"*

Activity: *Results from `DC3 Mock ComCam Survey` (DC3 DP)*

Host WG: WL *Started:* 10/01/19 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :

Objective: We will analyze the `DC3 Mock ComCam Survey` simulations to measure sys-

tematics for WL and other dark energy probes introduced by the proposed LSST observing strategy. Six-filter ($ugrizy$) simulations enable photo-z systematics to be included. We will measure the cosmological impact of the residual shear systematics for WL probes only, and with combining all probes – especially BAO.
Prerequisites: Deliverable *"*`DC3 Mock ComCam Survey` *Simulated Images"*

Activity: *Results from* `DC3 Mock Lightcone` *(DC3 DP)*

Host WG: LSS *Started:* 10/01/19 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21

URL :

Objective: Analyze `DC3 Mock Lightcone` simulations to search for unintended systematics and to measure level of residual systematics for all dark energy probes introduced by proposed LSST observing strategy. Six-filter ($ugrizy$) simulations enable photo-z systematics to be included. Verify that this observing strategy produces sub-dominant systematics in WL galaxy-mass correlation, galaxy bias, BAO signal, and window function uncertainties.
Approach: Merge all WG needs to make a joint DESC recommendation of an optimal observing strategy to the LSST Project.
Prerequisites: Deliverable *"*`DC2` *Simulated Images"*, R&D Activity *"Improved $p(z,\alpha)$ catalog"*

LSS Key Project (DC2 & DC3): Using Deep Drilling Fields to Reduce Dark Energy Systematics (CX12)
Host WG: LSS
Objective: The LSST Deep Drilling Fields (DDFs) will allow us to use significantly deeper (multi-wavelength) photometry to mitigate and estimate systematic errors in photometric redshifts, small-scale galaxy clustering, deblending, and WL shear. The improved photo-z obtained in DDFs can be used as "true" redshift distributions for each photo-z bin. This is a long-term effort, and we can test the approach with the DCs, where the truth is known, to determine how accurately the deeper, multi-wavelength photometry lets us measure redshifts, LSS, and WL. The LSS and WL DDF White Papers disagree on strategy for measuring photo-z distributions, with the latter arguing that hundreds of square degrees of DDFs are needed; we can investigate the area and depth requirements starting with a catalog-level Data Challenge in DC2.

Activity: *Catalogs for DC2 Deep Drilling Field simulations (DC2 DP)*

Host WG: LSS *Started:* 10/01/17 *Originally due:* 06/30/18
Status: active *Expected:* 06/30/18
URL :

Objective: Work with Simulations WG to create catalogs including realistic LSS and WL shear along with realistic photo-z errors including catastrophic errors. Errors will be realized for different combinations of depth and area achievable in fixed observing time, including 40 DDFs going ~ 1 mag deeper than the main Wide Fast Deep (WFD) survey and 10 DDFs going ~ 2 mags deeper than WFD, as well as for WFD depth across the same areas.
Approach: Coordinate with SN to implement reasonable cadences for each simulated DDF strategy.
Prerequisites: Deliverable *"$p(z)$ for DC1 Galaxies"*

Activity: *Precursor Data with appropriate Wide-Deep overlap (DC3 RQ)*

Host WG: LSS *Started:* 10/01/18 *Originally due:* 09/30/19
Status: active *Expected:* 09/30/19
URL :

Objective: Determine which precursor dataset offers the best imitation of the difference in depth between LSST WFD and DDFs and request DM pipeline reprocessing of these data (at both their wide and deep depths over their deep area).
Prerequisites: None

Activity: *Results from DC2 DDF catalog simulations (DC2 DP)*

Host WG: LSS *Started:* 10/01/17 *Originally due:* 12/31/19
Status: active *Expected:* 12/31/19
URL :

Objective: Measure the improvement in photometric redshifts, small-scale galaxy clustering, deblending, and WL shear estimation obtained in the DDFs for the various DDF survey designs versus WFD depth. This will inform our ability to use DDFs as empirical determinations of systematic errors in the eventual WFD analysis, including the key step of estimating the uncertainties created by treating DDF results as "truth". A salient example is the ability to understand the effects of cosmic magnification in the WFD survey by studying the dimmer galaxy population in DDFs that will enter WFD only after magnification.
Approach: Determine an optimal DDF observing strategy based upon these catalog simulation

results.
Prerequisites: R&D Activity *"Catalogs for DC2 Deep Drilling Field simulations "*

Activity: *Recommended DDF observing strategy for static sources (DC3 DP)*

Host WG: LSS *Started:* 10/01/19 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :

Objective: Use the DM-reprocessed Wide+Deep precursor data to inform our ability to use LSST DDFs as empirical determinations of systematic errors in the eventual WFD analysis. Combine these results with those from DC2 DDF simulations to recommend an observing strategy for the DDFs.
Prerequisites: R&D Activities *"Precursor Data with appropriate Wide-Deep overlap"* and *"Results from DC2 DDF catalog simulations"*

Activity: *Recommended DDF observing strategy (DC3 DP)*

Host WG: SN *Started:* 10/01/19 *Originally due:* 09/30/21
Status: planned *Expected:* 09/30/21
URL :

Objective: Combine the constraints from static DDF requirements with those of a DDF observing strategy optimized for SN cosmology. The DDF cadence must provide high-quality SN light curves to form the baseline SN sample for cosmological analysis.
Approach: Make use of SN observing strategy metrics developed in the R&D Activity *"Metrics code to evaluate and optimize observing strategy"*, along with SUPERNOVATYPE and SUPERNOVADISTANCE codes to optimize DDF observing strategy.
Prerequisites: R&D Activity *"Recommended DDF observing strategy for static sources"*

Activity: *On the use of the DDFs to reduce cluster mass systematics (DC3 DP)*

Host WG: CL *Started:* 10/01/19 *Originally due:* 09/30/21
Status: active *Expected:* 09/30/21
URL :

Objective: Cluster weak lensing systematics could benefit tremendously by observing existing value-added cluster fields to full survey depth early in the survey (e.g. Y1). The astronomical community has already spent significant resources, including deep multi-band HST imaging and multi-object spectroscopy campaigns, into comprehensive observations of a few clusters,

in particular the Frontier Fields and CLASH clusters. These data are invaluable for determining shear and photo-z systematics in cluster fields, but need to be coupled with actual LSST observations for precision calibration. While these fields would not be DDFs over the 10-year survey, they would have to be treated e.g. during Y1. In addition, randomly chosen DDFs would include a handful of clusters; these will be used to test the shear and photo-z calibration near the completion limit in cluster fields.
Approach: Evaluate the benefits of obtaining 10-year-depth imaging of selected value-added cluster fields within Y1. Identify the best targets, especially given multi-wavelength data available that can inform cluster-specific systematics. Work with SN and SL groups to determine best cadence choice, and with LSST Galaxies WG on additional science cases. Recommend a strategy for implementation into the survey observing strategy.
Prerequisites: R&D Activities *"Gather spec-z training sets for cluster lensing (CLSMURFS)"*, *"Cluster masses from shear maps, with baryons (CLMASSMOD)"*, *"ARCLETS2.0: shear normalization for realistic clusters"*, *"Cluster shears from DC2 simulations"*, and *"Measure the impact of blends on cluster shear profiles"*; realistic SEDs of faint cluster galaxies

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OSTF Key Project (DC2): Response to the LSST Call for White Papers on Observing Strategy (OSTF)
Host WG: OSTF
Objective: The DESC has an opportunity to provide input on the LSST Observing Strategy through White Papers due November 30, 2018. This activity (led by the Observing Strategy Task Force or OSTF) covers all primary probe working groups and photometric redshifts. While several probes have projects or deliverables on investigating survey strategy, the work in this key project is specifically to provide the inputs to the White Papers and the associated cross-probe journal article. Further work on single-probe observing strategy recommendations will be hosted by those working groups.

While the SN group are formally hosts of this key project, the Observing Strategy Task Force will oversee the activities and the Mgmt team will handle the shepherding of the white papers and journal articles through DESC publication review.

Activity: *Observing strategy recommendations for supernova cosmology (DC2 DP)*

Host WG: SN *Started:* 09/30/17 *Originally due:* 11/18
Status: active *Expected:* 11/18
URL : https://github.com/LSSTDESC/ObsStrat

Objective: The goal of this activity is to provide input to the Observing Strategy Task Force on the important factors for observing strategy to enable supernova cosmology, including metrics and high-level conclusions.
Prerequisites: Key Project “Observing Strategy Optimization for SN Ia Cosmology” (SN3)

Activity: *Observing strategy recommendations for strong lensing cosmology (DC2 DP)*

Host WG: SL *Started:* 09/30/17 *Originally due:* 11/18
Status: active *Expected:* 11/18
URL : https://github.com/LSSTDESC/ObsStrat
Objective: The goal of this activity is to provide input to the Observing Strategy Task Force on the important factors for observing strategy to enable strong lensing cosmology, including metrics and high-level conclusions.
Prerequisites:

Activity: *Observing strategy recommendations for weak lensing systematics (DC2 DP)*

Host WG: WL *Started:* 09/30/17 *Originally due:* 11/18
Status: active *Expected:* 11/18
URL : https://github.com/LSSTDESC/ObsStrat
Objective: The goal of this activity is to provide input to the Observing Strategy Task Force on the important factors for observing strategy for weak lensing systematics, including metrics and high-level conclusions.
Prerequisites: Deliverable *“WL studies of LSST observing strategy”*

Activity: *Observing strategy recommendations for large-scale structure (DC2 DP)*

Host WG: LSS *Started:* 09/30/17 *Originally due:* 11/18
Status: active *Expected:* 11/18
URL : https://github.com/LSSTDESC/ObsStrat
Objective: The goal of this activity is to provide input to the Observing Strategy Task Force on the important factors for observing strategy to enable large-scale structure systematics and cosmology, including metrics and high-level conclusions.
Prerequisites: Key Project “Systematics Caused by the LSST Observing Strategy” (CX11)

Activity: *Observing strategy recommendations for photometric redshifts to enable dark energy probes (DC2 DP*

Host WG: PZ *Started:* 09/30/17 *Originally due:* 11/18
Status: active *Expected:* 11/18

URL : https://github.com/LSSTDESC/ObsStrat

Objective: The goal of this activity is to provide input to the Observing Strategy Task Force on the important factors for observing strategy to enable robust photometric redshifts for dark energy probes, including metrics and high-level conclusions.
Prerequisites:

Activity: *Observing strategy recommendations for all static science cases (DC2 DP)*

Host WG: WL *Started:* 09/30/17 *Originally due:* 11/18
Status: active *Expected:* 11/18
URL : https://github.com/LSSTDESC/ObsStrat

Objective: The goal of this activity is to provide input to the Observing Strategy Task Force on the important factors for observing strategy to enable the static science cases collectively (WL, LSS, and CL), including metrics and high-level conclusions.
Prerequisites: Deliverable *"Observing strategy recommendations for weak lensing systematics"*, Deliverable *"Observing strategy recommendations for large-scale structure"*, Deliverable *"Observing strategy recommendations for photometric redshifts to enable dark energy probes"*

Activity: *Synthesized WFD observing strategy recommendations across all probes (DC2 DP)*

Host WG: OSTF *Started:* 09/30/17 *Originally due:* 11/18
Status: active *Expected:* 11/18
URL : https://github.com/LSSTDESC/ObsStrat

Objective: This activity will result in a synthesized set of observing strategy recommendations for the WFD survey, to go into a single cross-probe WFD White Paper. The OSTF leads will be assisted by Mgmt to ensure engagement with and review by representatives from all dark energy probes.
Prerequisites: Deliverable *"Observing strategy recommendations for supernova cosmology"*, Deliverable *"Observing strategy recommendations for strong lensing cosmology"*, Deliverable *"Observing strategy recommendations for weak lensing systematics"*, Deliverable *"Observing strategy recommendations for large-scale structure"*, Deliverable *"Observing strategy recommendations for photometric redshifts to enable dark energy probes"*, Deliverable *"Observing strategy recommendations for all static science cases"*

Activity: *Synthesized DDF observing strategy recommendations across all probes (DC2 DP)*

Host WG: OSTF *Started:* 09/30/17 *Originally due:* 11/18
Status: active *Expected:* 11/18
URL : https://github.com/LSSTDESC/ObsStrat

Objective: This deliverable is for a synthesized set of observing strategy recommendations for the Deep Drilling Fields, to go into a single cross-probe DDF White Paper. The OSTF leads will be assisted by Mgmt to ensure engagement with and review by representatives from all dark energy probes.

Prerequisites: Deliverable *"Observing strategy recommendations for supernova cosmology"*, Deliverable *"Observing strategy recommendations for weak lensing systematics"*

Activity: *Metrics summary for observing strategy across all probes (DC2 DP)*

Host WG: OSTF *Started:* 09/30/17 *Originally due:* 06/19
Status: active *Expected:* 06/19
URL : https://github.com/LSSTDESC/ObsStrat

Objective: This deliverable is to provide a clear summary of all metrics that contributed to the WFD and DDF White Papers, so that the LSST Project and broader scientific community can understand the origin of our observing strategy recommendations. Ideally some metrics will be integrated into MAF concurrently with the production of this metrics summary.

Prerequisites: Deliverable *"Observing strategy recommendations for supernova cosmology"*, Deliverable *"Observing strategy recommendations for strong lensing cosmology"*, Deliverable *"Observing strategy recommendations for weak lensing systematics"*, Deliverable *"Observing strategy recommendations for large-scale structure"*, Deliverable *"Observing strategy recommendations for photometric redshifts to enable dark energy probes"*, Deliverable *"Observing strategy recommendations for all static science cases"*

SN Key Project (DC2 & DC3): Photometric Calibration Systematics (CX13)

Host WG: SN

Objective: Systematic uncertainties from photometric calibration can limit precise and accurate measurements of dark energy parameters. Photometric Calibration and Systematics are also the topic of a dedicated working group, Section 4.5.

These issues are of particular importance for SN cosmology; photometric calibration uncertainties presently dominate the error budget in using type Ia supernovae to map the history of cosmic expansion the nature of the dark energy, and so improvements in photometric calibration translate directly into better physics constraints. We factor the SN photometry calibration challenge into four components: 1) the instrumental response function, including sensor anomalies and optical transmission, 2) attenuation, scattering, and differential refraction in the Earth's atmosphere, 3) extinction due to Milky Way dust, and 4) host galaxy and circumstellar extinction at the location of the supernova. Since the photon spectral energy distribution of type Ia supernovae differ significantly from those of stars and galaxies, this will require using template spectra to perform forward modeling through the effective photometric passband of each LSST image. Note that the calibrations for items 1) and 2) are largely the responsibility of the LSST DM, although we anticipate that substantial DESC participation will be crucial. Item 3) will be a DESC responsibility and is described in Section 4.5 and related sections. Item 4) is specific to the Section 3.5 WG.

There are also overlaps with Weak Lensing shear calibration (Section 8.1), Sensor Anomalies working group Key Project "Collection and reduction of astronomical data with LSST sensors" (SA3), Photometric Redshifts (Section 8.12), and others.

Activity: *Corrections for instrumental response function effects (DC2 SW)*

Host WG: SN *Started:* 10/01/16 *Originally due:* 12/17
Status: active *Expected:* 12/17
URL :
Objective: The PC and SN groups will work in partnership with the project team and the SAWG to establish methods to suppress instrumental artifacts for SN photometry. These methods will be incorporated into the SUPERNOVAMONITOR 2.0 pipeline (R&D Activity *"SUPERNOVAMONITOR 2.0"*), and the full instrumental bandpasses will be used in the SUPERNOVADISTANCE tasks (Key Project "Improved SN Ia Distances" (SN6)).
Prerequisites: R&D Activity *"Simulated SN Light Curves"*

Activity: *Corrections for atmospheric effects (DC2 SW)*

Host WG: SN *Started:* 10/01/16 *Originally due:* 12/17
Status: active *Expected:* 12/17
URL :
Objective: The variable attenuation due to aerosols, ozone and water vapor will be incorporated into simulations, to validate the photometric calibration methods being employed by LSST. These methods will be incorporated into the SUPERNOVAMONITOR 2.0 pipeline (R&D Activity *"SUPERNOVAMONITOR 2.0"*), and the full atmospheric uncertainties in the bandpasses will be used in the SUPERNOVADISTANCE tasks (Key Project "Improved SN Ia Distances" (SN6)).

Activity: *Corrections for Galactic extinction (DC2 SW)*

Host WG: SN *Started:* 10/01/16 *Originally due:* 12/17
Status: active *Expected:* 12/17
URL :

Objective: The SN group will participate in the DESC efforts to correct for Galactic extinction (Key Project "Galactic Extinction" (PC2)). These methods will be incorporated into the SUPERNOVADISTANCE tasks (Key Project "Improved SN Ia Distances" (SN6)).
Prerequisites: R&D Activities *"Required Precision"* and *"Quantify Galactic Extinction Residuals"*

Activity: *Instrumental Effects in SN Distances (DC3 SW)*

Host WG: SN *Started:* 10/01/18 *Originally due:* 03/18
Status: active *Expected:* 03/18
URL :

Objective: The SN group will lead efforts to apply knowledge of the LSST photometric system (passbands, zeropoints) into models for SN Ia light curves and resulting distances. This overlaps with the SUPERNOVADISTANCE tasks (Key Project "Improved SN Ia Distances" (SN6).)
Prerequisites: PCRP0

Activity: *observing strategy and data analysis plan (DC3 DP)*

Host WG: SN *Started:* 10/01/18 *Originally due:* 03/19
Status: active *Expected:* 03/19
URL :

Objective: The SN group will suggest observations (passbands, cadence) of supernovae with the commissioning camera (and associated calibration instruments) that can be used to validate the LSST photometric calibration plan for SNe and enable templates to be built that will facilitate SN identification in the early stages of the survey.

SN Key Project (DC2 & DC3): DESC Broker Investigation and Development (CX14)

Host WG: SN
Objective: The objective is to test and evaluate broker infrastructure and software from external organizations like community broker developers (eg. ANTARES, AMPEL, ALERCE,

LASAIR) and TOM developers (eg. LCO) as useful for SN and SL science, and to develop supplementary code and data products focused on supernova and strong lensing science. This research and development project extends over multiple research working groups (SN and SL), and also includes some pipeline components that are relevant to the SNWG (e.g. Deliverable *"Broker Sandbox"* and Deliverable *"Early SN classification system"*), as well the SLWG (Deliverable *"SLWG Broker Requirements"*).

Activities for this key project include developing DESC software to test broker efficiencies for early classification from the DM pipeline, classification at the image level, testing classification probabilities and DESC broker requirements.

Activity: *DESC Broker Requirements for SN (DC2 RQ)*

Host WG: SN *Started:* 10/01/16 *Originally due:* 12/19
Status: active *Expected:* 12/19

URL : https://confluence.slac.stanford.edu/display/LSSTDESC/DESC+Broker+services

Objective: This deliverable will be to assess the broker requirements for the SN group mostly based on their science needs, and documentation from LSST.

Activity: *DESC Broker Requirements for SL (DC2 RQ)*

Host WG: SL *Started:* 10/01/16 *Originally due:* 12/19
Status: active *Expected:* 12/19

URL : https://confluence.slac.stanford.edu/display/LSSTDESC/DESC+Broker+services

Objective: This deliverable will be to assess the broker requirements for the SL group mostly based on their science needs, and documentation from LSST.

Activity: *DESC Broker Tests (DC2 VA)*

Host WG: SN *Started:* 10/01/16 *Originally due:* 03/20
Status: active *Expected:* 03/20

URL :

Objective: This deliverable will be to test implementations of existing brokers with the computational resources of the DESC, to develop a plan for using existing resources or requesting additional resources. This will use implementations developed by Broker Developers with precursor data sets, and simulated data.

9 R&D Projects and Activities

Analogous to the list of pipeline, infrastructure and dataset deliverables in Section 7, we now list all the research and development Key Projects and Activities defined in the previous section, to provide a high level overview. NB: in the text below, deliverables and activities are presented with color coding determined by their status, as follows: "done" deliverables have hyperlinks like this, "defunct" deliverables have hyperlinks like this, "active" deliverables have hyperlinks like this, "planned" deliverables have hyperlinks like this, and "anticipated" deliverables have hyperlinks like this.

Research and Development

WL Key Project (DC1 & DC2): Requirements on shear estimation (WL1)

Activity: *Software for determining WL requirements* 03/16

Activity: *Create WL DC1 simulated datasets* 09/16

Activity: *Assess the DM stack shape measurement code* 12/31/19

WL Key Project (DC2): Images to shear catalog I (WL3)

Activity: *Develop shear catalog selection criteria* 12/31/19

Activity: *Generate and test shear catalog* 12/31/19

WL Key Project (DC2): Shear and LSS catalogs to science statistics I (WL4)

Activity: *Software for blinding the shear catalogs* 07/01/18

Activity: *Models of residual observational systematic effects on observables* 07/01/18

Activity: *Cosmological constraints* 12/31/19

WL Key Project (DC3): Images to shear catalogs II (WL5)

Activity: *Generate and test shear catalog* 09/30/21

WL Key Project (DC3): Shear catalogs to science statistics II (WL6)

Activity: *Develop pipeline for non-Gaussian statistics* 09/30/21

Activity: *Extended shear correlation functions* 09/30/21

Activity: *Cosmological constraints* 09/30/21

WL Key Project (DC3): Simulations for shear catalog testing (WL7)

LSS Key Project (DC1, DC2 and DC3): Determine LSS samples (LSS1)

Activity: *Code for generating LSS catalogs* 12/31/19

Activity: *Sampling and data compression* 07/01/20

Activity: *Field test of sampling methods* 07/01/20

LSS Key Project (DC1, DC2 and DC3): Code for Measuring Power and Cross-power Spectra (LSS2)

Activity: *Fast mock creation code* 02/18

Activity: *Field test of two-point software* 07/01/20

Activity: *Higher-order correlations* 06/30/20

LSS Key Project (DC1, DC2 & DC3): Cosmological constraints from LSS (LSS3)

Activity: *Robust modelling of galaxy clustering* 12/31/19

Activity: *Modeling photo-z systematics* 12/31/19

Activity: *Field test of likelihood module* 07/01/20

CL Key Project (DC1 & DC2): Cluster finding and catalog characterization (CL1)

Activity: *Projection Effects and miscentering of redMaPPer clusters (*CLOptCat*)* 03/18

Activity: *Cluster redshifts (*CLRedshift*)* 12/31/19

CL Key Project (DC1): Absolute mass calibration I (CL2)

Activity: *Cluster masses from weak-lensing shear maps (*CLMassMod*)* 03/17

Activity: *Calibrating reduced shear with properly distorted galaxies (*CLShear*)* 07/01/18

Activity: *Shear Profile Bias in Simplified Clusters (*CLShear*)* 12/16

Activity: *Gather spec-z training sets for cluster lensing (*CLSmurfs*)* 06/17

Activity: *Cluster masses from existing cluster observations (*CLAbsMass*)* 06/17

CL Key Project (DC3): Absolute mass calibration II (CL3)

Activity: *Cluster masses from shear maps, with baryons (*CLMassMod*)* 12/18

Activity: *ARCLETS2.0: shear normalization for realistic clusters* 12/18

Activity: *Cluster shears from DC2 simulations* 12/31/19

Activity: *Evaluate $p(z)$ algorithms with spec-zs in cluster fields* (CLSMURFS) 12/31/19

Activity: *Apply refined results to existing cluster lensing data* (CLABSMASS) 12/31/19

CL Key Project (DC2): Relative Mass Calibration (CL4)

Activity: *Low-scatter mass proxies from Chandra data* 12/16

Activity: *Low-scatter mass proxies from XMM-Newton data* 12/17

Activity: *Measuring the mass-observable scaling relations* 12/18

Activity: *A strategy for precise relative mass calibration with LSST* 12/18

CL Key Project (DC3): Analysis of `DC3 Mock Lightcone` and pre-cursor data. CC/SV observing plan (CL6)

Activity: *ComCam and/or SV cluster target list* 03/19

Activity: *Analyze `DC3 Mock Lightcone`* 09/30/21

Activity: *Cluster-finding on Project re-processed survey data* 03/20

Activity: *Cluster masses from Project re-processed survey data* 03/20

Activity: *Masses from other data processed with the DM stack* 03/20

SL Key Project (DC2): SLTIMER Development: The Second Time Delay Challenge (SL1)

Activity: `TDC2` *Requirements* 09/30/17

Activity: `TDC2` *Multi-filter Light Curve Generator* 10/01/17

Activity: `TDC2` *Simulated Light Curves* 06/30/18

Activity: `TDC2` *Community-inferred Time Delays* 12/31/19

Activity: `TDC2` *SL-Optimized LSST Main Survey Observing Strategy* 12/31/19

SL Key Project (DC2): SLFINDER: Target Selection in the `DC2` Survey (SL2)

Activity: `DC2` *(DC2)* SLFINDER *Target Catalogs and Assessment* 12/31/19

Activity: `DC2` SLFINDER *Candidate Samples and Assessment* 12/31/19

SL Key Project (DC2): Lens Environment Characterization (SL3)

Activity: *SL Environment Characterization and Assessment* 12/31/19

SL Key Project (DC3): SLTIMER Development: The Third Time Delay Challenge (SL4)

Activity: `TDC3` *Requirements* 09/30/19

Activity: `TDC3` *Simulated Light Curves* 06/30/20

Activity: *TDC3 Community-inferred Time Delays* 09/30/21

SL Key Project (DC3): End-to-end test (SL5)

Activity: *Lens Candidates* 09/30/21

Activity: *Time Delays* 09/30/21

Activity: *Lens Environments* 09/30/21

Activity: *SL Cosmological Parameter Accuracy* 09/30/21

SN Key Project (DC1): SUPERNOVAREALIZER Development (SN1)

Activity: *Improved SN template library* 06/16

Activity: *Simulated SN Catalog* 09/16

Activity: *Simulated SN Light Curves* 12/16

SN Key Project (DC2): Observing Strategy Optimization for SN Ia Cosmology (SN3)

Activity: *Metrics code to evaluate and optimize observing strategy* 09/17

SN Key Project (DC2): Novel Science with the Wide Field Survey (SN4)

Activity: *Isotropy science white paper.* 06/18

Activity: *Observing Strategy Recommendations* 12/17

SN Key Project (DC2): Cosmology from Photometric Supernova Samples DC2 (SN5)

Activity: *Application of* SUPERNOVATYPE 12/31/19

Activity: *Cosmological Constraint Systematics Covariance Matrix* 6/18

Activity: *Cosmological Constraint Covariance Matrix* 6/17

Activity: *Application to SN Typing and redshift estimation* 06/18

Activity: *Photometric SN Cosmology Forecast* 12/18

Activity: *Spectroscopic Follow-Up Resources: Selection and Resources Needed* 12/18

Activity: *Follow-up plans with specific resources* 12/18

Activity: *Spectroscopic Follow-Up Plan: Target Selection and Resources Needed* 12/18

SN Key Project (DC3): Improved SN Ia Distances (SN6)

Activity: SUPERNOVADISTANCE *Code: Light-curve and distance fitters for SN Ia* 06/18

Activity: *SN Distance Estimation Sufficient for LSST Year 1 SN Cosmology* 03/19

SN Key Project (DC3): Cosmology from Photometric Supernova Samples DC3 (SN7)

Activity: *Photometric SN cosmology workflow and chosen method(s)* 12/19

TJP Key Project (DC1): Cosmology Forecasting Frameworks (TJP1)

Activity: *Forecasting Software* 12/31/19

Activity: *Forecasts for Probe-specific Cosmological Constraints* 10/01/19

TJP Key Project (DC2 & DC3): Physics Beyond wCDM with LSST (TJP2)

Activity: *Models Beyond wCDM Testable with LSST Analyses* 07/01/18

Activity: *Cosmological Simulations with Novel Physics* 06/30/20

Activity: TJPCosmo*: Software to Perform Cosmological Analyses of Novel Physics* 06/30/20

Activity: *Forecasts for LSST Constraints on Novel Physics Beyond wCDM* 09/30/21

TJP Key Project (DC2 & DC3): Advanced cosmological parameter inference methods (CX7)

Activity: *Data compression methods* 06/30/20

Activity: *Alternatives to Gaussian likelihood inference methods* 09/30/21

TJP Key Project (DC3): Joint Cosmological Analysis with HSC/DES/KIDS Precursor Data (TJP3)

Activity: *Joint Probes Analysis of* `DC3 Mock Lightcone` 09/30/21

Activity: *Cosmological Constraints from LSST Precursor Data Sets* 09/30/21

TJP Key Project (DC3): Synergies with External Data Sets (TJP4)

Activity: *Calibration of Key Systematics with External Data Sets* 07/01/20

Activity: *Gravity Tests Combining LSST and External Data Sets* 09/30/21

Activity: *Requirements for joint simulations of LSST and external probes* 09/30/21

CS Key Project (DC1): Research and define all relevant measurements for cosmological simulations (CS1)

Activity: *Identify relevant galaxy properties* 12/15

Activity: *Document measurement definitions* 09/16

CS Key Project (DC1): Produce a system for mapping and ingesting simulation data (CS2)

Activity: *Define the schema required for input catalogs* 12/16

Activity: *Provide mappings from simulated parameters to schema fields* 06/17

CS Key Project (DC1): Validation of input catalogs (CS3)

Activity: *A document listing observation sets for validation* 06/17

Activity: *Validation protocol for input catalogs* 06/17

Activity: *A validation framework for the input catalog distributions.* 06/17

Activity: *Documentation and validation of all tools that deliver input catalogs* 12/17

Activity: *Validate input catalog properties.* 12/17

CS Key Project (DC1): Validate the input catalogs for `Twinkles` (CS4)

Activity: *Verify that existing input catalogs are sufficient* 09/16

Activity: *Verify that existing input variability models are sufficient* 09/16

CS Key Project (DC1): Generating prediction tools across cosmologies (CS6)

Activity: *Develop Prediction Tools* 09/16

Activity: *Assemble requirements for DC2 and DC3* 12/16

CS Key Project (DC2 & DC3): Simulation for Covariance Studies (CS8)

Activity: *Simulations for covariance studies* 06/17

CS Key Project (DC2 & DC3): Hydrodynamics simulations (CS9)

Activity: *Document Requirements* 12/17

Activity: *Produce Shear Maps* 12/17

Activity: *Validation* 12/17

Activity: *Simulations* 12/18

SSim Key Project (DC2,DC3): Emulation of LSST Catalog Data (SSim8)

Activity: *Galaxy Measurement Emulation Methods in DC2* 12/31/19

Activity: *Emulation of Lensed Quasar Measurements in DC2* 12/31/19

CI Key Project (DC1): Estimate Resource Needs and Recommend the Host for DESC Computing Resources (CI1)

Activity: *Estimate CPU and disk space requirements* 12/15

Activity: *Recommend the Computing Resource Host* 1/16

CI Key Project (DC2): Post-DC1 Requirements of the Software and Computing Environment (CI5)

Activity: *Updated Requirements for a DESC Software Framework* 08/18

CI Key Project (DC2): Port DESC Codes to NERSC architecture (CI9)

Activity: *Port codes to NERSC architecture* 01/18

SA Key Project (DC2): Brighter-Fatter effect (SA1)

Activity: *Detailed electrostatic sensor model* 12/17

Activity: *Science metrics and accuracy requirements for BF effect* 6/18

Activity: *Publish results on BF* 12/01/18

SA Key Project (DC2): Static sensor effects (SA2)

Activity: *Characterization of static displacement bias using multiple techniques* 06/18

Activity: *Science metrics and accuracy requirements for static effects* 06/18

Activity: *Publish results on the static electrostatic effects* 12/01/18

SA Key Project (DC2): Collection and reduction of astronomical data with LSST sensors (SA3)

Activity: *Astronomical data taken with MonoCam at NOFS.* 06/16

Activity: *Analysis of MonoCam data* 09/17

SA Key Project (DC2): Studies of the CCD parameter space (SA4)

Activity: *Characterization of tearing and persistence* 12/18

Activity: *Optimization of noise, crosstalk and power consumption.* 12/17

Activity: *Optimization of CTE, trapping and other parameters.* 12/18

PC Key Project (DC1 & DC2): Required Precision (PC1)

Activity: *Cosmology Bias* 12/18

PC Key Project (DC1 & DC2): Galactic Extinction (PC2)

Activity: *Required Precision* 12/18

Activity: *Quantify Galactic Extinction Residuals* 12/18

Activity: *Improve Galactic extinction modeling.* 12/19

PC Key Project (DC3): Model of the instrument response (PC3)

PC Key Project (DC3): Survey Uniformity (PC4)

Activity: *Compare uniformization methods envisioned for LSST* 6/18

Activity: *Position-dependent systematics* 2019

PC Key Project (DC3): Atmospheric extinction (PC5)

Activity: *Effective Atmospheric Extinction Models* 6/18

Activity: *Atmospheric monitoring with an Auxiliary Telescope Demonstrator* 12/2018

PC Key Project (DC3): Physical flux calibration (PC6)

Activity: *Compare NIST and CALSPEC flux scales on O(10) objects* 12/2018

Activity: *How DM will propagate and update the photometric calibration solutions* 2019

PC Key Project (DC3): Closing the loop with AuxTel (PC7)

Activity: *CBP demonstration* 2020

Activity: *Slitless spectro-photometry and atmospheric transmission measurement* 2020

Activity: *Photometric calibration of AuxTel data* 2021

PZ Key Project (DC1 & DC2): Photo-z Testbed (PZ1)

Activity: *Requirements for spec-z training sets* 06/30/18

PZ Key Project (DC2 & DC3): Tests of photo-z cross-correlation calibration (PZ2)

Activity: *Core cross-correlation code development* 12/31/19

Activity: *Cross-correlation tests of tomographic bins* 12/31/19

Activity: *Explore additional systematics of the cross-correlation calibration* 09/30/21

PZ Key Project (DC2 & DC3): Photometric redshift infrastructure development (PZ3)

Activity: $p(z)$ *for simulated catalog objects* 06/30/18

Activity: *Improved* $p(z, \alpha)$ *catalog* 06/30/20

PZ Key Project (DC2 & DC3): Develop infrastructure for spectroscopic redshift training sets (PZ4)

Activity: *Spec-z sample target selection algorithm* 12/31/19

Activity: *First spec-z sample training redshifts* 07/01/20

WL Key Project (DC1, DC2, & DC3): Impacts of Blending (CX1)

Activity: *Software to quantify impacts of blending* 09/16

Activity: *Quantify impacts of blending on parameter estimation covariances and pixel-noise* 10/18

Activity: *Measure the impact of blends on cluster shear profiles* 10/16

Activity: *Design and implement a blending testing framework* 03/19

Activity: *Generate custom simulations and perform blending tests* 09/19

Activity: *Use space data for blending tests* 06/19

Activity: *Inject known sources into real data for blending tests* 09/19

Activity: *Explore new algorithms for blended objects* 06/20

Activity: *Shear Deblending in DC2 cluster fields* 06/19

Activity: *Software to calibrate deblender residuals with extra data* 09/19

Activity: *Assessment of impact of blending on Photo-z* 07/01/20

Activity: *Requirements on DM deblender from cosmic shear* TBD

SL Key Project (DC1): Supernova and Strong Lens Light Curves (CX2)

Activity: SupernovaMonitor *1.0* 04/01/17

Activity: SLMonitor *1.0* 04/01/17

Activity: `Twinkles` *SN and SL Light Curves* 06/30/18

Activity: `DC2` *Light Curve Extraction Requirements* 06/30/18

TJP Key Project (DC1 & DC2): Impact and Mitigation of Key Astrophysical Systematics (CX5)

Activity: *Galaxy Intrinsic Alignments* 03/31/19

Activity: *Galaxy Bias and Assembly Bias* 03/31/19

Activity: *Baryonic Effects* 03/31/19

TJP Key Project (DC2): Cosmological Analysis Pipeline for LSST Precursor Data Sets (CX6)

Activity: *Mock catalogs with DC2 level astrophysics* 03/31/19

TJP Key Project (DC2): Improved Multi-Probe Data Covariances (CX7)

Activity: *Preliminary Covariance Matrices for Cosmological Analyses* 07/01/18

Activity: *Requirements for Tolerable Uncertainty in Covariances*	12/31/19
Activity: *Studies of Alternative Parameter Inference Methods*	12/31/19

TJP Key Project (DC2): Blinding Strategy for Cosmology Analysis (CX8)

Activity: *Blind analysis strategies for individual probe analyses*	03/31/19
Activity: *Blind analysis strategies for joint probe analyses.*	12/31/19

SL Key Project (DC2): Supernova and Strong Lens Light Curves (CX10)

Activity: SUPERNOVAMONITOR *2.0*	12/31/19
Activity: SLMONITOR *2.0*	12/31/19
Activity: `DC2` *SN and SL Light Curves*	12/31/19
Activity: *Light Curve Extraction Performance*	12/31/19

LSS Key Project (DC1, DC2 & DC3): Systematics Caused by the LSST Observing Strategy (CX11)

Activity: *Dither patterns for* `DC1 Phosim Deep` *simulations*	12/15
Activity: *WL studies of LSST observing strategy*	03/16
Activity: *Results from* `DC1 Phosim Deep`	06/30/18
Activity: *WL Recommendations for LSST observing strategy*	12/31/19
Activity: *Optimized LSST observing strategy*	12/31/19
Activity: *Results from* `DC3 Mock ComCam Survey`	09/30/21
Activity: *Results from* `DC3 Mock Lightcone`	09/30/21

LSS Key Project (DC2 & DC3): Using Deep Drilling Fields to Reduce Dark Energy Systematics (CX12)

Activity: *Catalogs for DC2 Deep Drilling Field simulations*	06/30/18
Activity: *Precursor Data with appropriate Wide-Deep overlap*	09/30/19
Activity: *Results from DC2 DDF catalog simulations*	12/31/19
Activity: *Recommended DDF observing strategy for static sources*	09/30/21
Activity: *Recommended DDF observing strategy*	09/30/21
Activity: *On the use of the DDFs to reduce cluster mass systematics*	09/30/21

OSTF Key Project (DC2): Response to the LSST Call for White Papers on Observing Strategy (OSTF)

Activity: *Observing strategy recommendations for supernova cosmology* 11/18

Activity: *Observing strategy recommendations for strong lensing cosmology* 11/18

Activity: *Observing strategy recommendations for weak lensing systematics* 11/18

Activity: *Observing strategy recommendations for large-scale structure* 11/18

Activity: *Observing strategy recommendations for photometric redshifts to enable dark energy probes* 11/18

Activity: *Observing strategy recommendations for all static science cases* 11/18

Activity: *Synthesized WFD observing strategy recommendations across all probes* 11/18

Activity: *Synthesized DDF observing strategy recommendations across all probes* 11/18

Activity: *Metrics summary for observing strategy across all probes* 06/19

SN Key Project (DC2 & DC3): Photometric Calibration Systematics (CX13)

Activity: *Corrections for instrumental response function effects* 12/17

Activity: *Corrections for atmospheric effects* 12/17

Activity: *Corrections for Galactic extinction* 12/17

Activity: *Instrumental Effects in SN Distances* 03/18

Activity: *observing strategy and data analysis plan* 03/19

SN Key Project (DC2 & DC3): DESC Broker Investigation and Development (CX14)

Activity: *DESC Broker Requirements for SN* 12/19

Activity: *DESC Broker Requirements for SL* 12/19

Activity: *DESC Broker Tests* 03/20

10 Appendices

This appendix contains:

- Notes on Working as a Collaboration
- Notes on Implementing the SRM
- A Summary of the Simulations Nomenclature
- An Overview of the LSST Hardware Testing Timeline
- An Overview of the LSST Project Data Management Timeline

10.1 Working as a Collaboration

Although the activities of different working groups are generally presented in separate sections of the SRM, we remain a single science collaboration working together to achieve common goals. In this section, we describe some of the ways in which the collaboration is working together across and beyond working group boundaries in order to avoid stove-piping which will limit our success.

Collaborative rather than competitive research: There are two broad approaches to science within collaborations. One is to work as a single collaboration in which members contribute to a common goal (including common science results and common publications). The other is to have teams within the collaboration compete against each other. Both approaches have advantages and disadvantages. They have in common the desire to create incentives for developing novel/innovative approaches and for publishing robust science results in a timely fashion. Within DESC, the first of these approaches is being adopted. To some extent this reflects a philosophical preference that has developed as the collaboration has grown, this is also a pragmatic choice necessitated by the amount and complexity of work involved. While it is clear that there will be natural tendency towards competition within the Collaboration as the LSST data arrives, a unified approach will allow a common focus on the construction of a single, optimal analysis pipeline and the associated integrated hardware and software framework to ensure that at least one analysis will be completed. This allows efficient use of computationally intensive simulations and provides recognition for members' efforts in building this essential infrastructure.

Human development and recognition: Its essential to have appropriate structures in place to facilitate and motivate collaborative coordination of DESC activities, and give appropriate recognition for sustained and critical efforts in preparing for the LSST data analysis. The

DESC Management Plan is the primary Collaboration document describing this but we summarize some of the important aspects here. Career development opportunities for junior members are essential as they transition through graduate, postdoc and junior faculty positions, to be the future leaders of the collaboration, during the period through first-year analysis. DESC must ensure visibility of junior members through speaking opportunities and recognition of effort reflected in publications, senior member mentoring and support, through letters of reference, and paths to leadership roles in science and governance activities. The DESC Publication Committee drafted and the Collaboration Council ratified a Publication Policy that reflects and rewards the contributions of DESC members in the publication process. In working together to build and use the collaboration analysis infrastructure, we believe individual and team scientific effort on the SRM projects can be appropriately rewarded through pre-first light publications. These could involve algorithm development, comparisons of analysis techniques, tests of survey capabilities using precursor and simulated data, etc. A collaborative approach will enable, and in no way preclude, the development and comparison of multiple, alternative algorithms and solutions to technical problems and their inclusion in the analysis pipeline.

Inclusion and Professional Conduct: the LSST DESC wants to maximize the contributions and harness the enthusiasm of members within the Collaboration. To ensure this, DESC has developed and adopted a Code of Conduct and a set of related practices that emphasize the Collaboration's commitment to collegial and respectful behavior between members in every aspect of collaboration life. This is essential to make certain that all members, from junior to senior, from all nations and backgrounds, feel able and encouraged to fully contribute to the Collaboration without fear of harassment, marginalization or exclusion.

Cross-working group activities: In the early stages of the Collaboration most efforts were focused within rather than across the boundaries of working groups. This has been important for building working group teams and establishing the plans of work for each science area that have become the backbone of the SRM. However many working groups are facing common systematics or the need for pipeline development activities that require diverse computing, technical and analytic expertise not found in a single working group or a single institution. In recognition of this, a major goal for the DESC is developing ways to build cross-working group and cross-institutional connections and working patterns. As an example, an increasing number of sessions at DESC collaboration meetings have been jointly hosted, cross-working group sessions on shared issues.

The next step is to actively conduct research in a cross-working group setting. One way this is being achieved is through "*Task Forces*". These are small dedicated groups of DESC members from multiple working groups and diverse institutions who are working together on specific, high priority, timely science goals, with clear deliverables, typically in a 6-12 month timeframe. Since October 2015 the DESC has had over a dozen Task Forces engaging with topics that directly feed into SRM plans. Examples include Task Forces on "Galactic Reddening" (relating to "Galactic Extinction" (PC2)), "Intrinsic Alignment Mitigation" ("Impact and Mitigation of Key Astrophysical Systematics" (CX5)), and "Observing Strategy" ("Systematics Caused by the LSST Observing Strategy" (CX11)). The Task Forces regularly organize dedicated sessions at the bi-annual collaboration meetings and associated Hack Days. The Collaboration is providing a small amount of travel support for a handful of the Task Forces to allow them to meet in between the Collaboration meetings to complete their goals. The aim is not only to stimulate completion of SRM deliverables, but also to cultivate cross-working group working practices across the collaboration.

Coordination and Interfaces with the Project: In addition to working together across working group lines within DESC, leveraging the knowledge and expertise of individuals associated with the LSST Project will be important to our success. A specific aim of the SRM is to provide a concrete timeline for DESC development activities that will be used to ensure consistency of DESC goals with Project timelines for hardware and DM development.

To facilitate this, it is important to maintain strong connections between DESC and Project personnel. The DESC has many members who are also working on the LSST Project in hardware development and testing and data management. The Collaboration has also put in place formal *Liaisons*, DESC members in leadership positions in the Project who act as specific points of contact for the Camera/Hardware and the DM system, to enable efficient communication between the DESC and the Project.

The LSST Facility will provide annual data releases during the survey that will include astronomical images with measurements of position, fluxes and shapes along with variability information, including both orbital parameters for moving objects and light curves. While the main focus of DESC will be the development and execution of "user-generated" software and data products that enable cosmological measurements to be made, the Collaboration will also work with the Project to optimize its annual release data products. The necessary work includes several aspects:

- identification of ways in which survey strategy may be optimized for dark energy science (e.g., dithering patterns will affect the level of systematics in LSS measurements);
- analysis of the pre-commissioning Verification Datasets using the DESC analysis pipeline, and re-processing them using the DESC's implementation of the LSST data release processing (DRP) pipeline in order to probe for systematics;
- quantifying requirements on photometric calibration and sensor characterization to achieve dark energy goals;
- providing feedback on the performance of the DM Stack and of common Project/DESC

tools such as GalSim and PhoSim; and

- proposing early operations tests/mini-surveys for ComCam and for commissioning following the full camera integration.

10.2 Implementation of the SRM

The collaboration has invested significant thought and effort in the development of the SRM, which lays out a plan of tasks and the timelines needed to meet our goals. To achieve those aims, however, will require coordinated and sustained action from DESC members and the necessary resources to support them. In this section we discuss various approaches we will use to successfully implement the SRM.

Assessing the level of the effort required: Version 1.3 of the SRM contained 192 completed, active or planned pipeline, computing infrastructure and dataset deliverables, and 186 R&D activities, spanning the 5-year DC1/DC2/DC3 period. Each deliverable or activity should represent at most one year's FTE effort, but we expect many to be significantly less; for example, roughly a third of all deliverables and activities are requirements (RQ) which may represent only a few months of sustained FTE effort. Rough estimates of scope suggest that an average of 0.7 FTE years per deliverable is a reasonable assumption. This implies that we will need the equivalent of about 25 individuals' full time effort per year (or equivalent) to complete the mission-critical software and dataset development "operations" work (Section 7) in the SRM, and a comparable level of effort to carry out all the R&D investigations in the same period (Section 9). In the majority of cases, this effort would most appropriately be supported by research funding, but a portion of the development work in Section 7 fits better within the DESC operations tasks.

The size of the DESC appears to be sufficient to meet this requirement. In April 2018, DESC had 190 Full Members of the collaboration, who have committed a significant fraction of their research time to the DESC, and over 750 Members in total. (The membership is currently growing at a rate of a few tens of members per year, to over 850 by January 2019.) At those levels, we would require $\sim 28\%$ of the effort of all Full Members alone to achieve all the SRM goals. The initial June 2017 collaboration "census" received 161 replies, in which non-operations staff respondents committed a total of some 25 FTE years of effort to the DESC operations program in FY18.

Based on these initial estimates, we can conclude that the work described in the v1.3 SRM is achievable, provided we are able to realize the committed effort and channel it effectively in well-organized, collaborative and energized teams. The operations staff play a key role in nucleating, driving and inspiring these teams. We will continually assess SRM progress and, if necessary, focus efforts on those areas of greatest need to ensure that we are prepared to handle commissioning/SV data from LSST. The operations management team will continue to assess the required effort as the SRM evolves, using the quasi-WBS structure and analysis referred to in Section 2, and taking into account the available effort revealed by the now-annual DESC census. The June 2018 DESC census indicated that the amount of effort available is increasing, for both research activities and mission-critical software and dataset tasks.

Task organization and tracking: The hierarchical structure of the SRM provides a natural framework for organizing and tracking the progress and completion of tasks and deliverables. The DESC working groups and management team currently use Confluence wiki pages to coordinate activities within working groups and to share documents, and shared repositories within the LSST DESC GitHub organization[11] for developing software, analyses and papers. Our publication management system (in interim and final forms) provides a way to list near-term projects, associate them with SRM deliverables and activities, and allow others to sign up to lead or contribute. The Collaboration is also exploring lightweight project management tools that will allow efficient progress tracking across multiple projects and working groups.

All deliverables must be made freely available within the Collaboration. Initially they should be stored and documented in a structured way in dedicated sections of the DESC Confluence wiki (for documents) and the DESC GitHub repository (for software). When decided upon, the project management tools must be kept up to date with status of deliverables and links to it. "Distributed Code Development Environment" (CI4) provided guidelines for software development best practices, including practices for repository management, assessment of software deliverable completeness, and organization, which the Publication Board is now evolving and maintaining. Software deliverables should conform to these recommendations to be considered complete. We will also ensure that the data indexing and sharing approaches are able to interface with those used by the Project DM system; e.g., our simulation data products should be able to be addressed via the DM "butler."

Prototypes: DESC's aim is to have a set of fully validated analysis pipelines, as well as a science team that is experienced with their use and therefore able to publish breaking science results in a timely manner, before LSST first light. Prototype projects in DC1 will provide a practical way to begin developing cross-working group coordination, to test project management tools, and to integrate computing infrastructure and analysis pipeline development through the combined efforts of computing professionals and science team members. Our intention is to take the lessons learned from the DC1 prototype to build a solid foundation which can be expanded to more working groups and larger datasets in DC2, as a step to full collaboration-wide implementation in DC3.

[11] https://github.com/LSSTDESC/

Twinkles was an illustrative example of a DC1 prototype. While Twinkles was a small-scale study, covering only 100 square arcminutes, it brought together the SN and SL working groups to analyze a common data set of LSST-like (10 year) simulated image data products. This provided the opportunity to put in place end-to-end workflow and software framework tools for image catalog production, storage, retrieval and analysis by multiple working groups.

Operations support: The timeline and scope of science activities described in the SRM constitutes the information needed to determine DESC operations resource needs up to first light, which will provide the context for any requests for governmental operations funding. Operations support can be utilized to enable and enhance the productivity and engagement of DESC members to maximize the science return on the investment in LSST. Areas of support could include items such as the provision of managed computational facilities, ranging from high performance computing to Collaboration communications infrastructure (database/wiki and remote conferencing tools, etc.); computing/technical professionals who will lead the construction of the software infrastructure and workflow systems to meet DESC's data processing and science analysis requirements as they scale up to the LSST data flow and who will assist in the development of robust data pipeline; and support for collaboration working meetings.

10.3 Simulations and Catalogs Nomenclature

Both the word simulation and the word catalog have multiple meanings when used without any context. For example, a simulation can be a simulated image, a simulated catalog, or the output of a cosmological simulation. Similarly a catalog can refer to a database of idealized objects used by CATSIM to realize a simulated image, or a text file containing the results of a simulated observation.

Because of this overloading, it is often confusing when different groups talk about simulations or catalogs. We propose that neither of these words be used alone and always are used with other describing words to give the context. It's very difficult to identify every possible use, but we itemize here some of the more common data products in use by the various working groups and suggest that we consistently use similar phrases when describing the same products elsewhere in documentation.

We list below the different ways the terms "simulation" and "catalog" are used in the DESC.

10.3.1 Simulations

- **Cosmological Simulations:** These are any result of cosmological simulations, including both gravity-only and hydrodynamical simulations. The results of cosmological simulations are rarely used "as is." They are used in various ways, e.g. to build prediction tools for different cosmological statistics, such as mass functions or power spectra, to investigate systematic effects, such as intrinsic alignments or mis-centering, and to provide estimates for covariances.

  Often, they are used as inputs to other systems for validation. In these cases, gravity-only simulations are populated with galaxies using a variety of prescriptions, depending on the resolution of the simulations as well as the targeted galaxy population. The prescriptions used, including semi-analytic models, subhalo abundance matching, halo occupation distribution models and many others, are still being developed and refinded and for the purposes of LSST DESC the generation and validation of reliable input simulations is a major research task. For example, the input simulations described next can come from a cosmological simulation with realistic galaxy properties assigned using a standardized prescription.

  Sometimes you hear the term **"Input Simulations"**. These are cosmological (or in principle, galactic) simulations that are used as input to CATSIM.

- **Image (or "Pixel-level") Simulations:**

  These come in two kinds, as follows:

  - **Simulated calibrated images, or "e-images":** these have none of the low level sensor effects included. This is the same as producing images where instrument signature removal (ISR; flat field, bias, etc.) is done perfectly. These images can be fed to the DM processing pipelines or other pipelines for measurement. With all simulated images, a major concern is choosing the observation parameters correctly.
  - **Simulated raw images.** For studies that probe the contribution of image calibration algorithms to down-stream measurements, it is likely necessary to simulate raw images and the associated calibration frames. Calibration products are very expensive to simulate correctly because of the vast number of photons needed (by far the most photons seen by any telescope are in the process of producing calibrations). Along with the other concerns, it is important to plan production of master calibration frames along with the catalog and reduction/analysis times.

- **Catalog-level Simulation.** This typically refers to the simulation of an LSST catalog dataset directly, without processing an image and automatically detecting and measuring objects on it. In the DESC, this process is also known as *emulation*, because our default method for making mock LSST catalogs is to simulate images and process them.

10.3.2 Catalogs

- **Input All-Sky Source Catalog:** This is a catalog produced using a cosmological simulation, Milky Way simulation, or other model to produce a realistic representation of the sky including realistic spatial distributions and realistic distributions of observables. These will be used by CatSim and so should adhere to a pre-arranged schema for the catalog contents.

- **Idealized Realization Input Catalogs:** Many times, it is beneficial to produce analysis catalogs with non-physical distributions of objects: e.g. grids of stars for PSF analysis, higher density than normal variable objects to test detection and characterization algorithms. These are also input catalogs, but are idealized in some sense over a purely realistic distribution.

- **Halo Catalogs.** These are a processed output of a cosmological simulation, made by running a halo finder on the particle (or density field) data.

- **Milky Way Catalog.** This is an input to CatSim, that contains stars drawn from a model for the Galaxy.

- **Extragalactic Catalogs.** These are catalogs of galaxies painted onto the halos in a halo catalog via some algorithm. It's called an extragalactic catalog because it does not contain stars or solar system objects, and by contrast with the Milky Way catalog used by CATSIM.

- **Data Release Catalogs.** The LSST annual data releases will consist of an image archive and an automatically-generated catalog, both produced by the data release production (DRP) pipeline. The data release catalog will be a database including tables of Objects, Sources, DIAObjects and DIASources, as well as many other tables of metadata (such as the CcdVisit table). It may be important to specify that a data release catalog has been made from simulated images by calling it a "simulated data release catalog."

- **Simulated observed, or "mock" catalogs.** Catalogs reflecting known error models at various levels of calibration can be produced. Elsewhere these are sometimes known as "mock catalogs," because they contain "mock data" like noisy apparent magnitudes. Mock catalogs are typically made by applying an observational error model to an extragalactic catalog directly. If the machine that does this transformation has been trained on a simulated data release catalog, then that machine is known in DESC as an "emulator," because it is enabling the user to avoid doing more image simulation and instead "emulate" the process of simulating images and running the DRP pipeline.

10.4 LSST Project Hardware Testing Timeline

We summarize here the observatory hardware performance parameters of greatest interest to the DESC. Rather than factorizing the performance of the Camera and Telescope subsystems, the end-to-end hardware system performance is provided by the LSST observatory team.

The Project carries current best estimates of performance against requirements. These estimates are based on detailed information from a variety of sources, including measurements of prototypes and materials, vendor studies, simulations, and analyses of relevant mechanical perturbations and tolerances. These estimates can be provided as needed; however, as these change over time, it is best to base DESC studies upon the requirements rather than the current best estimates. The parameters can be categorized as follows:

- **Image Quality and Ellipticity.** See the LSST System Requirements (LSR) document, sections 1.2 and 1.3.1.
- **PSF Intensity Dependencies and Nonuniformities.** This is coordinated by the SAWG, in consultation with the Camera Project.
- **Throughput as a function of wavelength.** See the LSR, sections 1.1 and 1.2.3, and the Observatory System Specifications (OSS) document, section 3.3, starting with OSS-REQ-0235.

The PSF intensity dependencies and nonuniformities are not directly specified by requirements, so those recommended parameter values should be coordinated through the SAWG, in consultation with the Camera Project.

The table summarizes the bases of the current estimates and the timeframes for updates, including as-built information. The method and format of information transfer are TBD, and should involve the DESC Technical Coordinator, LSST System Scientist, and Camera Liaison.

In the other direction of information flow, the DESC will provide estimates of the precision needed for the characterization of PSF intensity dependencies (*i.e.,* the brighter-fatter effect) and nonuniformities. This is under active discussion in the SAWG. These estimates are needed as soon as possible to help define optimal measurement and characterization plans.

Item	**Basis of current estimate**	**updates**	**As-built knowledge timeframe**
Image quality and ellipticity	Requirements and analysis, CCD measurements, full ZEMAX simulation including perturbations and active optics control. See LCA-17 for the stack up of Camera contributions.	2016, 2018	2020, then ongoing
PSF intensity dependencies and nonuniformities	CCD measurements and characterization	2016-17	ongoing
Throughput(λ)	Requirements, CCD measurements, vendor studies, materials properties. See LCA-18 for the stack up of Camera contributions.	2017-18	2019, 2021

Table 10.4.1: Hardware system performance parameters knowledge timeframes

10.5 LSST Project DM Timeline

The Data Management (DM) group for the LSST project is tasked with developing the Level 1 and Level 2 software for the LSST and with delivering data to the science community through a scalable archive and compute center. The Level 1 algorithms and data products are focused on the continuous processing of the nightly data from the LSST including the detection and characterization of objects that have changed in brightness or position. The Level 2 software and data products are based on annual data releases of the LSST data and include measures of positions, fluxes, shapes and variability information for detected sources (including the coaddition of multiple observations).

The DM software stack is expected to form the core platform for the development of DESC image processing software. It represents a well documented, state-of-the-art, high-performance, scalable, multi-camera, open source, O/IR survey data processing and analysis system. It comprises all science pipelines needed to accomplish LSST data processing tasks (e.g., calibration, single frame processing, coaddition, image differencing, multi-epoch measurement, asteroid orbit determination, etc.), the necessary data access and orchestration middleware, as well as the database and user interface components. Algorithm development for the LSST software builds on the expertize and experience of prior large astronomical surveys (including SDSS, Pan-STARRS, DLS, CFHTLS, and HSC).

DESC and the LSST will work to define a timeline for the development of the LSST project algorithms such that they are consistent with the goals and objectives of the SRM. The DESC will play a natural role in developing and validating core algorithms used by the LSST. In Figure 10.5.1 we show the timeline (in calendar years) for the DM development. The entries within this table represent the expected delivery time for the components of DM relevant for DESC.[12]

Complementing the simulated data sets described in Table 6.3.1 the DM group will process precursor survey data sets through the DM stack "end-to-end" and manually inspect the results. These "Verification Datasets" have been selected to address the four primary science drivers for the LSST: dark energy/dark matter, the Solar System, transients and variable sources, and the Milky Way. Source catalogs and images produced from these precursor survey data will test Level 1 alert production (e.g. difference imaging, transient detection) and DRP data release production (e.g. deep stacks, "static" sky) and will be made available to the DESC. Example data sets that will form part of the "Verification Datasets" include reprocessed versions of public data from DECam and DES, the COSMOS survey (deep, $\sim$26 AB mag, 3 sq. deg., $ugrizY$); the HiTS survey (multi-epoch, 30-40 per field, g and r band); and the CFHT Legacy

[12]Source: LSST document LDM-564, "Data Management Releases for Verification/Integration," http://ls.st/LDM-564. See here for more details about the release of DM software.

Survey (deep, ∼25 mag, $ugriz$, 154 sq. deg).

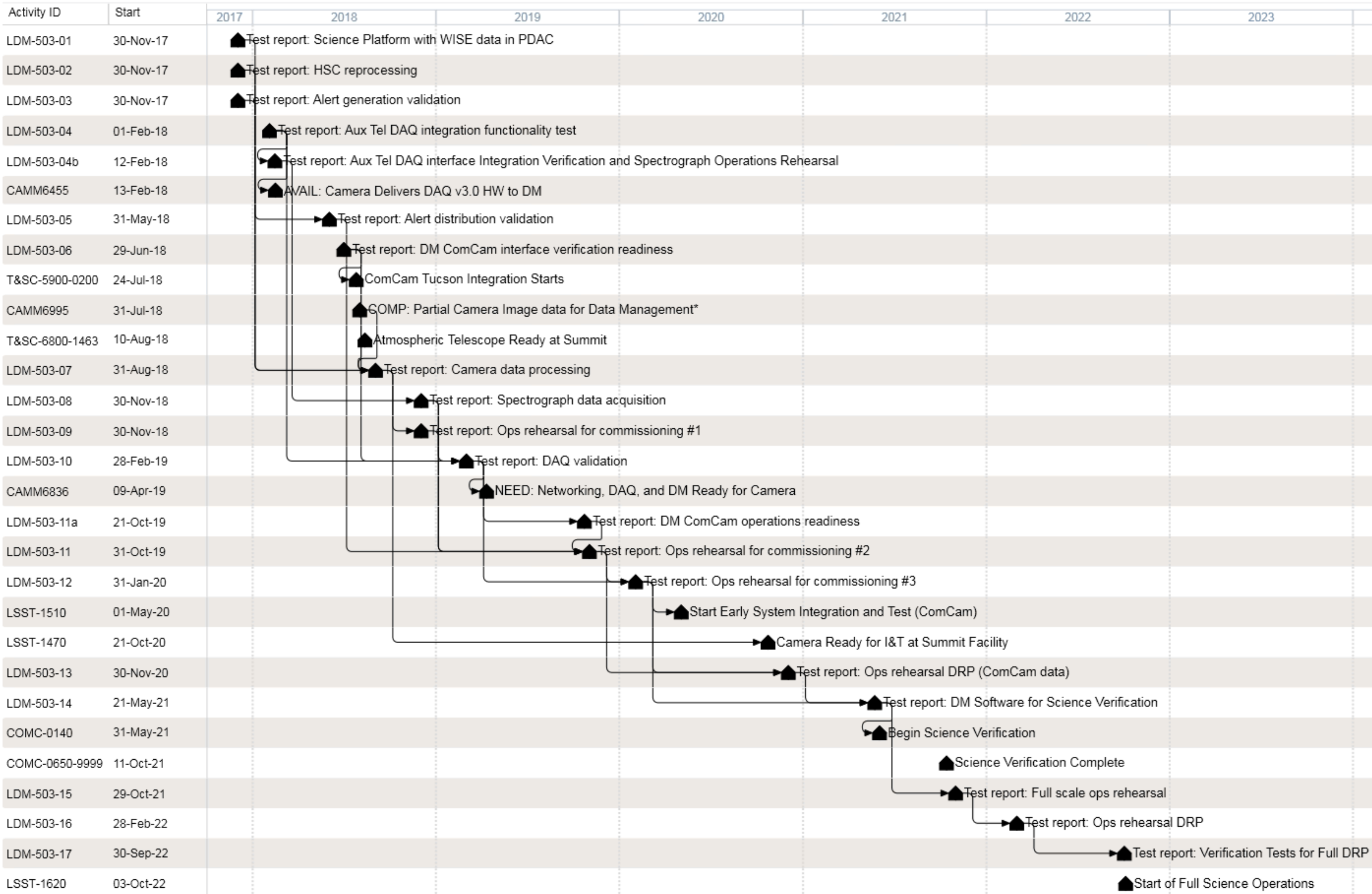

Figure 10.5.1: Major software delivery milestones for the LSST DM group.

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References

Becker, M. R., et al. 2015, arXiv:1507.05598

Bernstein, G. M., & Armstrong, R. 2014, MNRAS, 438, 1880

Bonvin, V., et al. 2017, MNRAS, 465, 4914

Collett, T. E., & Auger, M. W. 2014, MNRAS, 443, 969

Connolly, A. J., et al. 2010, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 7738, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series

Elmegreen, D., e. a. 2015, The National Academies Press

Grav, T., Jedicke, R., Denneau, L., Chesley, S., Holman, M. J., & Spahr, T. B. 2011, Publications of the Astronomical Society of the Pacific, 123, 423

Heitmann, K., et al. 2015, ArXiv e-prints, ArXiv:1508.02654

Hlozek, R., et al. 2012, ApJ, 752, 79

Hoekstra, H., Herbonnet, R., Muzzin, A., Babul, A., Mahdavi, A., Viola, M., & Cacciato, M. 2015, MNRAS, 449, 685

Ivezic, Z., et al. 2008, ArXiv e-prints

Jarvis, M., et al. 2015, arXiv:1507.05603

Jones, D. O., et al. 2017, ApJ, 843, 6

Jones, R. L., et al. 2014, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 9149, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, 0

Jordi, C., et al. 2010, A&A, 523, A48

Jurić, M., et al. 2008, The Astrophysical Journal, 673, 864

LSST Science Collaboration et al. 2009, LSST Science Book, ArXiv:0912.0201

—. 2017, ArXiv e-prints

Masters, D., et al. 2015, ArXiv e-prints, ArXiv:1509.03318

Matthews, D. J., Newman, J. A., Coil, A. L., Cooper, M. C., & Gwyn, S. D. J. 2013, ApJS, 204, 21

Newman, J. A., et al. 2015, Astroparticle Physics, 63, 81

Padmanabhan, N., et al. 2008, ApJ, 674, 1217

Perryman, M. A. C., et al. 2001, A&A, 369, 339

Peterson, J. R., et al. 2015, ApJS, 218, 14

Rowe, B. T. P., et al. 2015, Astronomy and Computing, 10, 121

Rozo, E., Rykoff, E. S., Bartlett, J. G., & Melin, J.-B. 2015, MNRAS, 450, 592

Schlafly, E. F., et al. 2012, ApJ, 756, 158

Sheldon, E. S. 2014, MNRAS, 444, L25

Suyu, S. H., Marshall, P. J., Auger, M. W., Hilbert, S., Blandford, R. D., Koopmans, L. V. E., Fassnacht, C. D., & Treu, T. 2010, ApJ, 711, 201

Suyu, S. H., et al. 2014, ApJL, 788, L35

Zuntz, J., et al. 2018, MNRAS, 481, 1149