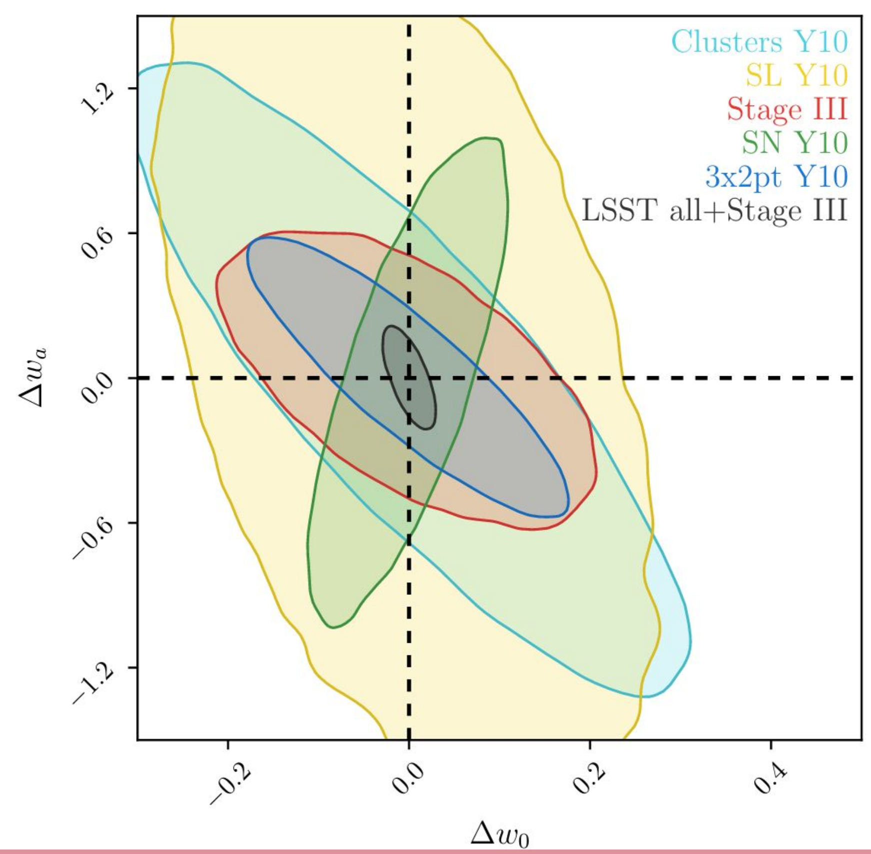


Tutorial Modeling part II

Cosmological inference with CosmoSIS and Firecrown

Agnès Ferté (SLAC)

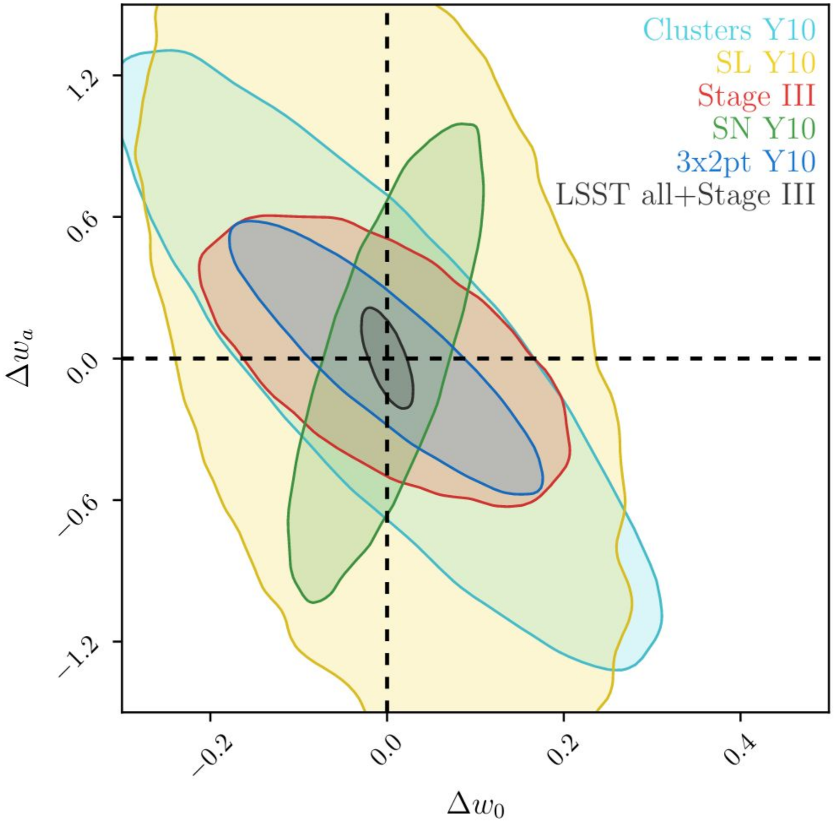
In part I, Paul showed us how to generate a simulated 3x2pt data vector.

Now, imagine we are in 2027, we worked really hard to measure the 3x2pt (or any statistics of DESC probes) data vector and corresponding covariance matrix from LSST Y1 data.

How do we infer properties of the Universe from these measurements?

What are the true values of S_8, $(w_o w_a)$, $(\sum_o, \mu_o)$?

☐ What are the LSST Y1 **cosmological constraints**?



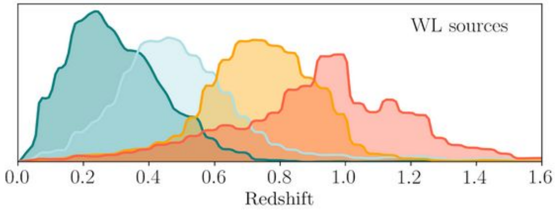
The standard is to do a Bayesian analysis

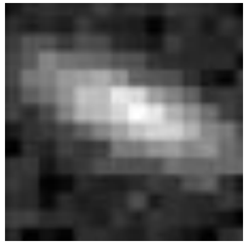
Probability of parameter values given our data vector in LCDM (Posterior) = [Probability of our data vector given parameters in LCDM (Likelihood) x Probability of parameters in LCDM (Priors)] / [Probability of our data vector in LCDM (Evidence)]

We generally assume a Gaussian likelihood

$$\mathcal{L}(\mathbf{D}|\Theta) \sim \exp(-\frac{1}{2}[\mathbf{D} - \mathbf{M}(\Theta)]^T C^{-1}[\mathbf{D} - \mathbf{M}(\Theta)])$$

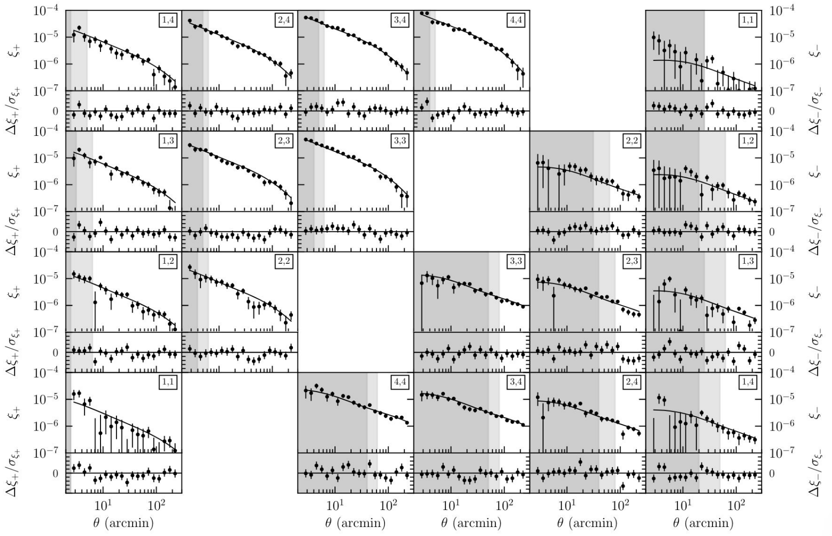
From galaxy **images** to **Measurements** of galaxy shape, position, redshift distribution





Measurements of **shear**

Covariance matrix



From Cosmological parameters to **model** of shear

A_s, n_s, Ω_m, Ω_b, Ω_ν, H_o

Theoretical predictions of **shear**

Credits: Bridle et al, 2009, Myles, Alarcon, et al, MNRAS, 2021, DES Collaboration, PRD, 2022

Modeling of cosmology and systematics effects

$$L(D|\Theta) \sim \exp(-\frac{1}{2}[(C_\ell - C_\ell^{th}(\Theta))C^{-1}(C_\ell - C_\ell^{th}(\Theta))])$$

Cosmology + systematics:
can quickly need dozens of parameters.

$$C^{ij}_{\rm EE}(\ell) = C^{ij\prime}_{\kappa\kappa}(\ell) + C^{ij}_{\kappa I_{\rm E}}(\ell) + C^{ji}_{\kappa I_{\rm E}}(\ell) + C^{ij}_{I_{\rm E} I_{\rm E}}(\ell)$$

$$C^{ij}_{\rm BB}(\ell) = C^{ij}_{I_{\rm B} I_{\rm B}}(\ell),$$

We have a data vector and its covariance matrix.
Now, we need 2 things:

- Compute **theoretical prediction** of our observables:
    - Matter power spectrum P(k,z)
    - Distances
    - CMB power spectra
- **Sample** the likelihood

☐ Cosmological inference softwares: **CosmoSIS**, **Cobaya**, NumCosmo, etc.

CosmoSIS is a cosmological inference software developed by Joe Zuntz. More information: https://cosmosis.readthedocs.io/en/latest/

It is a modular software that has samplers and code to model many cosmological probes. It's like a glue between the many existing codes in the community.
Cosmosis-standard-library has modules already interfaced with CosmoSIS.

The information between modules is carried through **data blocks**.

We will focus on a LSST Y1 shear-like case now but I recommend doing tutorials and examples in CosmoSIS (see link above) if you want to learn more.

Tutorial 1:

- Log in to Perlmutter at NERSC
- git clone https://github.com/aferte/desc_tutorial_cosmoinference_2024
- salloc --nodes 1 --qos interactive --time 01:00:00 --constraint cpu
- source /global/cfs/cdirs/lsst/groups/MCP/setup_forecasts_prod.sh

You are now in an interactive node with an environment with CosmoSIS, Firecrown, TJPCov, etc…

Now we can play with CosmoSIS:

- cd cosmosis_example
- cosmosis pipeline_test.ini

Let's take a look at this file and output.

- cosmosis pipeline_likelihood_test.ini

Let's take a look at this file and output.

Exercise (~5min)
Compute likelihood with a shear bias parameter of m_i = 0.01 using include.
Hint: ini files are in the shear_bias_inis directory

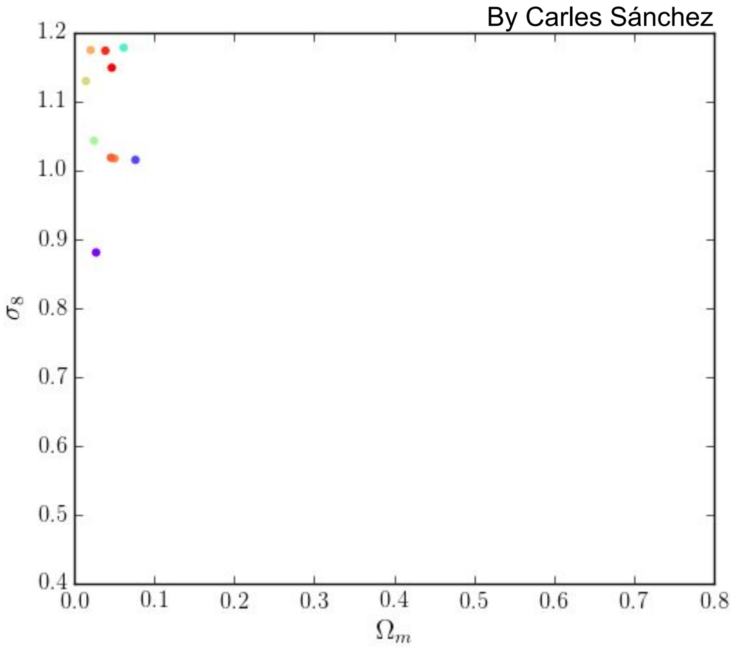
If you are done, plot the corresponding C_ell compared to the one with m_i = 0 and show us!

Map the posterior

- Dimension of parameter space is ~40 for DES Y6
  Goes up fast when there are more redshift bins!

- Many samplers on the market:
  - Standard is to use nested samplers:
    - Polychord.
    - Nautilus, PocoMC, multinest, …
  - Metropolis-Hasting, emcee

- Beware: some samplers are often claimed to be the best, the fastest but when applied to a more complicated parameter space or pipeline, they easily break (or are a pain to setup!!).
  e.g. in DES Y6 3x2pt with HMCode, both nautilus and PocoMC fail to converge (or at least not faster than polychord)!



Planned DESC setup for cosmological inference

- Measure a data vector and compute covariance matrix and store them as a **SACC file**

- Use a cosmological inference software like **CosmoSIS or Cobaya**: the ‘glue’ between standard codes where we plug in **firecrown as the DESC likelihood.**

Cosmological inference software (CosmoSIS, Cobaya)

Boltzmann code
P(k,z), CMB C_l, distances, …

→

Firecrown module
- CCL to model data vector give P(k,z), distances, etc. coming from the previous step
- Evaluation of the likelihood

Firecrown

Firecrown is an in-kind contribution to DESC from Brazil, by Sandro Vitenti, Marc Paterno and many contributors.

https://firecrown.readthedocs.io/en/latest/_static/intro_article.html
The documentation has several examples if you want to learn more. Here we will focus on how to use it in CosmoSIS to run a simple analysis.

Firecrown uses **connectors** to interface with CosmoSIS, Cobaya, NumCosmo and can be used to **generate** synthetic data vectors, compute **likelihoods.**

Tutorial 2:

- sh_dev
- source /global/cfs/cdirs/lsst/groups/MCP/setup_forecasts_prod.sh

In desc_tutorial_cosmoinference_2024 github repository:
- cd cosmosis_firecrown
- cosmosis test/lsst_y1_shear_test.ini

Let’s take a look at how the ini file is setup and how we build the likelihood.

Tutorial 2:

Let's run a chain!!

- sbatch nautilus/lsst_y1_shear_nautilus_run.sh

Let's learn about CosmoSIS campaign now:

- cosmosis-campaign campaign.yml --run sim_lssty1_shear
- cosmosis-campaign campaign.yml --run sim_lssty1_shear_desi
- cosmosis-campaign campaign.yml --run sim_lssty1_shear_desi_w0wa

Let's take a look…

Btw: using the pantheon likelihood in the above pipeline does not work and I don't understand why. Could be a sprint!

Exercise (~10min)

Chain or likelihood evaluation with a different intrinsic alignment amplitude than used to produce the DV, using campaign.