Artifact or science?

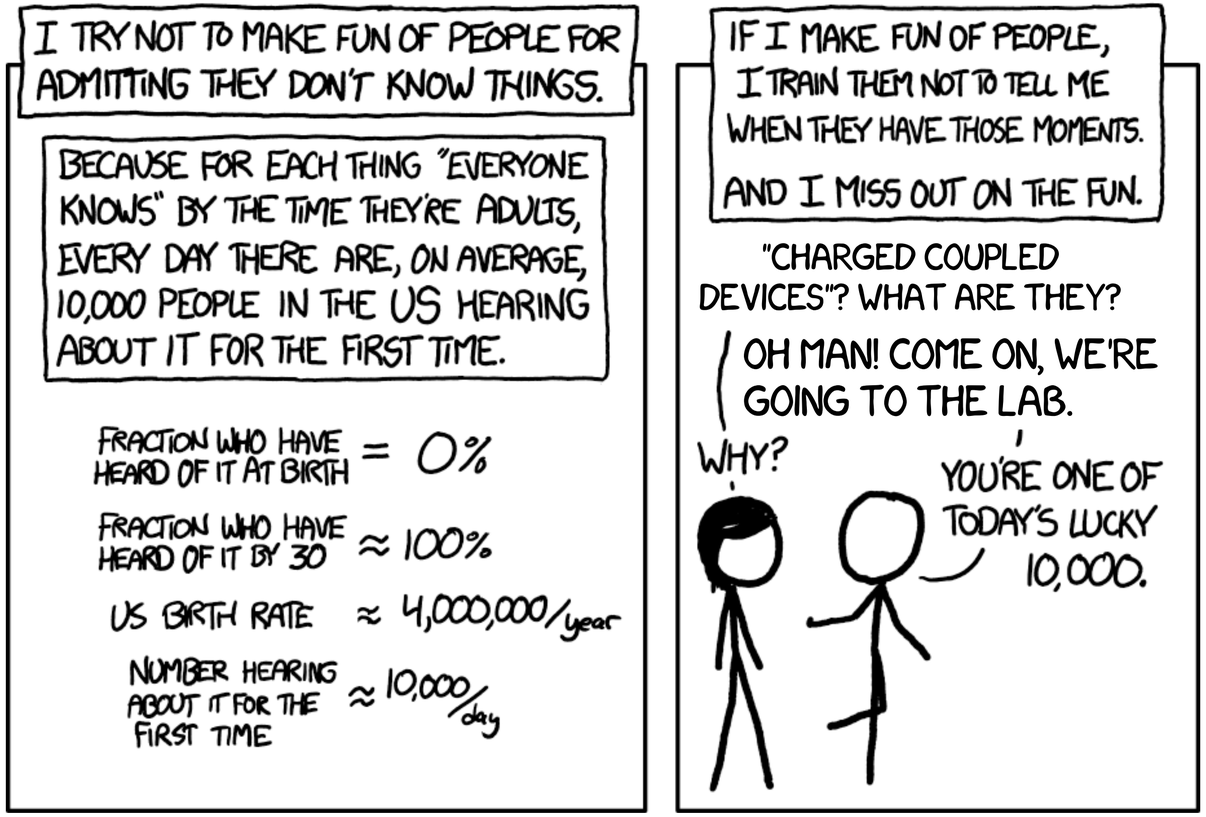
Instrument signature removal
(and adventures in telescope commissioning)

Merlin Fisher-Levine - August 1st 2022 - DESChool

Nobody is born knowing astronomy!

(even if a few might seem like they were)

- Note to the experts
  - Some here will know ~everything
  - Some here will know ~nothing
    - Try to help people work things out for themselves.
- Let's encourage wrong answers!
- Format:
  - I tell you something
  - You discuss/apply
  - I give the "answer"



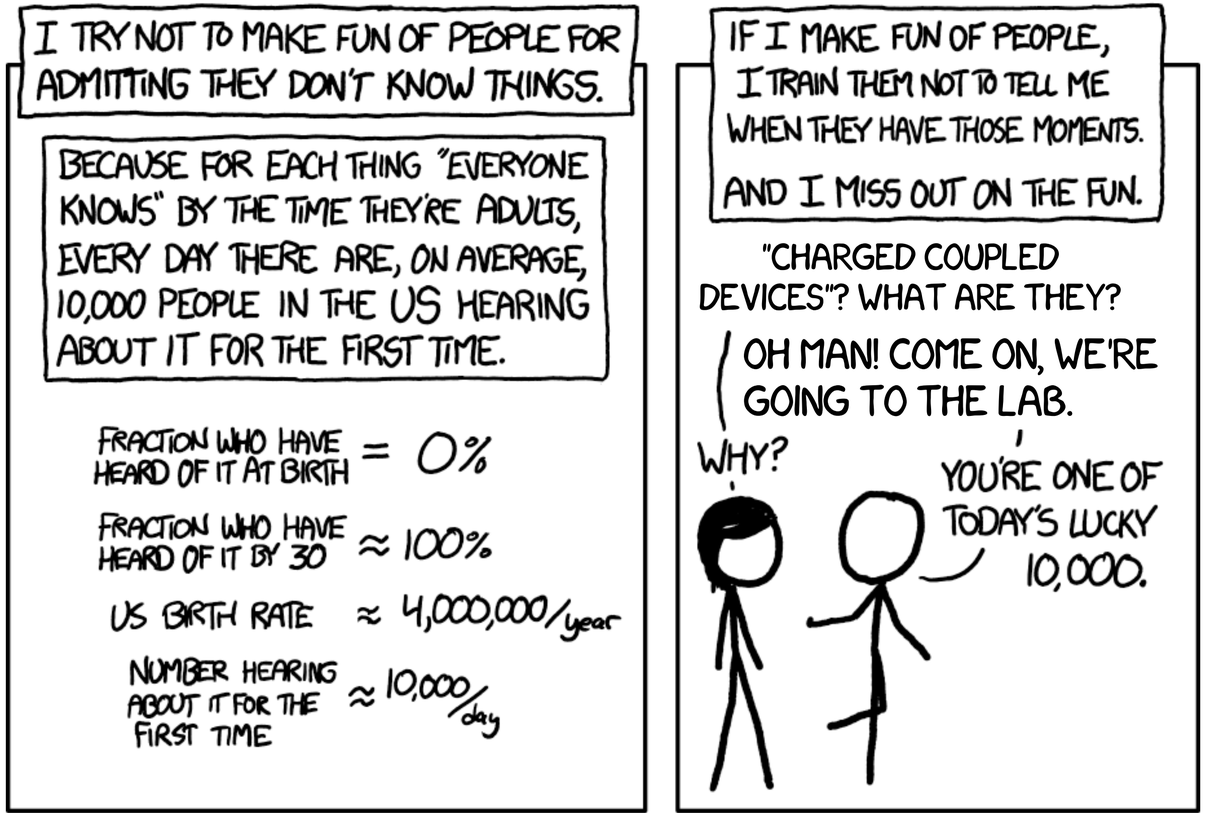
Saying "what kind of an idiot doesn't know about the brighter fatter effect" is so much more boring than telling someone about the brighter fatter effect for the first time.

Nobody is born knowing astronomy!

(even if a few might seem like they were)

- Note to the experts
  - Some here will know ~everything
  - Some here will know ~nothing
    - Try to help people work things out for themselves.
- Let's encourage wrong answers!
- Format:
  - I tell you something
  - You discuss/apply
  - I give the "answer"

There are some trick-questions / misleads to keep things spicy!



Saying "what kind of an idiot doesn't know about the brighter fatter effect" is so much more boring than telling someone about the brighter fatter effect for the first time.

Get to know your neighbours & work partners

- Zoom people: this is going to be intense - there are a lot of smaller questions!
  - You'll go in and out of your established groups. The notice period for ending breakouts is set to 10s, so when the room here falls quiet you'll be yanked back.
- ~~Who do we have:~~ Thanks Pat 😑
  - ~~Grad students/post docs/faculty etc?~~
- Level of experience/knowledge of CCD data and their pathologies on a scale of 1-10:
  - 1 = What is a CCD? How does a telescope work? 🤔
  - 10 = I am Jim [Gunn, Janesick, Chiang] / I literally wrote the book on this stuff 😏

The CCD revolution

the two sides of the coin

- **The good news...**
  - **is that they're not photographic plates!**
- The bad news...
  - is how they behave.
- The ugly(ness)
  - is how the images look before correction...

Get it right
or it's garbage in, garbage out!

CCDs - they're just perfect rectilinear grids 😇

- 100% quantum efficiency with no λ dependence
- No noise
- Perfectly linear response
- Can hold infinite electrons
- No memory of what came before, *i.e.*
  - The previous image
  - What's happened while collecting the image itself!

Bonus points:
Aside from the points on this slide,
why else is this image ***not***
representative of a CCD image?

Quick end-to-end overview

- The universe, just sitting there, waiting to be photographed } Our signal ☺️
- → Atmosphere
- → telescope, optics etc
- → bulk silicon → collecting wells
- → row & column (parallel & serial) shifts → digitisation
- → DAQ & file writing
- → Rendering (because numbers aren't pictures)

} Here be dragons 🐲 😬

Quick end-to-end overview

The universe

- Sits there and does its thing - no problems there by definition 👌
- Obviously one person's signal is another person's noise/ background/headache, but that that's their problem!
  - Deblending
  - Low surface brightness stuff
  - "Moving objects"
- As far as we're concerned for the "is it the instrument?" question, everything outside of the atmosphere and which is not orbiting the earth is "signal".

AI-generated image from DALL-E 2 using the prompt "*Painting of the universe posing for a picture with a photographer*".

Quick end-to-end overview

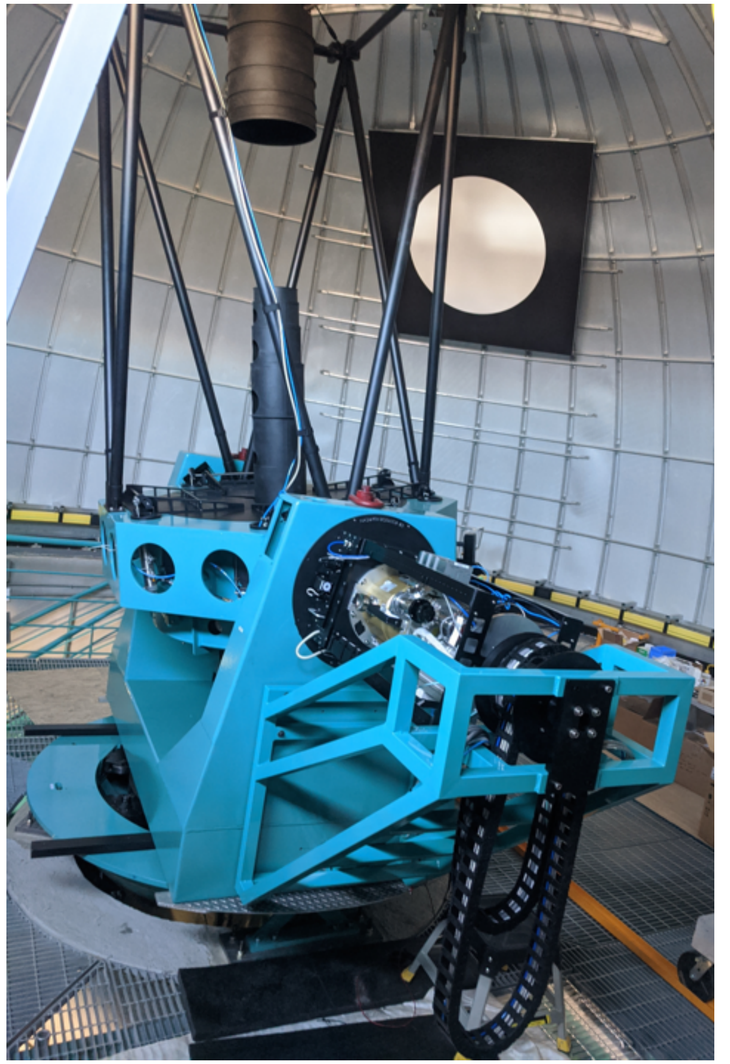
The atmosphere

- It's thick and therefore blurry
  - Thickness varies with elevation angle, from 1 to 🥣
- It's refractive
- It's both emits and absorbs light!
- Things fly through/just above it ✈️ 🛰️ (and even 🦅🦇)
- It's also windy, dewey, rainy and snowy, but these are (mostly) operational problems, though not *entirely...*

Quick end-to-end overview

The telescope & optics

- It has to track the sky
  - Sometimes with two axes, sometimes three
  - Rubin has three for both the AuxTel & the main telescope
- It has finite rigidity
- It has to be collimated & in focus
- It should try to not have a significant wavelength dependence
- It gets dusty



Quick end-to-end overview

The silicon

- Light hits silicon, converts into electron/hole pairs
  - Not just light - muons, soft electrons, etc...
- Gets collected in potential wells on the backside
- Read out by the bucket brigade
  - Row & column shifts
- What needs to be true of the serial register?

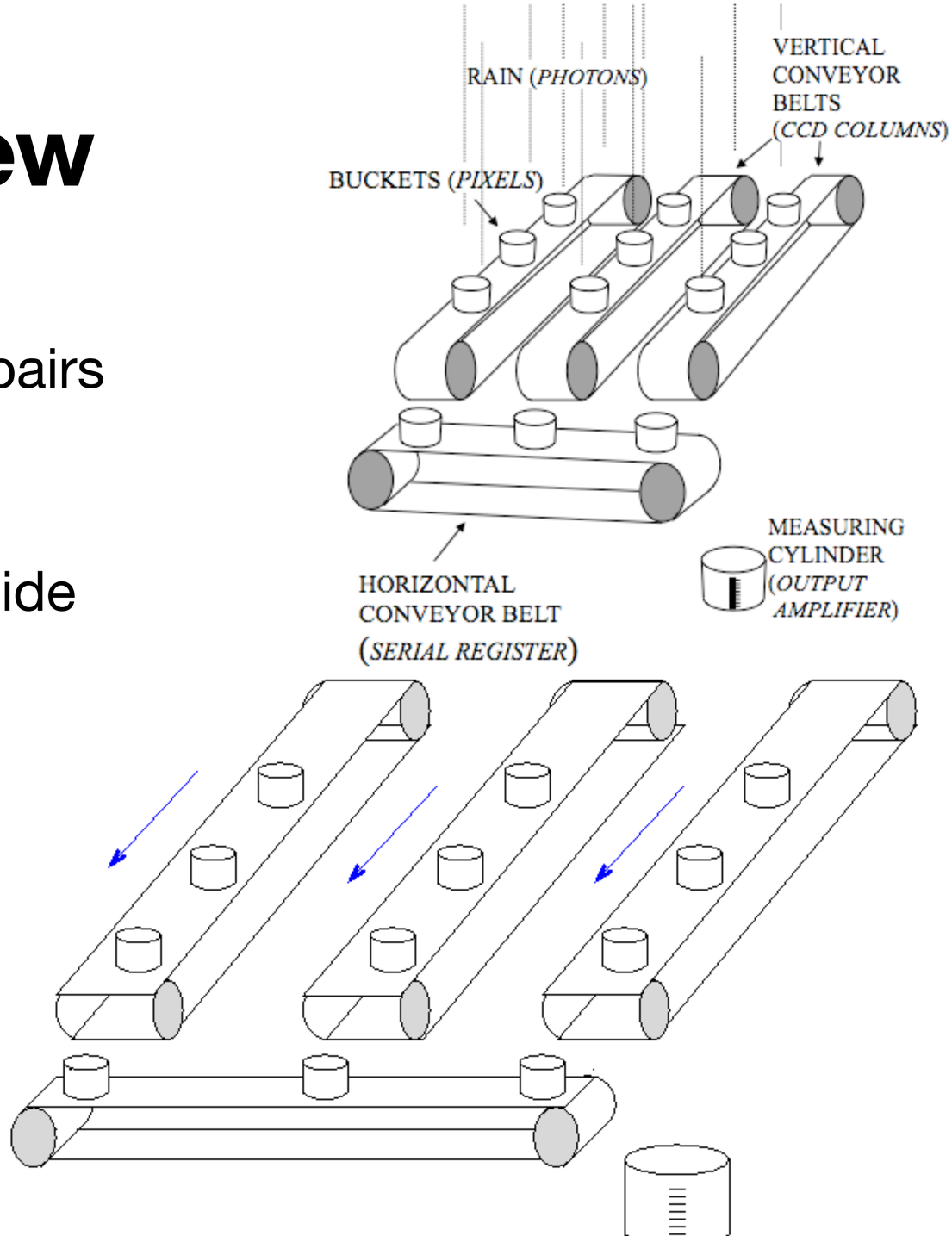


Image credit: Vik Dhillon

Quick end-to-end overview

The silicon

- Light hits silicon, converts into electron/hole pairs
  - Not just light - muons, soft electrons, etc...
- Gets collected in potential wells on the backside
- Read out by the bucket brigade
  - Row & column shifts
- What needs to be true of the serial register?

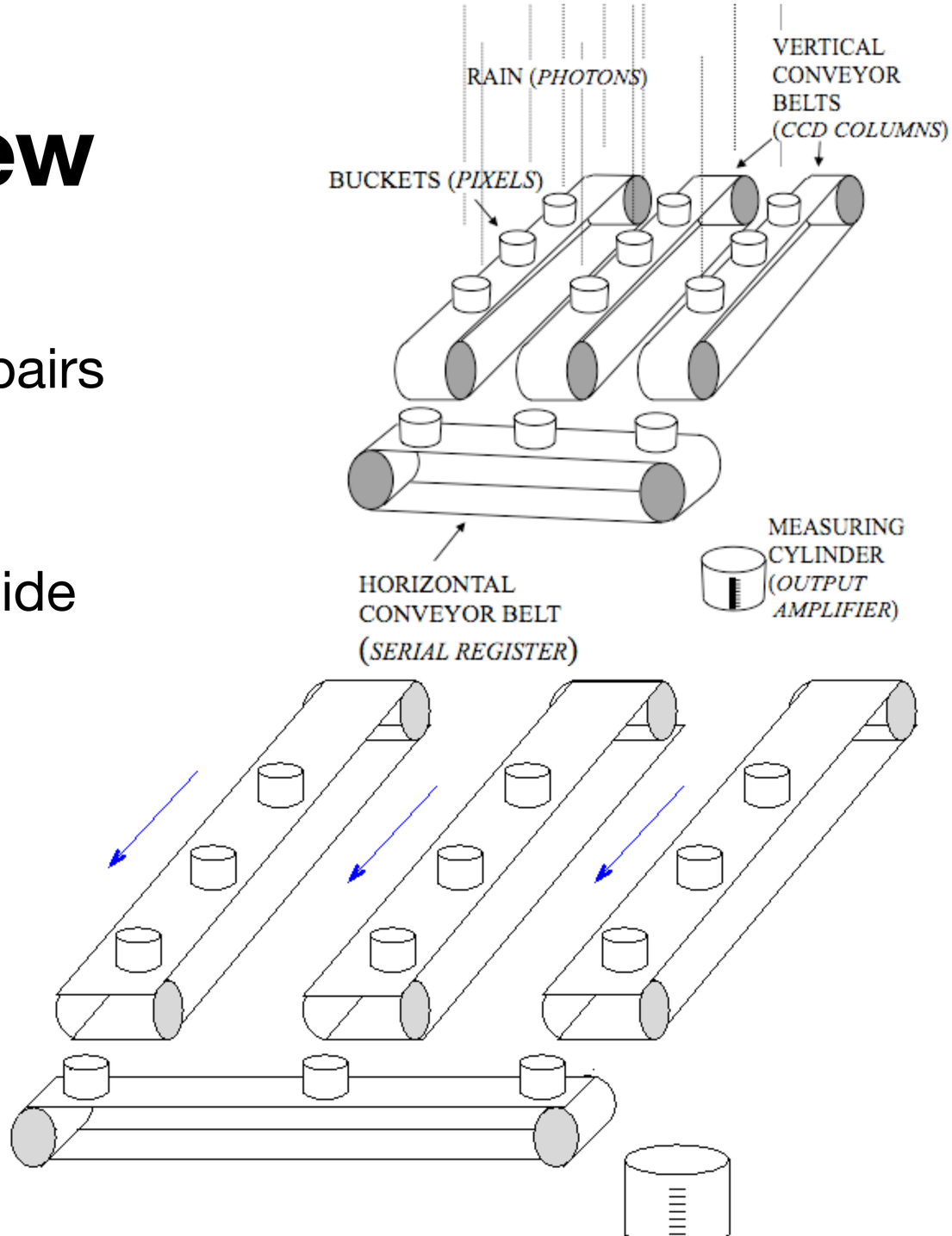
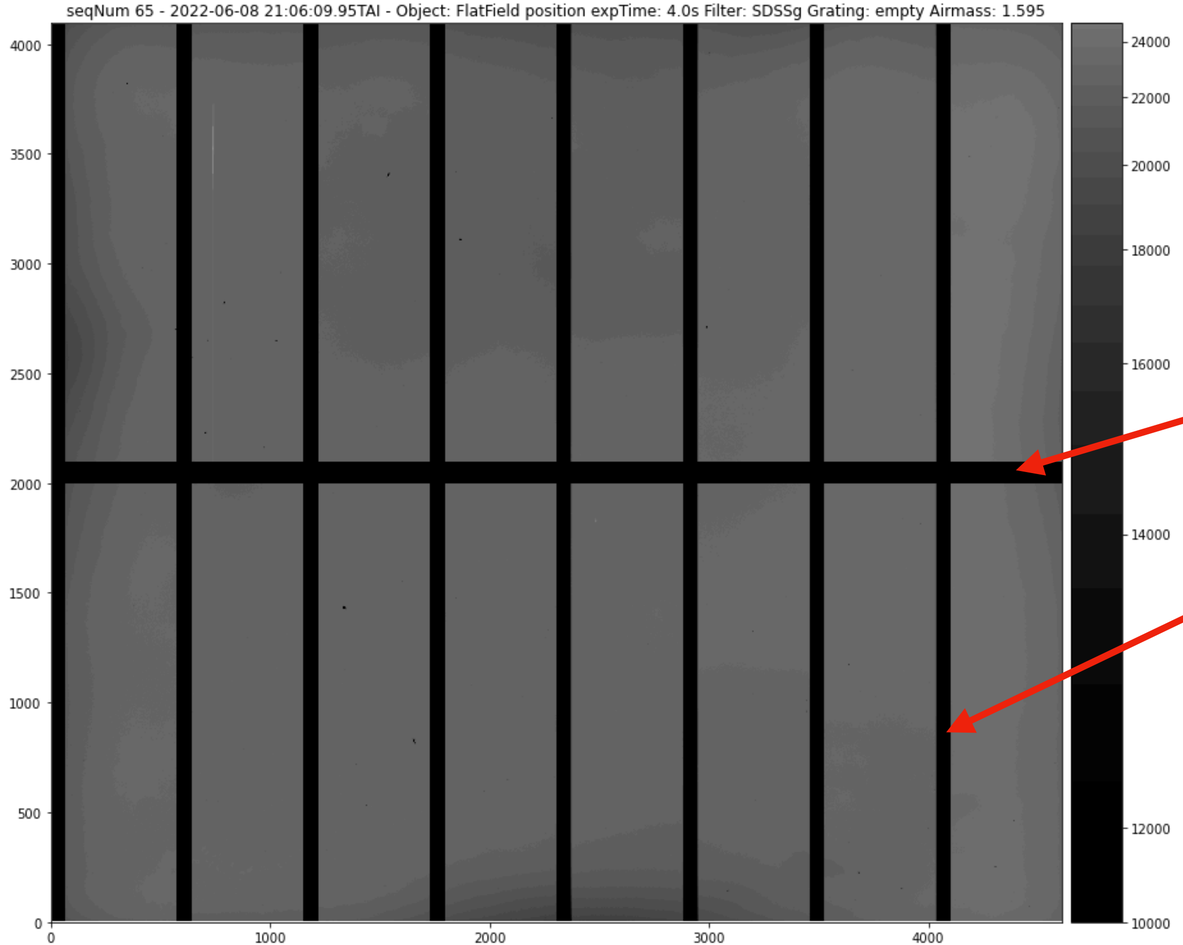


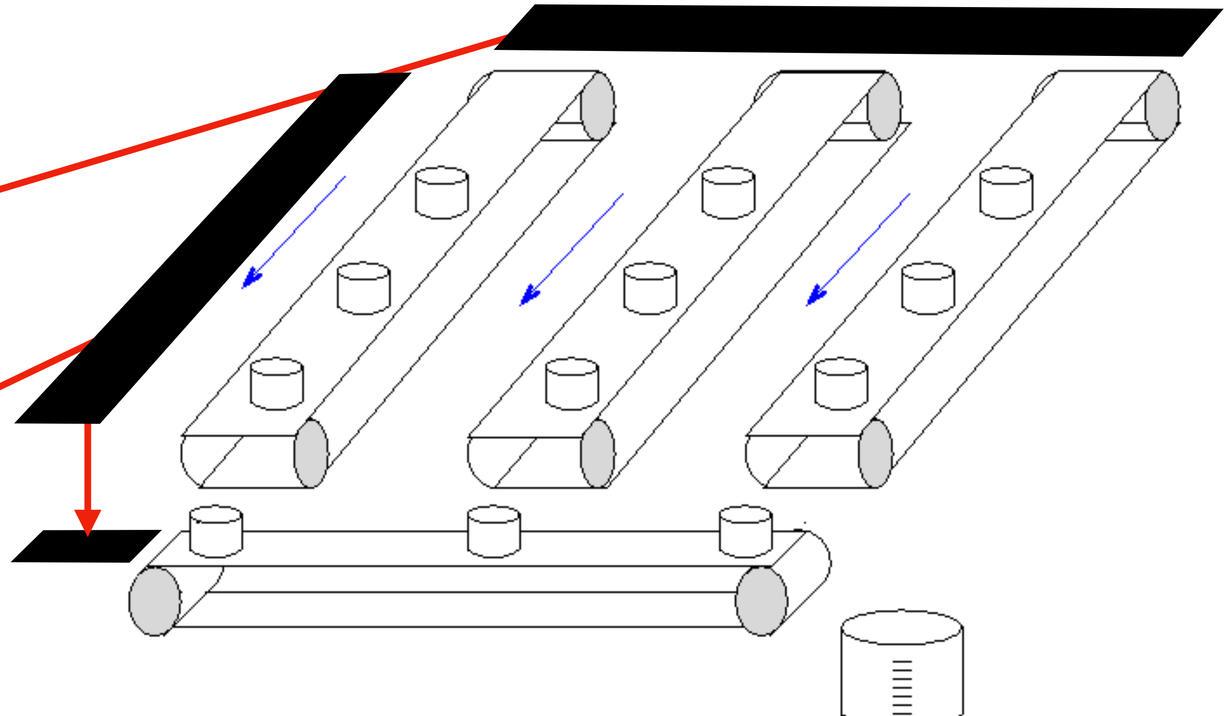
Image credit: Vik Dhillon

Overscans and subtraction

- What happens if we keep clocking out and reading once all the buckets are empty?

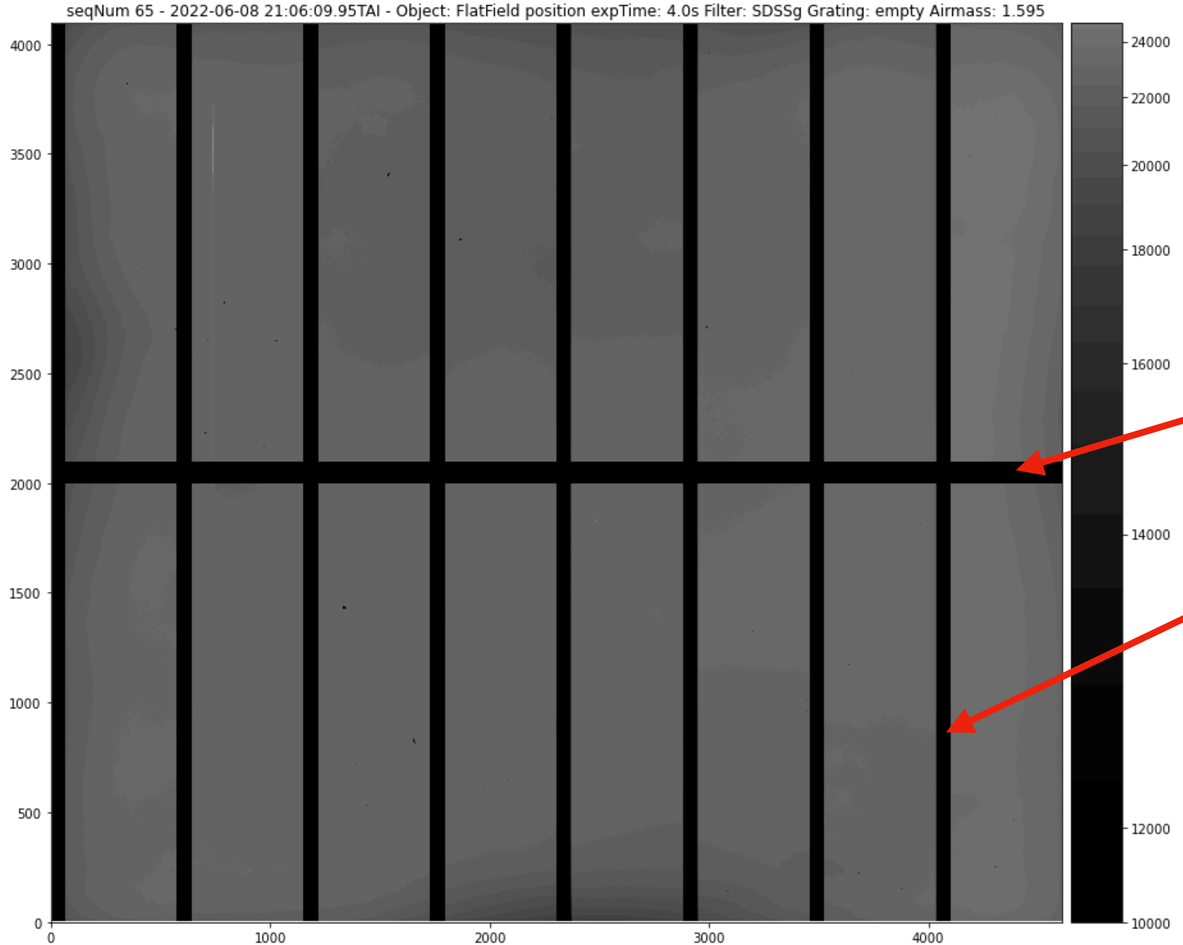


- What if these setups aren't perfectly electrically isolated?

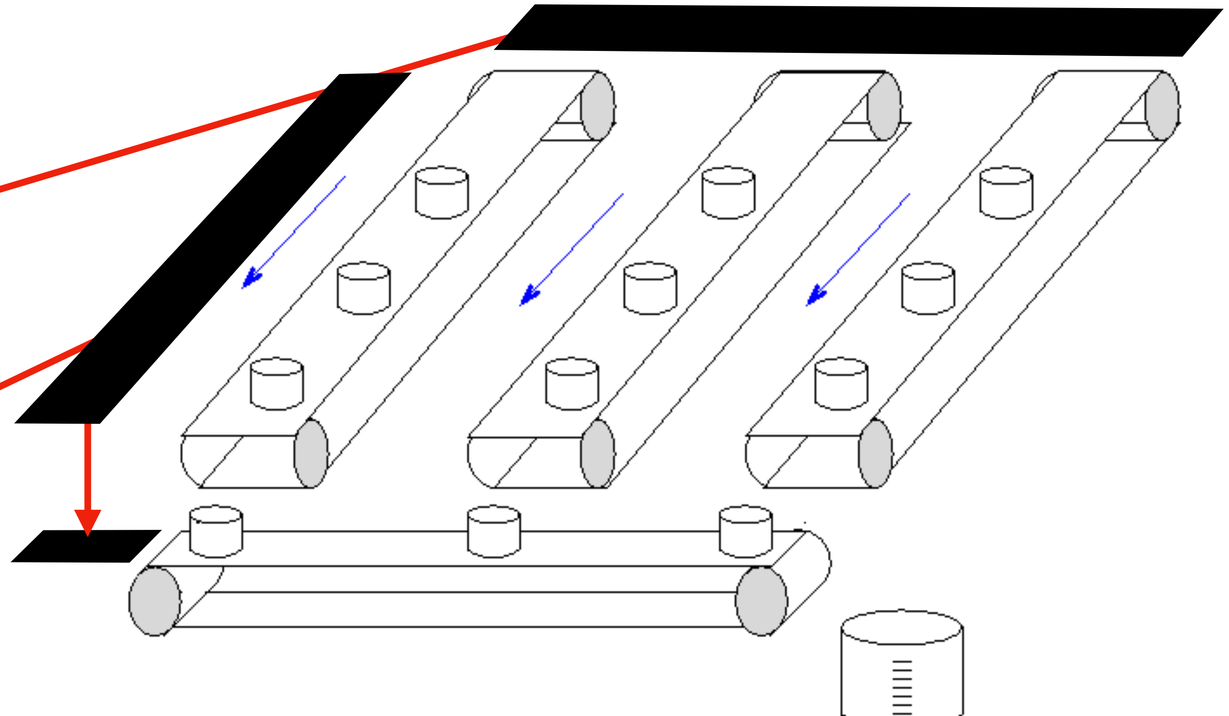


Overscans and subtraction

- What happens if we keep clocking out and reading once all the buckets are empty?

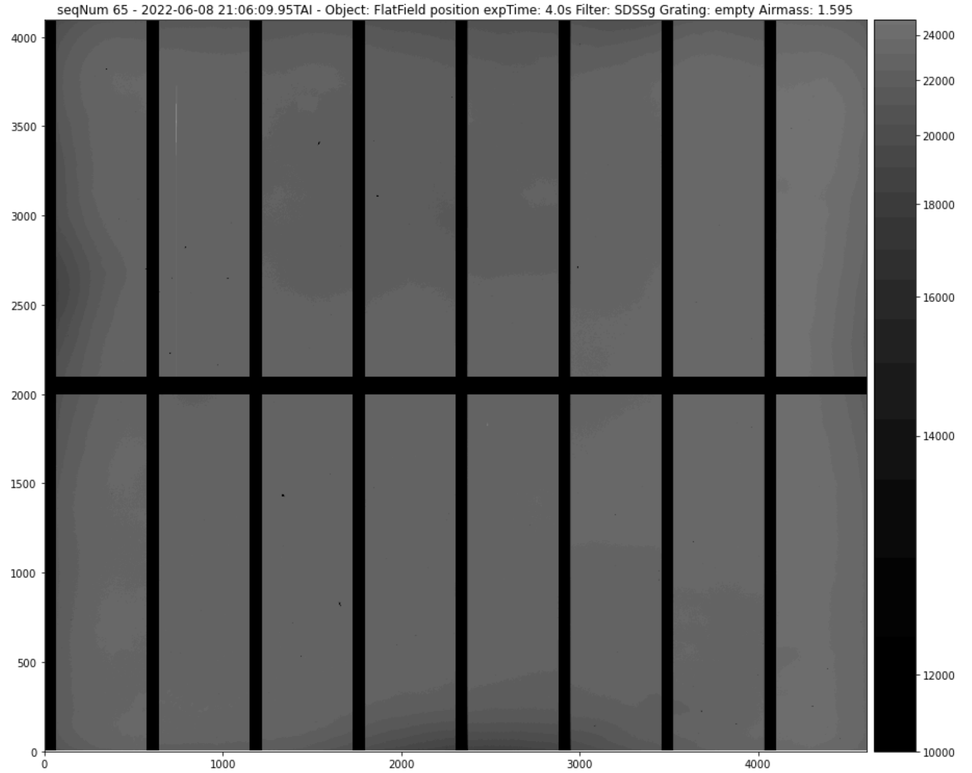


- What if these setups aren't perfectly electrically isolated?



Quick end-to-end overview

Readout & digitisation

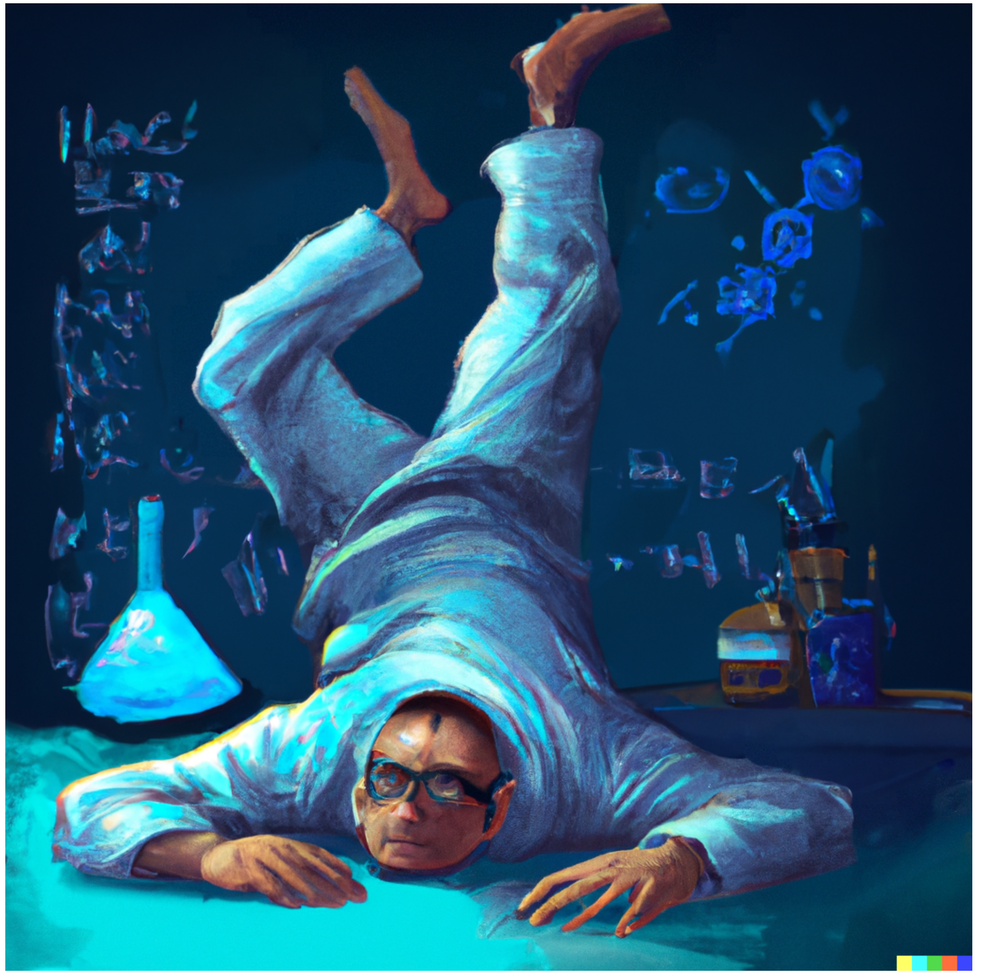


- Amplifiers:
  - We divide our chip into 16 amplifier to read out faster
- ADCs
  - We digitise the signal at 18 bits, with the gain tuned in order to sample the full well charge and the noise
- DAQs
  - This firehose of bits (>3 × 10^9 pixels at 18 bits in 2 seconds flat) has to be recorded!

Quick end-to-end overview

Rendering

- Your analysis algorithms can work on the raw (calibrated) data
- But *you* can't just look at numbers!
- A bad stretch is just as dangerous for interpreting your data as it is for my back!

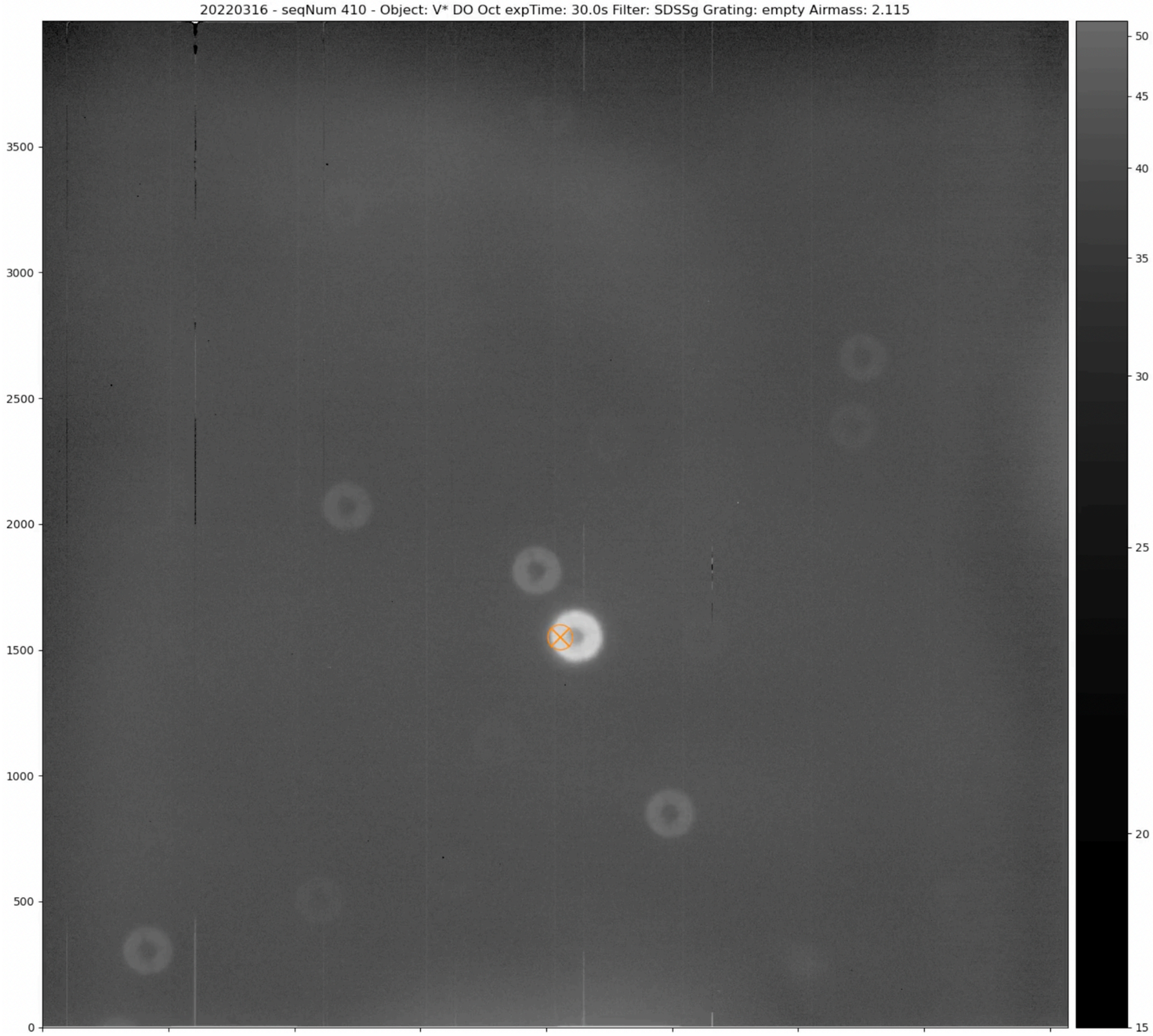


AI-generated image from DALL-E 2 using the prompt "*A scientist in distress while doing backbend in yoga in a chemistry lab, digital art*".

Two quick things you'll need to "just know"

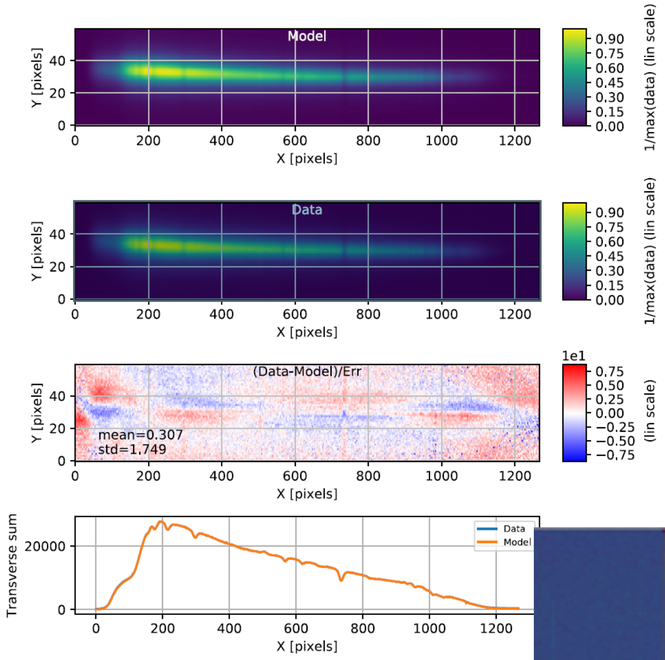
Donuts

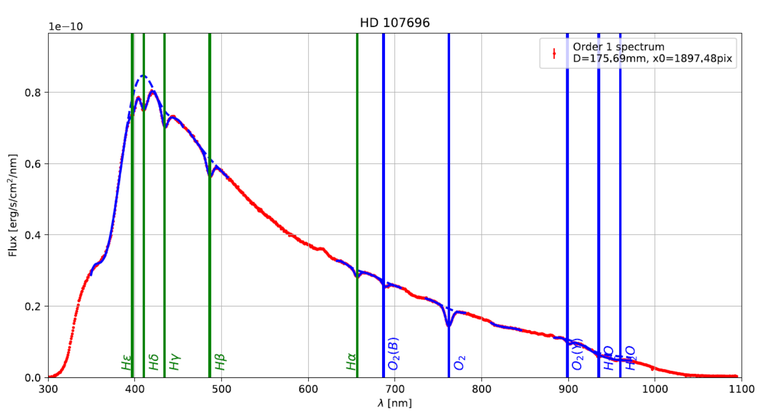
- Why do stars look like donuts?
- Not an accident, or a problem for once!
- Used for focusing

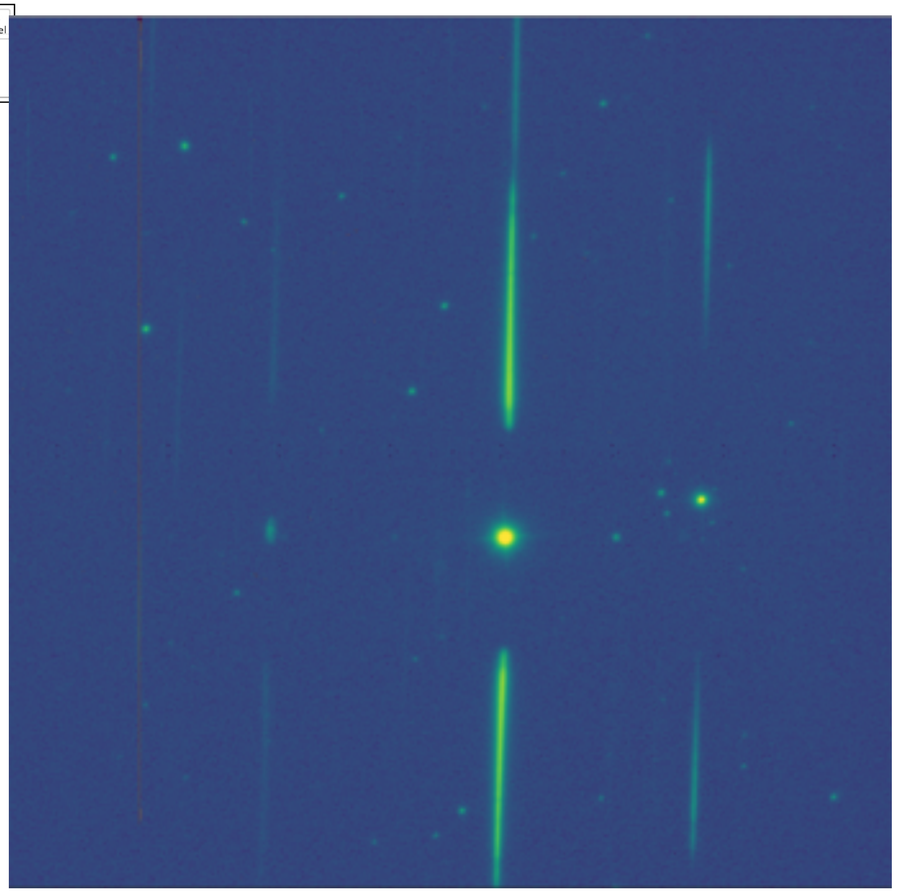


Spectra

- Why do stars look like lines?
- Not an accident, or a problem for once!
- This is a spectrograph, so when there is a disperser in the beam we get a spectrum



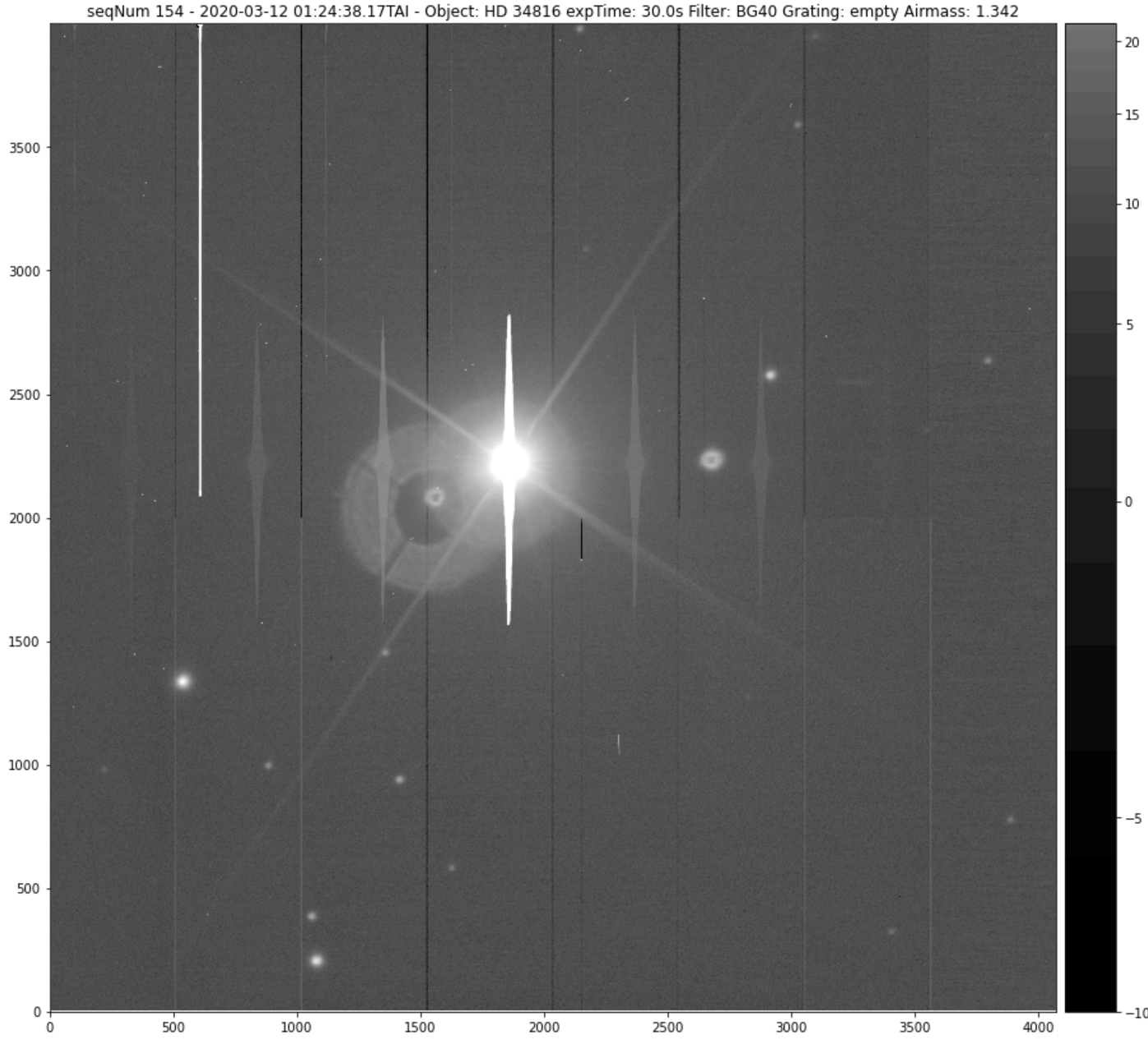




Now you know everything so let's put it all together!

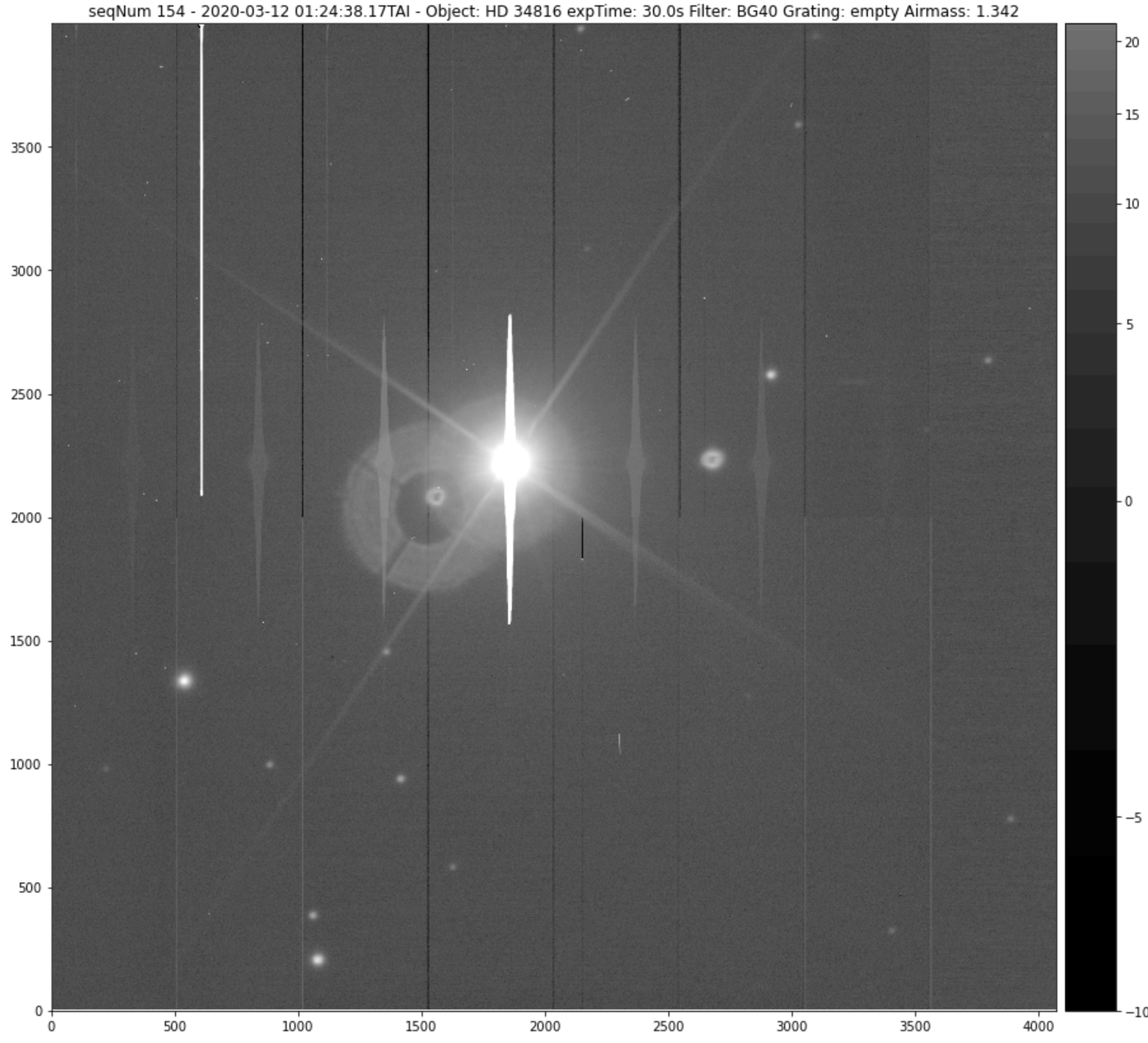
Group work

- In groups, list everything you can see going on



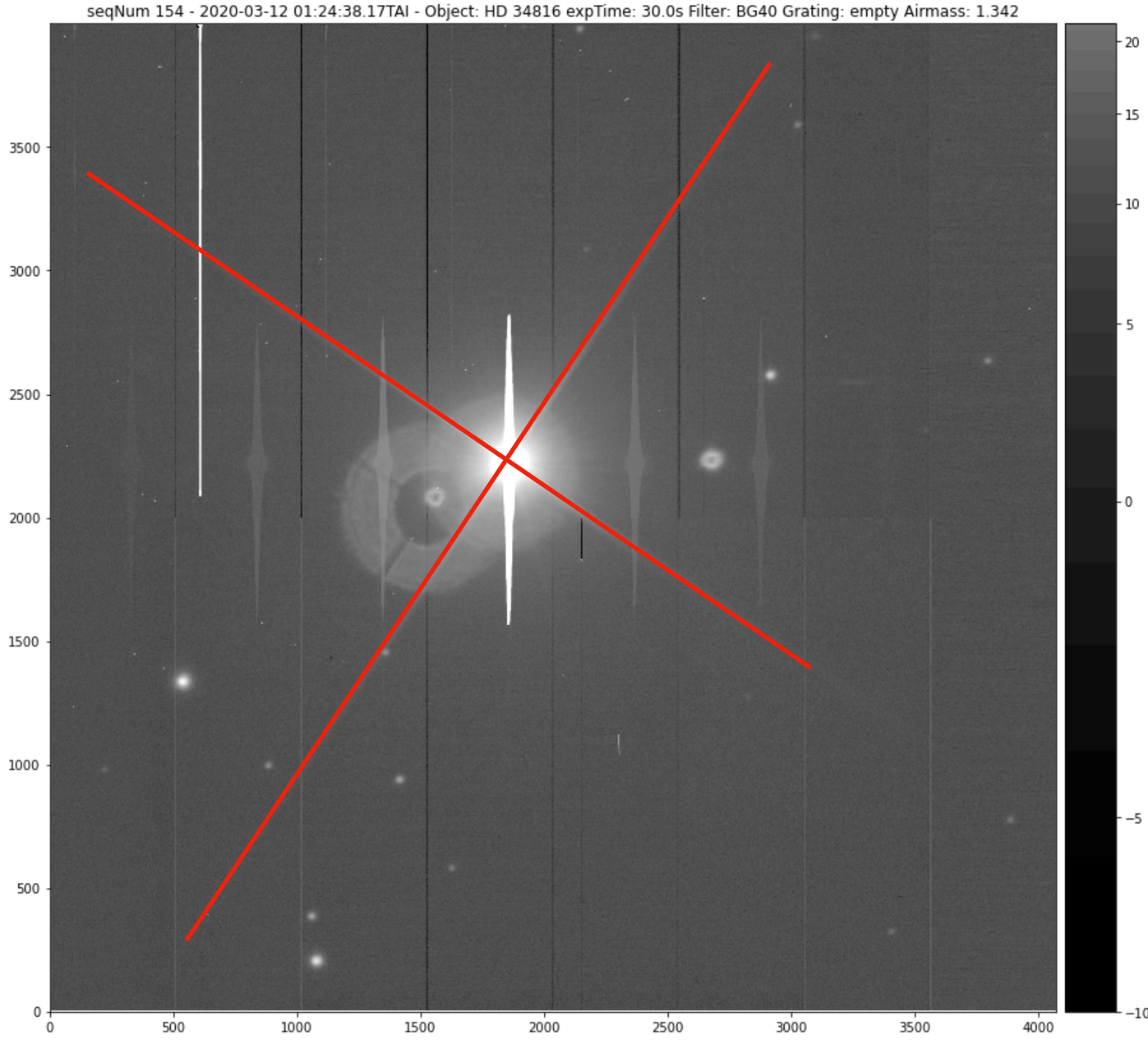
Explanation

- Diffraction spikes
- Amp boundaries
- Pupil ghosts
- Crosstalk
- Bleeding
- Column defect
- Cosmic rays/bright pixels



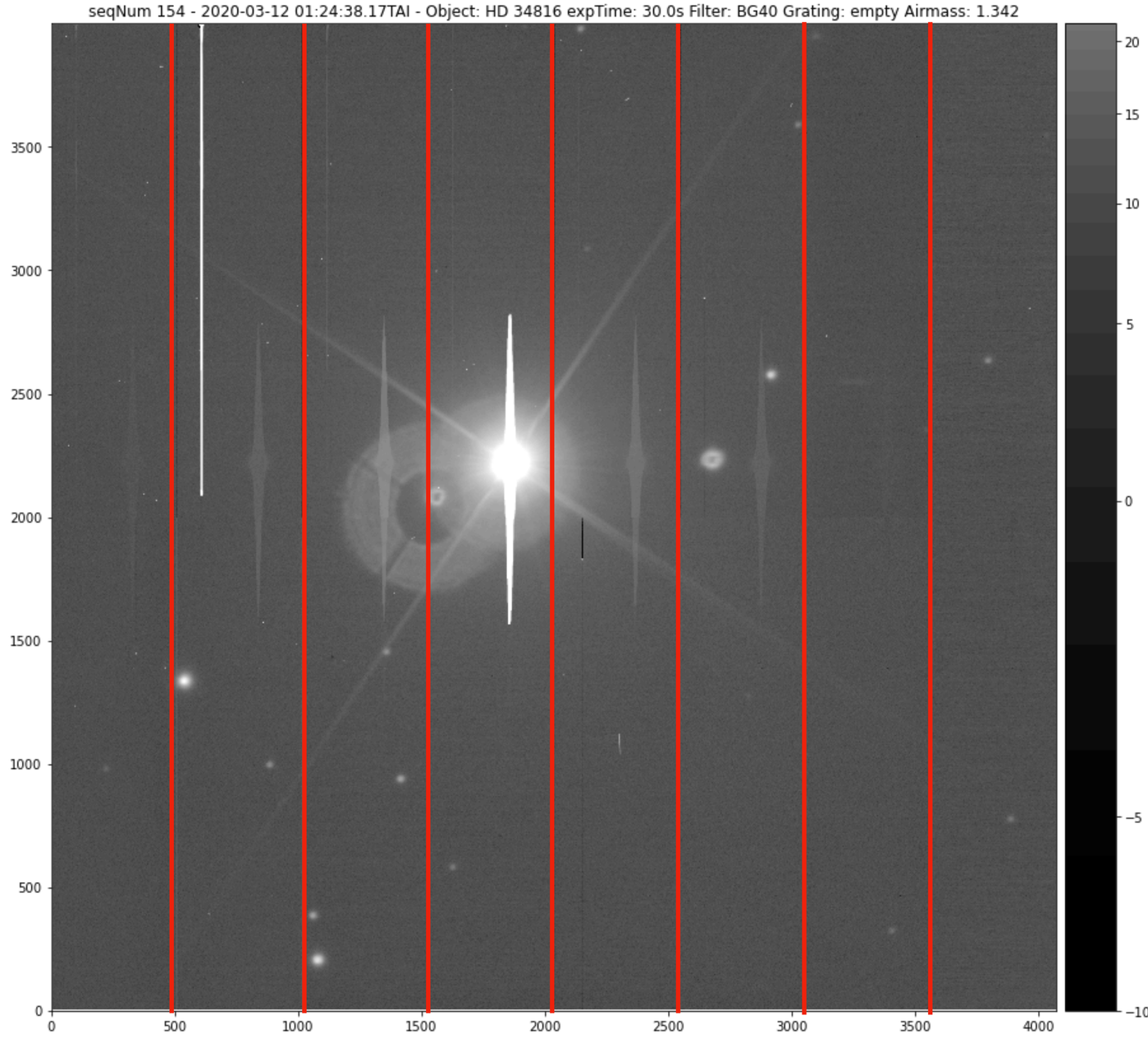
Explanation

- Diffraction spikes
- Amp boundaries
- Pupil ghosts
- Crosstalk
- Bleeding
- Column defect
- Cosmic rays/bright pixels



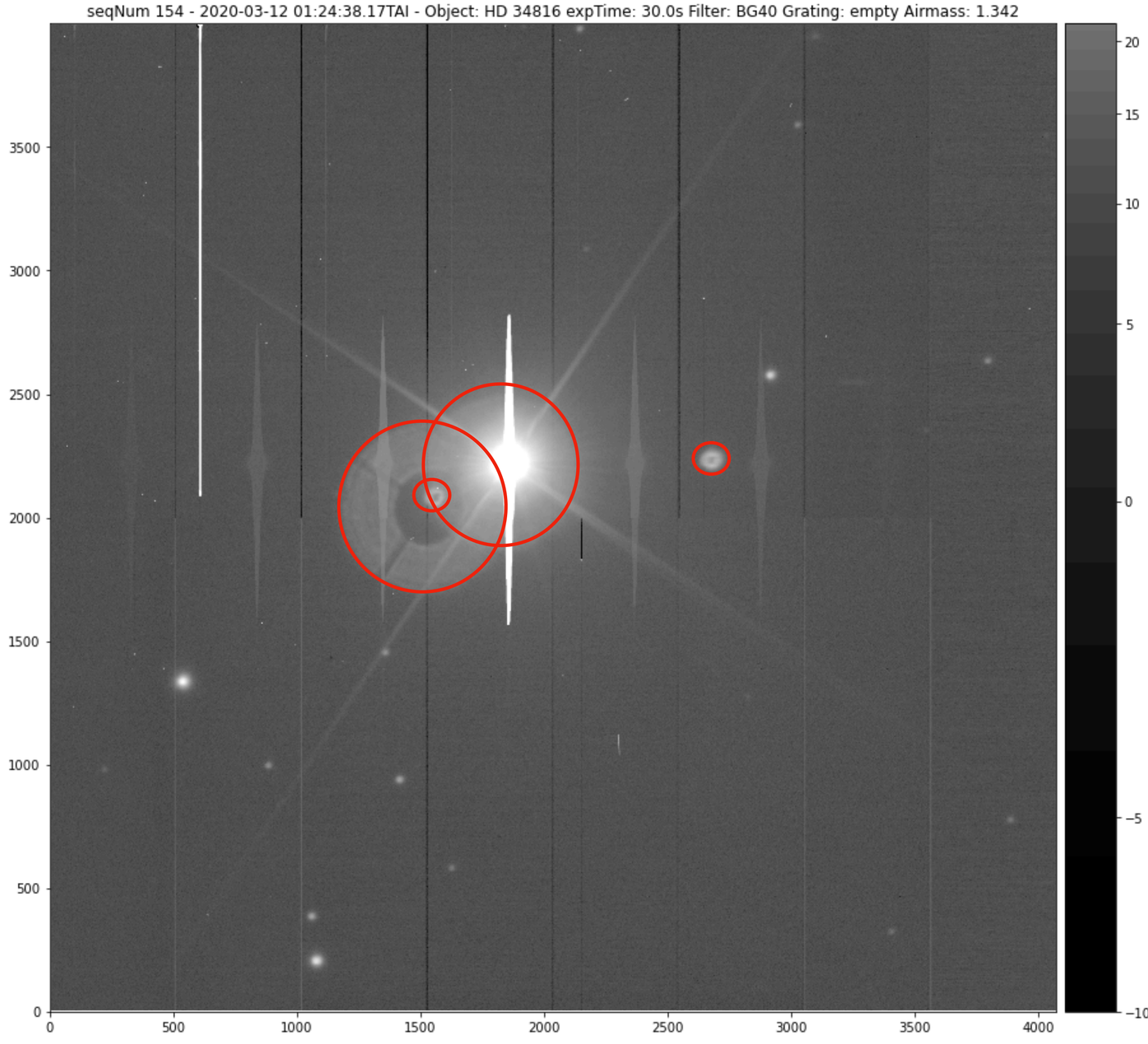
Explanation

- Diffraction spikes
- Amp boundaries
- Pupil ghosts
- Crosstalk
- Bleeding
- Column defect
- Cosmic rays/bright pixels



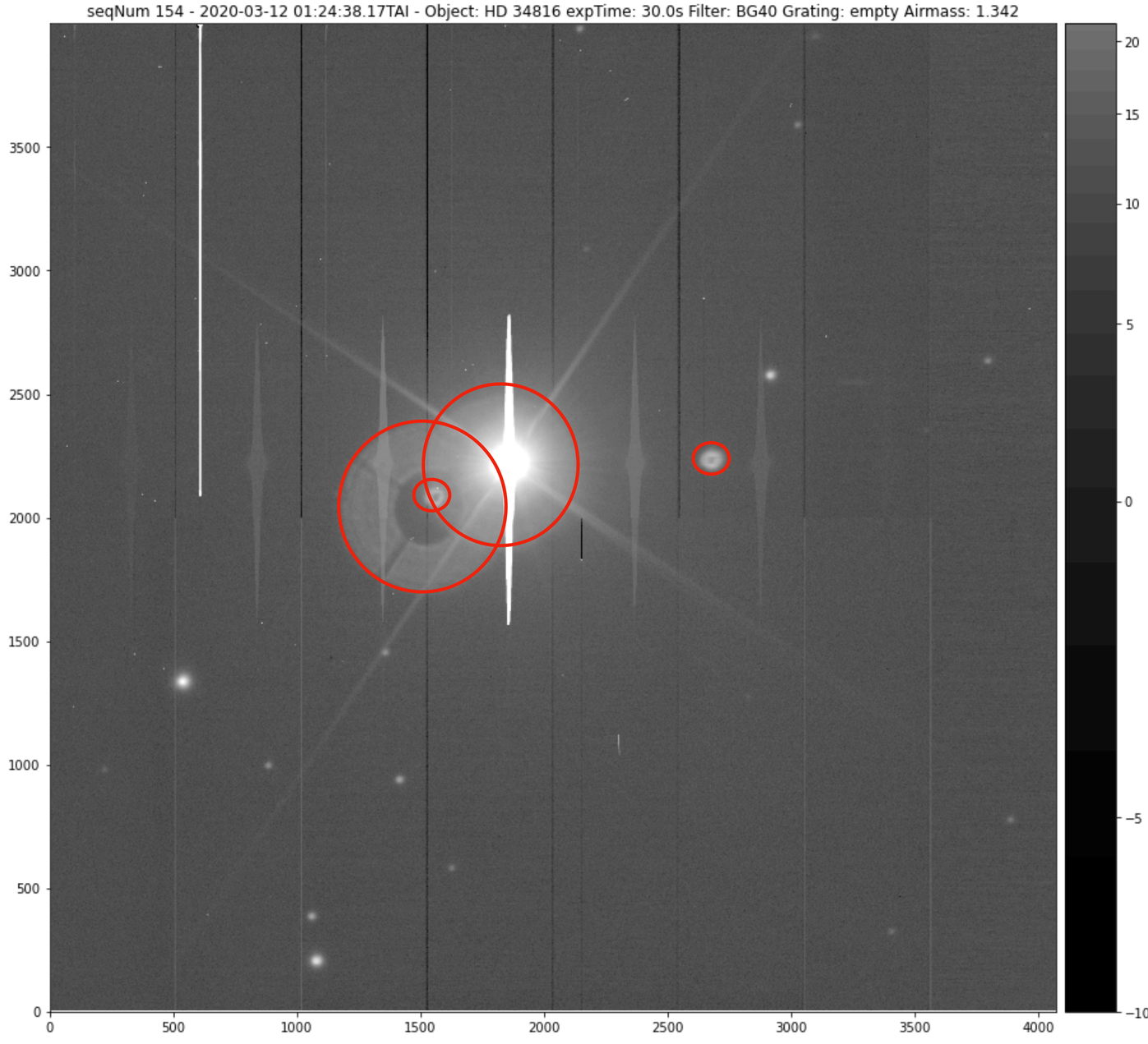
Explanation

- Diffraction spikes
- Amp boundaries
- Pupil ghosts
- Crosstalk
- Bleeding
- Column defect
- Cosmic rays/bright pixels



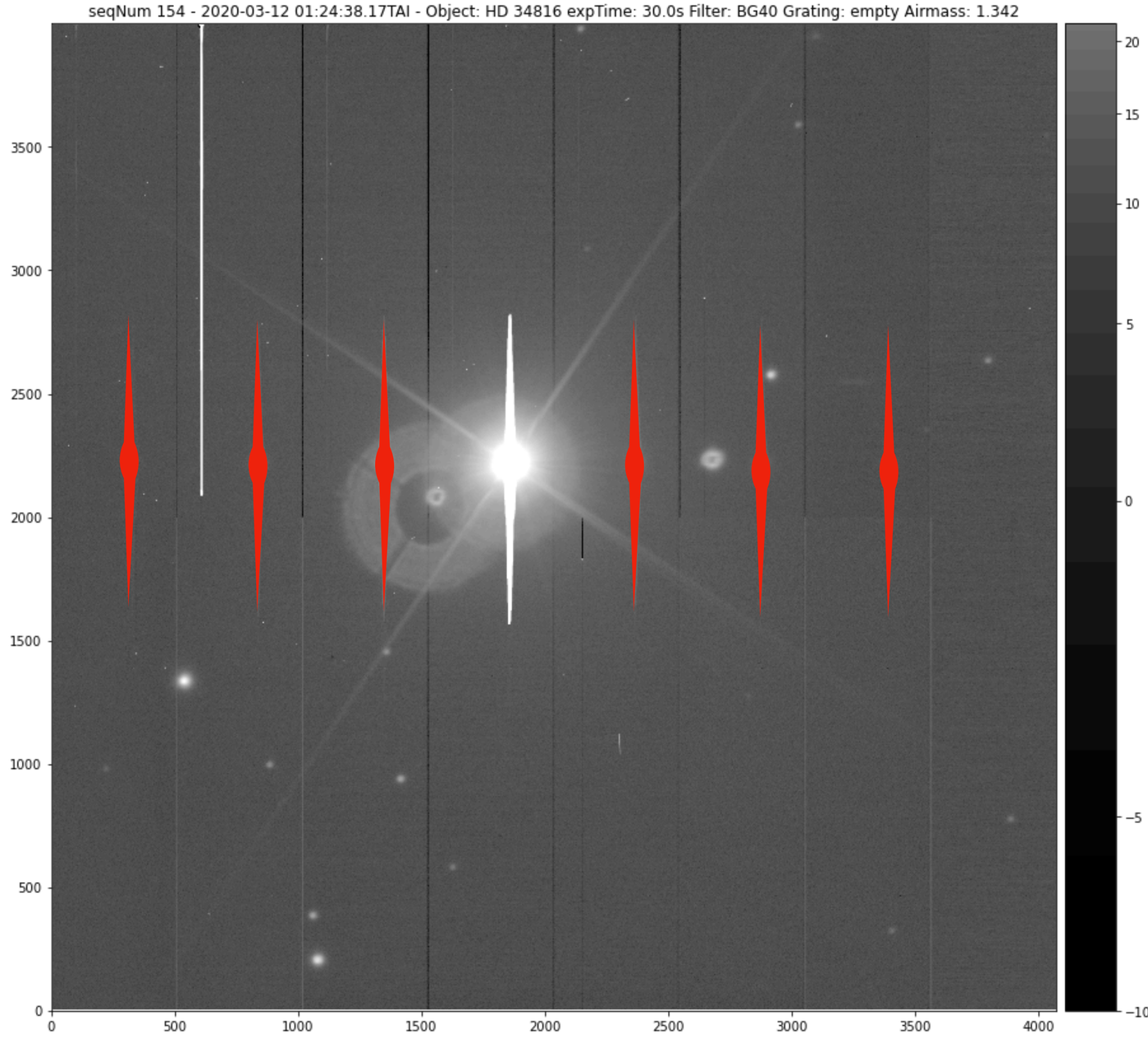
Explanation

- Diffraction spikes
- Amp boundaries
- Pupil ghosts
- Crosstalk
- Bleeding
- Column defect
- Cosmic rays/bright pixels



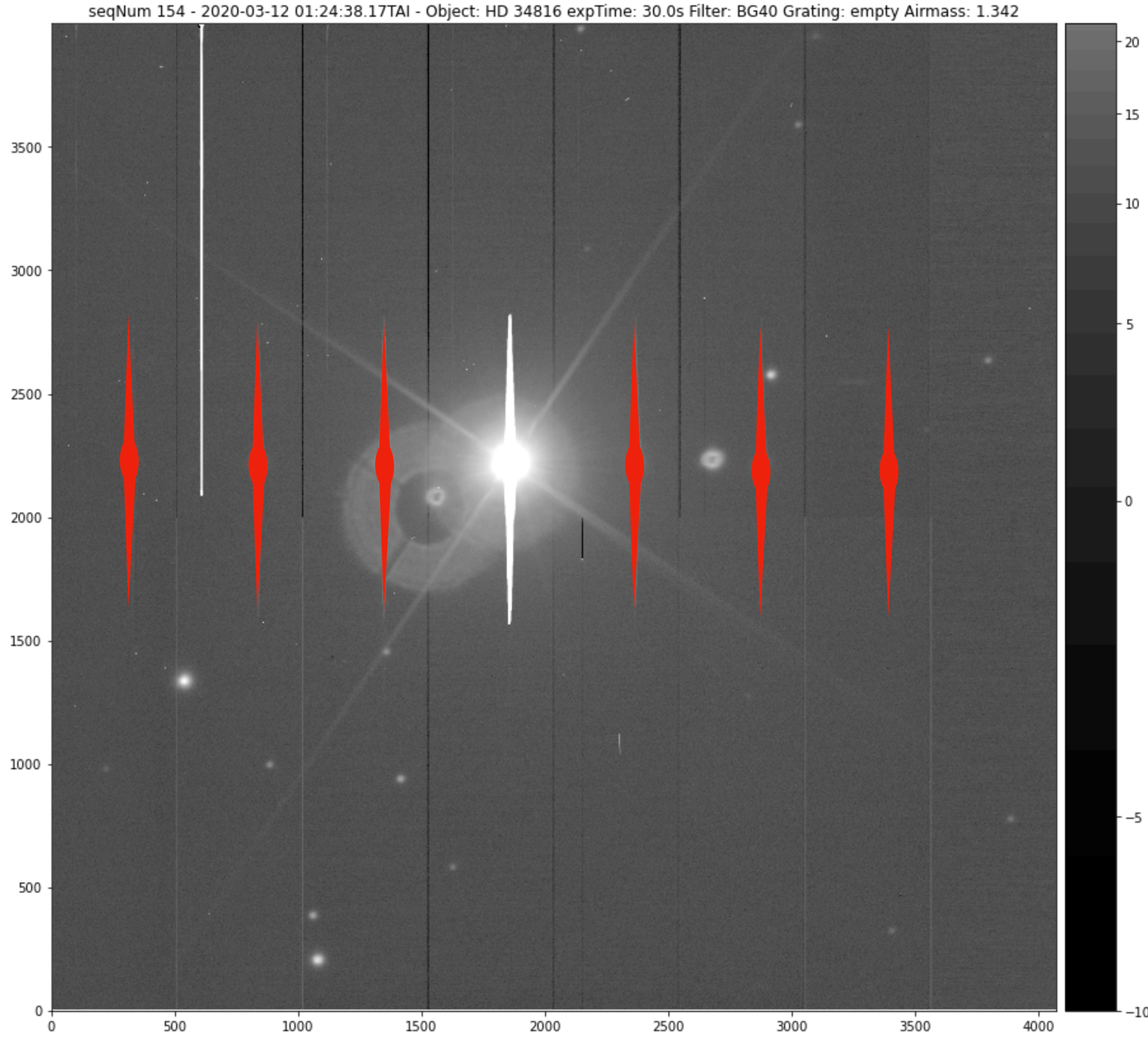
Explanation

- Diffraction spikes
- Amp boundaries
- Pupil ghosts
- Crosstalk
- Bleeding
- Column defect
- Cosmic rays/bright pixels



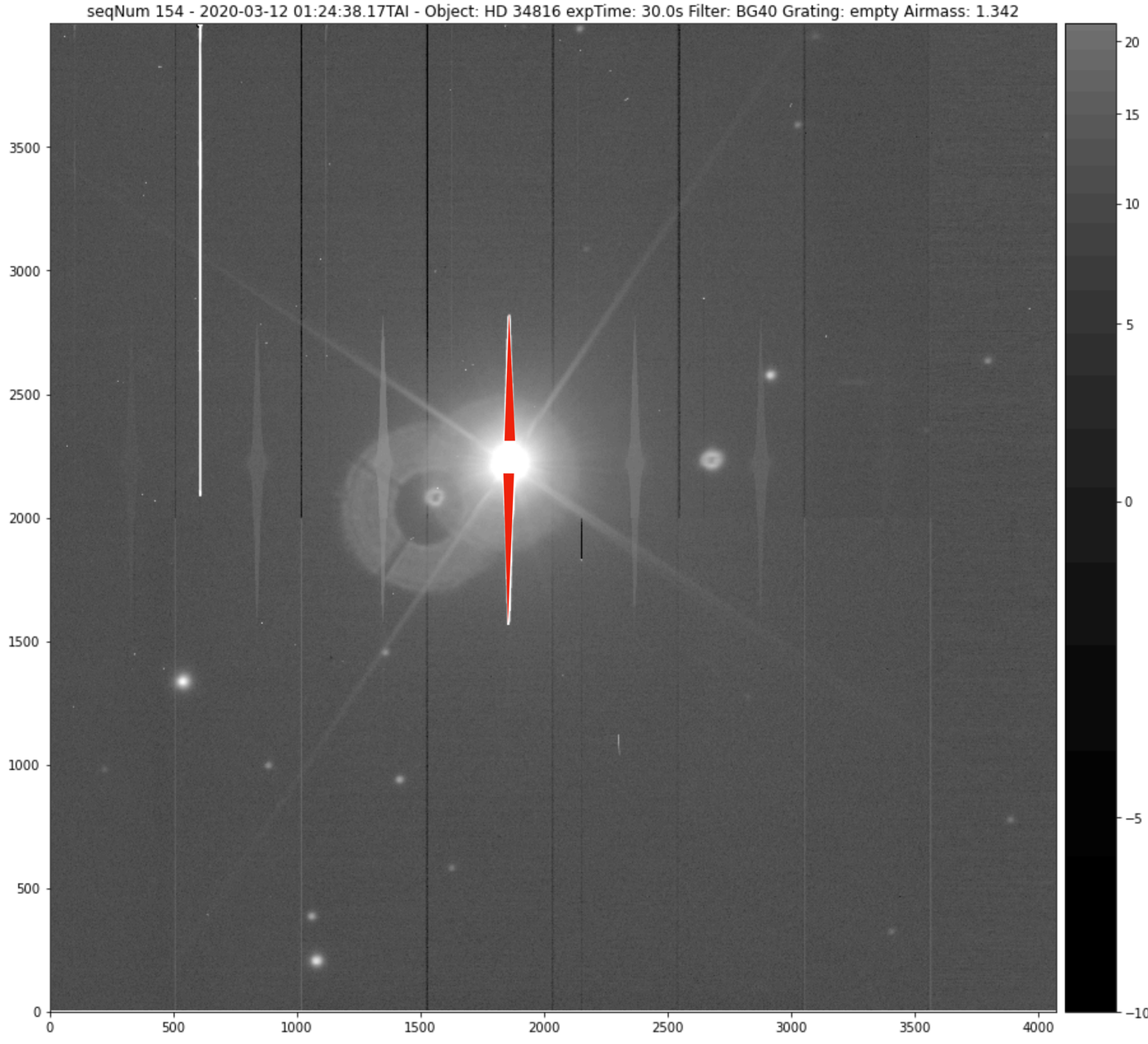
Explanation

- Diffraction spikes
- Amp boundaries
- Pupil ghosts
- Crosstalk
- Bleeding
- Column defect
- Cosmic rays/bright pixels



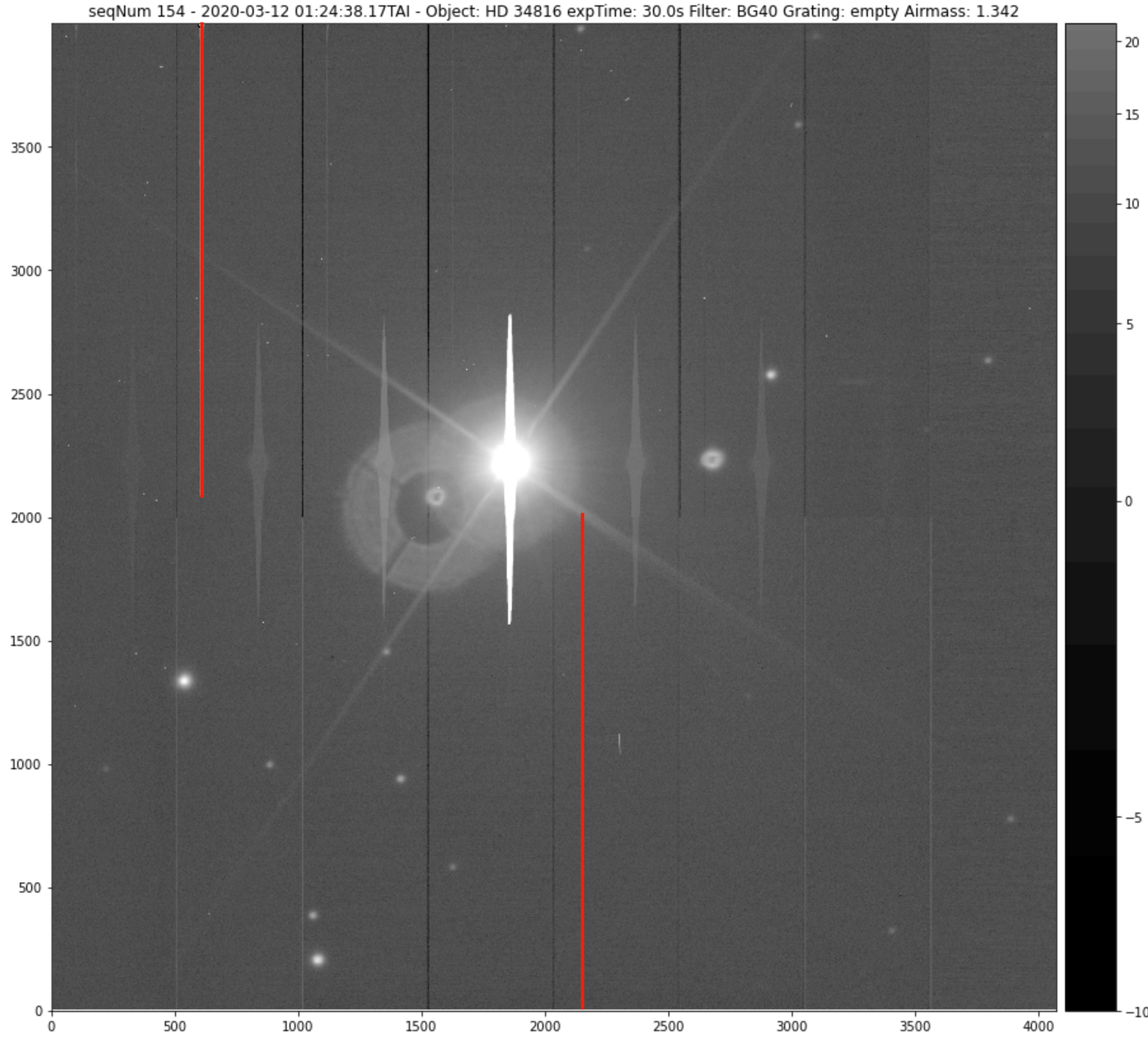
Explanation

- Diffraction spikes
- Amp boundaries
- Pupil ghosts
- Crosstalk
- Bleeding
- Column defect
- Cosmic rays/bright pixels



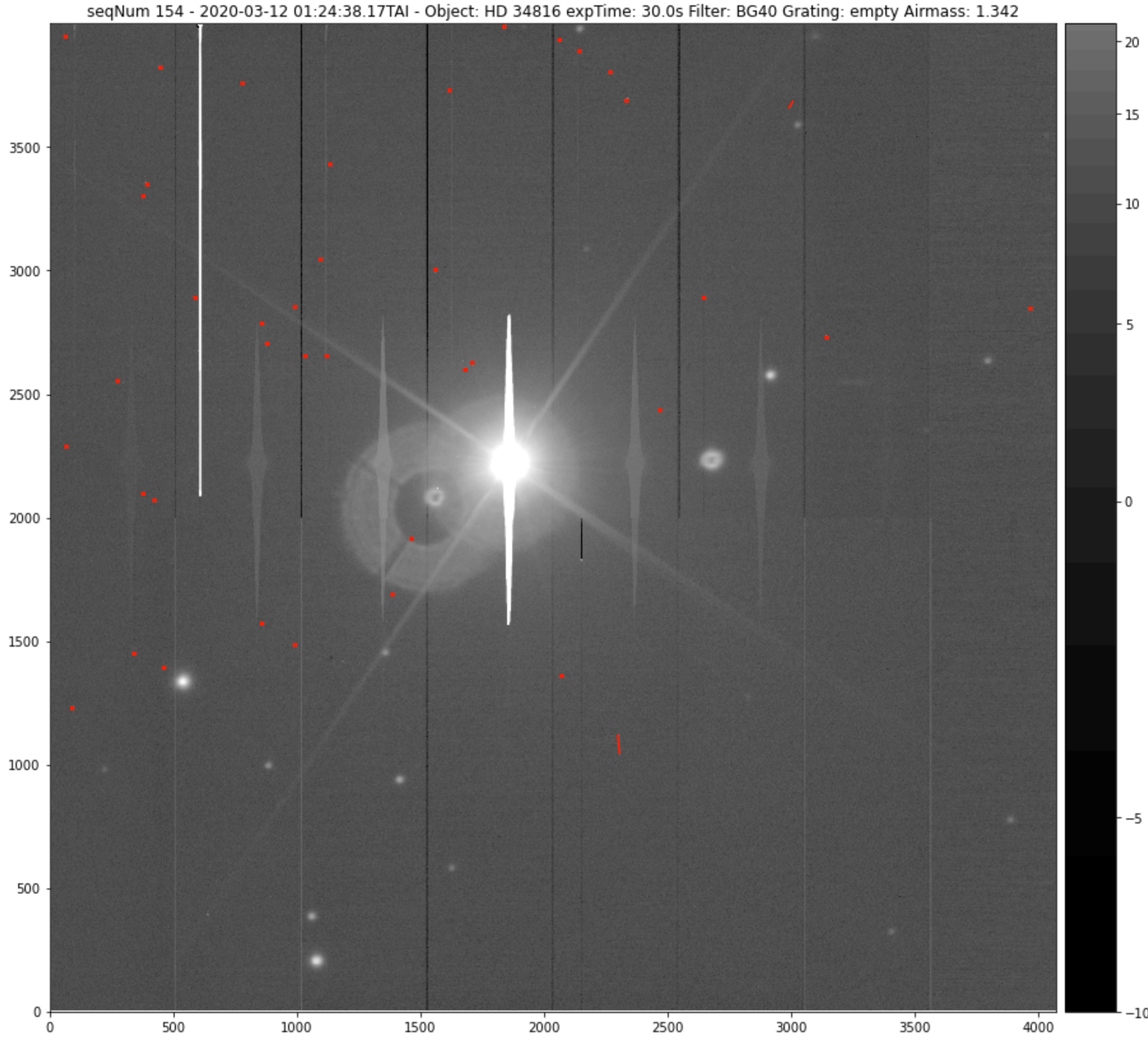
Explanation

- Diffraction spikes
- Amp boundaries
- Pupil ghosts
- Crosstalk
- Bleeding
- Column defect
- Cosmic rays/bright pixels



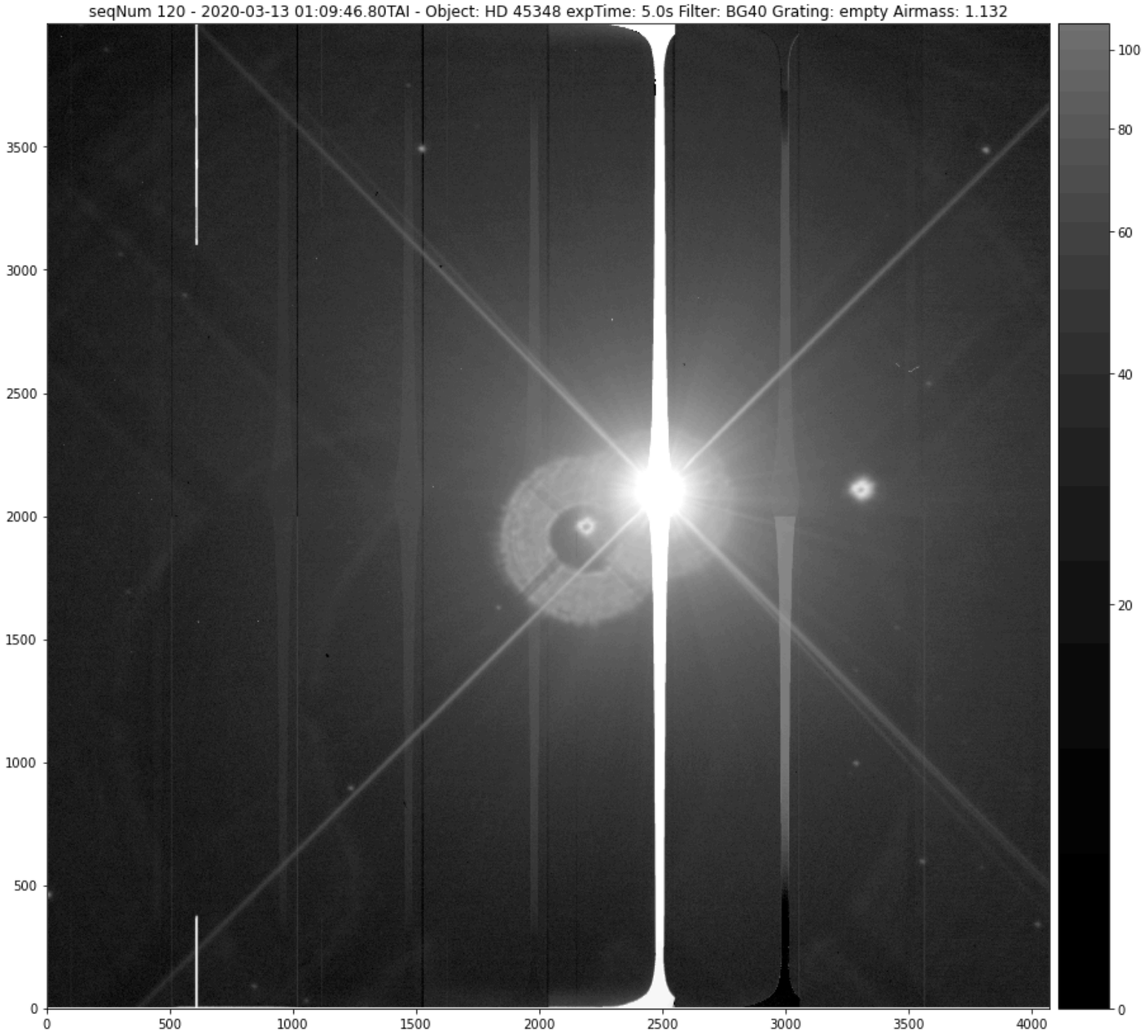
Explanation

- Diffraction spikes
- Amp boundaries
- Pupil ghosts
- Crosstalk
- Bleeding
- Column defect
- Cosmic rays/bright pixels



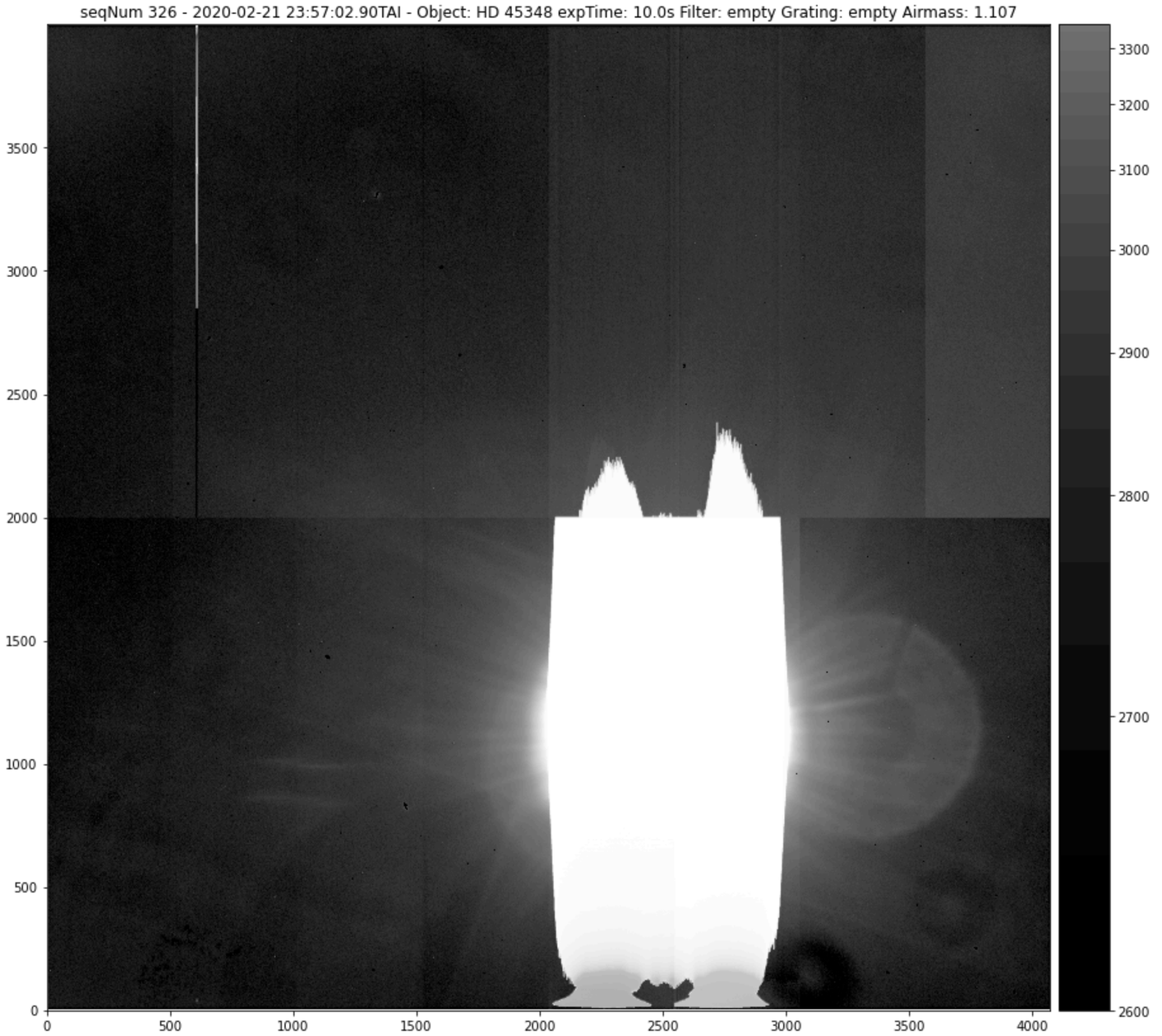
Group work

- Effects are similar here, but more
- What are we seeing now?



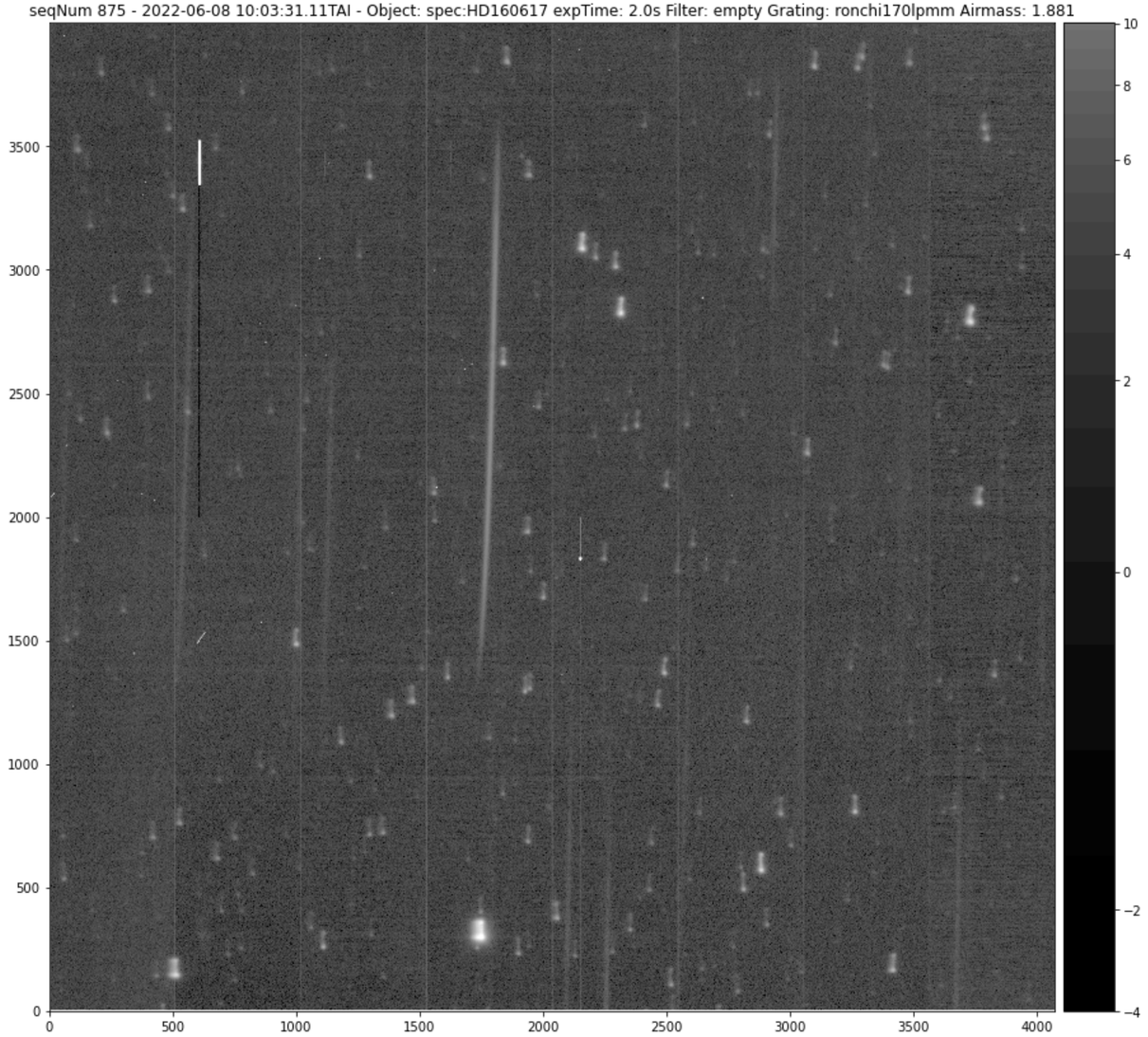
Group work

- Turning it up yet more...
- What are we seeing *now*, and why does it have this shape?



Group work - spot the difference

Two totally-different but similar-looking things happening here!



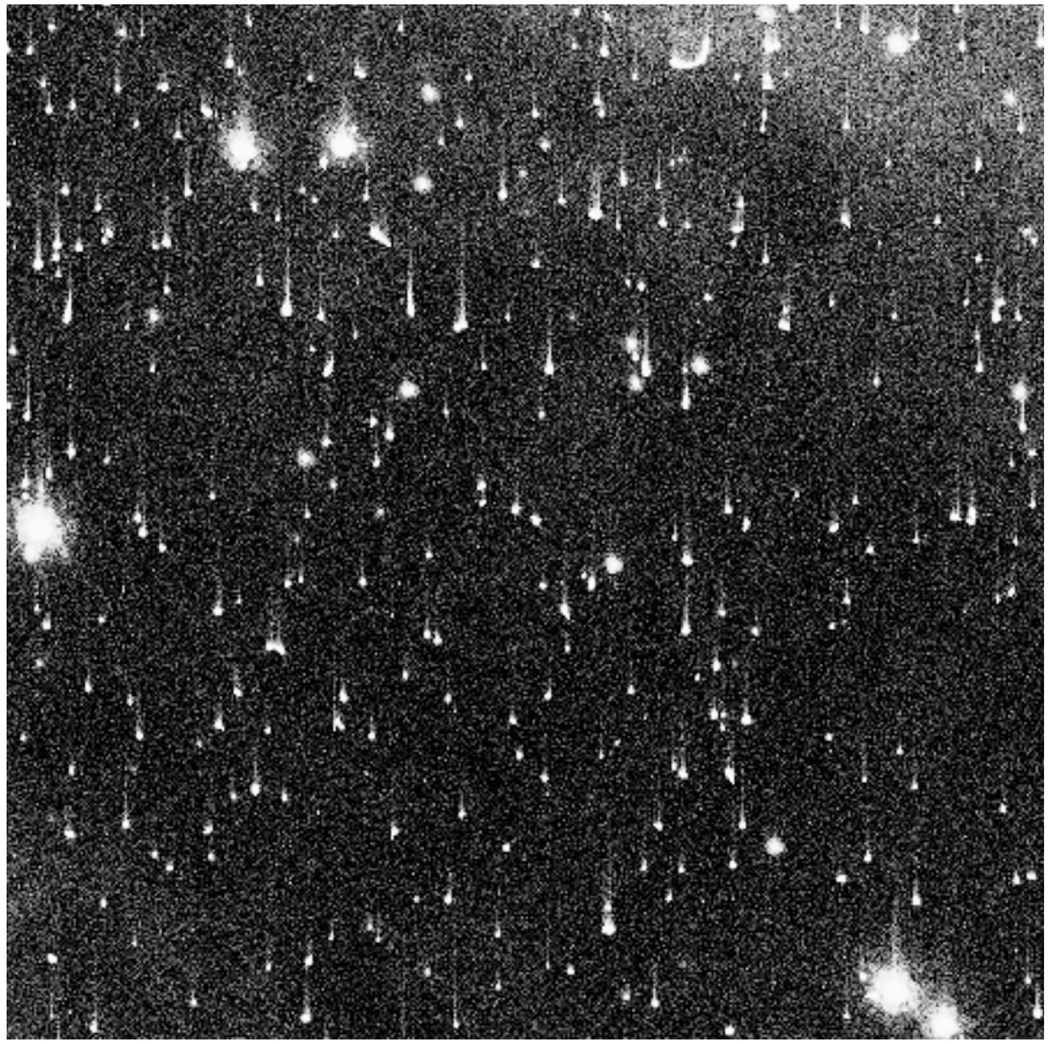
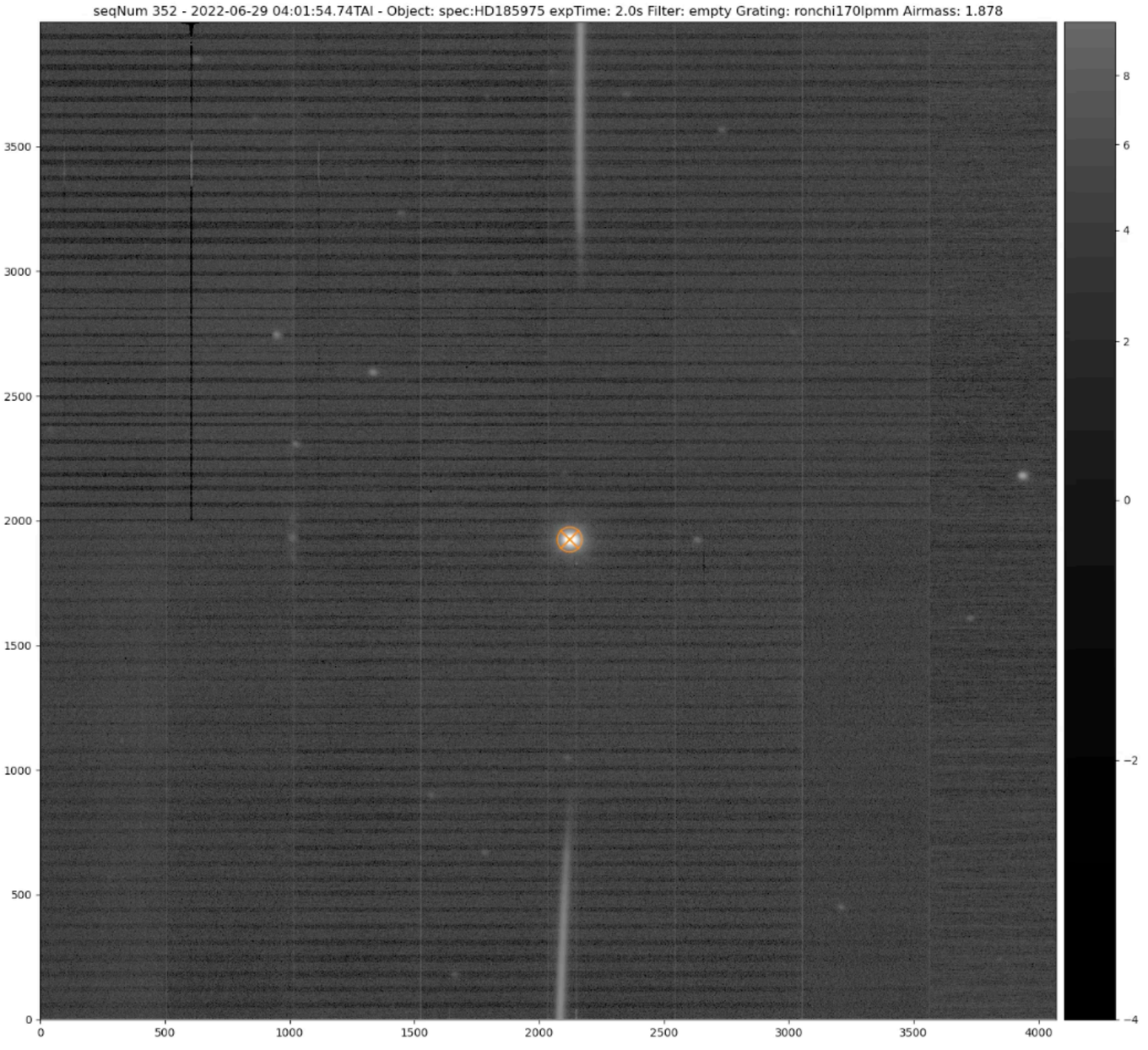
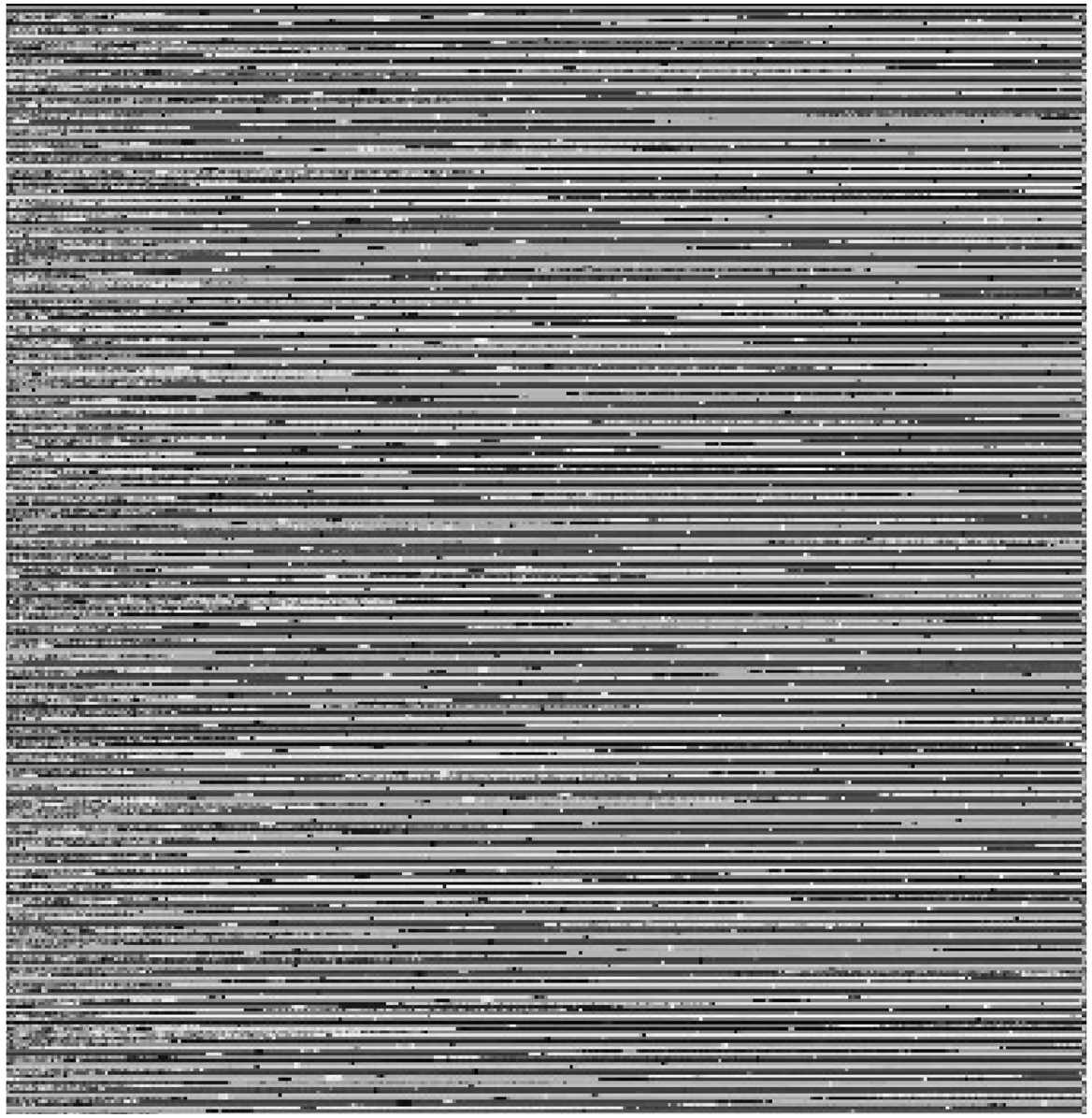


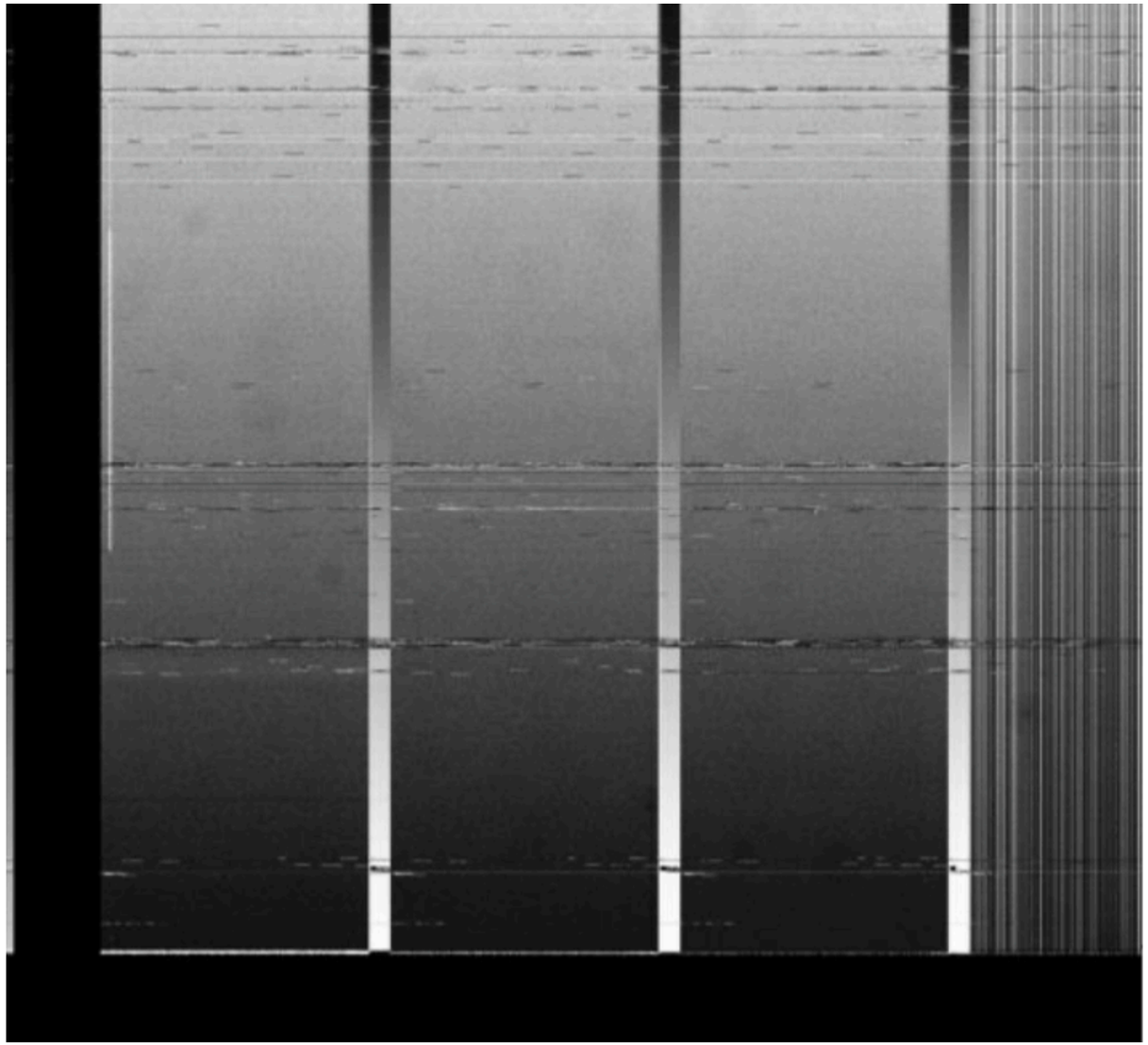
Image credit (*E. Sabbi*)
https://spie.org/news/6838-ensuring-high-quality-science-from-the-hubble-space-telescope-into-the-next-decade

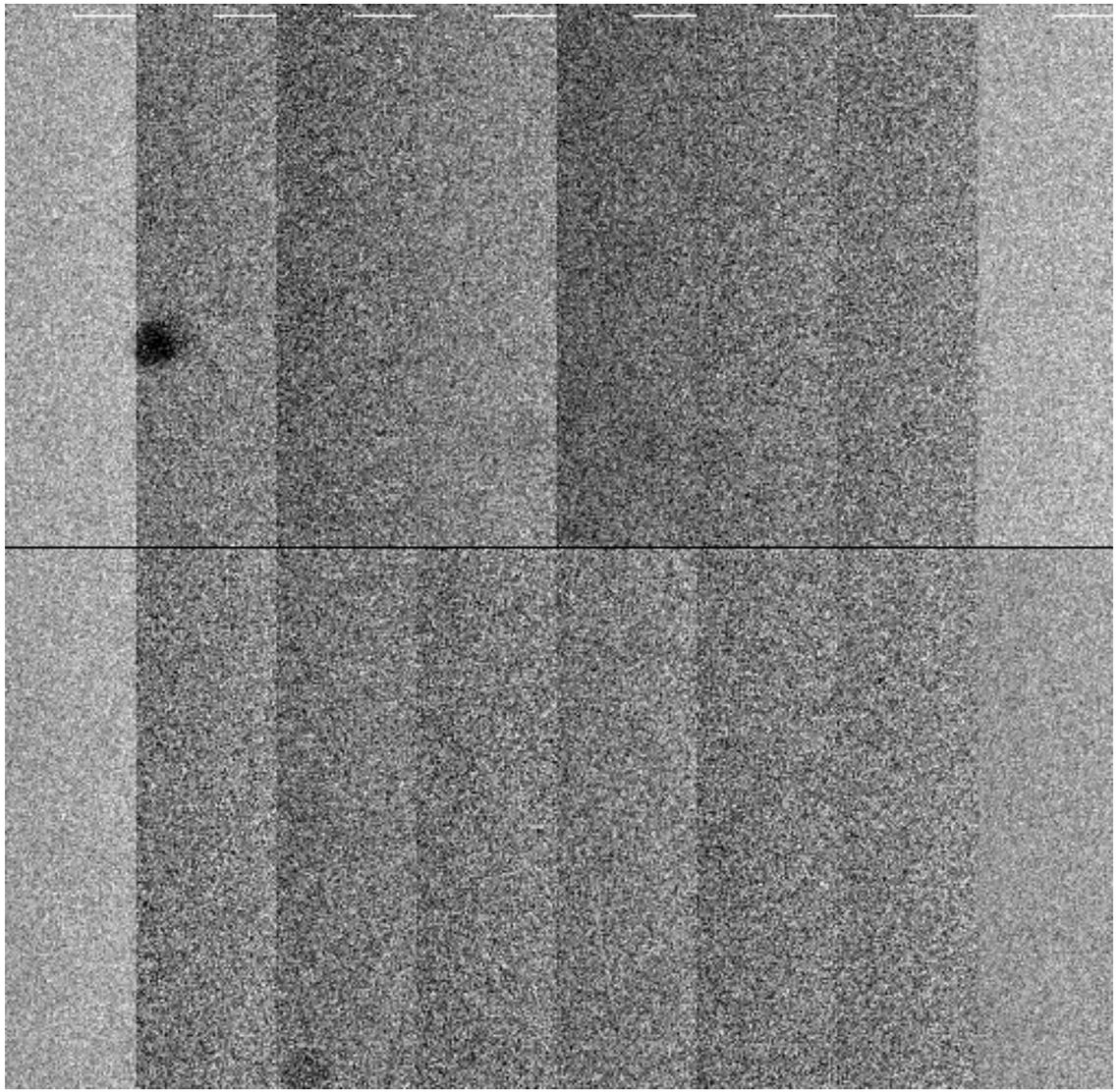
Group work - spot the difference



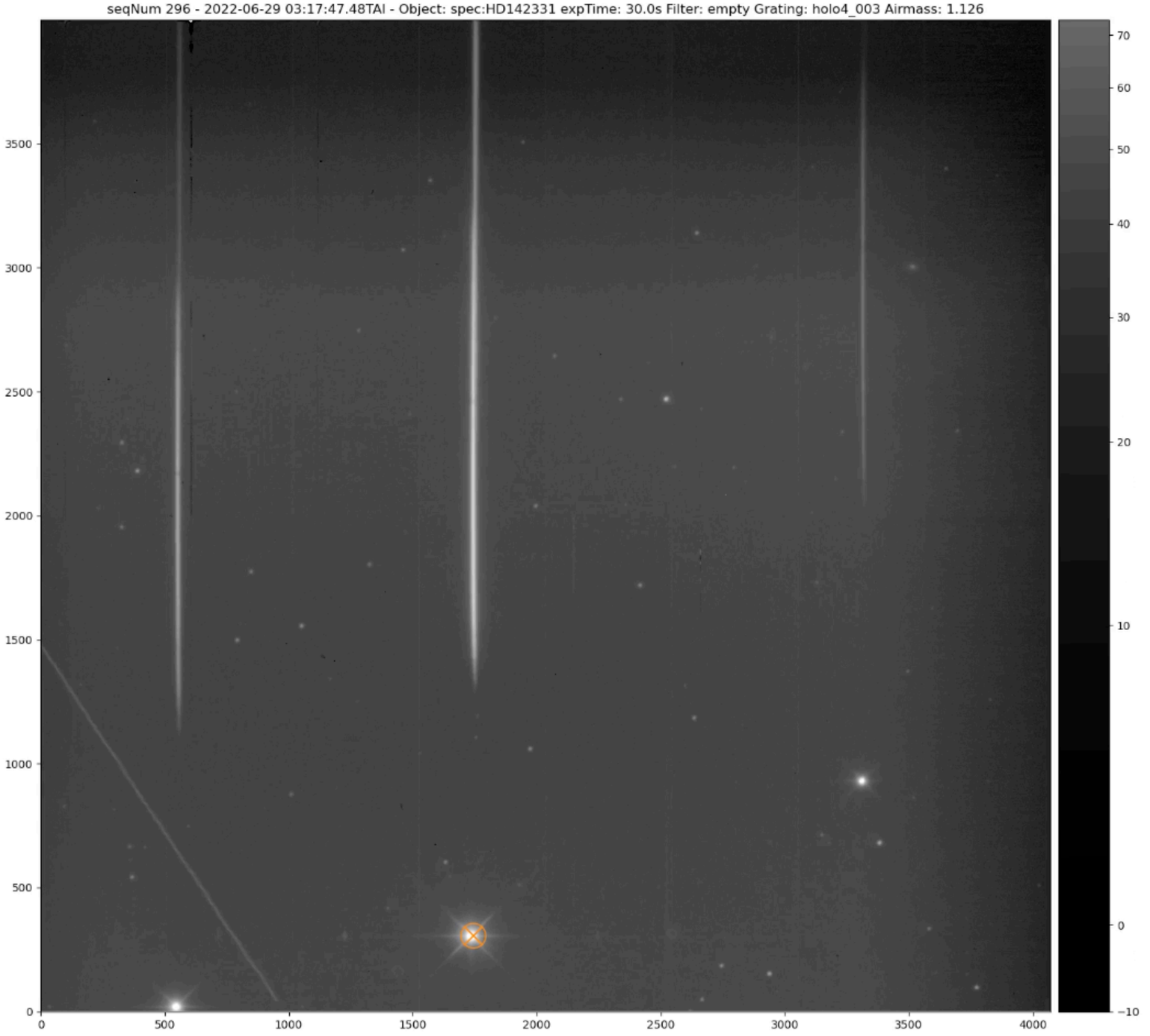


More examples of corruption

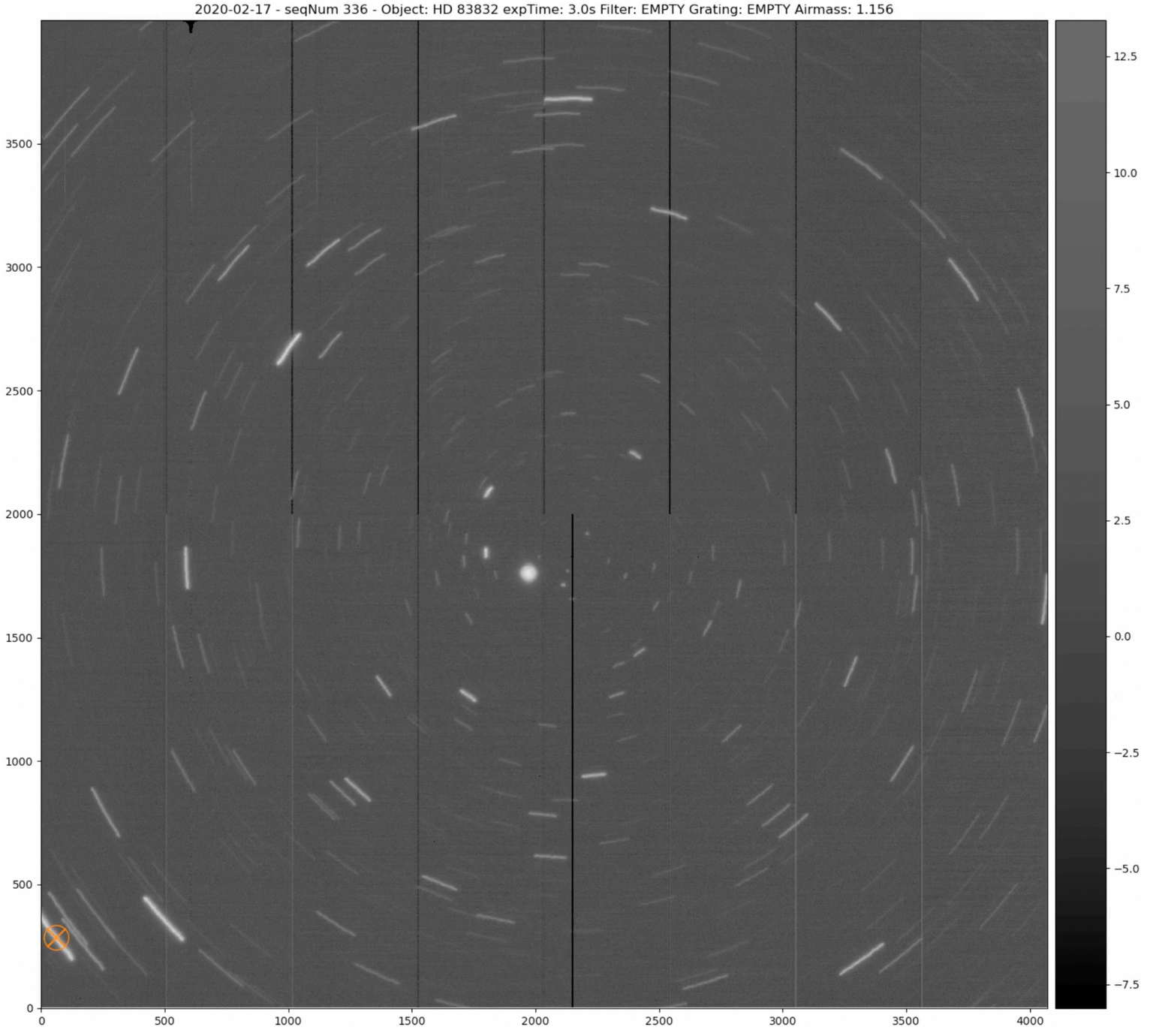




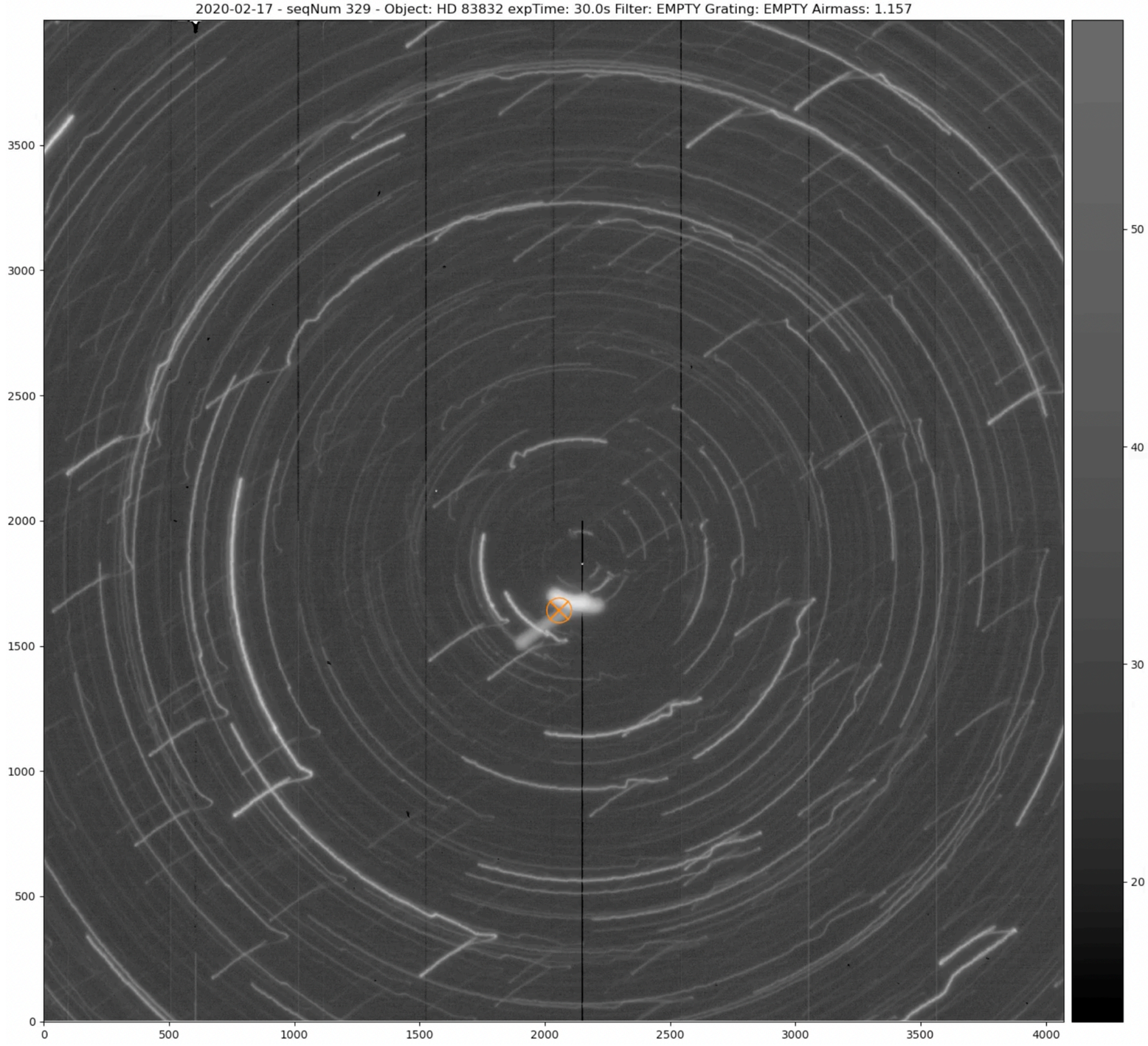
Quick fire round:



Quick fire round:



Quick fire round:



Let's list all the effects

Yes, it's quite a long list...

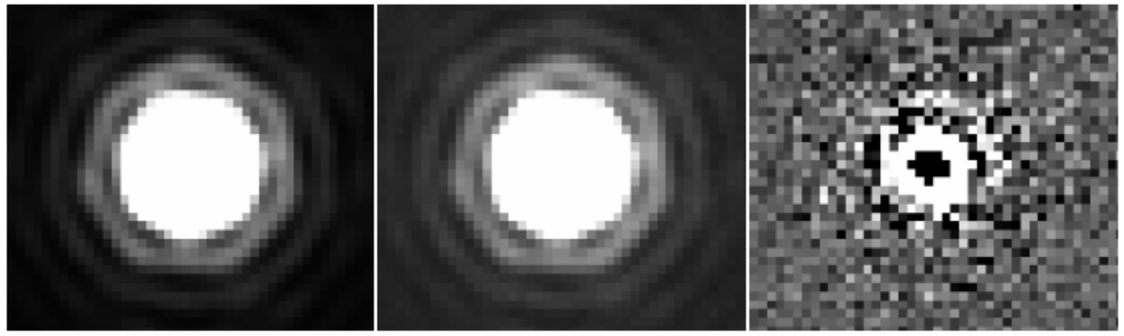
- Bleed trails
- Cosmic rays
- Physical damage to the CCD
- Bright defects
- Dark defects
- Glowing amplifiers
- Bias structure
- CTI (if it's bad enough)
- RF pickup
- Data corruption
- Diffraction spikes
- Ghosts
- Crosstalk
- Vignetting
- Occlusion
- QE variations
- Fringing
- Pointing problems
- Satellites
- Tearing
- ...

What did we miss?

- Some effects are directly visible in the images, some are not:
  - Linearity & gain variations
  - Brighter-fatter effect
  - Tree rings (there, but far too subtle to see)
- Most others can be seen...

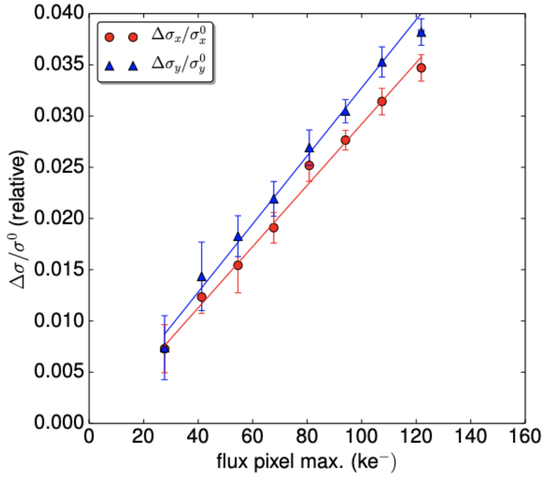
Brighter-fatter effect

- Why does it happen?
- How do we know?
- How do we correct for this?

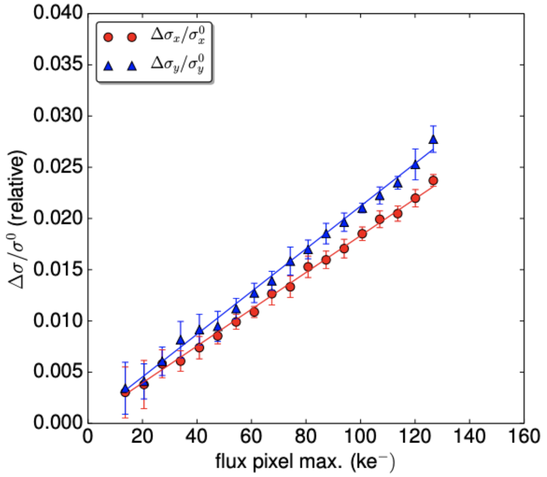


(a) 200-s exposures (b) 20-s exposures (c) subtraction (a)-(b)

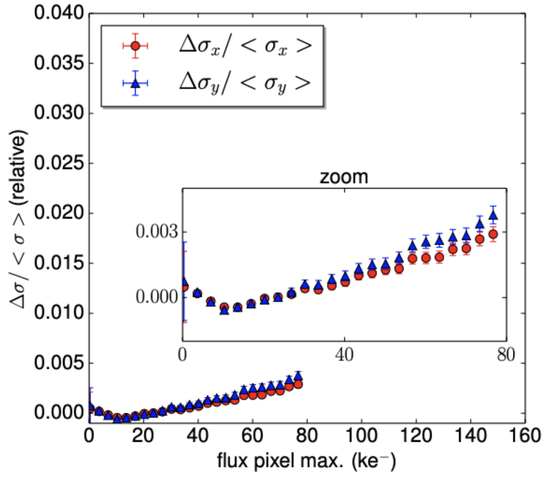
Guyonnet+15



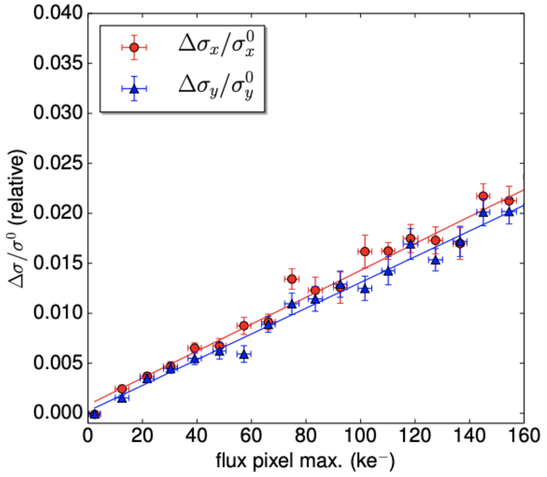
(a) LSST - E2V 250 - Spots 550 nm



(b) LSST - E2V 250 - Spots 900 nm



(c) MegaCam - E2V 42-90 - *r*-band stars



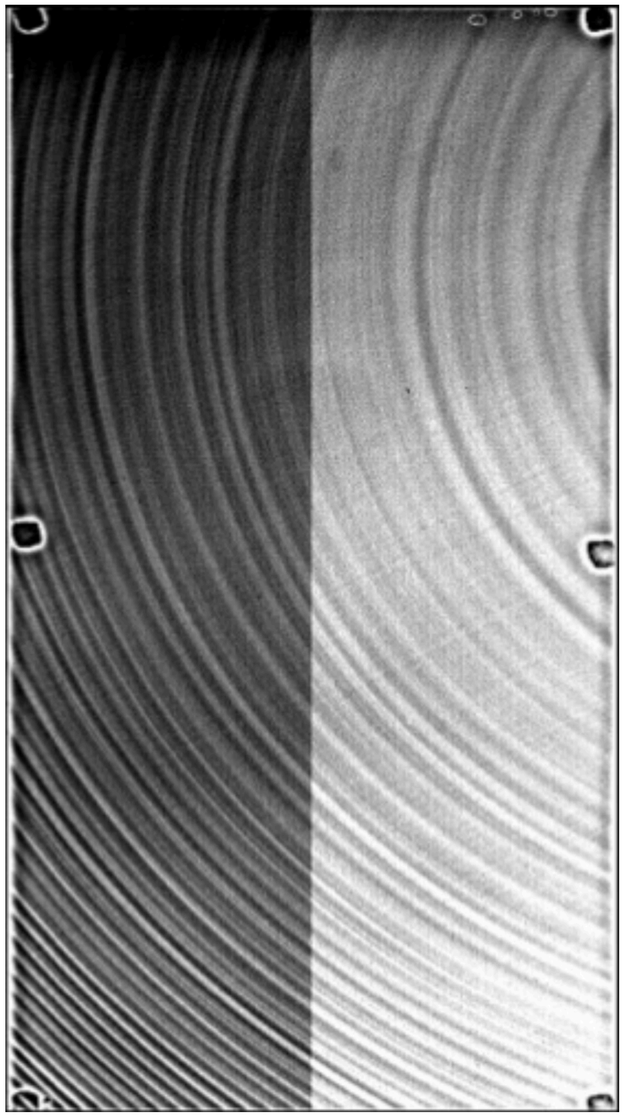
(d) DECam - LBL/DALSA - *r*-band stars

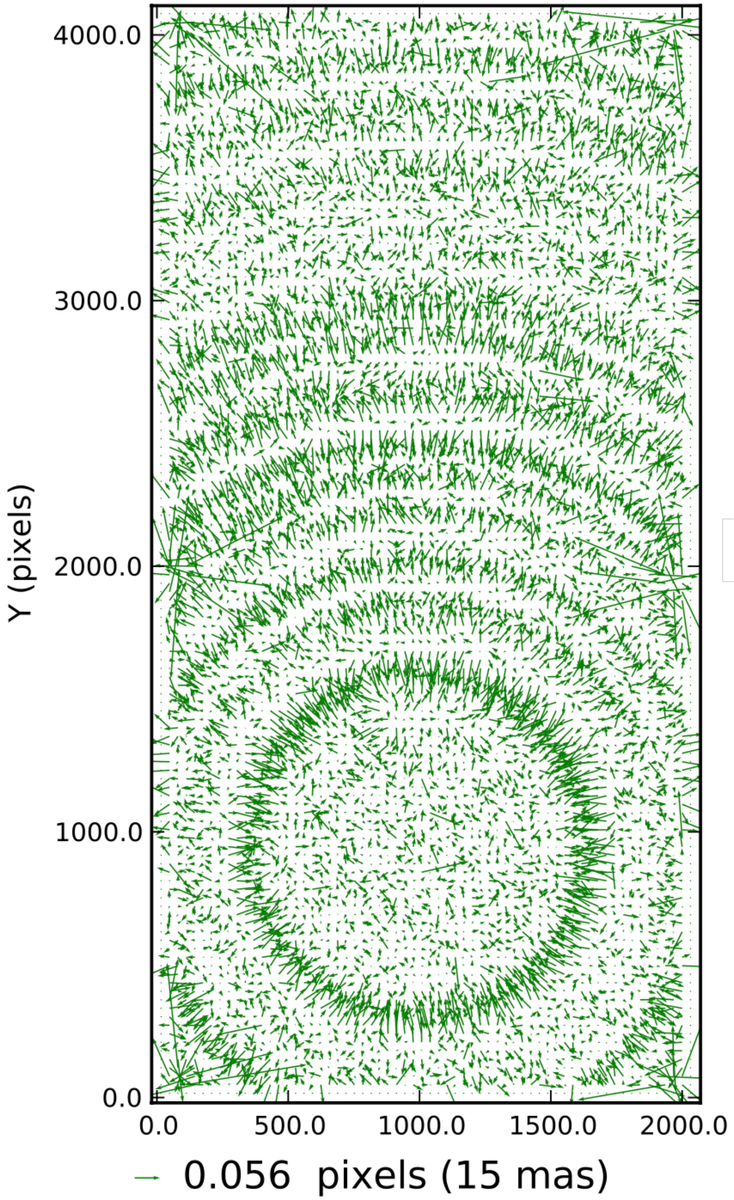
Guyonnet+15

Tree rings

- Silicon boules are grown
- Impurities in the gas vary
- Lateral electric fields
- Astrometric distortion

A silicon boule, as grown

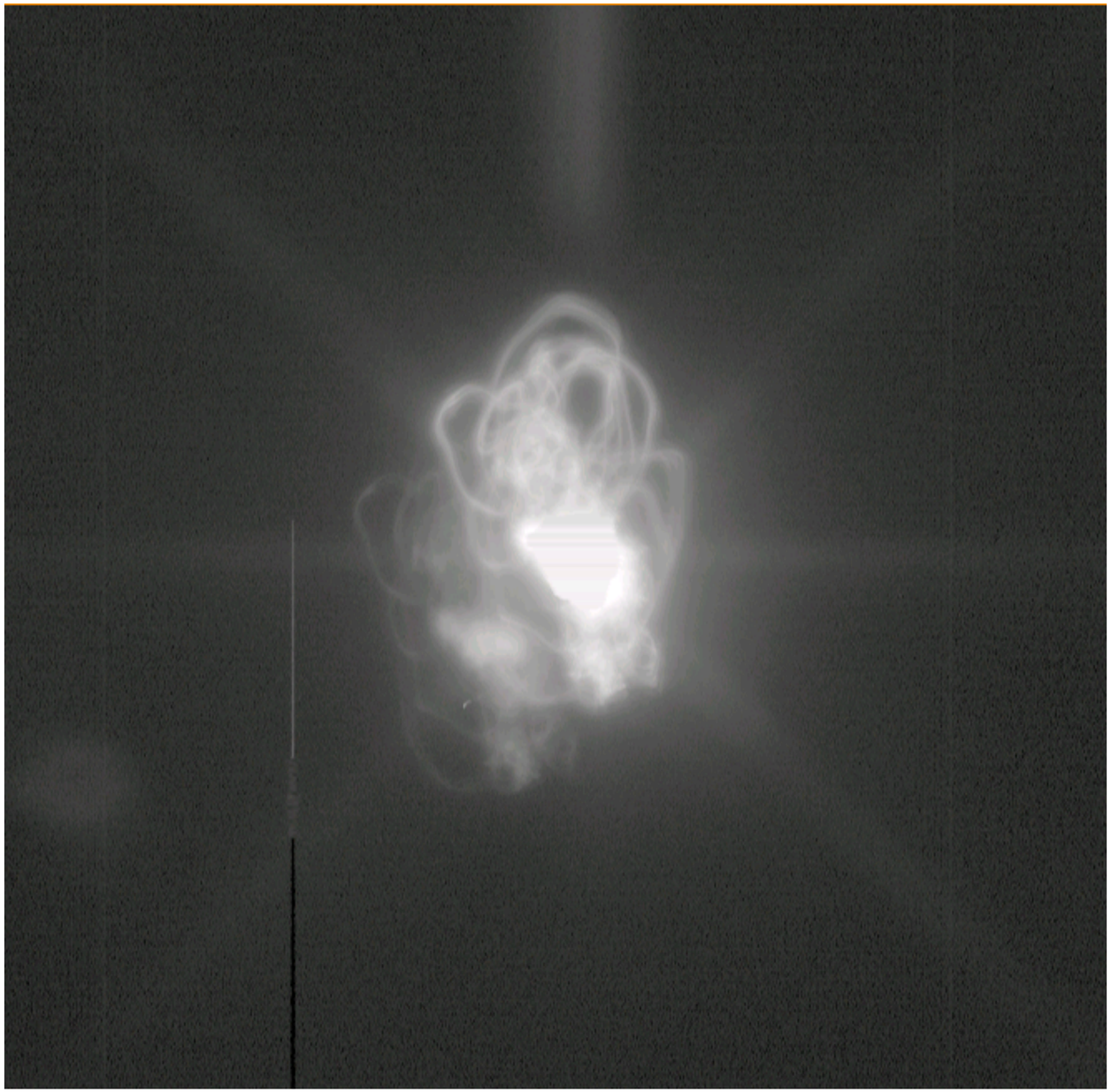




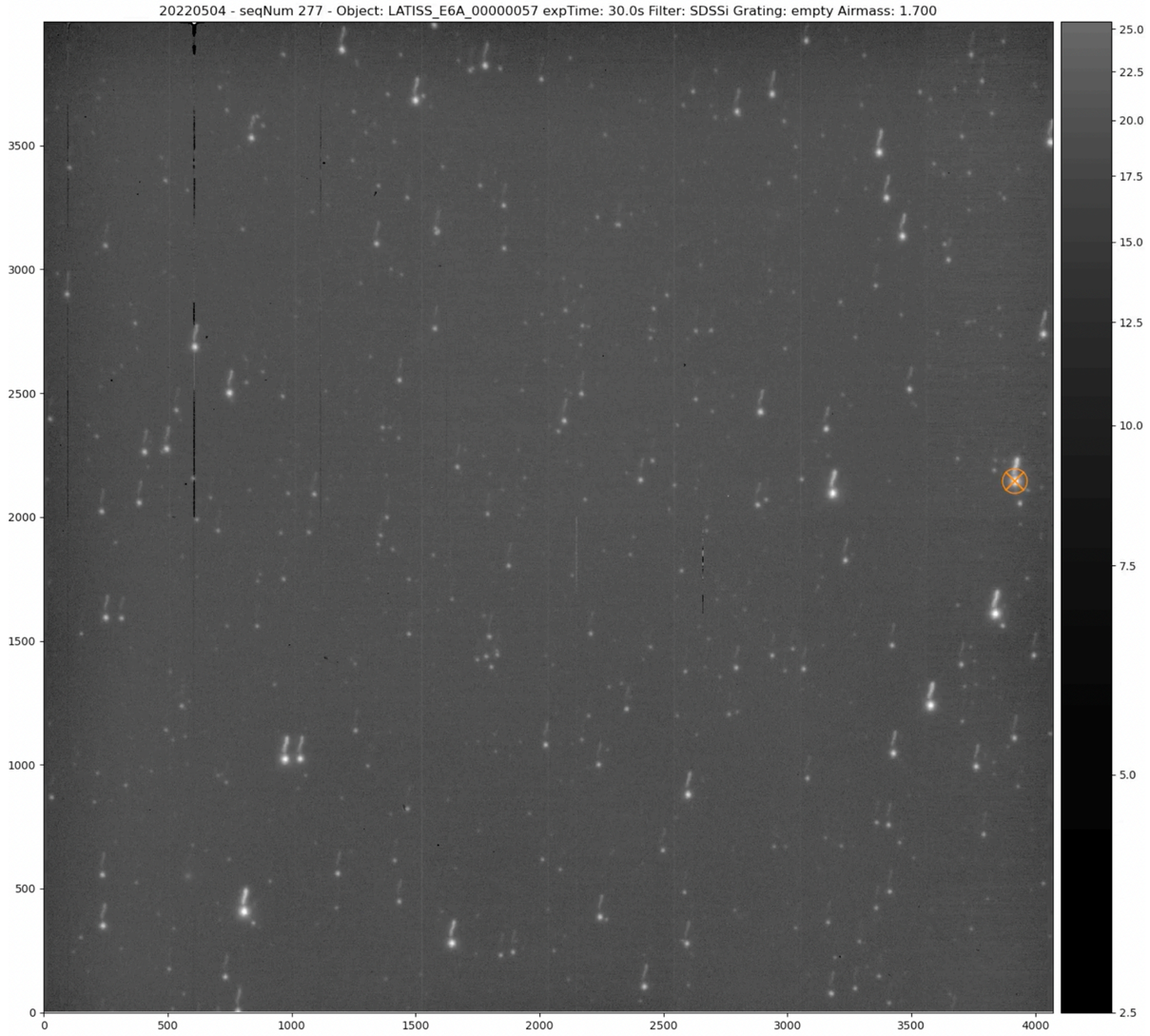
Bernstein, Armstrong, Plazas+17

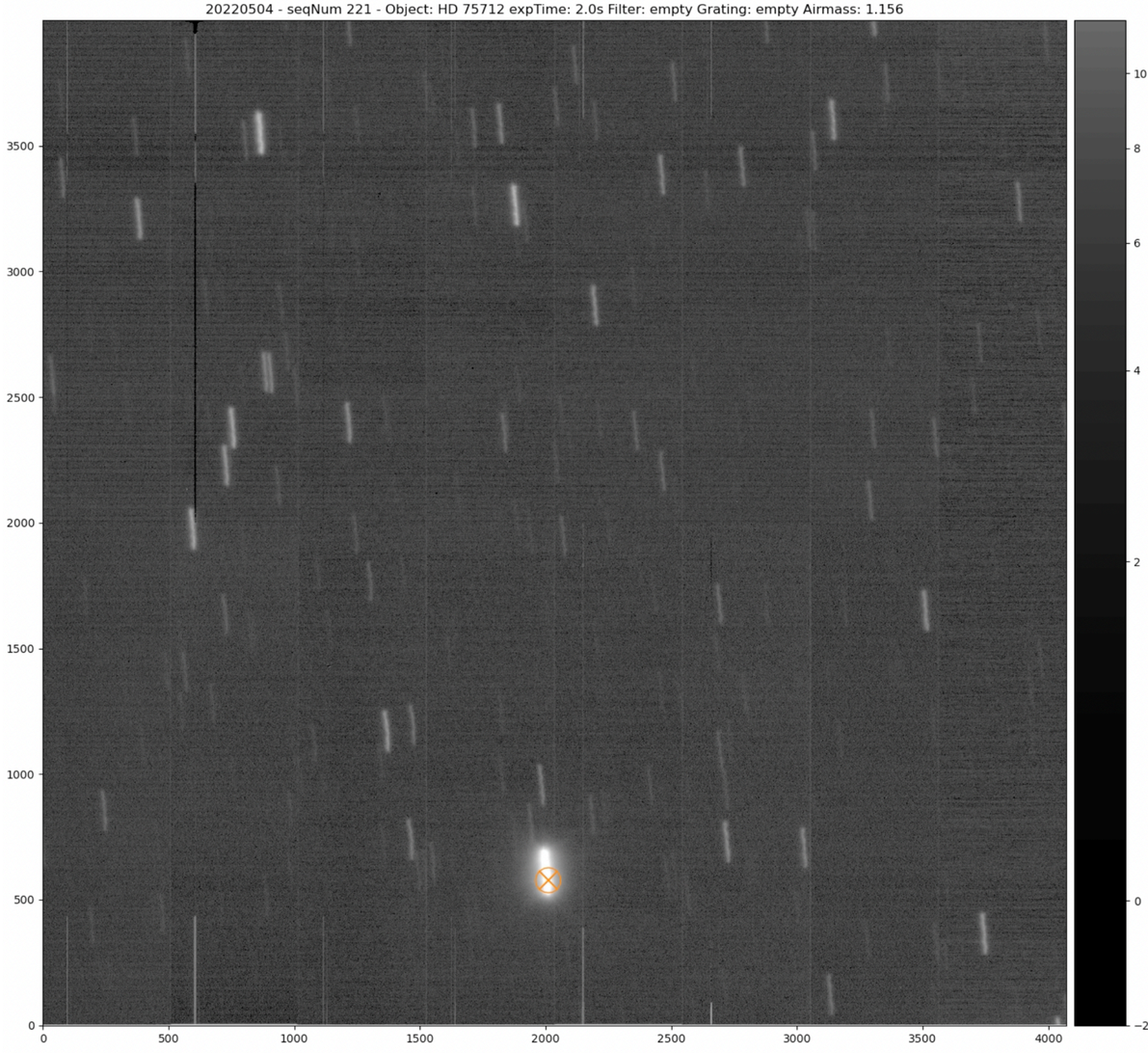
Extra credit:

What are we seeing here?



Extra credit: intro





Extra credit: Question

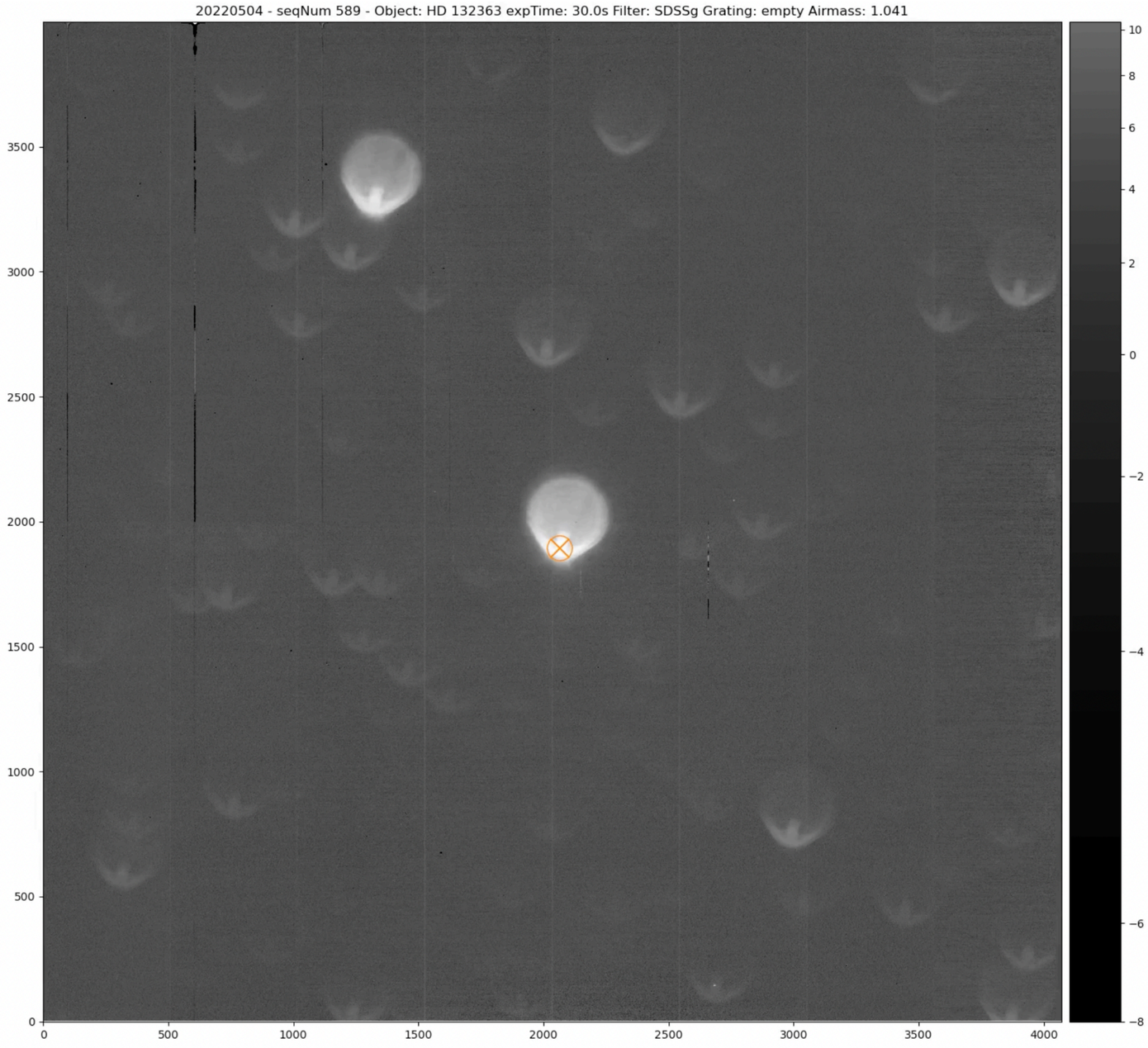
- Ignore the satellite in the upper part of the image.
- Question is: how can only a single star be trailed?!

Extra credit: Question

- Ignore the satellite in the upper part of the image.
- Question is: how can only a single star be trailed?!

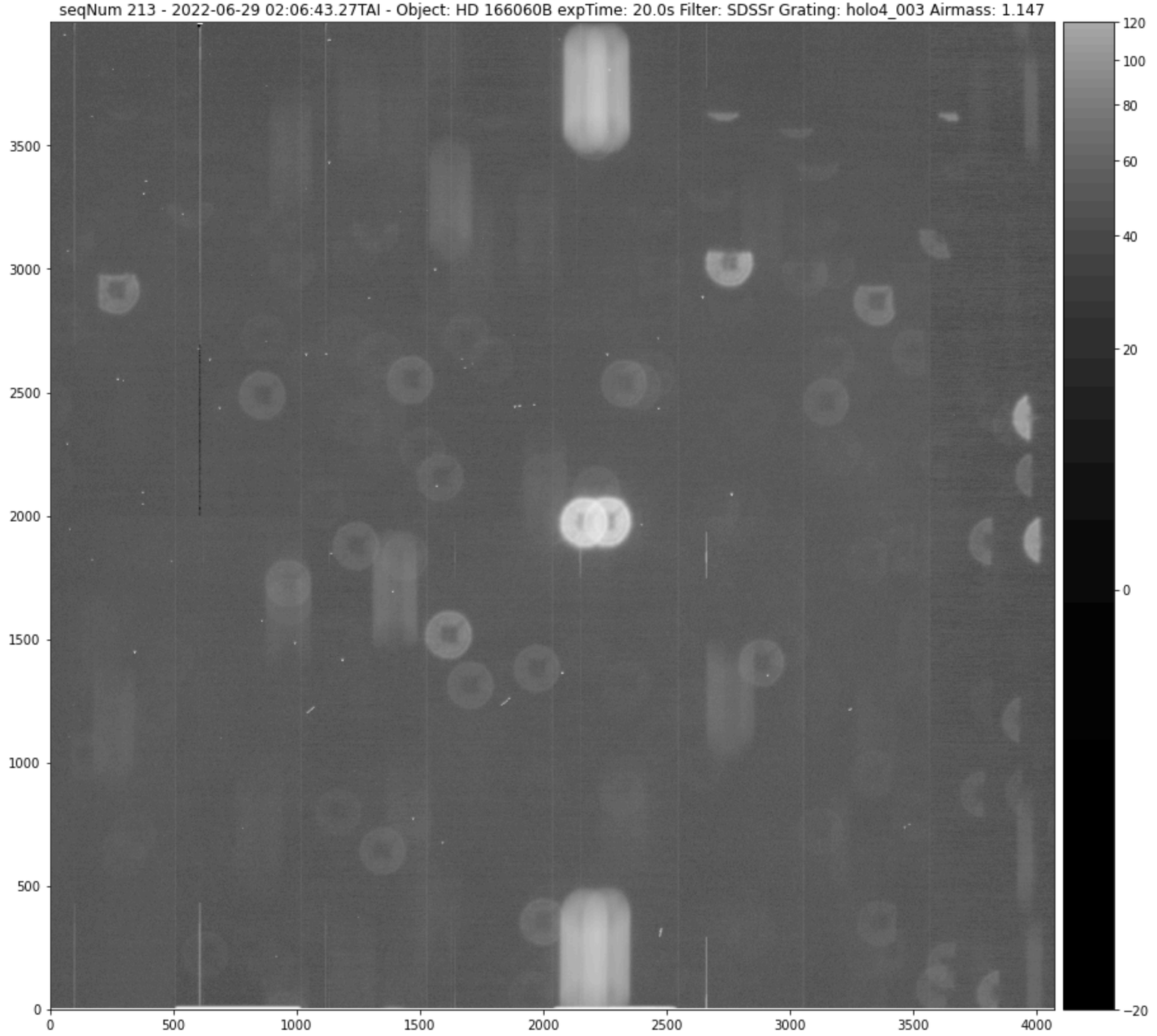
Extra credit:

- These don't look like normal donuts at all
- Image is filled with seagulls and parachutes...
- What is going on here?!



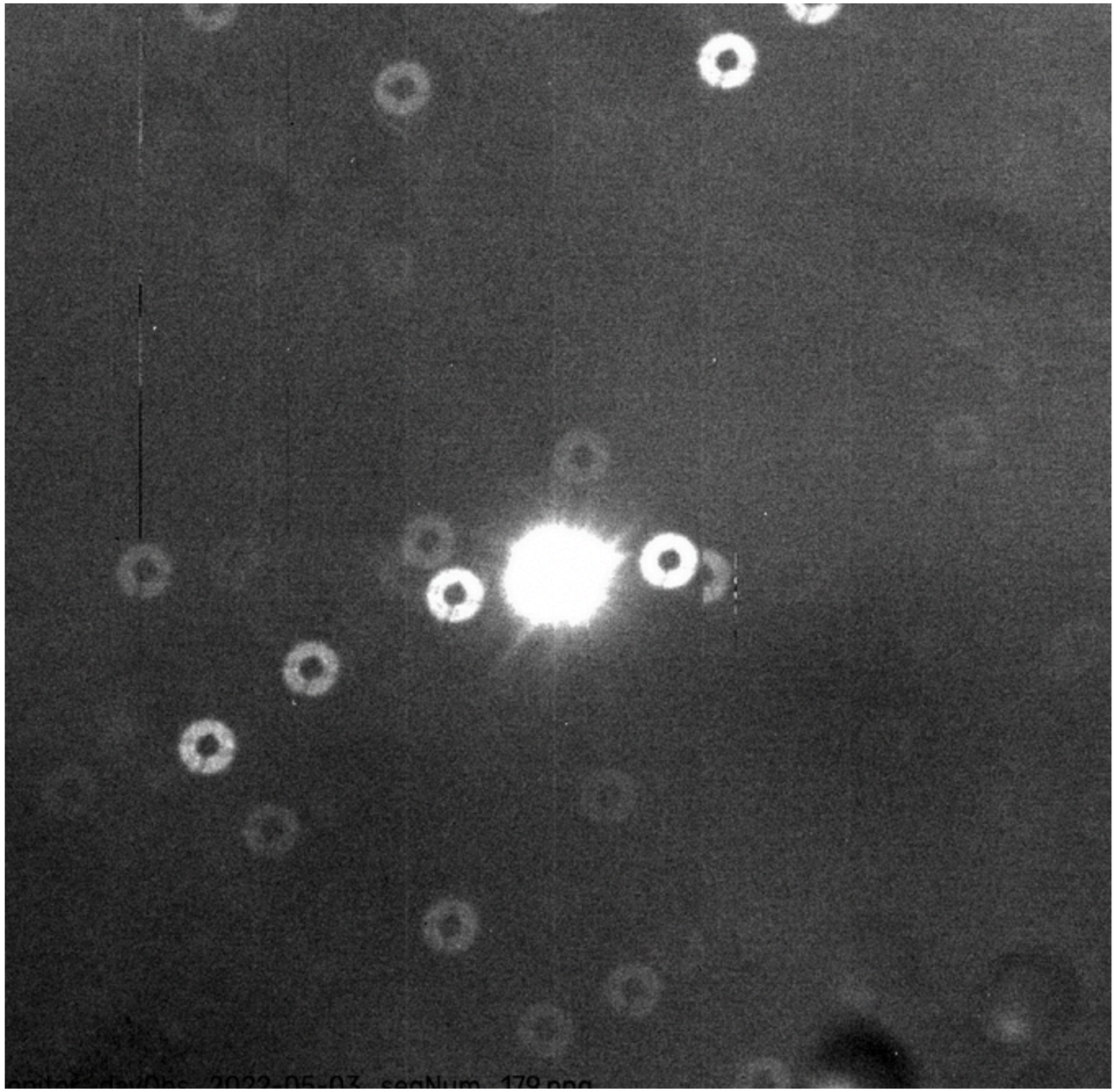
Extra credit:

- Why are some donuts cutup like that?
- Why are some from the sides, others from the top, others not at all?
- Why is the main source mirrored like that?

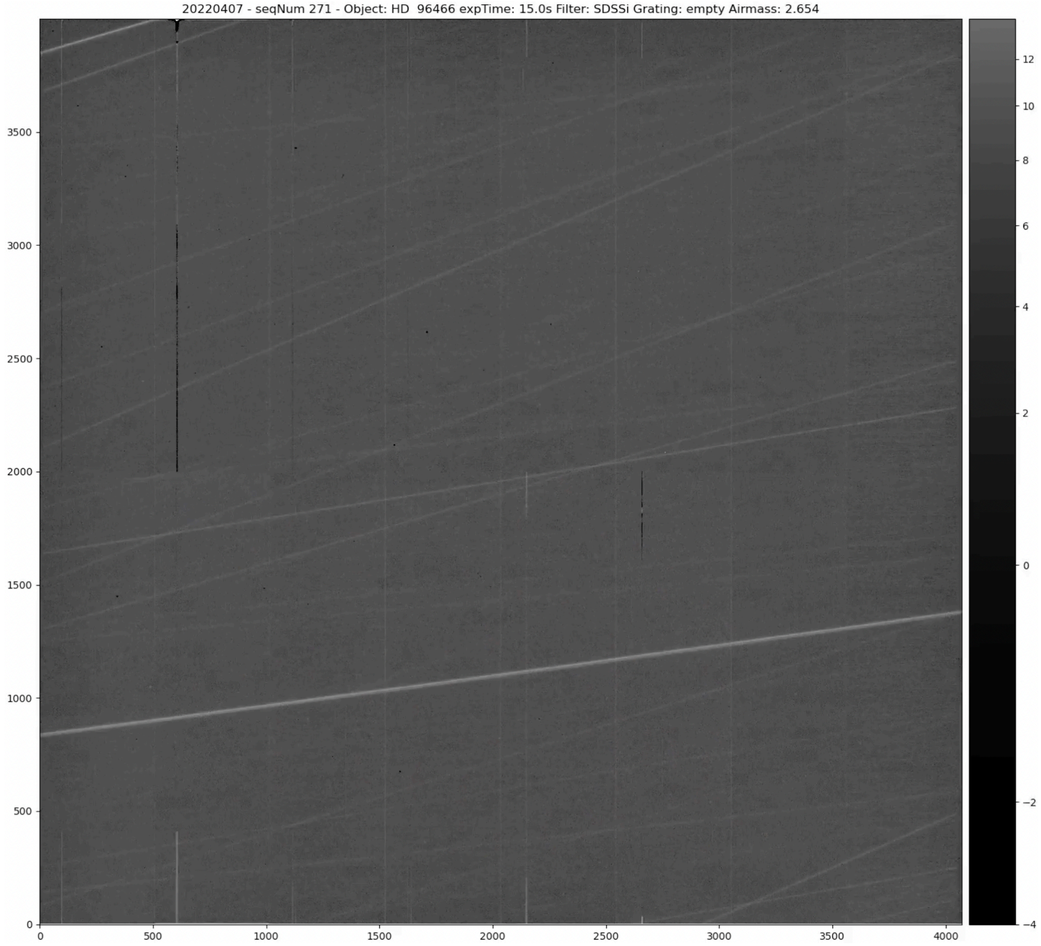


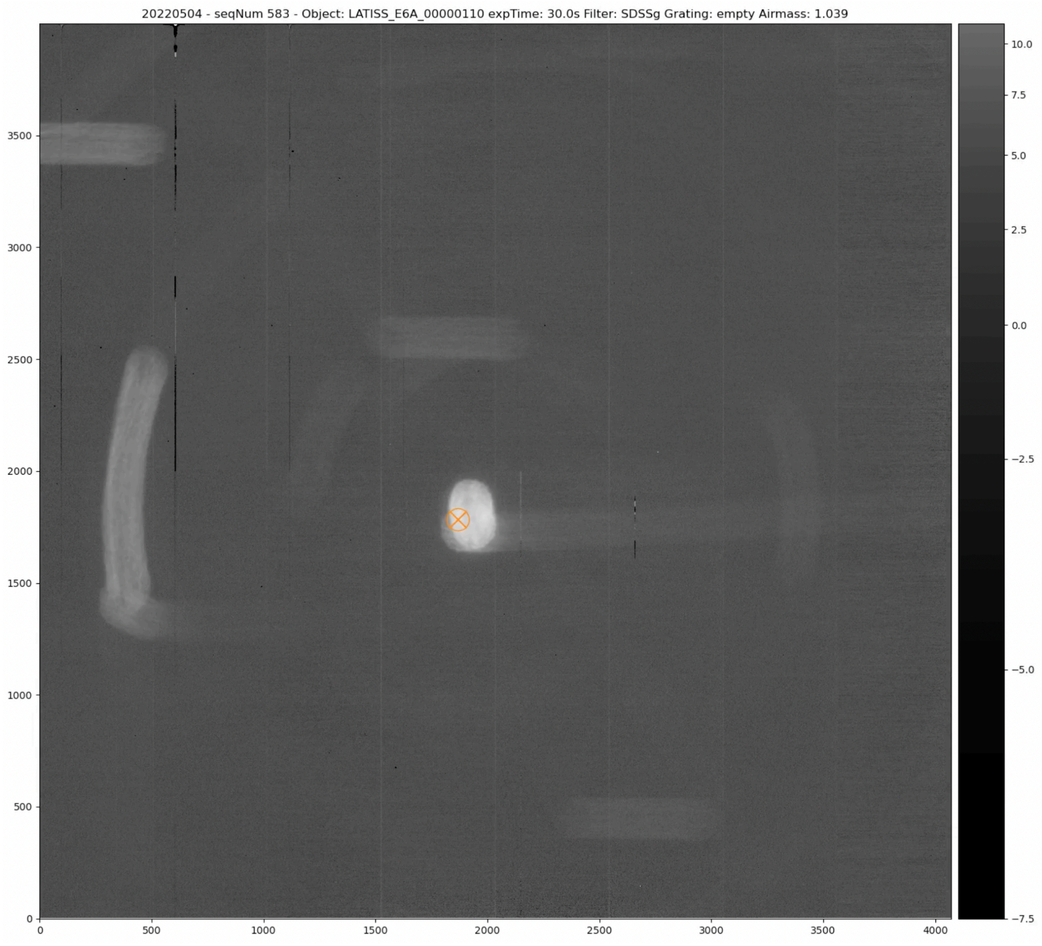
Extra credit:

- We've just seen about occlusions, but how can a single donut in the middle of the field be the only one?



Extra credit:



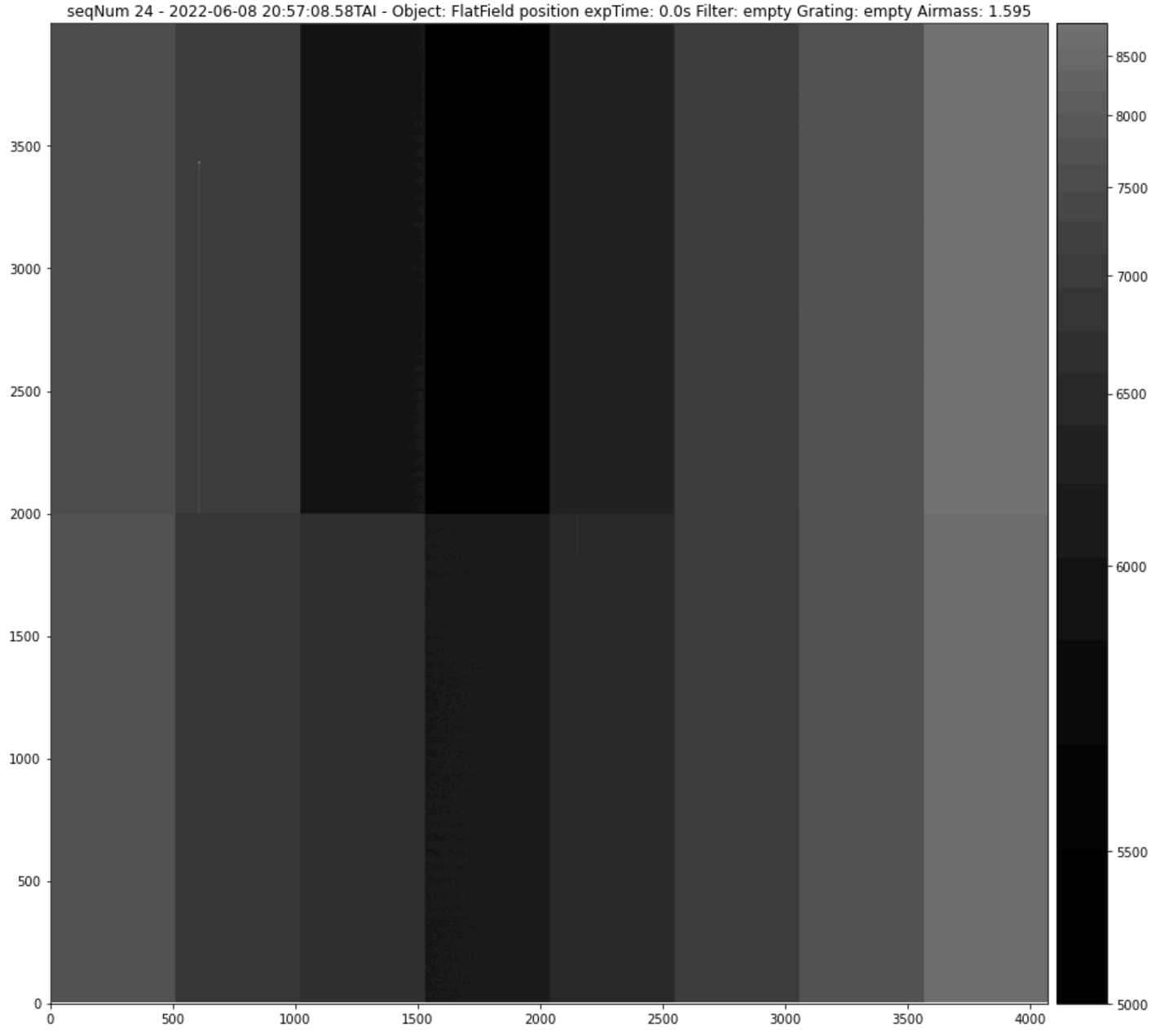


- There are several different angles for the straight lines. How can that be?

- Some streaks are curved, some straight
- How is any of this possible?

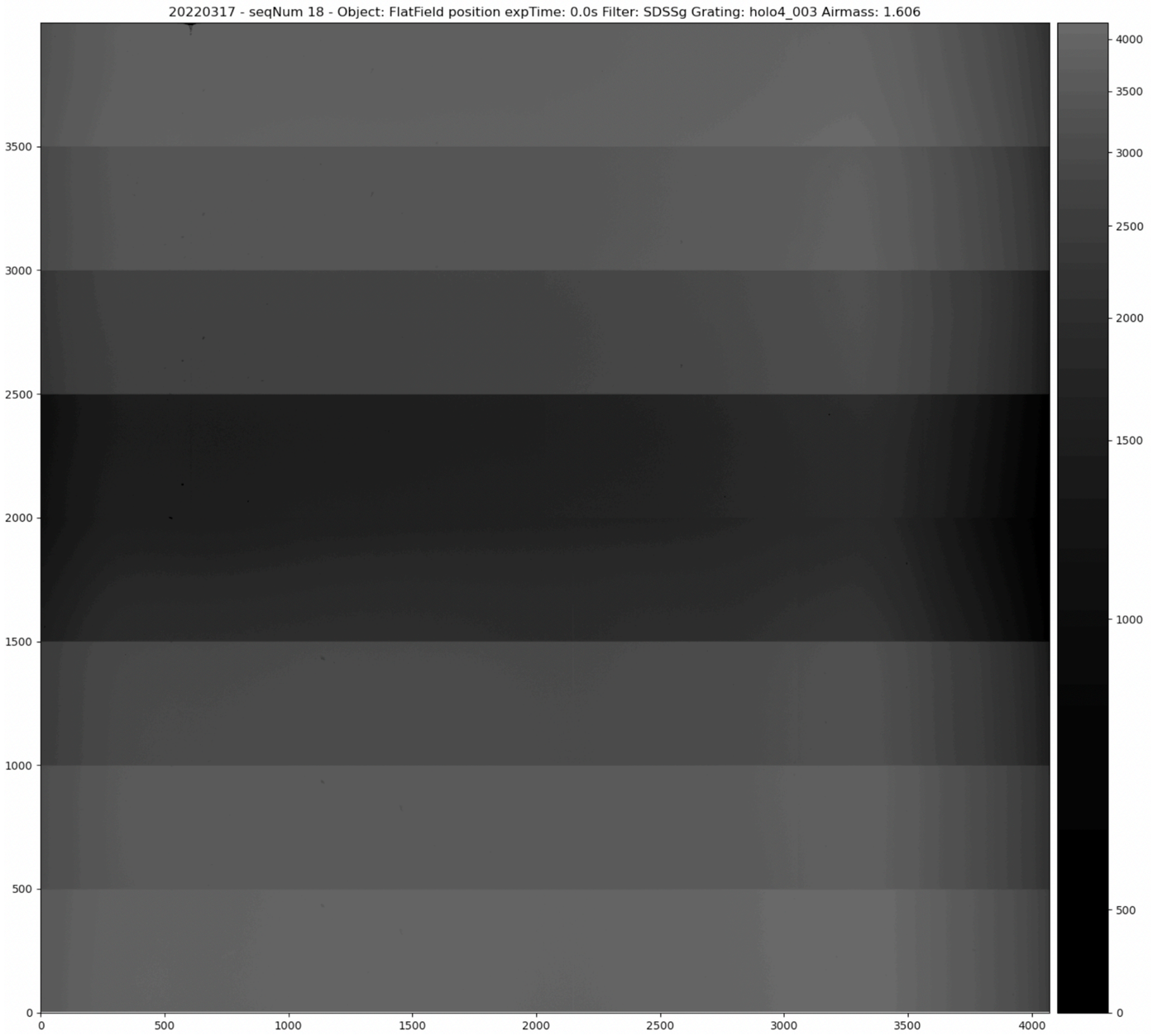
Extra credit: Setup

- We know our 8 amplifiers are arranged horizontally not vertically.
- This is what a raw bias or flat looks like.



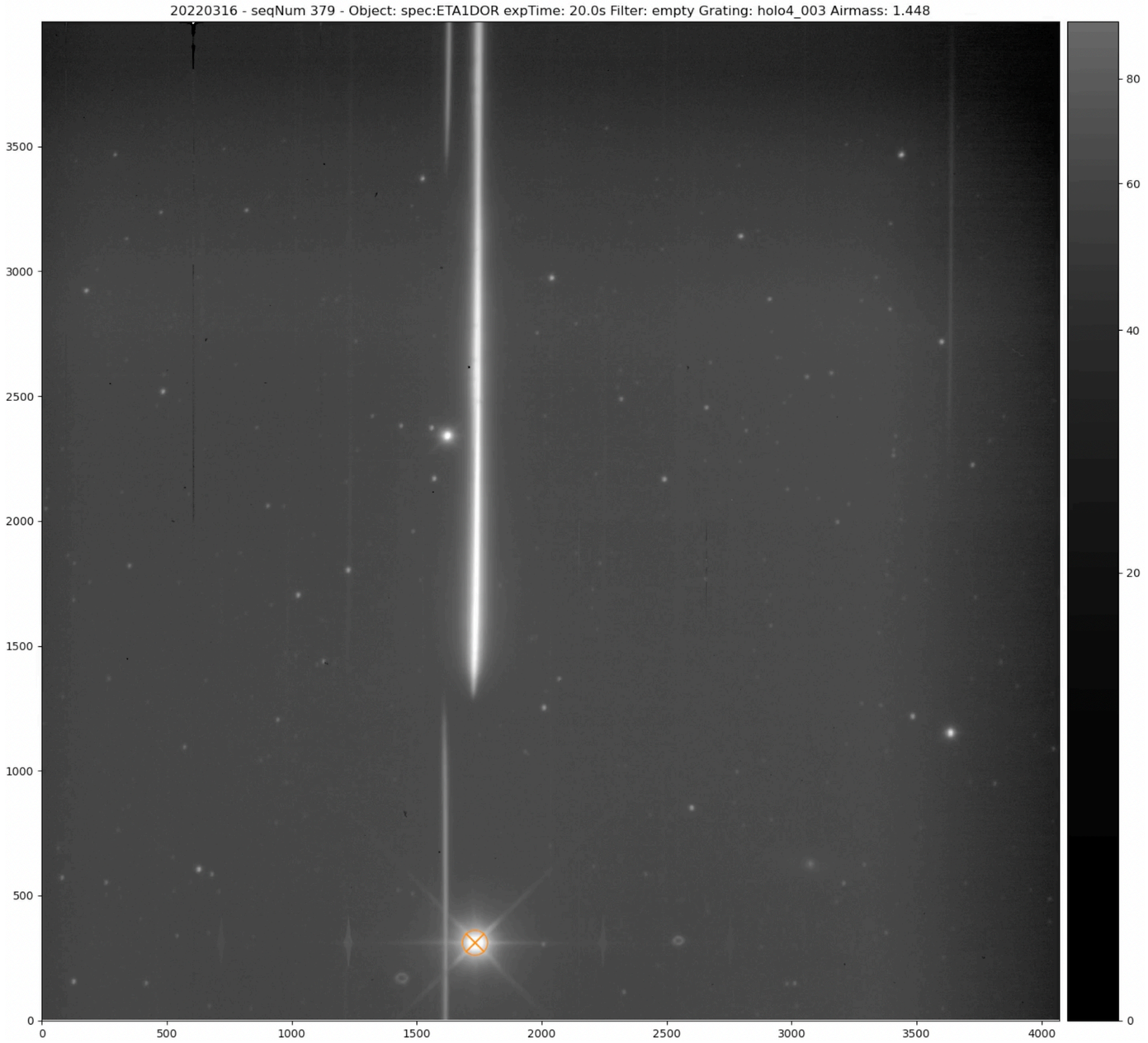
Extra credit: Question

- We know our 8 amplifiers are arranged horizontally not vertically.
- I have ***not*** rotated this image by 90º!
- Why does it look like this?



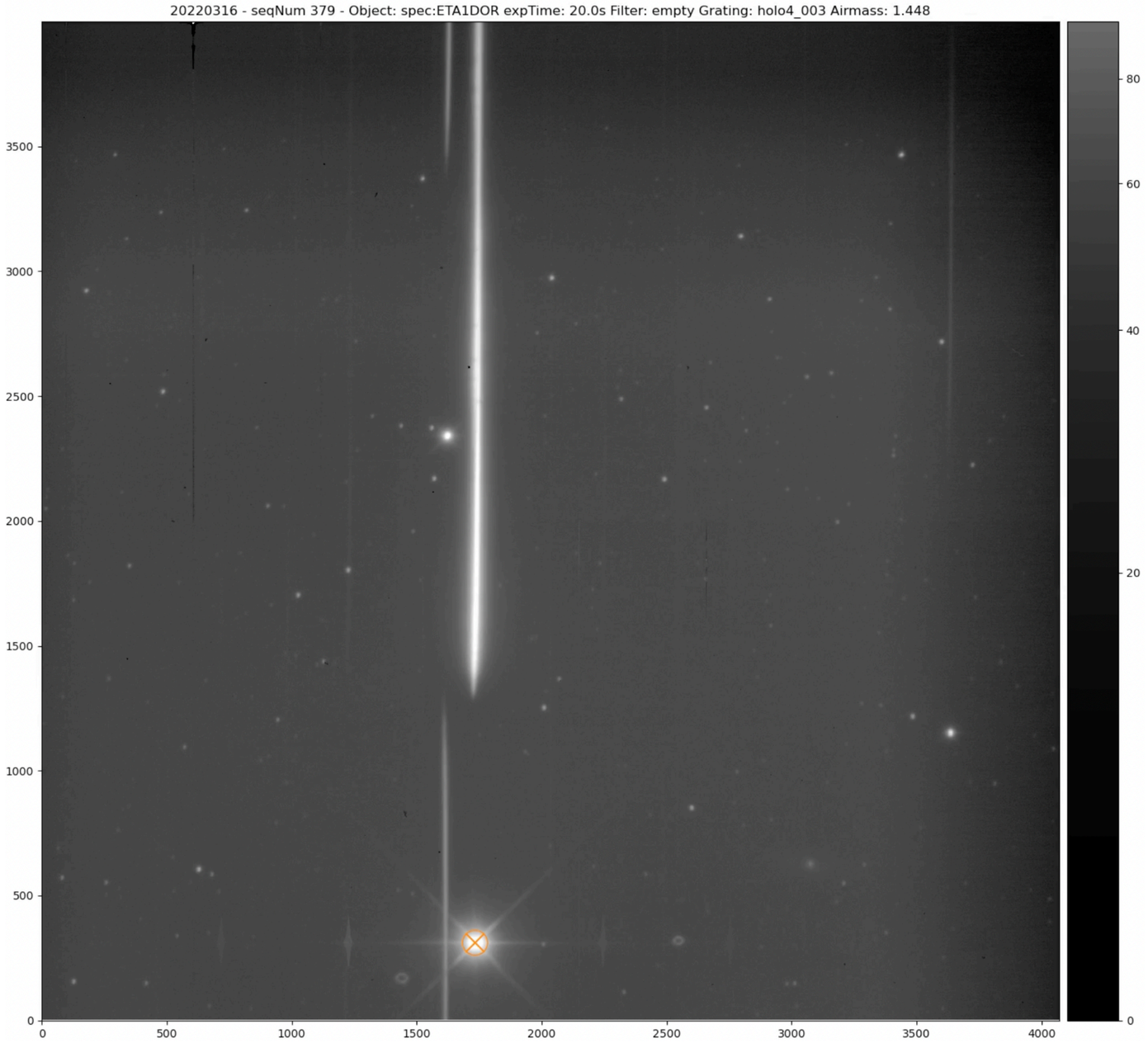
Extra credit:

- Here we have a totally normal looking spectrum
- What could cause the spectrum to bend like this?



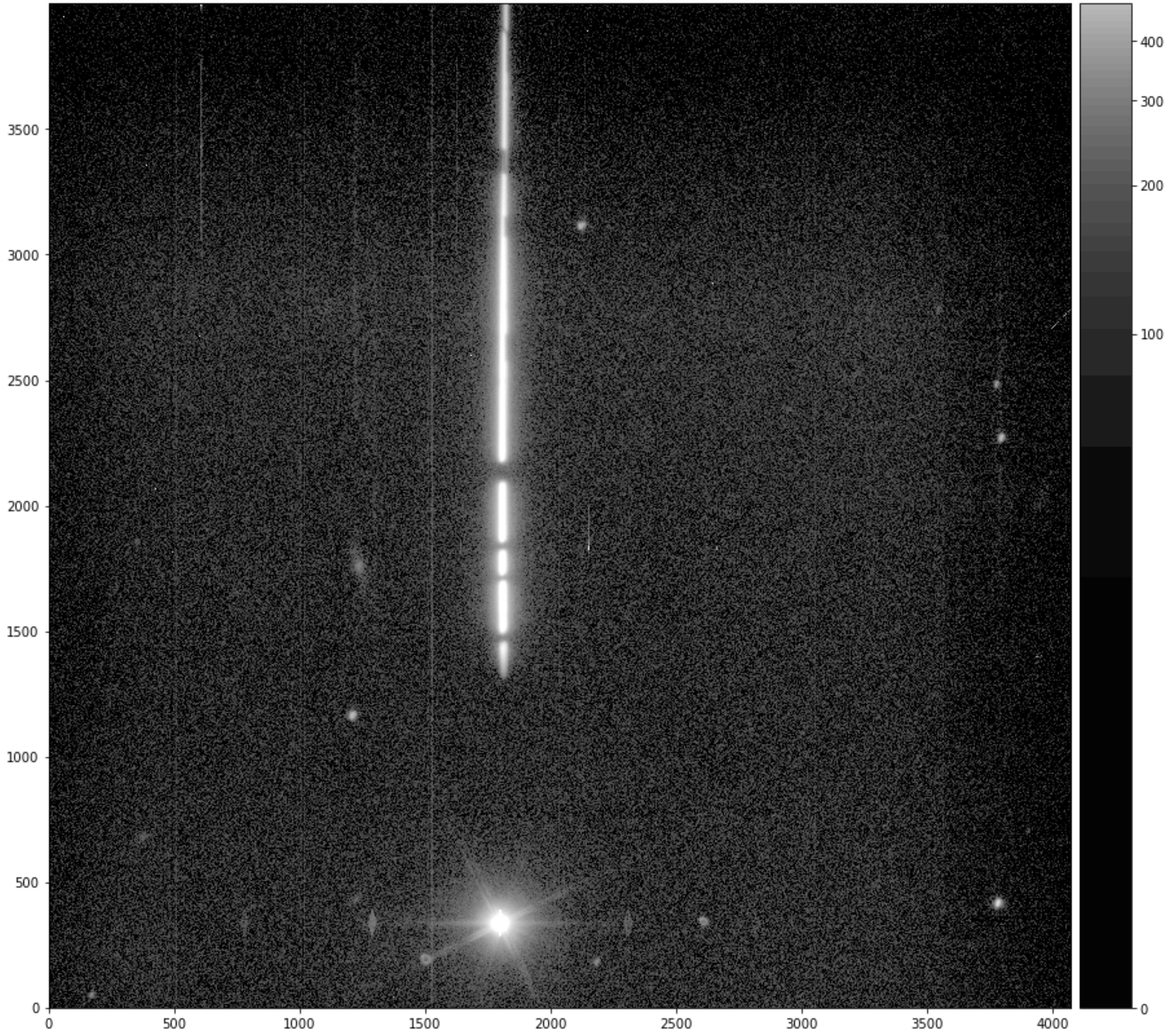
Extra credit:

- Here we have a totally normal looking spectrum
- What could cause the spectrum to bend like this?



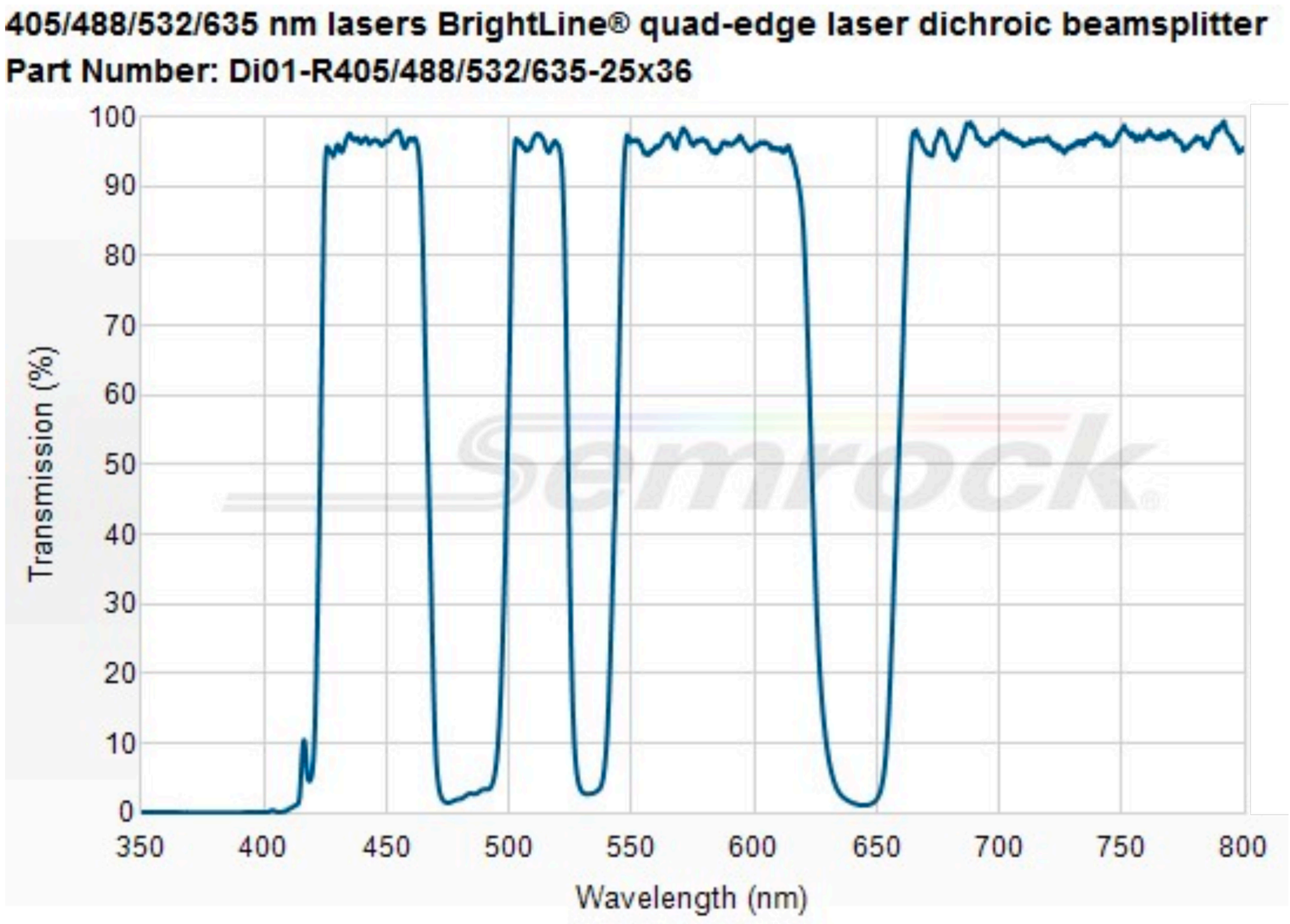
Extra credit

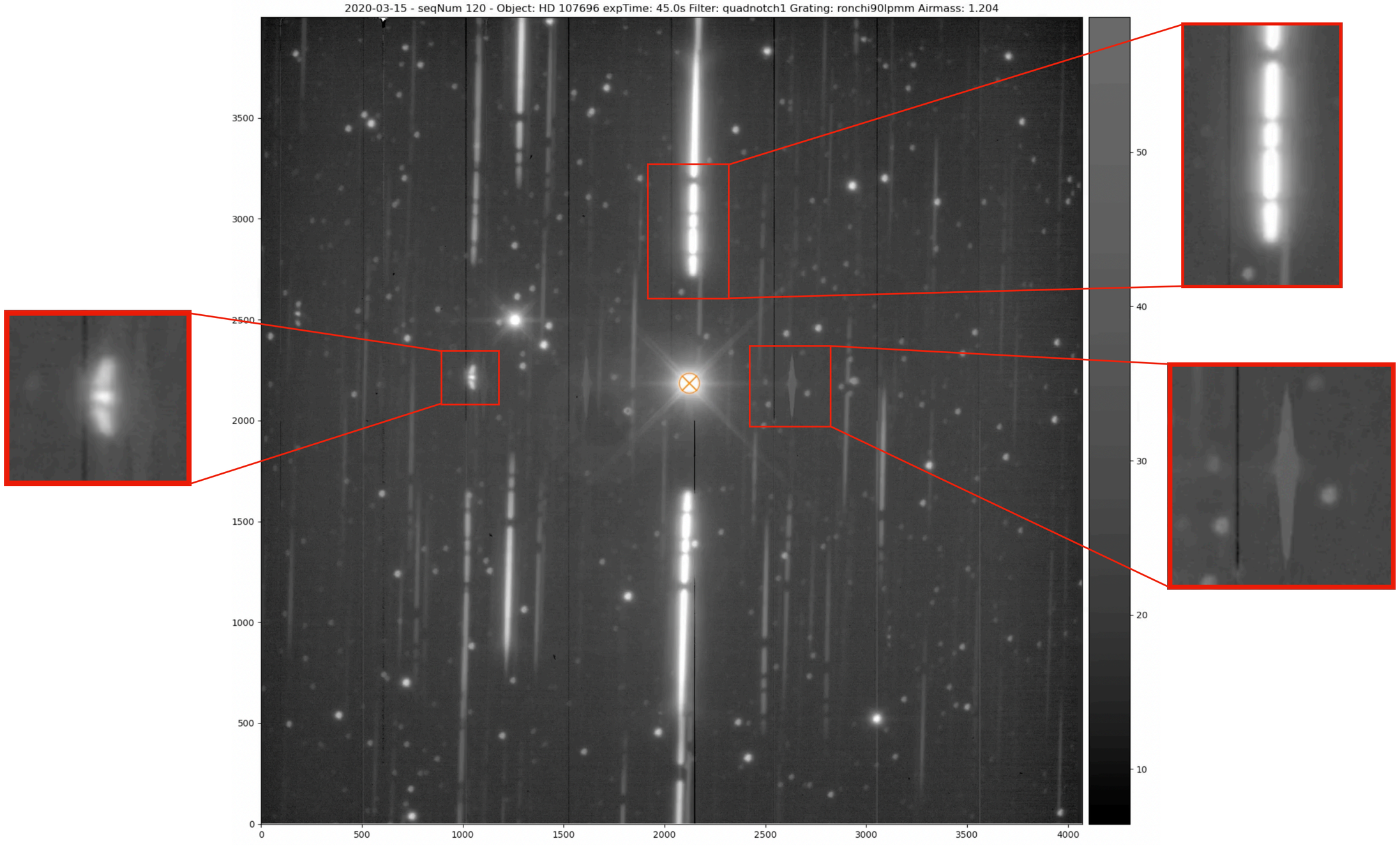
- What happened to the spectrum?!



Extra credit

- What happened to the spectrum?!
- Sorry, this is the only truly "trick question" but the filter in this image just has a very unusual bandpass!




2020-03-15 - seqNum 120 - Object: HD 107696 expTime: 45.0s Filter: quadnotch1 Grating: ronchi90lpmm Airmass: 1.204
0
500
1000
1500
2000
2500
3000
3500
4000
10
20
30
40
50

This slide intentionally left blank