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U.S. National Science Foundation

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Initial Pipeline Steps

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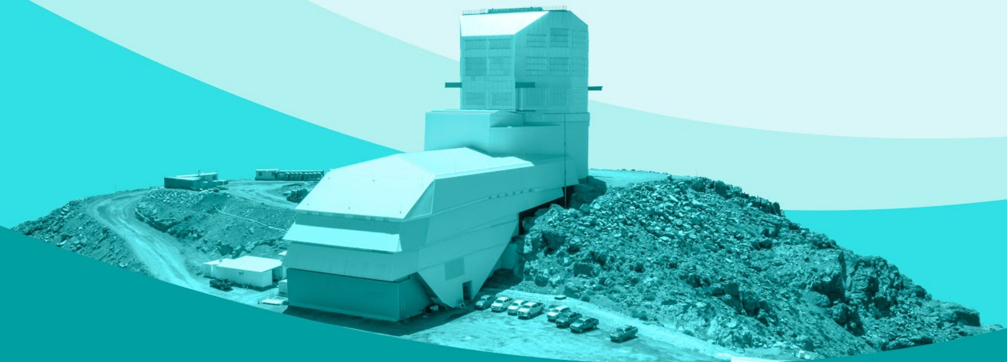


Outline

Goal of this session is to cover the steps of image processing starting from raws and up to the point of doing measurement.

- Instrumental Signature Removal — Focused on detector and telescope effects
    - Bias subtraction
    - Flat fielding
    - Gain normalization

- Background subtraction — dealing with the photons that are **not** from the source we want to measure

Instrumental Signature Removal

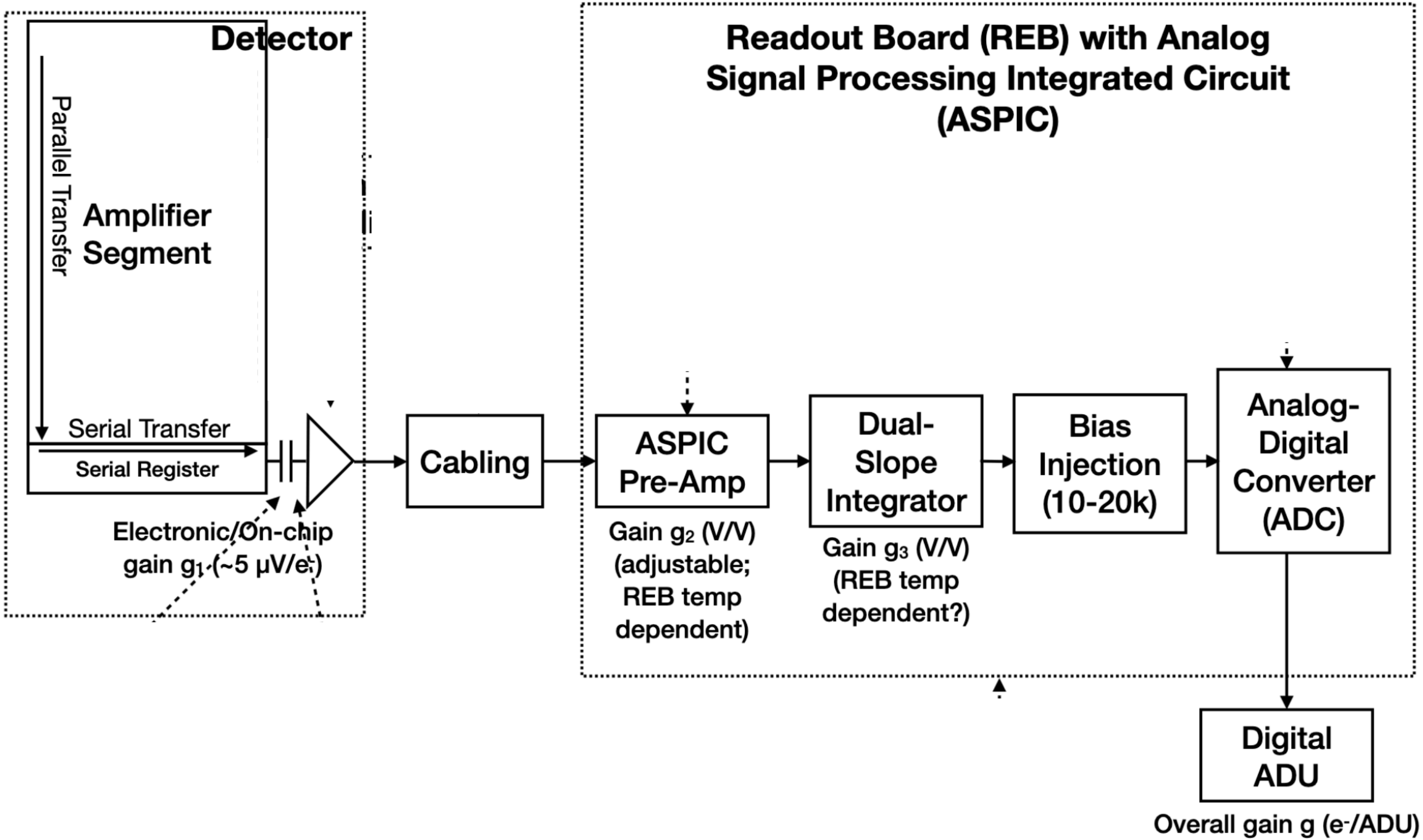
- The goal for ISR: output an image that accurately reflects the relative brightness of the sky in the area subtended by each pixel.

- Effectively we are going to “step backwards” through the path of a photon from the top of the atmosphere to a number in the image.

- Out of scope for ISR: absolute calibration (into nJy). ISR fixes all the *pixel* effects so that it will become easy to perform absolute calibration at the *catalog* level.

- Broadly speaking, these effects and their corrections are either:
    - Additive — some value is added (or subtracted), regardless of the signal from the sky
    - Multiplicative — some *fraction* of the incoming signal makes it to the next stage of the signal chain, so correction requires rescaling

- There are definitely exceptions to these, and worst of all there are a few nonlinear effects which are harder to deal with. Some features also just get masked as irrecoverable.



From the Rubin calibration plan: https://sitcomtn-086.lsst.io

Bias

- Part of readout involves converting the output of integration — a voltage, into a number — that's what the analog-to-digital converter does

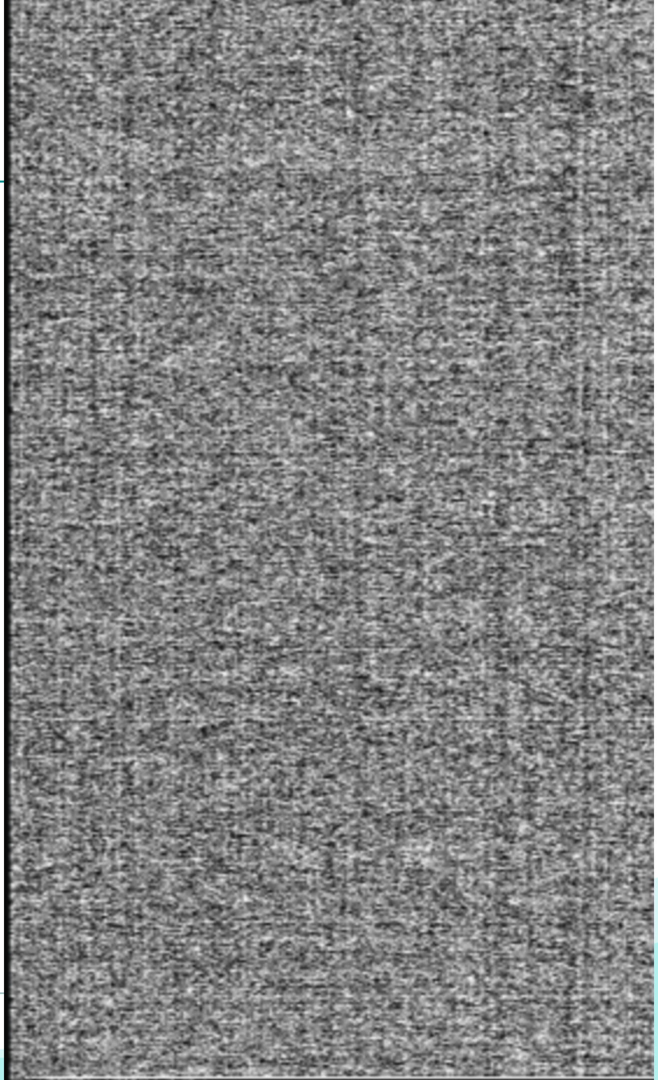
- ADCs do not want to be given negative volts, we don't want to get near negative volts, we want our lowest signal to never be too close to zero volts or else the ADC will misbehave.

- So the instrument **adds** a "constant" voltage to every pixel before the ADC.

- But: we know nothing is analog electronics is ever constant. Definitely not when you're reading out pixels at ~400 kHz.

- The bias has a time-dependence during readout, which gives the appearance of spatial structure.
- Fortunately we clock everything the same way during each readout, so if everything goes right then the bias structure is **repeatable,** and hence correctable.

- If it’s not repeatable, that’s bad news.



Dark current

- One of the effects that is generated in the bulk silicon, think of this as charge that ‘leaks into’ the pixels just from the process of integrating.

- This is essentially due to impurities/defects in the silicon. This was a big issue in the early days of CCDs when the vendors were still learning how to build detectors. But they got a lot better.

- It’s good to know it exists, but it’s also basically negligible at this point.

Multiplicative corrections

- Lots of instrumental effects alter the flux in a proportional way.

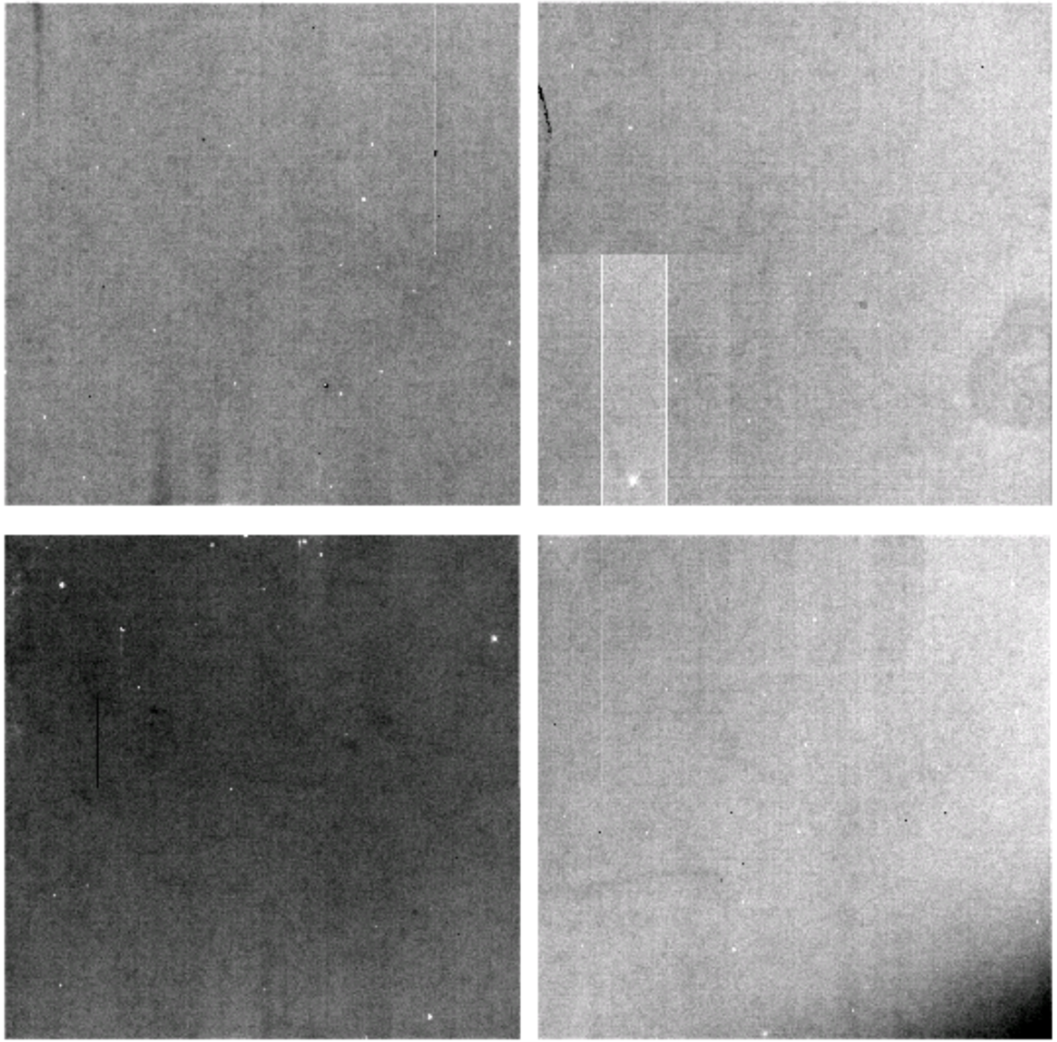
- We mostly lump these together into one “flat field correction”, where each pixel in the flat field image is a value around 1.0
  - If a pixel had say 5% of its flux removed (say a speck of dust), we give that pixel a value of 0.95 in the flat field image.
  - Dividing the input image by the flat field gives the corrected image.

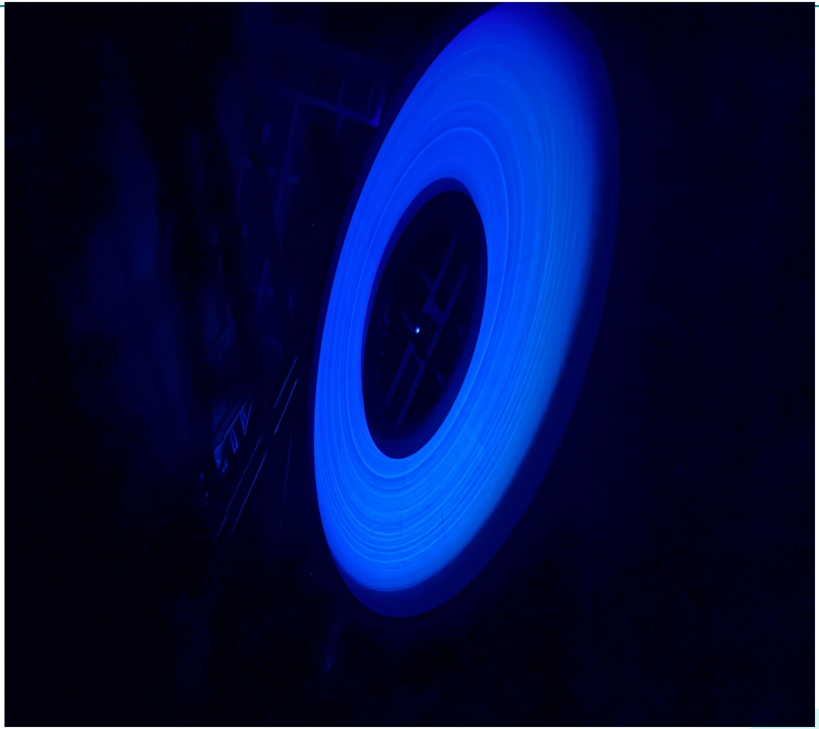
- We will look at actual flats in the hands-on section, so I will skip the tour for now.

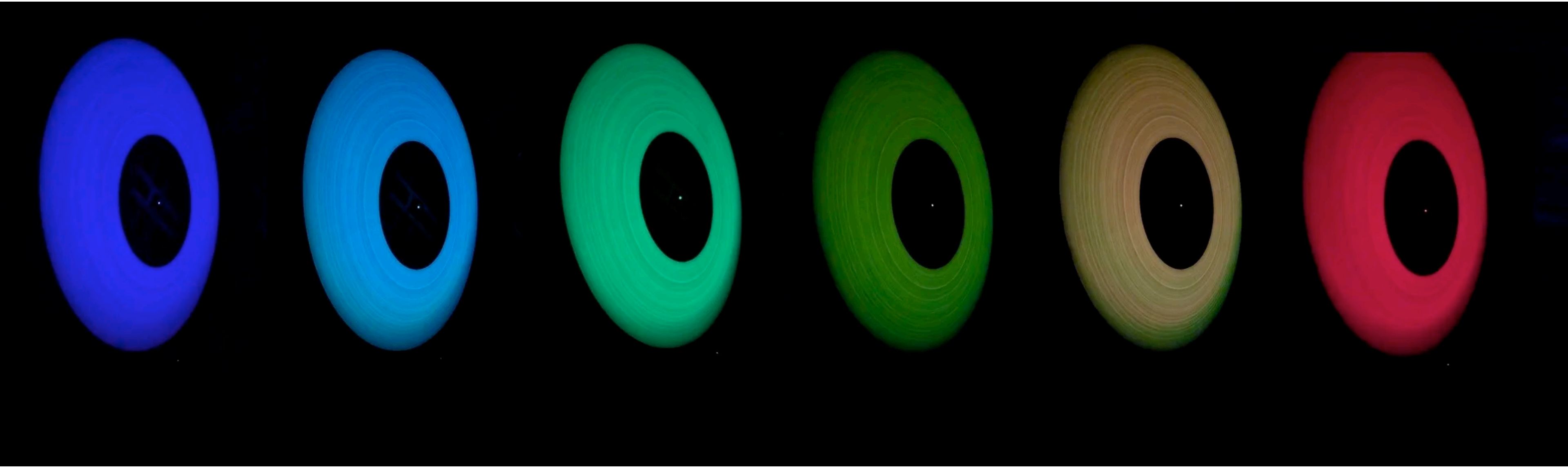
How do we measure flats?

- It’s really hard!
- Ideas? What do you want to observe?

- Twilight flats from ComCam:







Flat fielding is imperfect

To get good flats we're relying on

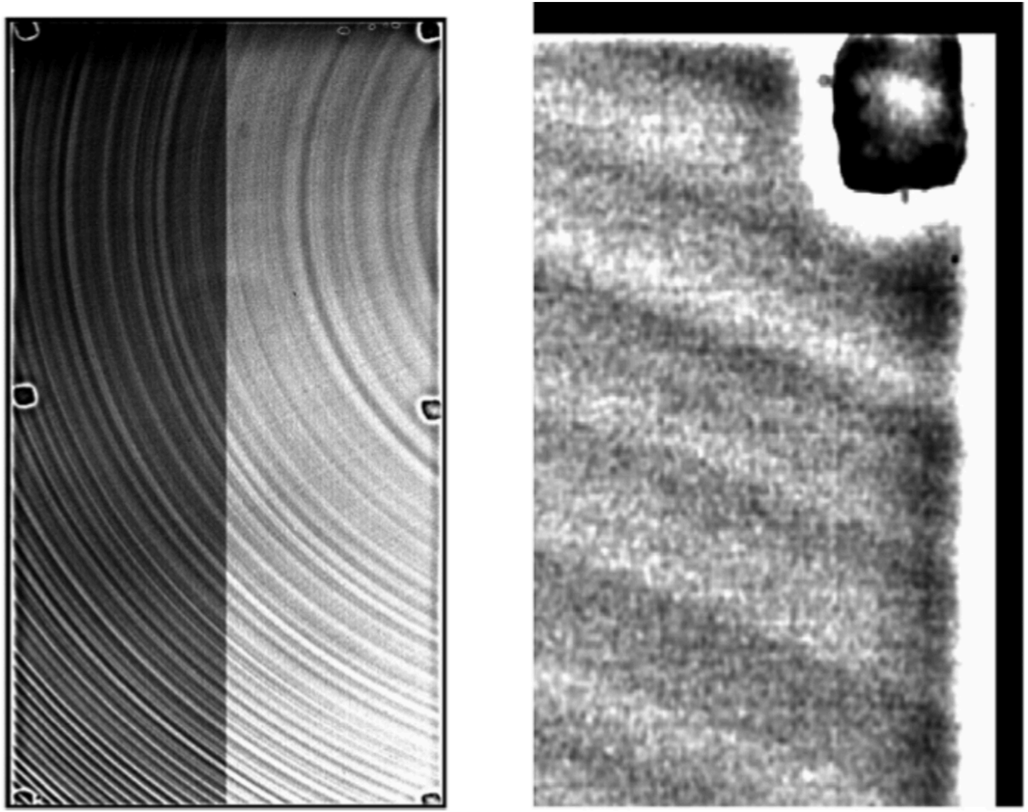
- Averaging over lots of exposures
- Averaging over any deficiencies in the calibration hardware
- Different effects have different spatial scales:
    - There might be a large-scale illumination gradient on the flat field screen, but we can fit that out in order to measure the small scale pixel-to-pixel variations in detectors

This gets extra hard at the edges of the focal plane, since vignetting means the flat field is changing rapidly AND you're not getting as many photons to measure it.

Historical interlude

- The bias/flats story we've covered so far was what we knew in the 2000's. Flat fielding was for correcting sensitivity variations.

- But when DECam went on sky, the flat field images showed these rings that were **not** sensitivity variations.

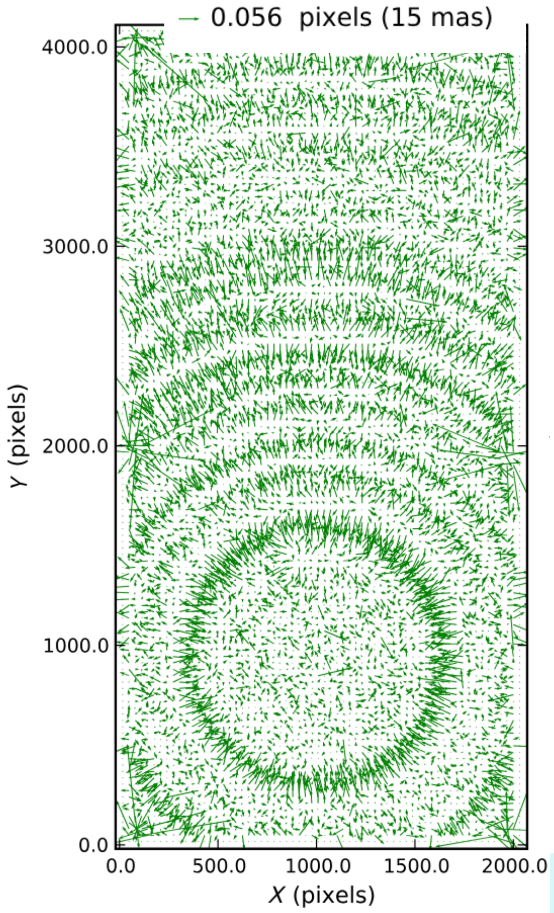


Plazas, Bernstein, & Sheldon 2014

- These rings are seen in the astrometry — stars appear shifted in position just slightly, correlated with the rings.

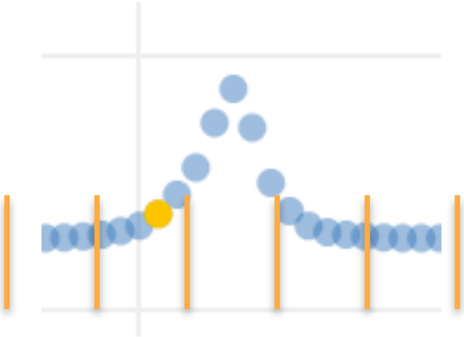
- The rings are not a sensitivity effect, they're the effective boundaries of the pixels being shifted very slightly

- The bright pixels in the flat field are effectively "bigger", not more sensitive.



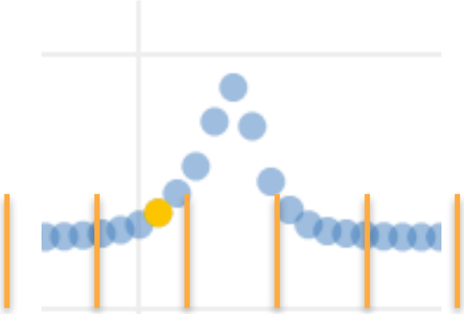
Plazas, Bernstein, & Sheldon 2014

Say this star has ~100 counts

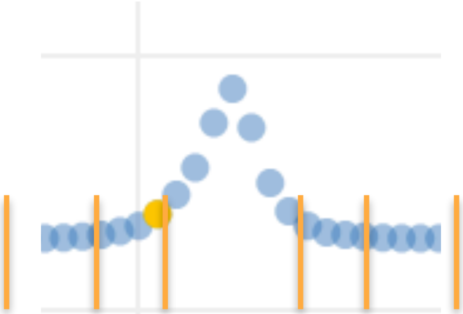


Pixel values: 0 10 80 10 0

Say this star has ~100 counts



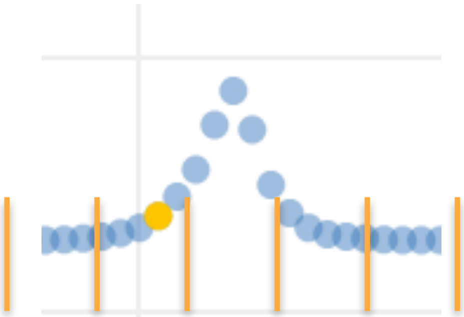
Same star, but what if one pixel was **bigger**



Pixel values:

	0	10	80	10	0
	0	5	90	5	0

Say this star has ~100 counts



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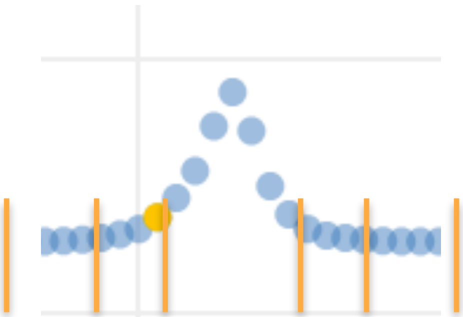
Same star, but what if one pixel was **bigger**

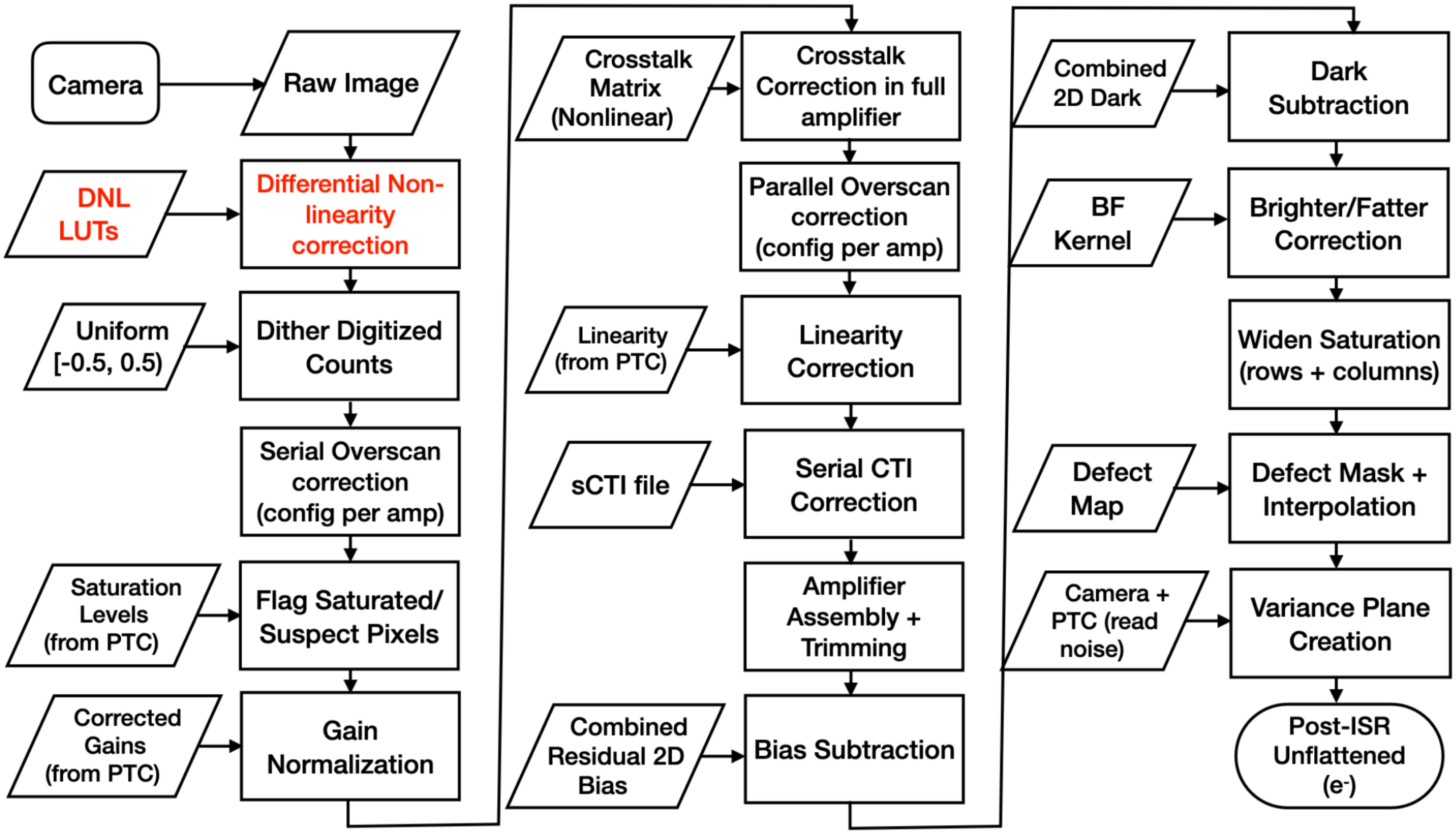


0 5 90 5 0

Now what if we divide by a flat field image?

5 / 1.0 = 5
90 / 1.1 = 81
5 / 1.0 = 5

Total: 91!



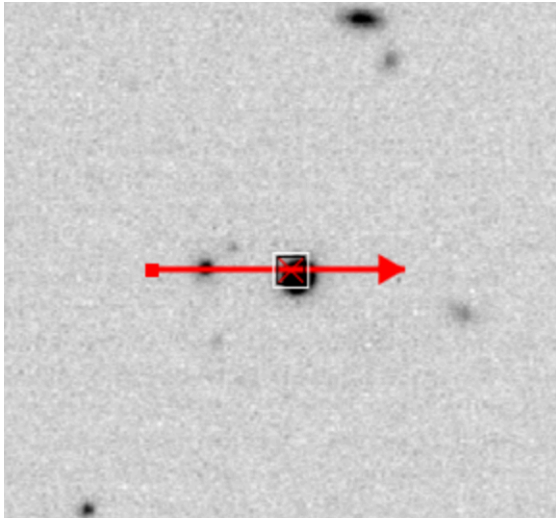
From the Rubin calibration plan: https://sitcomtn-086.lsst.io

Sky Background

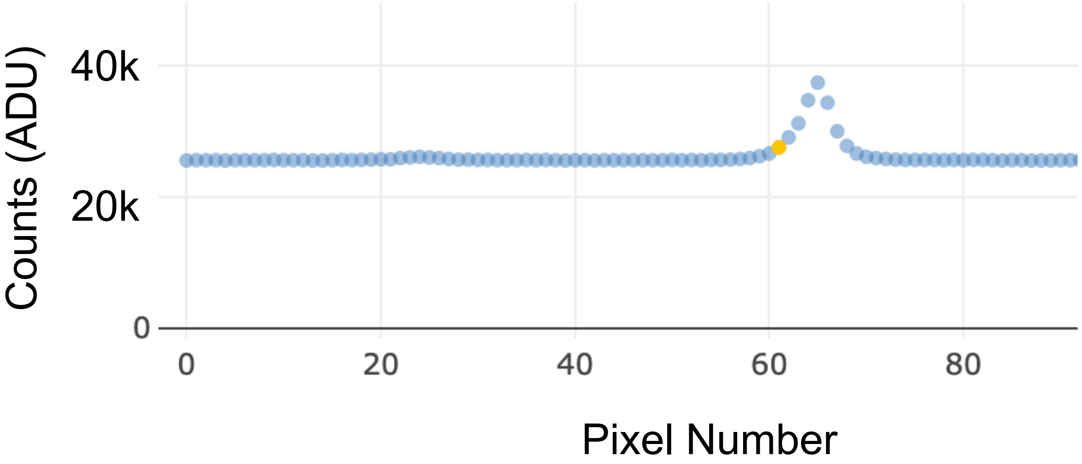
Backgrounds

- This is technically NOT ISR. But it’s possibly the hardest problem in all of image processing.

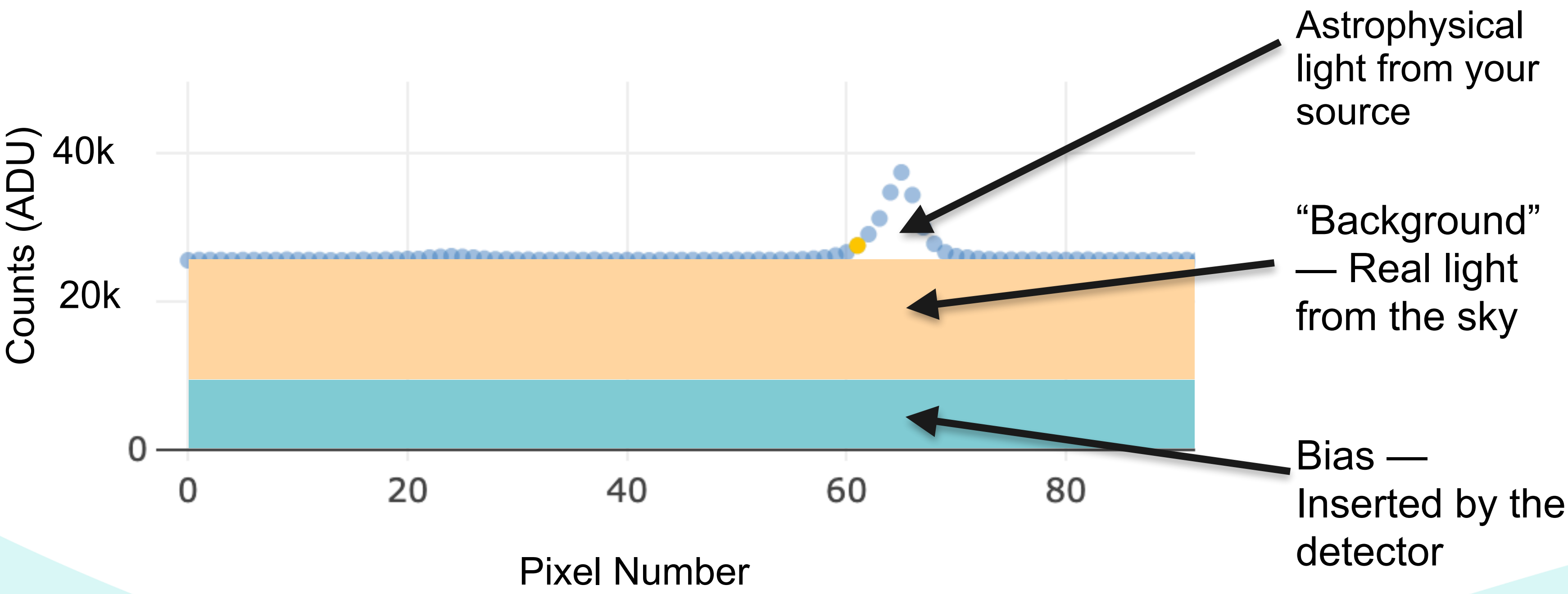
If we draw a line through the image and plot the counts:



Raw image



Bias vs Background

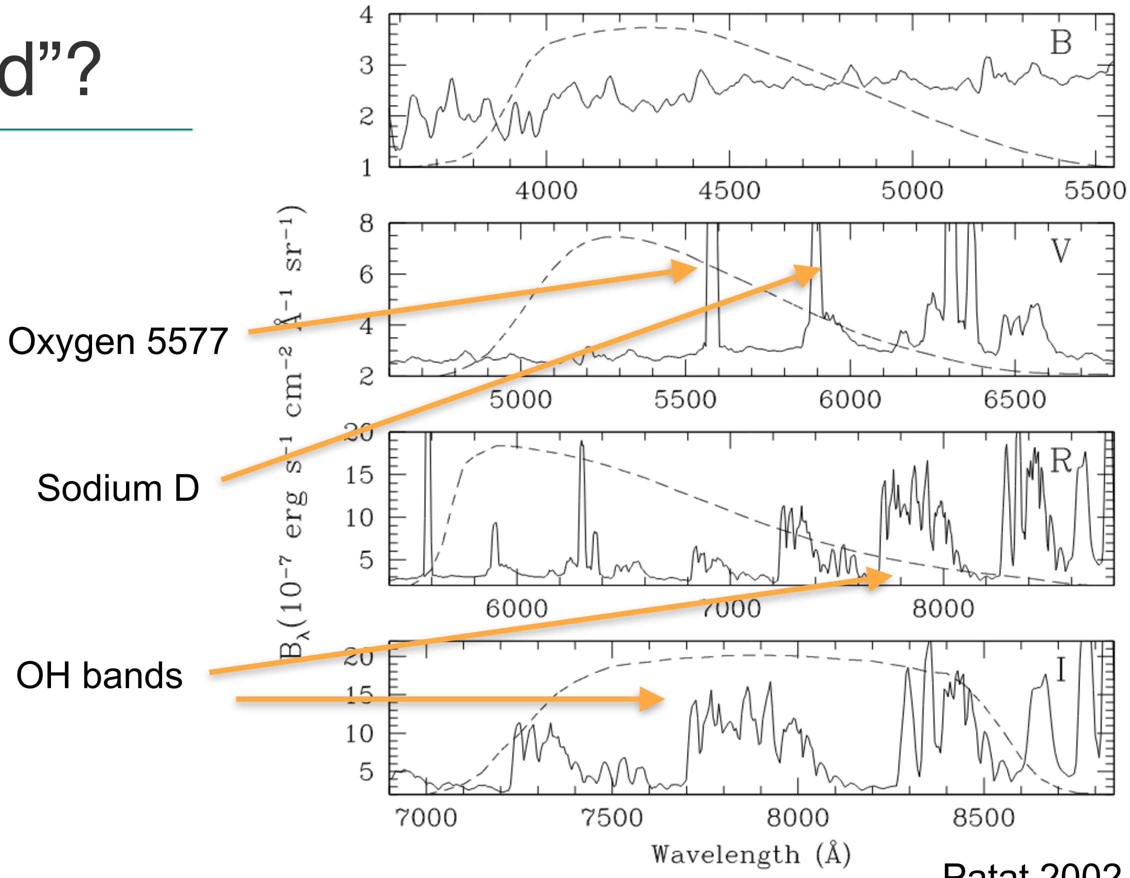


Bias vs Background

- We cannot do any photometry until we have addressed bias and background subtraction, otherwise we would add up way too many counts
- They correction is the same for both, a subtraction, but their different physical causes means that we estimate them in different ways:
- Bias — this is “baked in” to the camera, repeatable each time we take an image. Spatial structure is fixed in pixel coordinates.
- Background — mostly coming from Earth’s atmosphere, not fixed in time, might also have real astrophysical contributions.

What is "Background"?

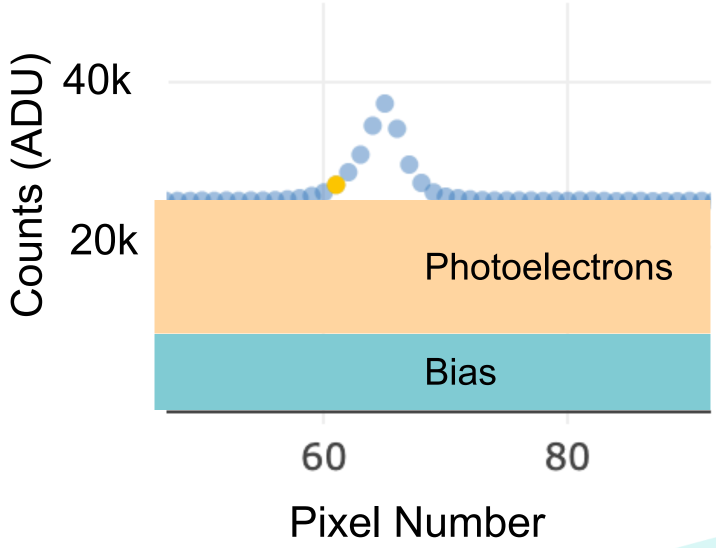
- Variety of atoms and molecules that cause emission, generally ~80-100km altitudes.
- Sky brightness is time-varying, non-uniform, depends on solar conditions, complicated!
- Typically ~20 mag/sq arcsec. Bright!



Patat 2002

Background contribution to noise

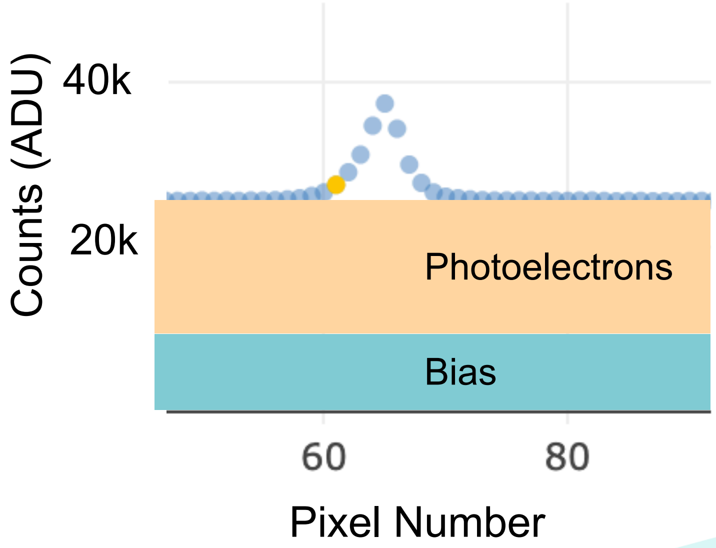
- Going back to the slice through the star, what contributes to the noise in measuring that star's flux?
- I.e. if we're Poisson noise dominated, what is the "N" in the "square-root of N"?



“Background Limited”

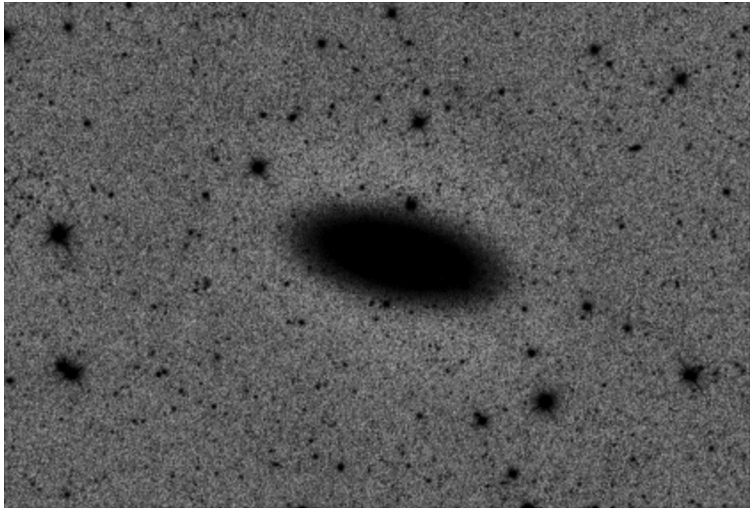
This noise from the sky background is fundamentally why:

- Darker sites are better
- Space is even better
- The moon is a problem for observers…
-



Pitfalls with background subtraction

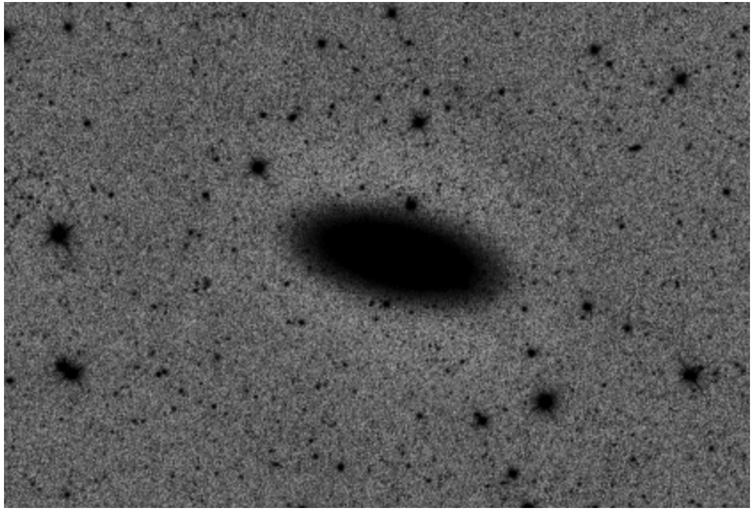
- How do you tell the difference between the outskirts of a galaxy and the background?
- Easy to over-subtract, leaving galaxies in a "divot" or a ring.
- This requires compromises and there's no easy solution, major challenge for all surveys.



Estimation of backgrounds

Typically this requires an iterative process to:

- Detect objects which are **not** background
- Mask them + some extra area around them
- Fit a function to the remaining pixels, that is sensitive to the “right” spatial scales, and doesn’t mind a lot of masked area



Summary of where we are now

We’ve gotten through:

- Bias subtraction
- Flat fielding
- Background subtraction

So now we have an image that’s ready for detection, measurement, and calibration.