CCD Readout Electronics

Amplifier(s)

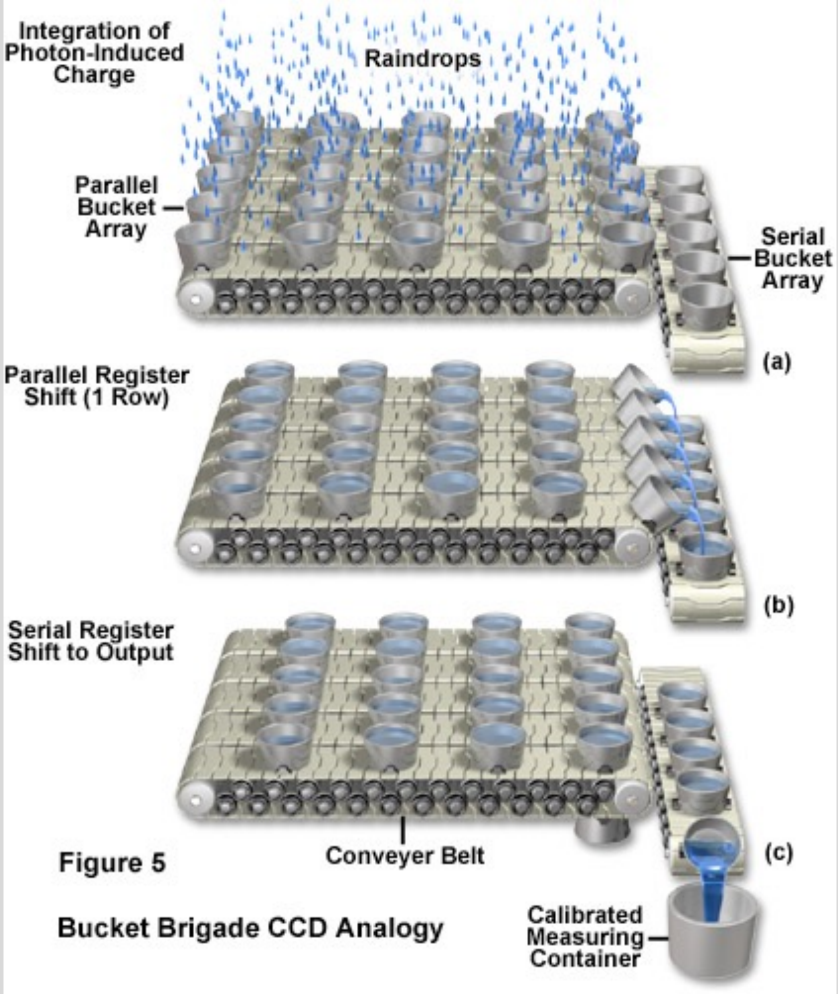
- converts the read-out charge to a voltage
- adds a **bias** or **pedestal** value to the signal

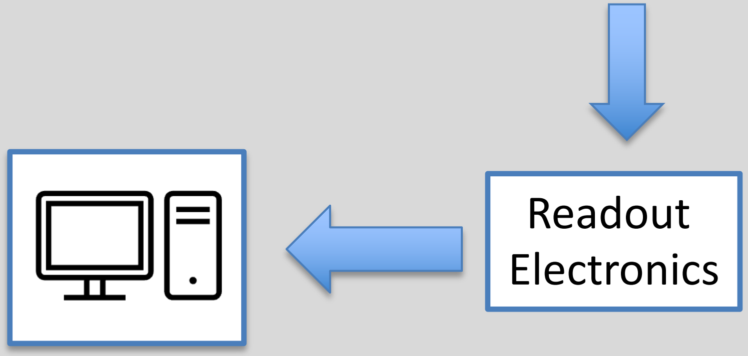
Analog to Digital Converter(s) (A/D Converters)

- turns output voltage into **counts**, aka "analog/digit units" (**ADU**)
- characterized by a **gain:** how many electrons does each count correspond to? (for example, 3 e^-/ADU)

Readout Noise

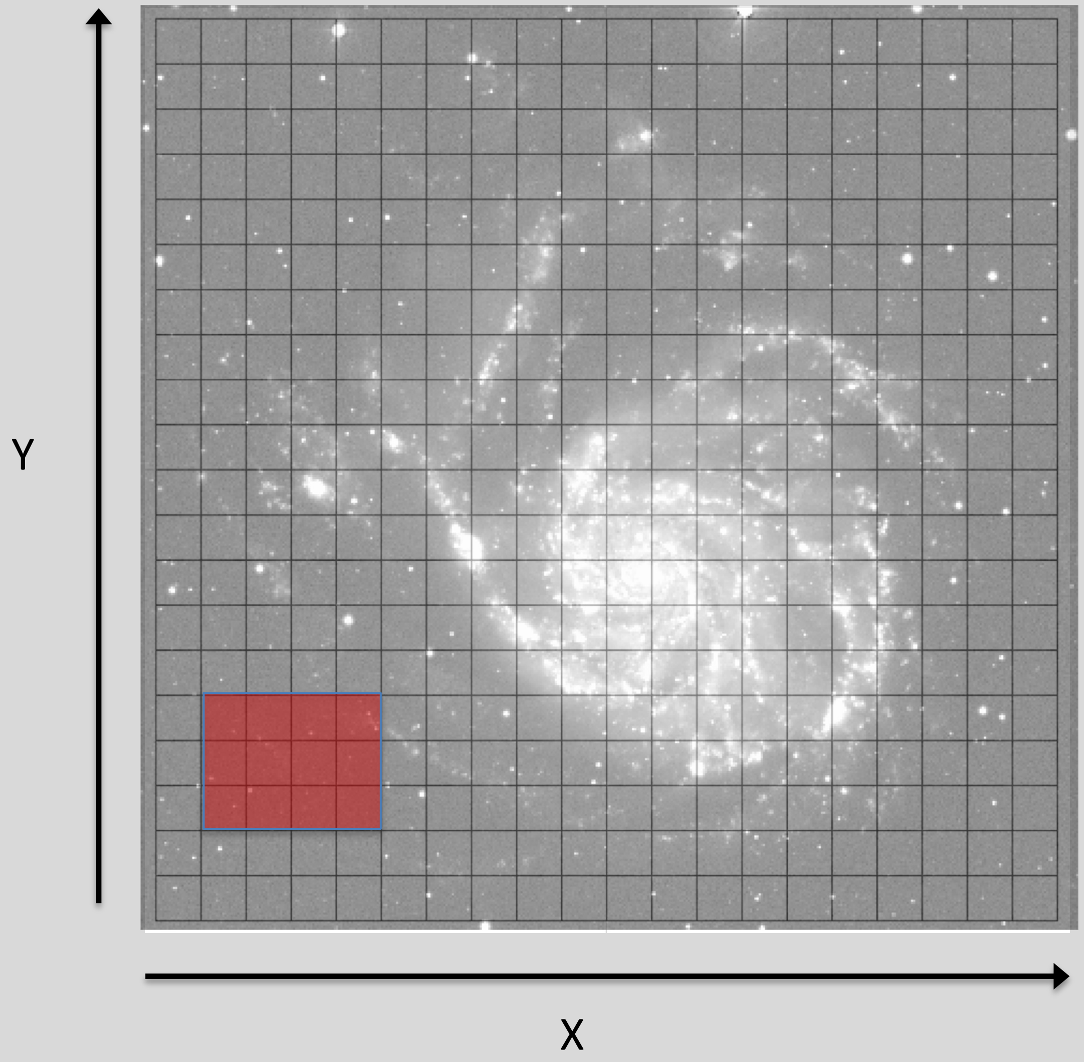
- CCD electronics inserting spurious electrons into the stream.
- conversion from analog signal to digital number is not perfectly repeatable.
- *faster readout usually produces higher readout noise*
- characterized as a certain number of electrons (e^-) per pixel



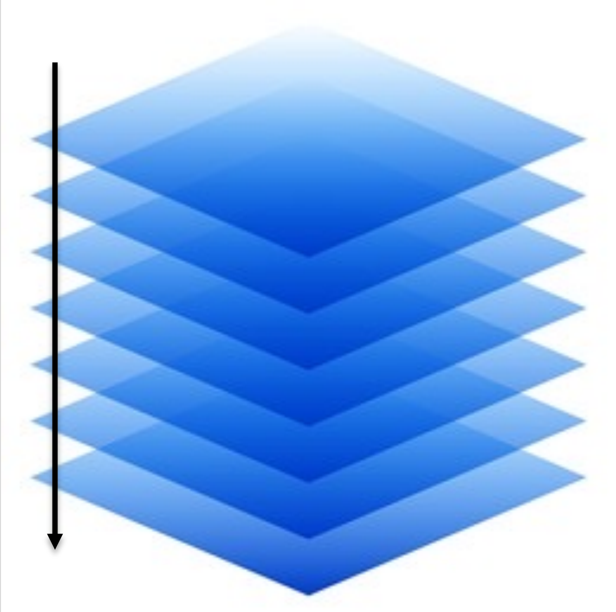


Concept of ”image math”

Images can be thought of mathematically as 2D arrays of intensity.



pixel-by-pixel math
along a multiple images.

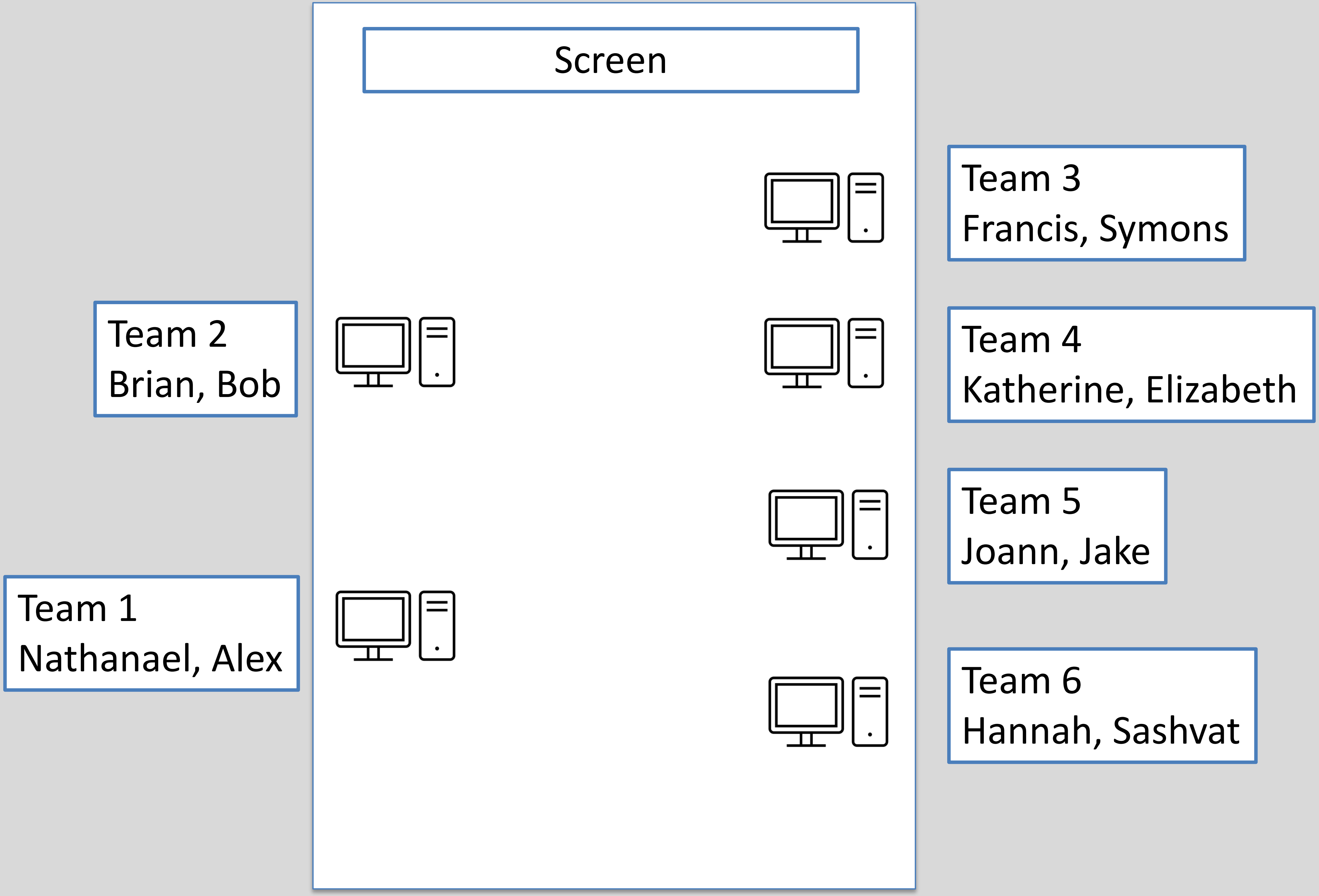


Images can be:

- added or subtracted
- multiplied or divided
- averaged or medianed

You can also do statistical analysis of regions:

- sums (measures total flux in a region!)
- standard deviation (measures flux variation in a region)


Screen
Team 3
Francis, Symons
Team 2
Brian, Bob
Team 4
Katherine, Elizabeth
Team 5
Joann, Jake
Team 1
Nathanael, Alex
Team 6
Hannah, Sashvat

CCD Data Reduction: Conceptual Steps

First question: what patterns does the readout process imprint on the image? In other words, what does an image look like if you don't expose the CCD to any light?

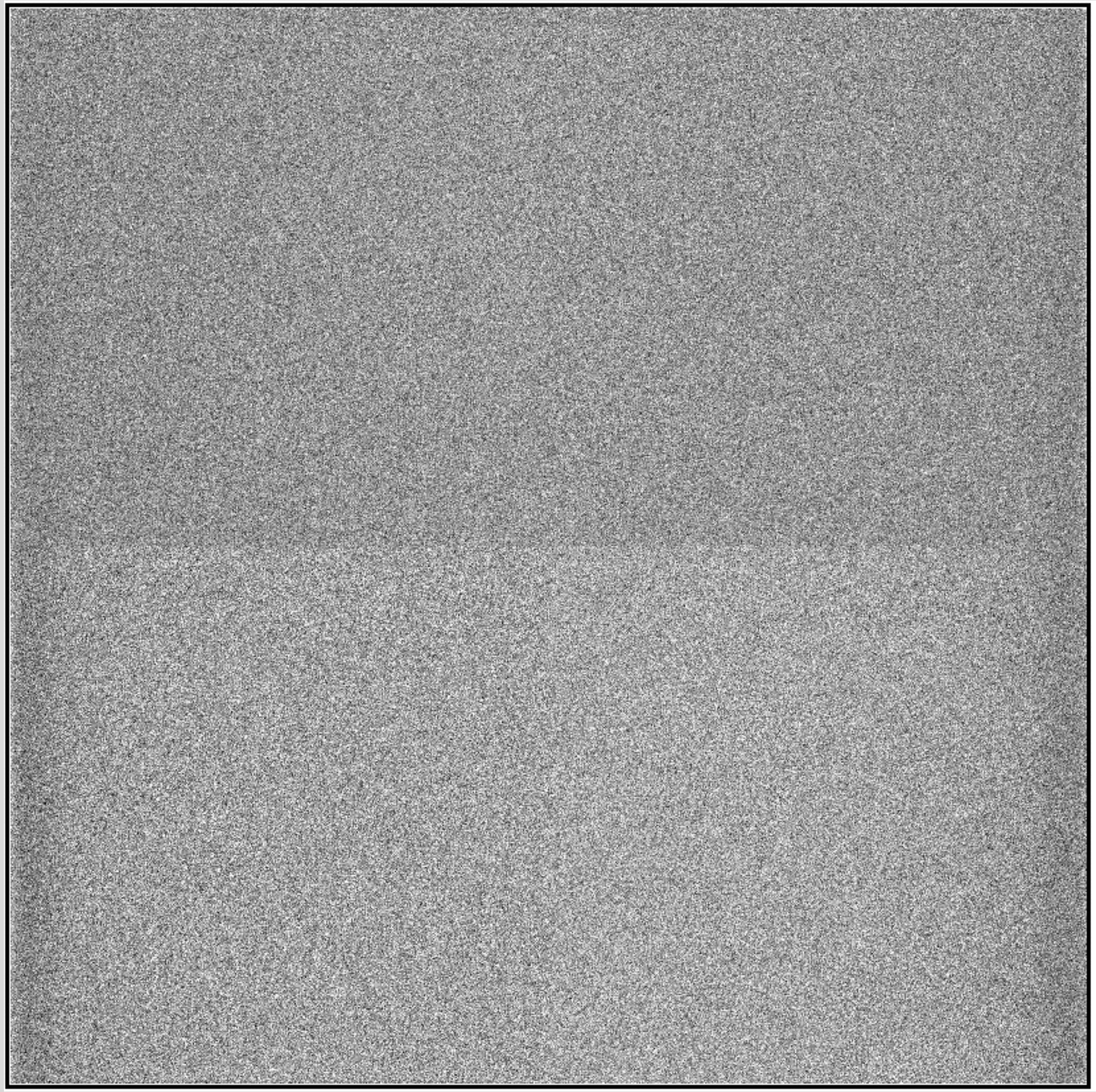
Zero images and Zero Subtraction

Read out the CCD without exposing it to light. This shows the readout noise and any systematic spatial pattern associated with it.

Every readout adds a **random noise signal** (the readout noise) to each pixel an image. This is random, and different, for every image.

It sets a "floor" to the noise level in a single image.

Schmidt CCD readout noise is $3.6e^{-}$ or about 1.4 ADU.



Schmidt 4Kx4K CCD zero image, showing fluctuations at the +/- 5 ADU level.

CCD Data Reduction: Conceptual Steps

First Concern: what patterns does the readout process imprint on the image? In other words, what does an image look like if you don't expose the CCD to any light?

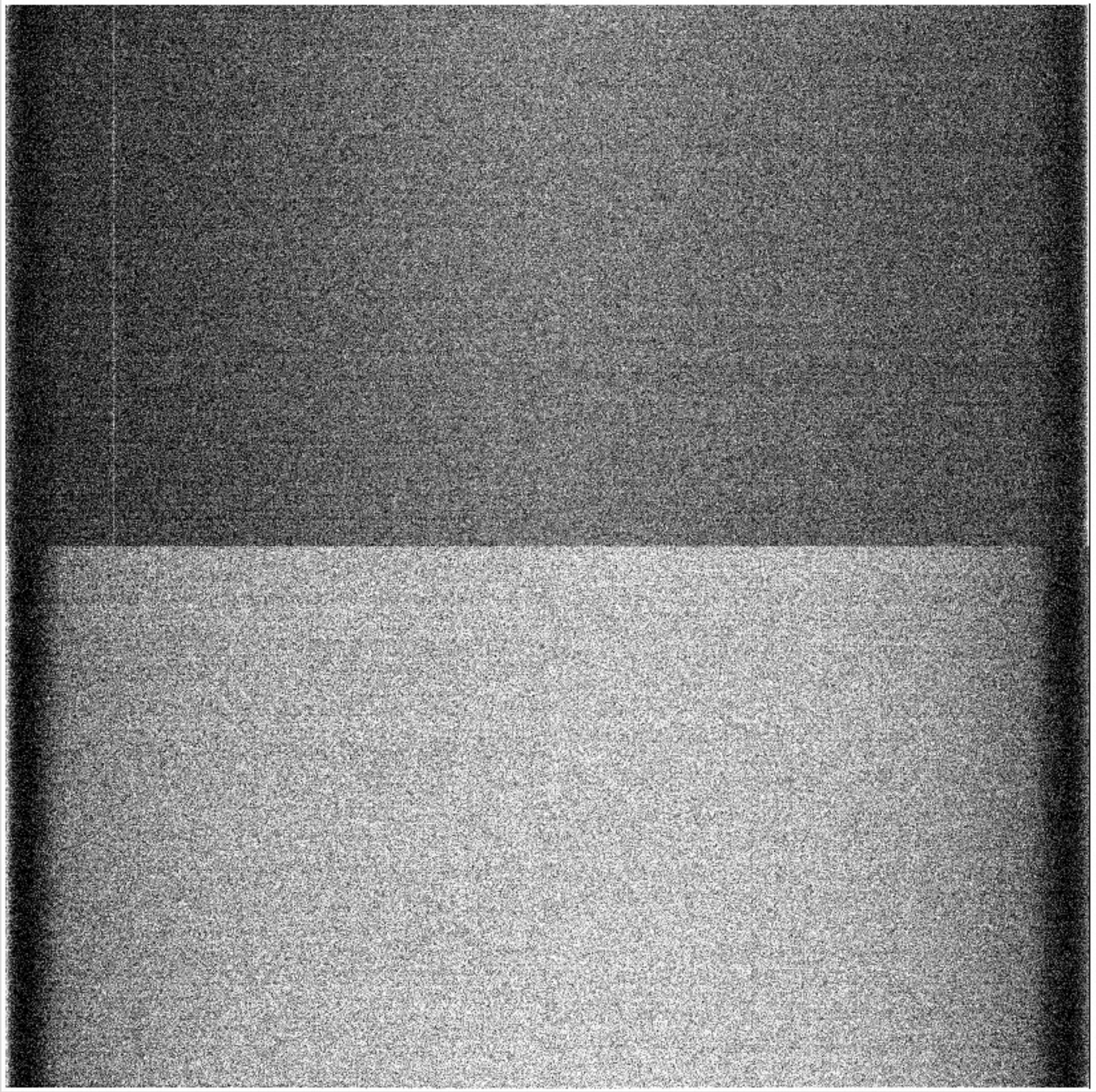
Zero images and Zero Subtraction

Read out the CCD without exposing it to light. This shows the readout noise and any systematic spatial pattern associated with it.

Schmidt CCD readout noise is 3.6e^{-} or about 1.4 ADU.

By co-adding many zero images, you can beat down the readout noise (hopefully by $\sqrt{N}$) and see the underlying systematic pattern: **fixed pattern noise**

This pattern can be removed by **subtracting the co-added zero** from every image taken, but the basic readout noise of each pixel will remain.



25 co-added Schmidt 4Kx4K CCD zero images, showing fluctuations at the +/- 1 ADU level.

CCD Data Reduction: Conceptual Steps

Second Concern: Is there a noise component that grows with time, so that longer exposure have more noise? The longer you expose the more problematic these noise sources will be.

Dark subtraction

Over the course of a long exposure, thermal electrons can jump from the valence band to the conduction band and introduce a **thermal or dark current**.

Also may have scattered light or "**light leaks**" in the telescope: light getting to the detector from extraneous sources.

To correct for this, take long exposures (**dark frames**) with the CCD blocked from being exposed to light. This dark frame can then also be subtracted from all your images.

Most modern optical CCDs have very low dark current, but the problem is much worse with infrared CCDs (which have a narrow energy gap between valence and conduction bands).

CCD Data Reduction: Conceptual Steps

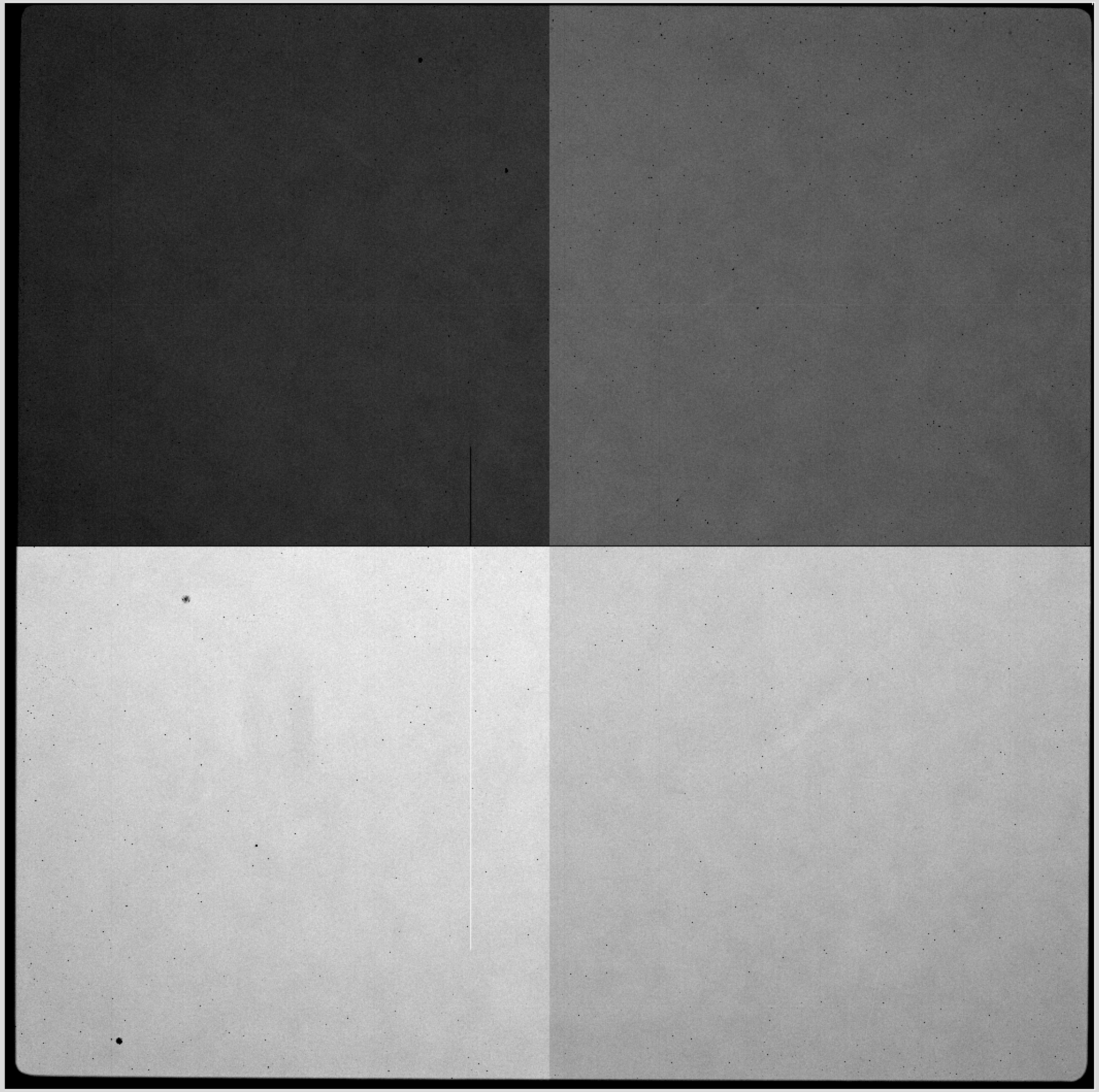
Third Concern: The sensitivity of the detector may not be unform across the field of view, or the gain (e^-/ADU) may differ in different parts of the detector.

Flat fielding

Expose the CCD to a source of illumination that is uniform across the field. These **flat field** images can be made using various techniques:

- **dome flat**: pointing telescope at a white screen on the dome
- **twilight flat**: pointing telescope at the twilight sky
- **dark sky flat**: co-adding many images of sparsely crowded night sky.

Schmidt 2019 flat field



Notice variations in gain in different quadrants

CCD Data Reduction: Conceptual Steps

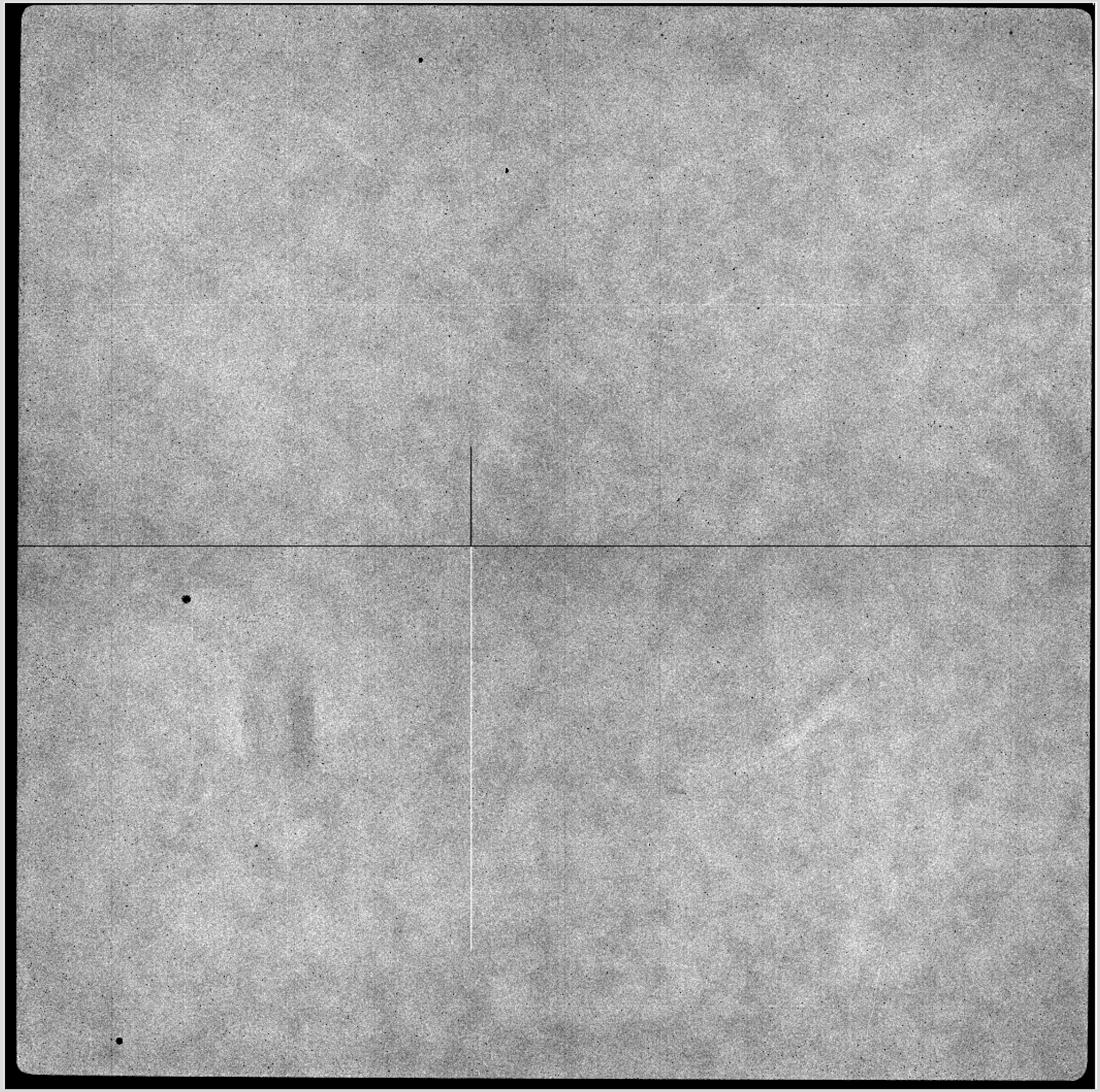
Third Concern: The sensitivity of the detector may not be unform across the field of view, or the gain (e^-/ADU) may differ in different parts of the detector.

Flat fielding

Expose the CCD to a source of illumination that is uniform across the field. These **flat field** images can be made using various techniques:

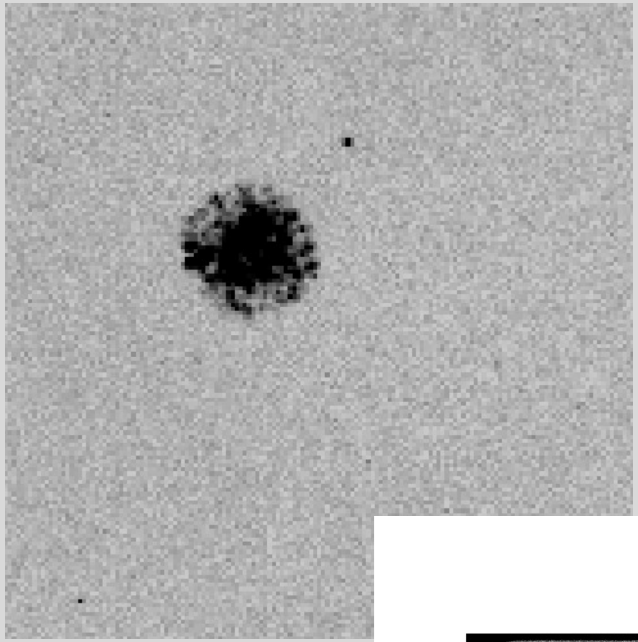
- **dome flat**: pointing telescope at a white screen on the dome
- **twilight flat**: pointing telescope at the twilight sky
- **dark sky flat**: co-adding many images of sparsely crowded night sky.

Schmidt 2019 flat field



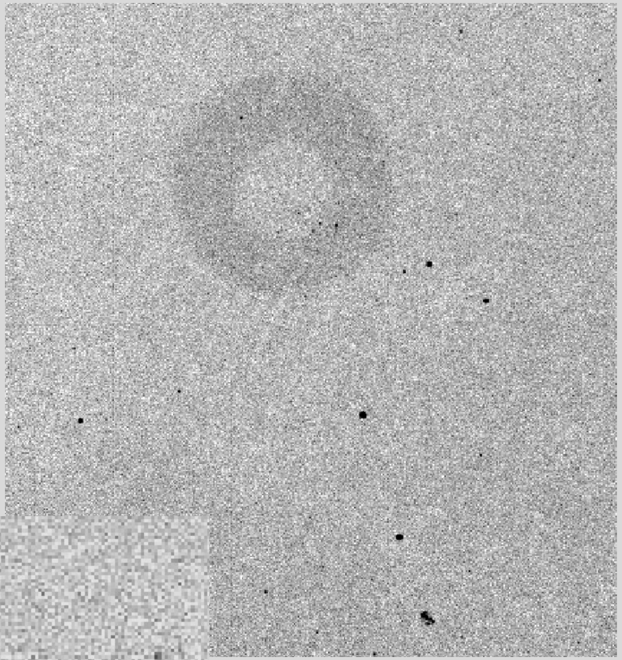
After removing gain variations we see sensitivity variations

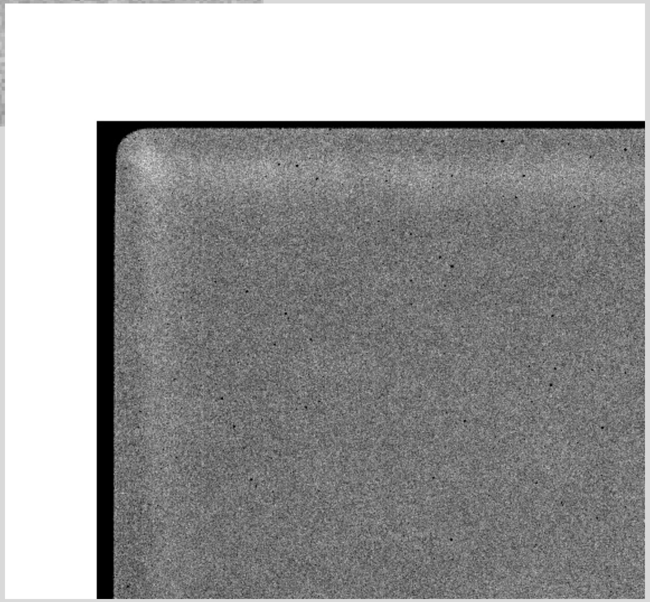
CCD Data Reduction: Flat field features



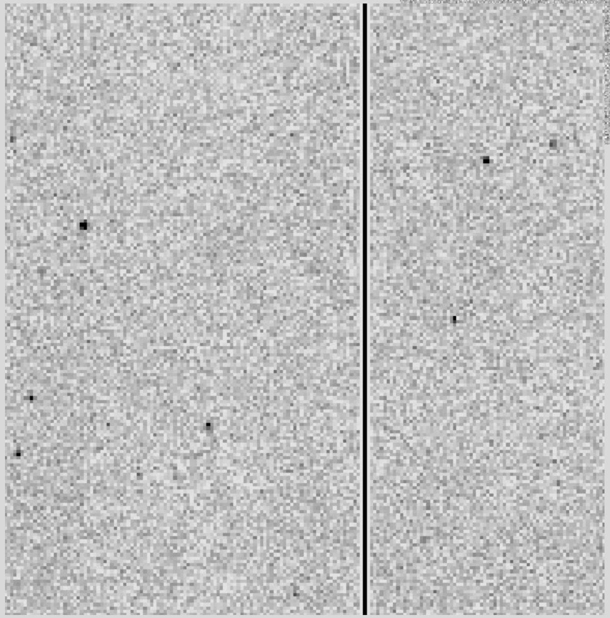
CCD blemish

dust spot





vignetting and large scale features



bad columns

CCD Data Reduction: Conceptual Steps

Third Concern: The sensitivity of the detector may not be unform across the field of view, or the gain (e^-/ADU) may differ in different parts of the detector.

Flat fielding

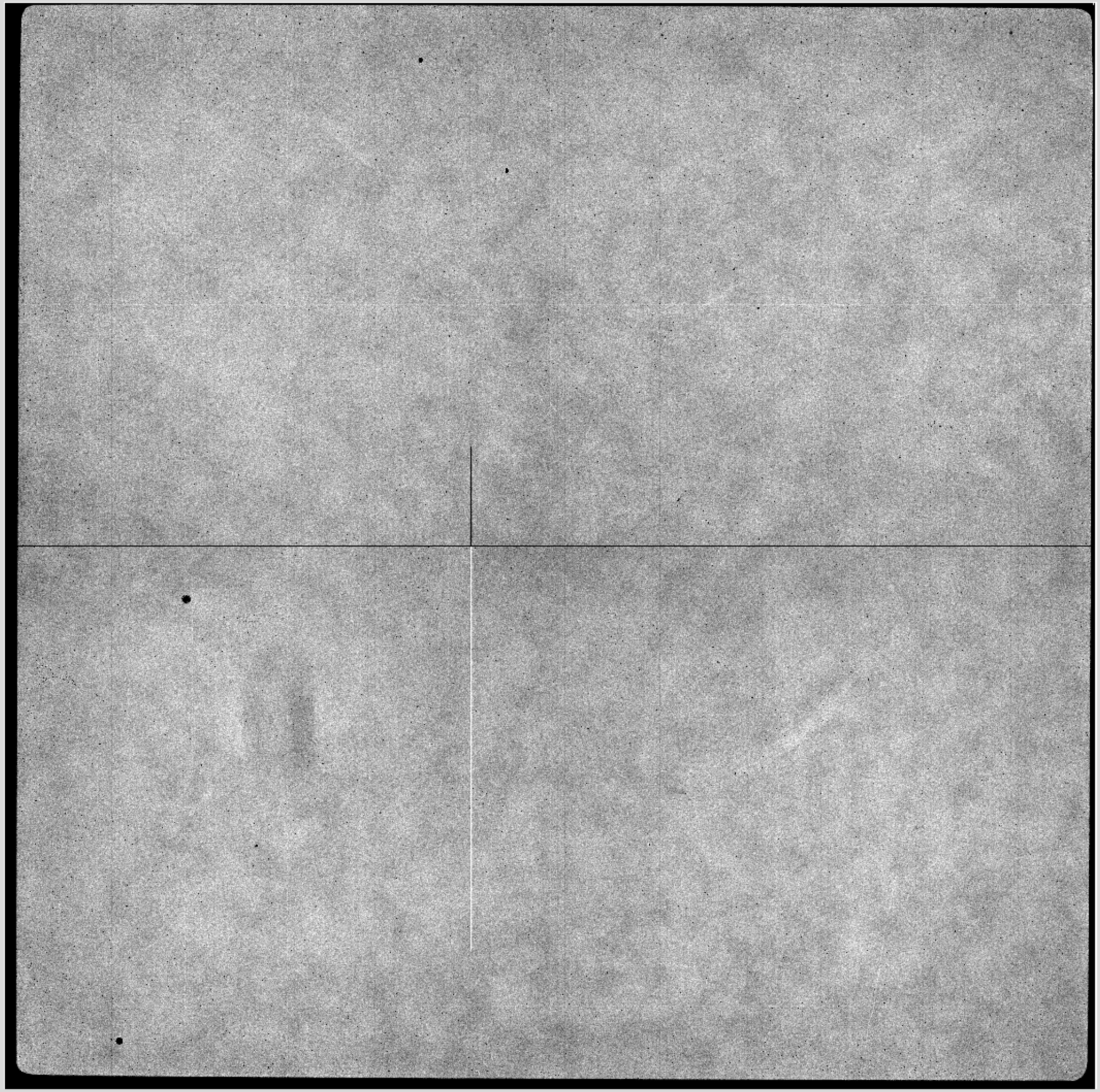
Expose the CCD to a source of illumination that is uniform across the field.

Normalize (rescale) the flat field image so that it has an average value of 1.0 across the image – some pixels will be higher than one (more sensitive) and some will be lower than one (less sensitive).

Then ***divide*** your science images by the flat field.

These sensitivity variations are wavelength dependent, so you must have a flat field taken through every filter you are observing with!

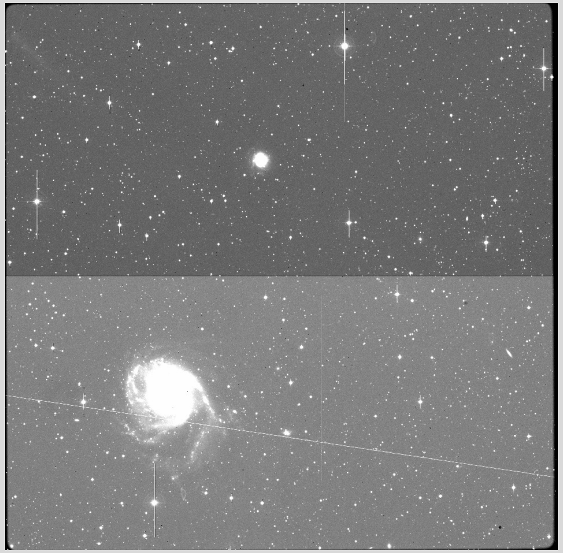
Schmidt 2019 flat field



After removing gain variations we see sensitivity variations

CCD Data Reduction: Conceptual Steps

Reduced Image = (Raw image – Master Zero [– Dark]) / Flat



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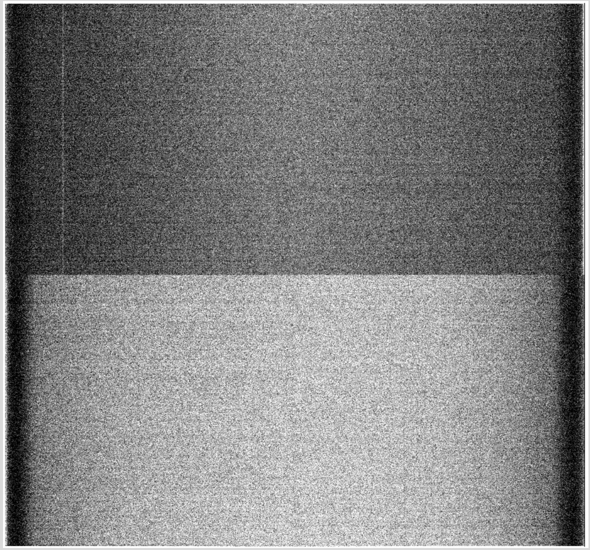

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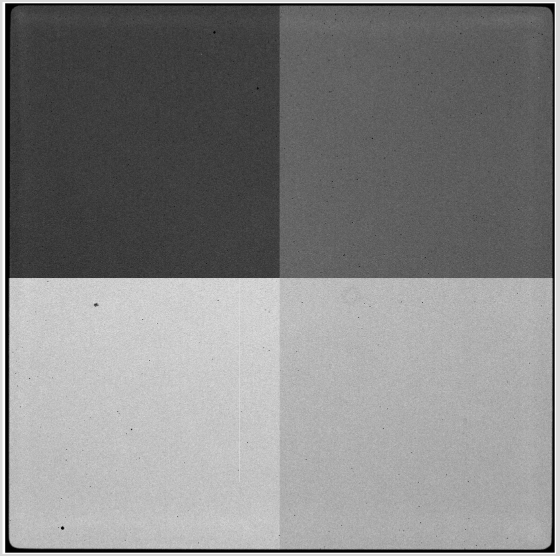

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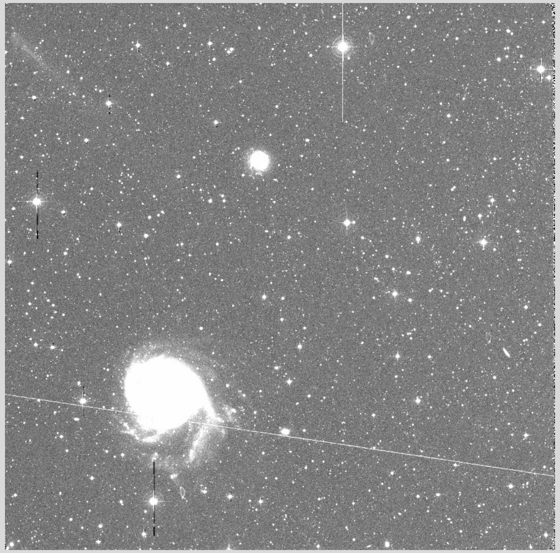
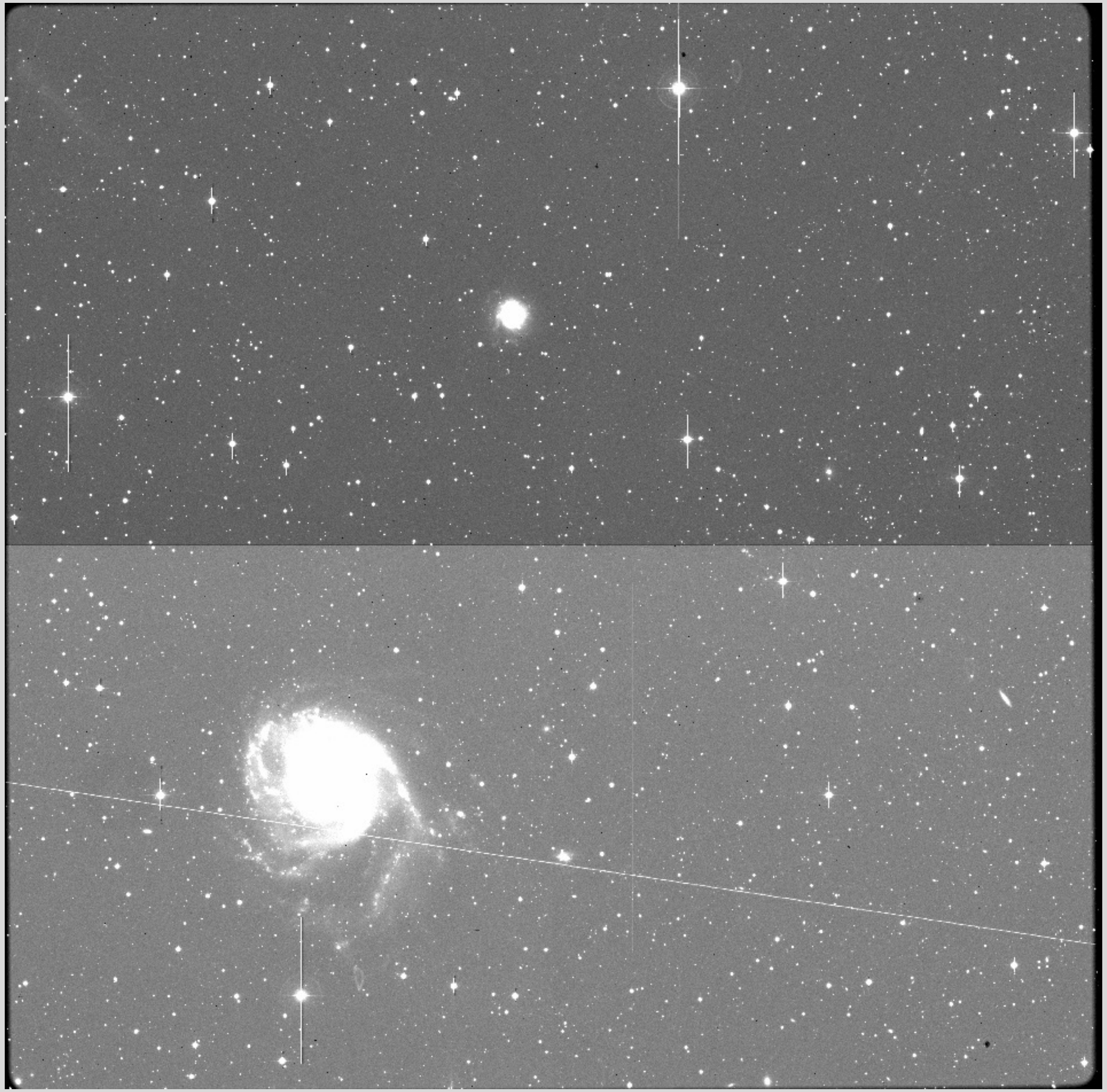


CCD Data Reduction: Conceptual Steps

Raw image



Reduced Image