Random notes on CCD image calibration

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Nova Car 2018 and η Car nebula
imaged by Joseph Brimacombe

Charge-coupled device (CCD)

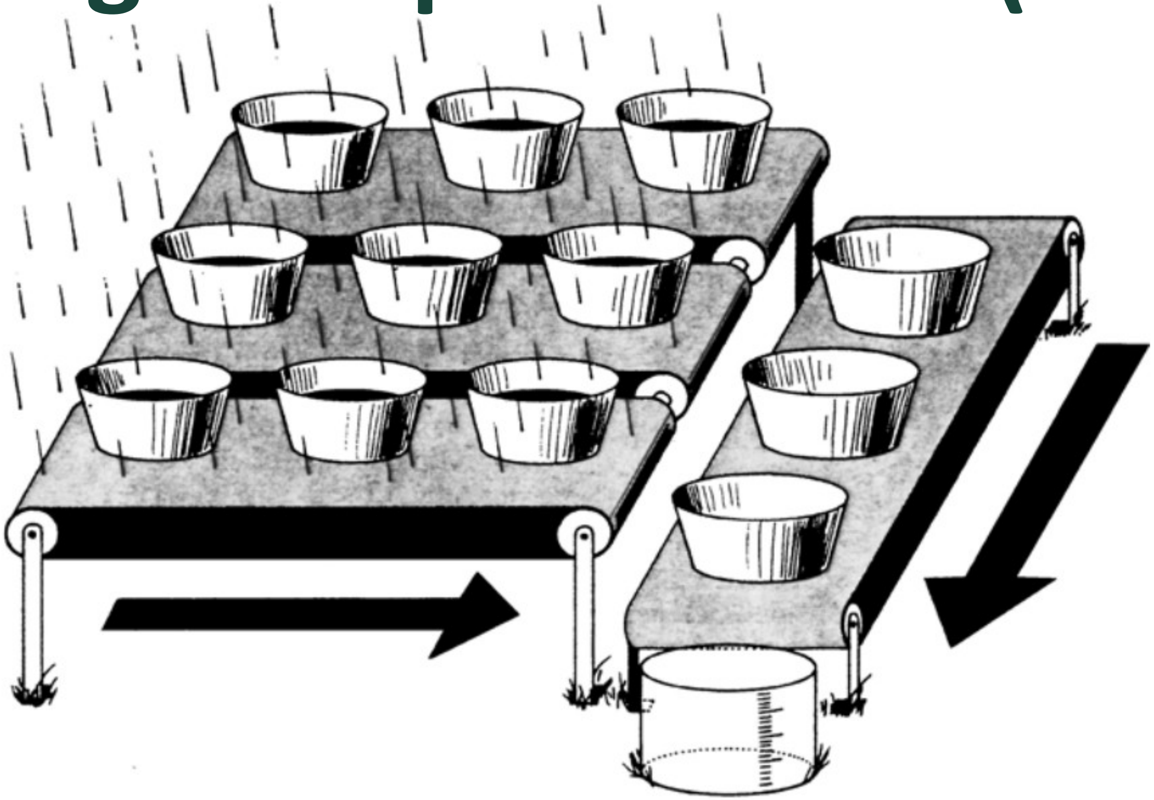


Fig. 2.1. CCDs can be likened to an array of buckets that are placed in a field and collect water during a rainstorm. After the storm, each bucket is moved along conveyor belts until it reaches a metering station. The water collected in each field bucket is then emptied into the metering bucket within which it can be measured. From Janesick & Blouke (1987).

CCD

KAF−16801 Full Frame CCD Image Sensor

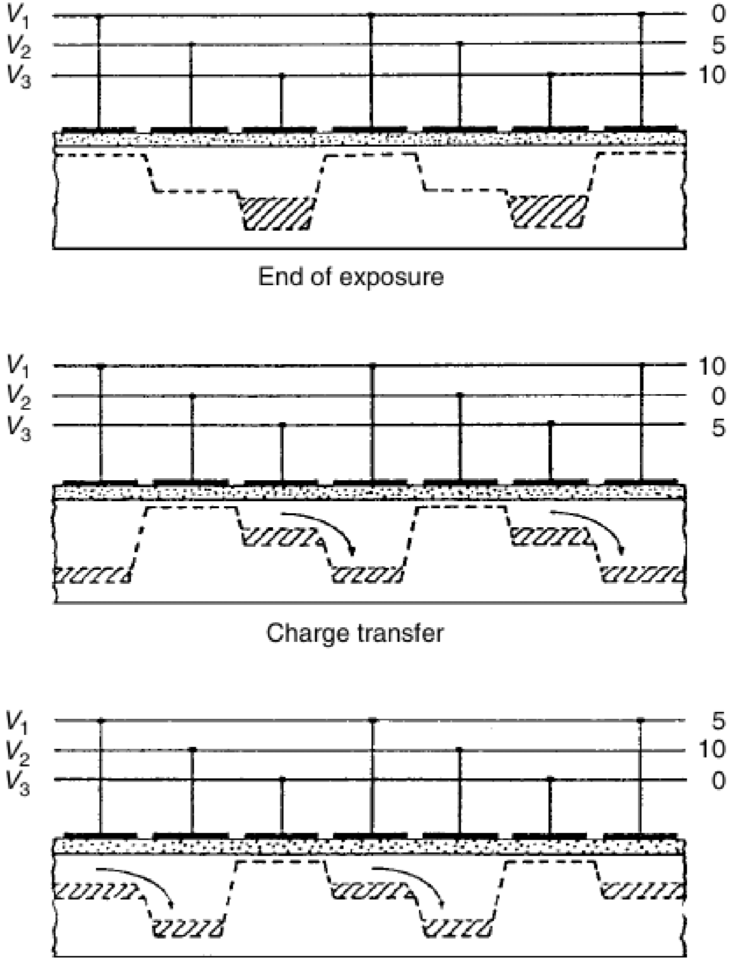
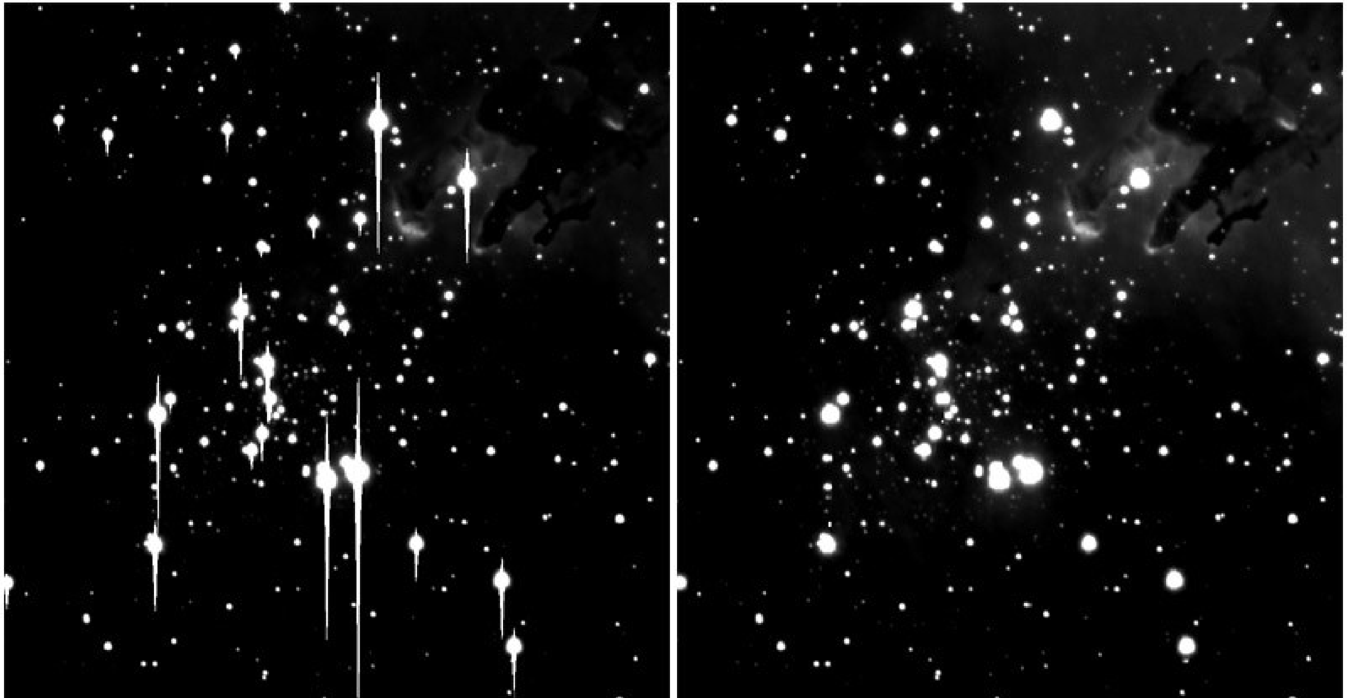


Fig. 2.2. Schematic voltage operation of a typical three-phase CCD. The clock voltages are shown at three times during the readout process, indicating their clock cycle of 0, 10, and 5 volts. One clock cycle causes the stored charge within a pixel to be transferred to its neighboring pixel. CCD readout continues until all the pixels have had their charge transferred completely out of the array and through the A/D converter. From Walker (1987).

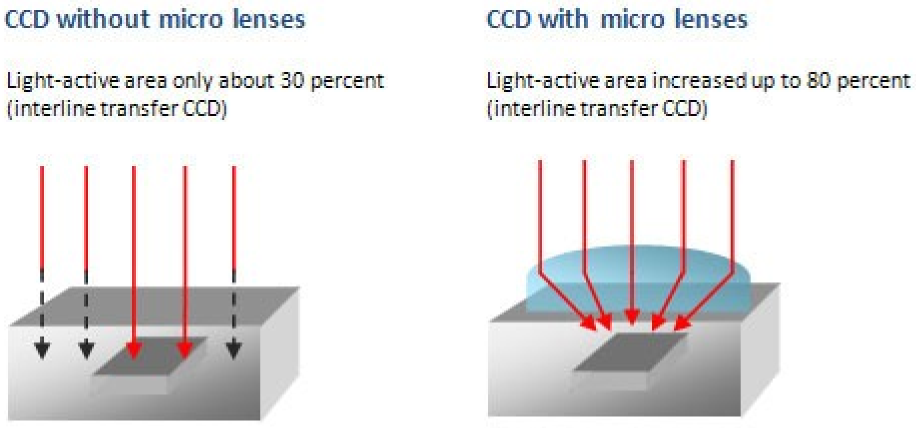
Anti-blooming electrodes

- Stop excessive charge from flooding other pixels
- Take up space - reduce quantum efficiency
- Introduce *slight* non-linearity

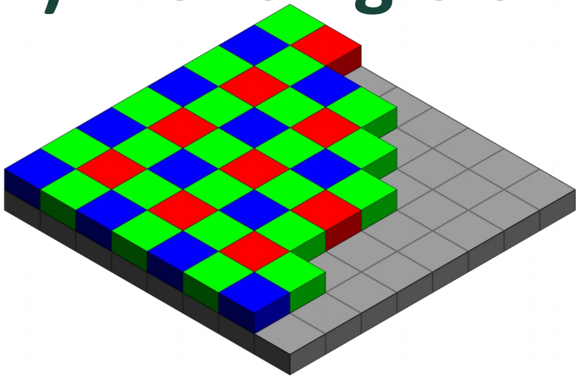


On top of a CCD chip one may find

- **Microlens array - increases sensitivity**



- **Bayer filter (matrix) - for single-shot color imaging**



CCD gain

ADU = gain * n_electrons

each pixel can hold up to a certain number of electrons

Analog-to-digital converter may output numbers in a certain range: 16bit - 0...65535

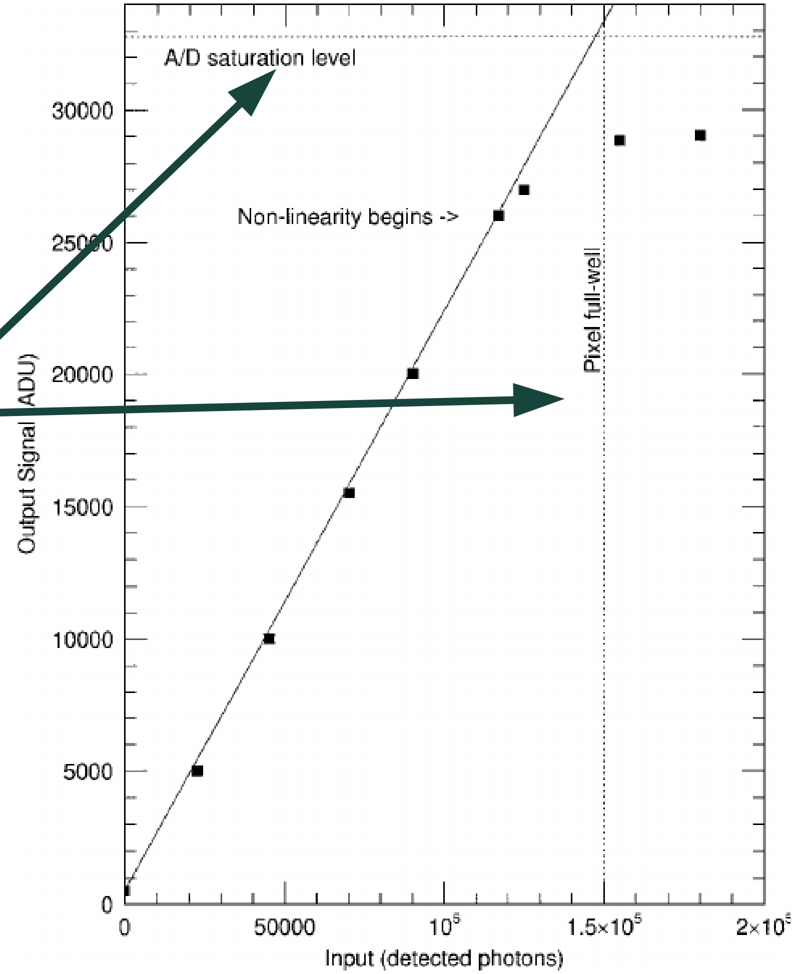
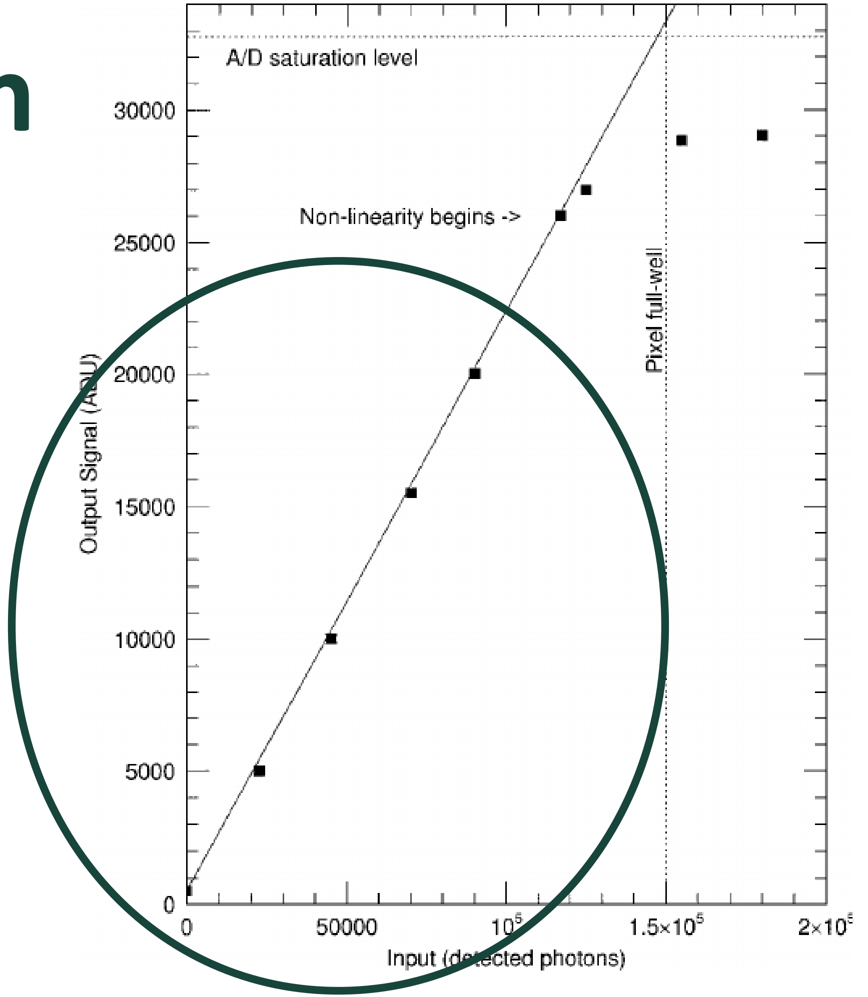


Fig. 3.9. CCD linearity curve for a typical three-phase CCD. We see that the device is linear over the output range from 500 ADU (the offset bias level of the CCD) to 26 000 ADU. The pixel full well capacity is 150 000 electrons and the A/D converter saturation is at 32 767 ADU. In this example, the CCD nonlinearity is the limiting factor of the largest usable output ADU value. The slope of the linearity curve is equal to the gain of the device.

CCD gain

In practice we just always stay in the linear regime



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In each CCD pixel

ADU = bias + dark_current * T + sensitivity * light * T

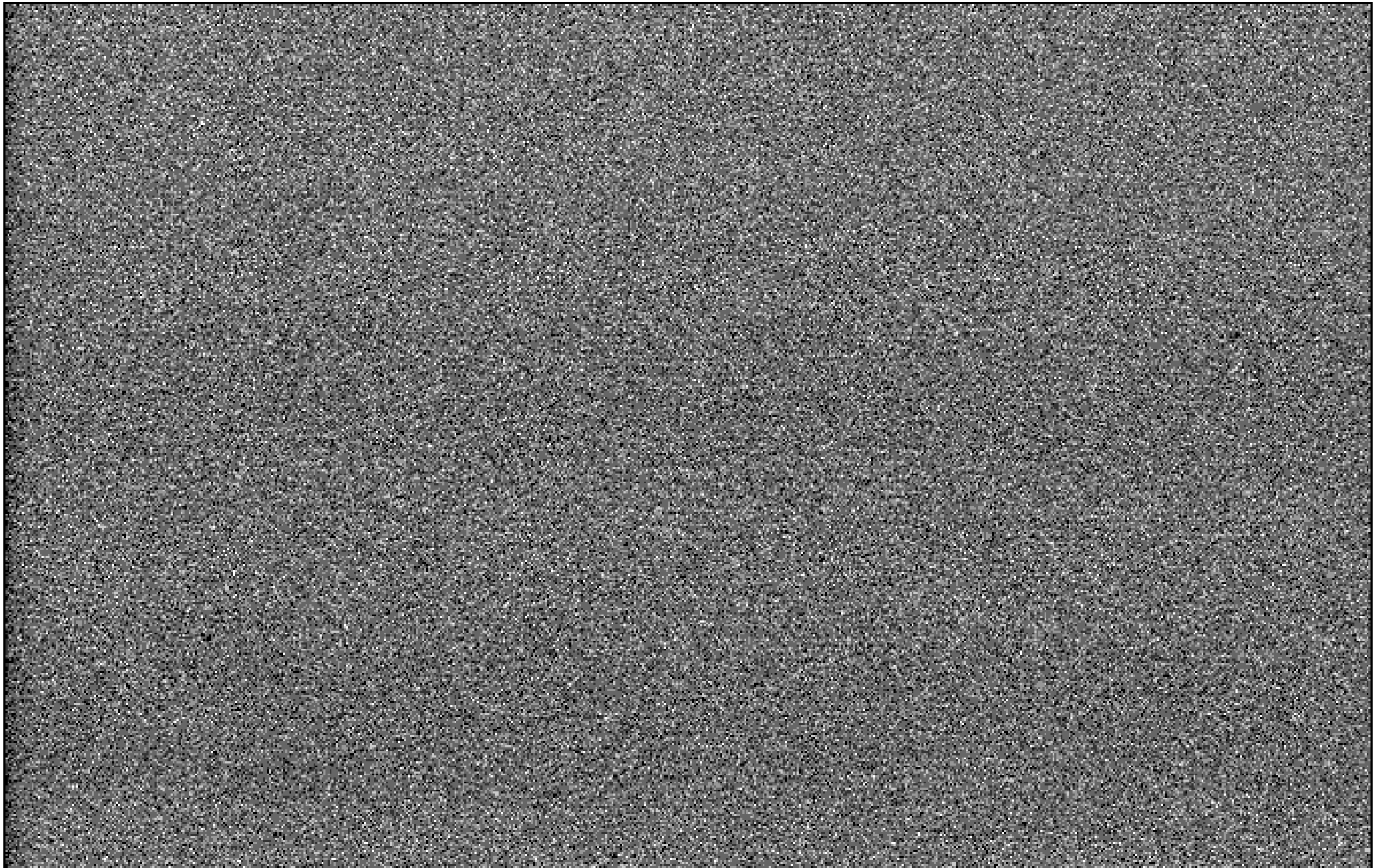
T is the exposure time (sec), bias in ADU, dark_current in ADU/sec, sensitivity is a factor <1 and light is in ADU/sec

Calibration frames

bias frame - zero-exposure image

ADU = bias + dark_current * T + sensitivity * light * T

Bias frame example



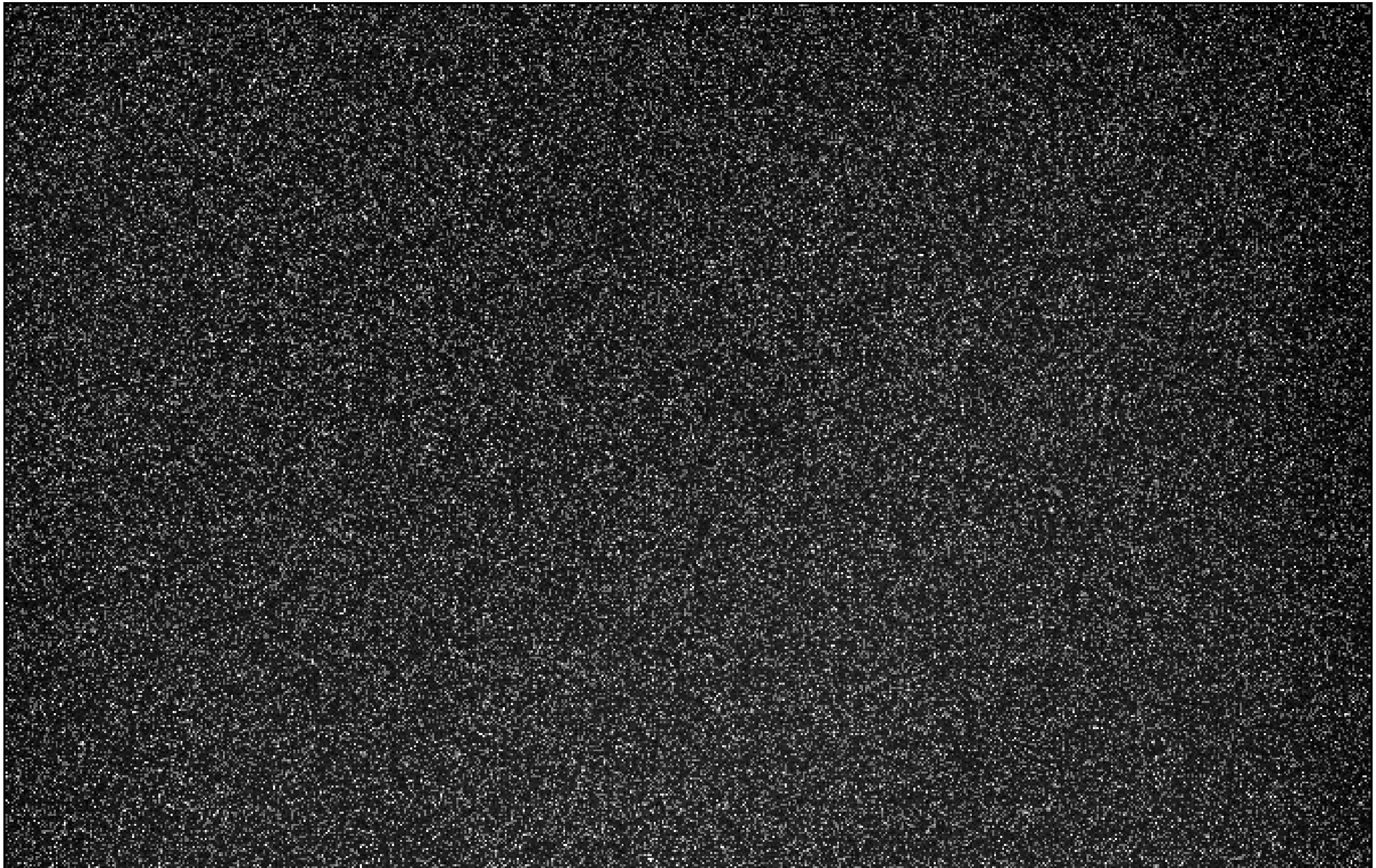
Calibration frames

dark frame - same exposure as the light image, but with the shutter closed

ADU = bias + dark_current * T + sensitivity * light * T

dark current is linearly proportional to exposure time

Dark frame example



Calibration frames

flat-field frame - light image of a uniform screen = sky

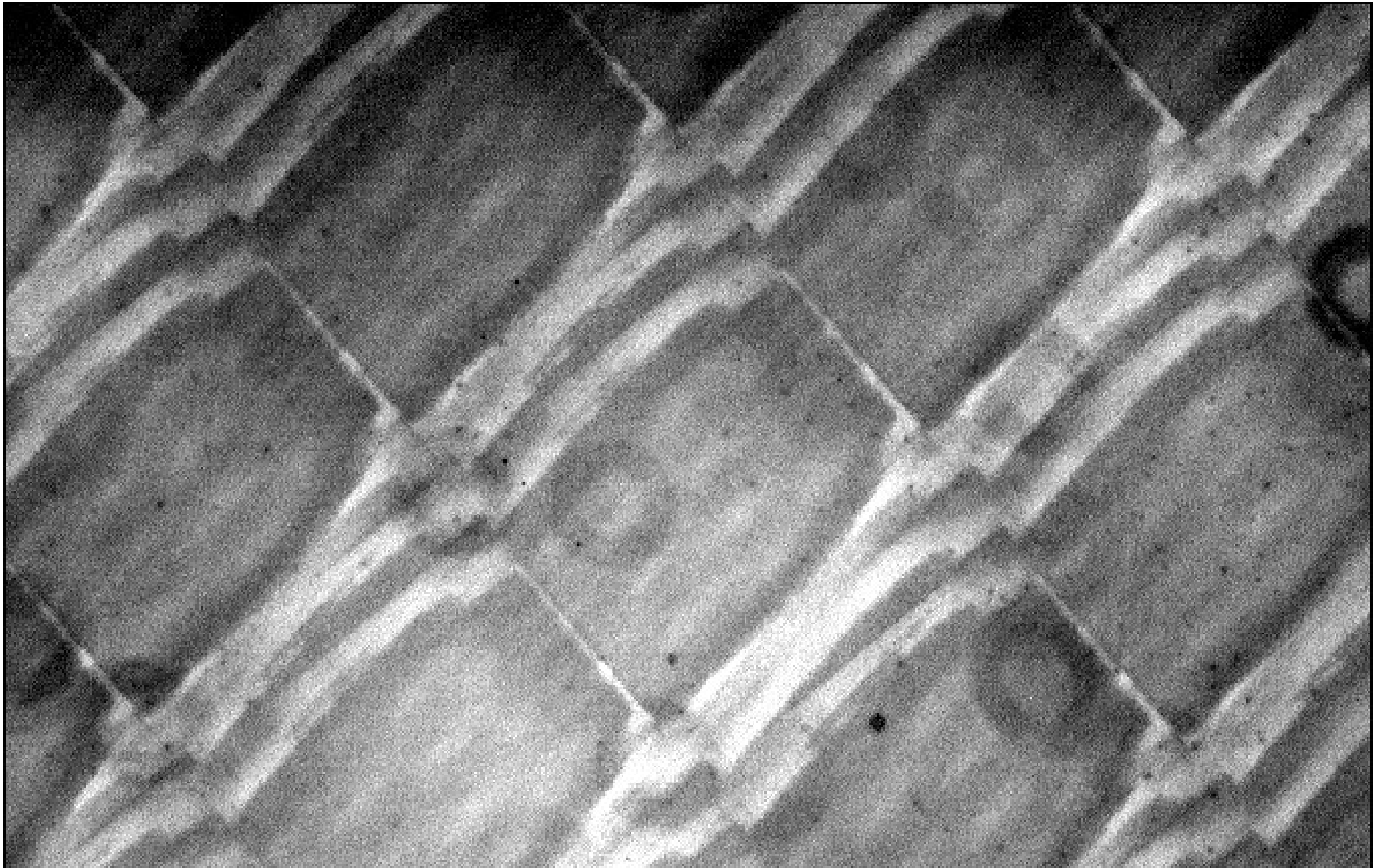
We care only about pixel-to-pixel sensitivity variations

Dark current can often be neglected (short exposure)

ADU = bias + ~~dark_current~~ * T + sensitivity * light * T

const =

Flat-field frame example

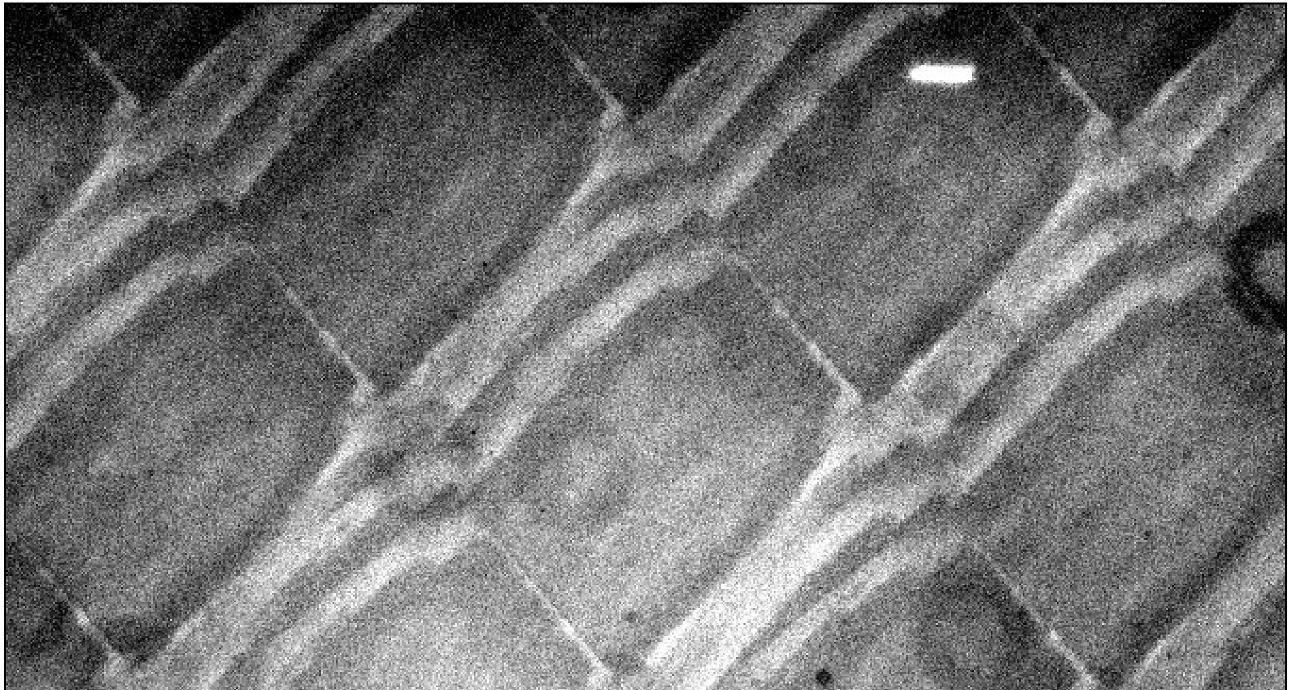


CCD image calibration

pixel-by-pixel: **ADU = (light - dark)/flat**

Why (median)-stack calibration images?

- Get rid of stuff that changes from frame to frame: cosmic rays on dark, stars on flat
- Reduce shot noise (think of Poisson distribution)



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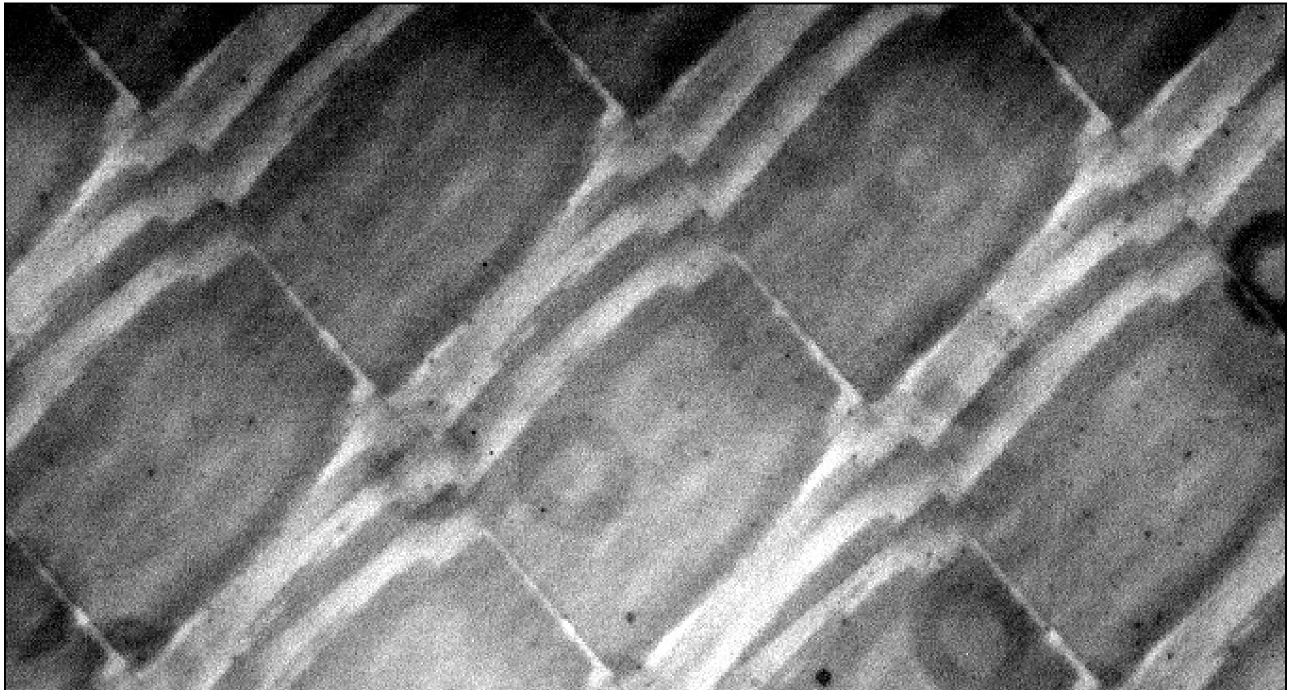
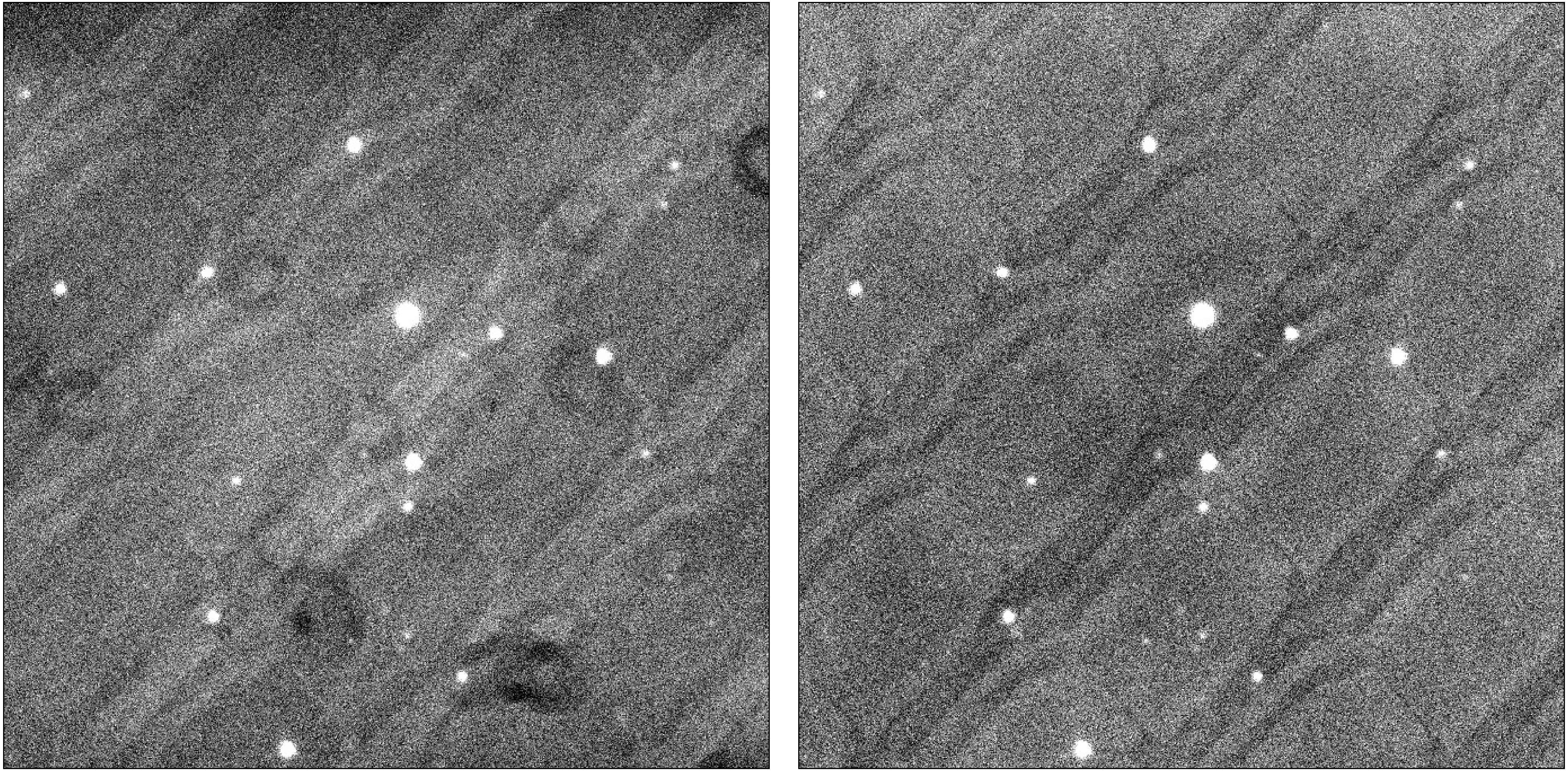


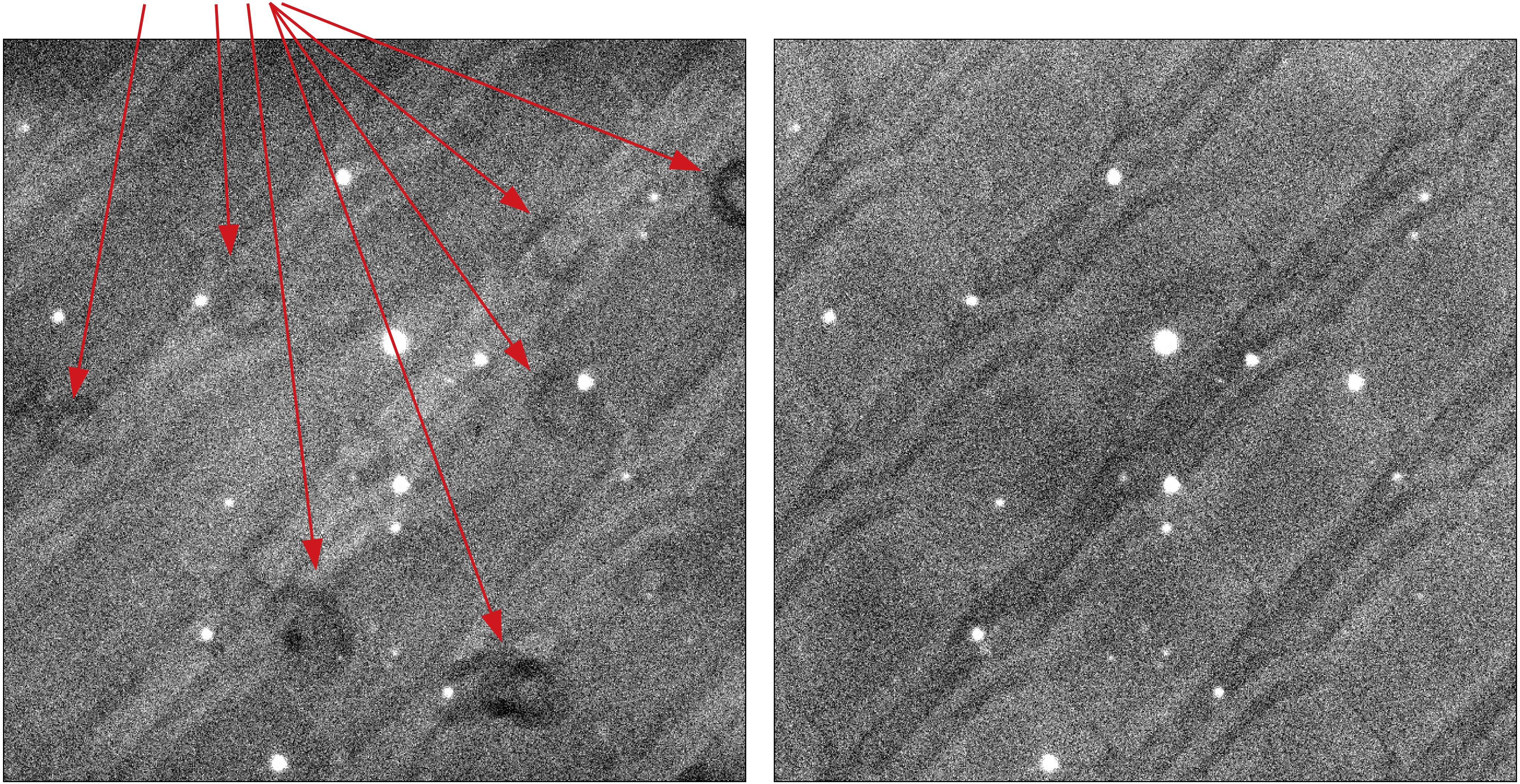
Note that...

- **Bias, dark, flat - all depend on CCD temperature**
- **LN2-cooled CCD has virtually no dark current**
- **CCDs in space often have issues with charge transfer efficiency (CTE) from pixel to pixel due to radiation damage. It can partly be corrected. Not a concern for ground-based observations**

CCD image calibration example



dust rings and vignetting are gone, but not the stripes



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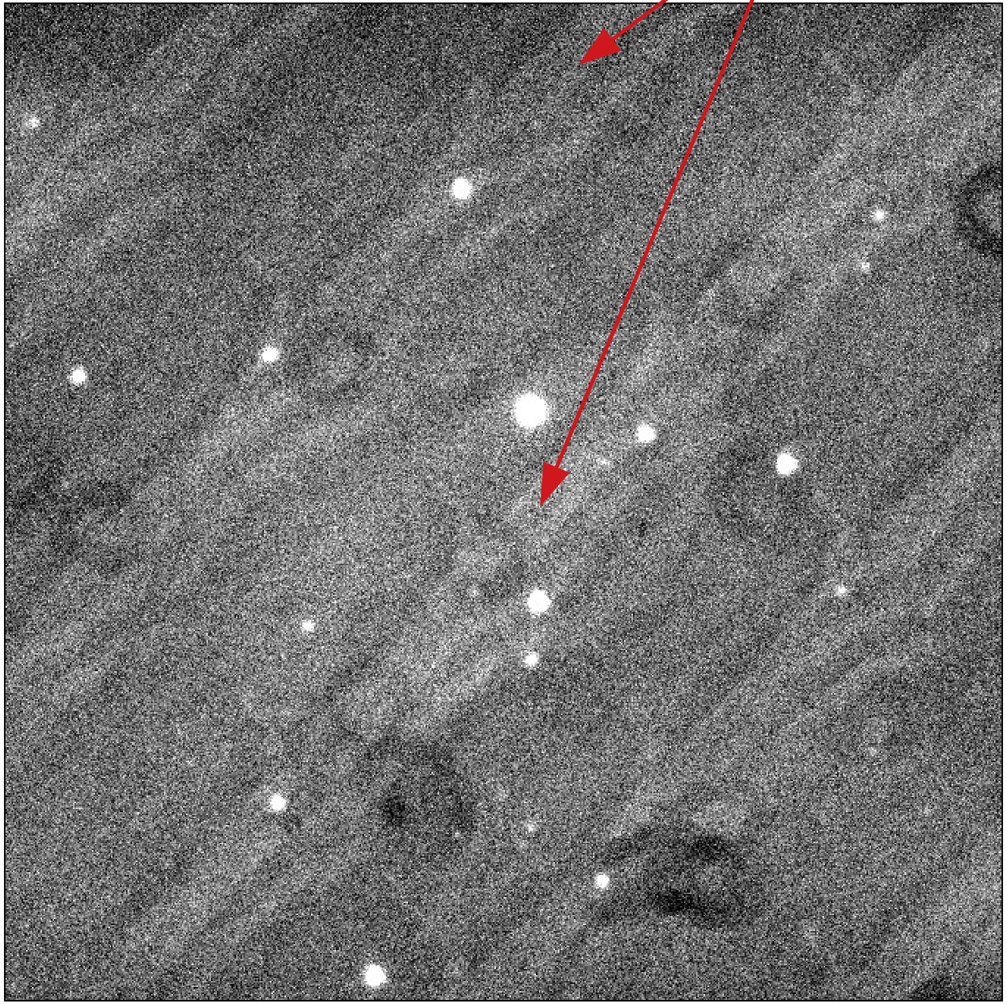
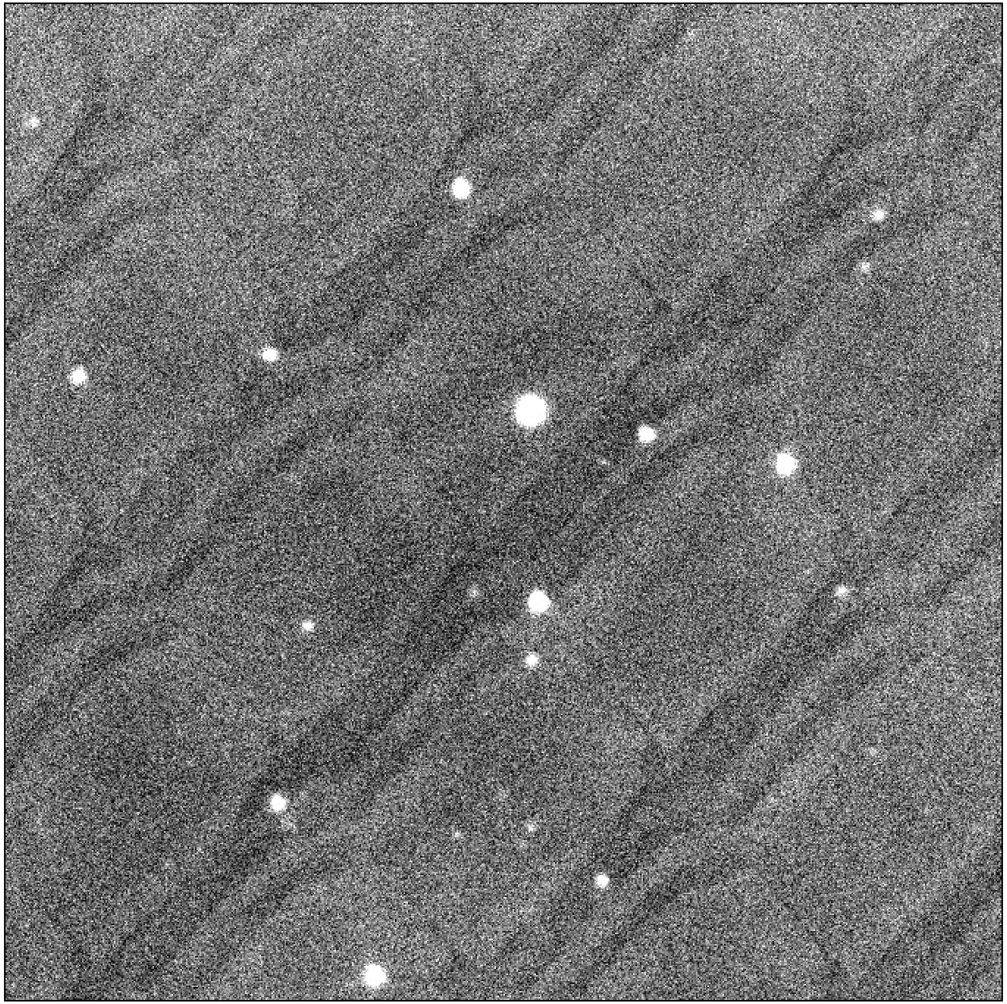
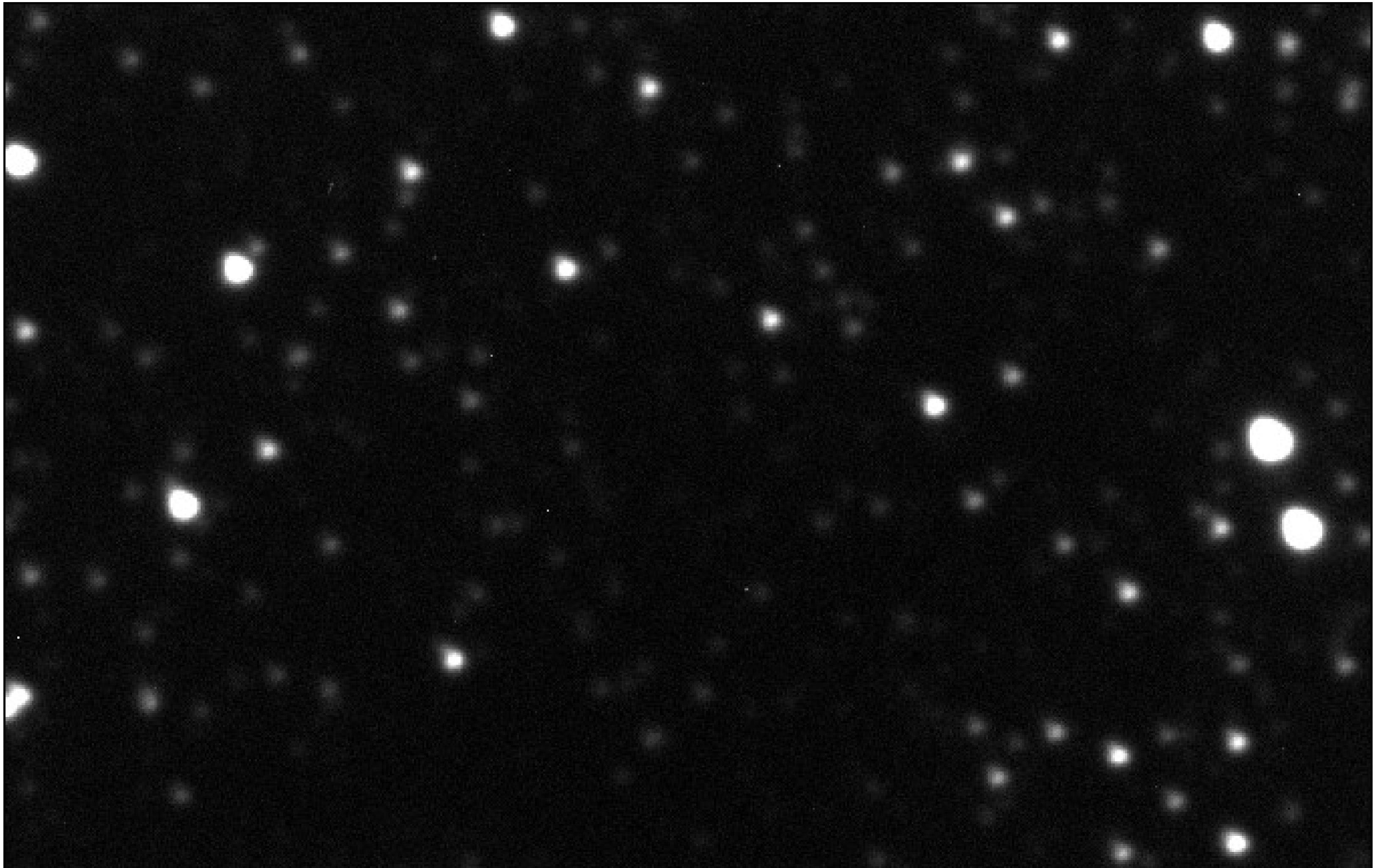




CCD image calibration example (raw)

CCD image calibration example (cal.)



Conclusions

- The **calibration** accuracy **limits the photometric accuracy**
- **Stack multiple calibration frames** to reduce shot noise
- Try to **keep star images on the same pixels** during photometry run to minimize effects of imperfect flat fielding