Laboratorio di Astromia

Basics of CCD data reduction

Laurea in Astronomia
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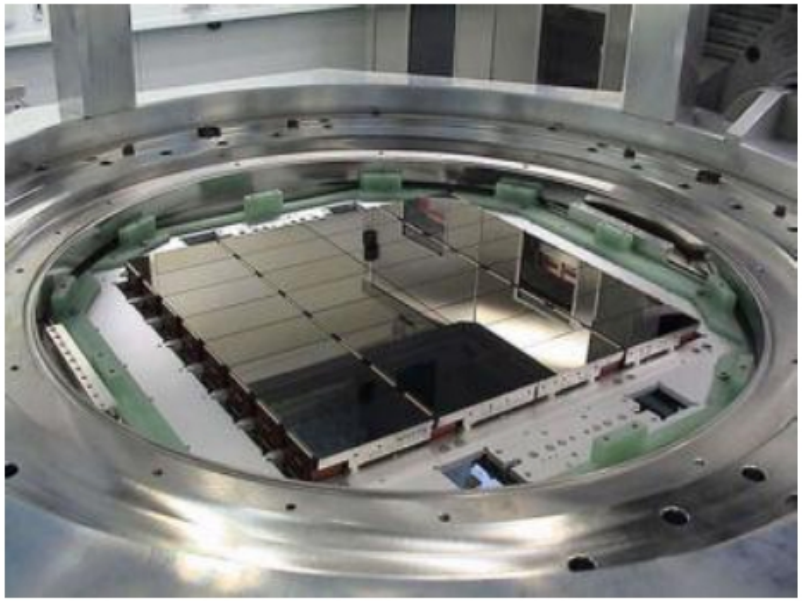
Imaging / Photometry



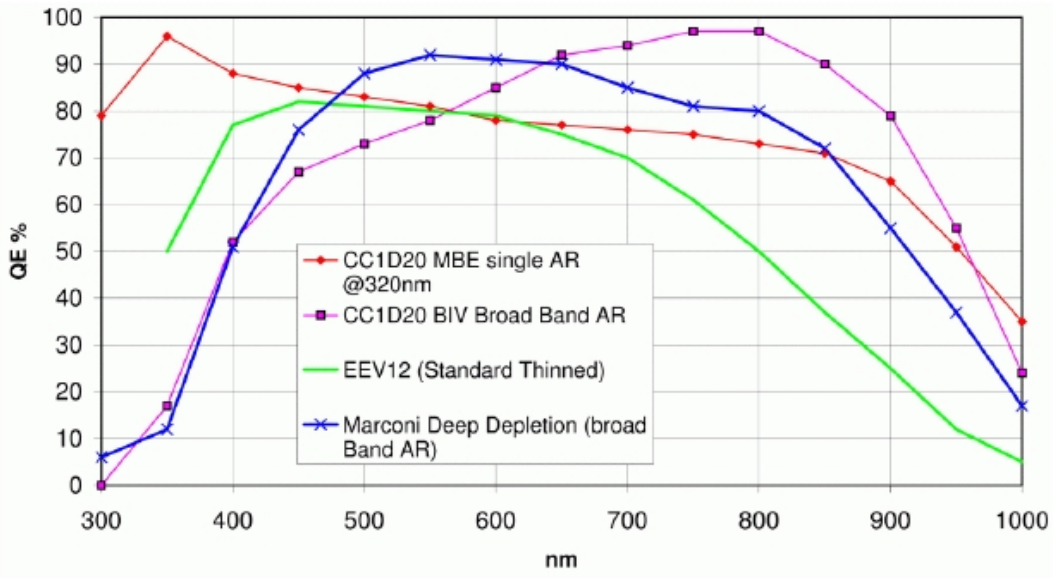
Photometry = Quantifying source brightness

Detectors

- CCDs are the de-facto devices for imaging cameras in the optical and IR
  - Digital encoding of signal
  - Linear response to light
  - Broad wavelength sensitivity
  - Many pixels (nowadays at least)



OmegaCam CCD mosaic
268 mega-pixels



Imaging with CCDs

- Detector calibrations
  - What is stored is the value of each pixel ; ADU
  - Remove BIAS level
  - Measure readout noise
  - Convert ADU to photons via gain (e/ADU)
  - Correct pixel sensitivities via FLAT FIELDS

- Photometry
  - Extract source brightness from calibrated images
  - Background subtraction
  - Flux calibration

$$ADU(x,y) = I(x,y) \times FF(x,y) + BIAS(x,y,) + DARK(x,y)$$

$$I(x,y) = (ADU(x,y,) - BIAS(x,y,))/FF(x,y)$$

T exp=0 --> ADU(x,y) = BIAS(x,y)

I(x,y) = 0; T exp>>0 -->ADU(x,y) = DARK(x,y)+BIAS(x,y)

I(x,y) = costant --> ADU(x,y)=FF(x,y)+BIAS(x,y)

BIAS



Mean offset added to ensure positivity of signal = BIASLEVEL

Pattern is noisy due to readout noise

BIAS frames are closed shutter readouts to determine bias level and readout noise

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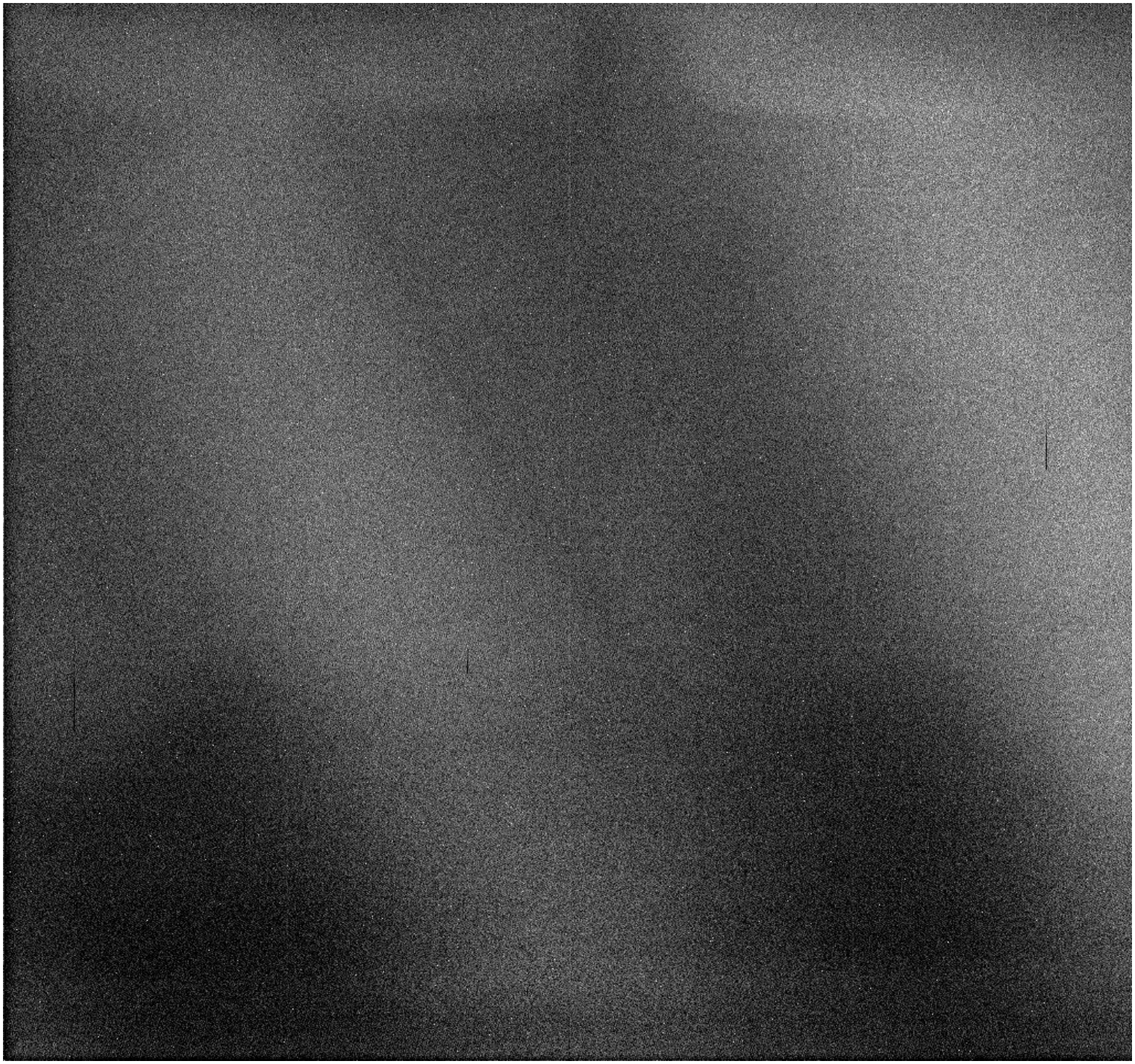
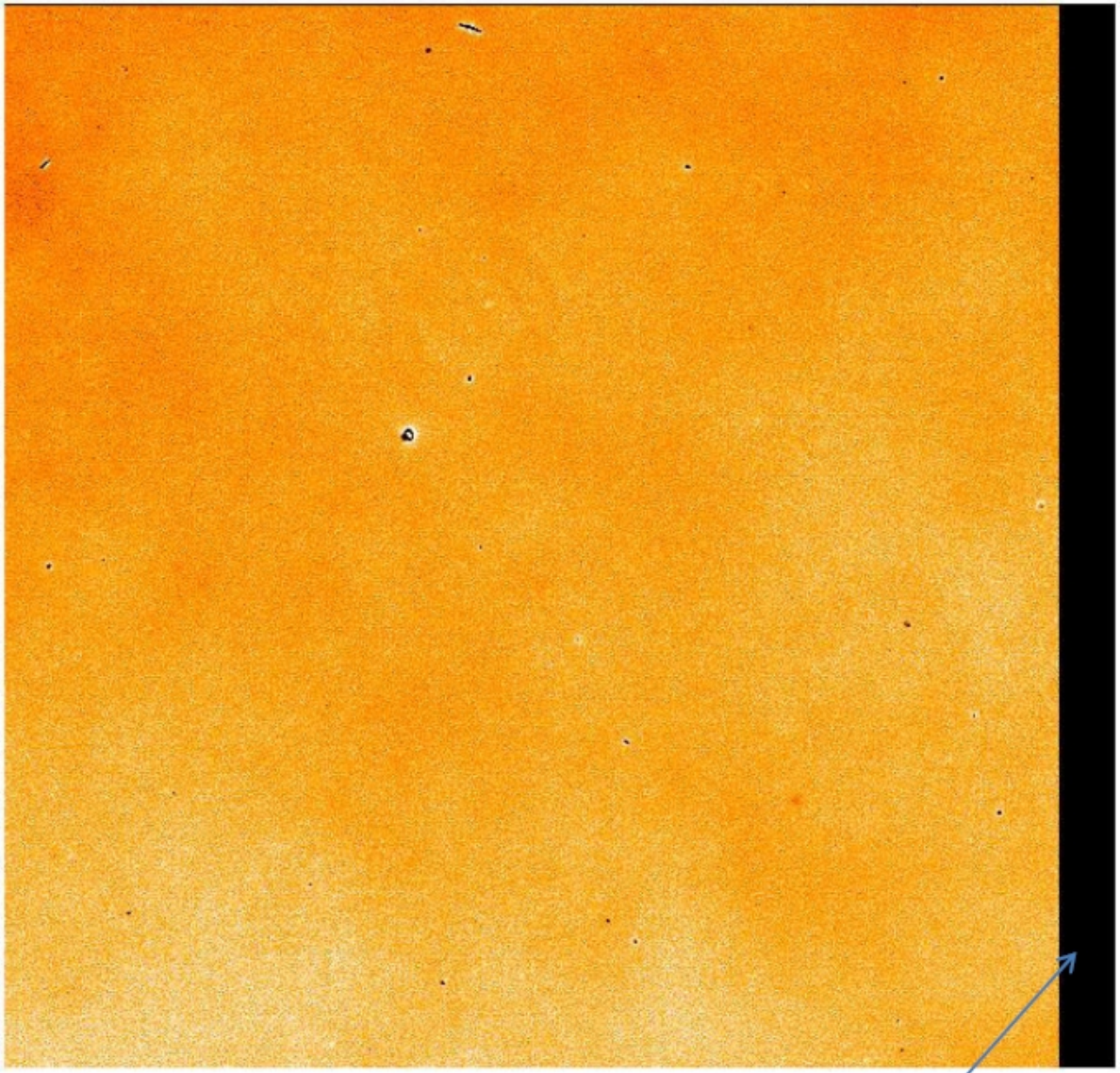
Dark Currents



FLAT



overscan strip to verify bias subtraction

Expose detector uniformly to measure pixel-to-pixel sensitivity variations and detector defects

Can use illuminated screens (domeflats) or the twilight sky (skyflats)

Can also use flats to verify gain factor to convert from ADU to photons

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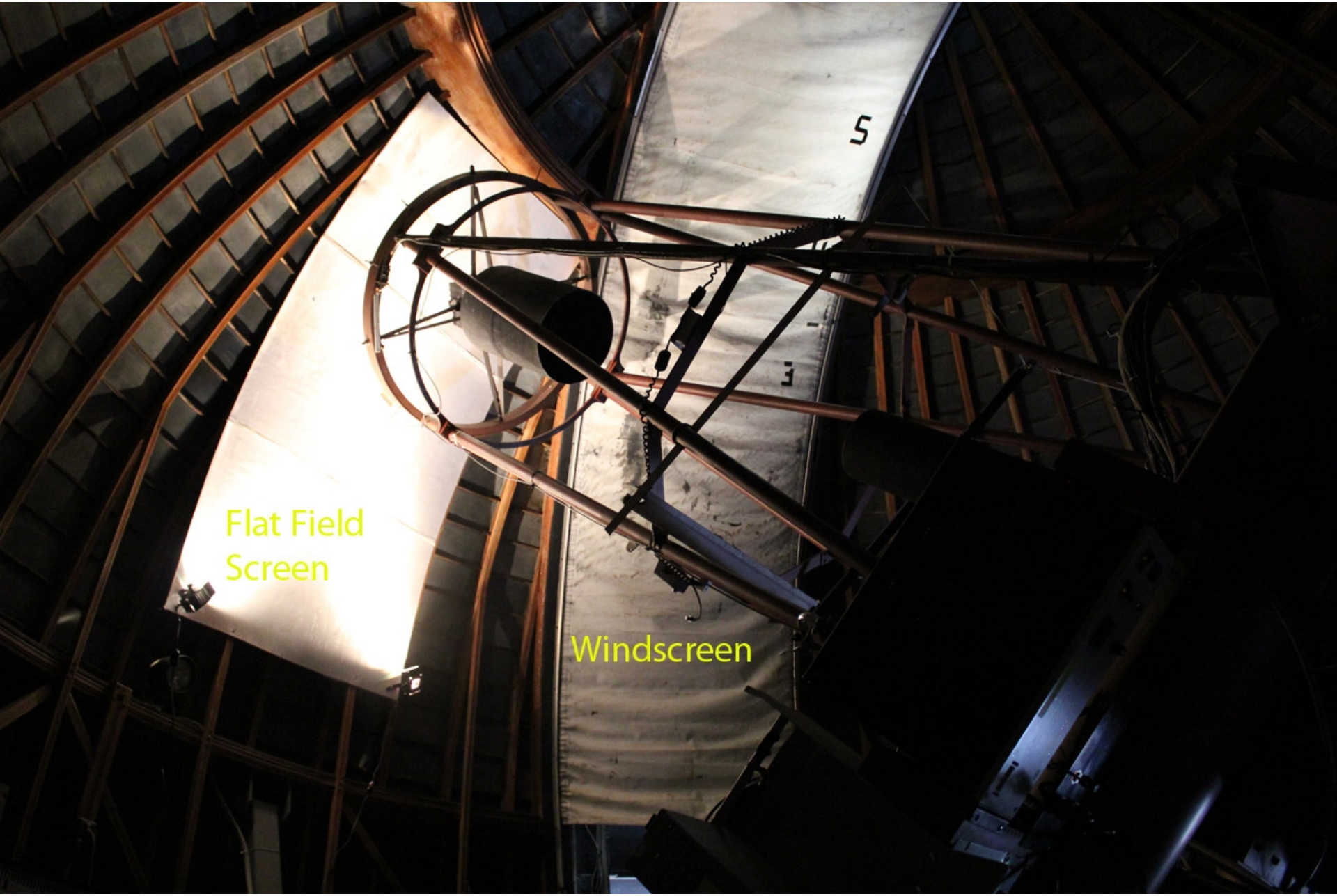
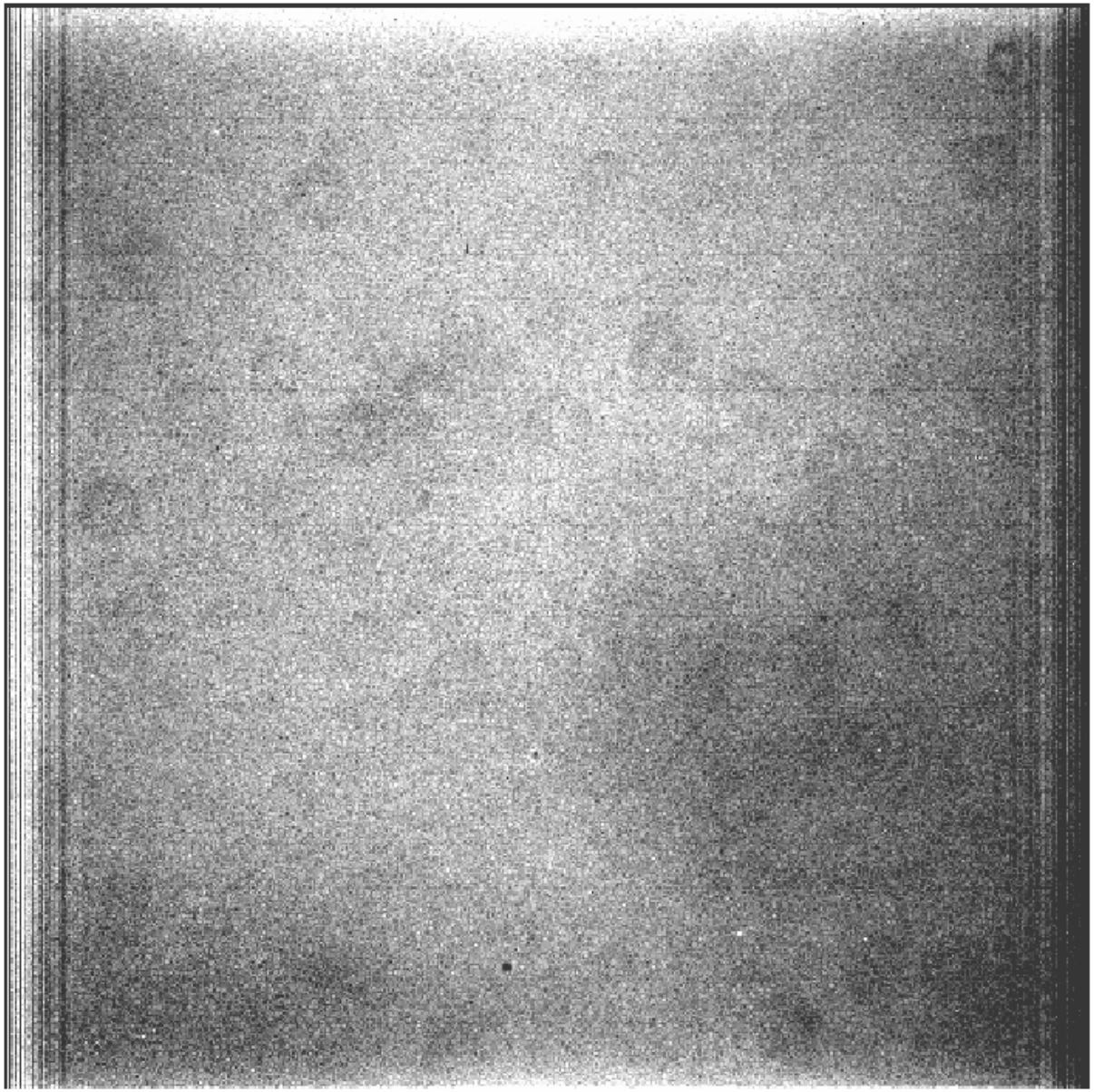
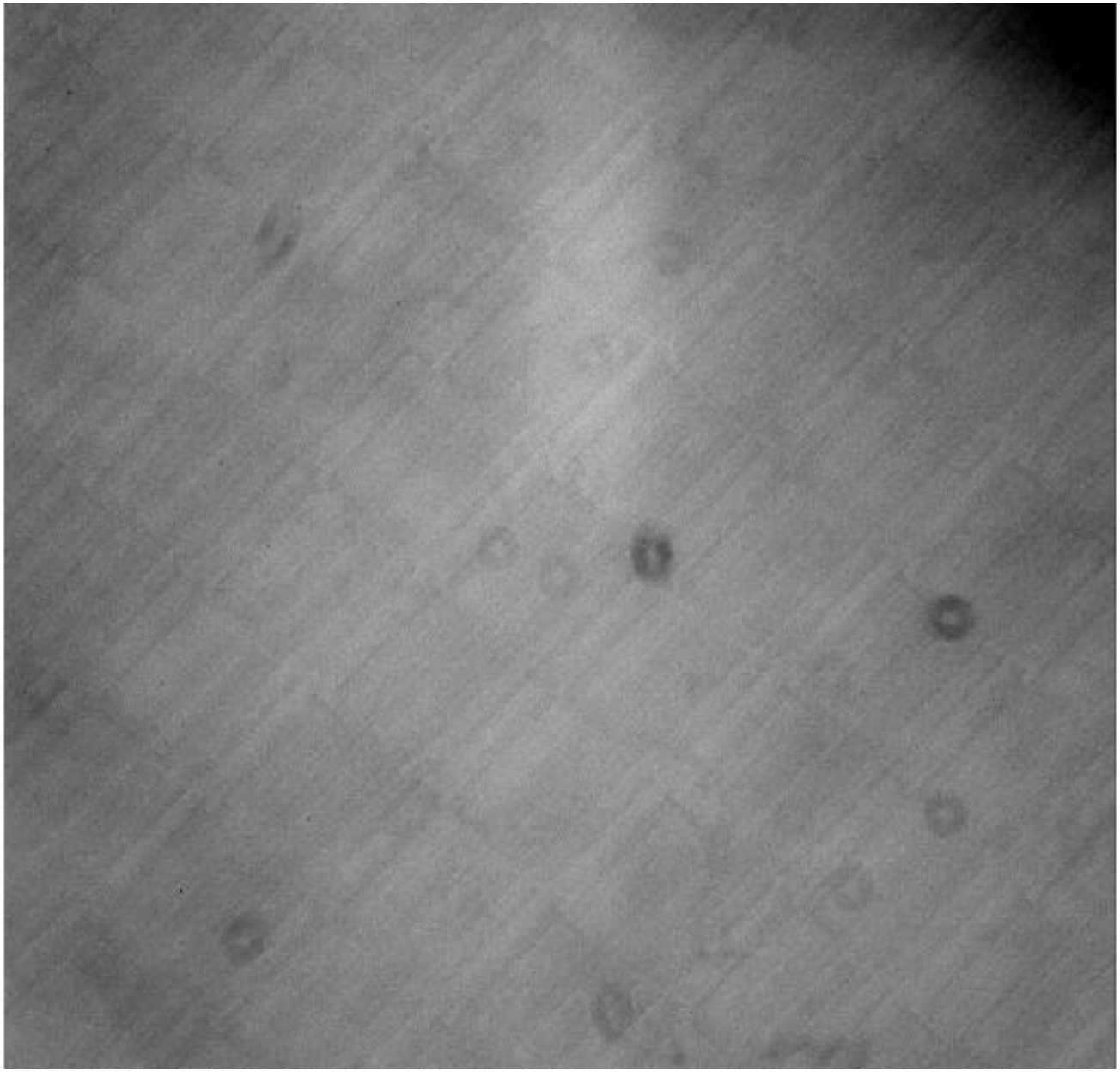
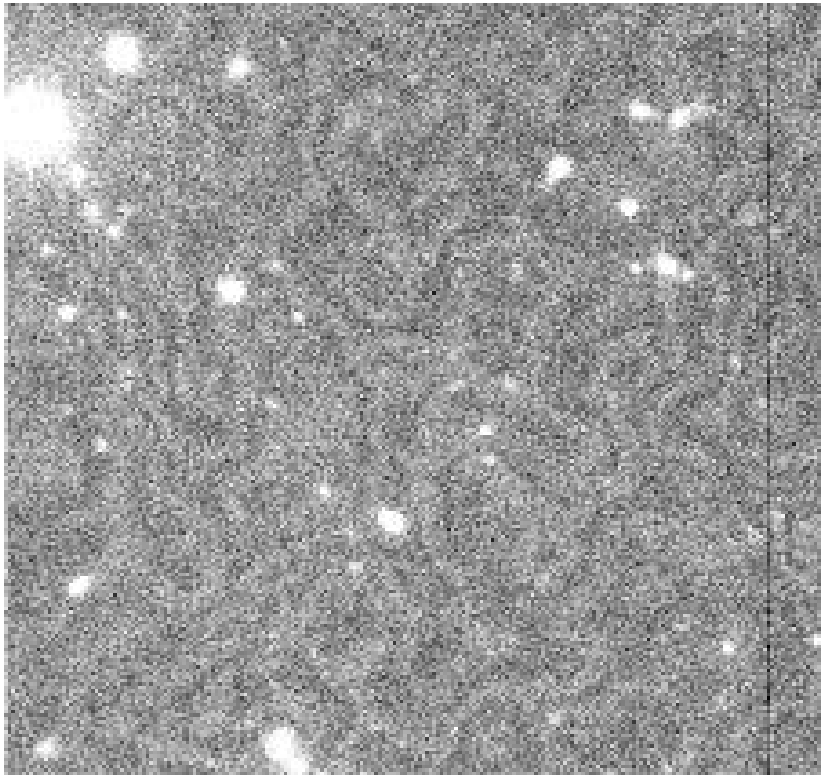
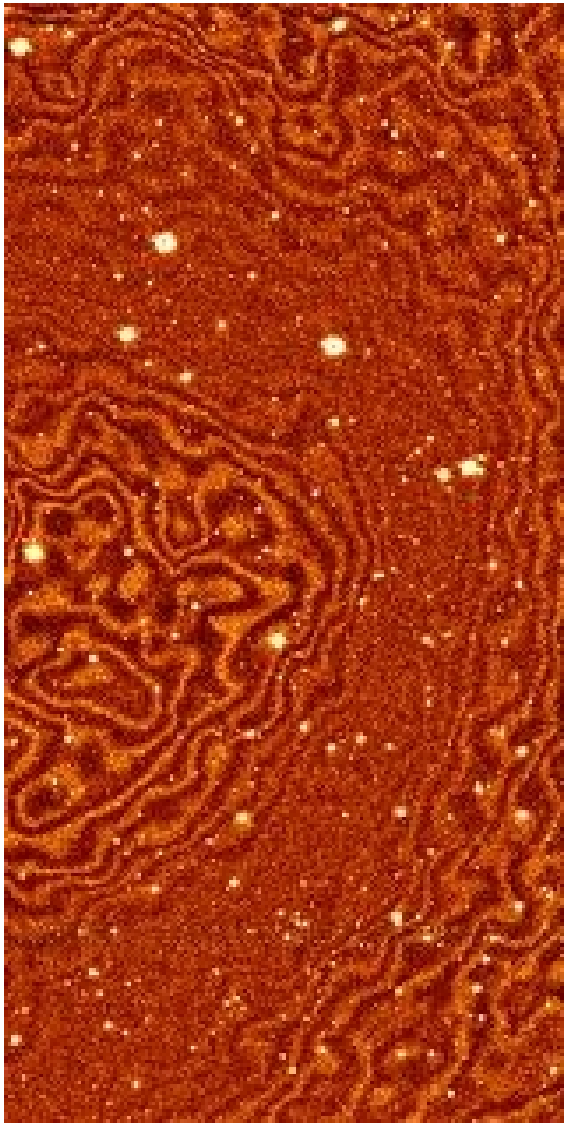

Flat Field
Screen
Windscreen



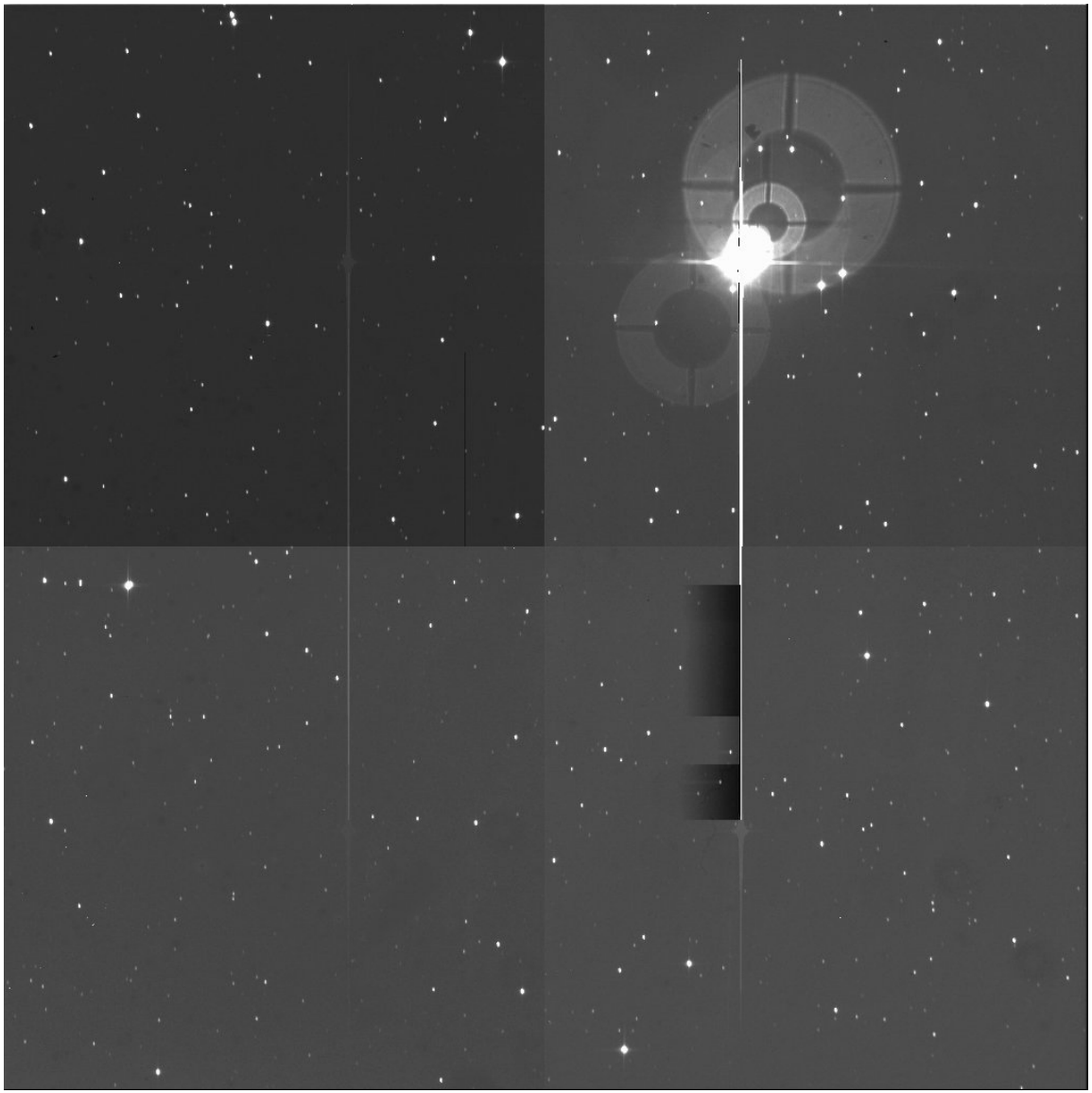


Fringing

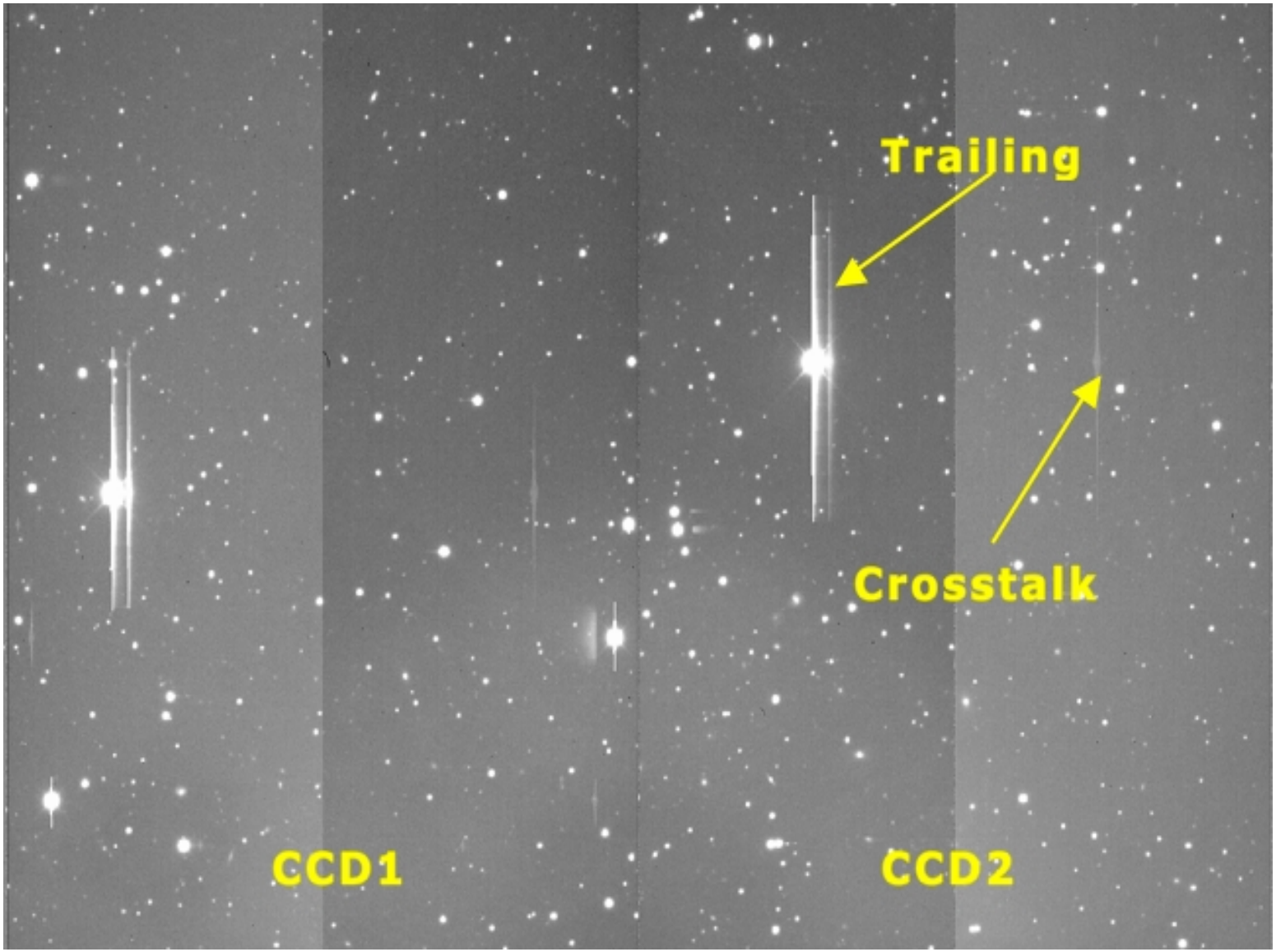




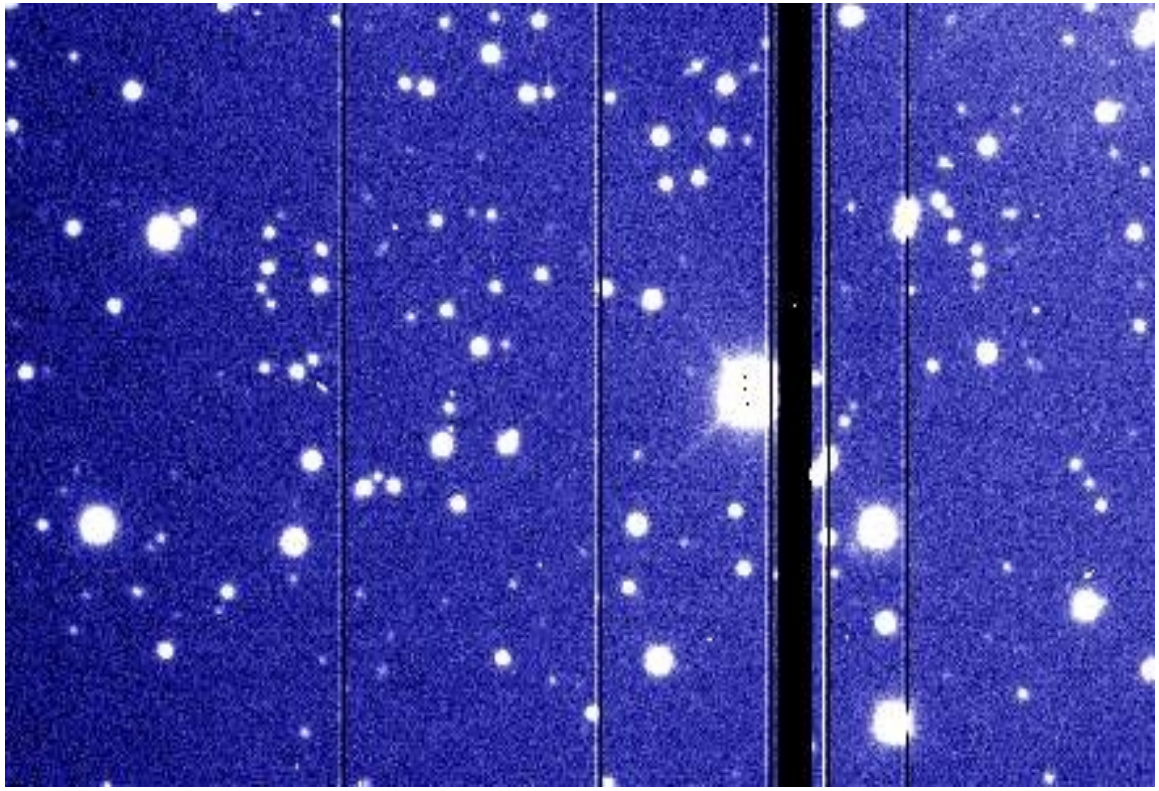
Ghosts



Crosstalk



Bad Columns (and hot pixels)



Cosmic Rays



BIAS: check stability, check read out noise (RON)
Usually several in a row to lower the noise

Noise(average n bias)= RON/sqrt(n)

FF: check the GAIN stability
electrons follow Poissonian statistics--> STD(e)=sqrt(mean_counts(e))

but counts(e)=GAIN*counts(ADU)
STD(e)/GAIN = sqrt(mean_counts(e)) /GAIN -->
STD(ADU) = sqrt(mean_counts(ADU)/GAIN)/GAIN =
= sqrt(mean_counts(ADU))/sqrt(GAIN)

sqrt(GAIN) = sqrt(mean_counts(ADU))/STD(ADU)

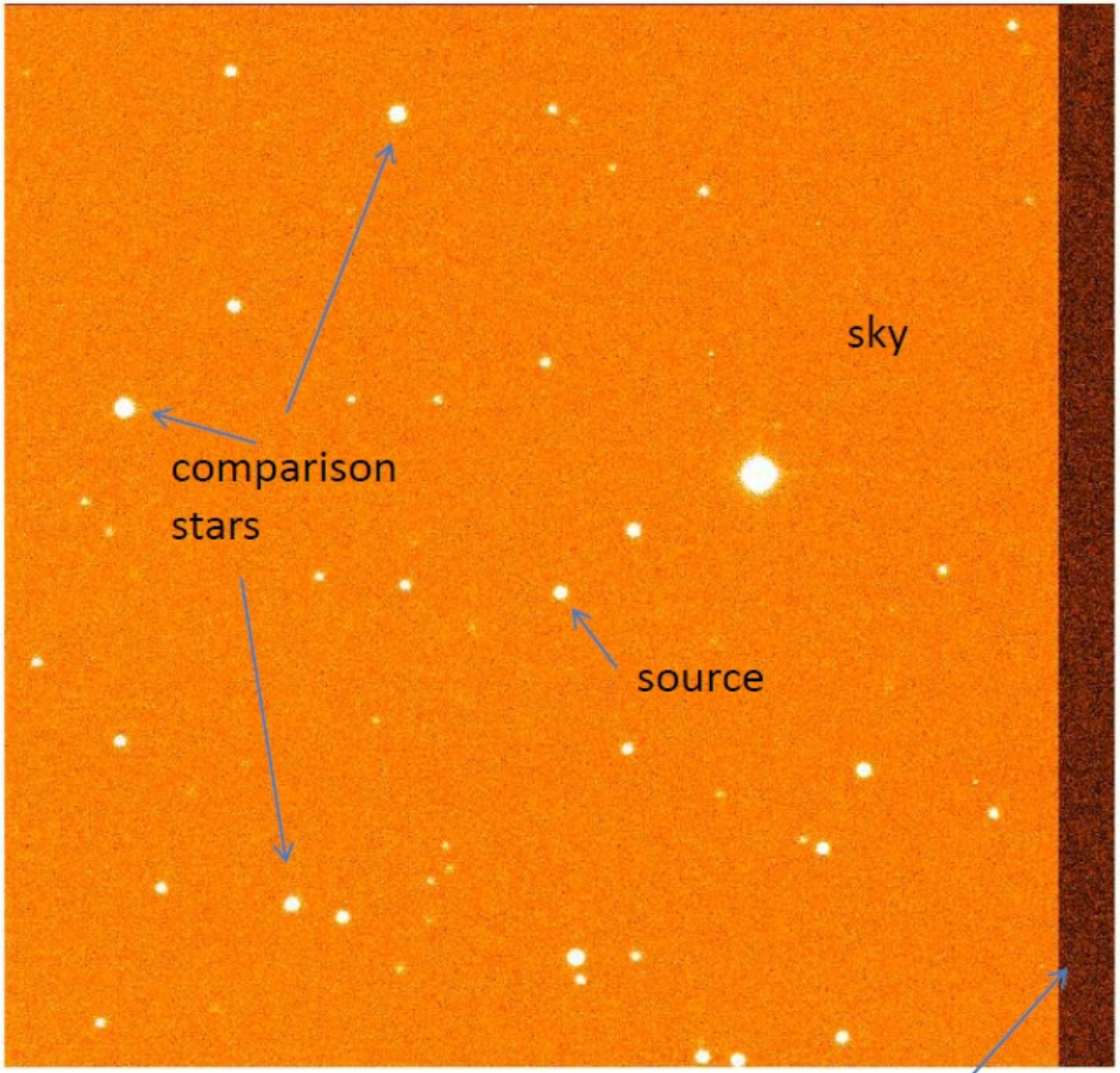
GAIN(e/ADU) = N(ADU)/STD^2(ADU) taking into account the RON

GAIN(e/ADU) = N(ADU)/(STD^2(ADU)-$RON(ADU)^2$)

#0001 p15539.fits CONTINU - d=10 , 5 s
#0002 p15540.fits CONTINU - d=1.0 , 5 s
#0003 p15541.fits CONTINU - d=1.1 , 5 s
#0004 p15542.fits HELIUM - d=2.20 , 2 s
#0005 p15543.fits HELIUM - d=2.20 , 2
#0006 p15544.fits HELIUM - d=2.20 , s
#0007 p15545.fits HELIUM - d=2.20 , 2s
#0008 p15546.fits HELIUM - d=2.20 , 2
#0009 p15547.fits NEON - d=2.20 , 2 s
#0010 p15548.fits NEON - d=0.00 , 20 s
#0011 p15549.fits CONTINU - d=0.48 , 10 s
#0012 p15550.fits NEON - d=0.00 , 20 s
#0013 p15551.fits NEON - d=0.00 , 2 s
#0014 p15552.fits NEON - d=1.10 , 2 s
#0015 p15553.fits NEON - d=2.20 , 2 s
#0016 p15554.fits NEON - d=2.20 , 2 s
#0017 p15555.fits CONTINU - d=0.48 , 10 s
#0018 p15556.fits CONTINU - d=0.48 , 10 s
#0019 p15557.fits CONTINU - d=0.48 , 10 s
#0020 p15558.fits CONTINU - d=0.48 , 10 s
#0021 p15559.fits CONTINU - d=0.48 , 10 s
#0022 p15560.fits CONTINU - d=0.48 , 10 s
#0023 p15561.fits CONTINU - d=0.48 , 10 s
#0024 p15562.fits CONTINU - d=0.48 , 10 s
#0025 p15563.fits CONTINU - d=0.48 , 10 s
#0026 p15564.fits CONTINU - d=0.48 , 10 s
#0027 p15565.fits OFFSET #

#0028 p15566.fits OFFSET
#0029 p15567.fits OFFSET
#0030 p15568.fits OFFSET
#0031 p15569.fits OFFSET
#0032 p15570.fits OFFSET
#0033 p15571.fits OFFSET
#0034 p15572.fits OFFSET
#0035 p15573.fits OFFSET
#0036 p15574.fits OFFSET
#0037 p15575.fits OFFSET
#0038 p15576.fits OFFSET
#0039 p15577.fits OFFSET
#0040 p15578.fits OFFSET
#0041 15579.fits OFFSET
#0042 p15580.fits ff_sky_60s
#0043 p15581.fits std_BB33_300s
#0044 p15582.fits std_BB33_300s
#0045 p15583.fits ic1210_40m
#0046 p15584.fits NEON - d=2.20 , 2 s
#0047 p15585.fits ic1210_40m
#0048 p15586.fits ic1210_40m
#0049 p15587.fits NGC_7177_2400s
#0050 p15588.fits NGC_7177_2400s
#0051 p15589.fits NEON - d=2.20 , 2 s
#0052 p15590.fits NGC_7177_2400s
#0053 p15591.fits NGC_6764_1200s

Target



Bias subtracted and flat-field corrected target frames are then ready for photometry

Exploit nearby stars for photometric reference

Differential photometry just determines brightness relative to comp stars

Absolute photometry requires flux calibration

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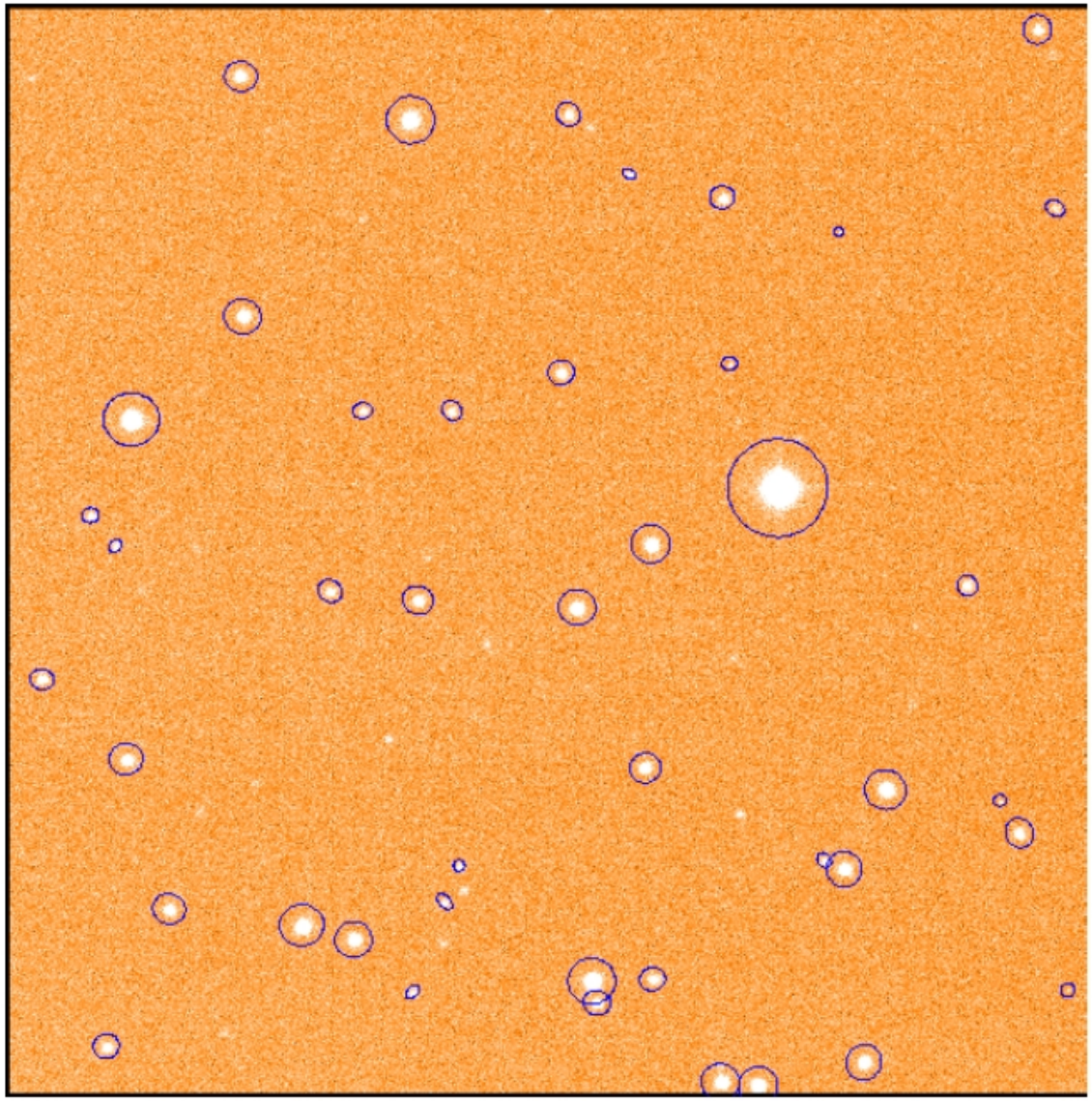
Source Detection



Establish locations where there is significant signal above background

Example; automatic source detection with *SExtractor* tool

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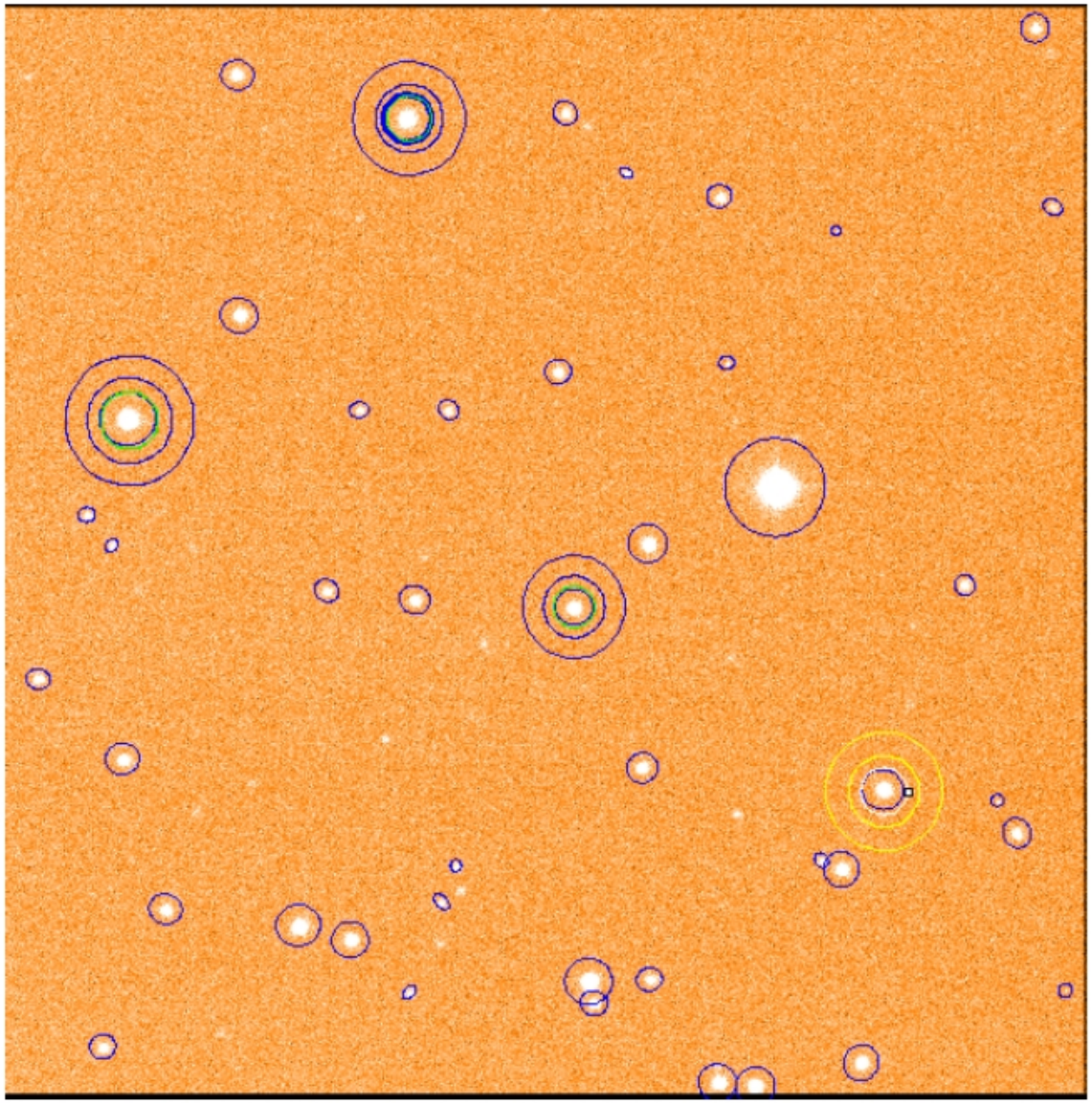
Source - Background



Define apertures that designate areas of source signal and corresponding background areas

Typically circular source aperture with background from source centered annulus with suitable inner and outer radius

Finite pixel sizes matter

S/N

- Readout noise, dark current and background impact achieved S/N

N_R = readout noise in electrons/pixel

N_B = #background electrons/pixel

N_D = #dark current electrons/pixel

N_* = #source electrons



Non-Poissonian

Then over a CCD area of n pixels:

$$S/N = N_* / (N_* + n(N_B + N_D + N_R^2))^{1/2}$$

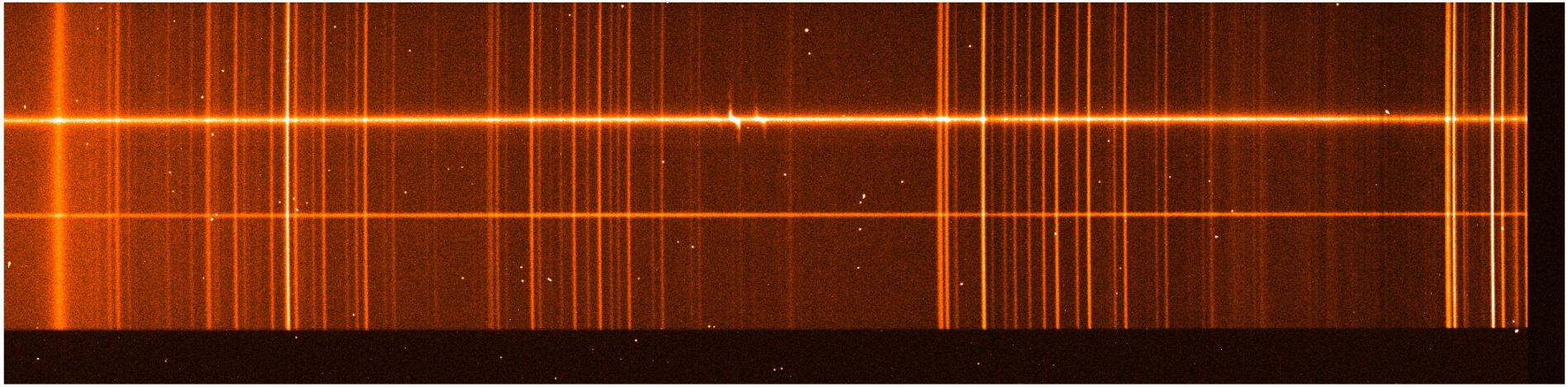
$$\approx N_*^{1/2} \text{ for large } N_*$$

QUESTIONS:

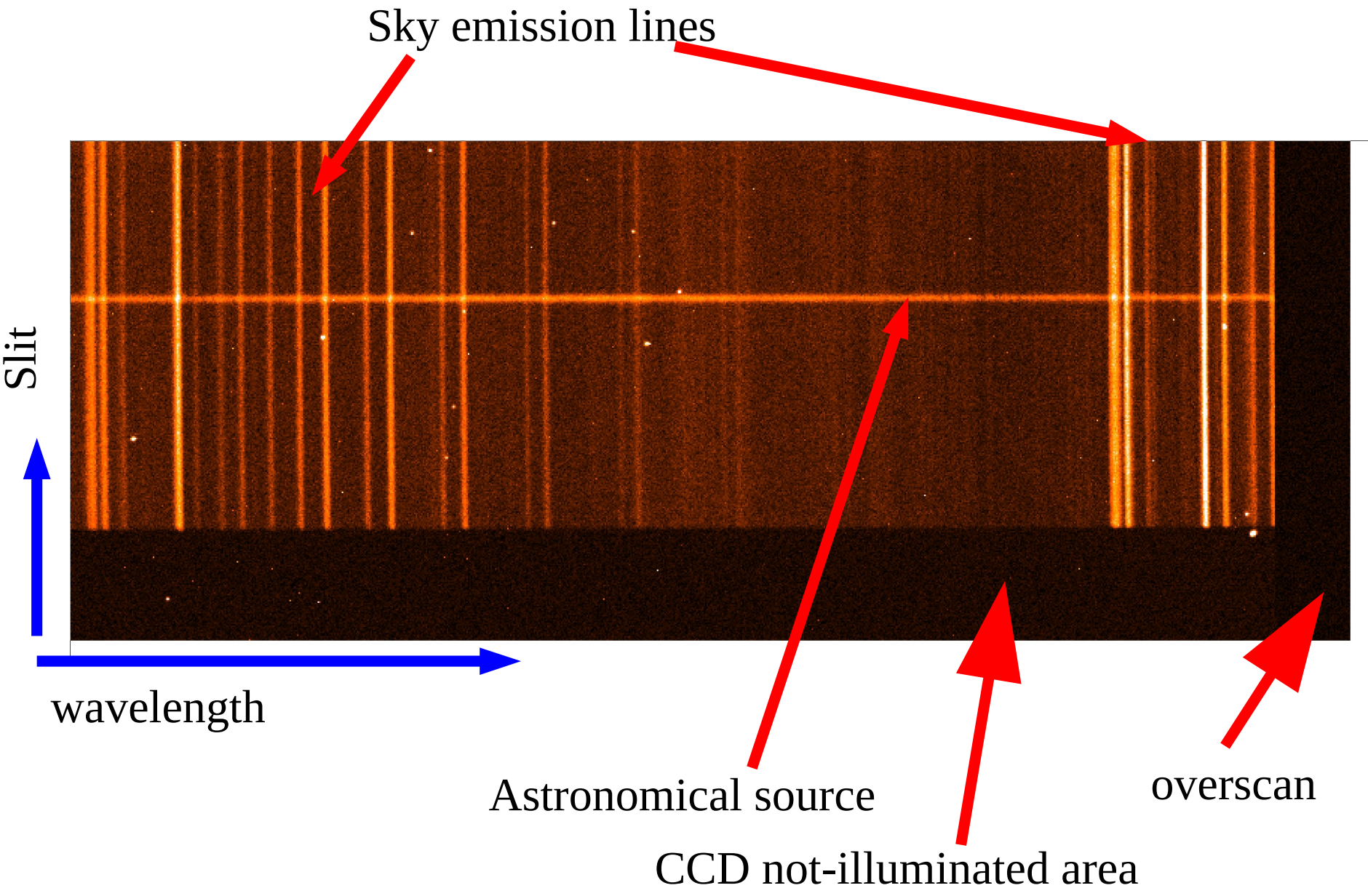
1) Why observing with the new moon (no moon) allows to reach fainter magnitudes? After all, a bright sky can be easly subtracted to the whole frame and then I'm back to the “dark sky” situation.

2) What bad seeing does to your faint sources?

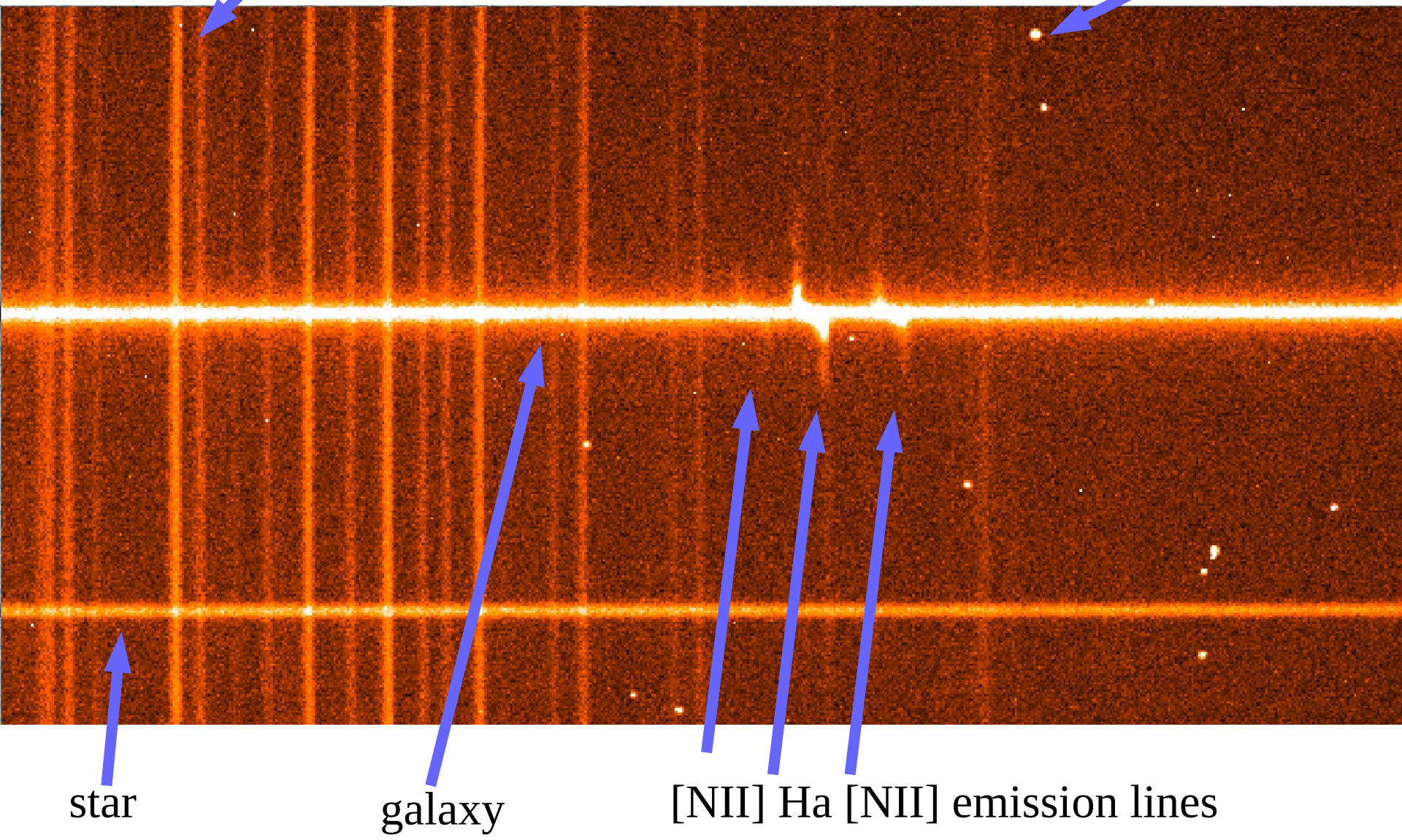
Spectra



Spectra


Sky emission lines
Slit
wavelength
Astronomical source
CCD not-illuminated area
overscan

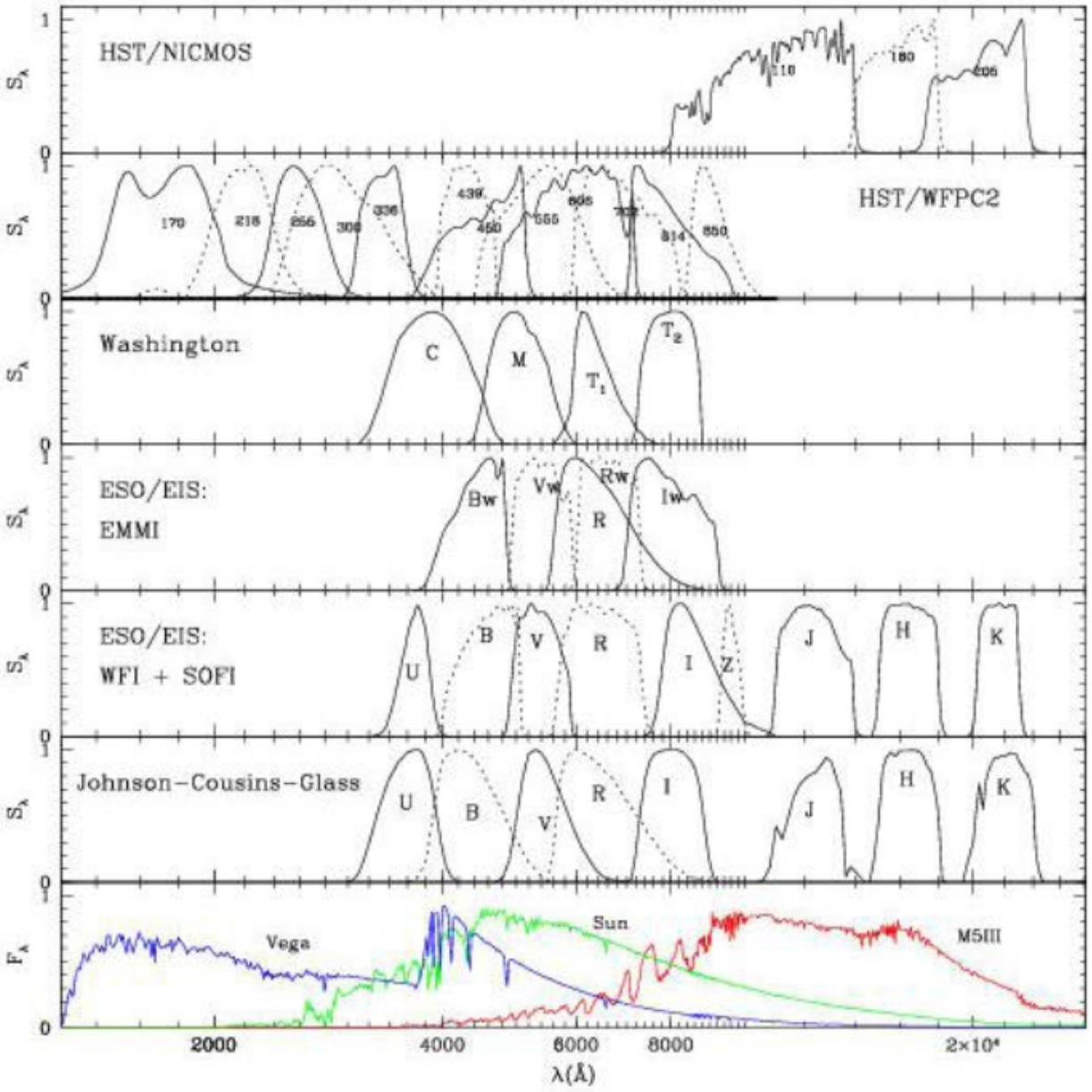
Spectra


Sky emission lines
cosmic rays
star
galaxy
[NII] Ha [NII] emission lines

Photometric Calibration

- If stars within the field are pre-calibrated, then differential photometry is easily turned into absolute photometry
- Otherwise standard fields need to be observed to derive a photometric calibration for the night
- Depends on suitably good ('photometric') conditions
- Extinction coefficients are also needed to correct for airmass differences between standard star and targets

Photometric Systems



- Nominally each telescope/ instrument combination has its own system as filters/ telescope throughput are never exactly the same
- Can transform between systems after extensive cross-calibration measurements (depends on spectrum of your source!)
- Vega systems (e.g. UVBRI) versus AB magnitudes (e.g. SDSS ugriz)
- See Bessell 2005, ARA&A for review

Sampling – Nyquist sampling theorem

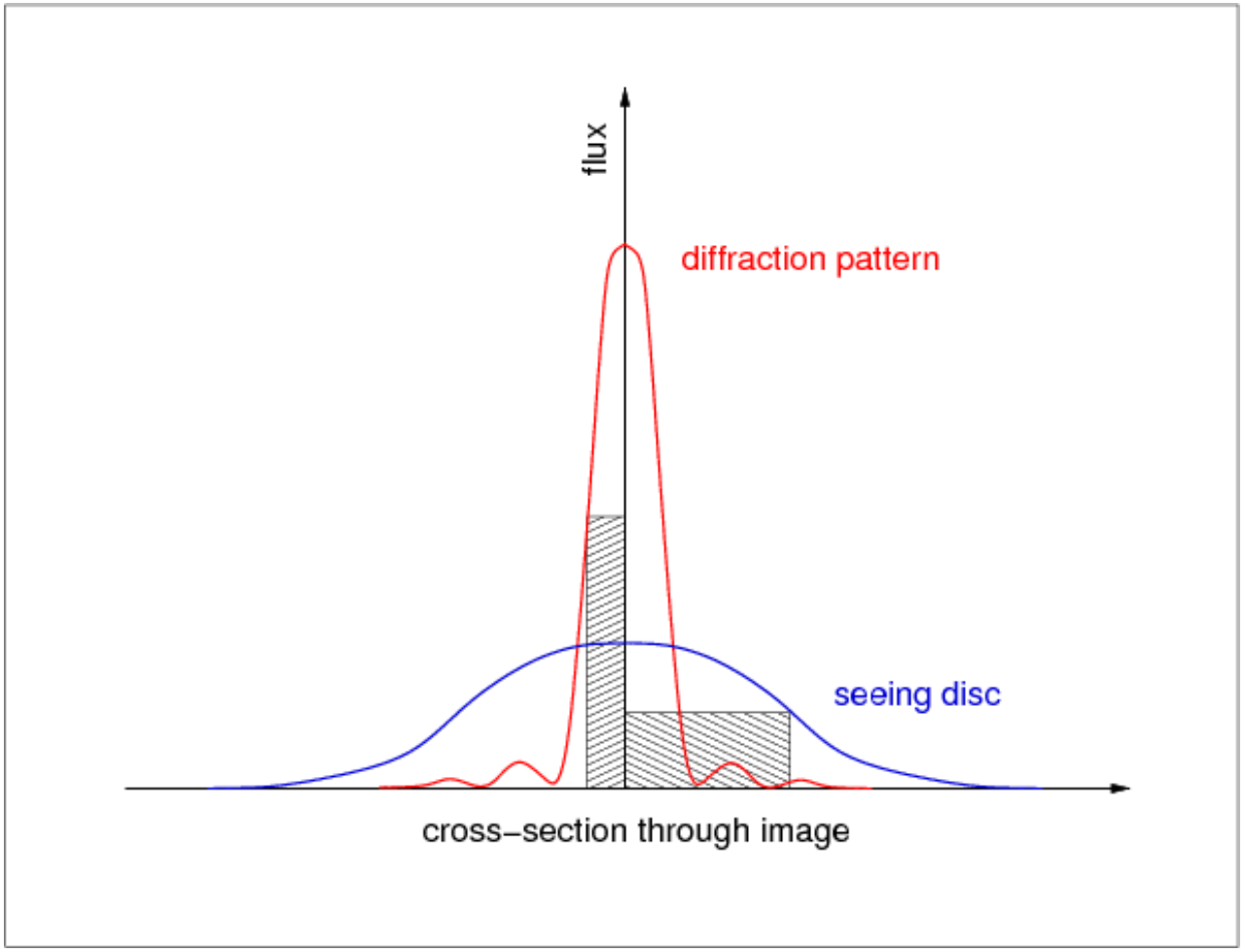
Sampling is the process of converting a continuous signal, in this context an image or spectrum in the focal plane of an astronomical instrument, into a discrete signal, by selecting values at evenly-spaced points in the focal plane. This latter function is performed by the pixels in a detector. The question is, how finely spaced (i.e. how big) do the detector pixels have to be in order to faithfully recover the input signal?

The solution is given by the Nyquist sampling theorem, which states that:

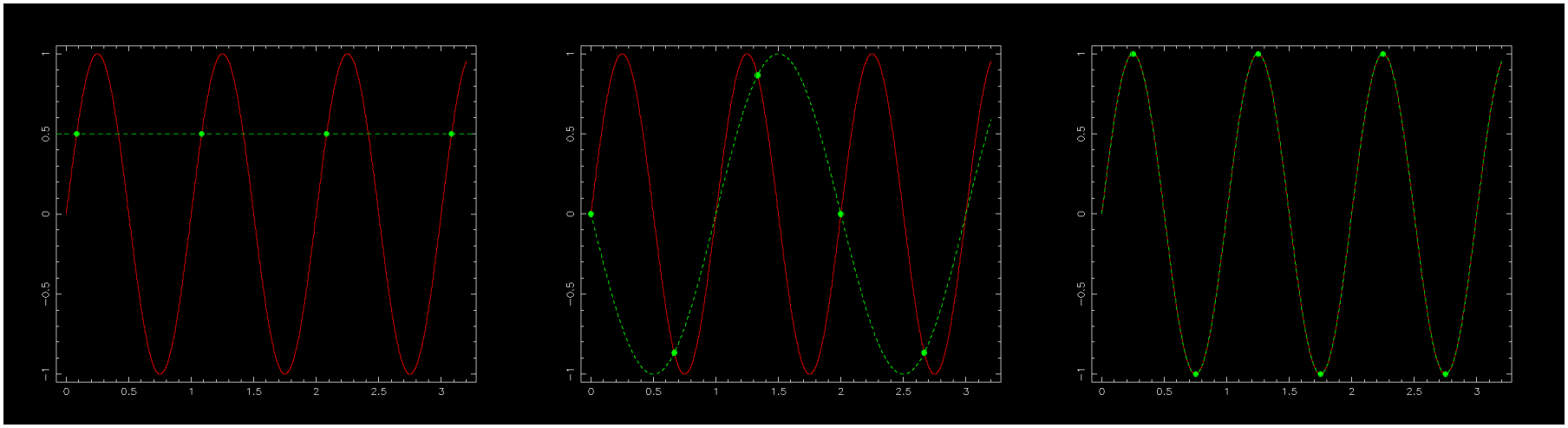
The sampling frequency should be greater than twice the highest frequency contained in the signal.

In other words, if the smallest feature in an image or spectrum has a dimension of x μm, then the pixel size must be no larger than x/2 μm!!

Sampling – Nyquist sampling theorem



Sampling – Nyquist sampling theorem



EXAMPLE: A signal consisting of a continuous sine curve with unit period is shown in red.

Left: Sampling only once per cycle (green dots) results in the signal being wongly interpreted as a constant (green dashed line).

Centre: Sampling every 2/3 of a cycle results in the signal being interpreted as a sine curve, but of an incorrect period. This is aliaising.

Right: Sampling twice per cycle, as suggested by the Nyquist theorem, allows the original signal to be recovered.

References:

- Danny Steeghs, Astrophysical Techniques Optical/IR photometry and spectroscopy; The university of Warwick
- Roberto Ragazzoni, Padua Observatory