Optical Observations in Astronomy

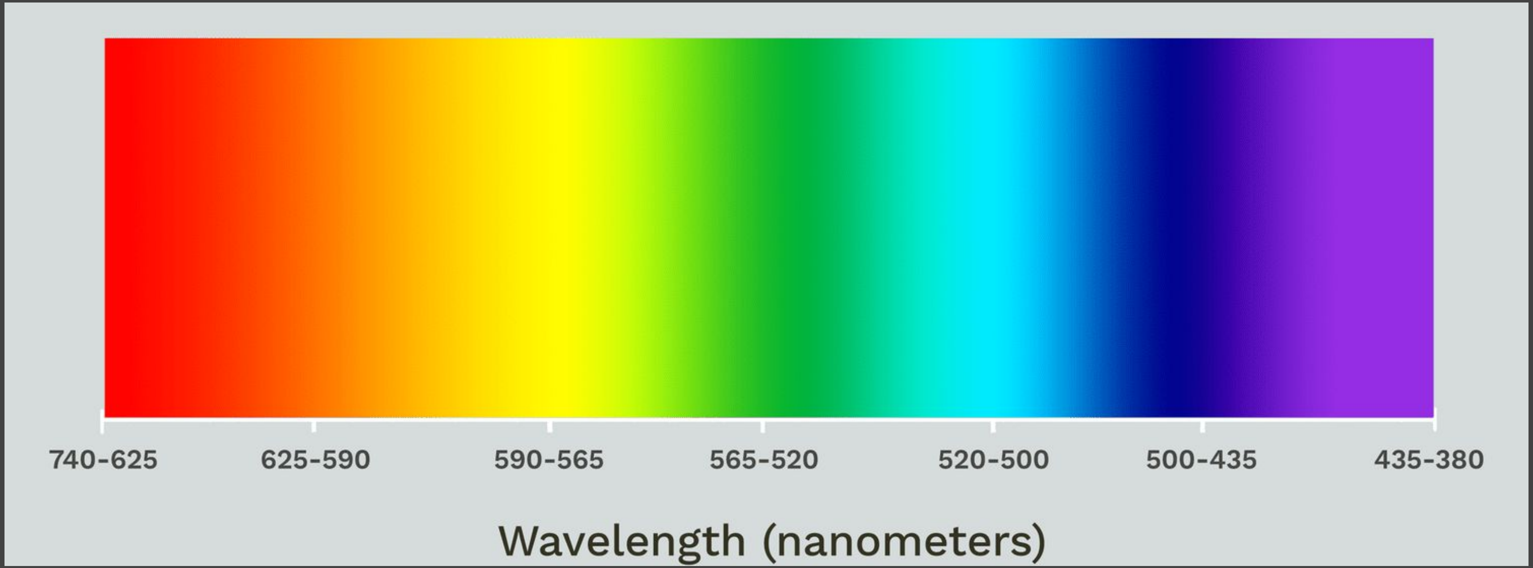
CCD Image Processing and Basic Data Reduction

ASTRO101: HOW on OAR, 28 August 2023
Nicha Leethochawalit
Researcher, NARIT

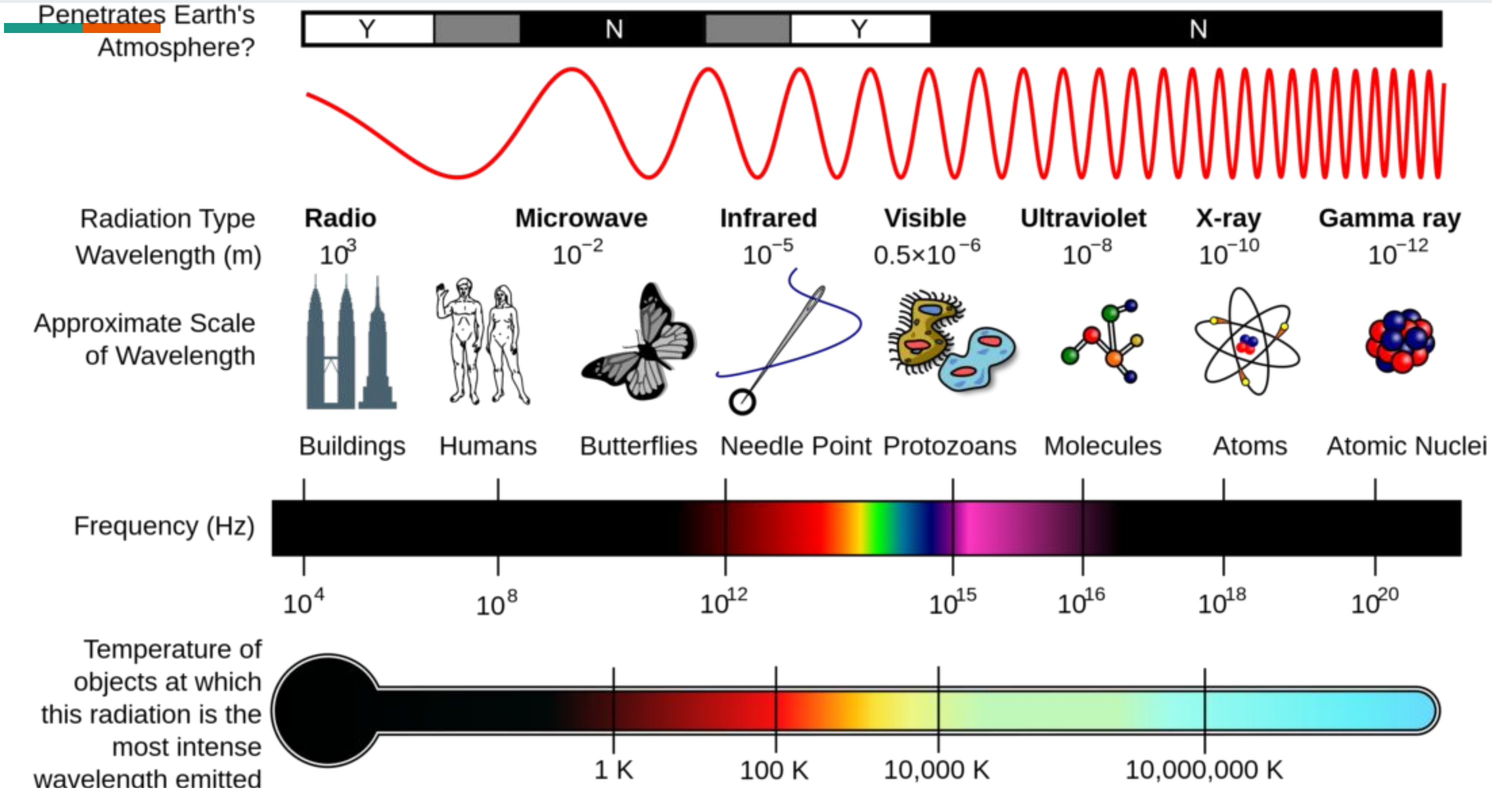
Astronomy is mainly an observational science

- Electromagnetic waves
- Neutrinos (1956-)
- Gravitational waves (2015-)

Most familiar form of EM is visible light, which is a part of multi-wavelength astronomy



Optical Astronomy = Wavelengths that we can use telescopes with optic system (with CCD-like detector)



Credit: astrobites:guide-to-the-electromagnetic-spectrum-in-astronomy-2/

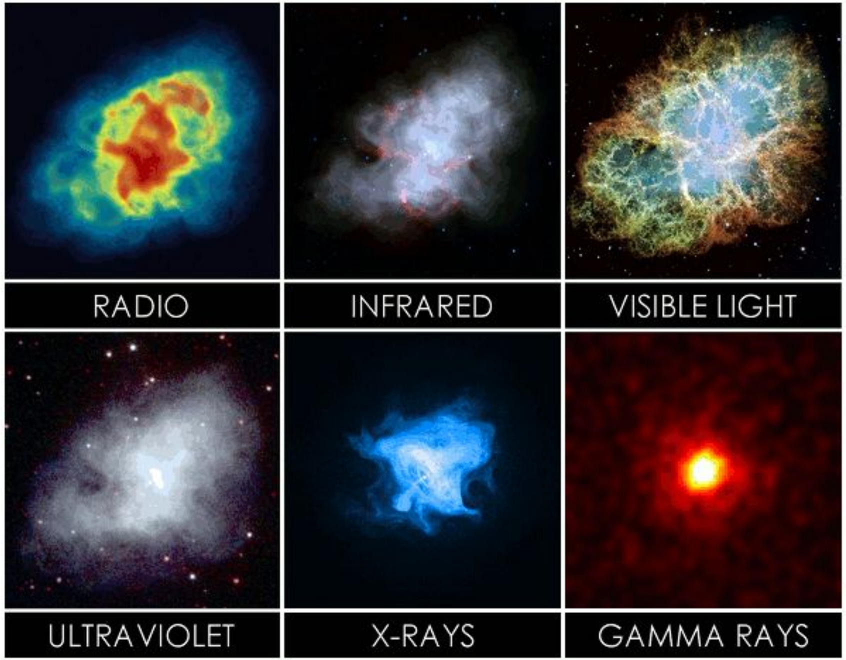
Optical Astronomy = Wavelengths that we can use telescopes with optic system (with CCD-like detector)

Dust, redshifted wavelengths

Synchrotron
(magnetic fields)

Stars, galaxies

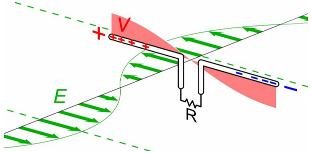
Hot young stars

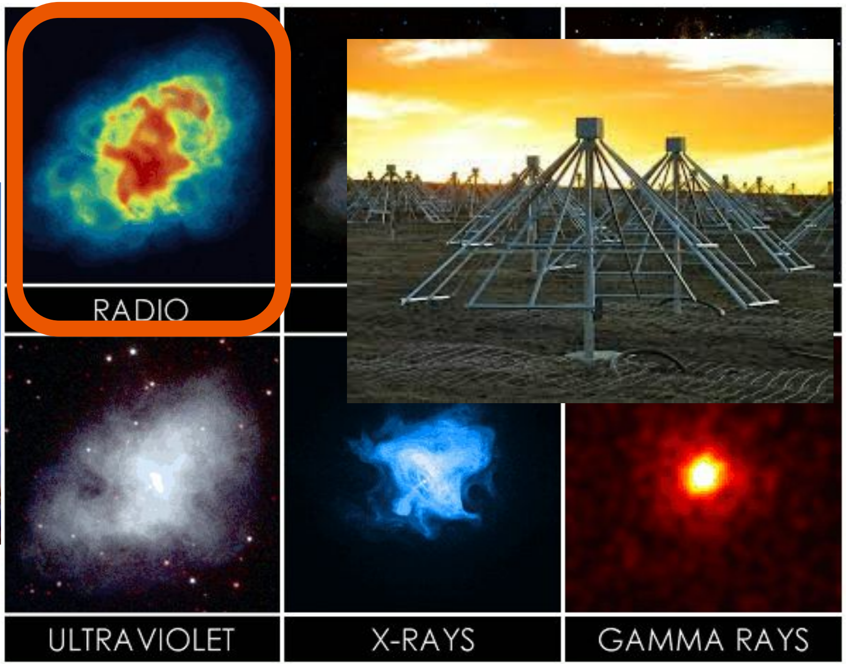


Bremsstrahlung emission

Credit: astrobites:guide-to-the-electromagnetic-spectrum-in-astronomy-2/

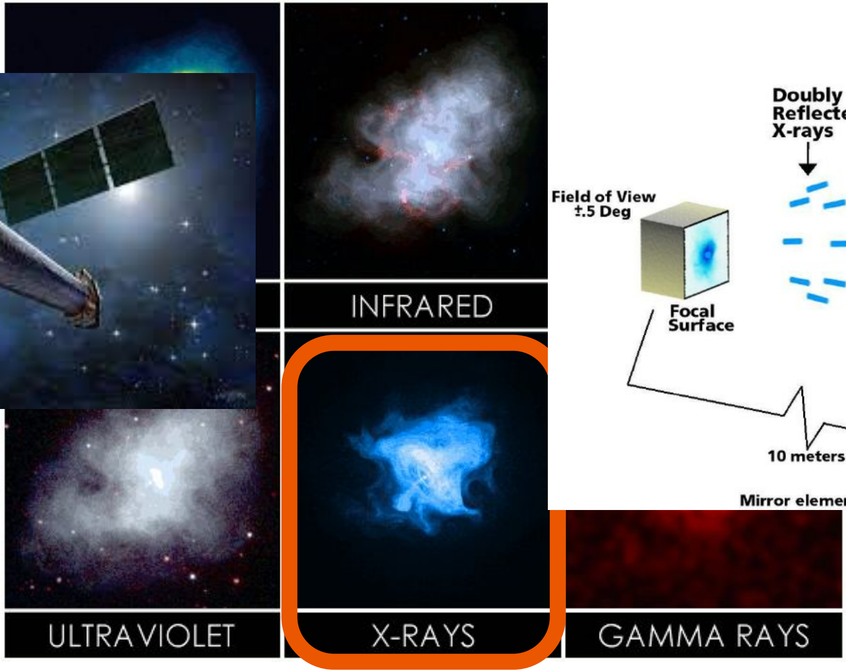
Optical Astronomy = Wavelengths that we can use telescopes with optic system (with CCD-like detector)

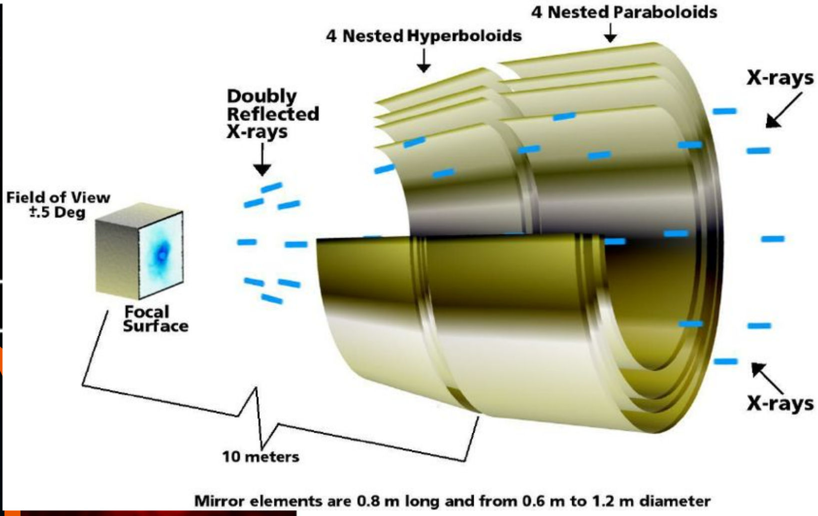




Credit: astrobites:guide-to-the-electromagnetic-spectrum-in-astronomy-2/

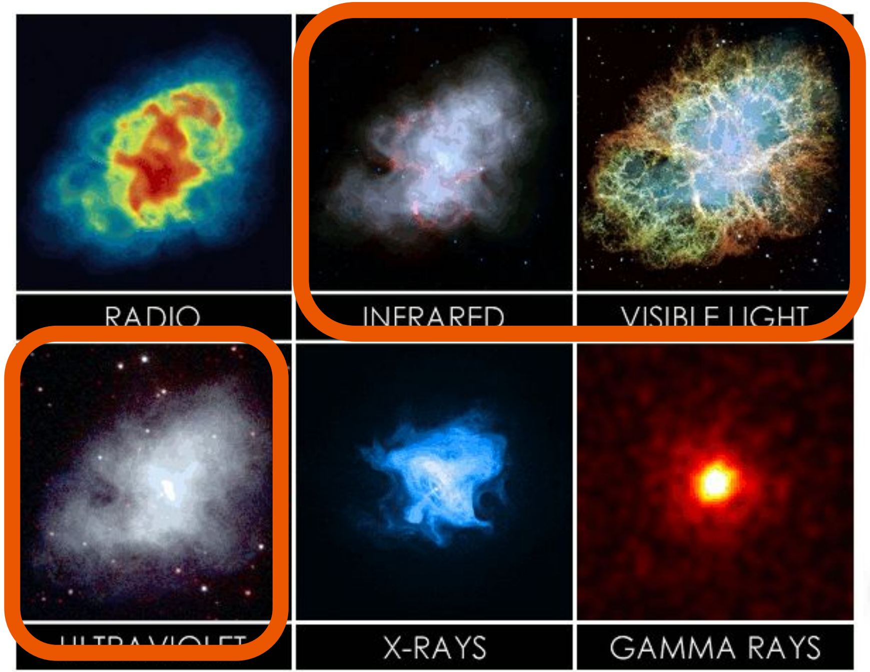
Optical Astronomy = Wavelengths that we can use telescopes with optic system (with CCD-like detector)

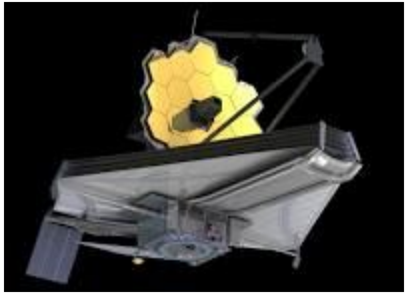


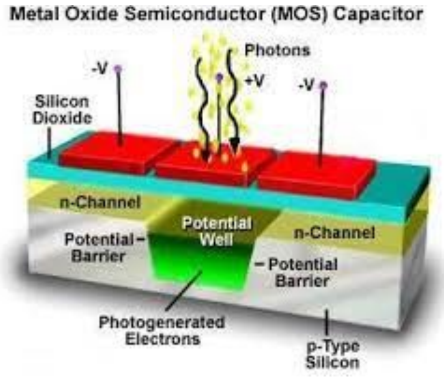


Credit: astrobites:guide-to-the-electromagnetic-spectrum-in-astronomy-2/

Optical Astronomy = Wavelengths that we can use telescopes with optic system (with CCD-like detector)







Credit: astrobites:guide-to-the-electromagnetic-spectrum-in-astronomy-2/

Telescope is essentially a camera

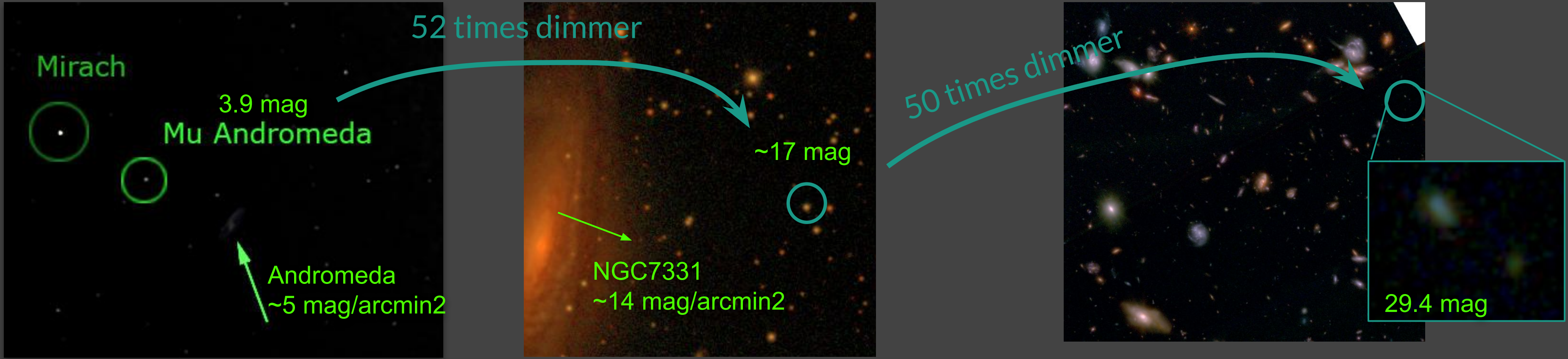
The objects telescopes observe are usually fainter than what eyes can see

JADES-GS-z13-0

Visible eyes

0.7-m Thai Robotic Telescope
50 s exposure time

6-m JWST
4-16 hrs exposure time



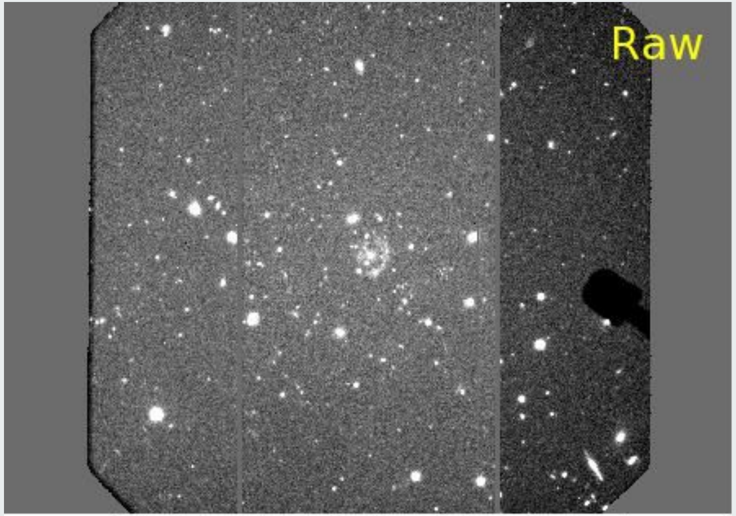
Credit: Richard McDonald

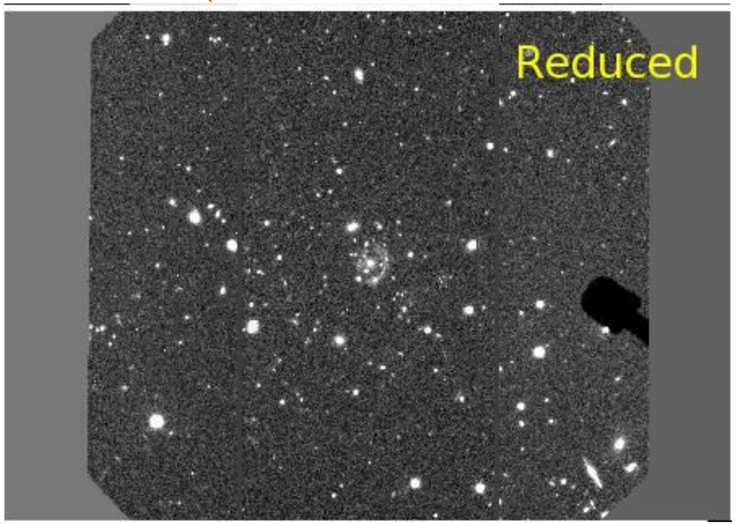
Credit: Samaporn, Nicha

Credit: Jades collaboration

Raw out-of-the-telescope images are usually noisy

What we are doing today





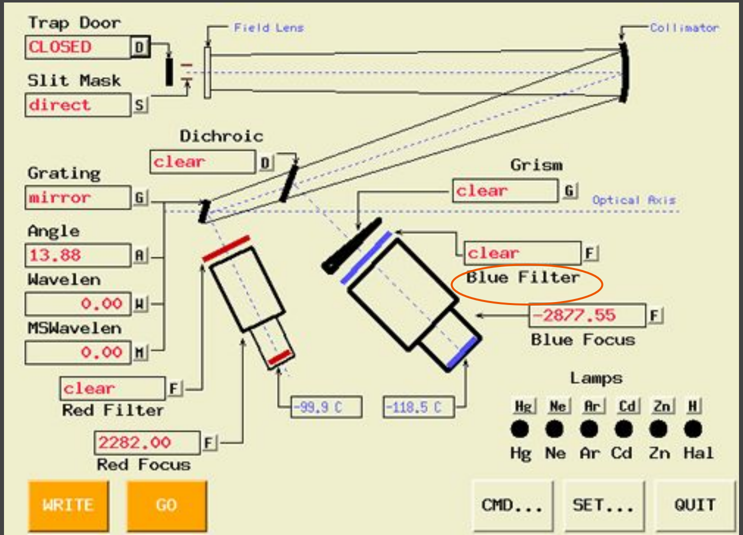
Credit: http://astro.dur.ac.uk/~knpv27/pg_dr_course/pg_dr_imaging.html

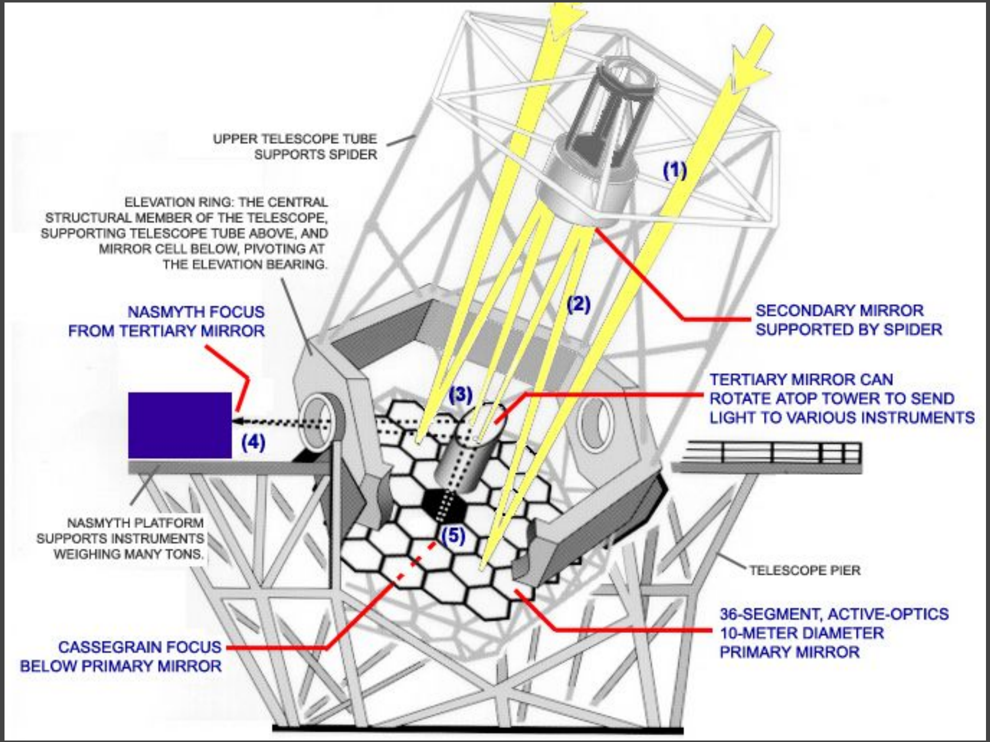
Goal of data reduction is to get images we can do science with it

- Pixel values reflect the fluxes from astronomical objects (not sky background, not instrumental noise).

- We can translate those pixel values into physical fluxes (erg/s/Hz/cm2) with reliable uncertainties

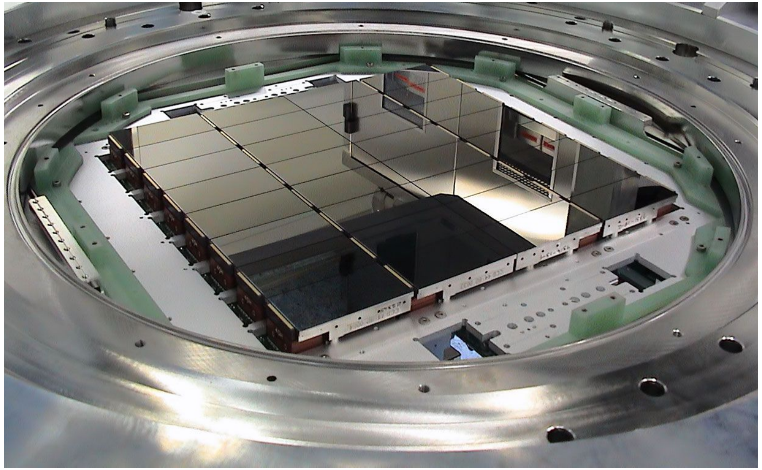
Telescope + instrument



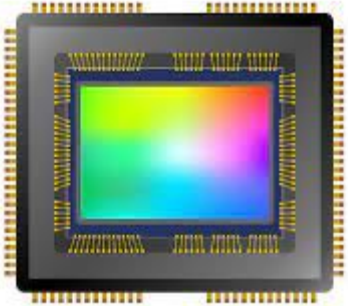


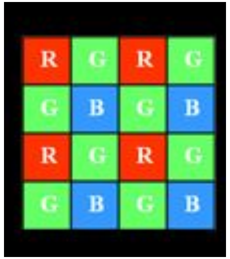
In astronomical instruments, filters are placed in front of the CCD.

In commercial camera, filters are on the CCD



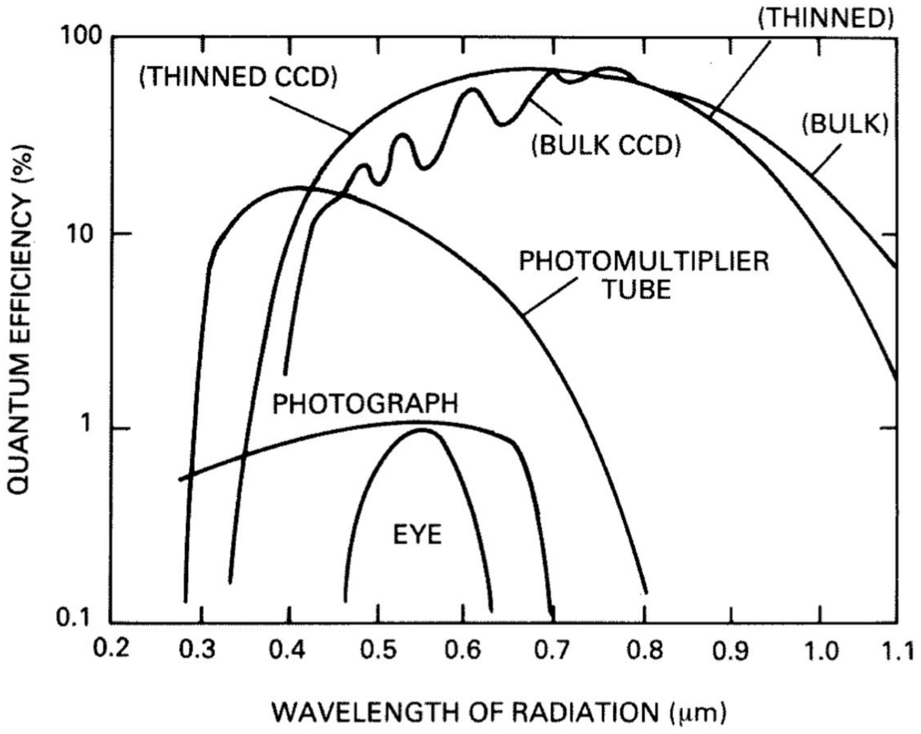
OmegaCAM on VLT
Credit: ESO/INAF-VST/OmegaCAM/O. Iwert

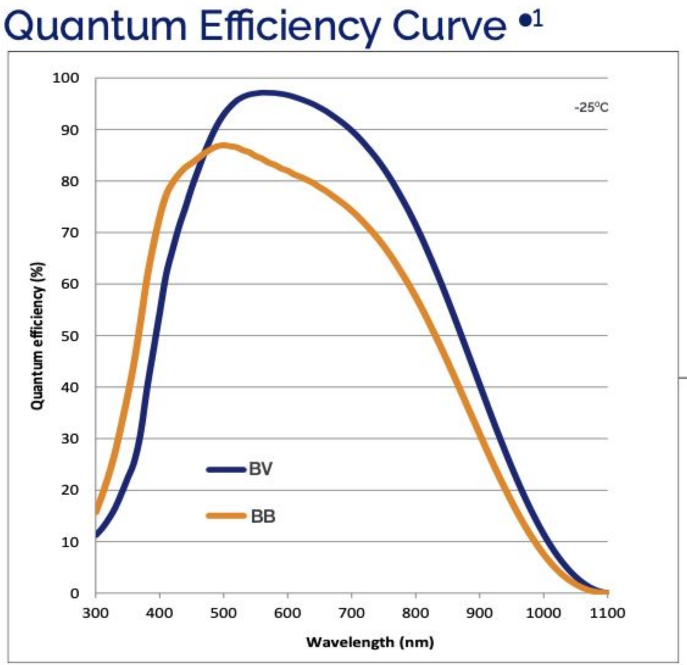




Therefore, raw images from telescopes are commonly monochrome
Colors come from combining three images taken with three different filters.

Most current astronomical images in visible/IR wavelengths are obtained with CCD (since 1970s)





Andor IKON-XL 230

During observation, CCD can be either exposing/integrating, reading out, or idling.

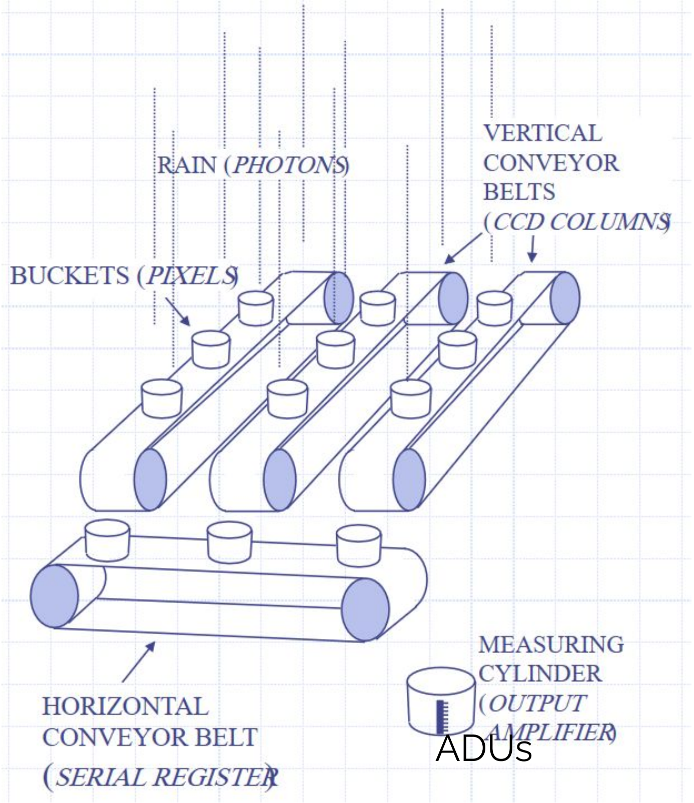
During an exposure

- Photons hit and are converted into electrons
- The electrons are collected in each pixel

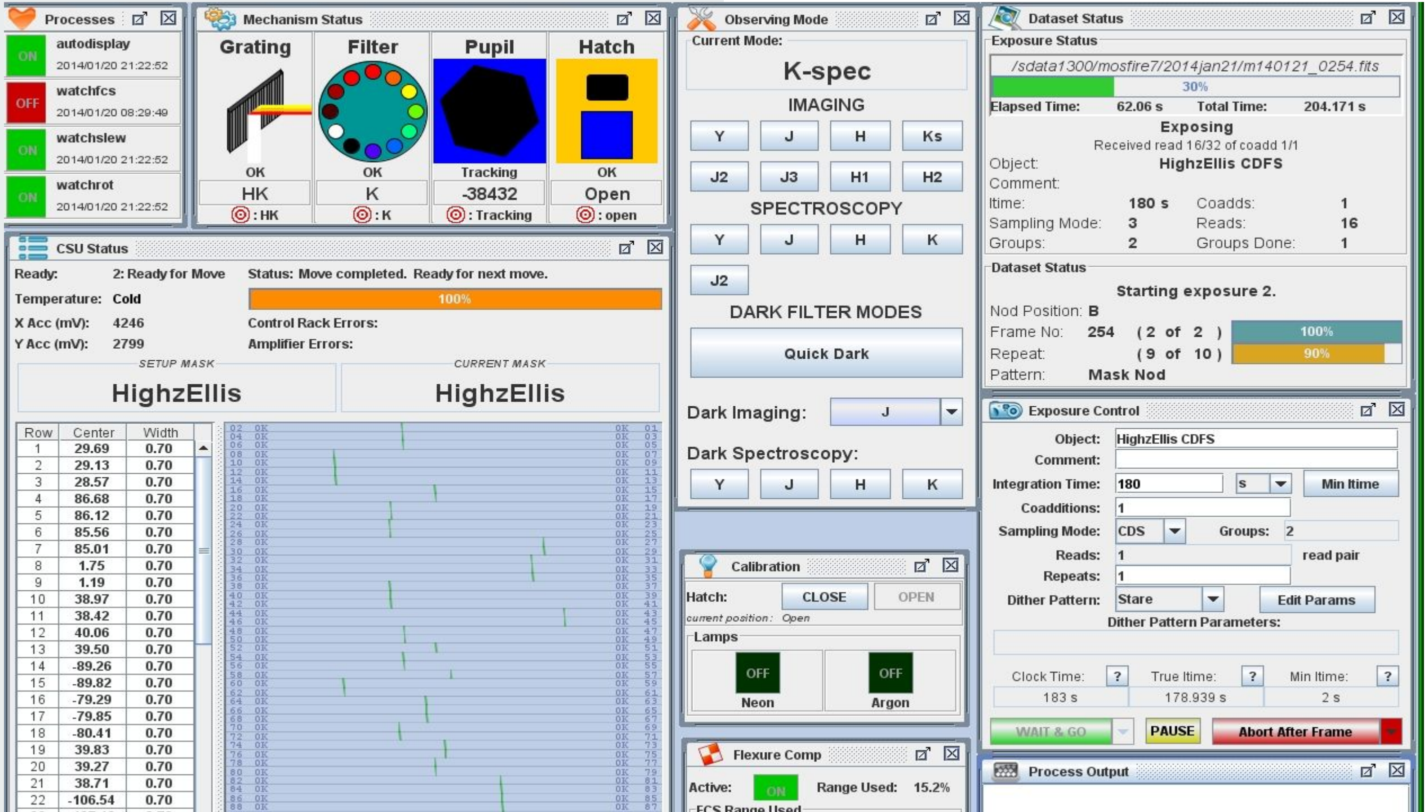
After the exposure

- The CCD move the electrons in 'conveyor belt' style to a reader

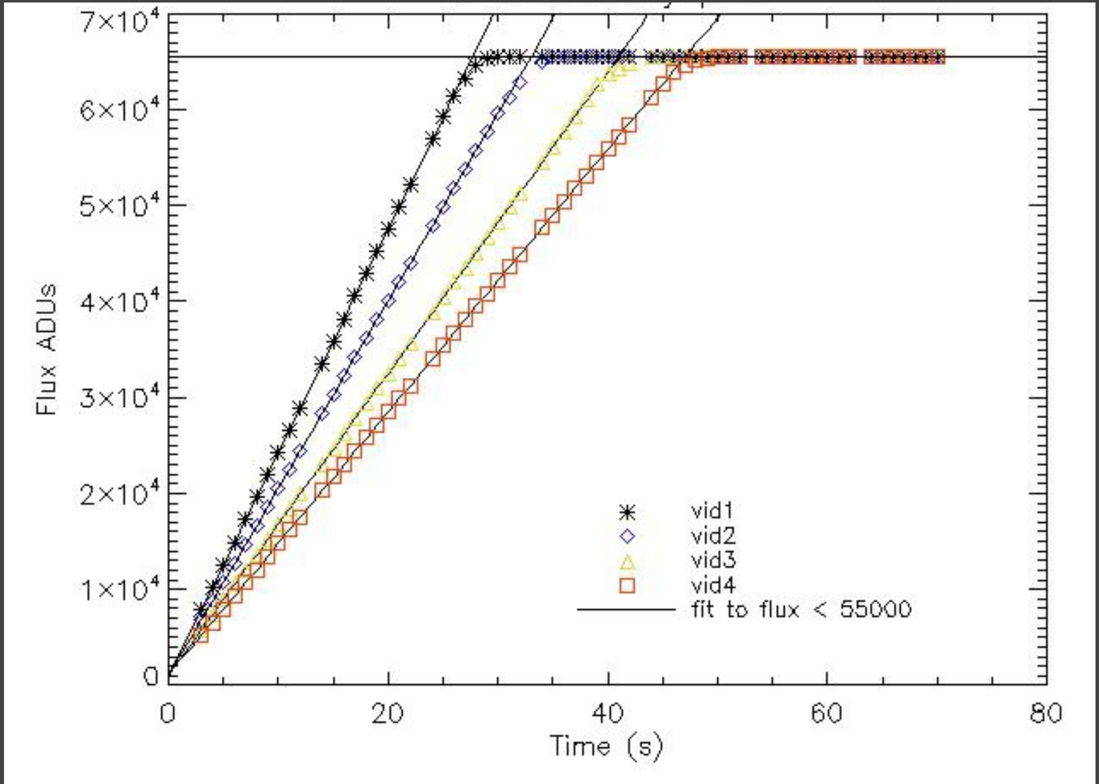
Repeat several times (at least 3)
- Think of science experiment -



During observation, CCD can be either exposing/integrating, reading out, or idling.



When a bucket is full, the pixel saturates

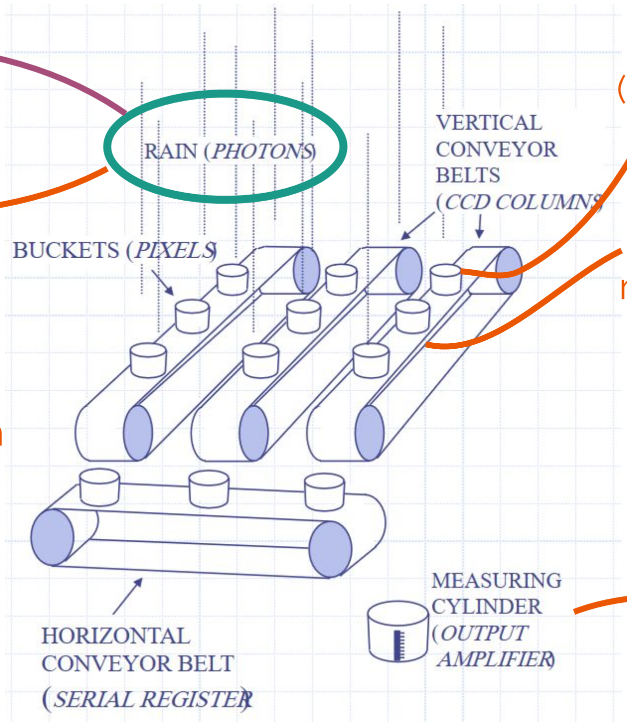


To reduce the data well, we need to know all sources of noise (extra electrons in the CCD that are not caused by astronomical sources).

Photons from astronomical sources (t)

Photons from background such as sky, moon, etc (t)

Flat
Pixel-to-pixel variation in quantum efficiency



Dark current (t)
(electrons leakage from CCD due to temperature)

Bias
(electrons from voltage applied to move them across the conveyor belt)

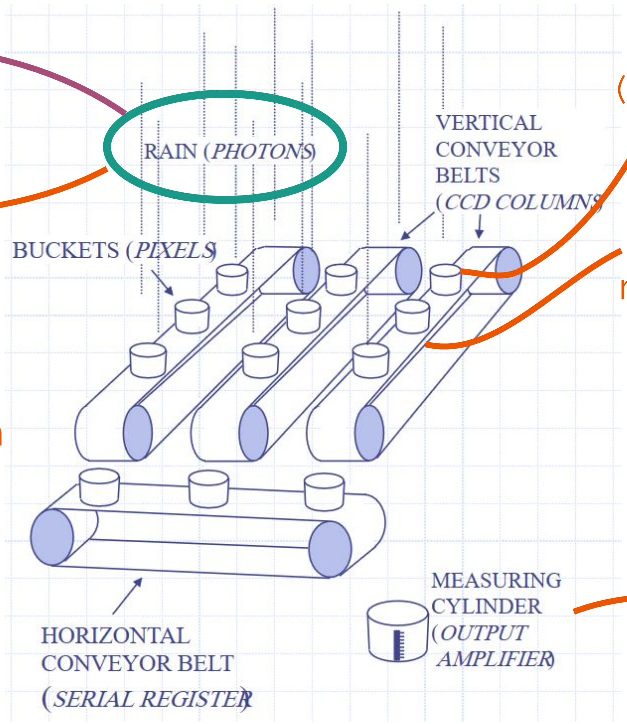
Read noise
(Random noise added by amplifier/reader)

The goal of image reduction is to get rid of the noises

Photons from astronomical sources (t)

Photons from background such as sky, moon, etc (t)

Flat
Pixel-to-pixel variation in quantum efficiency



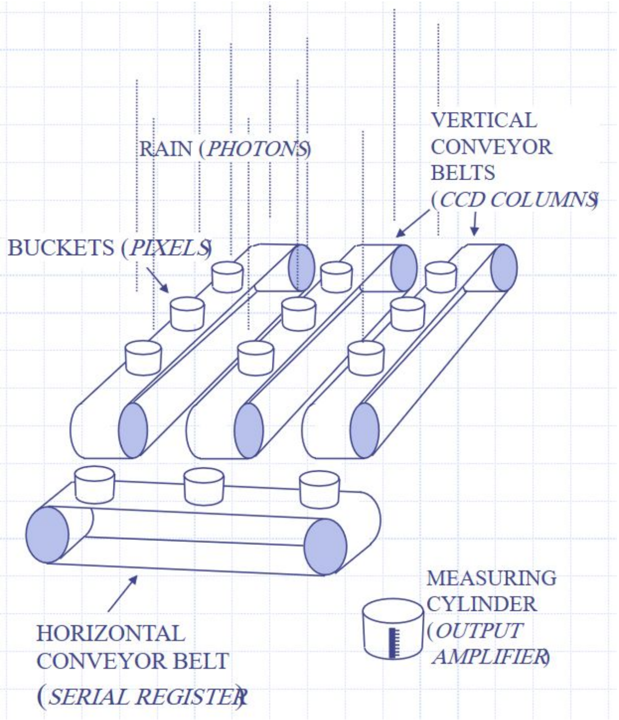
Dark current (t)
(electrons leakage from CCD due to temperature)

Bias
(electrons from voltage applied to move them across the conveyor belt)

Read noise
(Random noise added by amplifier/reader)

Bias can be measured with zero integration time. No exposure.

Bias = electrons from voltage applied to move them across the conveyor belt during the CCD reading



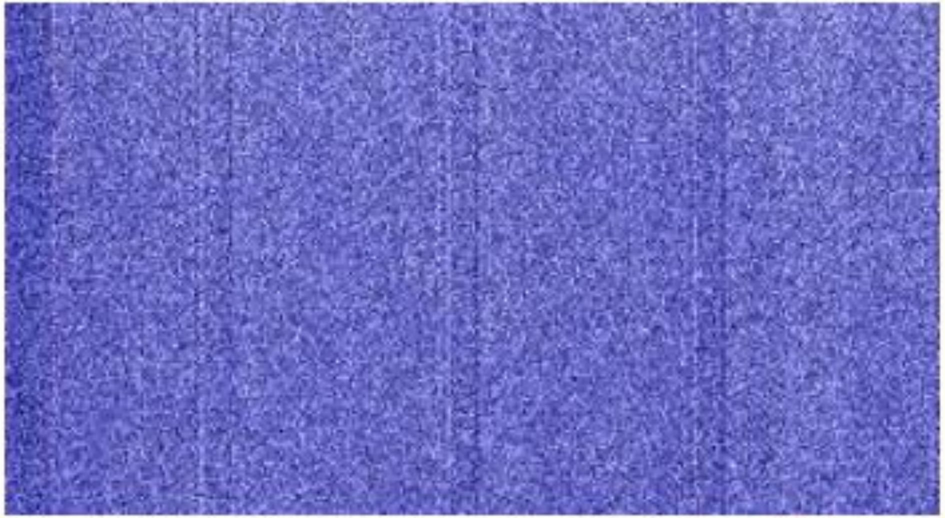


Figure 2: typical bias frame for the same CCD. (large 81k jpeg)

Flat can be measured by uniformly illuminating the CCD

Flat = Pixel-to-pixel variation in quantum efficiency

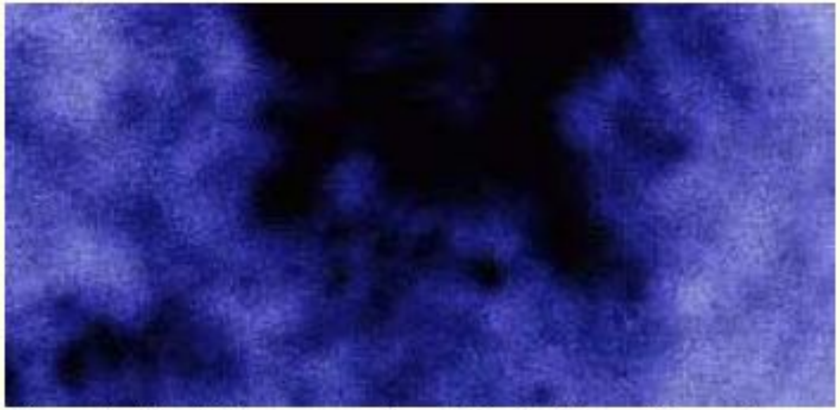
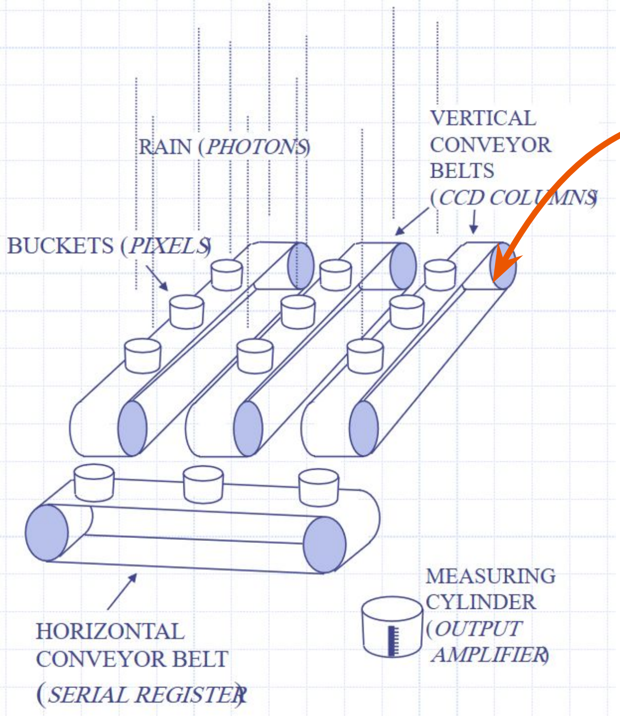


Figure 3: Flat field corresponding to Fig.1. The variations from black to white indicate changes of sensitivity of 10% . (larger 28k jpg)

Generally taken during sunset using sunlight (sky flat) or artificial light shined on the dome (dome flat)

Dark current can be measured by taking an image while the shutter is closed (dark) for the same time as the planned science exposure time



Dark current (t)
(electrons leakage from CCD due to temperature)

Usually taken in the afternoon <u>before</u> the observation night

In one observation night the followings are obtained

Before sunset (or after sunrise) with the shutter closed

- Bias (0-second exposure)
- Dark (n-seconds exposure)

During sunset with the shutter open

- Flat (varying exposure time to match the sky/dome brightness)

At night

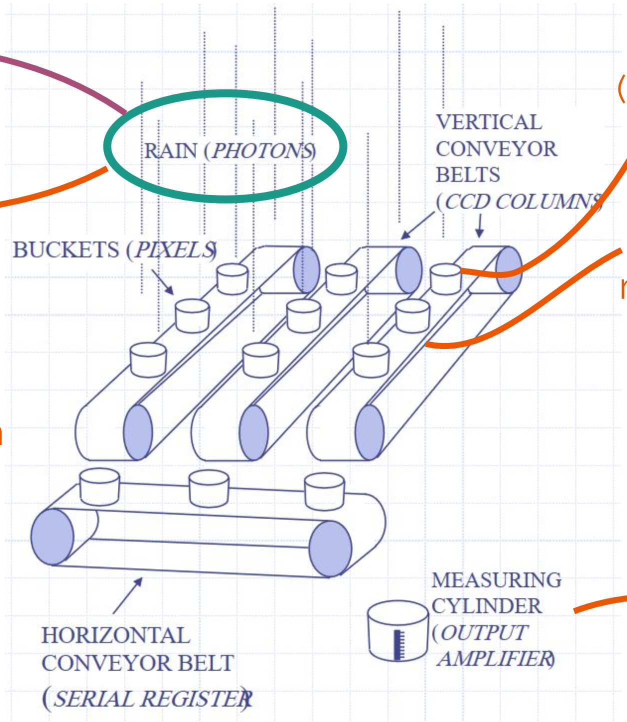
- Science targets
- Standard stars for flux calibration (if needed)

$$ADUs = Flat(x,y)\ Rain(x,y)\ t + Dark(x,y)\ t + Bias(x,y)$$

Photons from astronomical sources (t)

Photons from background such as sky, moon, etc (t)

Flat
Pixel-to-pixel variation in quantum efficiency



Dark current (t)
(electrons leakage from CCD due to temperature)

Bias
(electrons from voltage applied to move them across the conveyor belt)

Read noise
(Random noise added by amplifier/reader)

Data reduction is to solve for Source(x,y)

$$\text{ADUs}(x,y) = \text{Flat}(x,y)\ \ \text{Rain}(x,y)\ t\ + \text{Dark}(x,y)\ t + \text{Bias}(x,y)$$

$$\text{Rain}(x,y)\ t = (\ \text{ADUs}(x,y) - \text{Bias}(x,y) - \text{Dark}(x,y)\ t\ ) \ /\ \text{Flat}(x,y)$$

But $\quad \text{Rain}(x,y) \ = \ \text{Sky}(x,y) + \text{Source}(x,y)$

Therefore,

$$\text{Source}(x,y)\ t = (\ \text{ADUs}(x,y) - \text{Bias}(x,y) - \text{Dark}(x,y)\ t\ ) \ /\ \text{Flat}(x,y) - \text{Sky}(x,y)$$

References and further reads

- Basic image processing by O.Hainaut http://www.sc.eso.org/~ohainaut/ccd
- CCD Theory http://atomfizika.elte.hu/haladolabor/docs/ccd.pdf