A short horizontal bar with a teal-to-orange gradient, positioned above the title text.

Optical Observations in Astronomy

CCD Image Processing and Basic Data Reduction

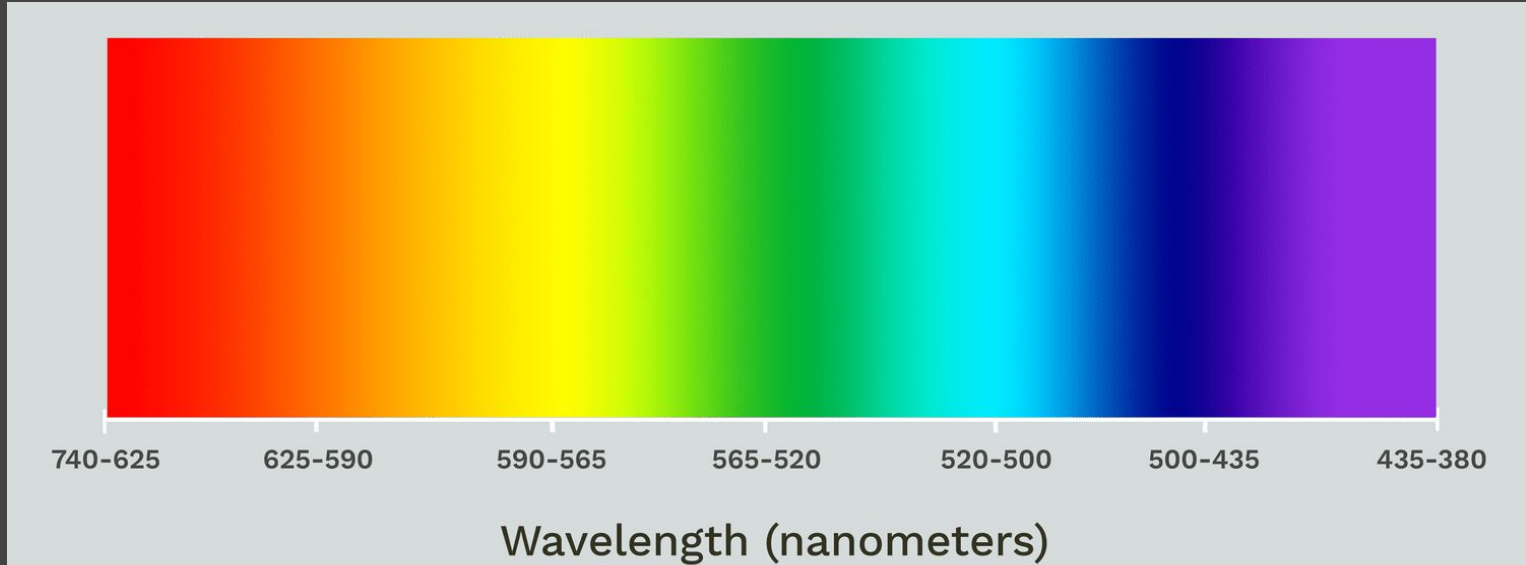
ASTRO101: HOW on OAR, 28 August 2023
Nicha Leethochawalit
Researcher, NARIT

Astronomy is mainly an observational science

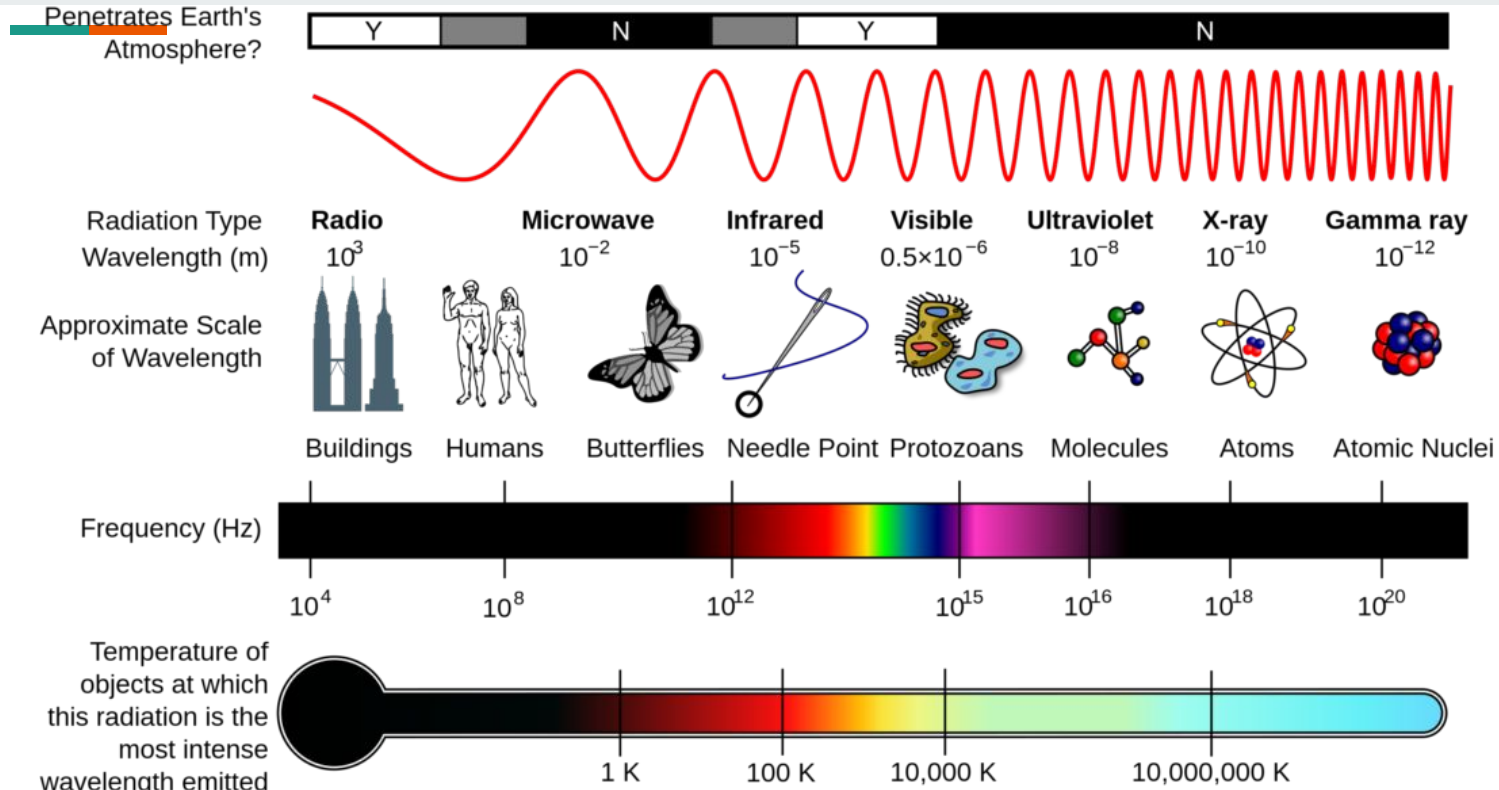


- Electromagnetic waves
- Neutrinos (1956-)
- Gravitational waves (2015-)

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

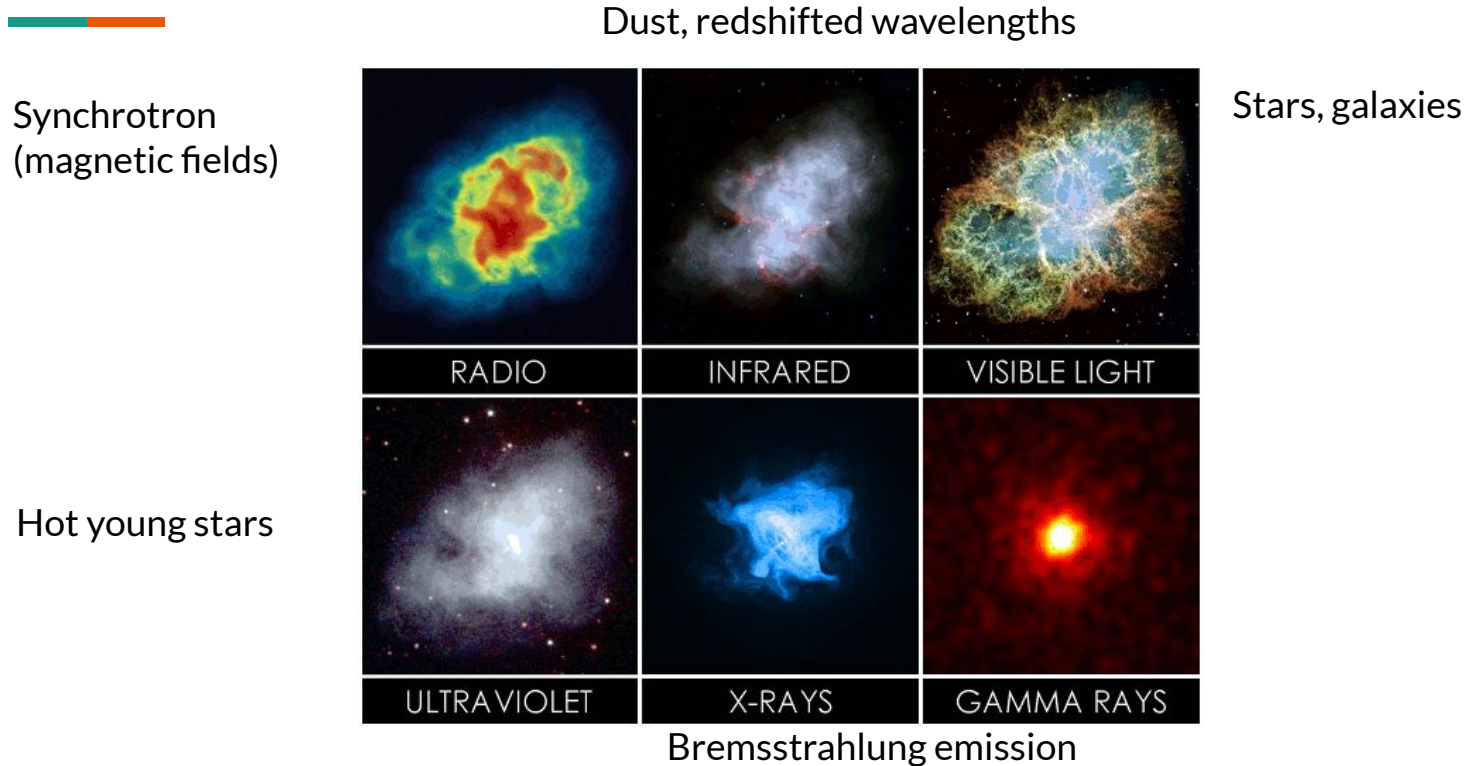


Optical Astronomy = Wavelengths that we can use telescopes with optic system (with CCD-like detector)

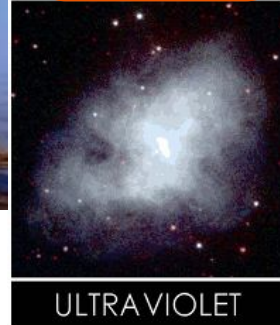
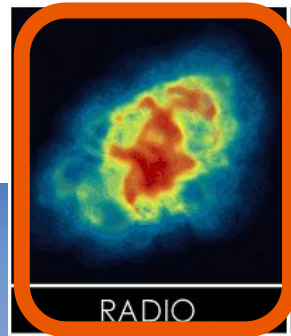
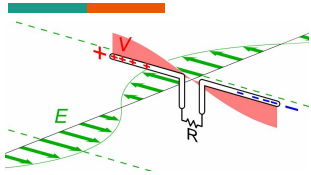


Credit: astrobites:guide-to-the-electromagnetic-spectrum-in-astronomy-2/

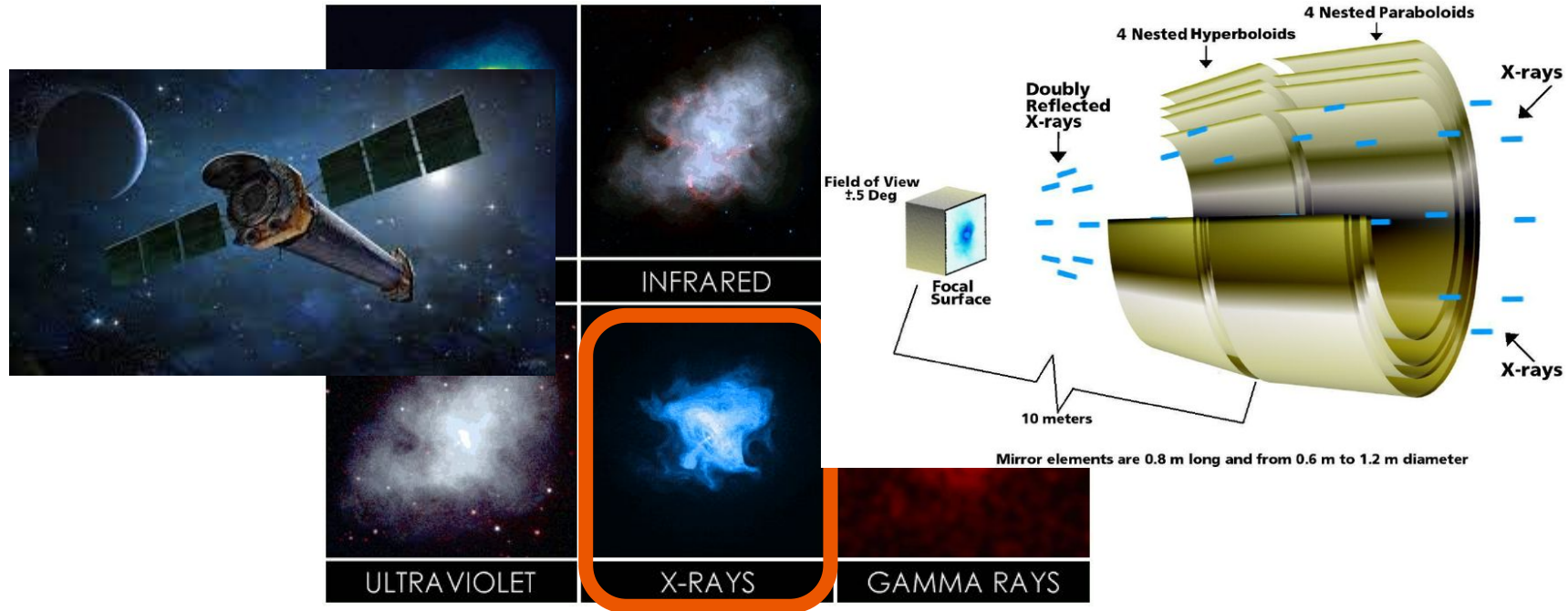
Optical Astronomy = Wavelengths that we can use telescopes with optic system (with CCD-like detector)



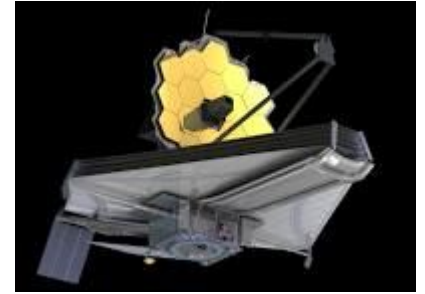
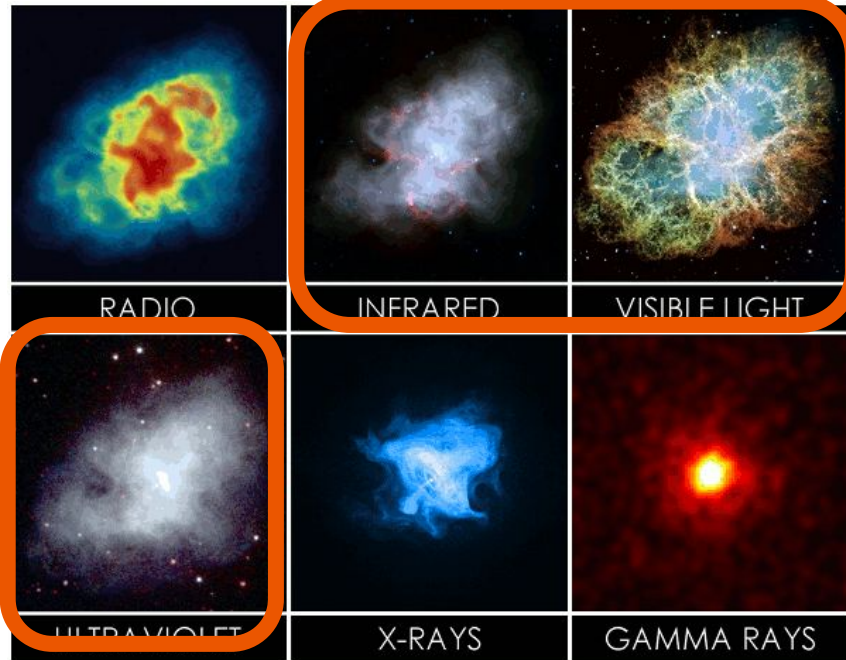
Optical Astronomy = Wavelengths that we can use telescopes with optic system (with CCD-like detector)



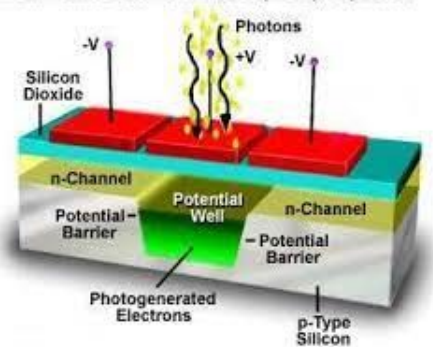
Optical Astronomy = Wavelengths that we can use telescopes with optic system (with CCD-like detector)



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



Metal Oxide Semiconductor (MOS) Capacitor



Telescope is essentially a camera



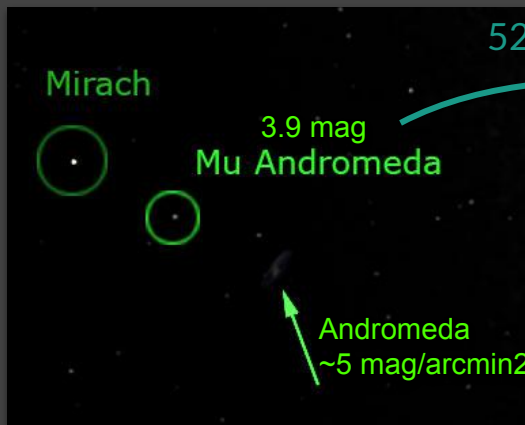
The objects telescopes observe are usually fainter than what eyes can see

JADES-GS-z13-o

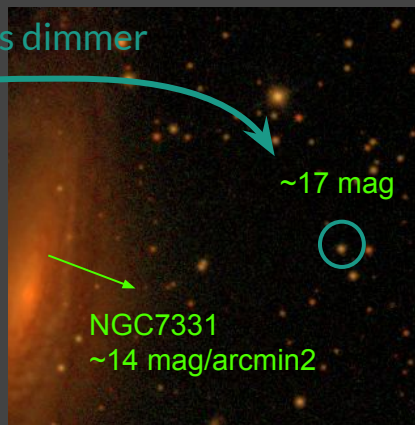
Visible eyes

0.7-m Thai Robotic Telescope
50 s exposure time

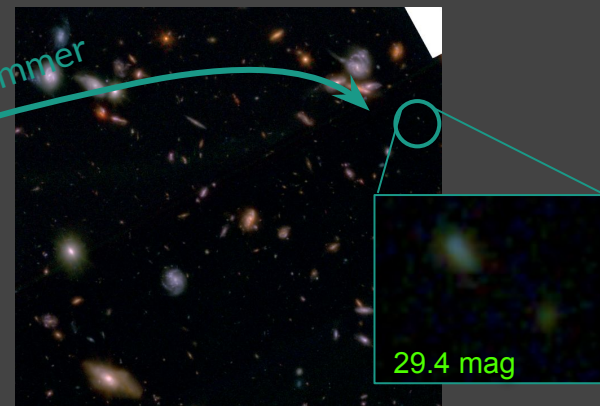
6-m JWST
4-16 hrs exposure time



52 times dimmer



50 times dimmer

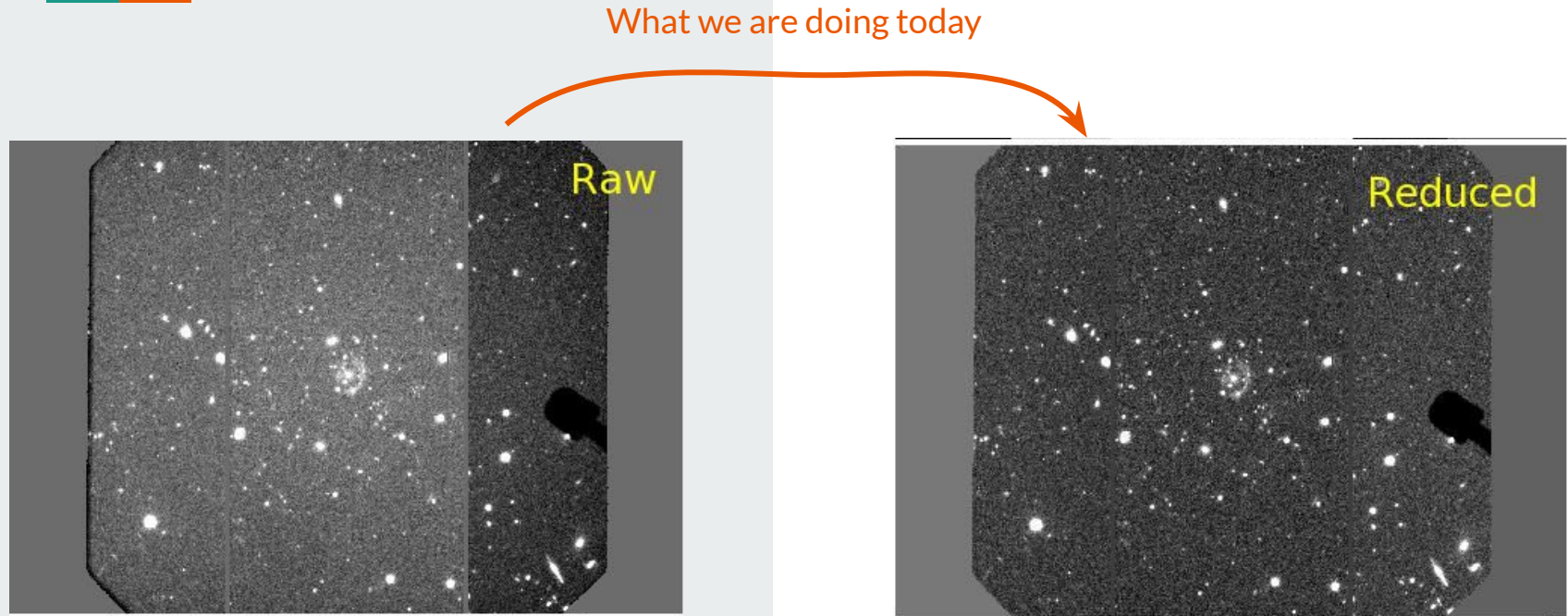


Credit: Richard McDonald


Credit: Samaporn, Nicha

Credit: Jades collaboration

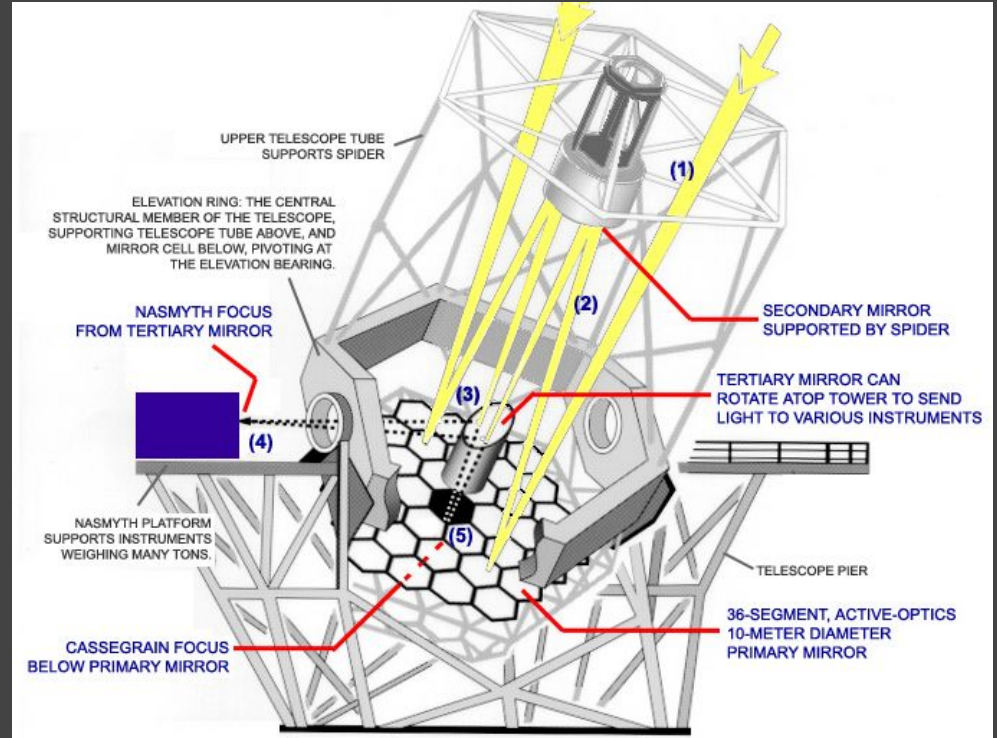
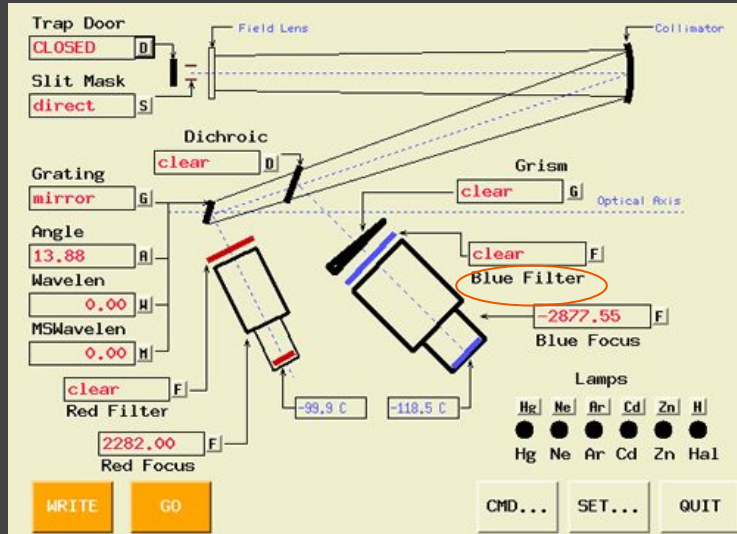
Raw out-of-the-telescope images are usually noisy



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

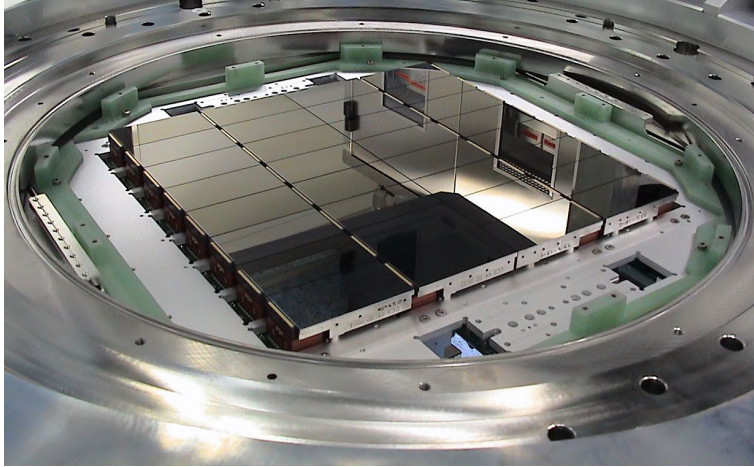
- 
- Pixel values reflect the fluxes from astronomical objects (not sky background, not instrumental noise).
 - We can translate those pixel values into physical fluxes (erg/s/Hz/cm^2) with reliable uncertainties

Telescope + instrument

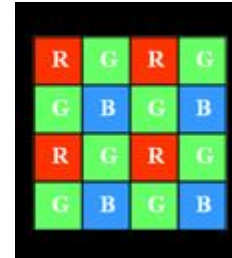
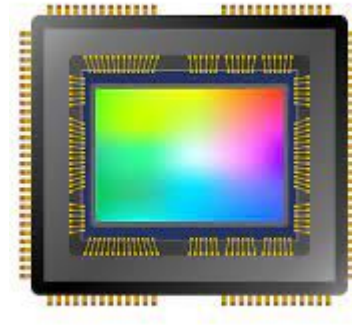


In astronomical instruments,
filters are placed in front of
the CCD.

In commercial camera,
filters are on the CCD

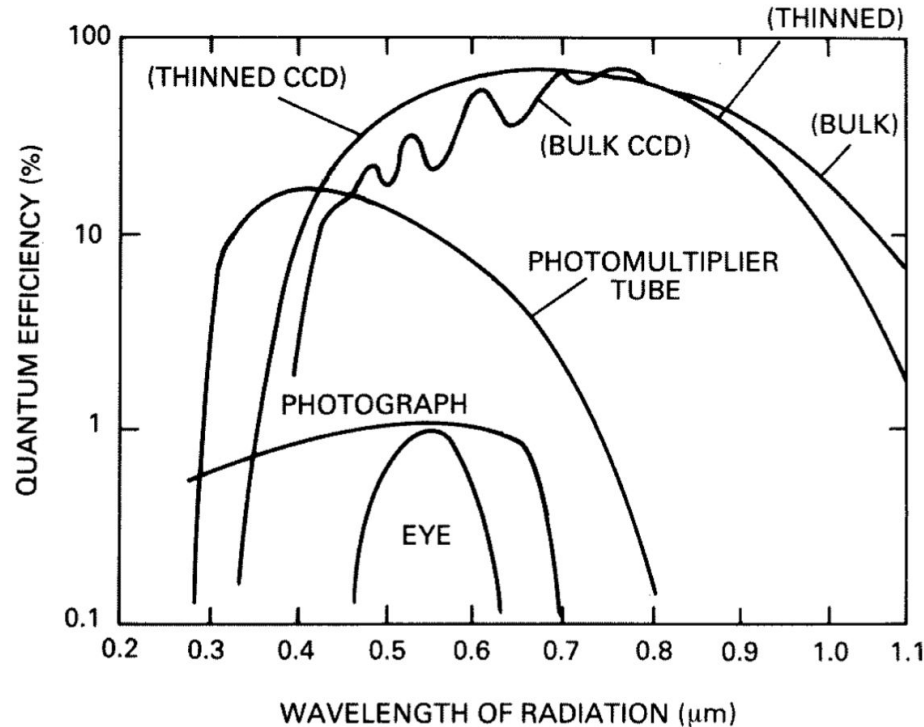


OmegaCAM on VLT
Credit: ESO/INAF-VST/OmegaCAM/O. Iwert

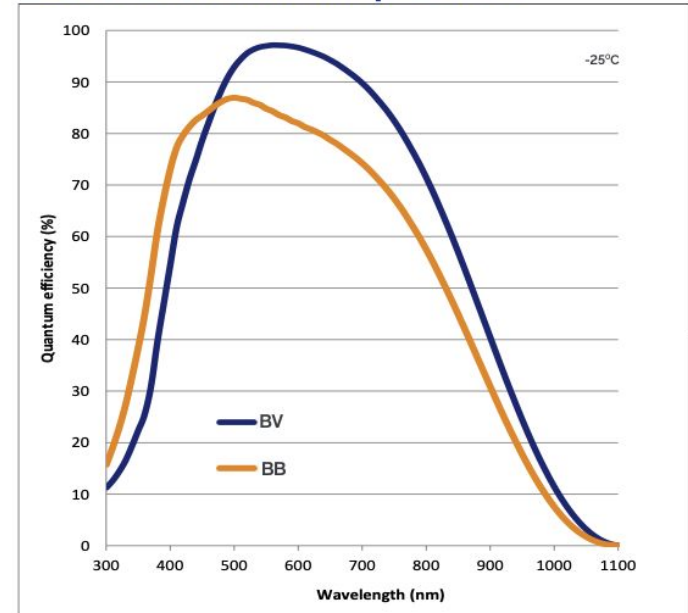


Therefore, raw images from telescopes are commonly monochrome
Colors come from combining three images taken with three different filters.

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



Quantum Efficiency Curve •¹



Andor IKON-XL 230

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

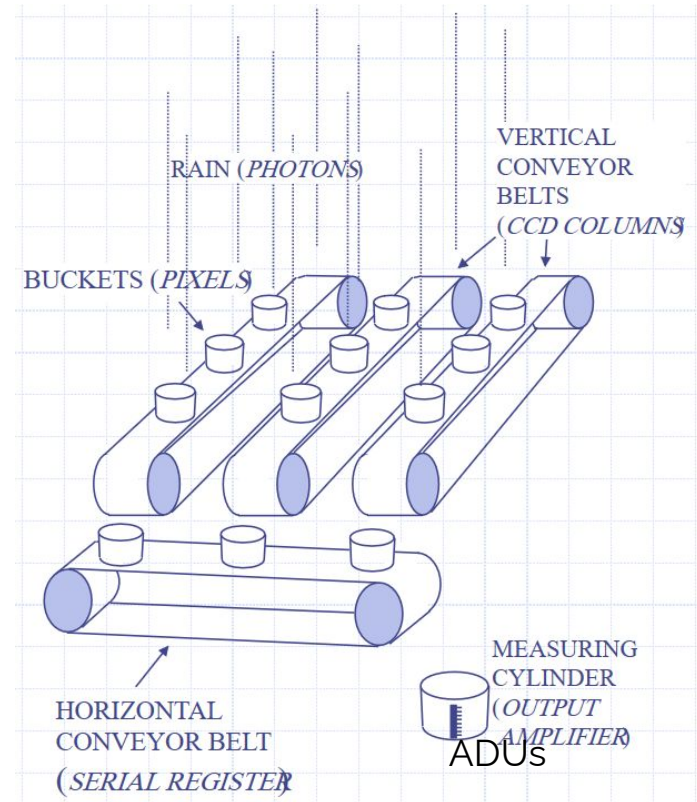
During an exposure

- 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 -



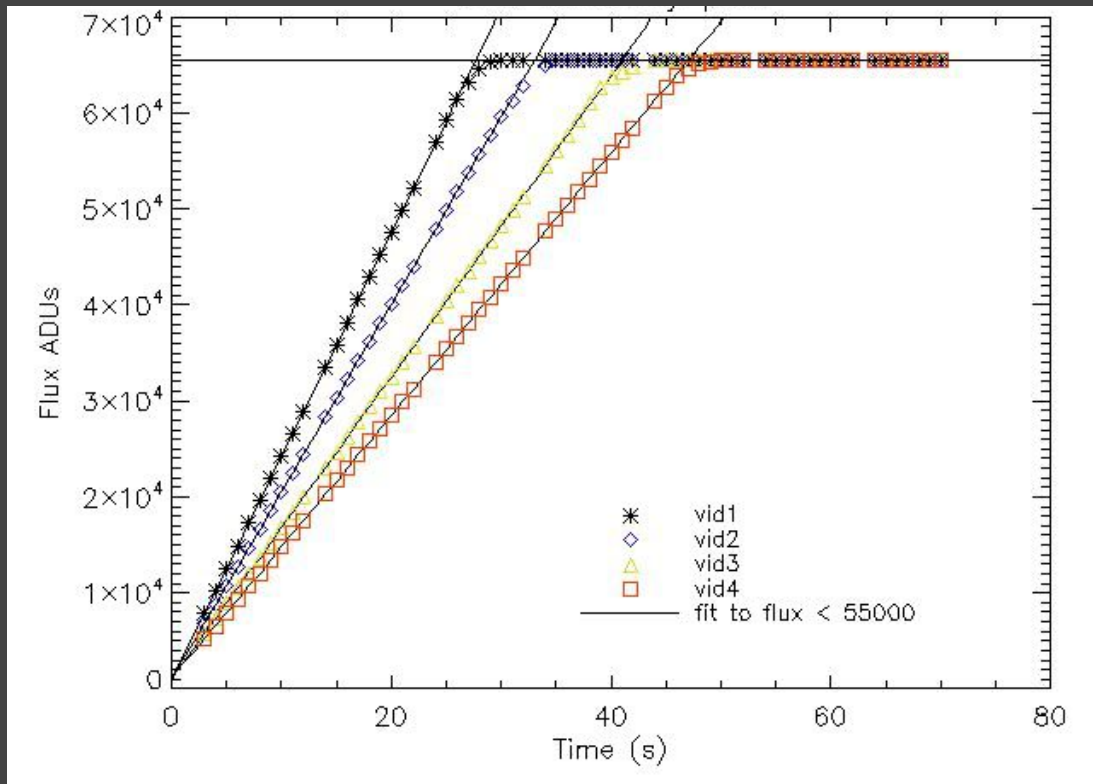
During observation, CCD can be either exposing/integrating, reading out, or idling.

The screenshot displays a comprehensive telescope control interface with several key panels:

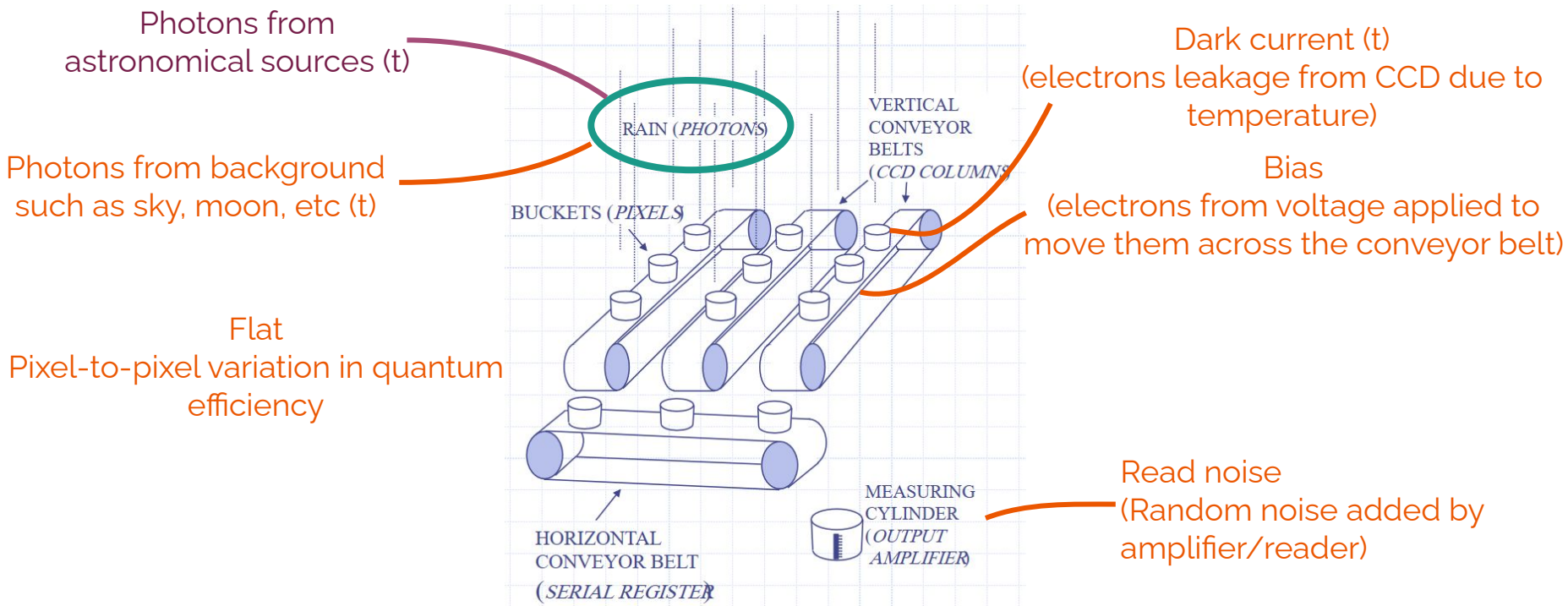
- Processes:** A list of background tasks including `autodisplay`, `watchfcs`, `watchslew`, and `watchrot`, each with a status indicator (ON/OFF) and a timestamp.
- Mechanism Status:** Visual indicators for the Grating, Filter, Pupil, and Hatch, showing their current positions and status (e.g., OK, Tracking, Open).
- CSU Status:** A section for the Corrector Servo Unit, showing temperature (Cold), acceleration (X Acc, Y Acc), and a progress bar for movement.
- HighzEllis:** A table of observation data for the HighzEllis field, including row numbers, center coordinates, and widths.
- Observing Mode:** A central panel for selecting observation modes (IMAGING, SPECTROSCOPY, DARK FILTER MODES) and controlling filters (Quick Dark, Dark Imaging, Dark Spectroscopy).
- Dataset Status:** Information about the current dataset, including exposure status, elapsed time, and object details (HighzEllis CDFS).
- Exposure Control:** A panel for managing exposure parameters such as integration time, coadditions, sampling mode, and dither pattern.
- Calibration:** A section for managing calibration lamps (Neon, Argon) and their status.
- Flexure Comp:** A panel for flexure compensation, showing active status and range used.

Row	Center	Width
1	29.69	0.70
2	29.13	0.70
3	28.57	0.70
4	86.68	0.70
5	86.12	0.70
6	85.56	0.70
7	85.01	0.70
8	1.75	0.70
9	1.19	0.70
10	38.97	0.70
11	38.42	0.70
12	40.06	0.70
13	39.50	0.70
14	-89.26	0.70
15	-89.82	0.70
16	-79.29	0.70
17	-79.85	0.70
18	-80.41	0.70
19	39.83	0.70
20	39.27	0.70
21	38.71	0.70
22	-106.54	0.70

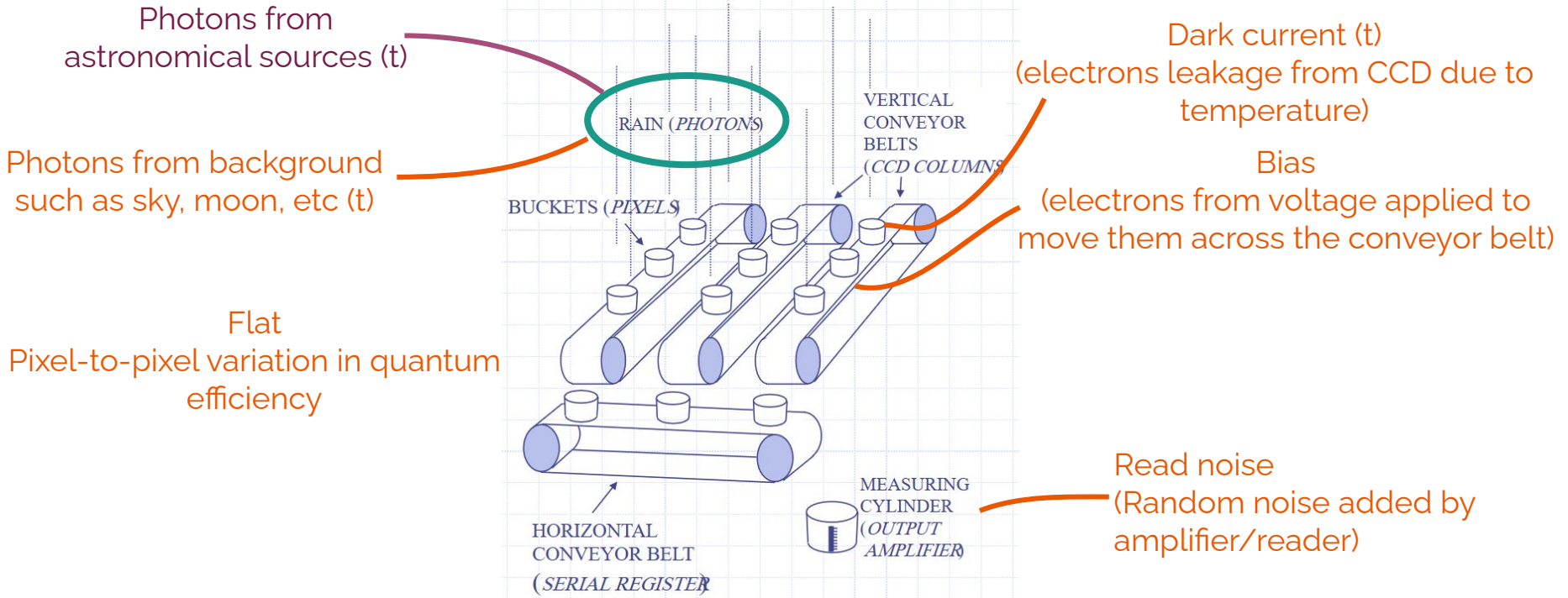
When a bucket is full, the pixel saturates



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).



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



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

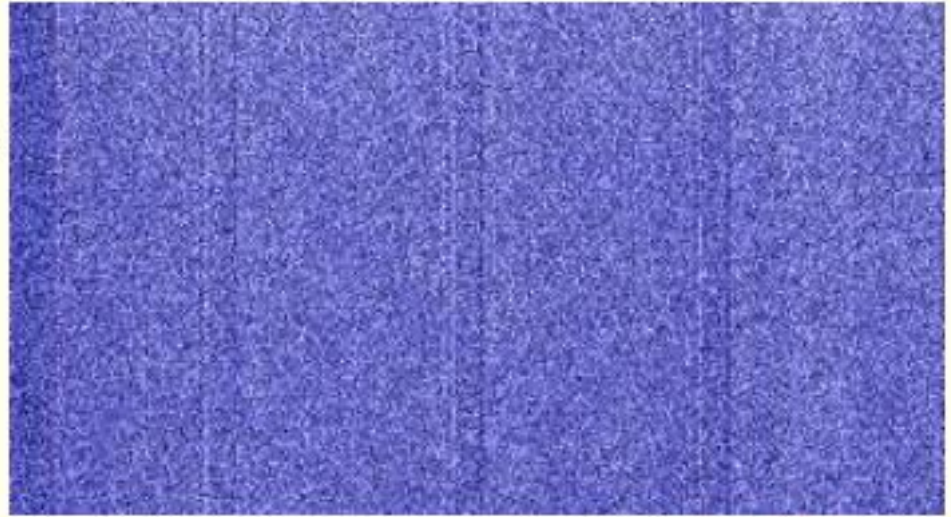
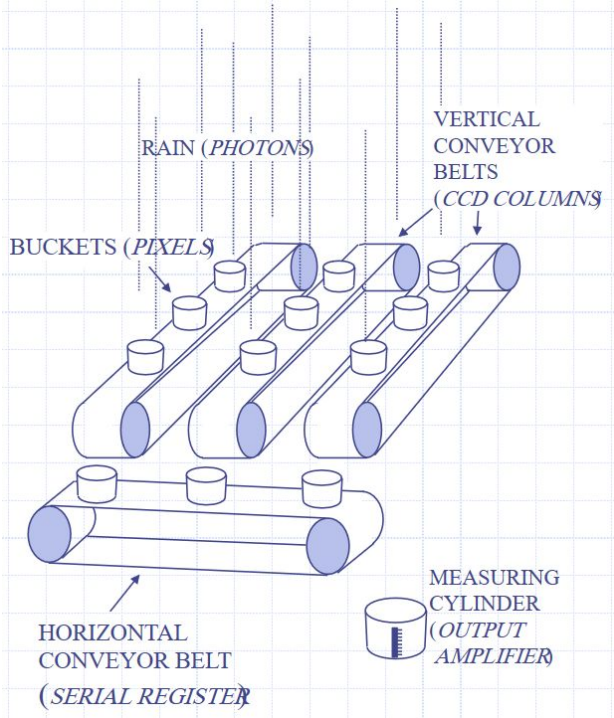


Figure 2: typical bias frame for the same CCD. ([large 81k jpeg](#))

Flat can be measured by uniformly illuminating the CCD

Flat = Pixel-to-pixel variation in quantum efficiency

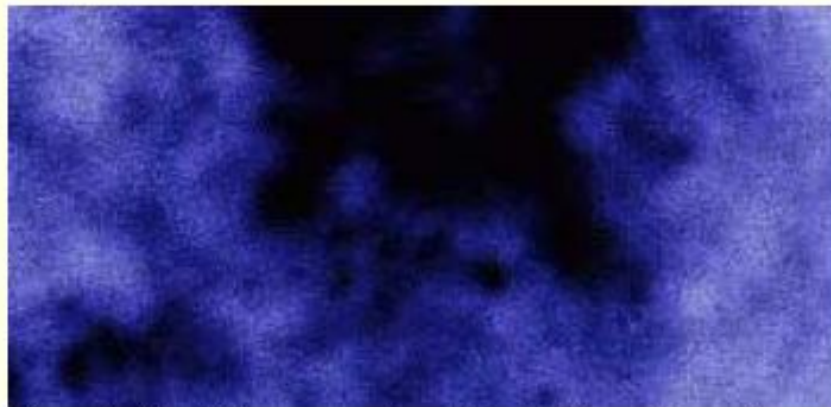
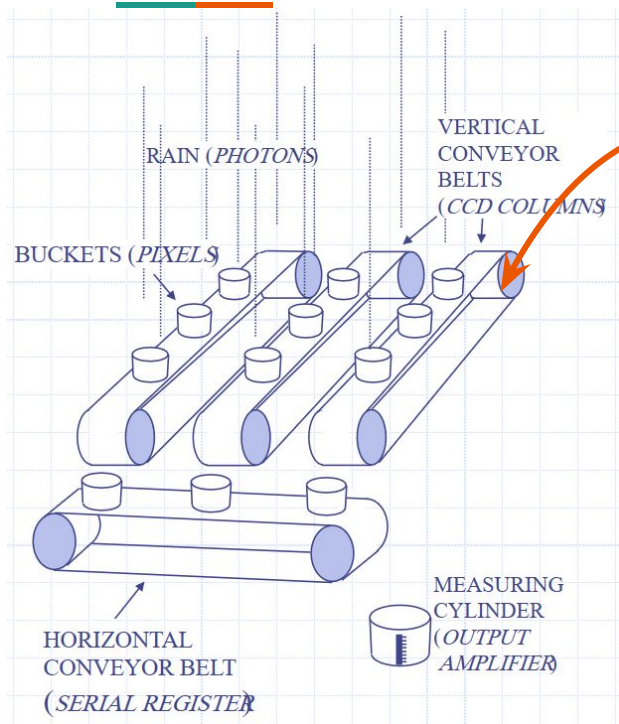


Figure 3: Flat field corresponding to Fig.1. The variations from black to white indicate changes of sensitivity of 10% . ([larger 28k jpg](#))

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 before 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

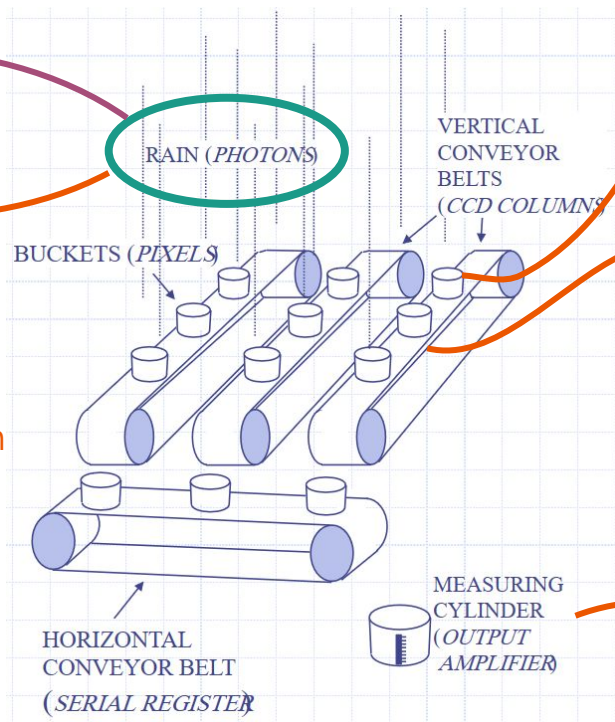
- Science targets
- Standard stars for flux calibration (if needed)

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

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

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>