Observations and calibrations

Observational Astronomy

Laboratory of Astrophysics

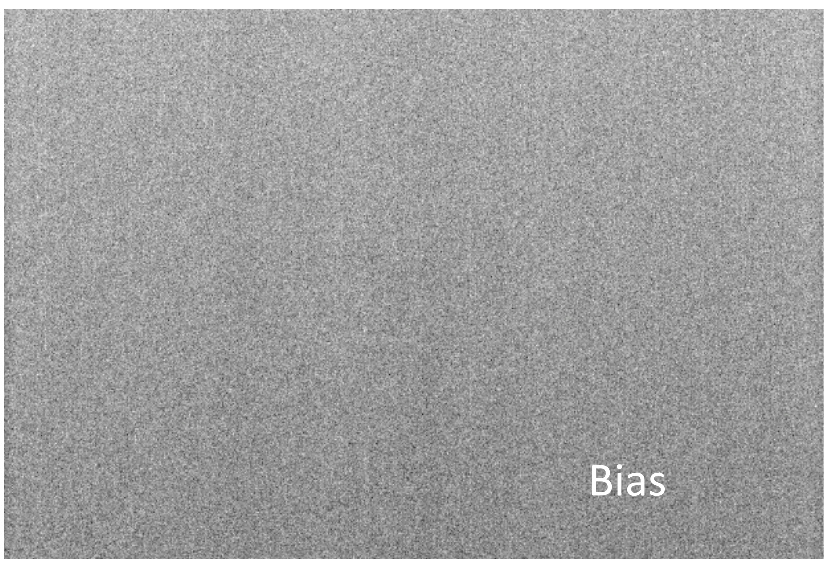
Calibrations

a. **Bias**
b. **Dark**
c. **Flat**

d. Bad pixel mask
e. Cosmic rays
f. Standard star

Calibrations: bias & darks

- A light frame is your science image
- A bias frame is an image with zero exposure time to obtain the signal from the electronics ➔ readout noise



- CCD measures number of e^- per pixel: N_e
- Total charge: $Q=eN_e$
- To measure charge, we use the capacitor: $V=Q/C$
- To store the data, we convert it to digital form: analog-to-digital converter (ADC) counts N_c:

$$N_e = \text{gain } N_c$$

$$VC/e = \text{gain } N_c$$

Bias must be subtracted from data

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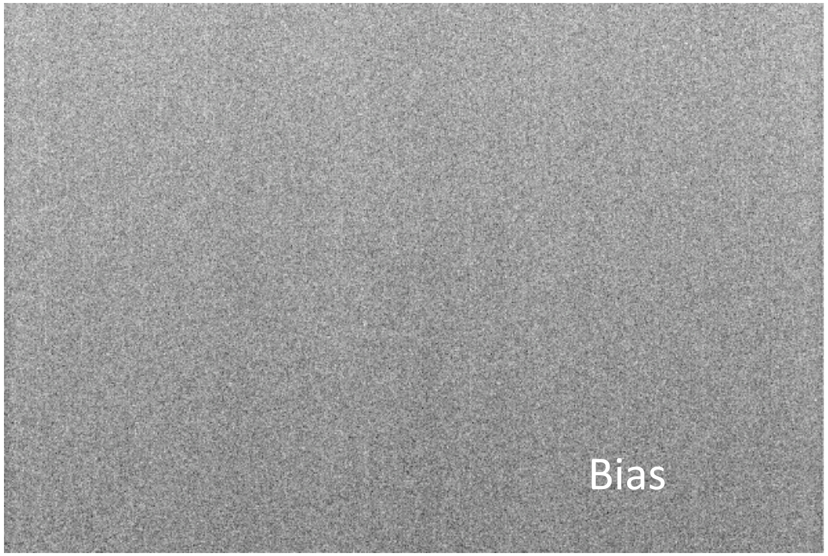


How to measure?

To measure bias we take a set of exposures with EXPTIME=0s and the shutter is closed

You may combine several bias frames into a **master bias**

Calibrations: bias & darks

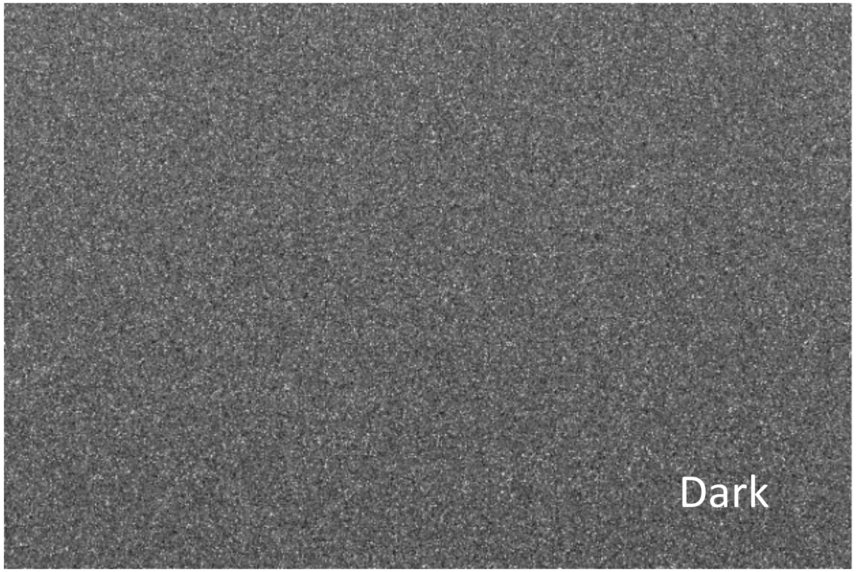
- A light frame is your science image
- A bias frame is an image with zero exposure time to obtain the signal from the electronics ➔ readout noise
- A dark frame is similar (no light) but with exposure time ➔ dark current. Ideally exposure time is **same** as light frame!

➢ Thermal fluctuations: some e^- might jump the potential well independent of the light hitting the detector

➢ Depend on temperature (some CCDs are cooled)

➢ Proportional to time

Darks must be subtracted from data!



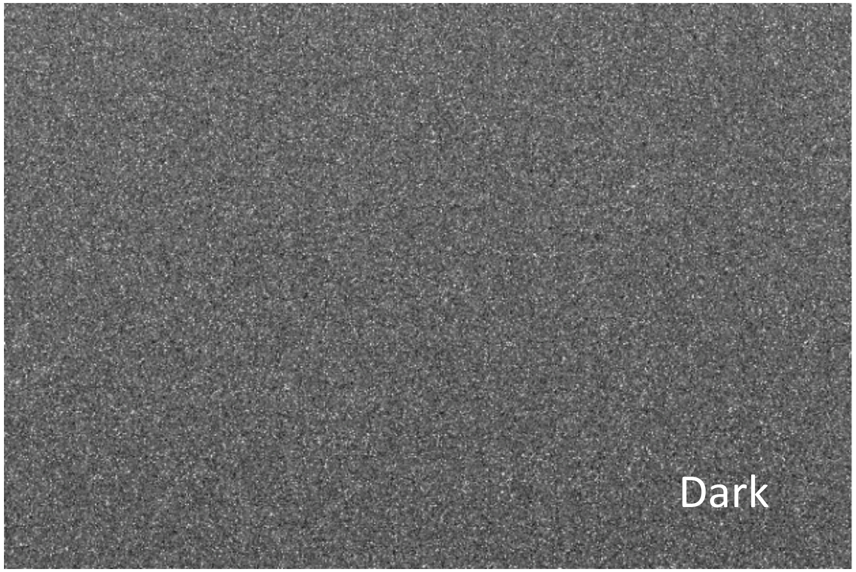
Calibrations: bias & darks

- A light frame is your science image
- A bias frame is an image with zero exposure time to obtain the signal from the electronics → readout noise
- A dark frame is similar (no light) but with exposure time → dark current. Ideally exposure time is **same** as light frame!

How to measure?

By taking a set of exposures with EXPTIME=EXPTIME(science) with shutter closed (no light)

You may combine several dark frames into a **master dark**



Calibrations: bias & darks

$$SNR = \frac{N_* Q_E t}{\sqrt{(N_* + S) Q_E t + I_D t + N_R^2}}$$

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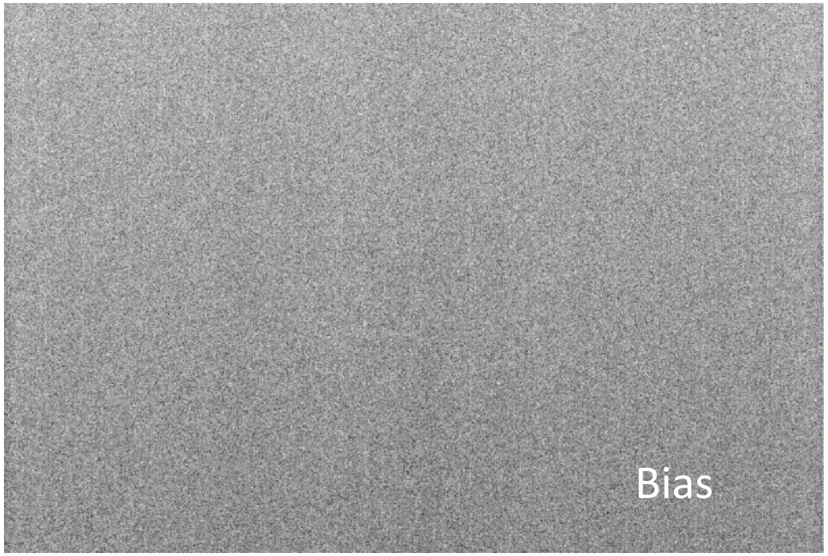
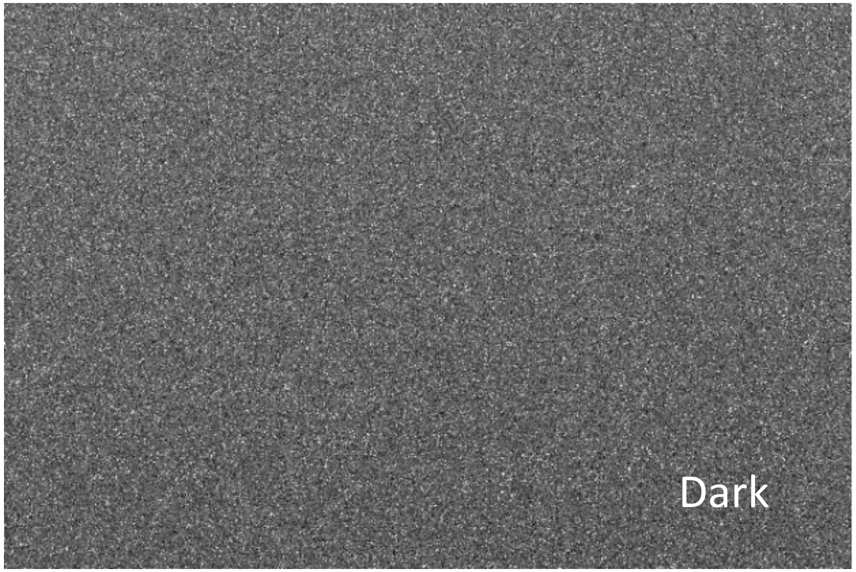




Calibrations: flats

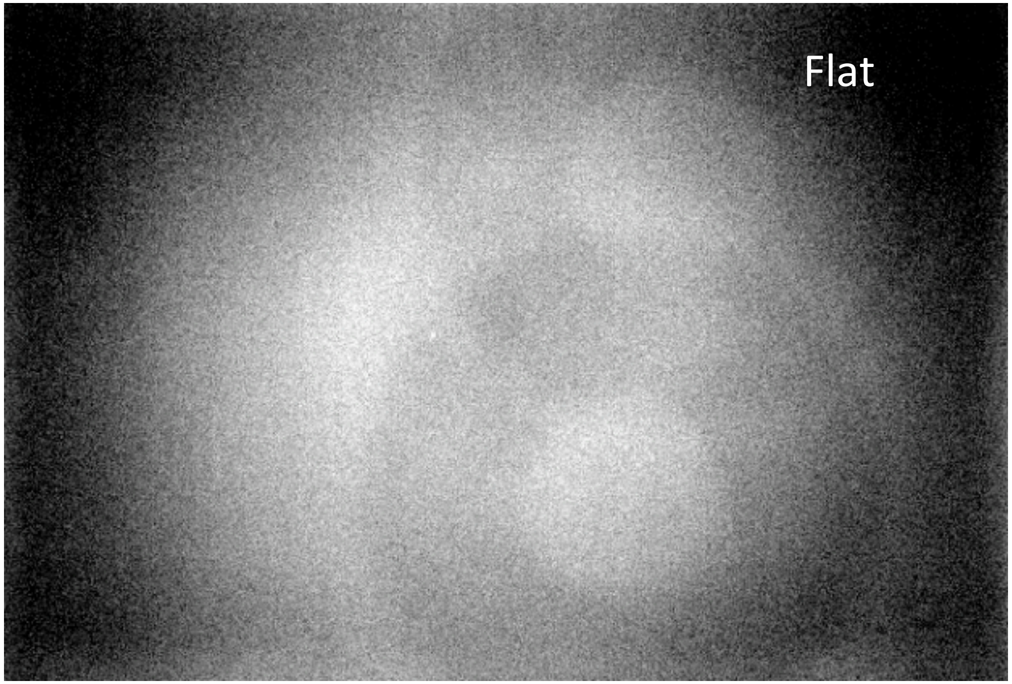
- A flat field is an image of a constant illumination through the CCD to see the count level per pixel:
  - Use of sky twilight (bright background, no stars)
  - Use of flat screens

Would this image have same background at every pixel?

Calibrations: flats

- A flat field is an image of a constant illumination through the CCD to see the count level per pixel:
  - Use of sky twilight
  - Use of flat screens
  - Done in all filters (light goes through)

Average count ~30k counts



- **Vignetting**: reduction of brightness at edges due to loss of light (in the 2ndary) from off-axis objects
- Pixel manufacturing differences
- Dust grains on optical elements: CCD window, filters

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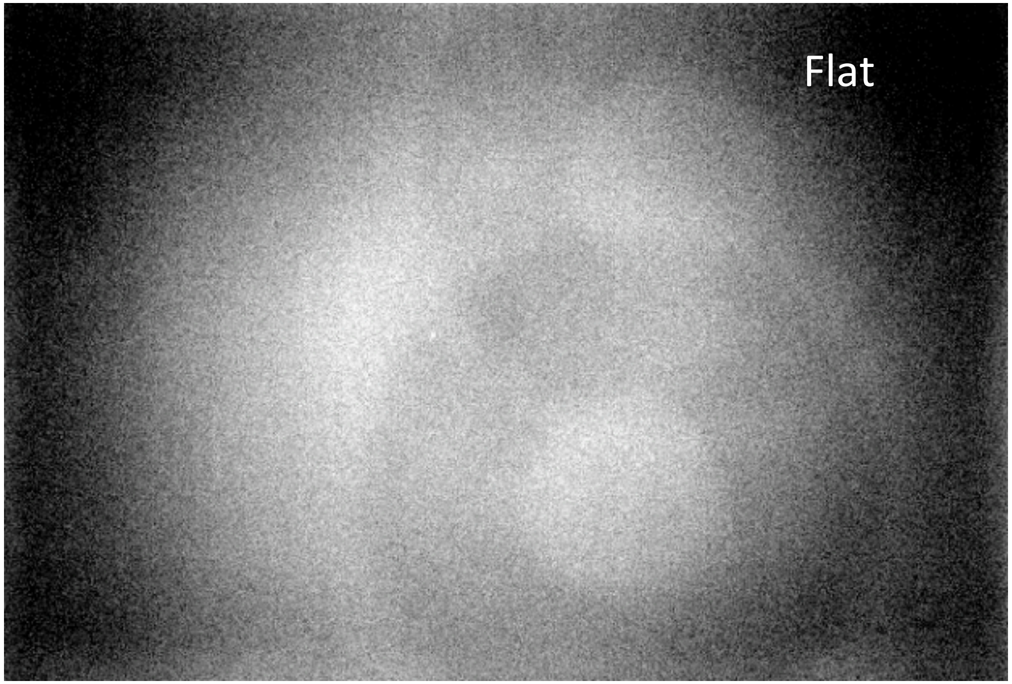

How to measure?

By using a constant source of light, illuminate your CCD (shutter open). Exposure time depends on sufficient counts without saturating.

Average count ~30k counts

Flats may change from day to day!

Calibrations: flats

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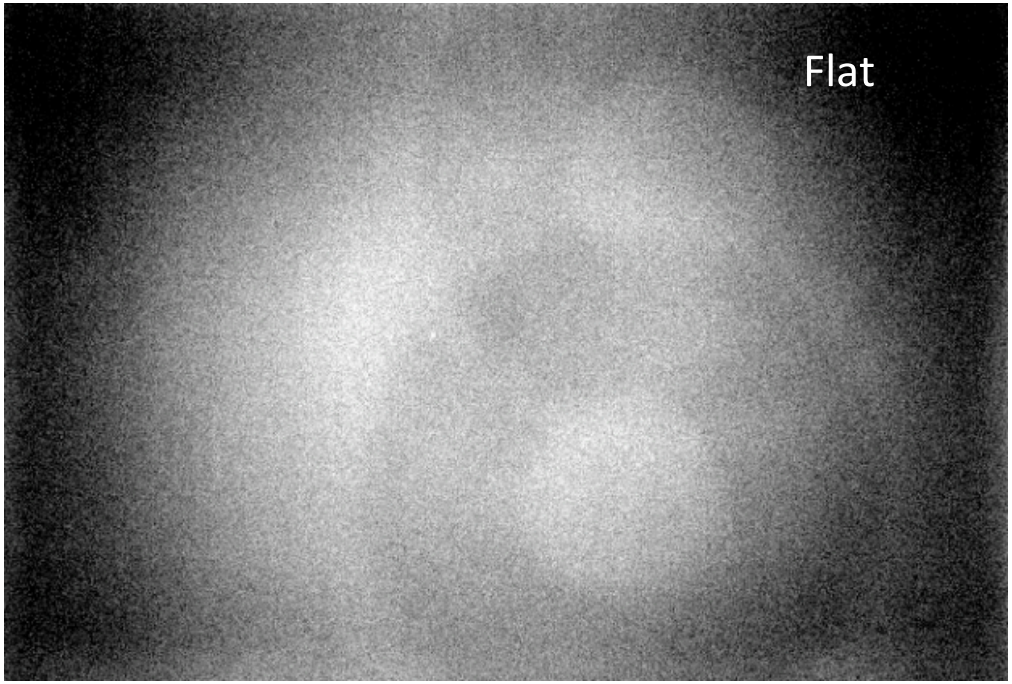

How to measure?

- Subtract bias/dark from flat
- Divide each frame by its median

Multiplicative effect: science is divided by flat

You can combine several flat fields to get a **master flat**

Some questions

Which of the following do we have to pay attention to when using a bias frame, a dark frame and a flat field?

- Exposure time
- Filter
- Chip number (FORS has two chips)

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Which of the following do we have to pay attention to when using a bias frame, a dark frame and a flat field?

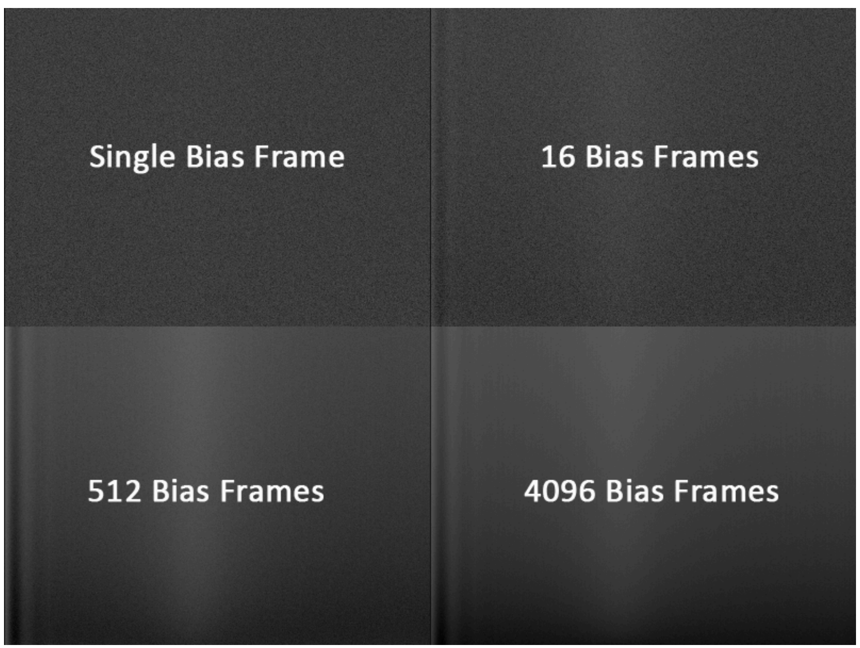
- Exposure time ~~BIAS~~ DARK ~~FLAT~~
- Filter ~~BIAS~~ ~~DARK~~ FLAT
- Chip number (FORS has two chips) BIAS DARK FLAT

Image stacking

To increase your SNR, increase exposure time. But things can saturate, so you can stack many images of shorter exposures: blend several images of the same target together. How: create a data cube with all the frames and median (average) in the 3rd dimension.

- Final image is not brighter (signal is the same)!
- Final image is smoother because it has less noise (noise is random and cancels out)

$$SNR = \frac{N_* Q_E t}{\sqrt{(N_* + S) Q_E t + I_D t + N_R^2}}$$



$$SNR \propto \sqrt{t} = \sqrt{N}$$

Create **master bias**, **master dark**, **master flat** through median

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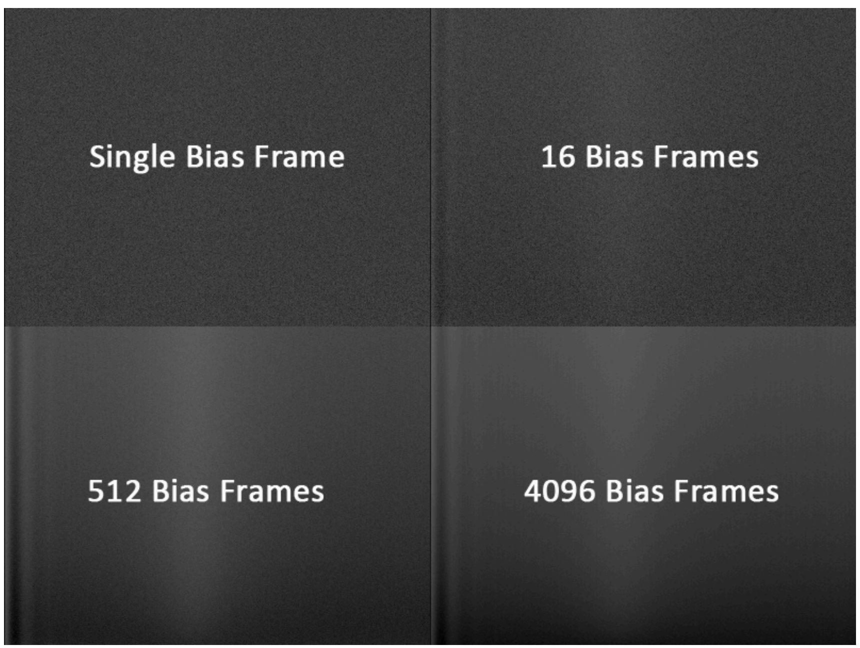
Be careful with alignment in science frames!



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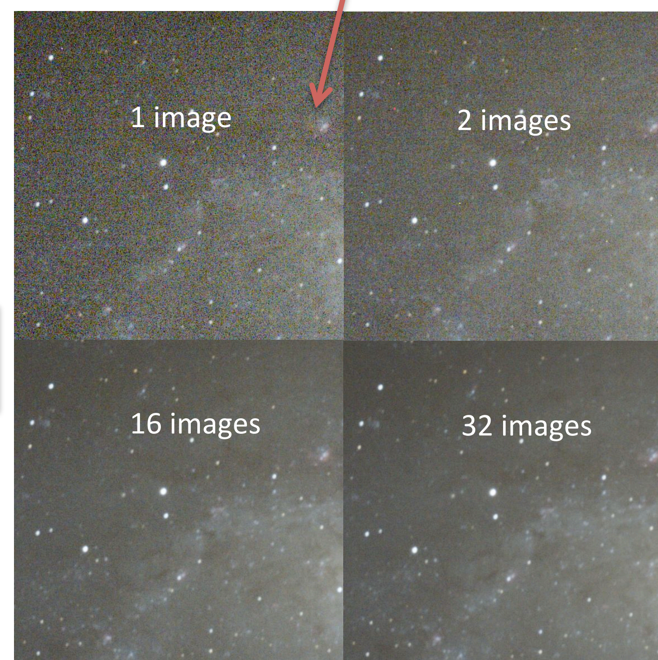


Create **master bias**, **master dark**, **master flat** through median

Calibration correction

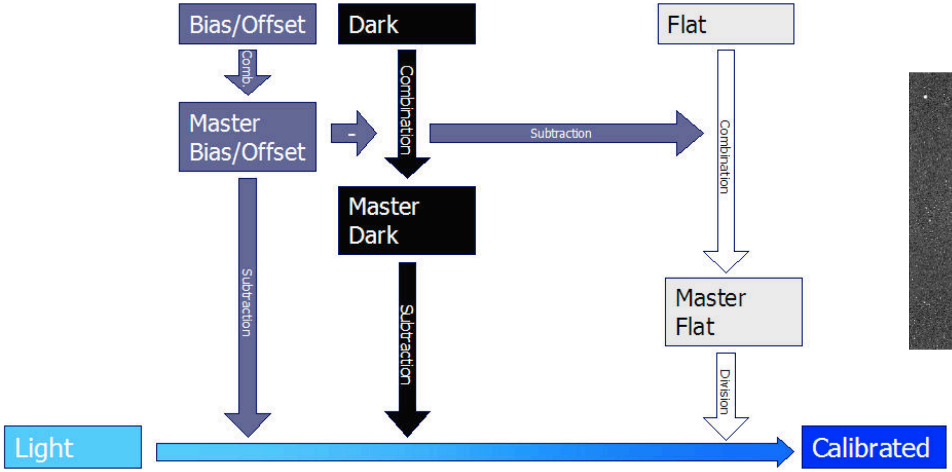
- Get master flat, master dark and master bias
- You may subtract bias from dark (not mandatory)
- Subtract raw science and flat by dark
- Divide raw science by flat
- Dark is very important for IR and long wavelengths. For optical and higher wavelengths you may have only bias correction

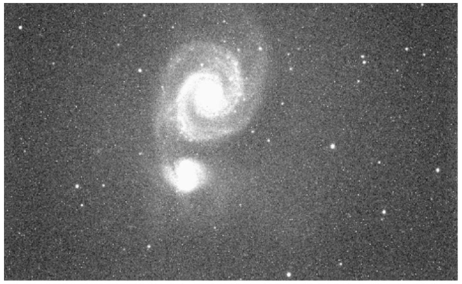
$$Corr = \frac{(Raw - Dark)}{(Flat - Dark)}$$

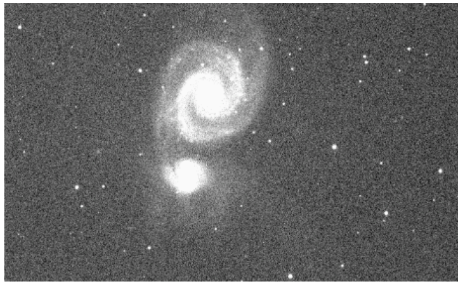
general

$$Corr = \frac{(Raw - Bias)}{(Flat - Bias)}$$

optical

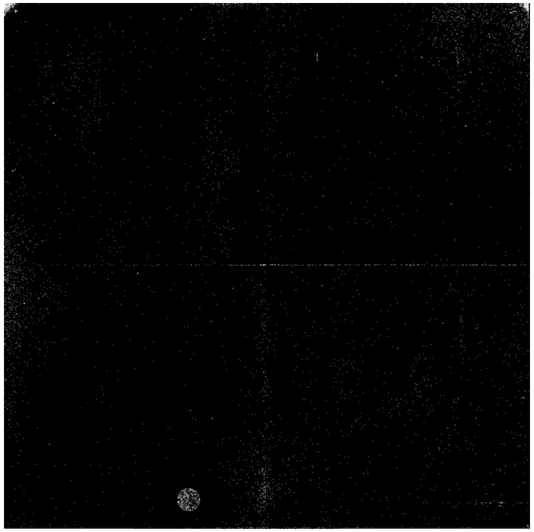


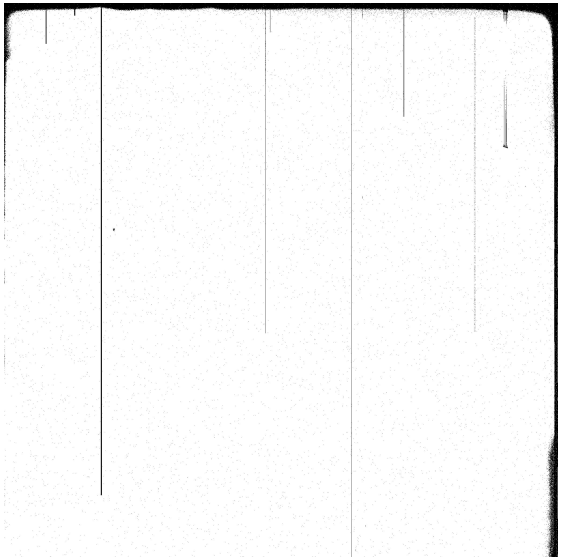




Bad pixel mask

- Some pixels are flawed and should be masked: flat-fields/ darks help to show them
- Bad pixels: hot pixels (darks), dead pixels (flats)
- Bad columns: columns of bad pixels
- Image stacking also helps remove bad pixels





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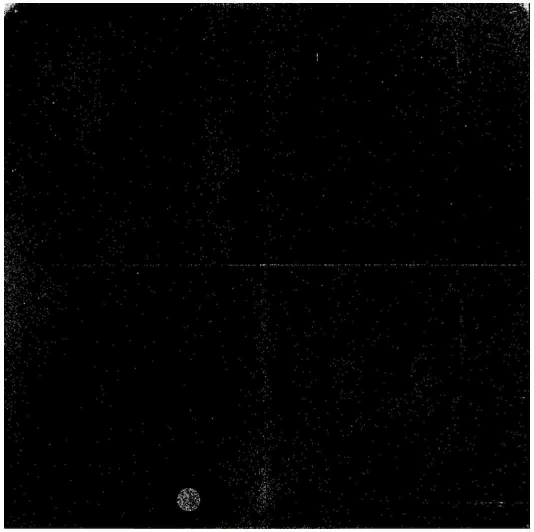
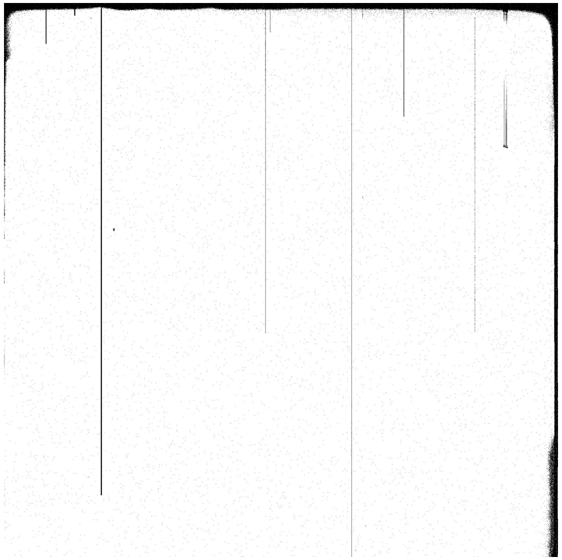
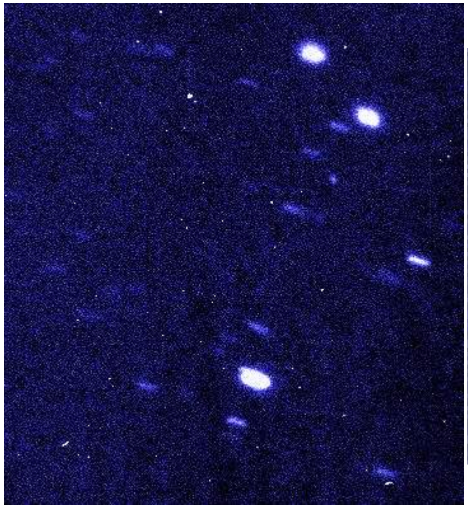




Cosmic rays



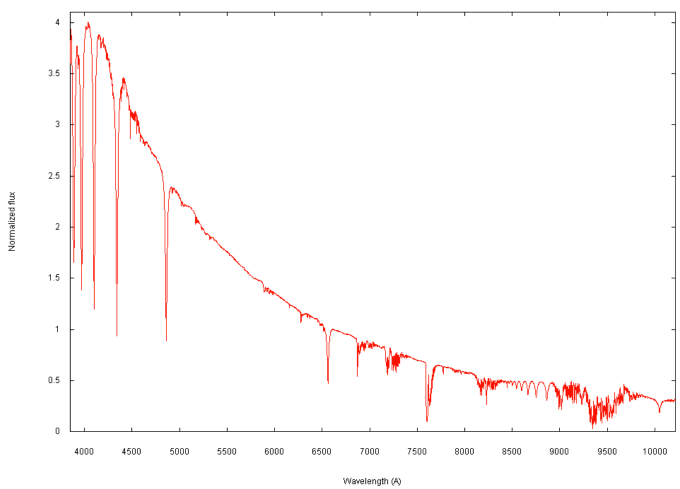
- Energetic particles from the cosmos that produce secondary particle showers on Earth's atmosphere.
- On CCDs, they liberate many electrons in just few pixels: they look very sharp
- Longer exposures have more of them!
    - Algorithms to remove them
    - Image stack help remove them
    - For short exposures and small fields of view, inspect images to decide if cleaning

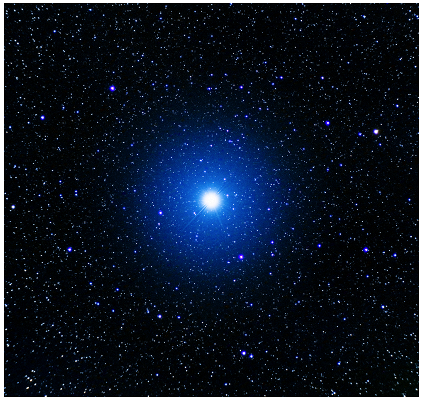
Standard stars

- **Photometric** standard stars: They have the brightness in several filters very well measured

Not all instrumental setups have same response. By comparing measured flux with standard stars, one can calibrate to obtain universal magnitudes.

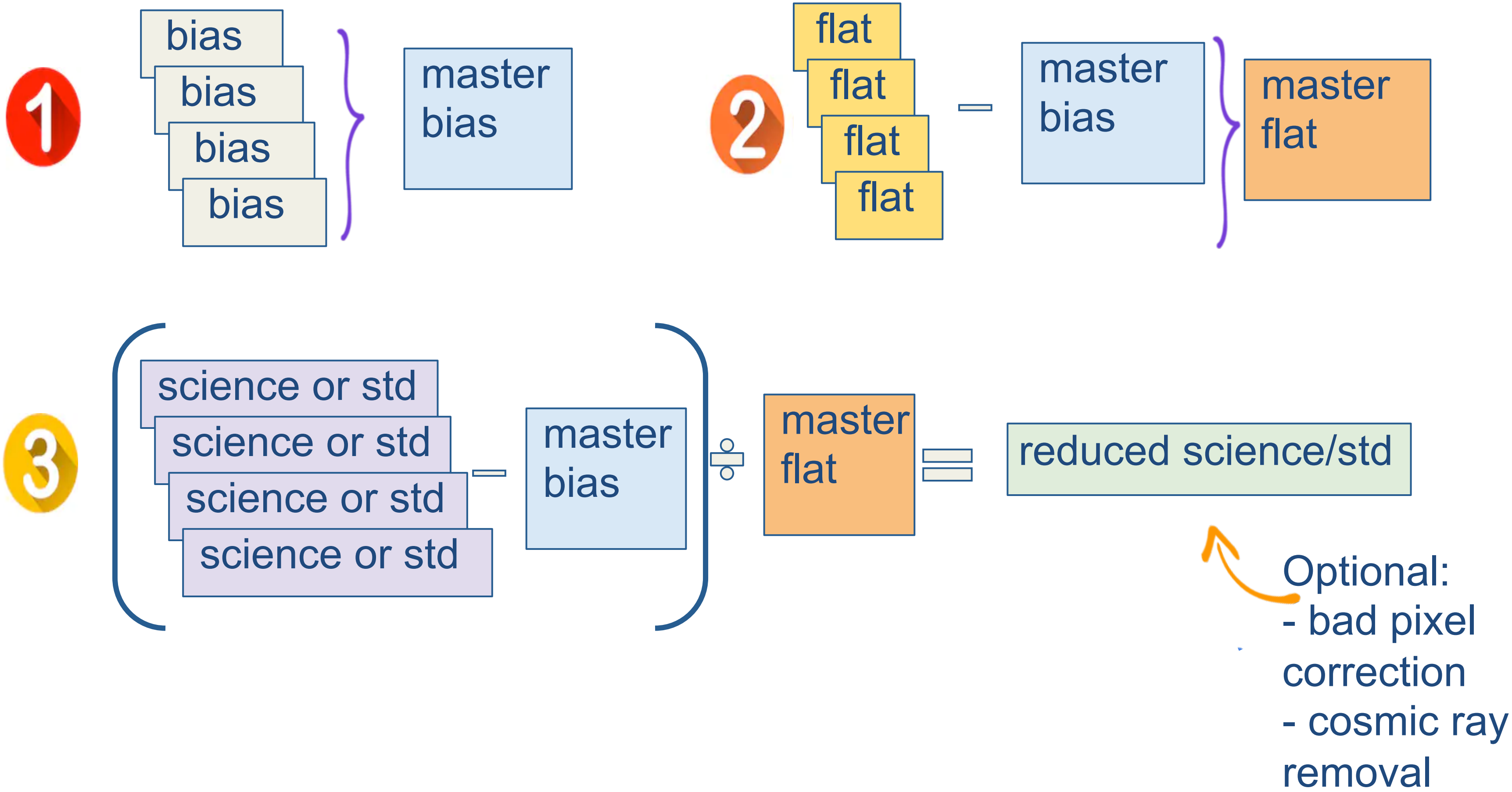
- **Spectrophotometric** standard stars: They have well-observed spectrum to calibrate with
- Example: Vega





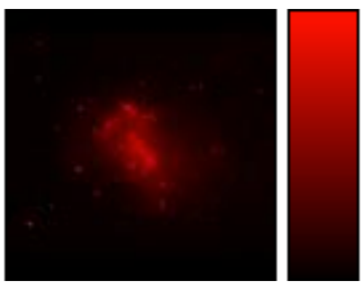
Same reductions are needed for STD stars

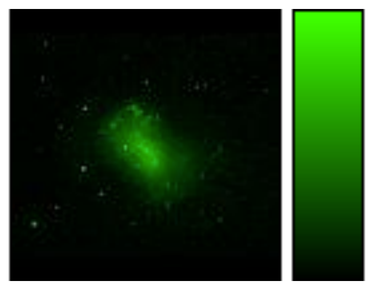
Data reduction - summary

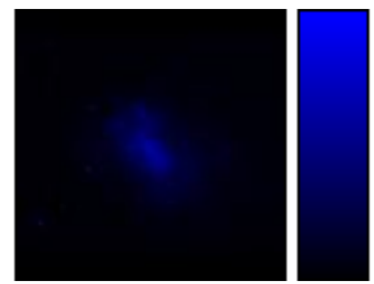


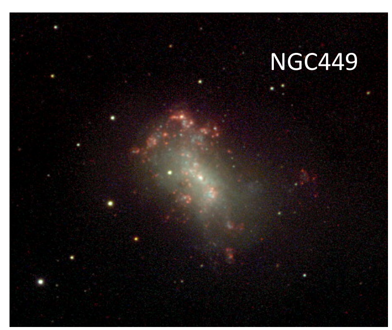
Color composite images

RGB color: additive mixing of three primary colors (eyes, computer): red, green and blue









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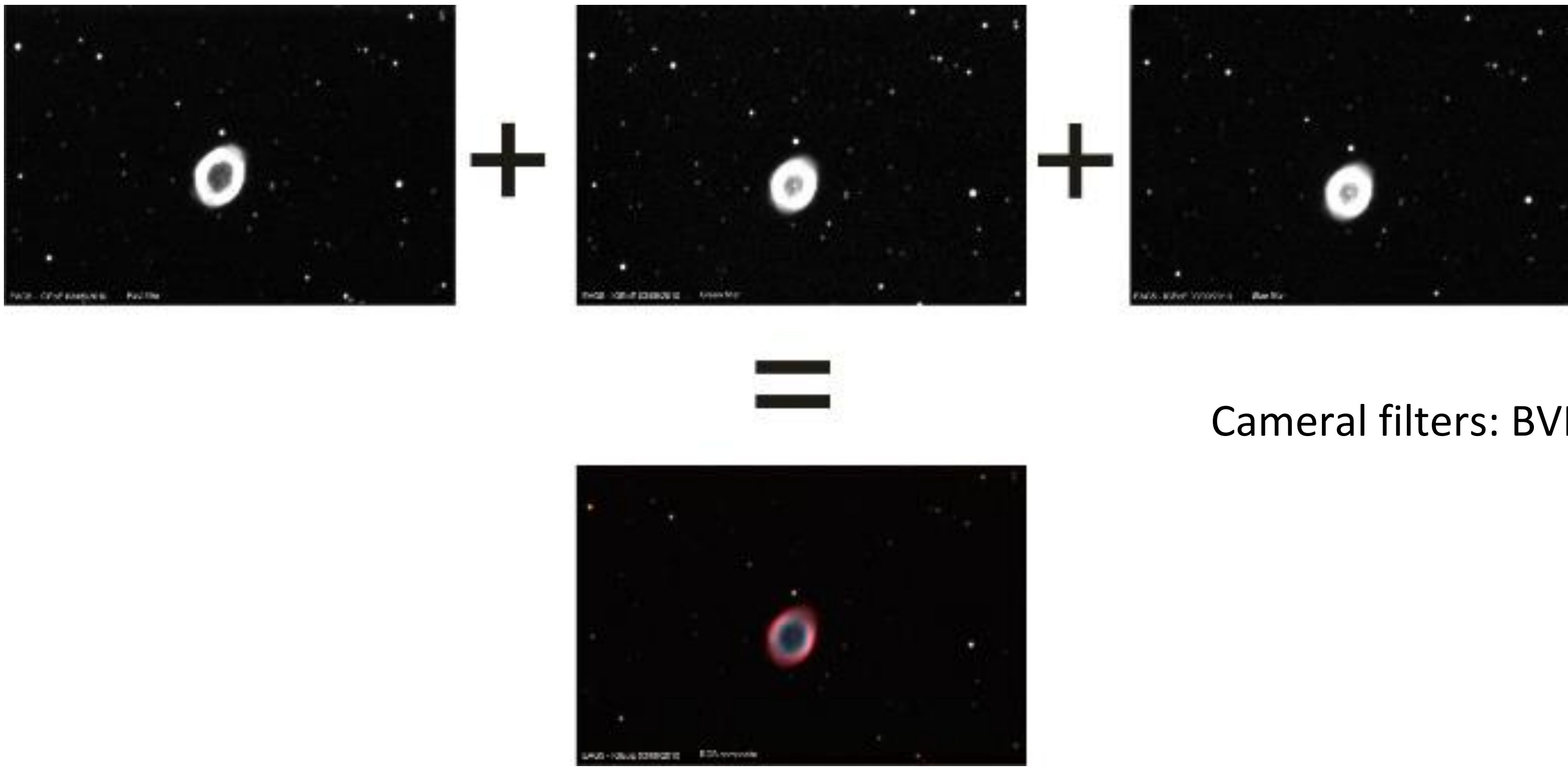

Cameral filters: BVR

M57, CIGeoE, Nuno Santos, Univ Évora e 5EAG

Data format: Basic tools

Image files & ds9

- Astronomy image file format is a FITS file: Flexible Image Transport System data file
- It can be viewed with: ds9, GIMP, Photoshop, SIPS…
- It can be processed with: C++, Fortran, Python, IDL, Java, Julia, Mathematica…

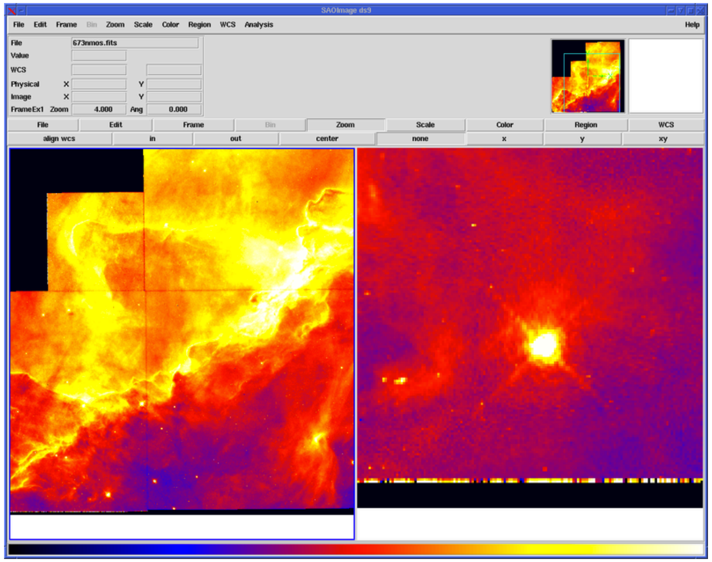

Image files & ds9

Many features and possibilities:

- Change contrast and colors
- Obtain counts and histograms
- Estimate the seeing (FWHM)
- Create images & color composites
- Load catalogs

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Hands-on!

Now play around with FORS2 files here:
https://archive.eso.org/eso/eso_archive_main.html