An overview of the data reduction process

why is it important to obtain reduction frames?

Every kind of measurement is usually affected by a number of unwanted factors. In astronomical photometry these are related to either the instrument or the sky conditions. Here we discuss about the most important instrument factors that can affect our observations. The process of correcting our observations (Science Frames) for these factors is known as the reduction process.

The reduction process requires three types of reduction frames known as the Bias, the Dark and the Flat Frames. It is important to obtain more than one frame from each type in order to minimise the effect of uncertainties (noise) during the reduction process.

Bias Frames

Bias Frames are frames with zero exposure time (practically), taken with the camera covered to avoid any external illumination. Covering the camera is just for safety, as any external source practically will not affect a frame with zero exposure time.

Bias Frames are used to remove the bias signal – i.e. signal produced by the electronics of the camera during the read-out process. The bias signal is present and constant in all frames, regardless of the exposure time.

Dark Frames

Dark Frames are frames of the same exposure time as the Science Frames (or longer), taken with the camera covered to avoid any illumination. Here, covering the camera is extremely important due to the non-zero exposure time.

Dark Frames are used to remove the dark signal – i.e. signal produced by the pixels themselves. As from every material at a temperature above absolute zero (-273_{o}C), electrons are freed from the silicon of the CCD, escaping from the valence band. The dark signal is present in all frames with a non-zero exposure time, and it is linear with exposure time.

Flat frames

Flat Frames are frames of non-zero exposure time (typically of a few seconds) capturing a uniformly illuminated area. This area could be an illuminated panel or wall, or the sky during twilight (sky flats). It is important to keep the signal in the Flat Frames high (about 2/3s of the full pixel capacity) to achieve more precise results. In the case of sky flats, it is important to capture the sky while it is still bright, to void capturing stars, too.

Flat Frames are used to correct the flat field – i.e. non-uniformities in the illumination of the CCD, caused by the geometry of the telescope and by dust on the optical elements or on the CCD itself. The flat field is present in all frames with a non-zero exposure time that capture external light sources, regardless of the exposure time.

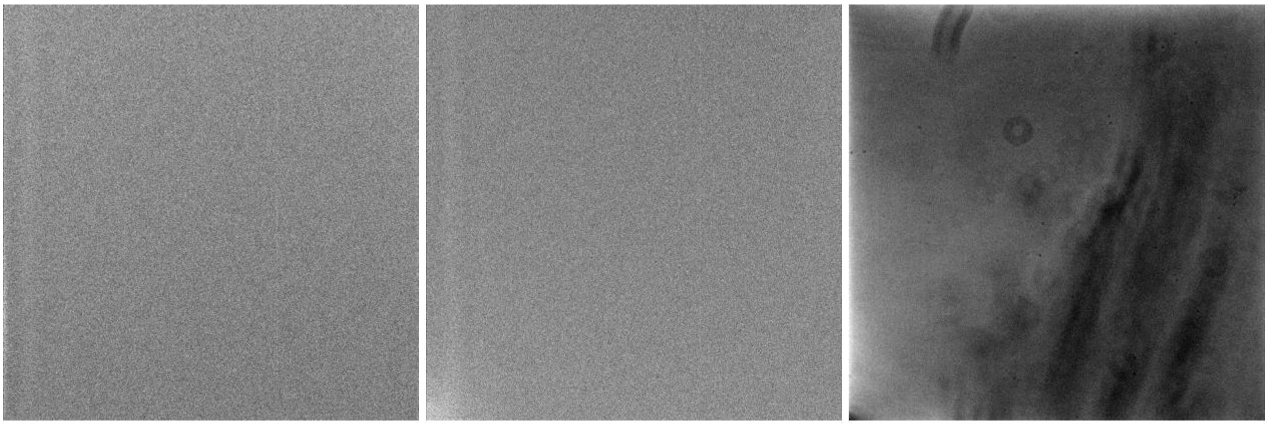

Figure 1. Examples of Bias, Dark and Flat Frames (from left to right).

Processing

There are a few steps involved in the reduction process:

1. The Master Bias is calculated as the median of all the bias frames.

2. The Dark Frames contain the bias signal, so the Master Bias is subtracted from every Dark Frame.

3. The Master Dark is calculated as the median of all the corrected Dark Frames, divided by the exposure time of the Dark Frames (effectively giving the dark signal per second).

4. The Flat Frames contain bias signal, too, so the Master Bias is subtracted from every Flat Frame.

5. The Flat Frames contain also dark signal, so a scaled version of the Master Dark (Master Dark × exposure time of the Flat Frame) is subtracted from every Flat Frame.

6. The Master Flat is calculated as the median of all the corrected Flat Frames, and divided by its median.

7. The Science Frames contain the bias signal, so the Master Bias is subtracted from every Science Frame.

8. The Science Frames contain also dark signal, so a scaled version of the Master Dark (Master Dark × exposure time of the Science Frame) is subtracted from every Science Frame.

9. The Science Frames are also distorted by the flat field, so every Science Frame is divided by the corrected Flat Field.

Note: the median is preferred over the mean, because it is less sensitive to extreme values (outliers) that may appear in one of the reduction frames.

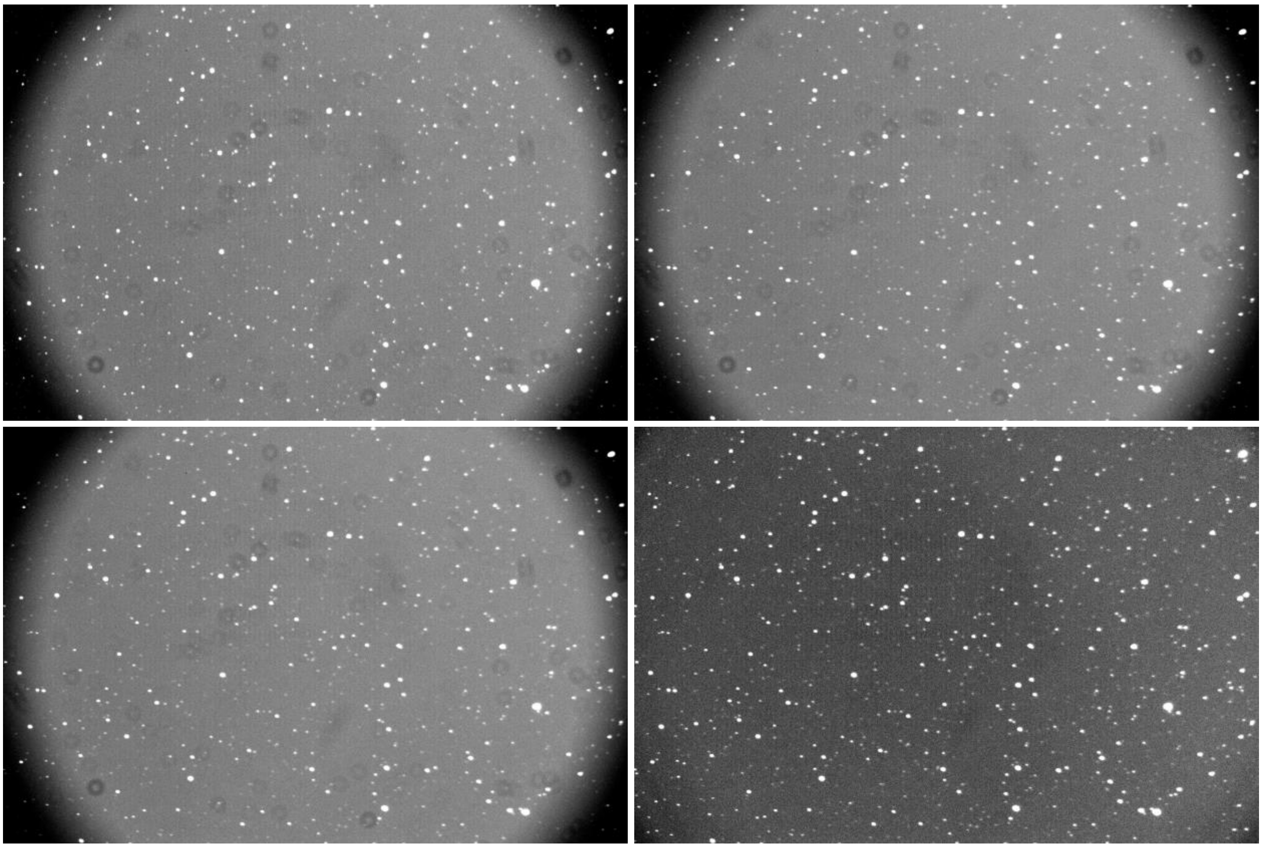

Figure 2. Different stages of the reduction process. Top-left: A raw Science Frame. Top-right: The same frame corrected for bias (after step 7). Bottom-left: The same frame corrected for bias and dark (after step 8). Bottom-left: The same frame corrected for bias, dark and flat (after step 9 – final product).

What to avoid while obtaining reduction frames?

As we can see from the above, the reduction frames require a very specific treatment to be implemented correctly. For this reason, we need to be careful and avoid common mistakes when obtaining or using them.

General:

- We should not obtain reduction frames at different temperatures. In this case, the reduction process will not remove the correct dark signal from the Flat Frames and the Science frames.

- We should not process a dataset without Bias Frames. In this case the Dark Frames will not be free of the bias signal and this signal will be scaled with exposure time (while it should not), leading to a wrong correction of the Flat Frames and of the Science frames.

Dark Frames:

- We should not uncover the camera when obtaining the Dark Frames. In this case, external illumination can affect them, leading to a wrong correction of the Flat Frames and of the Science frames.

Flat Frames:

- We should not obtain sky flat of long exposure. In this case, stars will become detectable in the Flat Frames, causing anomalies in the final reduced Science Frames.

- We should not obtain Flat Frames of low signal. In this case, the non-uniformities are not recorded with high enough precision.

How many reduction frames?

As mentioned earlier, it is important to obtain more than one reduction frame of each kind. This is to reduce the effect of the camera's readout noise on the reduction process. By obtaining two, five, ten or twenty reduction frames of each kind, the readout noise is reduced by approximately 30%, 50%, 65% or 75%, respectively. This means that five is a reasonable number, but if the camera used has a very high readout noise, we should obtain a higher number of frames, to minimise the effect.

In summary

	Dos	**Don'ts**
Bias Frames	• Cover the camera / telescope	• Don't forget them!
Dark Frames	• Cover the camera / telescope	• Don't use an exposure time shorter that the Science Frames
Flat Frames	• Aim to a uniformly illuminated area. • Aim to the 2/3s of the full pixel depth	• Don't observe stars (for sky flats) • Don't change filter
Overall	• Set the same temperature and binning as for the Science Frames • Obtain at least five reduction frames of each kind	• Don't obtaining the reduction frames under different conditions (e.g. during day time)

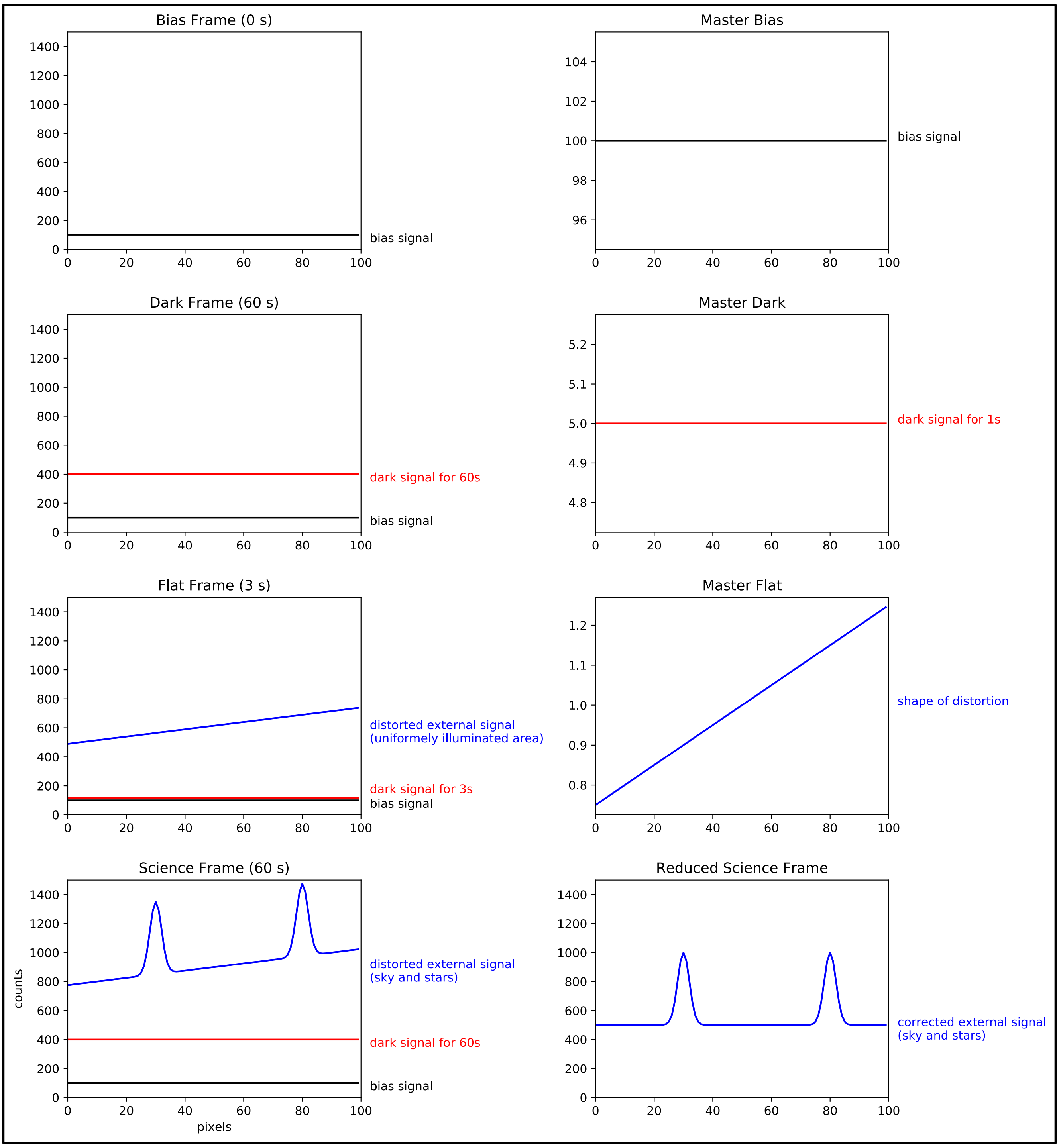

Figure 3. Schematic overview of the data reduction process. All plots show the profile of one line of a CCD (counts vs pixel number). Left: Raw Reduction and Science frames. Right: Processed Reduction and Science frames.