

1 The Preliminary Processing

Frames must be corrected for a bias level and quantum efficiency variations on all scales. For a minority of CCDs and most near-IR detectors, there is also a “dark current” that needs to be corrected for.

The corrections fall into two categories, those effects that are additive and those that are multiplicative. The bias level and any bias structure, dark current, and “charge skimming” are all examples of additive – for each of these there is a fixed number of counts added (subtracted for the charge skimming problem) to pixels (independent of the exposure time for the bias level/structure and exposure time-dependent for the dark current) independent of the number of counts in the sky or sources. The quantum efficiency variations on all spatial scales are multiplicative – one pixel will differ from another at a fixed ratio.

1.1 FITS files

Essentially all observatories record images to disk in FITS format – Flexible Image Transport System. Usually the files are written to an exabyte (8mm) tape and brought back, in many cases the networks are fast enough that you can also ftp or remote copy to transfer the files from observatory disks to home disks.

1.2 Bias correction

The bias refers to the count level that exists on a frame that is only read out through the amplifiers (obtained by taking a very short or 0-second exposure without opening the shutter). Typical mean-bias levels are between a few hundred and a thousand counts. There are sometimes gradients in the bias level with row or column number (or both). There is sometimes also additional structure in the bias frames. For each amplifier through which charge is read out, there is an “overscan” region – 20 to 50 columns worth of virtual pixels that were read out through the amplifiers but not attached to and real pixels in the CCD. This overscan region is used to find the mean bias level in the column directions (but doesn’t tell you anything about a gradient along rows).

The bias level and structure are usually removed via a two-step procedure. First, the mean level and any gradient along columns can be determined and subtracted using an IRAF task called **colbias**, usually called as part of the **ccdproc** package. You need to first identify the overscan region (or regions if more than one amplifier has been read out) and specify this in the **colbias** task. You can do this by inspection of a flat-field or image with a non-zero sky level. In IRAF, **imexamine** or **implot** can be used to plot the column values along a row or rows. This will look something like Figure 5. This frame was read out of two amplifiers and you can see the two sky levels with the change at around column 512. On the far right are the two overscan regions (one per amplifier) with slightly different bias levels. Figure 6 shows the right side of the chip expanded so

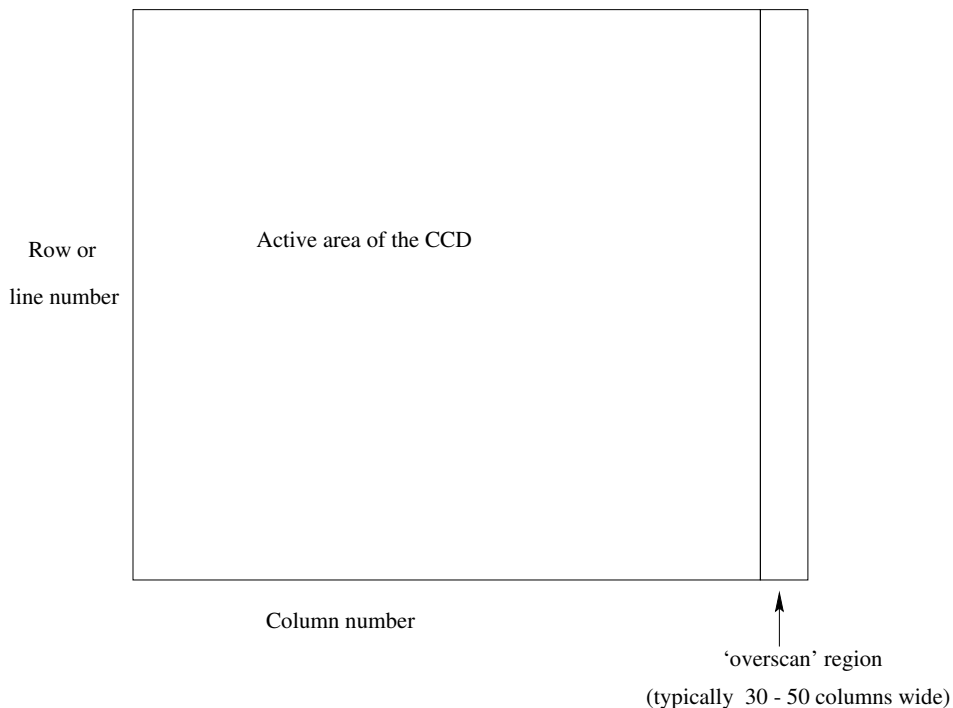


Figure 1: Schematic of a CCD plus overscan region

the two bias levels are more clearly seen.

For each row **colbias** averages the overscan columns that you specified (to beat down the Poisson noise) and then fits a function of your choice along the averaged column. If the CCD was set up properly, a low-order function should fit the averaged overscan. **Colbias** then subtracts the value of the fitted function at each row. When this is done, you have corrected the frame for an approximate mean bias level and any gradient in the “y” direction (along columns).

With some CCDs (mostly older ones) there was also a bias pattern of one kind or another. This was usually corrected by taking a large number of “bias” frames (0 second exposures), averaging them and then overscan subtracting the averaged bias frame. The result is called a “zero” frame and if there is no bias structure aside from the y-direction gradient corrected in *colbias*, the zero frame will have a mean of zero and no residual structure. If there is some structure in the zero frame, then you subtract this frame from all your other calibration and program frames.

1.3 Flat-fielding

All CCDs show quantum efficiency variations on all scales. Pixel-to-pixel variations are usually small (less than a few percent), but the large-scale variations can be larger. Any bits and pieces of stuff near the focal plane (dust on the dewar window or filter) create what are effectively low-QE regions on the CCD. The point of flat-fielding is to correct

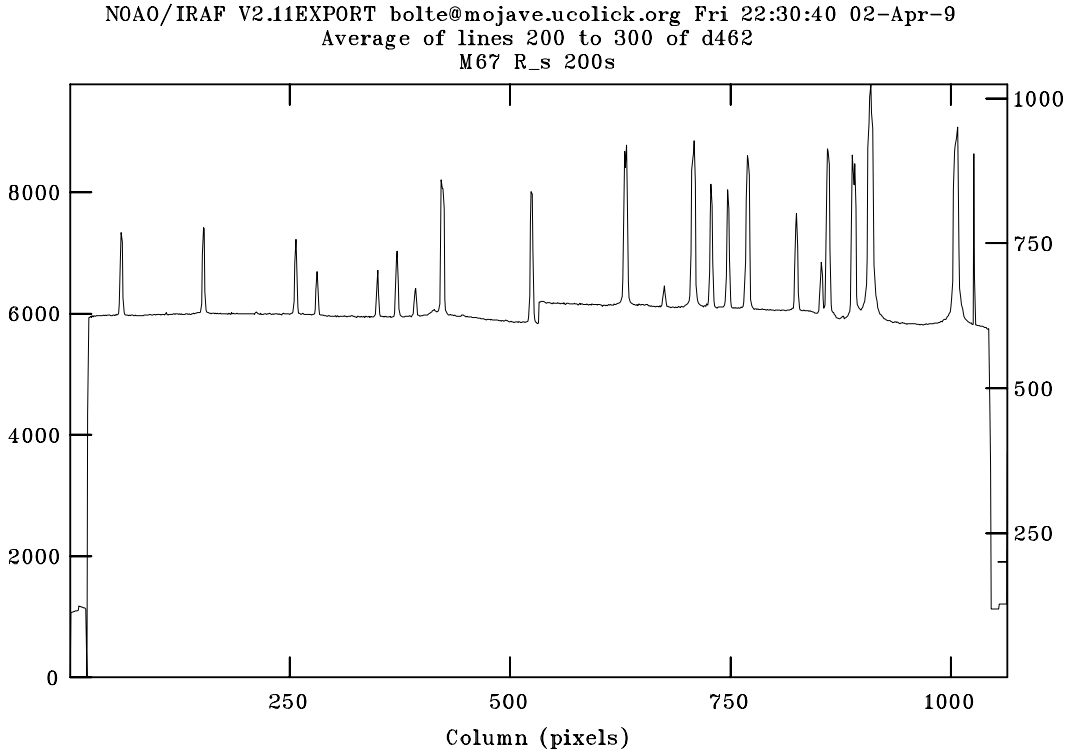


Figure 2: A plot of the average of 100 lines (rows) along columns. This CCD was read out of two amplifiers.

these variation. A good rule of thumb is to shoot for flat-fields with a total of a few times 10^5 counts. The Poisson noise for 10^6 counts per pixel is \sqrt{N} so you can hope to make the pixel-to-pixel corrections to one part in 10^3 or 0.1%.

1.3.1 F-F for direct imaging

For flat-fielding you need a uniform background of light that matches the color of the dark background sky and illuminates the CCD in the same way as the background sky.

There are three possibilities:

1. Dome flats. Most domes have a big white screen somewhere and a set of quartz lamps that illuminate the screens. The lamps are usually redder than the night sky and have a significant IR component. Sometimes they are filtered to make them bluer. The advantage of dome flats is that you can take them during the day (with a darkened dome) and build up an arbitrarily large number of counts per pixel. The disadvantage of them is that they usually do a lousy job at correcting the low-spatial-frequency QE variations across the chip. This is attributed to a poor color-match with the sky, red leaks in the filters, and/or the fact that the

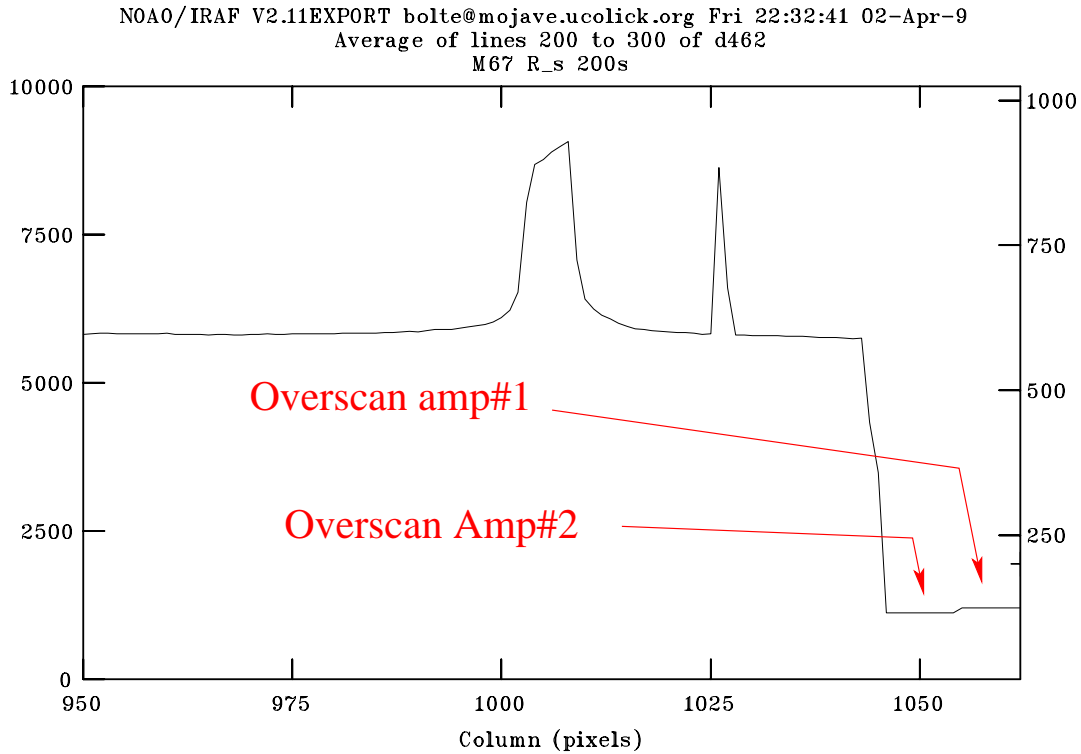


Figure 3: A blowup of the overscan regions of the previous plot.

screen is not at infinity and the illumination of the focal plane of the camera is different with the screen than it is with the sky.

2. Twilight Flats. Between sunset and astronomical twilight and then again between astronomical twilight and sunrise you have a little time to point the telescope at a pretty blank part of the sky and take images. You will be illuminating the CCD in the same manner as the dark sky, and the spectrum of the twilight sky – a G5V star – is not that different than the dark sky of zodiacal light and background galaxies. The twilight sky is polarized but I’ve never seen any effects of this when using twilight flats to flatten images.

Of course the twilight sky is not uniform. There is a gradient from the part of the sky where the sun has set or is about to rise to the opposite side of the sky. For small CCD fields of view, you will never see any evidence of this gradient, but as the big arrays come on line, it will require that you be aware of it. There is an article with some measurements of the size of the gradient as a function of this and that:

Chromey & Hasselbacher, 1996, PASP, 108, 944.

Even for small fields, there are the non-uniformities caused by stars and galaxies. To eliminate these the usual procedure is to move the telescope between each

exposure so that the stars and galaxies are in a different place on each exposure. When combining the twilights, scale the individual frames to a common mode value and use one of the **imcombine** options that clip out high pixel values in the unregistered stack of frames. My favorite is the “minmax” rejection option. For example if I have 10 twilight flats in a particular filter, I will combine them rejecting the highest 6 values in each pixel and the lowest one, averaging the remaining 3 (9th, 8th and 7th ranked values). This effectively eliminates the pixels that are above the true background value. Before doing the rejection, it is necessary to scale the images to a common mode. This is an option in **imcombine**. You also want to make sure that you have *FIRST* subtracted out the bias levels of the flats so the scaling is correct. For twilights that are severely contaminated with sources, it is possible to first go through the individual frames and replace or mask pixel values that are higher than some threshold above sky (**imreplace**).

3. Dark Sky Flats. These are the “super flats” that some people talk about. The idea is that if you have a number of targets in a particular filter during the course of a night or run you can make an unregistered combination of the frames using rejection criteria designed to eliminate higher-than-sky pixels in the stack. Dark-sky flats match the color of the background very well and illuminate the CCD in exactly the same way as the background. As is the case for twilights, in some cases it might be necessary to pre-eliminate pixels with large positive excursions about the mode level for the frames.
4. A trick. Often for a run you have dome flats with an accumulated number of electrons in the millions, but a poor match in illumination and color to the dark sky. You also have a limited number of twilight flats or dark-sky images that can be combined to make a dark-sky flat, but the total counts per pixel in either set of flats is not very high. A fairly standard procedure is to “median-smooth” dome and twilight or dark-sky flat. A median smoothing replaces each pixel with the median of the pixel values in a box of a given size on a side. The result is an image that has been smoothed on the scale of the smoothing box size.

A procedure for taking advantage of the facts that the large-scale flat-field variation of the dark-sky flat match that of the program frames and the dome flats have very high S/N in each pixel goes as follows:

- (a) Median smooth the combined, dark-sky flat — this improves the S/N and preserves the large-scale features of the flat.
- (b) Median smooth the combined dome flats using the same filter size as was used for the dark-sky flat.
- (c) Divide the combined dome flat by it’s median smoothed-version. The result is a frame that is flat on large scales but contains all the high spatial frequency flat-field information.

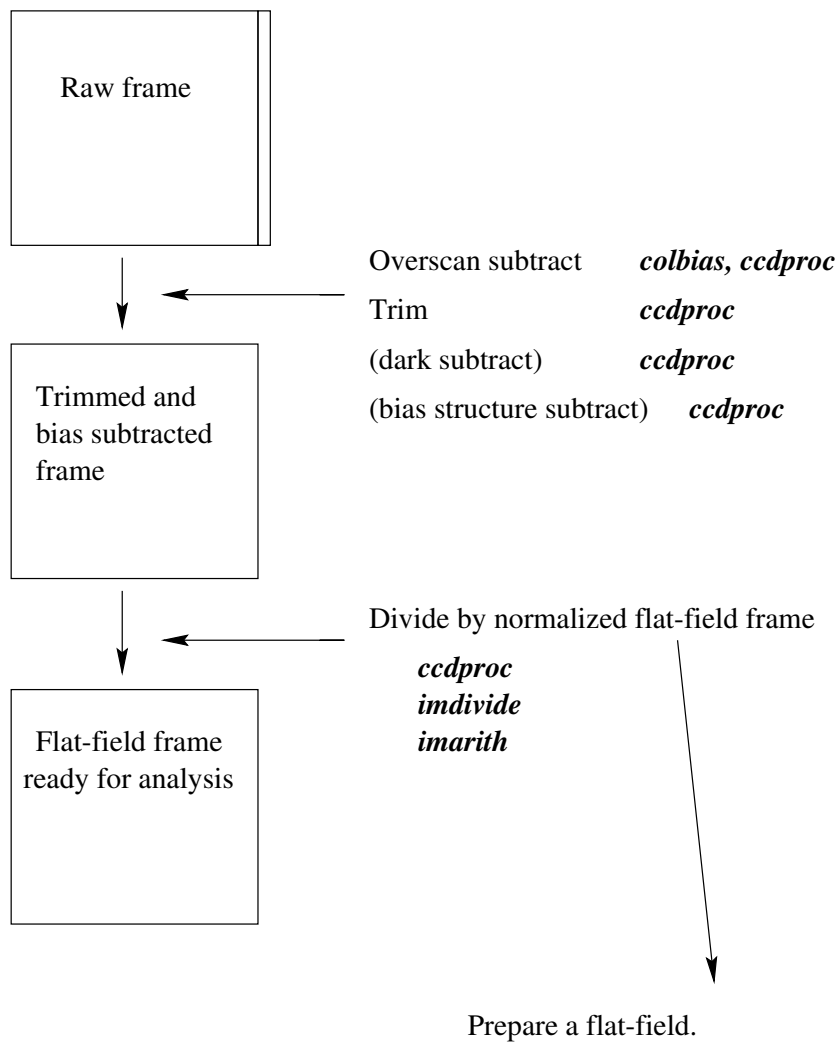
- (d) Now multiply the smoothed dark-sky frame and the result of the division in the previous step. You now have a flat-field with the low spatial frequency properties of the dark-sky flat combined with the high S/N, high spatial frequency properties of the dome flat.

1.4 Checking your master flat field

You have to be a little careful when inspecting any image with the image display tools. Autoscaling of the lookup table for grey-scale display can sometimes hide lots of problems near the level of the sky. To test one flat-field frame against another, divide them, then set your display so your full grey-scale range is +/- 5% of the sky in the divided frame. This will show up any low-level, low-spatial frequency problems very effectively. With the **display** command in IRAF, you can turn off auto-scaling and by using “zs- zr-” then set the two extremes of the lookup table with “z1=0.95 z2=1.05” (or whatever the appropriate values for your image might be). “z1” is the intensity that gets assigned white, “z2” is the intensity that gets assigned black and the values in between get assigned various levels of grey.

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display imagename zs- zr- z1=200 z2=2000
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However, to quantify the levels to which your flattening is working, use **implot** or **imexam** to plot the sky levels as a function of line or column or through the apparent problem areas. For most direct data, it is possible to remove gradients in the background (assuming it is truly flat) to better than 0.5% across the CCD.



- (1) *imcombine* darksky and twilight flats scaling by the mode for each frame and using some sort of pixel rejection to remove stars, galaxies and cosmic rays (minmax with the highest 80% rejected is very effective).

Note: check for shutter vignetting (short exposure/long exposure), non-linearity (high-background/low-background), and telescope position effects in the frames you are combining into a master flat-field

- (2) Determine master flat mean (*imstat*) and normalize (*imarith*)

Figure 4: A summary flowchart of the pre-processing procedure with relevant IRAF tasks shown