Creating a Flatfield Calibration Image

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Introduction

The flat-field calibration image is necessary to correct for the varying efficiency of the individual pixels. It should be constructed from **exposures taken of a maximually uniform object** (e.g. an illuminated screen or the daytime sky). The differences between pixels are then not due to intrisic structure of the observed object, but only due to the different detection efficiencies. Dividing the raw image by the flat-field image corrects for the individual pixel efficiencies: e.g. a pixel with only 0.80 of the normal signal can be brought up to the standard level by dividing the intensity by 1/0.80.

Since the flat-field correction is only intended to adjust the relative sensitivities of the pixels, it's best to normalize the flat-field image somehow to unity so that the pixels in any image corrected by the flat-field don't get changed dramatically in level. Depending upon how "flat" the flat-field is made, one can simply divide the flat-field correction image by the maximum typical value.

What observations and preparations does one need?

The type of flatfield observations depends upon the local possibilities, but here are typical methods in the order of increasing quality:

- **"Dome-flats"**
  are made by pointing the telescope at an illuminated screen. While this is simple, can be done even then the enclosure is closed, and produces images with high intensity levels, it is very difficult to get an illumination which comes even close to that seen by the telescope on the sky - the image of the screen is totally out-of-focus.

- **"Cloud-flats"**
  are similar to dome-flats, but clouds illuminated by the Moon or by city lights are used. While somewhat better than dome-flats (the screen is much farther away), the non-uniform shape and illumination of the clouds may create artificial patterns in the flatfield.

- **"Twilight-flats"**
  are "skyflats" made immediately before or after the night when the sky is dark enough that exposures of at least several seconds are possible (to insure that the camera shutter doesn't introduce it's own faulty pattern) but still bright enough that the illumination is flat and most of the stars are not visible in the images. To get good twilight-flats, remember:
    - minimize the gradients in the images by pointing the telescope in the opposite direction of the setting or rising sun;
    - shift the telescope between exposures so that the few bright stars which are seen anyway occur at random positions in the images;
    - you can simply simply turn off the telescope's tracking in order to insure that different star trails occur in your images, but only as long as the trails are short - otherwise it will take many images to remove the effects of the long trails;
    - you must time your observations carefully - the sky changes it's brightness very quickly; and
    - note that the sky is always darker in the red than in the blue.

- **"Night-flats"**
  are skyflats made from the normal observations of fields with few stars. As long as the pattern of stars between different objects is different, the nearly empty sky between the stars is a nearly perfect measure of the cameras performance on the sky. "Nearly" simply means that the sky is never empty: there are always faint stars and zillions of faint galaxies in the images which you may not see in a short exposure.

- **"Empty-field-flats"**
  are night-flats made in the direction of local dark clouds - interstellar gas and dust clouds which block out the light of both

stars and galaxies behind, and so can be nearly perfect empty screens against which the (nearly) uniform glow of the night sky can be measured (a ▸ link to a list of such fields ◂ is available at the end of the chapter). Even here, the telescope needs to be moved between exposures, since none of these fields are entirely empty.

In practice, most observes choose to make twilight-flats as a good compromise between effort and result when there are few or poorly suited night images and night-flats when there are enough suitable night images.

The maximum useable signal depends upon the camera electronics, the performance of the analog-to-digital converter, and the quality of the detector; any signal higher than this can result in strange images that generally are saturated (more light doesn't result in any higher numbers in the images).

Note that a flat-field calibration image is required for every different wavelength (filter) used.

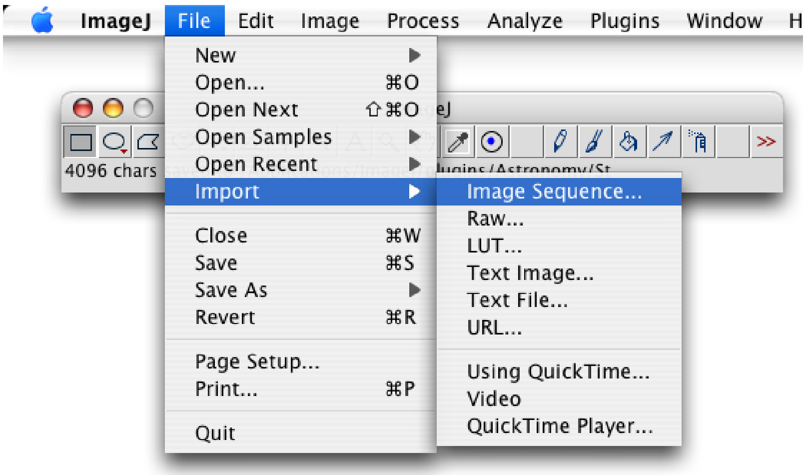
A "set" can consist of one, many, or dozens of images, depending upon how accurately the calibration should be performed. A good rule-of-thumb is that at least 5-10 images should be used so that statistical errors can be minimized by averaging, and more is better. It will be simpler to keep things organized if you keep the flatfield calibration images in their own sub-directory, e.g. in "`flats/`".

Your raw flatfield images are probably not all perfectly exposed and uniform, so you would think this step could be very tricky: if the images are all different, it is not sensible to calculate the median average. Fortunately, there is a simple and effective means to enable us to combine very different flatfield images: we only need to normalize the (bias- and dark-subtracted) flatfield images before combining them. Strictly speaking, we should weight the better-exposed images somewhat more (something automatically done in a simple mean averaging), but if the images are close enough to each other, this is a minor failing.

Creating the Average Flatfield Image

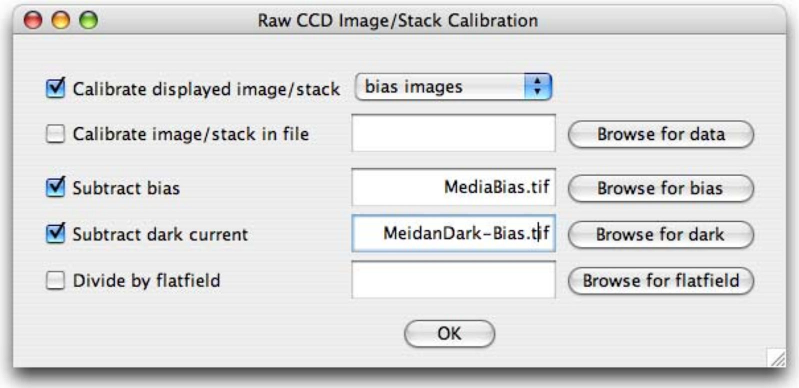
With good raw flatfield images, the process is almost as simple as producing the mean dark-current image:

1. Load the raw flatfield images into a stack using the same menu commands as before: `File > Import > Image Sequence ...`".



2. Subtract the median bias image from the average of the raw flatfield images using the `CCD Calibration` plugin routine (with only the bias-subtraction option selected unless you want to combine this stage with the next one below).

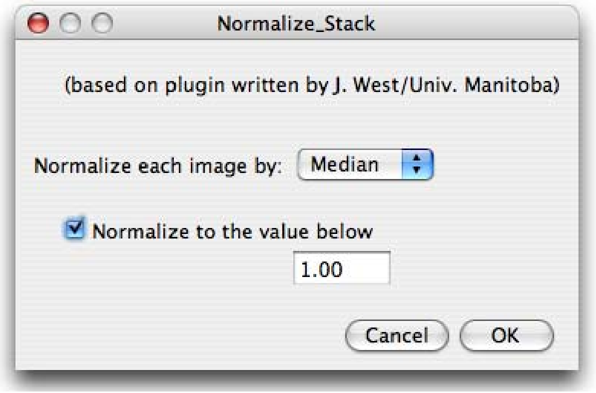
3. Subtract the right amount of dark-current (often not necessary since flatfield images tend to be made with very short exposure times). This can be done at the same time as the previous step.



Raw CCD Image/Stack Calibration

☑ Calibrate displayed image/stack: bias images
☐ Calibrate image/stack in file
☑ Subtract bias: MediaBias.tif
☑ Subtract dark current: MeidanDark-Bias.tif
☐ Divide by flatfield

4. Normalize all of the images in the stack using the `Plugins > Stacks > Normalize Stack` command. Select the `median` option and give a final normalization of unity.



Normalize_Stack

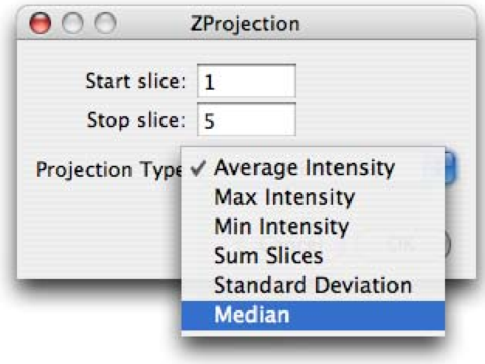
(based on plugin written by J. West/Univ. Manitoba)

Normalize each image by: Median

☑ Normalize to the value below: 1.00

5. Obtain an median flatfield from the stack via the usual `Image >`

`Stacks > Z-Project...` command using the "median" option.



Start slice: 1
Stop slice: 5

Don't forget to save the result in a file for later use (e.g. `AverageFlat-Bias-Dark.tif`).

Flat-fielding can be painful!

The problem with flat-fielding, is that it is very difficult to produce flat-field images which have the same distribution of light contained in the normal images:

- screens can be difficult to illuminated uniformly;
- the exposure times can be so short for bright illumination lamps, that the camera's shutter doesn't do a very good job of uniformly illuminating the detector, leaving strange large-scale patterns in the flat-field images;
- the sky often contains very strong gradients in brightness if the "sky-flat" images are taken in the evening or morning; and
- the optical path through a telescope is very different for photons coming from the ends of the universe and an illuminated screen only a few meters away.

If the flat-field images look very different from the normal images, then correcting the latter with the former will introduce strange patterns which may have nothing to do with the actual sensitivies of the detector: a poorly corrected normal image may be much worse than an image which hasn't been corrected at all!

If the normal images and the flat-field images look very different in their general pattern of illumination, there are three ways to deal with this situation (details of how to do this in ImageJ are in the ▸following section ◂):

1. the best way - throw away the old flat-field images and find a way to improve the new ones, generally tricky, and sometimes expensive or impossible.

2. the easiest way - attempt to create two flat-field images: one for the small-scale pixel-to-pixel variations (obtainable, e.g., by smoothing or filtering the flat-field obtained above to remove any larger hills and valleys in the sensitivity) and one for the large-scale variations (e.g. from a normal image with a strong but featureless background). This procedure is discussed below.

3. the safest way - construct a flat-field image out of the normal images by combining them in large numbers (e.g. if you have lots of images of empty star fields containing lots of smoothly distributed moonlight, one CAN remove the stars and average the rest), always tricky, always time-consuming, and always requires lots of appropriate normal images. This procedure is described in the sub-chapter ▸Creating a Sky-Flatfield Image.

4. the quick-and-dirty way - only correct for the small-scale pixel-to-pixel variations (as above) and ignore the large-scale variations.

One way of getting rid of the unwanted patterns in some particular raw flatfield image is to apply a digital filter which gets rid of the unwanted structures at some pixel scalelength while leaving the wanted structures in place. *ImageJ* offers just such a filter: `Process > FFT > Bandpass Filter ...`. This is a very powerful and flexible filter which can get rid of both very small-scale and large-scale unwanted structures. If we want to get rid of very large structures, so we enter something like "100" for the largest size structure we want to keep and "0" for the smallest (i.e. we want ALL the small structure with sizes smaller than 100 pixels). Conversely, if we want to keep ONLY the large-scale structures and get rid of the small-scale ones up to 100 pixels, we could enter the size of the image as the largest scale and "100" for the smallest. The value of the transition scale - here assumed to be 100 pixels - will depend upon the details of the flatfield problems, of course.

Once a flatfield image for large scales and another for small scales has been produced, one can create the final flatfield by multiplying the two together via `Process > Image Calculator...`.

No matter what filter we use, the result will be similar to the examples below: whereas the input flatfield image may have smooth-looking variations and little obvious fine strucutre, the filtered flatfield image will be really "flat" on long pixel scales and show lots of finer structure, including the "donut" holes produced by dust motes on the glass windows of the camera or filters.

Other Activities:

- *Creating a bias calibration image*
- *Creating a dark calibration image*
- *Creating a flatfield calibration image from sky-flats*

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