Calibrating Raw Images 

Topics:

- What is a digital detector?
- Why does one have to calibrate?
- What observations and preparations does one need?
- Using the `CCD` calibration scripts
- Using the `CCD Calibration` ImageJ plugin
- Removing cosmic ray hits
- Calibration Worksheet

Activities:

- *Creating a bias calibration image*
- *Creating a dark-current calibration image*
- *Creating a flatfield calibration image*
- *Creating a flatfield calibration image from sky-flats*
- *The detailed characterization of a CCD detector*

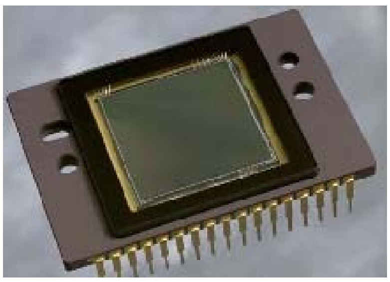
back

What is a digital detector?

All the images of real objects you see on a computer were created by devices that convert the light from the objects into digital numbers which can be displayed and manipulated by a computer. Such devices generally consist of a large number of very small light-sensitive "picture elements" or PIXELS arranged in a two-dimensional grid. The more pixels one has, the more details can be seen in the final picture. The final result is a digital image representing the original pattern and intensity of light that fell on the device.

Concepts

PIXEL


A Kodak KAI-4020 CCD chip

Electronic detectors have all but replaced the photographic emulsions in both professional astronomy and in consumer photography. These devices are special electronic integrated circuits consisting of a large number of very small pixels - typically only 10 or 20 microns in size - that can convert light into an electrical current via the photoelectric effect. Generally, so-called *CMOS* detectors are used in cheaper cameras or webcams and so-called *CCD* detectors are used in more demanding and expensive devices. In either case, the signal generated by the detected photons is converted from very small electrical currents to numbers in digital form using *analog-to-digital converters*.

Why does one have to calibrate?

A perfect detector would record every photon and would not have any "cosmetic" problems that would modify or mask the true signal. Unfortunately, all detectors are not perfect:

- **There are signals not produced by light**

  Detectors often show signals which show up even when there is no light falling on the detector at all and that are the same no matter how long one exposes: the so-called BIAS signal.

- **There are signals produced by the heat of the detector**

  Detectors show signals which grow the longer one exposes, but are present even when no light is present. This signal is due to thermal noise in the electronics, the so-called DARK-CURRENT. The amount of thermal noise rises rapidly with increasing temperature, so ideally the detector should be cooled as much as possible.

- **The sensitivity is not uniform**

  The devices can detect only a fraction of the photons which *could* be detected, are more sensitive to some wavelengths of light than others and are often totally blind to most photons outside their normal range. Every pixel in the detector has its own peculiar efficiency (although the variations from pixel to pixel are generally astoundingly small, of order a few percent for CCD's) and this efficiency is individually different for different wavelengths of light. Fortunately, this behavior is stable and can be corrected for by dividing the raw images by so-called FLAT-FIELD images containing nothing but these effects;

- **There is external noise**

  Detectors are often sensitive to things other than light, e.g. cosmic ray particles which can leave ugly spots and streaks usually called "cosmics".

- **The detectors have limited accuracy**

  All devices have a limited DYNAMIC RANGE: it is impossible for them to record a very small and a very large signal simultaneously, either because they cannot store more than a certain number of events in the pixel electronics or because the *analog-to-digital converters* don't have a large enough range of available numbers: e.g. an 8-bit analog-to-digital

Concepts

BIAS
COSMICS
DARK-CURRENT
DYNAMIC RANGE
FLAT-FIELD
SATURATION

converter in a cheap webcam can only handle numbers between 2^0-1 = 0 and 2^8-1 = 255 and an expensive 16-bit analog-to-digital converter produces numbers between 2^0-1 = 0 and 2^{16}-1 = 65535. Even with a very expensive 24-bit converter, the camera electronics may not be able to handle so many events.

- **There can be too much light**

  If more photons hit the detector than the detector can handle, then lots of things can happen: sometimes the signal spills out and fills up the surrouding pixels but, in any case, the intensity in the image no longer increases with further exposure to light - the pixel is SATURATED. Since one no longer knows how many photons were recorded, the information contained in the pixel is almost lost - one only knows the intensity must have been larger than a certain amount.

In order to obtain a "clean" image, all of these effects need to be corrected for or considered when interpreting what the raw image contains.

- The bias correction is very simple: **you need an image with zero exposure time and no light**. Every raw image then needs to have the averaged bias image subtracted from it.

- The dark-current correction is almost as simple: **take images of a given exposure time but with no light**, i.e. consisting of the *time-independent* bias contribution (which can be removed using the previous measurement) and the *time-dependent* contribution due to thermal noise. Of course, the dark-current calibration image should be taken at the same detector temperature as the normal observation. If the dark-current image has the exact same exposure time as the raw image, one can also use it to subtract the bias as well (since the raw dark-current image also contains a bias signal). Otherwise, one has to first subtract the bias and then scale the dark-current rate to match that of the image to be corrected (e.g. a bias-subtracted dark-current image taken over 10 minutes has to be divided by 20 before being used to correct a 30sec normal images).

- The flat-field calibration image necessary to correct for the varying efficiency of the individual pixels can be constructed from **exposures taken of a maximally uniform object** (e.g. an illuminated screen or the evening 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. Again, the raw flat-field images have to be corrected for bias and dark-current before being used.

Consumer digital cameras perform some but not all of these calibration functions for you. Daytime digital photography usually can depend upon so much light that the dark-current correction is generally not made unless the user can specifically request "long exposures" of a few seconds or more, for which an additional dark-current is made and subtracted. Scientific use generally requires that the images not only look nice, but that the numbers in the pixels can be used to measure the amount of light which originally hit the detector quantitatively, so these corrections are almost always made.

The construction of the calibration images - bias, dark-current, and flatfield - can be difficult in practice, even if not in principle. Those who must create their own calibration images are referred to the additional activities below, where each ImageJ reduction process is described in much detail.

Using the CCD Calibration Scripts

A set of ImageJ scripts is available in the `Plugins > CCD` directory that make the task of creating calibration images very simple. The tasks include

- creating a master bias image from a stack of raw bias images;
- creating a master dark image from a stack of raw dark images and a master bias;
- creating a master flatfield image from a stack of raw sky, twilight, or dome images, a master dark image, and a master bias image.

For experts, there are also scripts for calculating the read-out-noise and gain of the CCD, something needed to perform exact photometry (see the fields for these numbers in the `Set Aperture Photometry` plugin).

All of the scripts assume you have created a stack of raw input images and create master calibration images that you will want to rename and save (e.g. as FITS files) for later use.

How to use the `CCD Calibration` ImageJ plugin

Once all of the calibration images have been collected or created, they can be applied to clean up normal (grayscale) images. The three main calibration stages

1. subtraction of the bias
2. subtraction of the dark-current
3. division by the flatfield

are easily performed using standard ImageJ commands, but we have created a special plugin which can do all of these things in one step and which can keep track of where the calibration images are. It also automatically converts the images from an internal integer 8-bit (numbers between 0-255) or 16-bit representation (0-65535) to a floating-point/real representation where there is little danger of suffering from loss of precision during the arithmetic operations.

Invoke the plugin via the menu item `Plugins > Astronomy > CCD Calibration`. You will see 2 ways of selecting the raw image to be calibrated: select either on of the displayed images/stacks (the top pull-down menu) or the name of the raw image file to be calibrated (the 2nd text field to be filled in by hand or by browsing for the file). Below are three fields which let you select the type of calibration and the location of the calibration images. Each of the text fields can be filled by pressing the "`Browse for ...`" button. The final calibrated image or stack is obtained by pressing the "OK" button. The plugin then automatically converts all raw images to 32 bit format before calibrating, so no details are lost.

Removing Cosmic Ray Hits

Cosmic ray hits are easily distinguished from astronomical sources like stars because they are contained within a few pixels: the images of stars are smeared out slightly by atmospheric turbulence. ImageJ has what it calls a "despeckle" function which attempts to remove well-defined spikes in the images: try "`Process > Noise > Despeckle`".

Calibration Worksheet

Here is a rough plan for performing the calibration observations and creating the calibration images.

Calibration	Observations	Procedure	Input	Script or Plugin
Bias	Sequence of bias images (0 sec exposures, shutter closed)	Obtain median value	Stack	`Create Master Bias Image`
Dark-Current	Sequence of dark-current images (long exposures, shutter closed)	Correct for bias, obtain median value, possibly scale to other exposure times	Stack	`Create Master Dark Image`
Flatfield	Sequence of well-exposed images (>1/2 of maximum exposure, shutter open)	Correct for bias and dark, normalize to same scale, obtain median value	Stack	`Create Master Flatfield Image`
Application			image	`CCD Calibration`

Additional Activities

- *Creating a bias calibration image*
- *Creating a dark-current calibration image*
- *Creating a flatfield calibration image*
- *Creating a flatfield calibration image from sky-flats*
- *The detailed characterization of a CCD detector*
