**Lab 1: An Introduction to IRAF and CCD Preprocessing1**

**Abstract:**

Three images previously obtained at the DAO were subjected to reduction procedures using the most basic IRAF image processsing commands. The final image was obtained by floating-bias corrections, trimming, subtraction of bias, and flat-fielding. A summary of the IRAF steps to produce the final image can be written as the following formula: science image – bias / (flat image -bias).

Using the imstat command, the science image was inspected for the region of overclocked pixels. Using the mean, standard deviation, and number of pixels, a weighted mean was calculated for each of the three images. Using IRAF *imartith* command, new3c217I.fits – m(bar)x \*3c217correct.fits subtracted the floating bias offset level from the science image. The images were then trimmed for regions with overcloaked regions using the *imcopy* command. *Imarith* was again used to subtract the bias frame from the science image. Finally, the science image with the subtracted bias was divided by the flat image to obtain the final image.

**Questions:**

1. **Explain why the reduction procedures for bias, flat field, and data are different, and in particular why the reduction procedure consists of the steps mentioned above for each of these three classes of data.**

Processing the bias frame acts to show what a ‘zero’ gradient for a given CCD looks like; as the CCD is subject to variation in efficiency across each pixel, the bias frame will not be entirely dark, and show the bias noise, inherent to the CCD, and the readout noise, due to the imperfect efficiency of the signal amplifier. By using imarith to subtract the bias frame from the science image, the readout noise present when the aperture is closed is subtracted from the readout noise present in the science image. Due to variation in random noise, multiple bias frames taken throughout the observation can be stacked using *imcombine* and subtracted from the science image. A floating bias frame is mostly temperature dependant, as the electronics heat up. Overreading the CCD addresses the overscanned values compared with the value from the bias tell how the state of the CCD has changed, viz. the changing bias or the floating bias. Subtracting the floating bias removes the 2D pattern from the data image.

Flat fielding processing addresses the uneven distribution of light across the CCD. An image of an evenly illuminated surface, such as a lamp on the telescope dome or the twilight sky, is divided from the science image using *imarith* to equilibrate the illumination levels across the image. A number of flats can be taken and averaged to eliminate variations in noise.

The data image itself also needs correcting for reasons besides the uneven illumination of the CCD and bias noise: this includes removal of ‘bad’ pixels due to dust/optical aberrations, overclocked pixels, and fringing patterns.

The differences in preprocessing exist because they address different sources of noise. Photon, or Poisson noise stems from fluctuations in the number of photons that hit the detector over a unit of time. The S/N ratio can be obtained by taking the number of photons, N, and square rooting it. Stacking frames of the data can help reduce Poisson noise, as more signal is obtained.

Readout noise is inherent to the individual CCD device. Photons hitting the CCD are converted into a current, and the potential difference is converted by the A/D unit and produces counts. The readout amplifier is the source of the readout noise due to its imperfect efficiency in measuring the charge. Bias noise is also inherent to the CCD for the purpose of avoiding negative values. It can be calibrated for by over scanning (overclocked reads) and bias frames. Other sources of noise include thermal noise, cosmic rays, and dark current. Thermal fluctuations can mostly be minimized by cooling the CCD and subtracting dark frames, while cosmic rays usually affect an array of pixels that can be removed via pixel rejection algorithms.

1. **Why is it useful (although not essential) to “renormalize‘” the data frame after dividing by the flat field?**

Renormalizing the data frame preserves the mean value from the data frame after flat field division. Flat frames will have a large number of counts, especially if compared to a faint data image. Dividing by the flat may result in a very poorly defined data image. In this lab, we renormalized the data image after dividing it by the flat by multiplying the image by the mean of the flat (obtained using *imstat*).

1. **Suppose you had been given a raw dark frame as well. How would you reduce this frame? How would it then be applied to the reductions of other data frames?**

In order to improve the S/N ratio, dark frame correction can be used to reduce the noise in the data. Dark frames also account for dark current. Dark current is the residual electric current present in a lot of photosensors when no photons are entering the aperture 2.Bias and readout noise will be present in the dark frame and requires reduction, which can be done by subtracting the bias frame using *imarith*. The raw dark frame can then be subtracted from the flat image and the data image, averaging out any hot pixels that appear on both images.

1. **Two additional steps in preprocessing are “cosmetic” fixups: removal of bad rows and columns, and elimination of cosmic ray spikes. Explain from an algorithmic viewpoint how one might go about correcting these problems in the data.**

In the case of cosmic rays, IRAF has a package in which the task *cosmicrays* can be run to use a selective, statistically-based criterion to correct for cosmic rays. By identifying pixels affected by cosmic rays, the task replaces the pixel with the mean value of four pixels in the same proximity. A more manual approach would be to use *imcombine*, *minmax*, *ccdclip*, *crreject*. Minmax rejects low and high pixel values based on their *nlow* and *nhigh* parameters, meaning pixels with the highest and lowest values will be rejected, although this method is best used with multiple stacked images. Another method is to use the ccdclip algorithm, which utilizes the readout noise and gain to find values with high deviation (=*imstat*). This uses lsigma and hsigma to determine the which pixels to reject. Another method for correcting bad pixels is *sigclip* and *avsigclip*. These algorithms determine the median of each pixel and the standard deviation, and pixels values whose mean exceeds lsigma or hsigma \* standard deviation are rejected. This process repeats until there are no more deviant pixels. 3

Bad rows and columns can easily be fixed using the fixpix task, which uses interpolation across a specified region, and overwrites it. A method described by S.Andreon suggested removing columns of bad pixels by computing the median of the bad column, which is stored in the median’s row, erasing the low frequency from the median’s row, and applying the correction to the entire frame 4.

1. **It is of course desirable that the preprocessing does not degrade the noise of the original raw data frame - i.e., that any noise in the preprocessing bias and flat field frames not have a significant effect on the data. Explain what steps can be taken in “real life” observing and data reduction to minimize the effects of noise in the preprocessing frames on the final reduced data.**

One of the most important steps one can take to gather a significant amount of data of the object of interest (cluster, star, etc.) and flat, bias, and dark frames in order to perform data reduction. While the vast majority of noise is inherent to the electronics (CCD readout noise, thermal noise) or the nature of observation of light (Poisson noise, cosmic rays), taking multiple biases, flats, and dark frames that can be stacked to produce a master bias, master flat, and master dark frame will allow for a better average that can be subtracted from the final image. The quality of the calibration data may degrade the S/N ratio if only a single bias frame of less than desirable quality is subtracted, whereas an average of, say, 20 frames, would increase the noise by a significantly smaller percentage. A dark frame should be taken at an equal time interval as the longest exposure time, and processing the dark frame by subtracting the master bias frame will show the prominence of dark current, which can then be corrected for. The same goes for flat field frames; the illumination should be fairly uniform and produce enough counts to avoid further degradation of the S/N in the final frame.

1. **Your final frame may contain some “fringing”. Explain how these fringes arise. How might they be corrected?**

When a CCD is illuminated by monochromatic light, such as that present in the night sky due to mercury lamp emissions, it can give rise to a fringing pattern. Fringing is especially prominent in the V, R, and I spectral regime. Fringing is also a characteristic of the chip itself, with some chips giving rise to fringing patterns more than others. As the long wavelength light is reflected within the layers of silicon, the reflection between two surfaces creates an interference pattern, also known as Newton’s rings5, with distinct circular light and dark bands.

While fringing can be avoided through preventative measures 6 such as avoiding long VRI exposures when the emission lines in the night sky are most prominent, and avoiding centering the objects of interest on the area on the CCD where the fringing is known to be worst, the frame can be calibrated to get rid of the pattern by taking a long background frame during the early hours of the night and then divide the frame with the fringe pattern (after it has had the bias subtracted from it and was divided by the flat) from the frame of interest.

**Sources:**

1. Lab manual: <http://www.astro.uvic.ca/~yang/a329/labs/lab1.pdf>

2**.** Dark Current, <https://en.wikipedia.org/wiki/Dark_current_(physics)>

3. Cleaning Images of Bad Pixels, Lisa A. Wells & David J. Bell, <https://www.mn.uio.no/astro/english/services/it/help/visualization/iraf/clean.pdf>, page 10

4. S.Andreon paper, [http://articles.adsabs.harvard.edu//full/1993ESOC...47..219A/0000221.000.html](http://articles.adsabs.harvard.edu/full/1993ESOC...47..219A/0000221.000.html)

5.Newton Rings <https://en.wikipedia.org/wiki/Newton%27s_rings>

6. <http://www.astro.uvic.ca/~yang/a329/irafdoc/pdf/ccduser3.pdf>, page 32

**Final Image:**

