

## THE REDUCTION OF CCD IMAGES FOR STELLAR PHOTOMETRY ON THE VATT

R. Janusz<sup>1</sup>, R. P. Boyle<sup>2</sup> and A. G. Davis Philip<sup>3</sup>

<sup>1</sup> *University School “Ignatianum”, ul. Kopernika 26, 31-501 Kraków, Poland*

<sup>2</sup> *Vatican Observatory Research Group, Steward Observatory, Tucson, AZ 85721, U.S.A.*

<sup>3</sup> *Union College and Institute for Space Observations, 1125 Oxford Place, Schenectady, NY 12308, U.S.A.*

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**Abstract.** We briefly describe a method of organizing all the star field exposures taken in a complete CCD observational run. By a “CommandLog” (to be published in *J. Astron. Data*) one can organize all the observations and process them within IRAF in an orderly, automated manner to arrive at stellar photometry calibrated into a standard photometric system (in our case, Strömvil). During the course of this processing we determine the error of the flat and try to correct it.

**Key words:** techniques: photometric – CCD photometry, reductions

### 1. INTRODUCTION

The reduction of the CCD images, obtained on a telescope, to derive quality stellar photometry, is something of an art; it is difficult to give strict criteria for yielding the best photometry. Only general criteria can be given; every star field object must be treated separately. It is difficult to estimate the flat field error and quality of calibration of a given object field.

The work is based mainly on images from the Vatican Advanced Technology Telescope (VATT). Our aims are the following: (1) establishment of an automatic method for CCD image reduction; (2) determination of the flat field gradients; (3) determination of the calibration quality; (4) reducing the errors of the flat fielding and calibrations. In our processing of CCD images we try to decrease

any “ad hoc” decisions by use of our special tool, the “Command-Log”.

## 2. THE COMMANDLOG

The CommandLog is a set of guiding and helping instructions organized as an HTML-document, as well as a set of our custom tasks (CL and PERL scripts) of IRAF.<sup>1</sup> The CommandLog allows us controlled code input by pasting commands with the mouse into the IRAF-CL. This semi-manual approach makes it possible to control all important steps and figure out what is going on inside a set of images. On the basis of this information we try to find better parameters to minimize some systematic measurement errors. Without this semi-manual inspection of the data it would be difficult to “guess” optimal parameter settings. To check a new and better flat field we need some results with which to compare. The CommandLog allows us to create a unified data organization (data structure) as well as to follow the same algorithmic path of IRAF tasks.

### 2.1. The frame database

We have decided to use “ttable” text databases to organize all important information used for all images. Passing through the CommandLog the main database is in continuous update on the basis of some helping databases. This main database can be exchanged within our group to have the same point of reference for our investigations.

### 2.2. The raw images

At the telescope we simply collect images. This is a simple data structure: each image has just a name and any logical structure between them is yet hidden. In one run we obtain about 1000 FITS images. Besides “technical” images concerning the instrumental system (bias, flat, pin-hole), we collect several object images in all filters. They are not only images of the fields of interest, but also images of the easily acquired calibrating star field (M67). This calibrating field helps us to determine the flat field signature of our instrumental system to apply it to other fields of interest. But there is also another very important purpose in using M67: we can try to remove systematic flat field error (seen on this known field) and use the corrected

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<sup>1</sup>IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

flat field images for other unknown fields. In other words, M67 is a “calibrating cluster” used by us as a “background field” to test the quality of other fields. Without this calibrating object it would be very difficult to judge how large the systematic error is.

Every object field usually has six images in two families: three rotated and three normal images all made with a small shift of about 12 arcsec in telescope pointing. These small shifts allow us to eliminate stars on bad columns. If a star on one image touched a bad column on the CCD detector, it can be eliminated; but two other images, shifted by a small distance, should have good quality information for that star.

Besides these small shifts, some “big shift” images about 1/3 field-of-view are taken. Together with the rotated images we have sufficient data to measure the flat field quality on the larger distance/rotation of the CCD surface, i. e., we can calculate the distributions of the differential photometry  $\delta = mag(x, y) - mag'(x', y')$  for the brightest stars of the calibrating object (M67) covering well the CCD surface. These stars have very good signal-to-noise signature, so they probe very well the large scale illumination correction signature. Raw images also have a convention to code the images for bookkeeping purposes (see Philip et al., this meeting).

### *2.3. Logical data structure and algorithms*

The CommandLog allows us to create a more logical structure for the unordered raw images. We can order our images by two categories: object kinds and filter types.

The system of subfolders, as well as databases, facilitates organizing, processing and calibrating the data. Together with databases listing candidate stars for forming a point-spread fitting function we have consistent information to use with the CommandLog algorithms: we calculate the magnitudes, transform coordinates, and do the statistical analysis of the mean magnitudes. On the basis of this information we are able to determine the flat field errors and try to remove them.

### *2.4. Calibration*

After going through two filters, we are able to make an initial calibration into the standard photometric system. In the common object folder we prepare a catalog of standard stars in common with the CCD observed field and a configuration file for performing the color transformation into the standard system. So here we are calibrating the

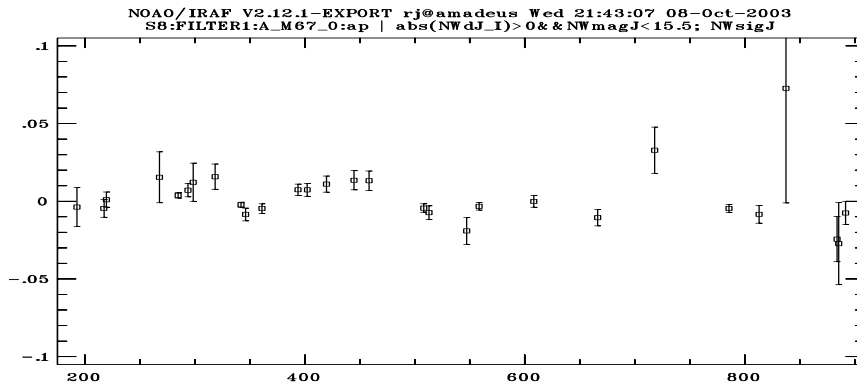
CCD data by following instructions also offered by the CommandLog. We evaluate the residuals of the differences between the standard and the CCD magnitudes, and having collected data of previous steps, we may also want to minimize these residuals. Unfortunately, it can happen that improving the instrumental system might not improve the calibration quality.

### 3. FLAT FIELD CORRECTION

Passing through the CommandLog requires only one semi-manual process to get basic insight into the data. During this process we create the data structure, databases, a reference frame, PSF candidate databases, data and configuration files, etc., as well as estimate quantities to be minimized. Now, our process can be automatically repeated with improved parameters or improved flat field images. We present below how our methods can improve the flat field image.

#### 3.1. The dome flat

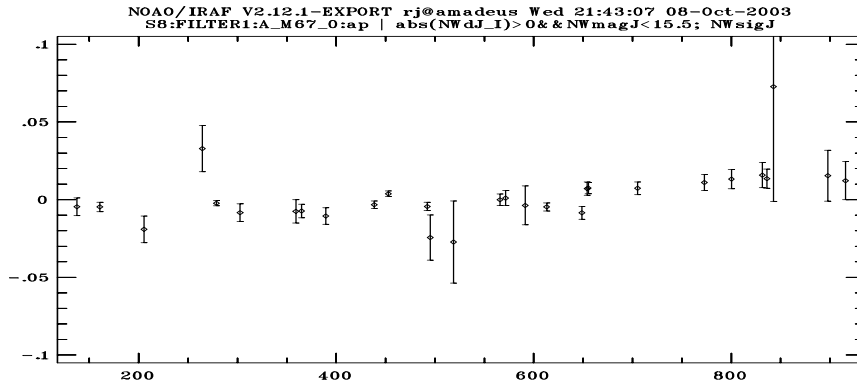
The classical CCD reduction starts with mean dome flats for all filters. We have processed six images in one filter using this averaged dome flat; three images were normal, and three rotated ( $180^\circ$ ) with small shifts between them. We calculated three types of means: for all six images, for three normal and for three rotated.



**Fig. 1.** The dome flat  $x$  gradient

On the first plot (Figure 1) we can see the spatial distribution of differential photometry [ $\langle \text{all} \rangle - \langle \text{normal} \rangle$ ] in the  $x$  direction. Besides the gradient a significant scatter also is seen.

On the second plot (Figure 2) the  $y$  gradient is very clear, although all parameters are the same. This plot makes us sure that 1% pho-



**Fig. 2.** The dome flat  $y$  gradient

tometry using dome flats only is not possible with our instrument. We must apply a kind of illumination correction to remove the gradient. Below we will discuss the  $y$  flat gradient because, just in this example, it is more evident and publication space is limited.

### 3.2. The blank sky illumination correction

One very efficient method to improve the dome flat is to apply a blank sky illumination correction.

But the blank sky needs a very long exposure time, so it is a very expensive object. In Figure 3 we can see how the blank sky illumination correction removes the error of the dome flat. Sometimes even this type of correction does not remove a gradient completely.

### 3.3. The differential photometry correction map

Another method of finding a large-scale CCD illumination correction is to use the calibrating object (M67) photometry to “probe” the quality of the “flatness” of a flat. Knowing the magnitude of a given star, measured in different places of the CCD, we *know* that it should have the same value. On this basis, we can calculate the correction of the magnitude at this point on a reference image.

Doing it for all stars bright enough and with translations/rotations of the CCD camera, we create a map image of magnitude corrections.

Because not every place on the CCD can have this signature, we make a smoothing task which is sensitive only on large scale effect and so we prepare another type of illumination correction based on “digging” and “building” corrections in the magnitude space and smoothing the correction map. The result of applying only the map image

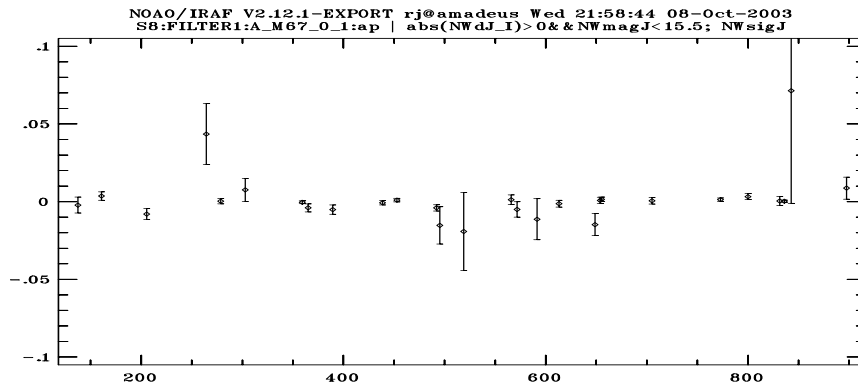


Fig. 3. The blank sky correction ( $y$ )

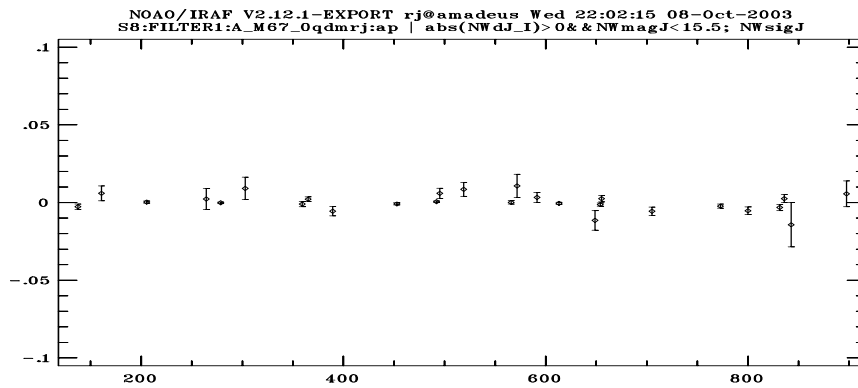


Fig. 4. The “map” correction ( $y$ )

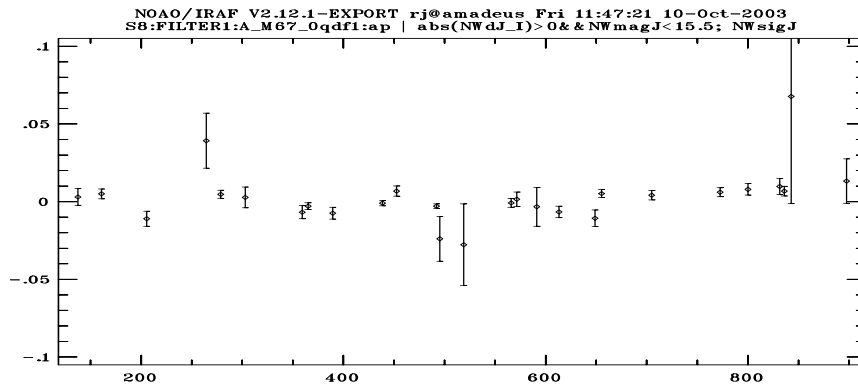
correction, i.e., unsmoothed, to the dome flat is shown in Figure 4.

### 3.4. The differential photometry fit

Another method of correcting the flat is to use the differential photometry data of the calibrating object (M67) for immediate creation of a surface of low-order polynomial. This surface is sensitive on the large scale gradients. Figure 5 shows the results of this method. It is better than dome flat.

## 4. CONCLUSIONS

In our investigations of the CCD photometry we have a helpful tool (the CommandLog) to automate our calculations. We discovered that scattered light is present in the instrument, so the dome flats need a correction. The blank sky is a very expensive illumina-



**Fig. 5.** The “fit” correction ( $y$ )

tion correction object and even after using it, sometimes we must still remove a gradient. We do it for the calibrating object (M 67) to use the corrected flat for other object fields of interest.

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