# FLAT-FIELDING FOR CCDs IN AAVSO OBSERVATIONS, I

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## Abstract

Flat-field correction for CCD chips is necessary to correct for the relative sensitivity to light of each pixel in the array as well as non-uniformities in the focal plane of the telescope + filter combination. This has been a serious issue for AAVSO CCD observers. Each observer tends to have a different method of performing flat-fielding, and even in the professional astronomical ranks there is no agreement as to how flat-fields should be obtained. We present a simple method that can be used at any time of day or night to make an accurate flat-field for CCD observing.

## 1. Introduction

Celestial observations taken with a CCD contain inherent errors due to the non-uniformities of the telescope, the filters, and the pixels on the CCD chip (Newberry 1996). These errors prevent the image in the computer from representing the true sky and must be corrected. The electrical bias of the pixels and the dark current that is produced during an exposure must also be removed. The dark and bias are most easily removed together by taking a "dark" frame of duration equal to the celestial exposure and subtracting the dark frame from the celestial frame. Software for this subtraction comes with all CCD image-processing packages, and is easily done.

Removing the remaining non-uniformities from a celestial exposure is done after dark correction by the process of flat-fielding: correcting the celestial image using another image of a uniformly-illuminated source called a flat. This flat is used to transform the raw image of the celestial source into an accurate representation of the true sky. Therefore, flat-fielding is an attempt to remove artifacts in the focal plane caused by telescope problems (vignetting, etc.), filter problems (dust specks, cleanliness), and the non-uniform response of the CCD pixels themselves. To obtain a good flat, it is necessary to have a uniform source of light that works in an observatory situation. Historically, the twilight sky has been used, but there are problems, such as the fact that CCD's are so sensitive that they can record stars in the twilight sky, and that gradients exist in the sky brightness (Chromey 1996). To eliminate stars one must take multiple flats in all filter bands. There is frequently not enough twilight available at the correct intensity for all this observing. Added to this is the problem that it may be cloudy (or raining) at sunset, but later turn into a clear night suitable for observations.

## 2. Method and results

We have tested various types of light sources in combination with a diffusing screen placed over the telescope aperture. We have found several methods that provide good flats with a minimum of time: one that uses the twilight sky, and one that uses a white

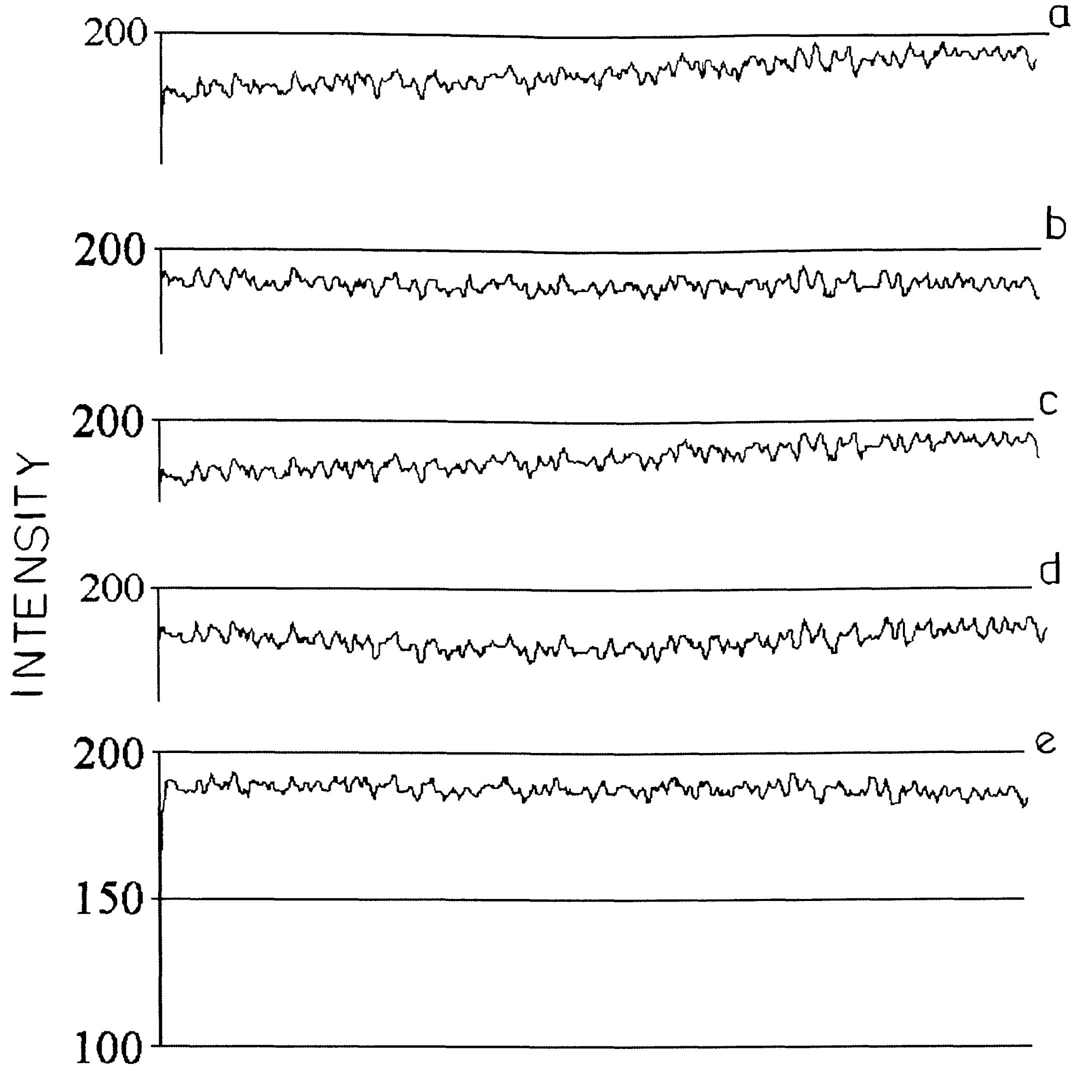


Figure 1a-e. This figure shows scans through the same section of the standard field. 1a shows the scan through the field corrected only for dark and bias. 1b shows the quite uniform scan obtained when the flat of twilight + diffusing screen is used. 1c and 1d are scans in which the morning and evening twilight illuminating the painted panel were used as flats. 1e is the scan using the flat made with 40 watt desk lamp illumination of the painted panel with a diffusing screen. Scans 1b and 1e are clearly the most uniform. All scans were reduced to an arbitrary intensity scale of 200 units.

screen in the observatory. In each method we use a diffusing screen of white plexiglass which covers the telescope aperture. The diffuser eliminates the problem of stars in the twilight sky and solves the problem of non-uniformities in the white screen and in its illumination.

For these tests we took a well-exposed CCD frame of a random star field far away from the Milky Way and any extended sources, and then corrected it for dark and bias. This became our "standard frame" used throughout all our experiments with various methods of flat-fielding. To construct the flat for each source of illumination, we took 5 separate exposures, corrected them for dark and bias, and then normalized them to a level of 10,000 digital units. All five images were combined to produce a median image that we called the final flat. These final flats were then used to process our standard frame.

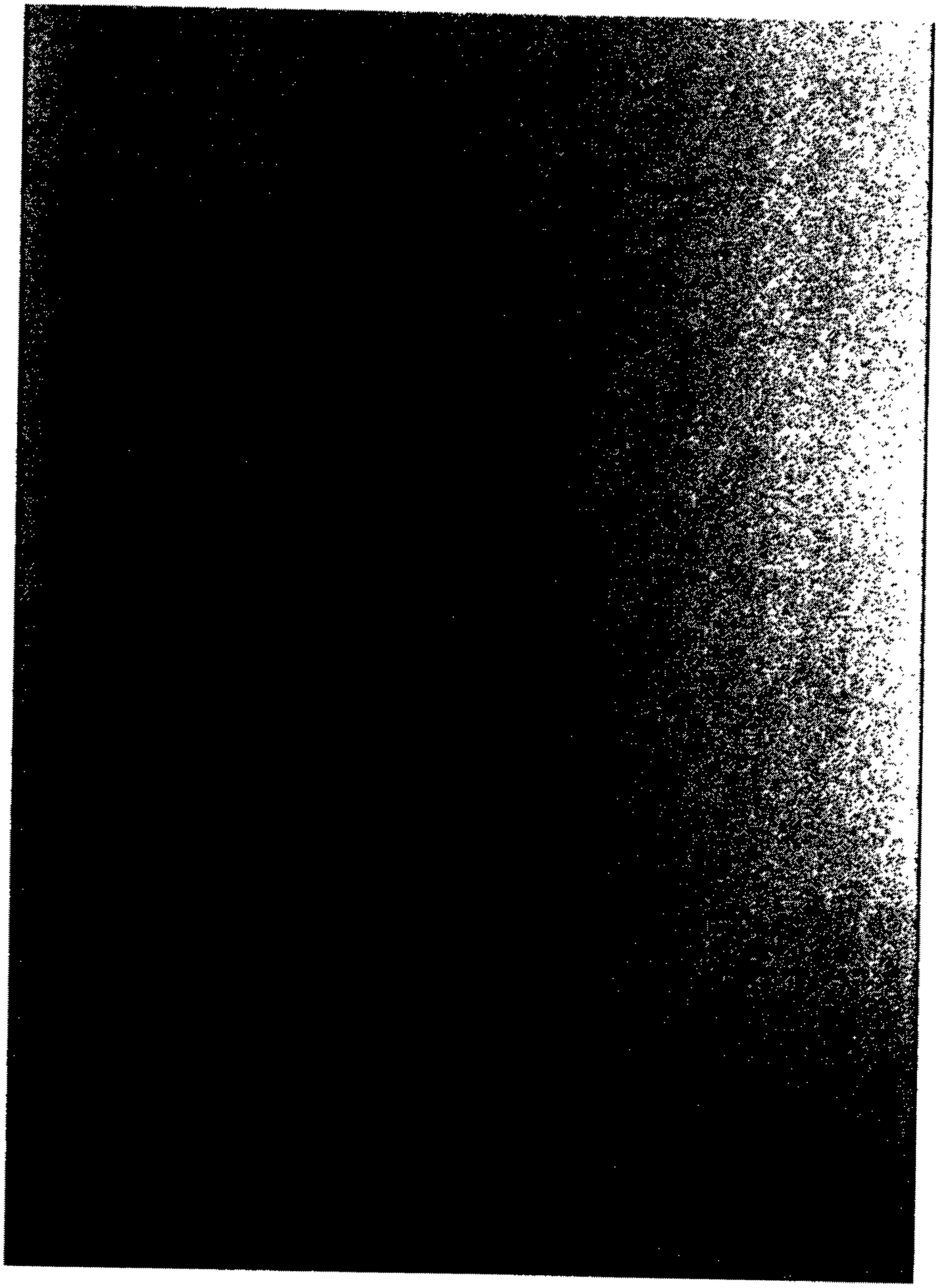

Figure 2. High-contrast image of the flat obtained by using evening twilight + a white plexiglass screen. This image is essentially a map of the non-uniformities in the CCD image of a uniform source. Two doughnuts caused by dust motes are clearly visible.

A flat taken with a low-level exposure will be dominated by photon noise that is the square-root of the signal. Therefore, a signal in each pixel of greater then 10,000 counts is necessary to achieve 1% accuracy (signal-to-noise of 100:1, or an accuracy of 0.01 magnitude). It is important that flats have enough counts in them that they meet this criterion for accuracy.

Uniformity was estimated by taking a scan across the background sky of the standard frame, avoiding star images as completely as possible, at the same location on the frame for each different flat reduction. The resulting scan represents the background sky brightness. It should be uniform and constant across the image.

Figure 1a shows a scan through the standard image without any flat fielding; it shows non-uniformities in level that are clearly apparent. All scans in Figure 1 are reduced to an arbitrary intensity level of 200.

The standard frame was then reduced using a flat obtained by the method that one of us (GPE) has been using for the last two years: twilight sky plus a white plexiglass diffusing screen. Figure 1b shows the result, and it is very smooth. The actual flat is shown in an image with a narrow intensity difference (to exaggerate the contrast) in Figure 2. Figure 2, since it is a flat, is basically a map of the non-uniformity of the telescope focal plane. Note on this figure the presence of the "doughnut" images, one large and one small, near the right-hand edge. These doughnuts are caused by dust specks in the optical train, one close by the CCD and one farther away. These particular dust specks are stable and are present on every flat we took. Obviously, the flat would change if the dust specks moved about. We will discuss this effect on observing techniques later in the paper.

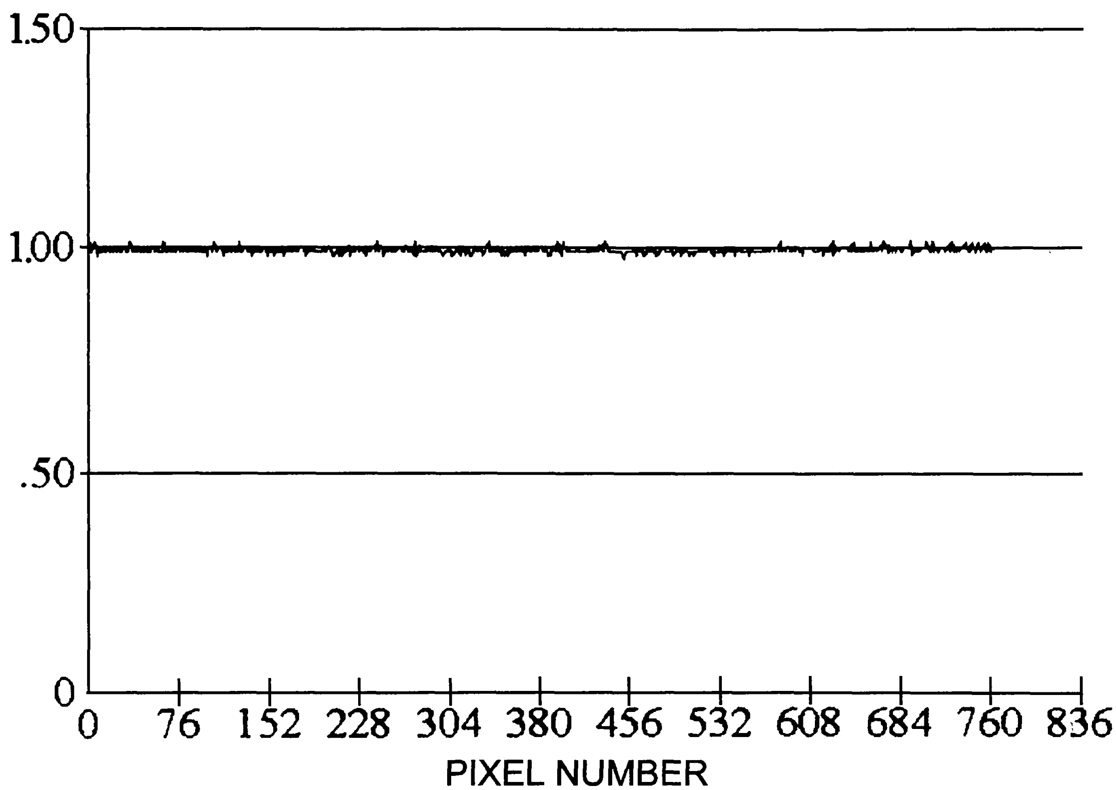


Figure 3. This figure shows the result of a division of the best twilight flat (Figure 1b above) by the best illuminated painted panel flat (Figure 1e above). The uniformity of the resulting scan indicates that the two methods are equivalent in producing high-quality flats.

Figures 1c and 1d show the scans reduced with two flats taken using a very uniformly white-painted screen illuminated by morning twilight and evening twilight, respectively. The screen was mounted in the observatory on a vertical wall with the roof pushed back completely (a slide-roof observatory). Neither of these results was truly uniform. They both show variation in the sky level as the scan crosses the frame.

The final flat used the same white-painted screen illuminated by a 40-watt desk lamp located in front of the telescope and (necessarily) off to one side. A diffusing screen of white plexiglass was also held over the aperture during these exposures. This crude arrangement of only one illuminating lamp located 12" off to one side of the screen and 30" away from the screen could not have produced a uniformly illuminated screen, but the presence of the diffuser was sufficient to produce the very uniform scan shown in Figure 1e. When we divided the scan obtained in Figure 1a (twilight + diffuser) by that of Figure 1e (lamp-illuminated screen + diffuser) we obtained the very good 1:1 correspondence shown in Figure 3.

## 3. Discussion

We feel that we have found a simple way to obtain flats for a CCD + telescope + filters in an observatory setting. The use of a diffusing screen adds effectively no scattered light to the telescope image and it has the benefit of producing a uniform exposure, even when the source of illumination is not quite uniform. The question remains: how often should an observer take a flat field with each filter he is using? If nothing changes in the optical path, and with the inherent uniformity of the individual pixels in the newer chips, it may be necessary to take a new set of flats only every month or so. There is, however, always the problem of dust motes, and without a smooth filter wheel, the constant removal and replacement of filters as well as the consequent removal and replacement of the CCD onto the telescope makes the shifting of dust motes on the filters and on the cover screen of the CCD inevitable. We would recommend that the CCD + filter not be moved at all as long as a single set of flats is being used. We recommend that the observer not attempt accurate multicolor photometry without having a stable filter wheel system and a fixed CCD in place. Removal of the CCD to change filters or to make other uses of the telescope should always be followed by a new set of flats.

In telescopes that move the primary mirror as a means of focusing, check to see if there is an image shift during focusing. If there is a shift then the mirror may move as the telescope is pointed toward different parts of the sky. This means that an accurate flat-field may not be possible with this instrument. Paper II of this series will discuss flats taken with various types of amateur telescopes.

How accurately can an observer obtain magnitudes without using flat-fielding at all? We reduced all the stars with reasonable signal-to-noise ratios that were on the standard frame using the various flats described above as well as with the standard frame corrected only for dark and bias. We compared the resulting magnitudes for the stars, and to our surprise, the closest results to those obtained with the best flats were those of the frame corrected only for dark and bias. It appears that the use of a poor quality flat is worse than not using any flat at all!

Perhaps this is true because the setup condition of telescope + filter + CCD we were using is a very good one with an inherently uniform focal plane. We do not believe that this result would be obtained using a telescope with vignetting present in its field (current catadioptric telescopes may have this) and would not recommend reducing frames without high-quality flats.

## 4. Summary

The main finding of this series of tests is that the use of a diffusing screen of simple white plexiglass makes it possible to take flats of excellent quality in either a twilight environment or in one's observatory with an illuminated screen. Using a high-quality flat with signal-to-noise greater than 100:1 is necessary for achieving the same 1% accuracy (0.01 mag) in one's measured magnitudes.

## References

Newberry, M. V. 1996, *CCD Astron.*, **3**, 18.
Chromey, F. R. 1996, *CCD Astron.*, **2**, 18.