Are Flats Really Flat?

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Introduction

As part of a campaign to determine the light curve of the eclipsing variable EY Cepheus, I investigated various characteristics of the ST7E camera/C11 combination. Preliminary results showed that flats taken using a variety of methods (flats using Tee shirts, dome flats, sky flats, etc.) all tended to show a positive 2% gradient downward on the CCD image, and to some degree positive toward the two sides. However, star data taken with the camera in its normal position and in its flipped position showed that the star calibration changed less than 1%, thus demonstrating that the gradient was associated with taking flats, rather than any intrinsic calibration error across the chip.

If a flat containing a gradient is used to correct the raw image, it will then introduce up to a 2% calibration error when measuring stellar brightnesses. In most, but not all cases, the usual methods of measuring relative stellar magnitudes will not be affected by this error (discussed in more detail below). The slight gradient introduced in imaging, as opposed to photometric situations, can normally be removed without much difficulty.

I should also note that I had earlier observed a very small gradient increasing to the right, amounting to about 10-12 counts, independent of exposure duration. This is the result of a tiny light leak generated by the shutter mechanism in the ST7 camera (private communication from SBIG). In most cases, this added count is small compared to the background and will rarely cause a problem (evidently, SBIG is also able to retrofit a camera to eliminate it).

Experiment

As a result of this observation, I examined the problem of flats in more detail by taking flats under controlled conditions with the scope/camera combination. After observing that the problem was probably in the camera itself, I tested the camera by itself under a variety of conditions of incoming light patterns, and with various field stops in the optical path.

Conclusion and Discussion

My conclusion from a large number of tests showed that when light entering the camera falls outside the chip itself, the light can be internally reflected inside the camera. Some of this reflected light ultimately reflects onto the chip itself where it is added to the desired image with a gradient pattern. As proof, I found I could eliminate the gradient in the image by placing a simple mask on the outside of the entry window. The mask is made of thin cardboard, cut with a razor knife, and shaped to be about 1-2mm larger than the footprint of the CCD/guide chips (thus not restricting a light cone coming in at a substantial angle to the optical axis). A simple circular hole was not nearly as effective as a rectangular hole in eliminating the gradient.

After the tests of the ST7 by itself, I reinstalled it on the C11 in the same optical setup as before (C11 operating at f/6.3 using a Celestron Reducer). In my previous imaging of the EY Cepheus, I normally ran all night, shutting the system down at dawn. Usually, the final set of images would be overexposed, as the dawn clouds and sunlight developed. Before the images (taken at one-minute intervals) are saturated, there are usually at least 5-10 images in which the background light is sufficiently large that the image will function quite well as a “dawn flat”. Comparing the dawn flats with and without the ST7 mask shows that the mask HAS removed the 2% gradient, consistent with the tests of the ST7 by itself.

Several comments can be made.

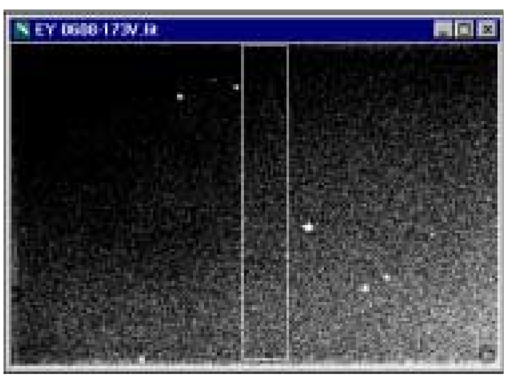
- The presence of the mirror that directs light to the guide chip in effect blocks much of the light from outside the top of the image that might otherwise contribute to a gradient there.
- Use of the ST7 with a fast optical system and/or use of the ST8 will cause the rays to enter the camera at fairly large angles (f/6 implies about 4.6 degrees). With such systems, there is the possibility that some vignetting will occur as the result of the mask. Calibration with a suitable flat will largely correct this error, without introducing a gradient in error.

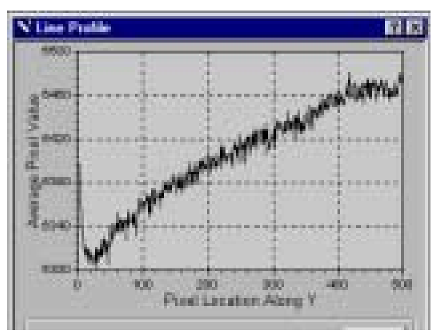
It should be noted that flats are normally taken under very different conditions than are typical images. Most images can be considered as a low brightness field with bright points (stars) scattered about. The light that scatters does add to the background (as well as to the much brighter stars), introducing a gradient as noted. However, because the average brightness is low, one does not normally notice this gradient. Further, in a photometric measurement, one normally uses an aperture to measure star brightness, which removes this very small addition to the background reading.

However, when you take a flat, the whole chip and surrounding area are illuminated more or less uniformly, with the total light reaching the chip contributing to the flat. When you use the flat to calibrate an image, the image pixel values are modified in proportion to corresponding pixel values on the flat. A gradient in the flat will translate into a gradient on the image which will modify the pixel values in both background and stars. Subsequent photometric measurement values from that image will then reflect this gradient. If the star images are all in the same respective positions on all flat corrected images to be compared, there is no net error. However, in the real world, the stars will often be in different spots on the image, or even reversed locations (e.g., if the camera is on a German Equatorial that has been flipped). In these situations, error may be introduced as one attempts more precise photometry (1%=.01 mag).

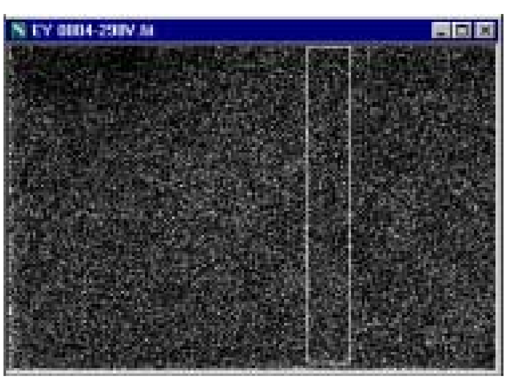
It should be noted that if the system is very clean (no dust images to be corrected), and if there is no significant vignetting, then one could choose not to flat correct the images. Similarly, one could always be careful to keep the images of stars to be measured in the same locations region in all images. However, applying a mask to the entry window is very easy, is reversible, and is surely the desirable way to handle this problem.

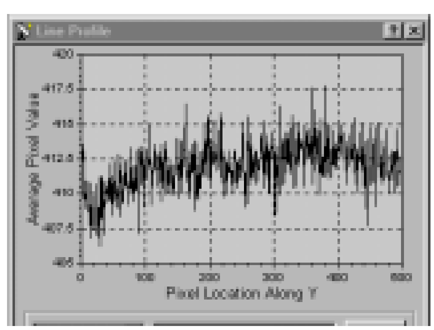
Flats1





Dawn flat with no mask. Approx 2% gradient.





Dawn flat with ST7 mask. Well below 1% gradient.