High-Precision Photometry with CCDSs on Small Telescopes

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Abstract

From the theory of CCD operation and our experience since 1986 with a Photometrics CCD camera, we provide practical suggestions for achieving high-precision photometry on a small telescope (61-cm).

1. Introduction

Since 1986, we have employed a Photometrics CCD camera on our 61-cm telescope at Capilla Peak Observatory (Laubscher et al., 1988). One goal of this instrument has been to achieve high-precision photometry of point sources with the camera operating as a multichannel photometer. We have devised solutions that should apply to any other small observatory attempting to attain quality results. These issues include: superbias frames, flat-fielding techniques, calculations of exposure time, technique of sky subtraction, and matching of filters to CCD response functions to obtain linear transformations to standard photometric systems. With care, an observer can produce a precision of a few millimagnitudes for differential photometry.

2. CCD S/N for Sky-Subtracted Data

Newberry (1991) has provided an excellent analysis of the operation of a CCD and its use for sky-subtracted observations. In the case of a photon-limited noise (and with no "external" noise, such as scintillation), the CCD S/N equation implies the following practices for optimizing the actual S/N: (1) Increase object counts by using a CCD with high QE and insuring that the system has clean optics; (2) reduce average background count per pixel relative to object count by working at a dark site on a moonless night, choosing a CCD with low dark count, and minimizing scattered light in the system; (3) reduce number of pixels under object (but not less than 2 or will undersample) by superpixeling the CCD, changing f-ratio with reimaging optics to match the pixel size, and maintaining good focus and guiding; and (4) maximizing the number of pixels recording the sky background. Following these guidelines, even an old RCA CCD chip (which has high readout noise – about 80 electrons!) can achieve a S/N $\approx$ 1300 for a V-magnitude of 13 with a 61-cm telescope.

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3. Capilla Peak Observatory

We have achieved such results with our Photometrics 815 CCD camera on a Boller and Chivens telescope at Capilla Peak Observatory in New Mexico. The site has a high elevation (2835 m) with good transparency, dark skies (V = 21.2 mag/ arcsec^2), and typical seeing of 1.3 arcsec (with occasional subarcsec seeing). Weather is photometric about 1/3 the nights; for multichannel differential photometry, we can work with light clouds and so have about half the nights available for observing. We have taken great care to keep the optics clean. The overall reflective transmission is now 95% and has stayed at that level for the past five years. When we are not observing, we run a positive-pressure ventilation system to keep dust out of the dome. The CCD camera is a dedicated instrument and rarely taken off the telescope.

From our experience observing both bright and faint point sources, we have developed the following guidelines for high-precision work: (1) Keep stars on the SAME pixels by offsetting from reference stars, maintaining good guiding (an autoguider is essential; we built our own with an intensified Fairchild CCD camera), and choose a software mask for data reduction that is about 3 times seeing for a given night; (2) try to use comparison stars in the SAME CCD field; (3) Use the shortest exposures possible to obtain the required object count, as estimated from CCD S/N equation; (4) Use the SAME (and LARGE) pixel area to measure the sky in the frame and apply a uniform software mask that avoids obvious sources.

Noise can be added in the course of CCD data reduction. To keep this noise contribution to a minimum, we have relied on the following procedures. First, we have taken a number of "superbias" frames, the mean of a few hundred exposures at the same temperature (which we keep stable to ± 0.1°C). Bias-subtracted frames contain at least the noise of the bias frame. Second, we observe the sky at twilight and at night (in blank fields) to generate our flat fields. These have been separately median-filtered to make a "master" flat field at each color for flat-field division. The S/N of the flat field must be higher than that of any pixel to which it is applied so that the S/N in the reduced object frame is not degraded.

By applying these techniques, we have achieved a precision of a 2 to 3 mmags for differential on point sources. We are now basically limited by scintillation noise. As far as accuracy is concerned, we learned a fundamental lesson when we first started observing with a KPNO CCD filter set. We found that the transformations to the Johnson-Kron-Cousins system were badly nonlinear. We therefore did synthetic photometry (Beckert and Newberry, 1989) to match the integrated response of our chip and its filters to the JKC system. Over a fairly wide color range, our custom-designed filter set is linear to ± 0.05%, so we can attain an accuracy on that order with high-precision observations.

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References:

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Discussion

T.J. Kreidl: *Have you considered binning (2x2) to decrease the high readout noise of the RCA chip by* $\sqrt{2}$*, as well as reducing the readout time? We have found that to work very well with the old RCA system we have at Lowell Observatory.*

Zeilik: We have the ability to *superpixel* the chip. But in real-time, on-site evaluation of the data, we have found doing a superpixel or subarray more trouble than they are worth.

S.M. Howell: *I would just like to point out that the high readout noise of the RCA is likely not to be a problem for you due to your application to bright, high S/N sources. In fact, the large well depths are probably an advantage.*

Zeilik: That's correct. The high readout noise of the RCA chip does not affect high S/N observations of bright stars, especially cool ones.