Bias, Darks, and Flats for CCD/CMOS Calibration

rev 2, 25 Oct 2018, DESI-DOC 4373v2, M.Lampton UCB SSL

Purpose: Accurate CCD/CMOS imaging usually requires a set of bias frames dark frames, and flat field frames that are used to remove the individual pixel bias pattern, dark current pattern, and QE pattern. Here I present a basic way to combine these to obtain a calibrated science frame.

Assumptions Assuming that the sensor is linear, and that the darks and signal frames are taken at the same temperature, I adopt these four equations in four unknowns:

$$
\begin{aligned}
BF &= B \\
DF &= B + D \cdot T_d \\
FF &= B + D \cdot T_f + F \cdot Q \cdot T_f \\
SF &= B + D \cdot T_s + S \cdot Q \cdot Ts
\end{aligned}
$$

On the left hand side BF, DF, FF, and SF are the bias frame, dark frame, flat field frame, and science frame; all are measured and therefore are known. Also known are their exposure times: bias frames have zero exposure time, dark frames have T_d, flat frames have T_f, and the science frame has T_s. The flat field illumination F is taken to be uniform: not a pattern but a number. (Its purpose is to reveal the quantum efficiency pattern Q.) The unknowns are the true bias pattern B, the true dark current pattern D, the true QE pattern Q, and finally the corrected science frame S. So, four equations in four unknowns.

Solving for the true (corrected) science image S gives:

$$S = \frac{F \cdot T_f}{T_s} \cdot \frac{SF - BF * (1 - T_s/T_d) - DF * T_s/T_d}{FF - BF * (1 - T_f/T_d) - DF * T_f/T_d}$$

Interesting to see that if $T_s = T_d$ then the bias frame disappears from the numerator: the dark frame contains just the right amount of bias to de-bias the science frame. Or, if $T_f = T_d$ then the bias frame disappears from the denominator: the dark frame contains just the right amount of bias to de-bias the flat. Or, if $T_s = T_d = T_f$ the bias frame is eliminated everywhere, giving the simpler formula

$$S = \frac{F \cdot T_f}{T_s} \cdot \frac{SF - DF}{FF - DF}$$

meaning that the dark frame totally corrects both the numerator and denominator.

When to use these frames? This correction process deals only with the image systematics. The measured calibration frames BF, DF, and FF will of course contribute random noise to the image correction, although such noise can be reduced by averaging many frames of each type. If their individual patterns dominate their noise levels, then correction will reduce the total error. Otherwise it will worsen it: better to simply set that frame to zero. For exposures that are short and taken with a cooled sensor, the dark current may contribute only a negligible pattern amplitude. For bright targets, the most important correction may well be the QE pattern.

Cost: Multiple bias frames are cheap: they have zero exposure time, and bias hardly changes over time, so they are reusable. Flats can be bright and brief, and again the QE pattern is expected to be stable over long time periods for a given sensor, although many flats will need to be averaged to reduce the shot noise to a level below the QE pattern. Darks are far more expensive of time, needing longer exposures and yielding patterns that depend strongly on chip temperature.