Assessment of Performance of Photon Focus Camera to meet COSMO K-Coronagraph Requirements

Joan Burkepile
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Summary
The performance of the Photon Focus 12-bit CMOS detector is examined for use with the COSMO Mauna Loa K-Coronagraph. Results indicate that it meets the science requirements identified in Burkepile (2010). Maintaining a clean objective lens and use of pre-filters to remove light leaks in the blue wing of the filter are also needed to meet requirements.

I. Photon Focus Camera

Nelson has identified the 12-bit Photon Focus CMOS 1K x 1K camera as a candidate for the COSMO K-coronagraph (private communication). Characteristics include a well depth of 200,000 e^−, readout noise of 100 e^−, and a frame rate of 150 Hz. The detector will be used to record polarization brightness images of the solar corona at high time cadence as described in Burkepile (2010). The noise properties of the Photon Focus camera were examined by Tomczyk (2010) and are plotted in Figure 1 vs. the camera integration time. Noise levels are given in units relative to the solar disk [B/Bsun]. A variety of background scattered light conditions (referred to as ‘sky’ in the plot) and signal-to-noise (S/N) levels are examined. The colored lines in the figure illustrate the different S/N levels from 1 to 2. The solid lines are noise levels for a sky and scattered light noise of 10 millionths B/Bsun and the dashed lines are for 20 millionths.

The current Mauna Loa K-coronameter (Mk4) has a noise level of 3x10^-9 and takes 3 minutes to scan around the entire corona. The Photon Focus camera can record a Mk4-like image in just under 3 seconds for a scattered light background level of 10x10^-6 and a S/N of one (solid black line in Figure 1). That is a typical background level for a slightly dirty objective lens at viewing heights of 1.5 solar radii (R_⊙). Scattered light conditions at Mauna Loa are discussed in the next section and in detail in Elmore 2007b. Longer integration times are needed to achieve higher S/N levels, as indicated by the red and green lines in Figure 1, or in the presence of higher background scattered light as shown by the dotted curves in Figure 1.
Figure 1. The Photon Focus camera noise vs. integration time for 3 different S/N levels and 2 different sky and scattered light noise levels. Results are from Tomczyk 2010.

Figure 2. The Photon Focus camera noise vs. integration time as in Figure 1. The vertical lines indicate the maximum integration time vs. CME speed to limit pixel smearing to 10 pixels.
The COSMO K-coronagraph is designed to record images of the K-corona at high time cadence and a lower noise level of $1 \times 10^{-9}$ that allow for the study of coronal mass ejection (CME) acceleration profiles and of fainter structures such as coronal holes. A complete description of the science requirements is given in Burkepile (2010). The requirements necessitate a noise level approaching $1 \times 10^{-9}$ in 15 seconds for the rare CMEs (<1% of all events) that move faster than 2000 km/sec. All other events can be studied with integration times of 20 seconds or greater. The science goal of $3 \times 10^{-10}$ can be achieved for slow-moving CMEs at integration times approaching 3 minutes. These integration time limits are needed to minimize smearing of CME structure across pixels as they moves through the field-of-view (FOV) as discussed in Burkepile (2010). Steady coronal structures, such as coronal holes and helmet streamers, can have integration times over 3 minutes to meet the $3 \times 10^{-10}$ noise level.

In Figure 2 we compare the Photon Focus camera noise to the noise level requirements and integration times required for CMEs. The vertical lines represent the integration time allowed to limit CME smearing to 10 pixels based on the speed of the CME through the FOV. The Photon Focus camera will achieve $1 \times 10^{-9}$ noise level ($S/N=1$) at ~20 seconds for a modest background noise of 10 millionths. This will meet or exceed the noise level requirement for 99% of all CMEs (see Table 2 in Burkepile, 2010). Steady structures, such as coronal holes, can be integrated over longer time periods. An integration time of 3-4 minutes can achieve the GOAL noise level of $3 \times 10^{-10}$ under clear skies with a clean objective lens meeting the noise level and integration time requirements for the new coronagraph.

Scattered Light and Sky Brightness

The solar corona is inherently difficult to observe as it is a million times dimmer than the solar disk and dimmer than the background sky as shown in Figure 3. The brightness of the ‘true’ corona, known as the K-corona is labeled ‘K’ in the figure and shows the coronal brightness during maximum solar activity relative to the solar disk and to typical background skies. Optimal viewing of the white light corona from the ground is achieved at dry sites at high altitude and by exploiting the fact that the corona is highly polarized and the sky is not.

Sky brightness values at Mauna Loa are reported to be $\sim 1 \times 10^{-6}$ B/Bsun under cloudless skies (Elmore 2007a) making it an ideal site for coronal observing. Scattered light analysis of the Mauna Loa Mk4 K-coronameter by Elmore 2007b shows that dust on the objective lens, not sky brightness, is the primary source of scattered light in the instrument. Scattered light levels of 10 to $25 \times 10^{-6}$ B/Bsun are common due to dust as shown in the plot of total brightness observed by Mk4 in Figure 4. Maintaining a clean objective lens will ensure low noise levels that meet science requirements. The Mk4 instrument also observes a severe bright ring around the occulter and seen in Figure 4 as the sharp peak in brightness at low solar radii. Simulations by Tomczyk (private communication) indicate the bright ring is due to leakage in the blue wing of the prefilter. Using a series of prefilters with sharper cutoffs will remove the bright ring in the new coronagraph allowing for the detection of the corona down to $1.05 R_S$ to meet science
requirements. A saturation level of $50 \times 10^{-6}$ is sufficient to accommodate scattered light and bright sky days when the corona is still detectable.

**Figure 3.** Comparison of background sky and coronal component brightness in units of brightness relative to the solar disk vs. distance in solar radii from sun center.
Figure 4. Log of total brightness vs. log of solar radius in units of B/Bsun from Mauna Loa Mk4 on Jan 20, 2009. The total brightness is the sum of sky brightness, scattered light and corona. A leak in the prefilter blue wing causes a bright spike in brightness around the Mk4 occulter.

References

