Laboratory and On-Sky Tests of a Simultaneous 3-Color CMOS Imaging Camera

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Abstract

We report results of laboratory and on-sky testing at **Lick Observatory** of a camera utilizing the Foveon F13 CMOS sensor. The CMOS Prototype #0 Camera (C3P0Cam) produces simultaneous images in 3 colors on short (20 ms subrastered to 0.2 s full-frame) timescales. We have verified **1-2% level photometric accuracy** for time variable objects at $V \approx 14$ Mag. We discuss the device quantum efficiency and noise properties as well as the relation between the three C3P0Cam colors and standard photometric bands. Novel analysis software exploits the non-destructive readout for the F13 to generate, despite poor single-image bit depth (8-bits currently), **factor** $> 10^6$ **effective-dynamic-range** images not affected by blooming near bright sources.

1 Introduction

A new observational era for in transient object astronomy is unfolding thanks to space-based observations by *Swift* and *GALEX* (and soon *GLAST*) and thanks to upcoming deep, high duty-cycle synoptic surveys (Pan-STARRS, LSST) of extremely large regions of the sky. The classification, discovery, and study of new Gamma-ray Bursts (GRBs), supernovae, extra-solar planets and heretofore undiscovered classes of bursting objects, as well as characterization of fine-timescale variability in dMe-type flare stars (e.g., Welsh et al., 2006) and cataclysmic variable stars (e.g., Pretorius & Knigge, 2007), will depend (in part) on rapid cadence photometry in multiple filters. The capacity to image simultaneously in multiple filters is especially important, because it allows close spacing of observations and provides spectral information on short timescales. Such fine windowing of potentially rapidly varying spectra has proven particularly fruitful for studies in the Infra-red of GRBs (Blake & Bloom, et al., 2005; Butler et al., 2006; Perley et al., 2007). Multicolor imaging is important for transit surveys to discover extra-solar planets because stellar companions of a difference temperature than the primary will cause a color change across the transit whereas planets do not.

Figure 1: NB, JSB, and JS in front of our small camera (Left Figure), mounted to the Cassegrain focus of the Nickel 1 m telescope (Right Figure) at Lick Observatory.

2 F13 Sensor and Prototype Camera Design

With these science goals in mind, we have built and tested an inexpensive camera — the CMOS Prototype #0 Camera (C3P0Cam) — utilizing the Foveon F13 sensor. The camera electronics were provided by Alternative Vision Inc., using an EPIX PIXCI interface to a PC running Linux.

Wheras most commercially available, single-chip color sensors require four pixels to detect the full range of color, and full-resolution color requires expensive and bulky multichip cameras. By analogy with the vision structure in the human eye, however, the F13 captures full color at every pixel by utilizes the changing absorption coefficient of silicon versus frequency. Unlike traditional astronomical color imaging, no signal is lost due to the use of filters and the color observations are simultaneous and co-spatial.

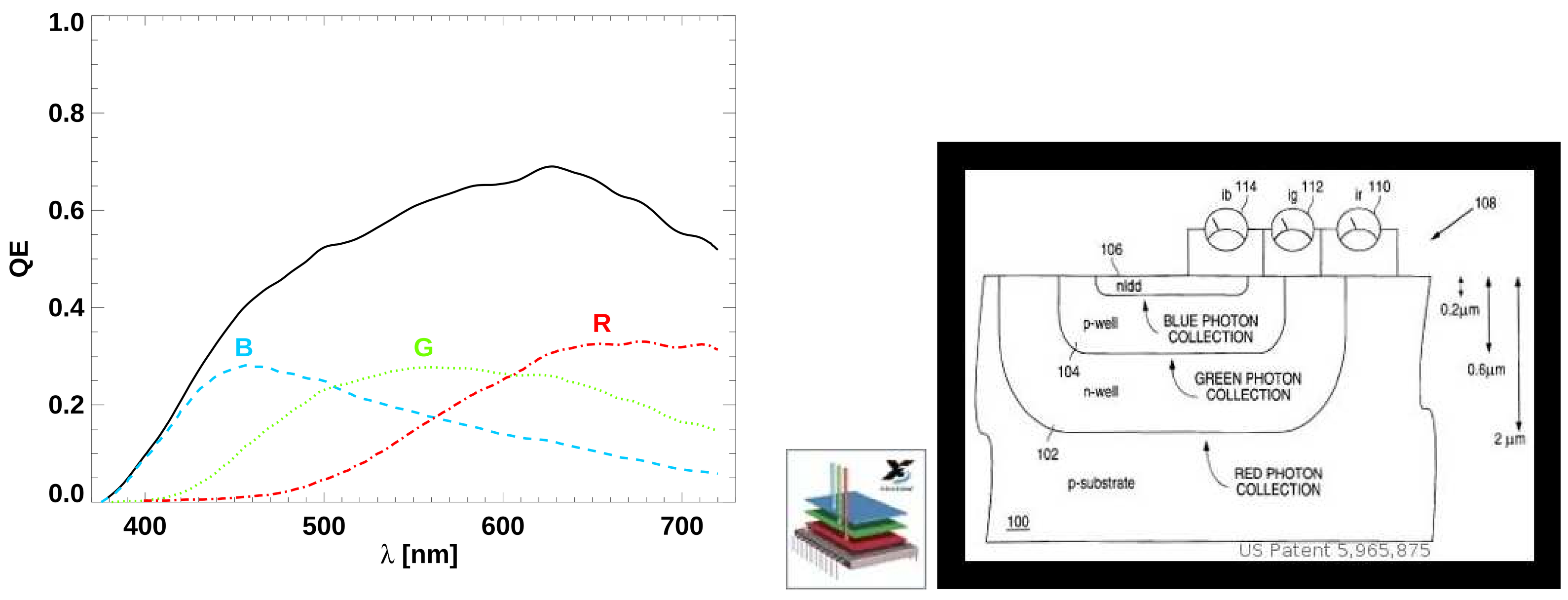

Figure 2: Quantum efficiency curves (Right Figure). A schematic of the F13 pixel from the US patent office (Left figure). The F13 sensor is a Complementary Metal Oxide Semiconductor (CMOS) device consisting of 3 vertically-stacked photodiodes per pixel. The shortest frequency optical light ($\lambda \gtrsim 400$ nm or "B" light) interacts in the top-most photodiode layer on average and is read out at the pixel. Red "R" ($\lambda \lesssim 900$ nm) light interacts in the deepest photodiode well, while intermediate wavelength "G" light interacts with the silicon in the middle photodiode well.

The F13 quantum efficiency from 530 nm to beyond 660 nm is ~ 60%, with a dark current at room temperature below 100 e^-/s. Thermo-electric cooling by 20 degrees C decreases the dark current to 40 e^-/s, which corresponds to 1 ADU$/s$ for our current electronic's inverse gain of 40 e^{-1}/ADU. A non-destructive readout allows for extremely broad-dynamic-range and simultaneous imaging of bright and faint nearby sources without blooming. Thanks to the affordability and uniformity ($\lesssim$1%) of this generation of CMOS detectors, precision photometry of very wide fields is possible.

3 C3P0Cam Observations

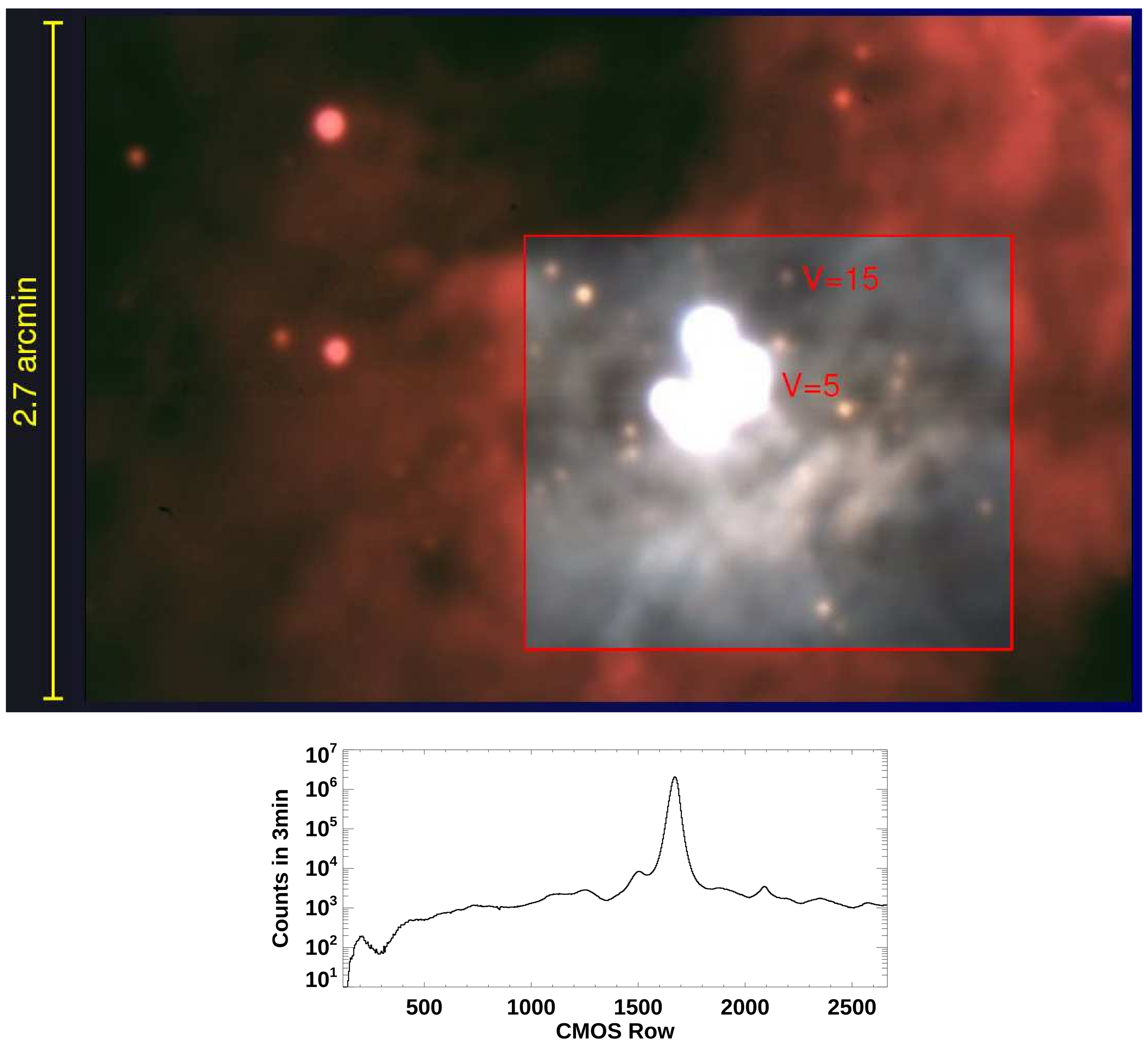

Figure 3: Three-color exposure in 180s of the Trapezium in the Orion Nebula. The inset shows the broad dynamic range obtained without bloom near bright stars. We are oversampling stellar PSF's by a factor ~ 16 to enable on-sky verification of the sensor gain uniformity, $\delta g \lesssim 1$%.

Figure 4: Simultaneous 3-color (inverted) exposure of the Ring Nebula in 180s.

We have mounted C3P0Cam to the Cassegrain focus of the Nickel telescope and observed over the past several months in a variety of readout modes. The sensor gain is uniform at the 1% level. Our data reconstruction algorithms exploit the non-destructive read to monitor for saturated sources and to correct for telescope motions and seeing variations. We reach $V = 17$ mag in 3 min. Our (relative) photometric accuracy for variable sources has been verified to be < 1% at $V = 14$ mag.

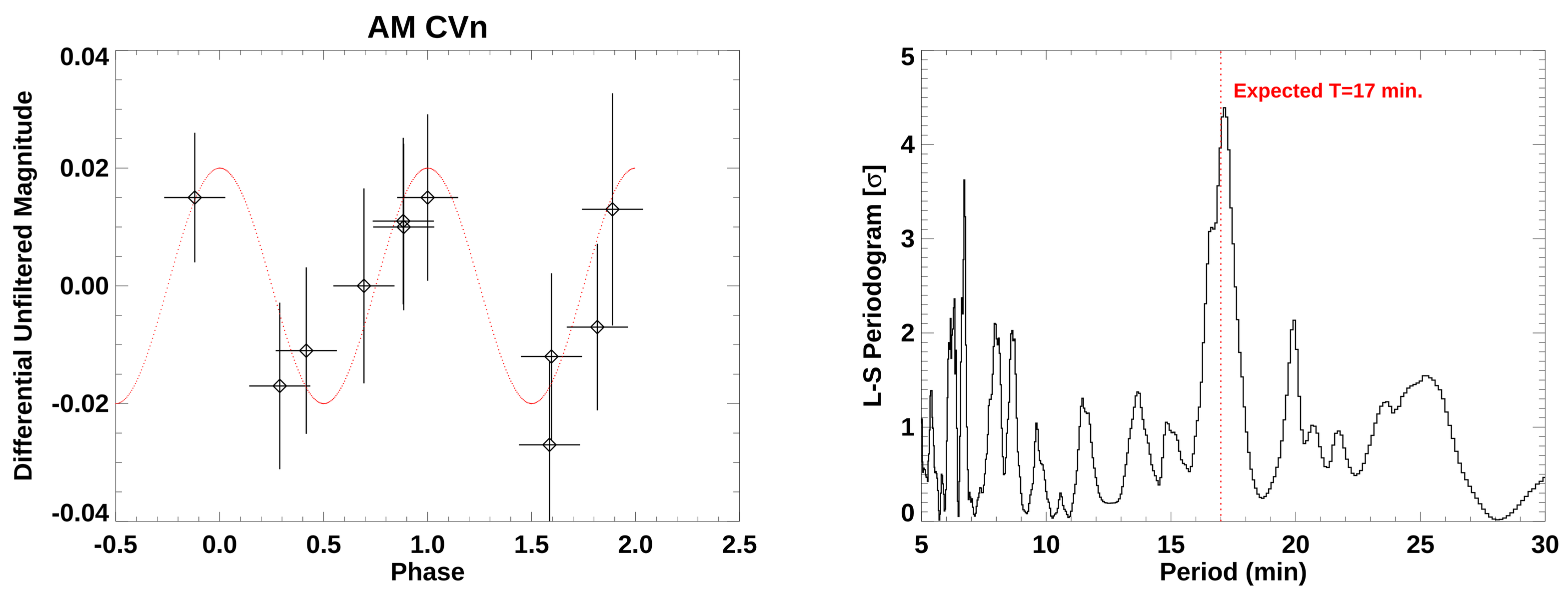

Figure 5: AM CVn is the prototype of a class of closely-interacting white dwarf binary systems which are expected to be a dominant source of gravity waves for Advanced Ligo and LISA (e.g., Nelemans et al., 2004). We demonstrate 1% level (relative) photometric accuracy in detecting the period of the system in 1.5 hours of observations. Constraints on the color variation < 2% (not shown) are consistent with prior work.

References

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