An Optical Test Bench for Precision Characterization of the TESS CCD Detectors

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INTRODUCTION

The Transiting Exoplanet Survey Satellite (TESS) is an Astrophysics Explorer mission selected by NASA for launch in 2017 to search for planets transiting bright dwarf stars. The CCD detector assembly consists of four deep-depletion back-illuminated MIT Lincoln Laboratory CCID-80 devices. Each CCID-80 device consists of 2kx2k imaging array and 2kx2k frame store regions, with 15x15 μm pixels.

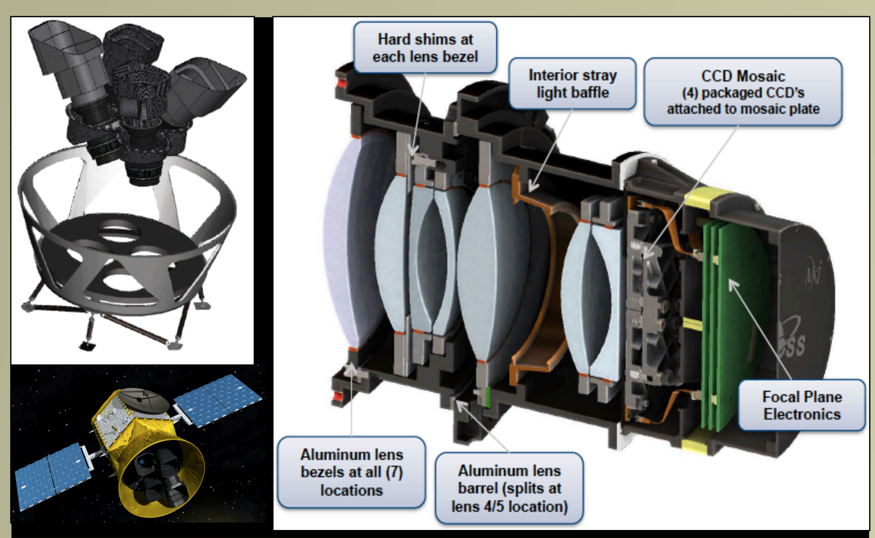

Figure 1: TESS camera assembly.

Quantum efficiency (QE) is the percentage of photons that produces charge carriers. A combination of QE and CCD gain yields the sensitivity of the CCD signal. The quantum efficiency along with read noise is one of the most important parameters of the photometric noise budget for TESS. The design goal of the present work is to develop a precision optical test bench capable of automated absolute quantum efficiency measurements over the spectral range of 650-1050 nm with an absolute error of 1.5 - 2 %.

EXPERIMENTAL SETUP

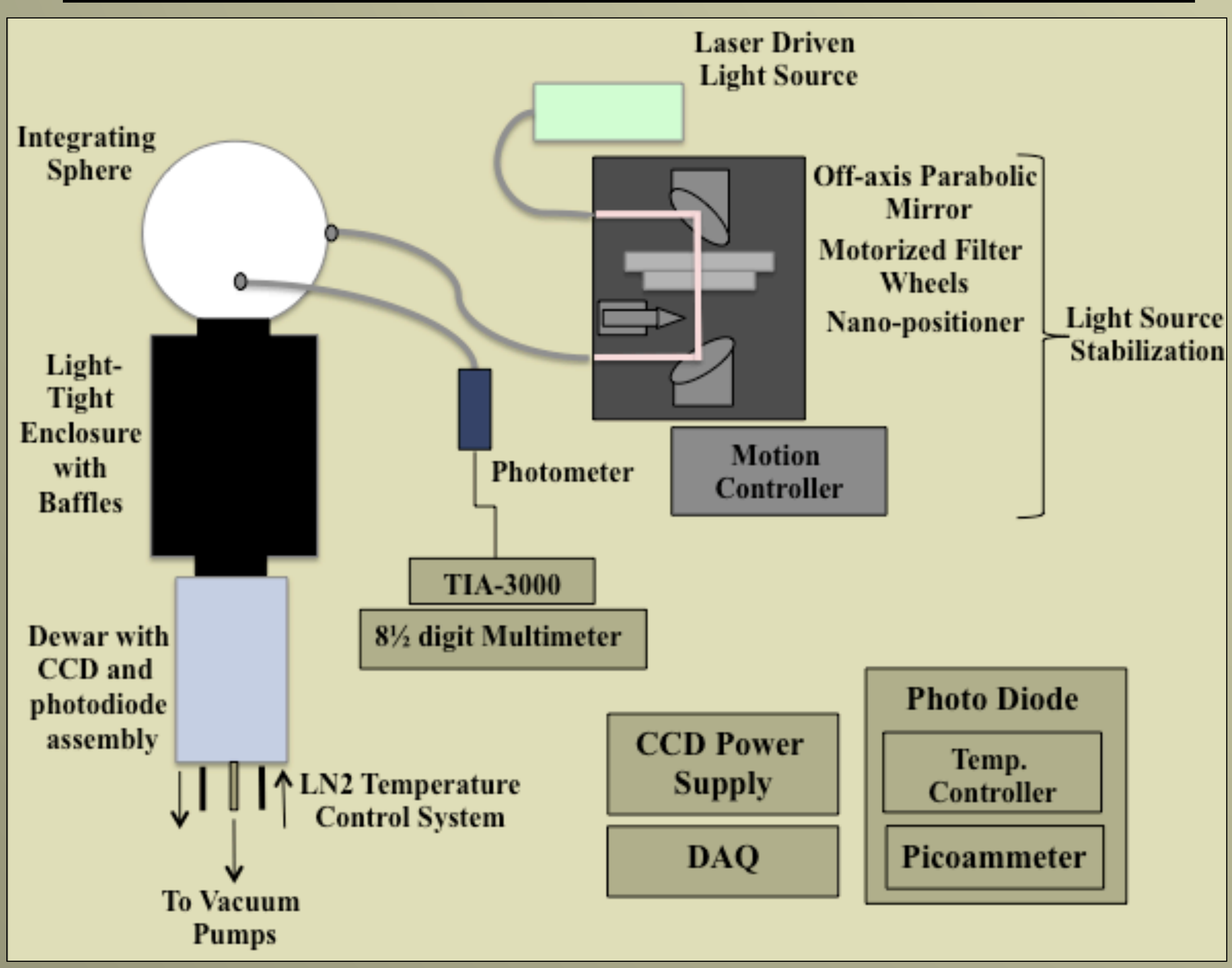

Figure 2: Precision optical test bench for QE measurements.

The experimental setup, illustrated in Figure 2, consists of a vacuum dewar with a single MIT Lincoln Lab CCID-80 device mounted on a cold plate that is maintained at the operating temperature of -70℃ to reduce the dark current to a negligible level. A calibrated reference photodiode is mounted next to the CCD and maintained at the calibration temperature of 25℃.

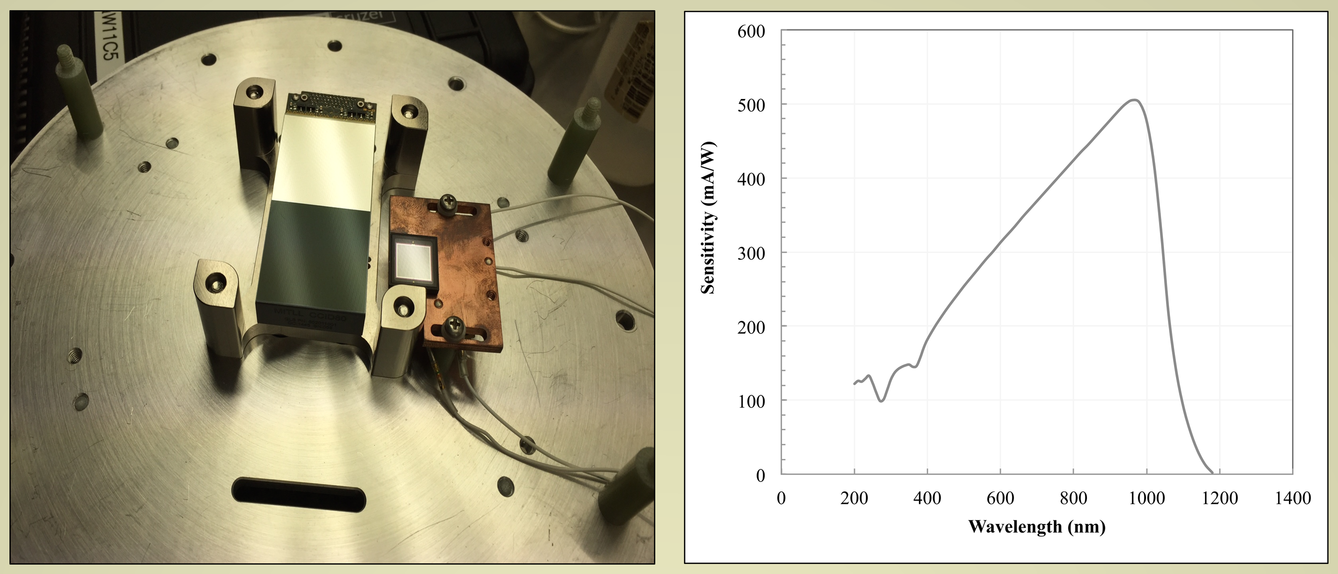

Figure 3: [Left] CCD and reference photodiode assembly, [Right] Reference photodiode sensitivity plotted against wavelength.

Band-pass filters over the range of 600 nm – 1064 nm with 10-nm bandwidth are used for wavelength selection. A very stable laser-driven light source (LDLS) is integrated with the Super Stable Source (SSS) stabilization unit, a patented development by the Characterising ExOPlanetS (CHEOPS) Team at the University of Geneva [Francois Wildi, 2015], to control variations of the light source down to a few parts-per-million when averaged over 60 s. Light from the stabilization unit enters a 20-inch integrating sphere. The output light from the sphere produces near-uniform illumination on the cold CCD and on the calibrated reference photodiode inside the dewar. The ratio of the CCD and photodiode signals provides the absolute quantum efficiency measurement.

RESULTS

Light source stabilization:

The instantaneous variation of the LDLS is about 1-3%. The measurement uncertainty of the photometer system is about 5 ppm at 15 Hz and 24-hour accuracy below 1 ppm. The stabilization stage operates at approximately 10.5 Hz for an output signal noise of about 700ppm rms and yields a stability of 4.95ppm when averaged over 60 seconds.

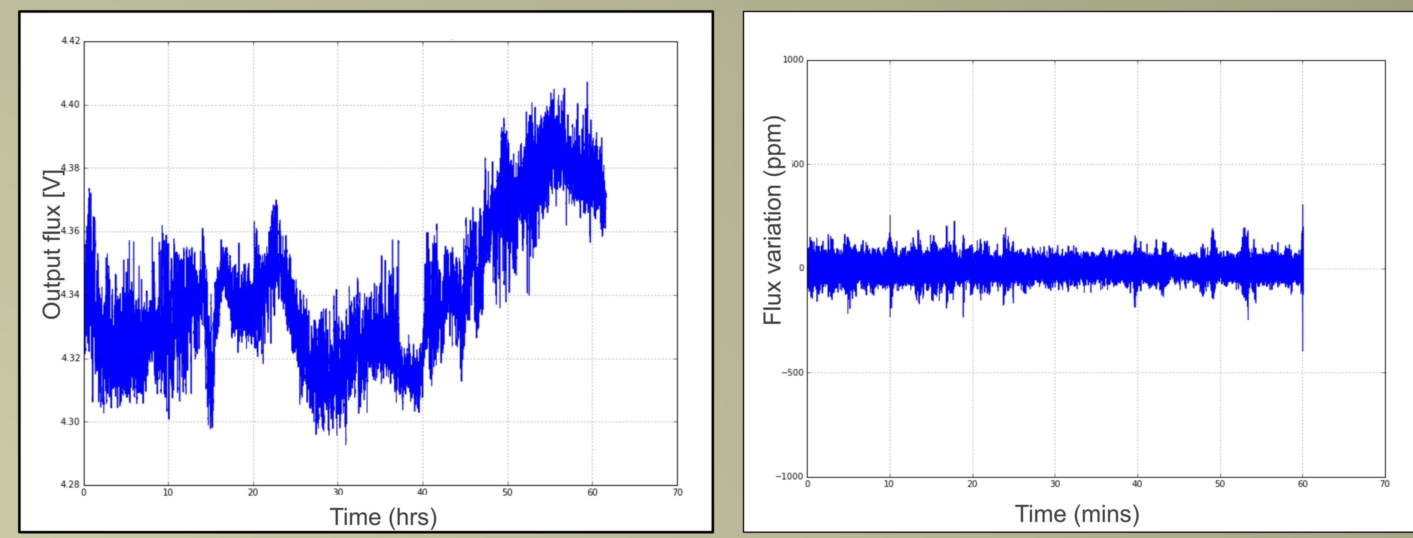

Figure 4: LDLS output flux before and after stabilization.

Gain Measurements:

The gain is the conversion factor between the electrons collected in the CCD and the Analog-to-Digital readout Units (ADU). Gain is dependent on the temperature of the CCD and is measured using the Fe55 and Cd109 Kα and Kβ peaks. The gain measured using X-rays is 6.99 ± 0.01 e-/ADU.

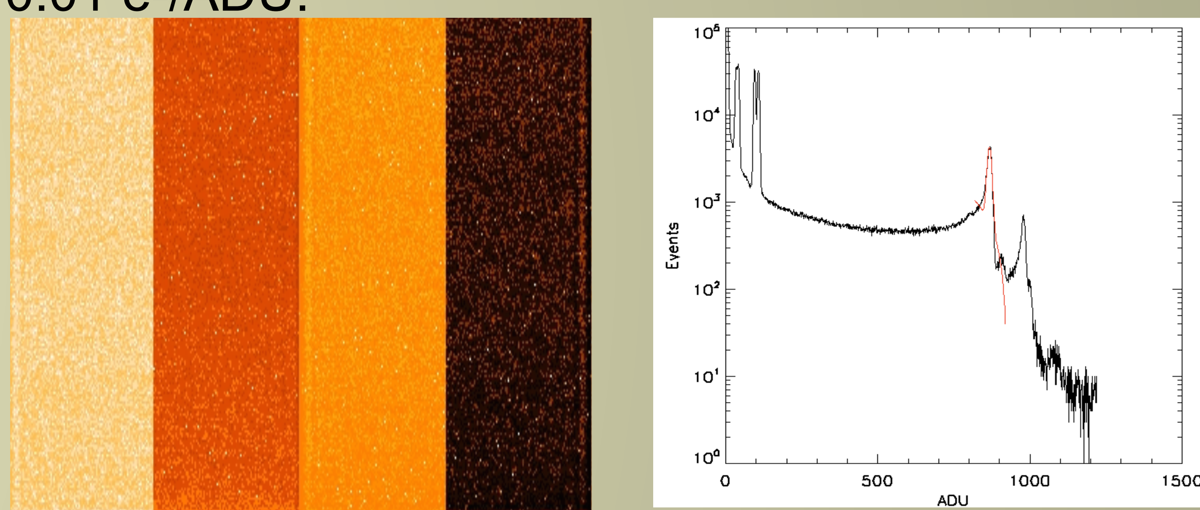

Figure 5: A ^{109}Cd source is used to create X-ray events.

Quantum Efficiency:

For the data presented below, flight-grade engineering CCD along with pre-flight electronics was used. The operating temperature of the CCD was maintained at -25℃, -50℃ and -70℃. The exposure time was 2 seconds.

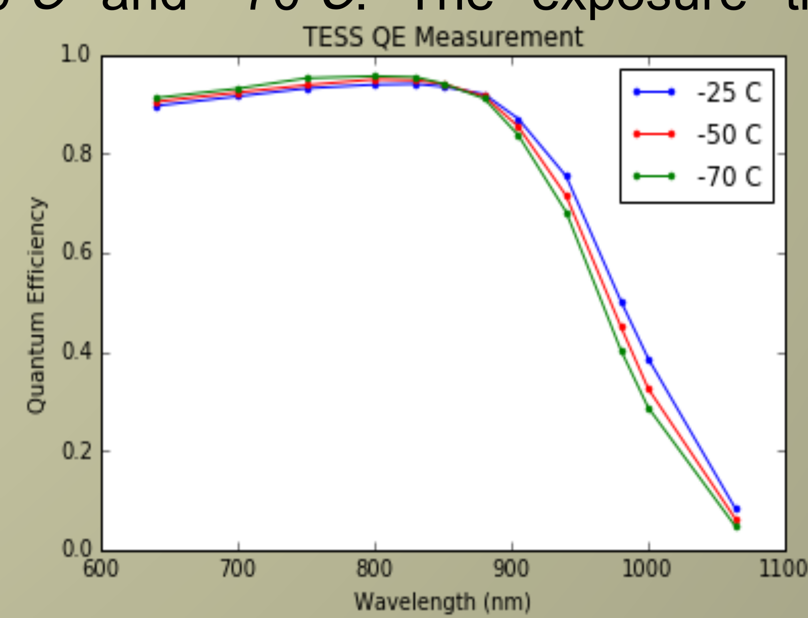

Figure 6: Measured QE curve of a 100-micron thick CCID-80 device.

REFERENCES

1. Ricker, G. R., Winn, J.N., Vanderspek, R., et al., “Transiting Exoplanet Survey Satellite,” J.Ast. Inst. Sys. 1, 014003 (2015).
2. Groom, Donald E., et al. "Quantum efficiency of a back-illuminated CCD imager: an optical approach." *Electronic Imaging'99*. International Society for Optics and Photonics, 1999.
3. Wildi, F. P., A. Deline, and B. Chazelas. "A white super-stable source for the metrology of astronomical photometers." *SPIE Optical Engineering+ Applications*. International Society for Optics and Photonics, 2015.