VUV Testing of Science Cameras at MSFC: QE measurement of the CLASP Flight Cameras

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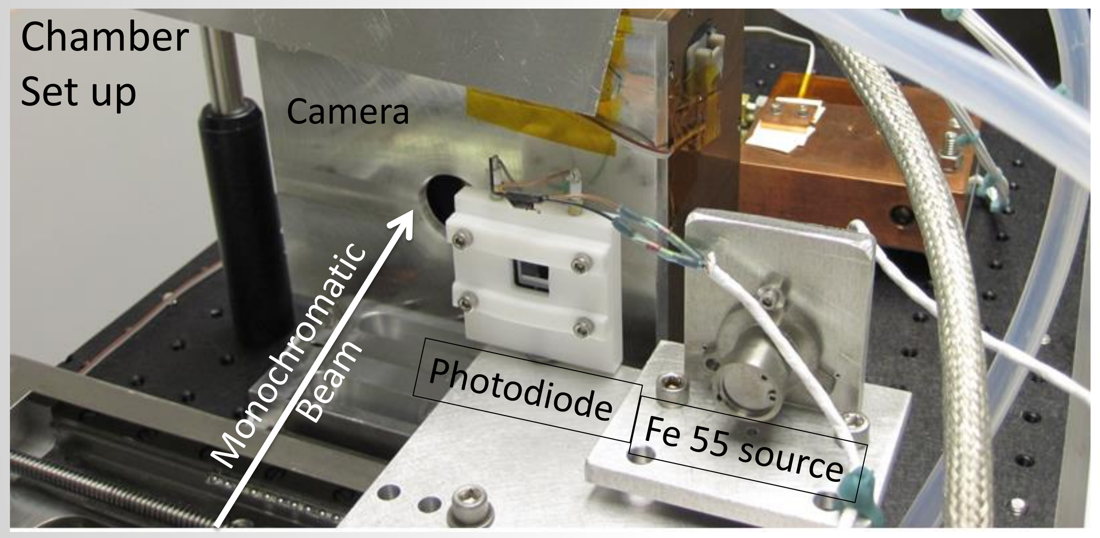
Abstract

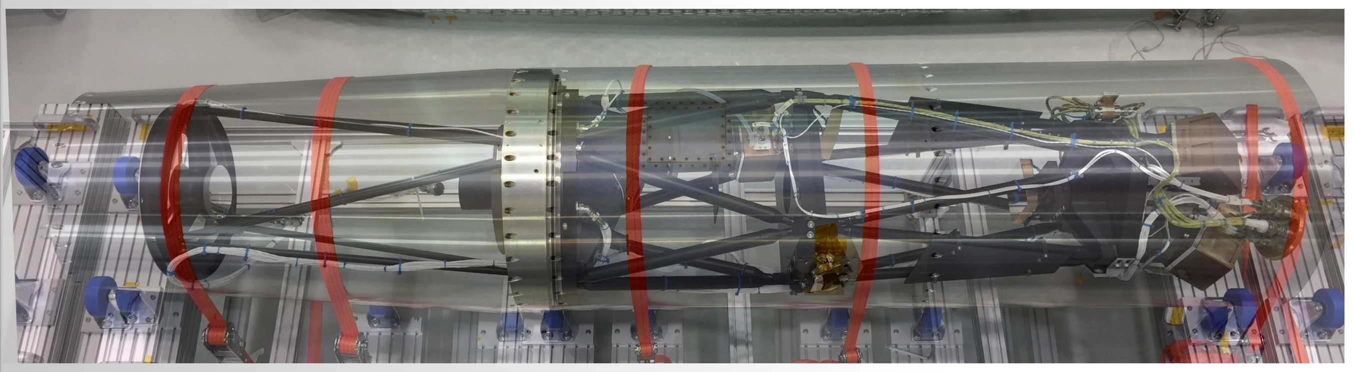
The NASA Marshall Space Flight Center (MSFC) has developed a science camera suitable for sub-orbital missions for observations in the UV, EUV and soft X-ray. Six cameras were built and tested for the Chromospheric Lyman-Alpha Spectro-Polarimeter (CLASP), a joint National Astronomical Observatory of Japan (NAOJ) and MSFC sounding rocket mission. The CLASP camera design includes a frame-transfer e2v CCD57-10 512x512 detector, dual channel analog readout electronics and an internally mounted cold block. At the flight operating temperature of -20C, the CLASP cameras achieved the low-noise performance requirements (≤25 e- read noise and ≤ 10 e-/sec/pix dark current), in addition to maintaining a stable gain of ≈ 2.0 e-/DN. The e2v CCD57-10 detectors were coated with Lumogen-E to improve quantum efficiency (QE) at the Lyman-α wavelength. A vacuum ultra-violet (VUV) monochromator and a NIST calibrated photodiode were employed to measure the QE of each camera. Four flight-like cameras were tested in a high-vacuum chamber, which was configured to operate several tests intended to verify the QE, gain, read noise, dark current and residual non-linearity of the CCD. We present and discuss the QE measurements performed on the CLASP cameras. We also discuss the high-vacuum system outfitted for testing of UV and EUV science cameras at MSFC.

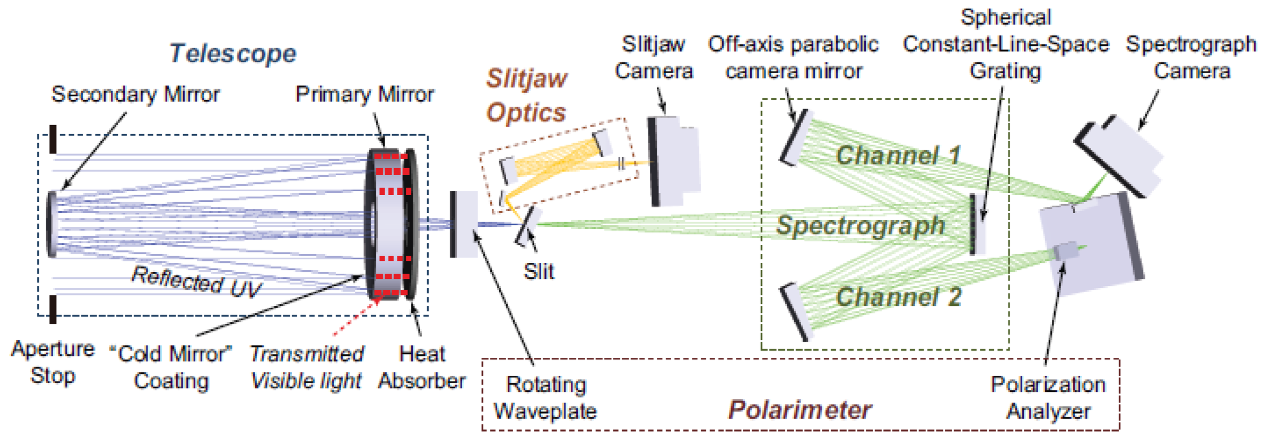
Introduction

- The purpose of CLASP is to measure the linear polarization profiles caused by scattering processes and the Hanle effect in the Ly-α line (121.6 nm).
- Highly sensitive polarization measurements impose strict performance requirements on the CLASP cameras.
- The CLASP cameras achieved stable, high speed, low-noise performance.
- Extensive testing was performed in high-vacuum (<10E-6 torr) to measure and verify performance requirements for dark current, read noise, gain, and quantum efficiency.



CLASP Instrument





Telescope	
Type	Cassegrain
Aperture	ø277.4 mm
Eff. Focal Length	2614 mm (F/9.42)
Primary Mirror	ø290 mm (clear aperture), F/3.54
Secondary Mirror	ø119.4 mm
Visible Light Rejection	"Cold Mirror" coating on primary mirror

Slit	
Slit Width	18.4 μm (1.45 arcsec)
Slit Length	5.1 mm (400 arcsec)

Slitjaw Imaging System	
Wavelength	Lyα (band-pass filter)
Optics	- Fold mirror with multilayer coating - Off-axis parabola x 2 - Lyα filter x 2
Detector	512 x 512 CCD, 13μm pixel
Plate Scale	1.03 arcsec / pixel
Resolution	2.9 arcsec (spot RMS diameter)
FOV	527 arcsec x 527 arcsec

Polarimeter	
Measurements	Stokes I, Q, U
Capability	Simultaneous measurement of orthogonal polarizations
Optics	- Rotating 1/2 waveplate - Polarization analyzer x 2

Spectrograph	
Spectrograph Type	Inverse Wadsworth mounting
Grating Type	Spherical constant-line-space with 3600 mm^{-1} groove density
Grating Size	ø106 mm (clear aperture)
Wavelength	Optimized for Lyα (121.567 nm)
Camera Mirror	Off-axis parabola
Resolution	0.01 nm (spectral; RMS diameter) 2.8 arcsec (spatial; RMS diameter)
Magnification	0.73

Spectrograph Cameras	
Detector	512 x 512 CCD, 13μm pixel
Exposure Time	0.3 sec (nominal)
Plate Scale	0.0048 nm / pixel (spectral) 1.40 arcsec / pixel (spatial)
Field of View	121.567±0.61 nm (spectral) 400 arcsec (along slit)

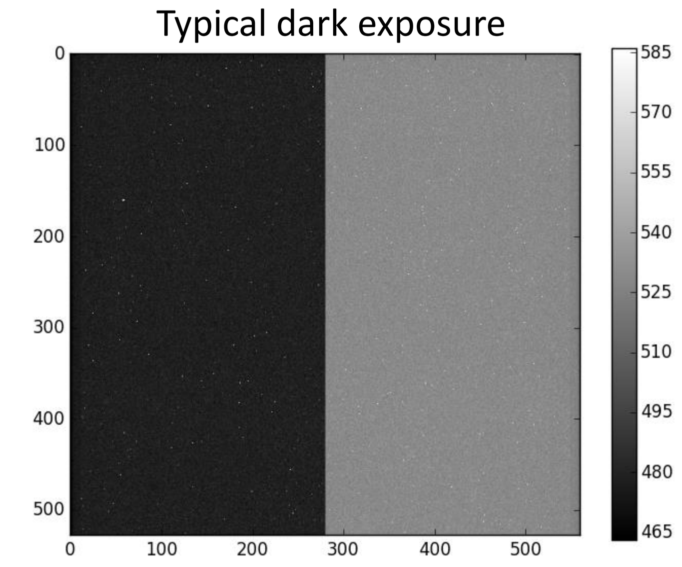
Results

Characteristic	Requirement	SN1	SN4	SN5	SN6
Left/Right Gain [e- / DN]	2.0 ± 0.5	1.97 / 2.04	1.92 / 2.04	1.94 / 2.03	1.88 / 1.90
Left/Right Dark Current [e-/sec/pix]	< 10	0.3 / 0.2	0.4 / 0.3	0.3 / 0.1	0.5 / 0.4
Left/Right Read Noise [e-]	≤ 25	5.4 / 5.6	5.3 / 5.6	5.5 / 5.6	5.6 / 5.4
Quantum Efficiency [%] *	30*	14.2 ± 1.5	12.1 ± 1.5	20.0 ± 2.5	20.0 ± 1.9

* Quantum efficiency requirement based on data sheet of QE of Lumogen from Princeton Instruments. This was later found to be an error in the data sheet.

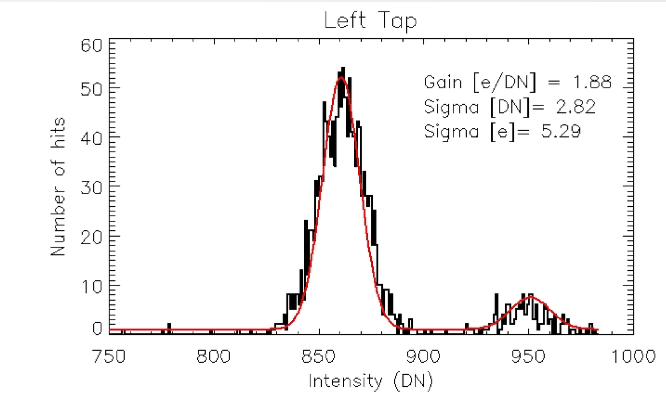
Dark Current & Read Noise

- To determine dark current, CCD was cooled to -20 C (the expected flight temperature for CLASP).
- A set of dark images was obtained at a range of exposure times between 0.3 ms (the flight exposure time) and 10 s.
- The average dark current was calculated for each exposure time. A linear regression was then performed to determine the average dark current rate.
- The standard deviation in the signal was also calculated to determine read noise.
- Each side of the detector was treated independently.



Camera Gain

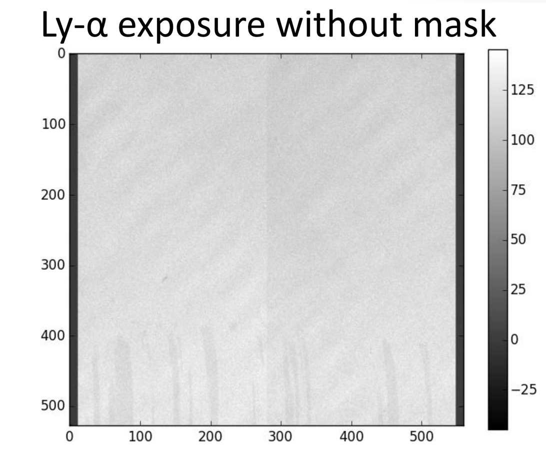
- To calculate camera gain, an Fe 55 source was moved in front of the detector (see Chamber set up figure).
- Data was recorded with a 0.3 s exposure time for 10 minutes.
- Fe 55 decays and releases photons of fixed, known energies. This energy can be deposited into one or more pixels. We selected pixels from the data that appeared to be "single pixel hits" meaning the pixel had a high signal and all pixels surrounding it was at the level of the noise.
- We generated histograms of the signal associated with single pixel hits and fit with a quadruple Gaussian functions. The fitting routine fixed the width of the Gaussians to be the noise and the relative amplitudes and centroids to be the known offsets from atomic data.

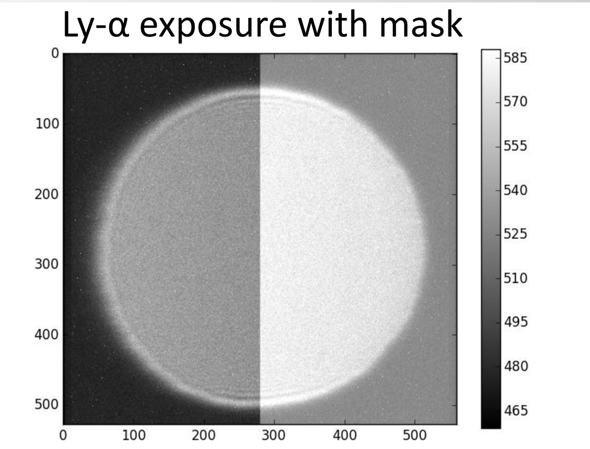


An example of the gain calculation for a single tap of one camera. The black line is the data, the red line is the fit.

QE Measurement

- The quantum efficiency at Ly-α of each of the 4 flight-like cameras was measured in high-vacuum (1.0 x 10^6 torr).
- The cameras were mounted to a C-plate fixed to an optical bench in the chamber, while the NIST calibrated photodiode was mounted to a translation stage positioned in front of the C-mount (see Chamber Set up Figure).
- The camera and photodiode were exposed to the monochromatic Ly-α beam (originating from a deuterium lamp and monochromater tuned to Ly-α) in alternating sets, over a period of a one hour. Multiple data points were needed to average out any instability of the deuterium lamp.
- After the initial data was taken, it was determined the beam from the monochromater was not uniform. A mask was inserted to insure the same part of the beam was sampled by the camera and photodiode. SN1 was re-tested. A correction factor was determined from the re-test and applied to all camera measurements.





Conclusion

- The camera designed by Marshall Space Flight Center meets the CLASP requirements for read noise, dark current, and gain.
- The quantum efficiency measured for the flight cameras was lower than expected based on the Princeton Instruments data sheet for Lumogen. It was determined through discussions with the vendor that the data sheet was in error.
- Cameras based on the CLASP design, but with larger detectors, will be used for the upcoming Hi-C, ESIS, and MaGIXS rocket instruments.

Acknowledgements

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