Linearity Analysis and Efficiency Testing of The Chromospheric Lyman-Alpha Spectro-Polarimeter (CLASP) Science Cameras for Flight

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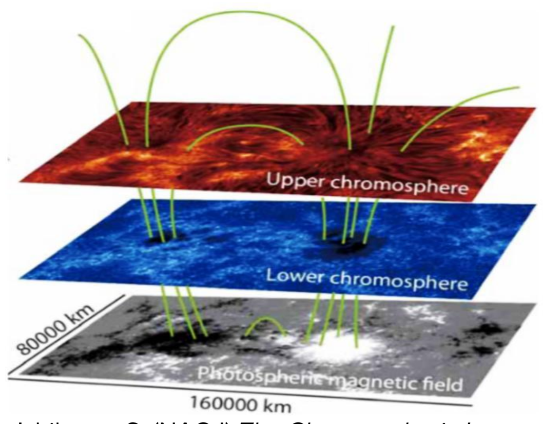
Abstract

To unveil the complexity of the solar atmosphere, measurement of the magnetic field in the upper chromosphere and transition region is fundamentally important, as this is where the forces transition from plasma to magnetic field dominated. Measurements of the field are also needed to elucidate the energy transport from the lower atmospheric regions to the corona beyond. Such an advance in heliospheric knowledge became possible with the first flight of the international solar sounding rocket mission, CLASP. For the first time, linear polarization was measured in Hydrogen Lyman-Alpha at 121.60 nm in September 2015. For linear polarization measurements in this emission line, high sensitivity is required due to the relatively weak polarization signal compared to the intensity. To achieve this high sensitivity, a low-noise sensor is required with good knowledge of its characterization, including linearity. This work presents further refinement of the linearity characterization of the cameras flown in 2015. We compared the current from a photodiode in the light path to the digital response of the detectors. Pre-flight CCD linearity measurements were taken for all three flight cameras and calculations of the linear fits and residuals were performed. However, the previous calculations included a smearing pattern and a digital saturation region on the detectors which were not properly taken into account. The calculations have been adjusted and were repeated for manually chosen sub-regions on the detectors that were found not to be affected. We present a brief overview of the instrument, the calibration data and procedures, and a comparison of the old and new linearity results. The CLASP cameras will be reused for the successor mission, CLASP2, which will measure the Magnesium II h & k emission lines between 279.45 nm and 280.35 nm. The new approach will help to better prepare for and to improve the camera characterization for CLASP2.

1. Scientific Motivation

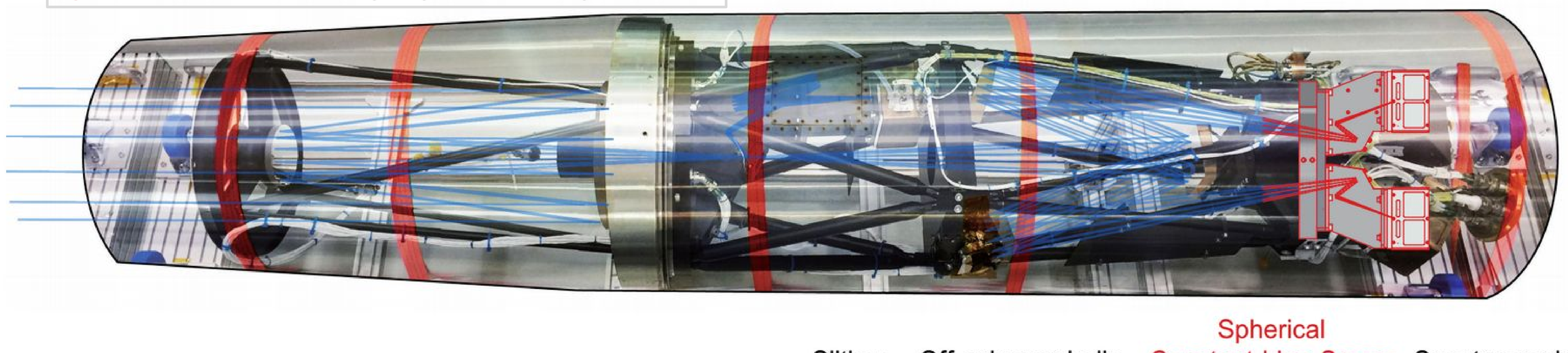
To understand the solar atmosphere, measurement of the magnetic field in the upper chromosphere and transition region is fundamentally important, as this is where the forces transition from plasma to magnetic field dominated. In the photosphere, the magnetic field is moved by the plasma. There, gas force is greater than magnetic force. In the corona, plasma follows the magnetic field, where magnetic force is then greater than gas force. Measurement and interpretation of the strength and structure of the magnetic field in such regions is the intent of this project.

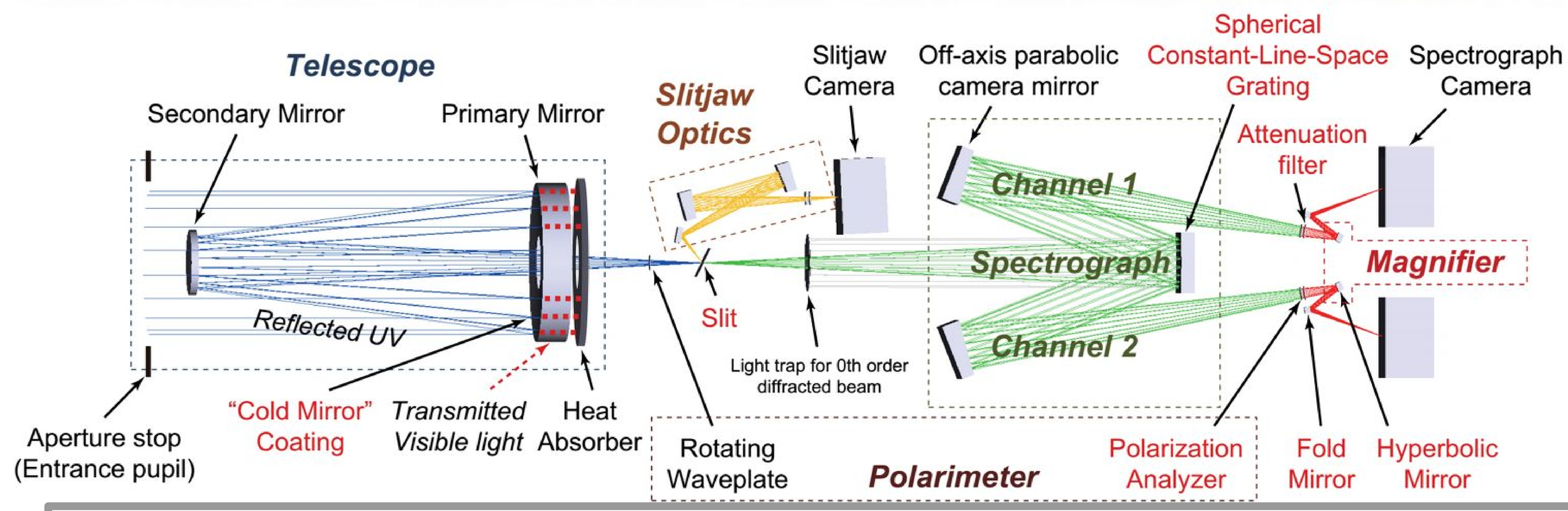


Ishikawa, S. (NAOJ) *The Chromospheric Lyman-Alpha Spectro-Polarimeter* [PDF document]

Figure 1: Two-dimensional observations of the 3-dimensional solar atmosphere. Green lines represent likely magnetic field lines.

Figure 2: CLASP-2 instrument design. Figure from Narukage et al., 2016





2. Introduction

The CLASP instrument measures the polarization in the Hydrogen Lyman-Alpha line, which comes from the chromosphere. The polarization in this ultraviolet line contains information about the chromospheric magnetic field. This polarization signal is very weak; to measure it, it is important to characterize the entire CLASP system, including the camera.

The first measurement of linear polarization in the Hydrogen Lyman-Alpha emission line at 121.60 nm occurred from the successful international solar sounding rocket mission, the Chromospheric Lyman-Alpha Spectro-Polarimeter (CLASP) launched in September of 2015.

4. Project Objectives and Description

The focal objective of this project involved characterizing the camera linearity by improving the linearity analysis of CLASP-1 to gain a greater understanding of the cameras for their second flight on on the CLASP-2 payload.

With miniscule intensity variation to begin with, maintaining low noise levels is required to prevent the polarization signal from drowning in noise. Hence for linear polarization measurements in the H Lyman-Alpha emission line, high sensitivity is required due to the relatively low strength polarization signal compared to the intensity. To achieve high sensitivity, a low-noise sensor is required with good knowledge of its characterization, including linearity.

We compared the current from a photodiode in the light path to the digital response of the detectors. Pre-flight CCD linearity measurements were taken for all three flight cameras and calculations of the linear fits and residuals were performed.

3. Instrument Assembly

The CLASP-1 payload was designed to survey ultraviolet spectra formed by hydrogen ions residing in the chromosphere, collectively forging the Hydrogen Lyman-Alpha UV emission line. It consists of a Cassegrain telescope, Slitjaw optics, and a Spectro-polarimeter. Within the Cassegrain telescope resides a continuously rotating half waveplate that allows for selection of the linear polarization direction. Also found within the Cassegrain telescope, the cold mirror permits for only a slim, narrow band to reflect the target wavelength, Hydrogen Lyman-Alpha, then rejects and transmits remaining visible light collected within the telescope.

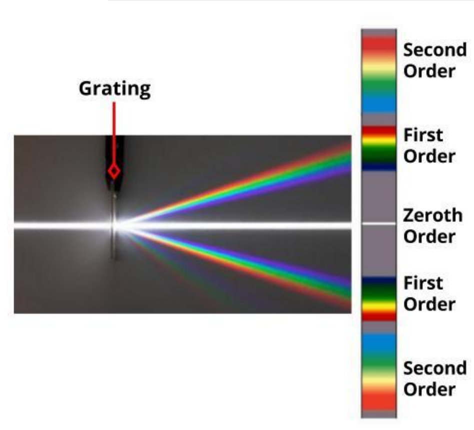


Figure 3: A general display of light diffraction, casting its 0th, 1st, and 2nd orders. This emulates the diffraction in the Spectro-Polarimeter (Figure 4).

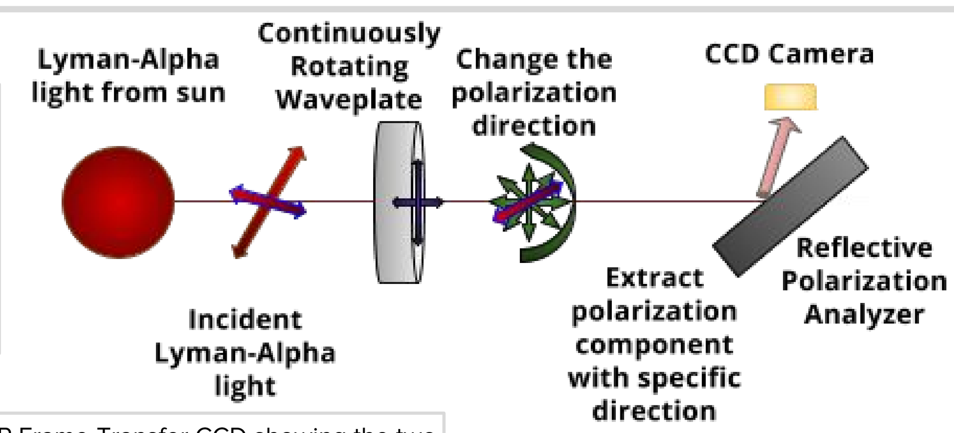


Figure 4: Displays general travel of light, polarization process, and camera data collection within CLASP-1 instrument.

5. Design and Operation of Science Cameras

The science cameras used contain frame-transfer ccds. The composition of the ccds themselves persist of dual parallel register clocks, two individual components, including an image array and storage array. The image array is a light-sensitive photodiode that collects photons casted onto the ccd. Essentially, the image focusing is done in the image array, where it then gets temporarily held prior to readout in the storage array. The parallel register clocks allow for charge to shift independently among the two arrays. This operation efficiently enables for continuous frame transfer at rapid succession and in the absence of a shutter.

Frame transfer is performed by shifting rows individually in parallel to reach the serial shift register where it is then shifted through output as quantifiable data.

Figure 5: A CLASP Frame-Transfer CCD showing the two distinct regions: image and storage array. The dark area is the image region, where light is gathered. The opaque light shield on the storage array blocks photons from reaching the rest of the sensor.

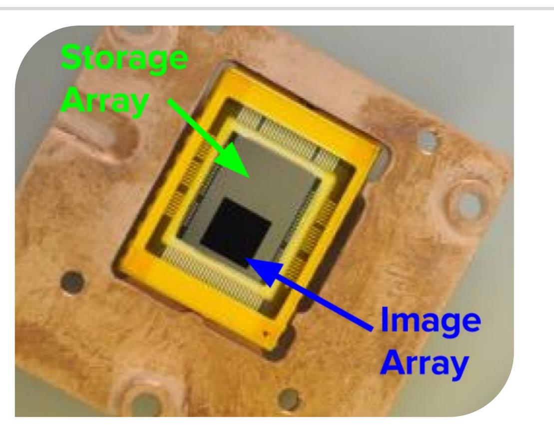
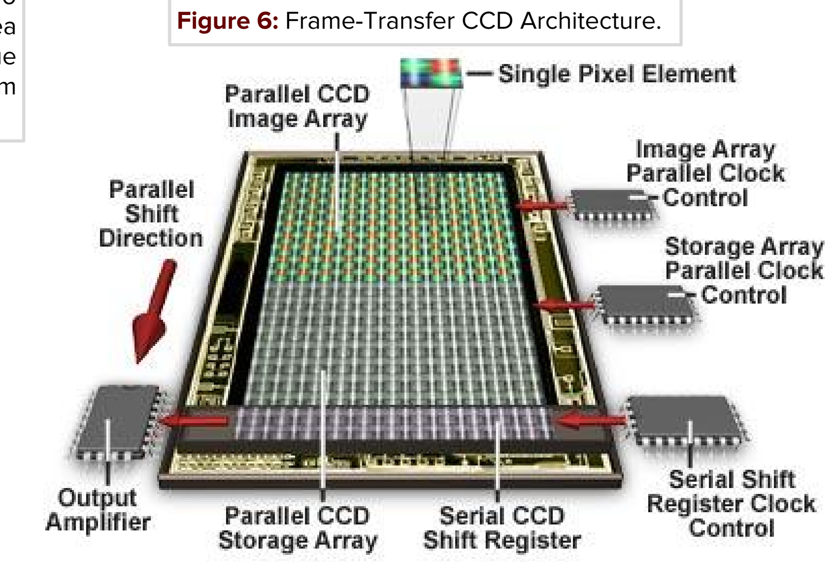
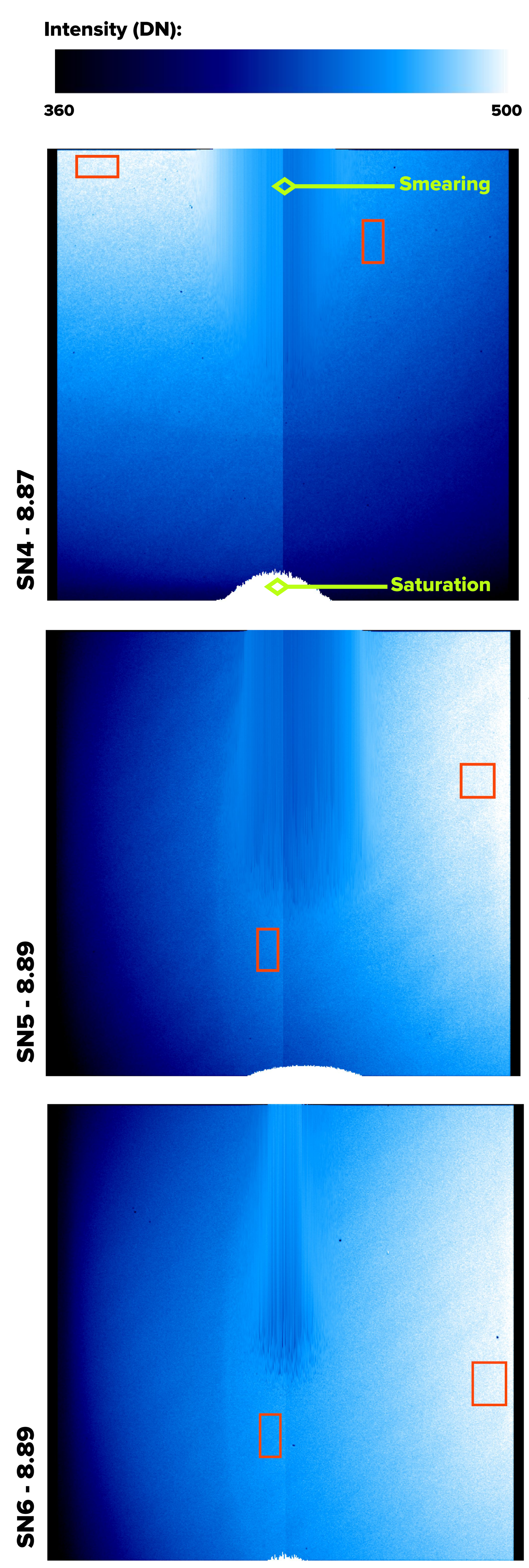


Figure 6: Frame-Transfer CCD Architecture.





Figures 9-11: Camera No. - Voltage (Brightness). Saturated frame for each CLASP camera. These images show the saturation and smearing pattern in strongly illuminated frames.

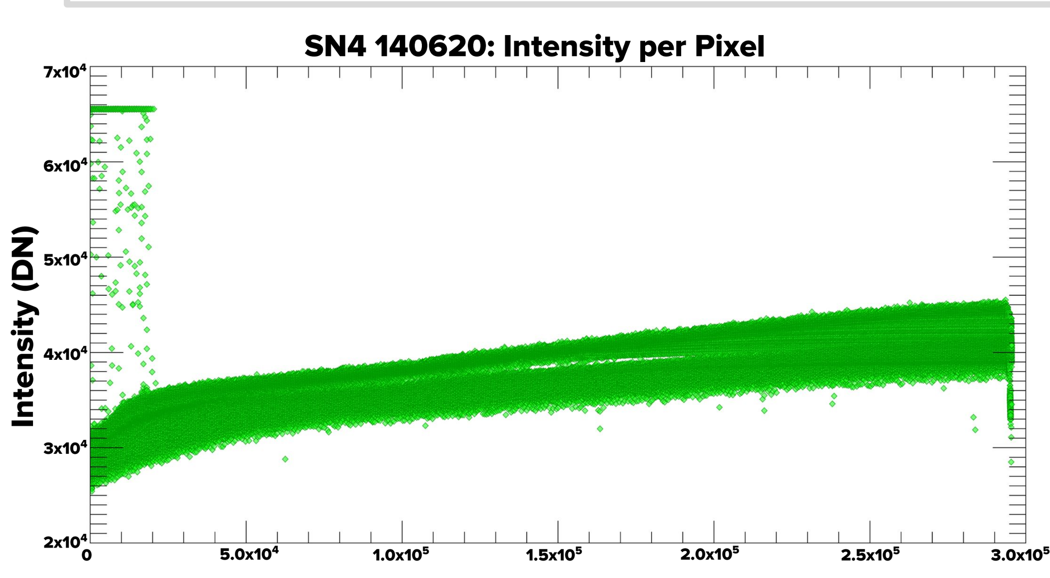


Figure 7: Intensity per Pixel for the SN4 image on the left. Notice the few points above the main concentration. These are the pixels in the saturation region.

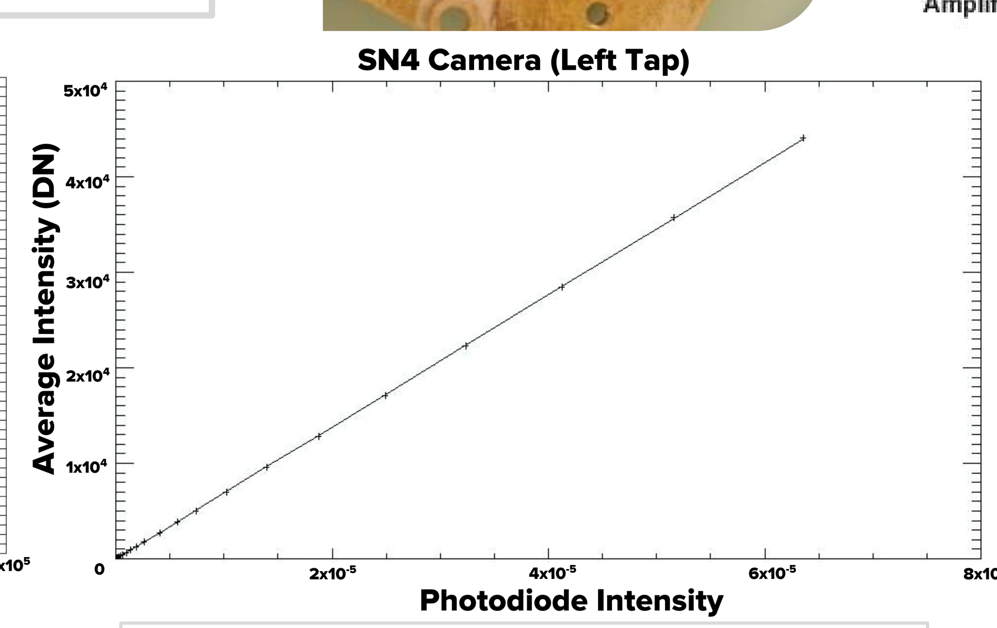


Figure 8: Linearity plot for left half of SN4. Average Intensity (DN) in a subregion of the camera (left red box in top-most Figure 9) compared with the average current recorded by the photodiode.

6. Linearity Analysis

The previous calculations included an unexpected smearing pattern and a digital saturation region on the detectors which were not properly taken into account. In our camera, each pixel is allocated 16 bits of memory. Digital saturation occurs when the digital signal from any pixel is over 2^{16}. Full well saturation, on the contrary, occurs when the incident light produces more electrons in the pixel than can be physically contained.

Observation of the images with highest voltages just before they reach saturation display a middle smear region coupled with saturation that is a steady feature throughout all cameras. The saturation and smearing regions are related. Since these regions are not always located within the brightest area, we cannot conclude the smearing and saturations originate from digital or full well saturation due to the incoming light. Digital sensors are designed to dissipate excess charge exceeding the full well capacity, for very bright parts of the scene, excess charge from a saturated pixel can spill over to adjacent regions (Hasinoff / Google Inc. & MIT) which is known as blooming, a possible explanation for these smear regions. Though another likely reason for smearing and saturation among these images could be a result of not having the readout register properly cleared prior to sampling images.

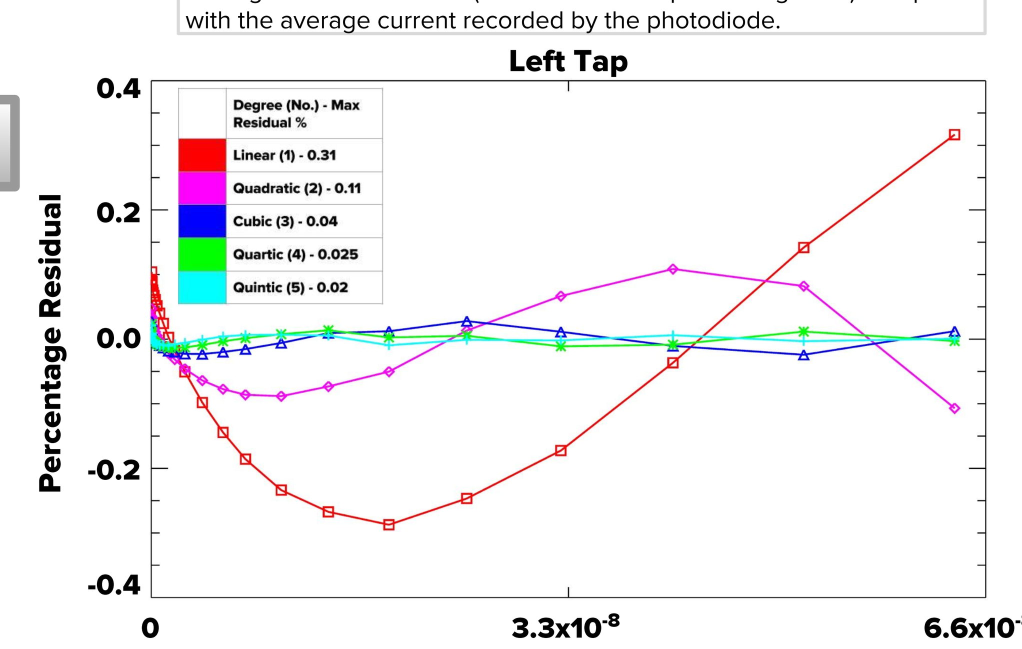


Figure 12: Photodiode Intensity and Percentage Residual comparison for differing degrees (1-5) of polynomial fits to linearity data for the left tap of the SN4 camera.

We tried a variety of polynomial functions to fit the linearity relationship. We found that as the degree of the polynomial is increased, the maximum percentage residual decreases. In reference to Figure 11, the 1st degree, the max residual of 0.31% completely differs in comparison to the 5th degree, 0.02%. The results show a smooth residual, perhaps not quite a polynomial, but is close enough.

7. A New Approach

The new approach will help to better prepare for and to improve the camera characterization for CLASP2 launch in Spring of 2019.

The cameras from the first flight of CLASP-1 will be reused for the successor mission, CLASP2, which will measure the emission lines at longer wavelengths, Magnesium II h & k, which lie between 279.45 nm and 280.35 nm.

8. References & Acknowledgements

Hasinoff / Google Inc., S. W., & MIT. (n.d.). Saturation (imaging).

Ishikawa, S. (NAOJ) *The Chromospheric Lyman-Alpha Spectro-Polarimeter* [PDF document]

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