Novel Measurements of Solar Corona during the July 2 2019 Total Eclipse over Chile

Austin T Monaghan,[1,2,3] Paul Bryans, [1] Ben Berkey, [1] & Yeimy Rivera[1,4]

1 - High Altitude Observatory, National Center for Atmospheric Research

2 - Colorado School of Mines

3 – Laboratory for Atmospheric and Space Physics, CU Boulder

4 - University of Michigan

Abstract

Physical features of the solar corona such as temperature, density, and magnetic field, have been demonstrated to affect the polarization of coronal light making polarimetry one of the most crucial diagnostic tools for solar research. Although the history of polarimetry in solar physics is long, the ever-advancing world of technology continually provides opportunities for implementation with new instruments and new methods. The pursuit of new measurements could shed light on long-standing unsolved problems of the solar corona, and increase our understanding of the corona, solar weather, and our sun. The PolarCam snapshot micropolarizer camera from 4D Technologies could hold the potential for novel exploration of the solar corona. Developed for use in interferometric measurements, the PolarCam is sensitive to linearly polarized light on a pixel scale and has the unique potential for size- and weight-constrained measurements such as CubeSat deployment. Similarly, the relatively unexplored Si X emission line (1.43 microns) could provide novel measurements of the solar corona, and shows great promise for magnetometry.

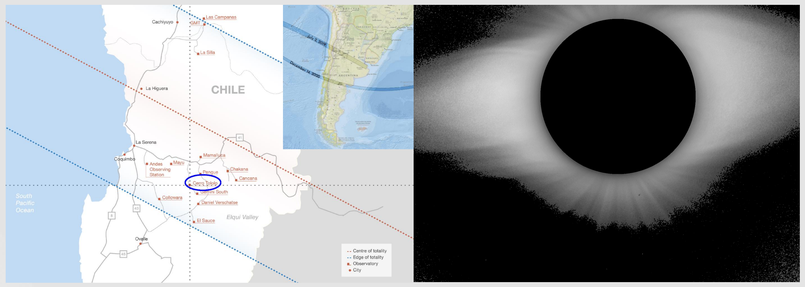
The 2019 Total Solar Eclipse in Chile provided an opportunity for the exploration of the Si X line as well as an investigation into the potential of PolarCam and similar technology. A team from the High Altitude Observatory (HAO) in Boulder observed the eclipse from Cerro Tololo Inter-American Observatory, taking measurements of Si X (1.43 micron) and white-light (734 nm) polarization. PolarCam observations, taken during total solar eclipse, were quantitatively compared with ground-based white-light coronagraph measurements, demonstrating the capabilities and limitations of such a detector for coronal measurements. The instrument's potential for future deployment in expeditions or cubesat missions is also evaluated. Finally, preliminary data from the Si X experiment is presented and possible avenues for further exploration are proposed.

Eclipse Chasing: Why Bother?

Instruments like NCAR's Mauna Loa K-Coronagraph (K-Cor) are capable of measuring features of the solar corona, but only with **great effort and cost.**

Daytime sky brightness creates a substantial noise signal in coronal data, as the solar disk is approximately 1,000,000 x brighter than the corona. Additionally, sky light is about 75% polarized, adding to the difficulty of polarimetric observations.

During an eclipse, the skies are over 1,000 x darker, reducing this noise level by a substantial factor. This factor could be the difference between detecting or missing coronal features!



***(Left)** Map with eclipse path provided by ESO with minor changes to the original. Top right map is copyrighted Michael Zeiler 2014 – 2017. **(Right)** PolarCam degree of linear polarization image (dolp) = polarization brightness / Intensity.*

Instruments and Controls

White light polarization images were acquired using the PolarCam: a novel pixelated-polarizer based snapshot imager capable of taking instantaneous polarimetric measurements. This camera is equipped with a 2.0 MP CMOS sensor masked by an array of pixel-matched linear polarizers in four alternating orientations. The polarizer array eliminates the need for instrumental polarization optics, which introduces many possibilities in spatially-constrained experiments such as CubeSat missions (Brock et. al.). The PolarCam system is shown below-left. Data acquisition and instrument control on both experiments was executed using NI LabView. 4D Technologies provides LabView libraries with the PolarCam.

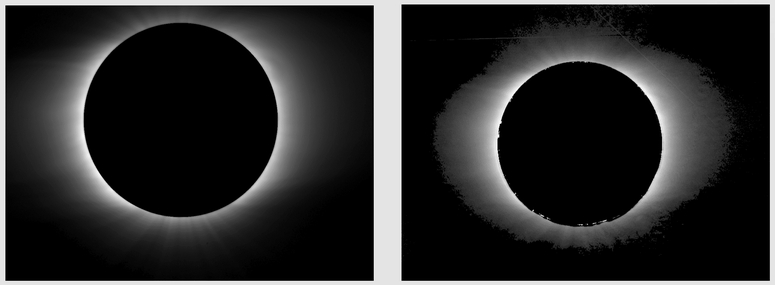
(Left) PolarCam camera (blue) mounted on a Stellarvue SV70T telescope. Note that no further instrumental optics are required for full polarization data acquisition. (Right) Si X experiment instruments, including a Rockwell Scientific Hawaii IR camera. In contrast to the white-light experiment, two filter wheels are required for polarization measurements.

White-light Polarization Experiment

Observations were conducted at NSF's Cerro Tololo Inter-American Observatory (CTIO), approximately 40 km SW of the centerline of the eclipse at an elevation of 2022 m.

Totality lasted approximately 2m 06s with maximum occurring at about 20:39:35 UT.

White-light images were collected over totality at 70 ms exposures. To eliminate noise, images were averaged from 20:39:00.0382 to 20:39:05.0945, a total of 73 images. **Qualitative coronal features are comparable to K-Cor results**, demonstrating PolarCam's imaging potential.

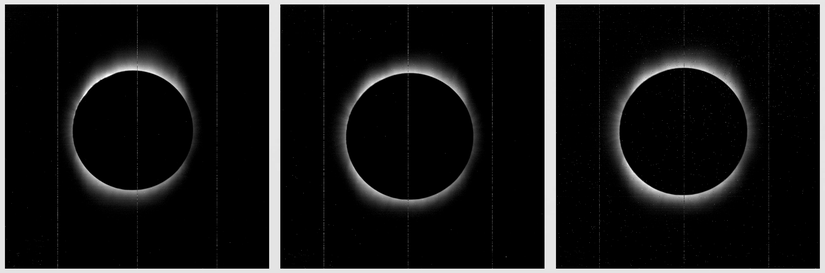


Calibrated pB images from PolarCam (left) and the NCAR Mauna Loa K-Coronagraph (K-Cor) instrument (right). K-Cor observes every day (weather permitting). More information and L1.5 data are available on the MLSO website: https://www2.hao.ucar.edu/mlso/mlso-home-page.

Si X Investigation – A First Look

In contrast to PolarCam, the Si X experiment required instrumental polarization optics for polarimetric observations. The totality sequence consisted of first acquiring on-band data, 10 seconds per polarizer position. On-band data was followed by a loop of off-band (continuum) data. Images were taken at 250 ms exposures, providing about 42 images per filter / polarizer position. A preliminary look at the Si X data revealed that one of the polarizer positions failed to acquire data. This is only a minor setback, as extracting Stokes parameters from the three remaining positions is possible.

Extracting scientific information from data, such as stokes parameters, will require further calibration.

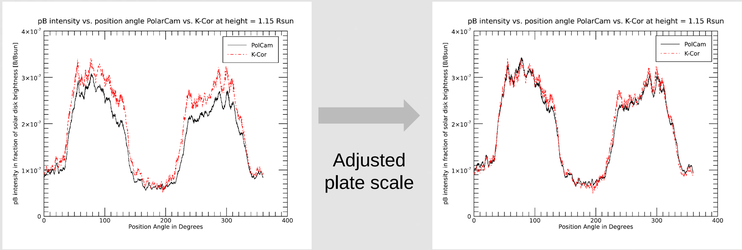


*Flat-dark corrected Si X images for each of the three working polarizer positions averaged over 10 seconds. Although preliminary, **images indicate successful data acquisition** and already coronal features are visible. Full experimental results are currently under analysis.*

Issues to Resolve

Preliminary azimuthal scans of calibrated polarization brightness (pB) show a discrepancy between PolarCam and K-Cor data. Reducing PolarCam's scan height by approximately 3% scales intensity and features to appropriately fit K-Cor data. Conversely, increasing K-Cor scan height by the same factor yield excellent agreement. This suggests an issue with determining scan height as opposed to a discrepancy in measurement. Further analysis could reveal an instrumental source of error.

Other issues include focus and centering issues. While the focus should not have an effect on data, FOV off of Solar North is limited to 1.27 Rsun.



Azimuthal scans of K-Cor and PolarCam at 1.15 Rsun. PolarCam scans appear to overestimate scan height (left). Reducing the scan height provides good agreement with K-Cor (right). Further calibration could reveal an instrumental source for this discrepancy.

IN CONCLUSION prelimary experimental data indicates that

1 – the PolarCam and snapshot imaging polarimeters like it are capable of acquiring high quality coronal data without additional expensive, bulky, and sensitive polarization optics.

2 – the Si X experiment was successful in terms of data acquisition and the results could prove to be a critical new frontier in magnetometry.

3 – Instruments must be further calibrated upon their return for further scientific data evaluation.

References

Brock, Neal et. al. (2011). A pixelated polarizer-based camera for instantaneous interferometric measurements. Proceedings of SPIE. 10.1117/12.896608.

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