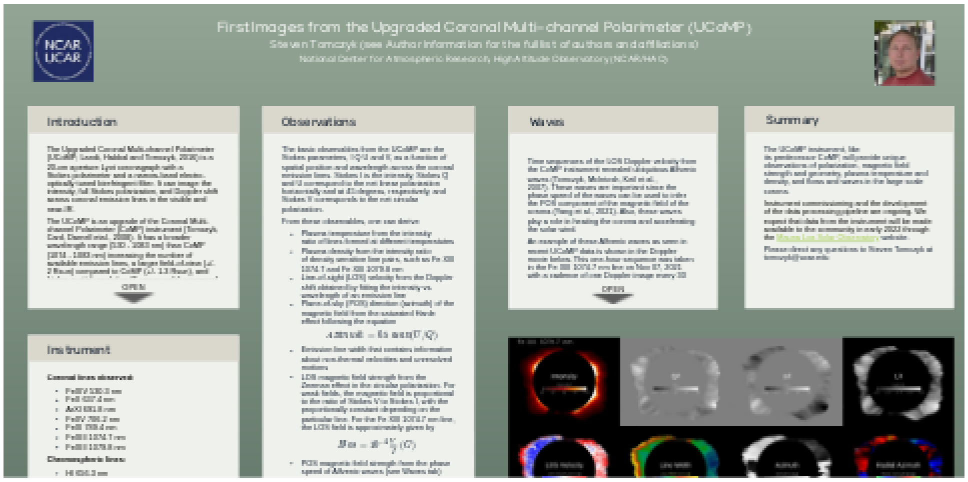
First Images from the Upgraded Coronal Multi-channel Polarimeter (UCoMP)



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PRESENTED AT:

INTRODUCTION

The Upgraded Coronal Multi-channel Polarimeter (UCoMP; Landi, Habbal and Tomczyk, 2016) is a 20-cm aperture Lyot coronagraph with a Stokes polarimeter and a narrow-band electro-optically tuned birefringent filter. It can image the intensity, full Stokes polarization, and Doppler shift across coronal emission lines in the visible and near-IR.

The UCoMP is an upgrade of the Coronal Multi-channel Polarimeter (CoMP) instrument (Tomczyk, Card, Darnell etal., 2008). It has a broader wavelength range (530 - 1083 nm) than CoMP (1074 - 1083 nm) increasing the number of available emission lines, a larger field-of-view (+/- 2 Rsun) compared to CoMP (+/- 1.3 Rsun), and higher spatial resolution (6 arcseconds) compared to CoMP (9 arcseconds). The UCoMP demonstrates the technology of a large aperture (50 mm) tunable birefringent filter based on Lithium Niobate crystals and is a pathfinder instrument for the Coronal Solar Magnetism Observatory (Tomczyk et al., 2016). The instrument is located at the Mauna Loa Solar Observatory (MLSO) of HAO/NCAR.

The UCoMP was installed in the Spring of 2021, and started taking data May 26, 2021 and is currently undergoing comissioning.

INSTRUMENT

Coronal lines observed:

- FeXIV 530.3 nm
- FeX 637.4 nm
- ArXI 691.8 nm
- FeXV 706.2 nm
- FeXI 789.4 nm
- FeXIII 1074.7 nm
- FeXIII 1079.8 nm

Chromospheric lines:

- HI 656.3 nm
- HeI 1083 nm

Spatial Resolution:

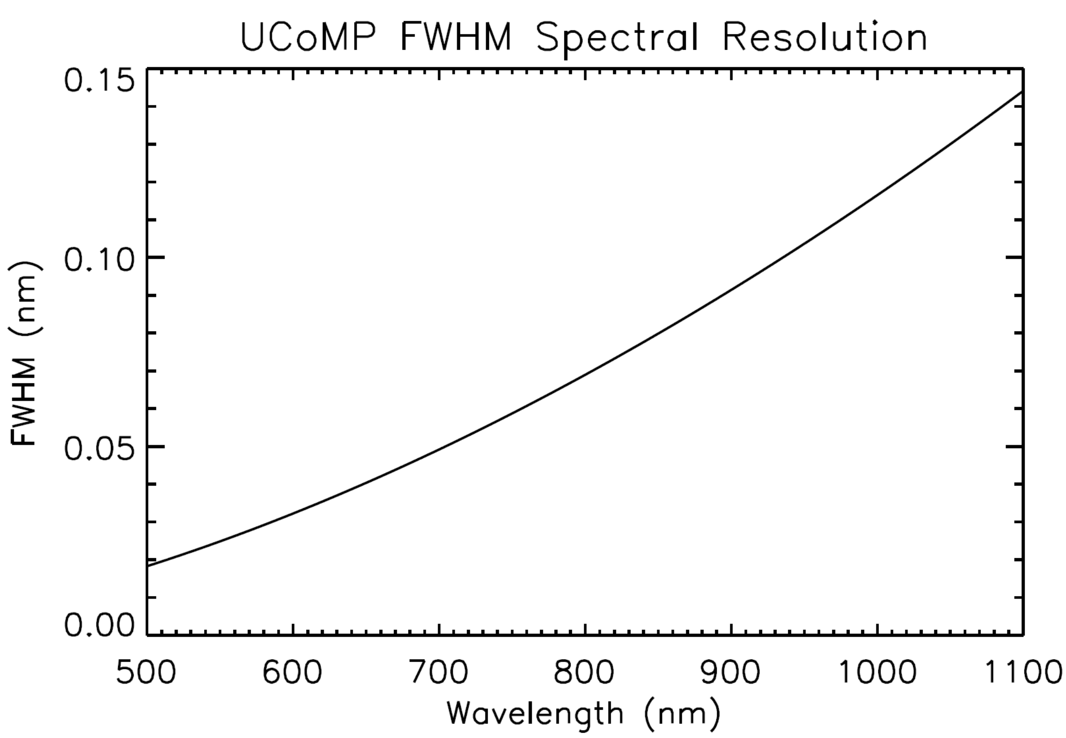
- 6 arcseconds (3 arcseconds/pixel)

Field of View:

- Above the limb from 1.04 to 2 Rsun

Spectral Resolution:

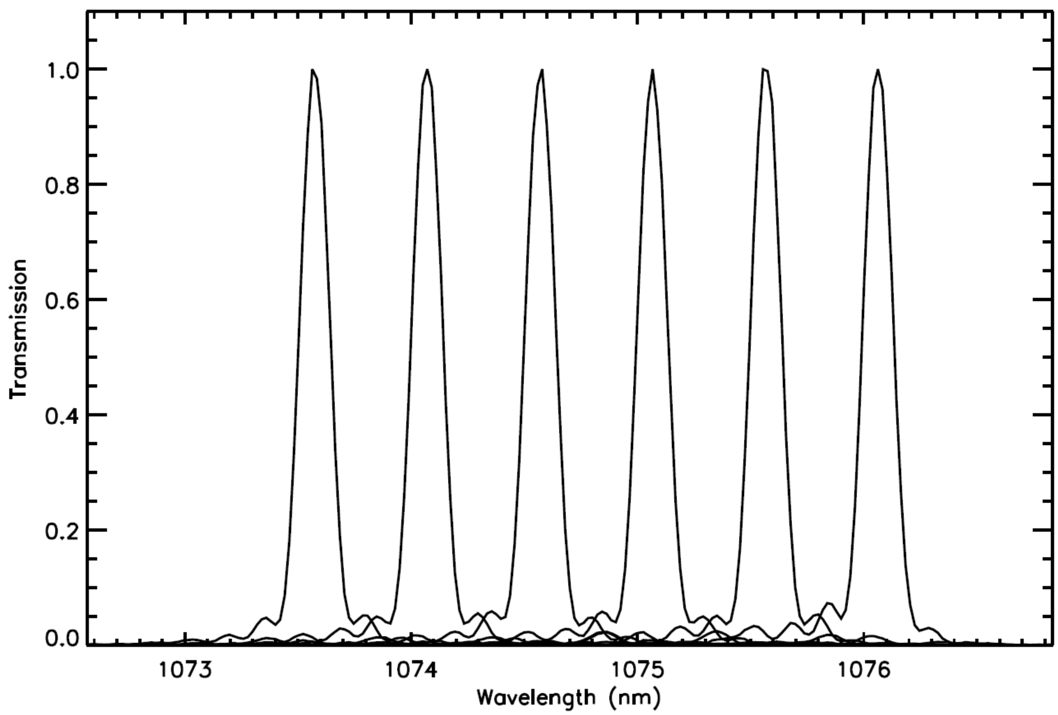
The spectral resolution of the UCoMP is set by the birefringence of the Lithium Niobate crystals in the birefringent filter.



The wavelength variation of the FWHM of the filter is shown in this plot.

Electro-optical tunability:

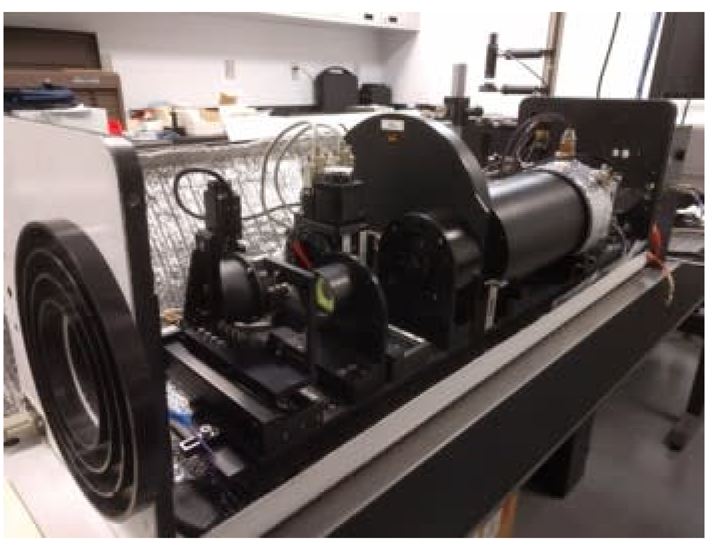
The UCoMP is tuned by varying the voltages to the 5 Nematic Liquid Crystals in the birefringent filter.



An example of 6 tunings of the filter in the vicinity of the Fe XIII 1074.7 nm line is shown here.

Polarimeter:

Polarization is encoded into intensity by a modulator consisting of 2 Ferro-electric liquid crystals and a fixed waveplate, followed by a polarizer (Tomczyk, Casini, de Wijn and Nelson, 2010). The polarimeter is calibrated by a polarizer and retarder that can be inserted into the beam and independently rotated.



Picture of the back end of the UCoMP instrument taken in the lab before deployment.

OBSERVATIONS

The basic observables from the UCoMP are the Stokes parameters, I Q U and V, as a function of spatial position and wavelength across the coronal emission lines. Stokes I is the intensity, Stokes Q and U correspond to the net linear polarization horizontally and at 45 degress, respectively, and Stokes V corresponds to the net circular polarization.

From these observables, one can derive

- Plasma temperature from the intensity ratio of lines formed at different temperatutes
- Plasma density from the intensity ratio of density sensitive line pairs, such as Fe XIII 1074.7 and Fe XIII 1079.8 nm
- Line-of-sight (LOS) velocity from the Doppler shift obtained by fitting the intensity vs. wavelength of an emission line
- Plane-of-sky (POS) direction (azimuth) of the magnetic field from the saturated Hanle effect following the equation

$$Azimuth = 0.5\ atan(U/Q)$$

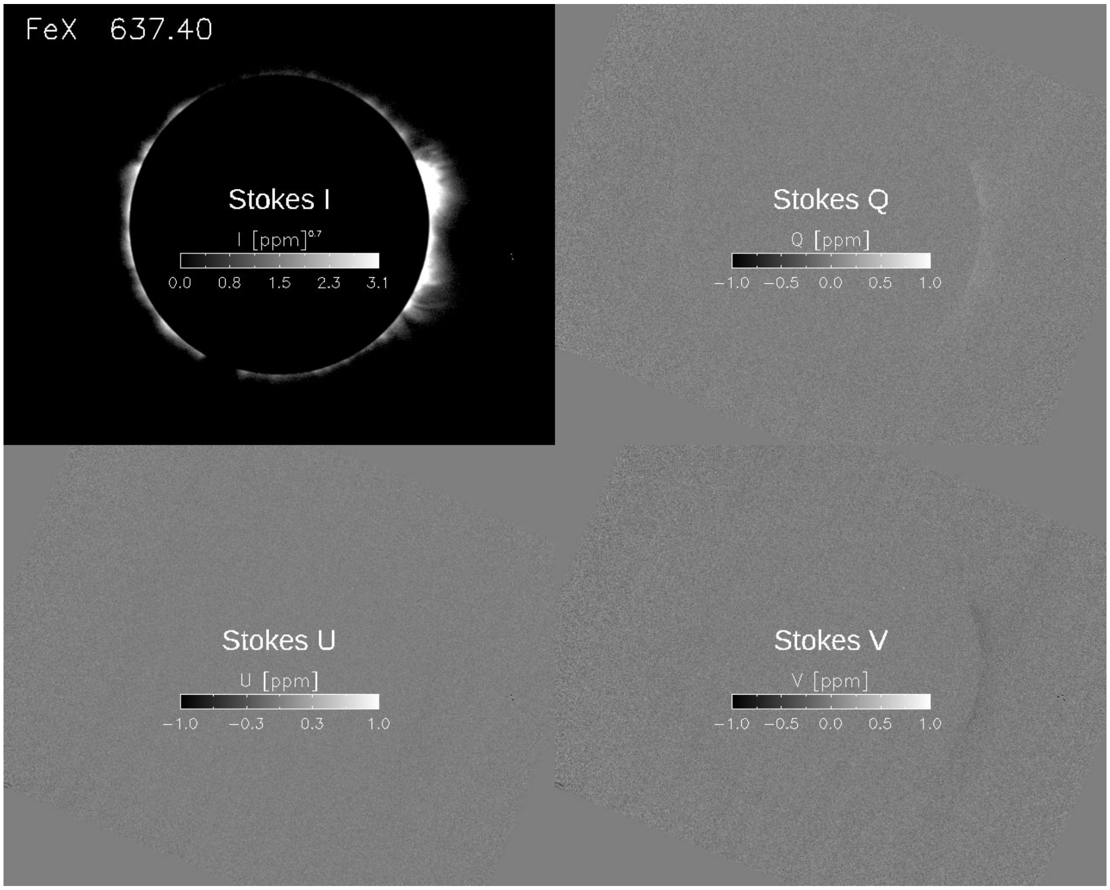
- Emission line width that contains information about non-thermal velocities and unresolved motions
- LOS magnetic field strength from the Zeeman effect in the circular polarization. For weak fields, the magnetic field is proportional to the ratio of Stokes V to Stokes I, with the proportionally constant depending on the particular line. For the Fe XIII 1074.7 nm line, the LOS field is approximately given by

$$Blos = 10^{-4}\frac{V}{I}\ (G)$$

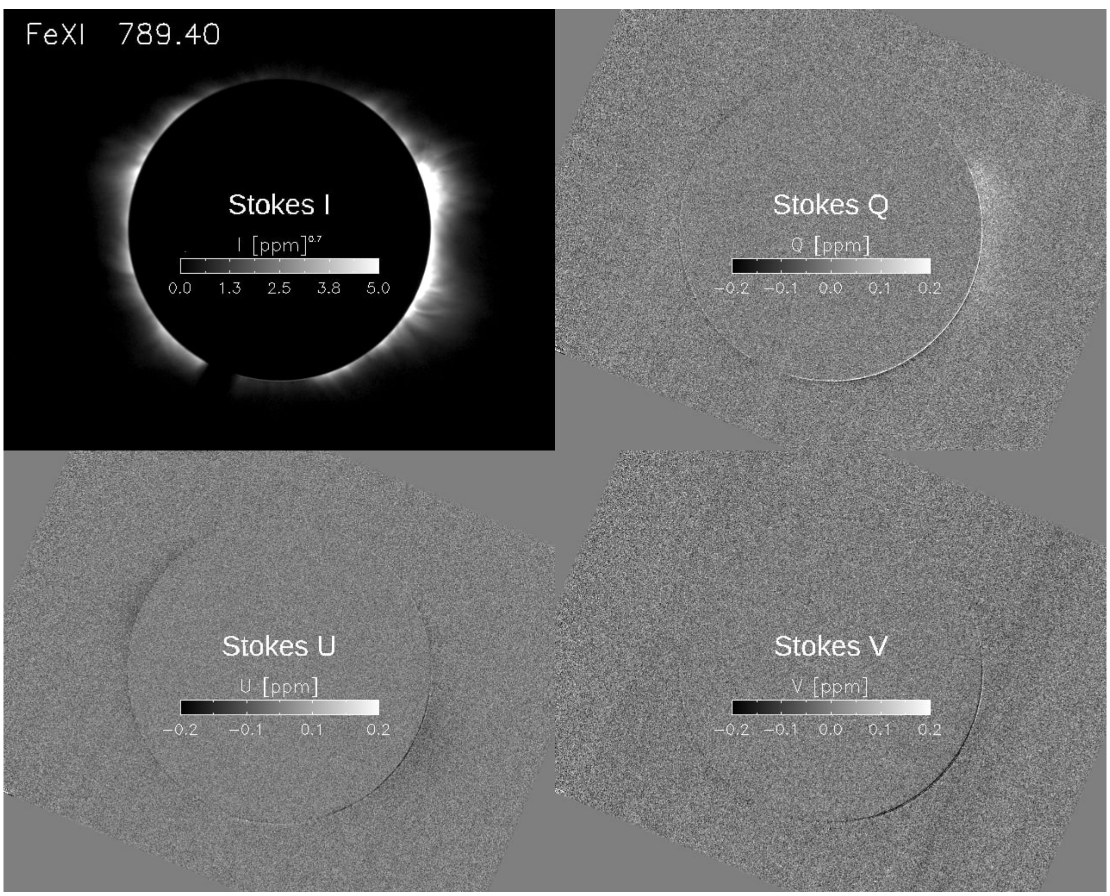
- POS magnetic field strength from the phase speed of Alfvenic waves (see Waves tab)

Example Data Products

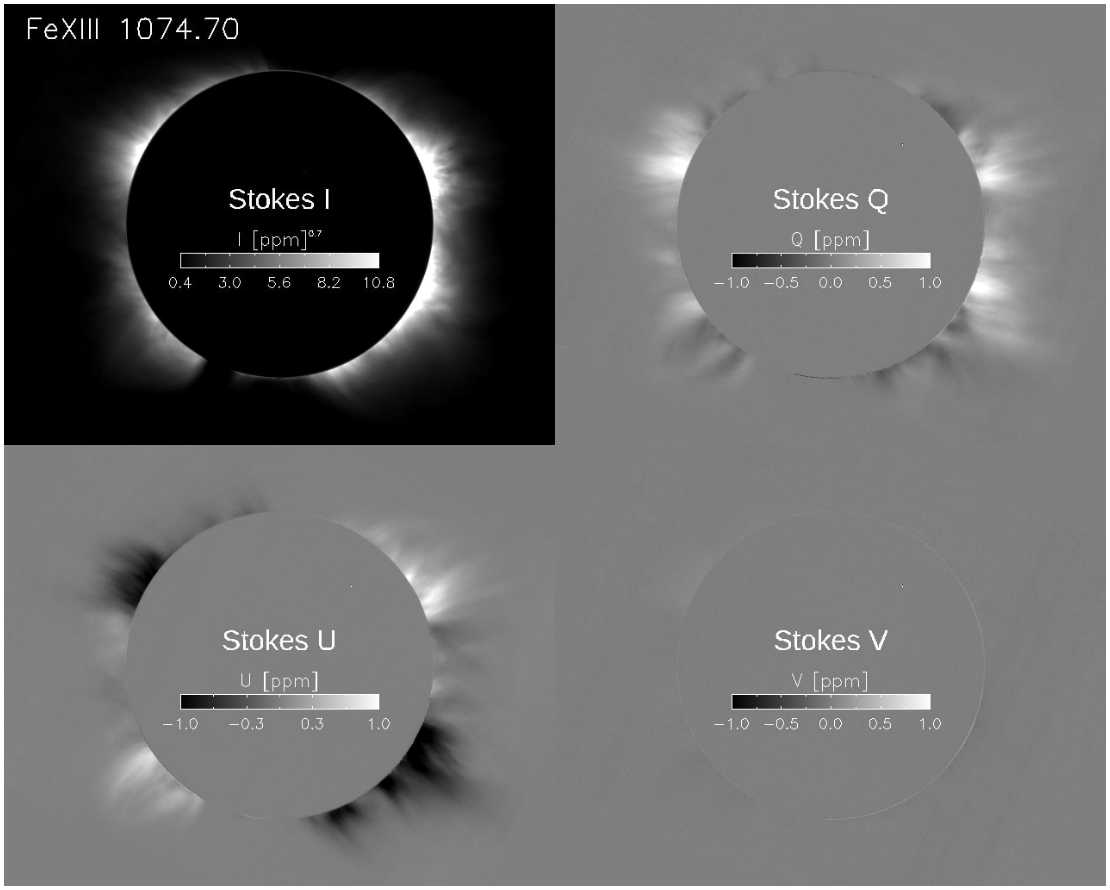
All of the following data were taken on Nov 7, 2021. Units are parts per million (ppm) of the solar disk center intensity.



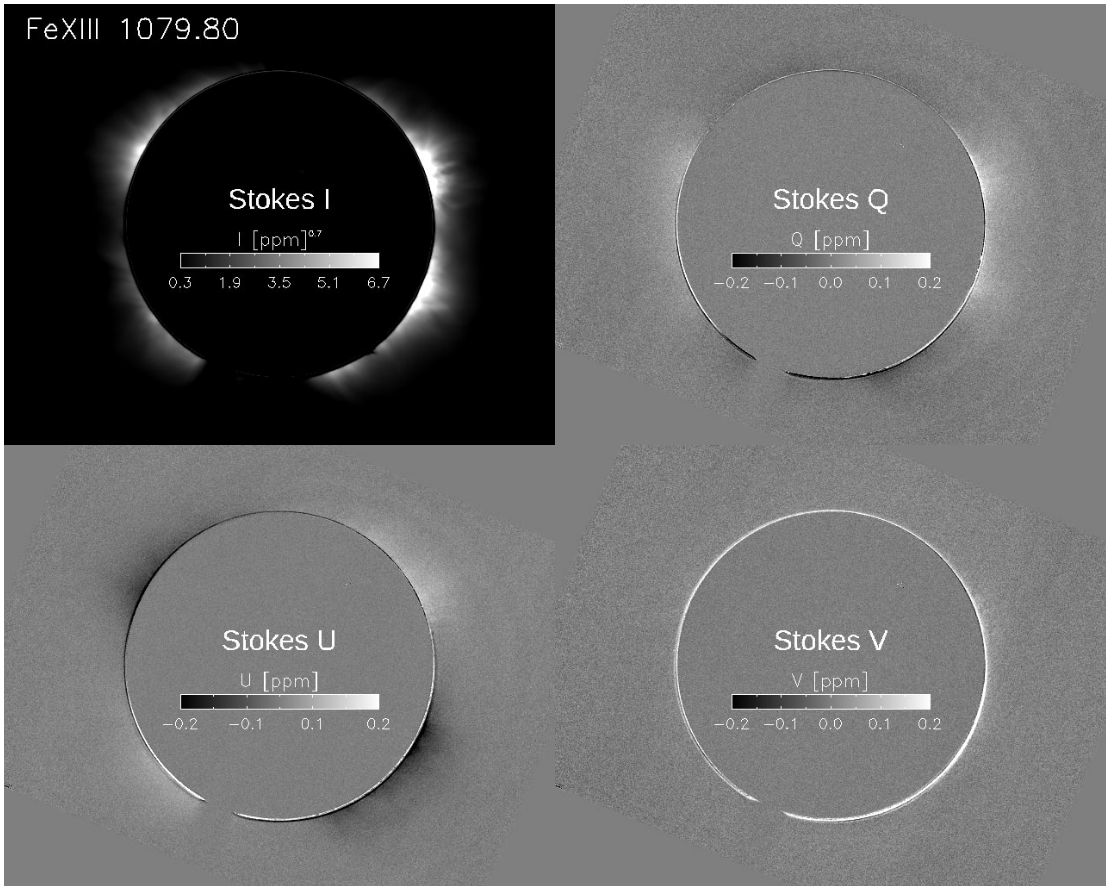
Stokes I Q U and V at line center for Fe X 637.4 nm.



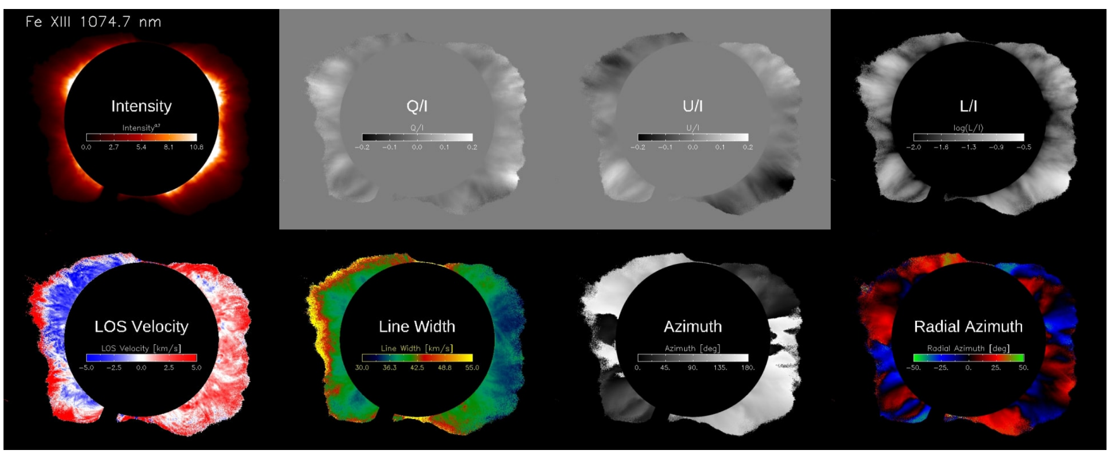
Stokes I Q U and V at line center for Fe XI 789.4 nm.



Stokes I Q U and V at line center for Fe XIII 1074.7 nm.



Stokes I Q U and V at line center for Fe XIII 1079.8 nm.



Some Level 2 data products derived from the Level 1 data products are shown in the above plot. I Q and U are as defined above. L = linear polarization = sqrt(Q^2+U^2). The rotation of the corona is visible as the blue to red variation of the LOS velocity. The line width shown here includes the instrumental profile. The Azimuth of the magnetic field is measured CCW from horizontal and is subject to a 180 degree ambiguity. The Radial Azimuth of the magnetic field is the azimuth measured CCW from the local radial direction.

WAVES

Time sequences of the LOS Doppler velocity from the CoMP instrument revealed ubiquitous Alfvenic waves (Tomczyk, McIntosh, Keil et al., 2007). These waves are important since the phase speed of the waves can be used to infer the POS component of the magnetic field of the corona (Yang et al., 2021). Also, these waves play a role in heating the corona and accelerating the solar wind.

An example of these Alfvenic waves as seen in recent UCoMP data is shown in the Doppler movie below. This one-hour sequence was taken in the Fe XIII 1074.7 nm line on Nov 07, 2021 with a cadence of one Doppler image every 30 seconds.

[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1639173962/agu-fm2021/8C-06-75-50-64-B9-8A-32-C2-97-D2-4C-B9-B5-A0-2A/Video/movie_tnohrk.mp4

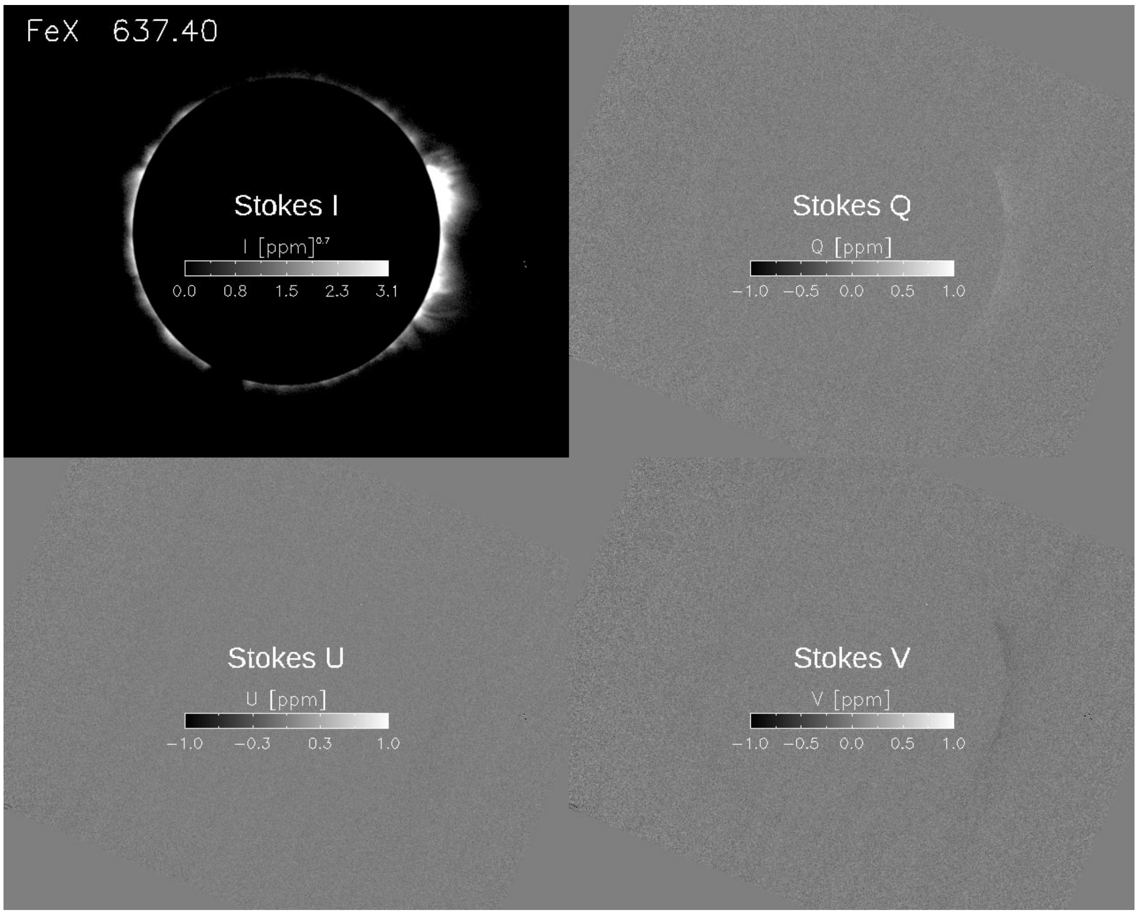
One hour time sequence of the LOS velocity. Black and white correspond to +/- 2 km/s.

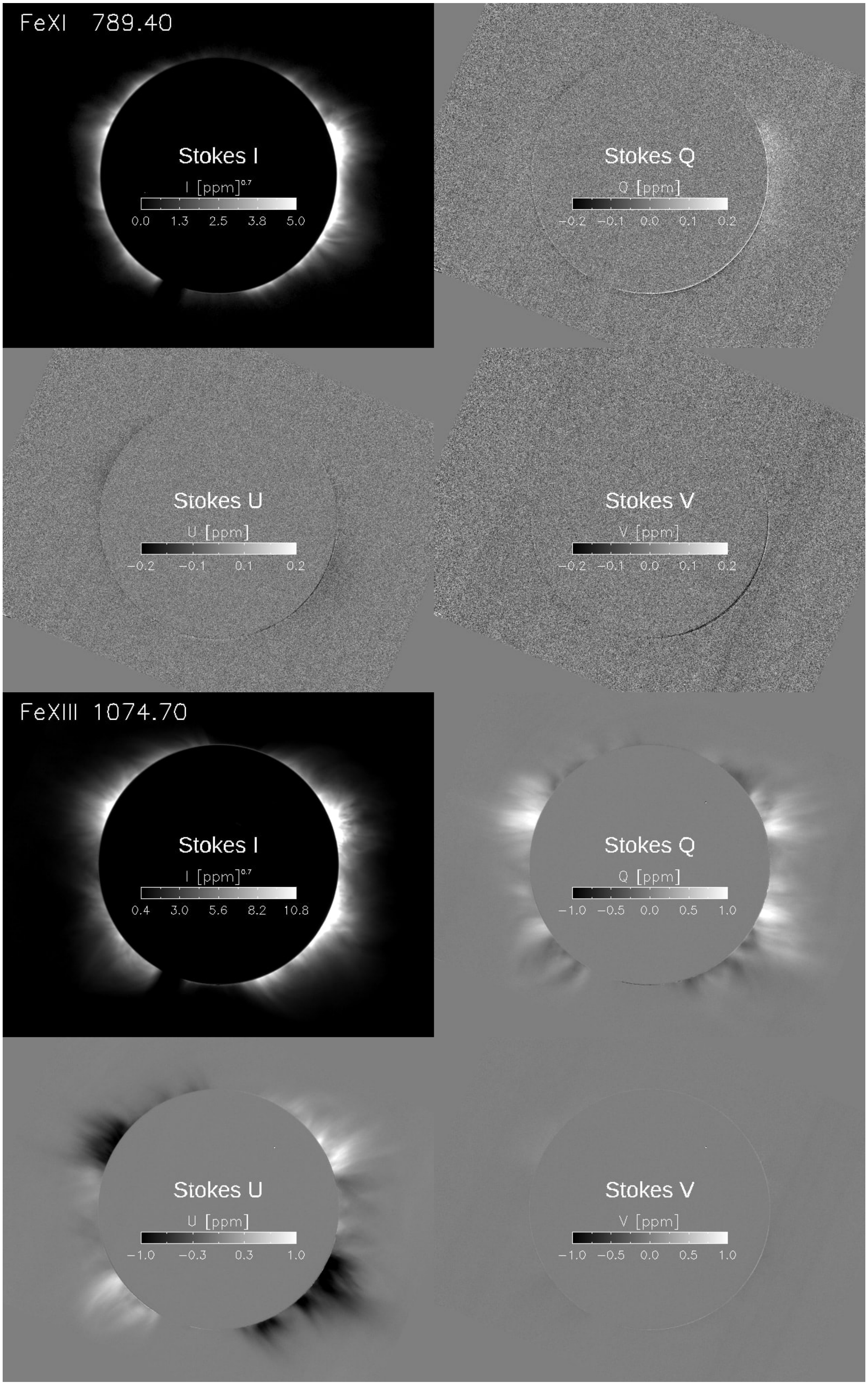
SUMMARY

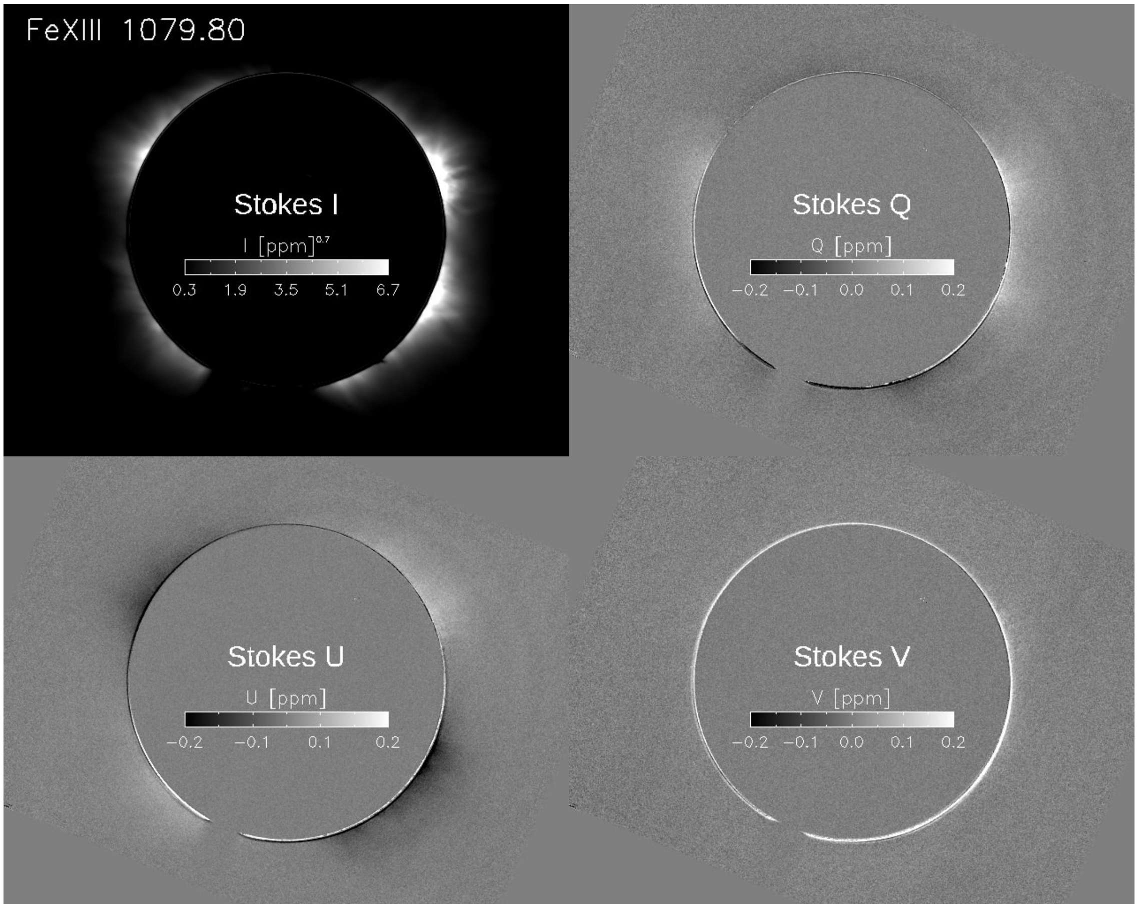
The UCoMP instrument, like its predecessor CoMP, will provide unique observations of polarization, magnetic field strength and geometry, plasma temperature and density, and flows and waves in the large scale corona.

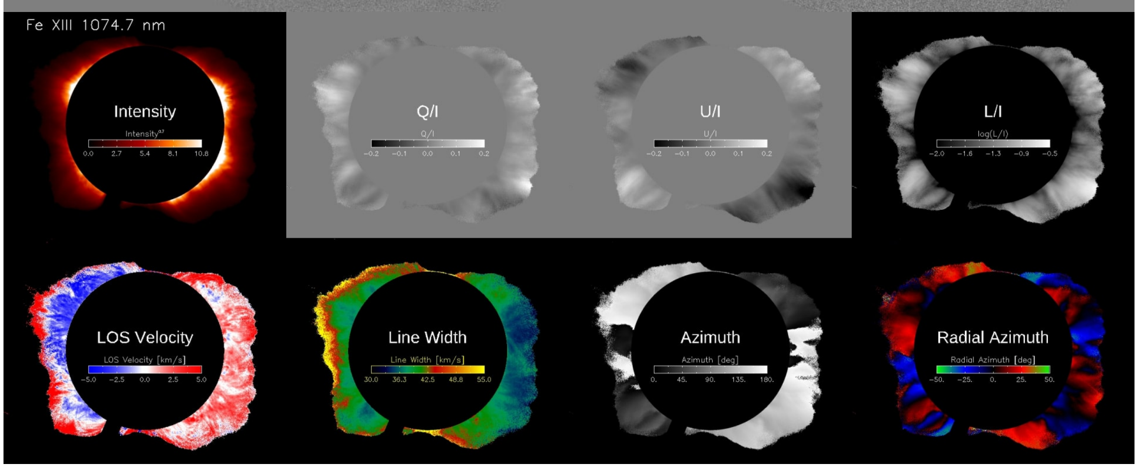
Instrument commissioning and the development of the data processing pipeline are ongoing. We expect that data from the instrument will be made available to the community in early 2022 through the Mauna Loa Solar Observatory (https://www2.hao.ucar.edu/mlso/mlso-home-page) website.

Please direct any questions to Steven Tomczyk at tomczyk@ucar.edu




FeXI 789.40
Stokes I
I [ppm]$^{0.7}$
0.0 1.3 2.5 3.8 5.0
Stokes Q
Q [ppm]
−0.2 −0.1 0.0 0.1 0.2
Stokes U
U [ppm]
−0.2 −0.1 0.1 0.2
Stokes V
V [ppm]
−0.2 −0.1 0.0 0.1 0.2
FeXIII 1074.70
Stokes I
I [ppm]$^{0.7}$
0.4 3.0 5.6 8.2 10.8
Stokes Q
Q [ppm]
−1.0 −0.5 0.0 0.5 1.0
Stokes U
U [ppm]
−1.0 −0.3 0.3 1.0
Stokes V
V [ppm]
−1.0 −0.5 0.0 0.5 1.0


FeXIII 1079.80
Stokes I
I [ppm]^0.7
0.3 1.9 3.5 5.1 6.7
Stokes Q
Q [ppm]
−0.2 −0.1 0.0 0.1 0.2
Stokes U
U [ppm]
−0.2 −0.1 0.1 0.2
Stokes V
V [ppm]
−0.2 −0.1 0.0 0.1 0.2


Fe XIII 1074.7 nm
Intensity
Intensity^0.7
0.0 2.7 5.4 8.1 10.8
Q/I
Q/I
−0.2 −0.1 0.0 0.1 0.2
U/I
U/I
−0.2 −0.1 0.0 0.1 0.2
L/I
log(L/I)
−2.0 −1.6 −1.3 −0.9 −0.5
LOS Velocity
LOS Velocity [km/s]
−5.0 −2.5 0.0 2.5 5.0
Line Width
Line Width [km/s]
30.0 36.3 42.5 48.8 55.0
Azimuth
Azimuth [deg]
0. 45. 90. 135. 180.
Radial Azimuth
Radial Azimuth [deg]
−50. −25. 0. 25. 50.

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ABSTRACT

The Upgraded Coronal Multi-channel Polarimeter (UCoMP) is a coronal polarimeter with a narrow-band tunable birefringent filter capable of imaging the intensity, full Stokes polarization, and Doppler shift across the coronal emission lines of FeXIV 530.3 nm, FeX 637.4 nm, ArXI 691.8, FeXV 706.2 nm, FeXI 789.4, FeXIII 1074.7 and 1079.8 nm and the chromospheric emission lines of HI 656.3 and HeI 1083 nm. The UCoMP is an upgrade of the CoMP instrument. It has a broader wavelength range (530 - 1083 nm) than CoMP (1074 - 1083 nm) increasing the number of available emission lines in order to observe the corona over a wide range of temperatures, a larger field-of-view (+/- 2 Rsun) compared to CoMP (+/- 1.3 Rsun), and higher spatial resolution (6 arcseconds) compared to CoMP (9 arcseconds). The UCoMP demonstrates the technology of a large aperture (50 mm) tunable birefringent filter based on Lithium Niobate crystals and is a pathfinder instrument for the Coronal Solar Magnetism Observatory. The instrument was shipped to Mauna Loa Solar Observatory in December of 2020, installed in the Spring of 2021, and started taking data May 26, 2021, followed by a period of instrument commissioning. This talk will describe the instrument and present the first images taken with the UCoMP.

REFERENCES

Landi, E., S. R. Habbal, and S. Tomczyk (2016), Coronal plasma diagnostics from ground-based observations, J. Geophys. Res. Space Physics, 121, 8237–8249, doi:10.1002/2016JA022598.

Tomczyk, S., et al. (2016), Scientific objectives and capabilities of the Coronal Solar Magnetism Observatory, J. Geophys. Res. Space Physics, 121, 7470–7487, doi:10.1002/2016JA022871

Tomczyk, S., G. L. Card, T. Darnell, D. F. Elmore, R. Lull, P. G. Nelson, K. V. Streander, J. Burkepile, R. Casini, and P. Judge (2008), An instrument to measure coronal emission line polarization, Sol. Phys., 247, 411–428.

Tomczyk, S., R. Casini, A. G. de Wijn, and P. G. Nelson (2010), Wavelength-diverse polarization modulators for Stokes polarimetry, Appl. Opt., 49(18), 3580–3586.

Tomczyk, S., S. K. Mathew, and D. Gallagher (2016), Development of a tunable filter for coronal polarimetry, J. Geophys. Res. Space Physics, 121, doi:10.1002/2016JA022682.

Tomczyk, S., S. W. McIntosh, S. L. Keil, P. G. Judge, T. Schad, D. H. Seeley, and J. Edmondson (2007), Alfven waves in the solar corona, Science,
317, 1192.

Yang, Z., Bethge, C., Tian, H., Tomczyk, S., Morton, R., Del Zanna, G., McIntosh, S.W., Karak, B.B., Gibson, S., Samanta, T., He, J., Chen, Y., Wang, L.: 2020, Global maps of the magnetic field in the solar corona. Science 369, 694.