Exploring the Corona With the Newest Coronagraph at the Mauna Loa Solar Observatory

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Mauna Loa homepage

ABSTRACT

HAO has successfully deployed the new Upgraded Coronal Multi-Channel Polarimeter (UCoMP) to the Mauna Loa Solar Observatory (MLSO). UCoMP is a major upgrade of the CoMP instrument. Its expanded capabilities include: observations over a wide range of coronal temperatures to explore the magneto-thermal structure of the corona; a larger field-of-view; higher spatial resolution; and dramatically faster collection of the full Stokes polarization that provides higher quality polarimetry measurements. UCoMP will provide powerful diagnostic measurements of the coronal magnetic field and plasma properties. The larger field-of-view allows it to explore the magnetic and thermal properties of dynamic structures such as Coronal Mass Ejections (CMEs), and ambient coronal structures out to greater heights. The UCoMP observations complement the MLSO K-Cor white light coronagraph, that is designed to track CMEs at a very high cadence (15 seconds).

UCoMP is nearing completion of its commissioning phase. This work included validation of the calibration and processing steps used to produce Level-1 and Level-2 science data. We provide examples of the variety of UCoMP science data products and highlight some of the science that can be explored with these exciting new observations. We illustrate how UCoMP and K-Cor coronagraph data can be combined and used with models to explore coronal magnetic field and plasma conditions. We discuss synergies of UCoMP observations with DKIST, FASR and other missions.

UCoMP

MLSO operates two coronagraphs: the COSMO K-Cor white light coronagraph; and our newest instrument, the Upgraded Coronal Multi-Channel Polarimeter (UCoMP). UCoMP is a 20 cm aperture imaging spectropolarimeter with a field-of-view (FOV) from 1.04 to ~2 solar radii and 3 arcsec pixels that observe full Stokes polarimetry in 9 spectral lines covering a broad range of coronal and chromospheric temperatures. It provides diagnostics on the coronal magnetic field and plasma properties including electron density, ion temperatures from thermal line widths and ratios of Fe lines of varying ionization states, line-of-sight Doppler motions, and coronal MHD wave diagnostics. It is designed to explore the magneto-thermal conditions in active regions, streamers and coronal holes. Examples of various intensity Images acquired on March 10, 2022 as well as a temperature 'map' comprised of three Fe ionization states is shown in Figure 1. Examples of UCoMP higher level products produced from the Fe XIII 1074 nm emission line on Feb 10, 2022 are shown in Figure 2.

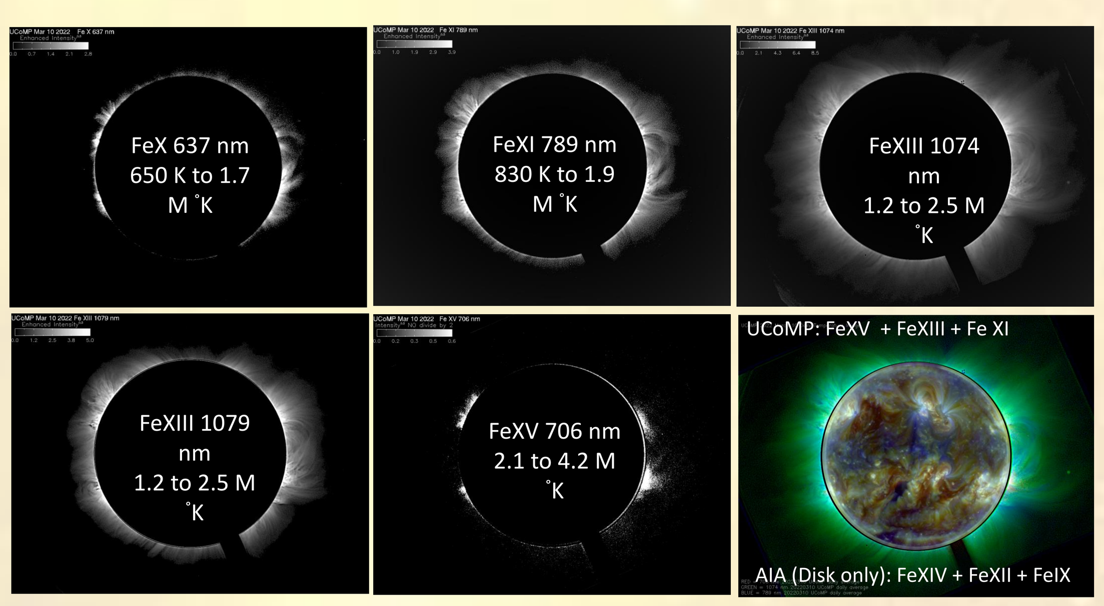


Figure 1: March 10, 2022 UCoMP images from a variety of iron (Fe) coronal emission lines sampling a range of coronal temperatures. Lower right is a temperature map composed of UCoMP FeXV, FeXIII and Fe XI limb observations. The solar disk is an AIA image of Fe XIV, FeXII and FeIX. The hottest region in the corona *above the solar limb* are colored white; mid range temperatures are green and the coolest coronal regions are blue.

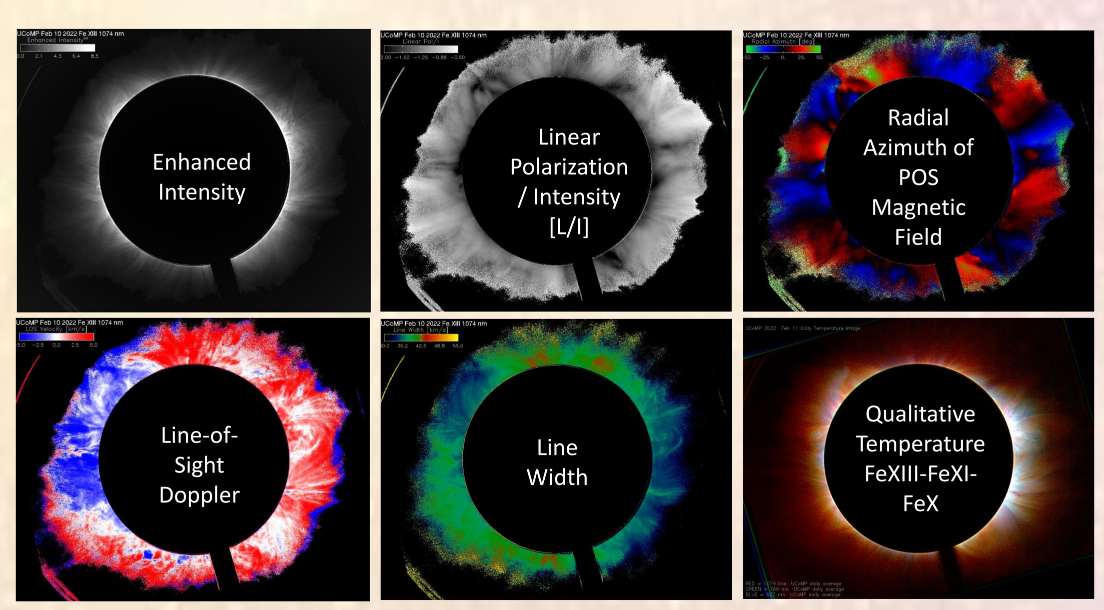


Figure 2: Feb 10, 2022 UCoMP data products from Fe XIII 1074 nm. The upper row center and right products are produced from linear polarization, providing information on the direction of the magnetic field and magnetic field topologies. Lower panel displays Doppler data, spectral line width, and a temperature map from 3 iron (Fe) ionization states: FeXIII, FeXI and FeX. The white regions in the temperature map show the coolest part of the corona while the red show the hotter regions. Note the coolest regions coincide with the narrowest line widths.

UCoMP QUICK LOOK IMAGES ARE AVAILABLE from the MLSO homepage (use QR code in Upper Left or URL at end of poster)

FOR MORE DETAILS on the UCoMP Hardware, Observing sequences and data processing please see the poster by Ben Berkey et al. in WG1 section: The Upgraded Coronal Multi-Channel Polarimeter (UCoMP).

Measuring MHD waves in closed and open magnetic structures

UCoMP line-of-sight (LOS) Doppler images have been widely used to identify and study Alfven and other MHD waves in the magnetically-closed corona (Tomczyk et al. 2007, Tomczyk, Steven; McIntosh, Scott W., 2009) and to study their propagation in magnetically open-field regions (Morton et al. 2015, Banerjee et al. 2021). These studies have shown that outward moving Alfven waves in closed region have more power than downward moving waves suggesting dissipation of wave energy in the corona and counter-propagating Alfvénic waves exist on open coronal magnetic fields, and can reflect in the upper atmosphere and propagate into the solar wind. These studies provide insights in mechanisms behind coronal heating and provide constraints on models of turbulence of Alfven wave.

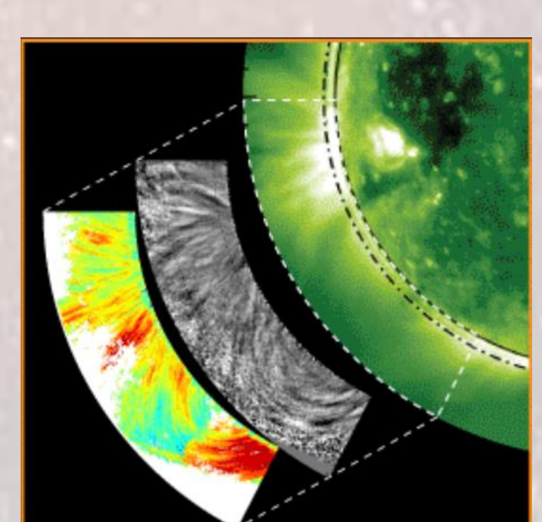


Fig 4. adapted from Tomczyk and McIntosh 2009 shows the CoMP limb Fe-XIII image superposed with AIA disk image at 193 Angstroms. The b/w figure in the middle shows Alfven waves and the colored arc-shaped figure in the lower left shows power in outward and inward moving waves.

Doppler observations are also used to track CME motions and coronal deflections, and can be used in conjunction with density and plane-of-sky (POS) magnetic field direction to produce POS magnetic field measurements.

Coronal Magnetic Fields

This precipitous drop in plasma density between the solar photosphere and low corona results in magnetic energy being the dominate force in the low and the major source of energy driving solar activity. Measurements of the coronal magnetic field can transform our understanding of fundamental physical processes in the corona and advance space weather studies. The UCoMP (and the older CoMP instrument) is designed to study magnetic conditions in the corona via linear polarization measurements in coronal Forbidden emission lines

Yang et al. 2020 used CoMP Fe XIII linear polarization, Doppler, and density measurements to determine the plane-of-sky (POS) coronal magnetic field, as shown in Figure 4.

Kramar et al. 2016 used CoMP FeXIII polarization and vector tomographic inversions to create global 3D coronal magnetic field synoptic map.

UCoMP provides a larger FOV, higher spatial resolution and better quality polarization than CoMP to extend observations of the magnetic field to greater heights.

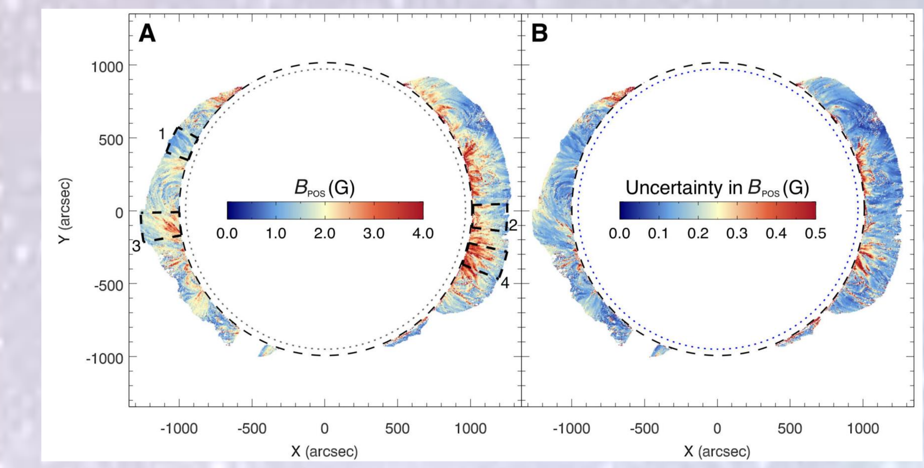


Figure 4. POS coronal magnetic field map (above left) from Yang et al. 2020 using MLSO CoMP observations. The uncertainties in the measurements are provided In the map in the above right image.

Coronal magnetic topology

It is essential to identify the magnetic topology of coronal structures to understand conditions observed in solar wind by Parker Solar Probe and other missions. MLSO data, combined with forward- and MHD-models, connect the corona to the solar wind.

Pseudo-Streamers vs Helmet Streamers

A component of slow solar wind originates in the vicinity of helmet streamers (dipolar field above streamer), while a source of hybrid solar wind (intermediate between fast and slow) originates from pseudo-streamers (PS) (unipolar field above streamer). For more info see Abbo et al. 2015

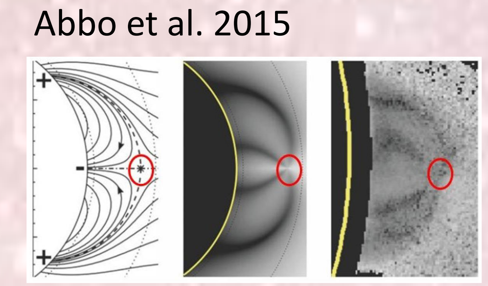
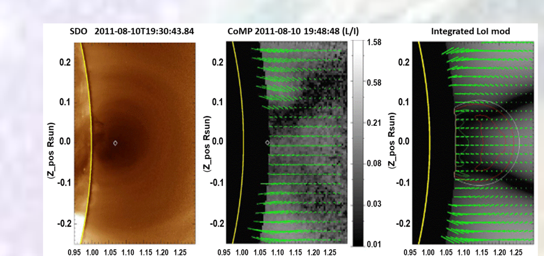


Fig. 5: Pseudo-streamer (PS) from Gibson et al. 2017. Far left: 2-D idealized field lines in PS, Center: LOS polarization of PS, Right: CoMP observed polarization. Red is location of magnetic null.

Fig 6. From Lee et al. 2021 shows two PS (indicated by arrows) in the corona as seen by Mauna Loa K-Cor.

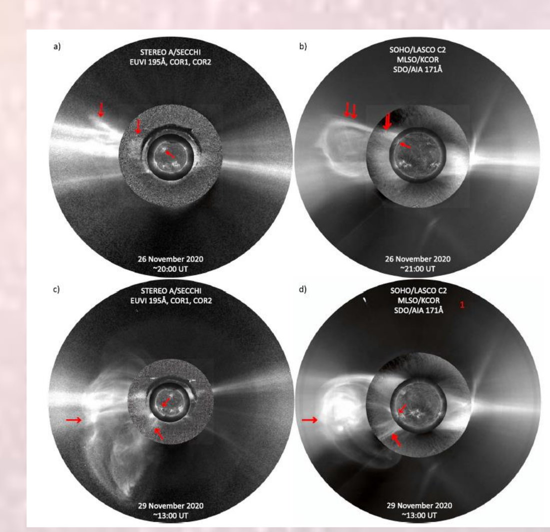
Lee et al. 2021 used MLSO K-Cor (Fig 6.) to identify pseudo- and helmet-streamers and tracked blobs above these structures in LASCO to 6 Rsun. They found that blobs above helmets are slower than those above pseudo-streamers. Both MLSO K-Cor and UCoMP observations can be used to identify these topologies.

Magnetic Flux Ropes



Bak-Steslicka et al. 2013 (above) used CoMP data to identify a magnetic flux rope in a coronal cavity seen in AIA (left). CoMP (center) polarization is consistent with flux rope model (right). Flux ropes are strongly correlated with CMEs.

Coronal Mass Ejections (CMEs)



CMEs are a major driver of space weather. MLSO K-Cor has a FOV of 1.05 to 3 Rsun and 15 sec cadence to track CMEs from onset through the middle corona; filling an observational. It also provides plasma density diagnostics. Nieves-Chinchilla et al. 2022 (Fig. 7) used STEREO, AIA, LASCO and MLSO K-Cor in conjunction with forward modeling and numerical propagation models to demonstrate that the two CMEs were interacting in the vicinity of the Parker Solar Probe. K-Cor data are used in the right had column of Figure 7. Combining a wide variety of observations with modeling sheds light on the internal structure of CMEs.

At left: Fig 7. showing CMEs from Nov 29, 2020 (top) and Nov 29, 2020 (bottom) from STEREO and from Earth-Sun-line

UCoMP Complementarity to DKIST and FASR

The full coronal field-of-view (FOV) of UCoMP and K-Cor, complements the very high resolution, small field-of-view (FOV) of DKIST. The recent Decadal Survey, Pathways to Discovery in Astronomy and Astrophysics for the 2020s, cited the need for global synoptic measurements of the coronal magnetic field to supplement the restricted FOV of DKIST. UCoMP and K-Cor can track large-scale dynamic structures such as CMEs, which DKIST cannot, and provide DKIST with excellent coronal context imaging. FASR will provide disk and limb observations of strong magnetic fields and high energy plasma while UCoMP is able to provide conditions on quiet Sun regions as well as active regions.

SUMMARY

MLSO provides unique measurements of the very low corona into the middle corona to identity coronal magnetic conditions and topologies, provide plasma properties such as density, temperature, motions and MHD wave diagnostics, have the capability of tracking CMEs and their evolution from onset through the middle corona and can be used with models to connect coronal sources to revolutionary new observations from Parker Solar Probe, Solar Orbiter, STEREO and future missions such as NASA PUNCH, CCOR and ISRO Aditya-L1.

MLSO web page: QR CODE IN UPPER RIGHT OF POSTER / https://www2.hao.ucar.edu/mlso/mlso-home-page

References

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