Synergies of ground-based solar observations with PUNCH NFI and other space-based coronagraphs

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ABSTRACT

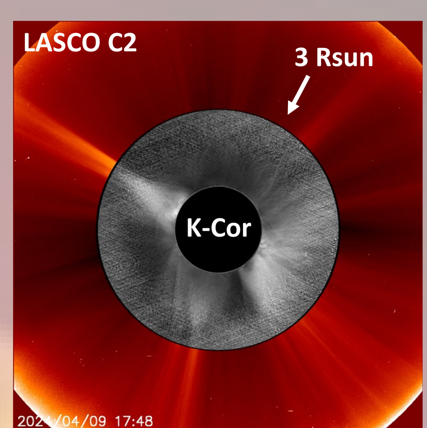
PUNCH will deliver the first observations of polarized brightness of the heliosphere over a nearly full field-of-view from the base of the outer corona to nearly 1 AU.

Ground-based observations in the visible, near IR and radio provide critical information on plasma and magnetic field conditions and sites of magnetic reconnection and particle acceleration in the low and middle corona, where CMEs originate. Ground-based magnetic field measurements of the photosphere and chromosphere, coupled with helioseismology observations of far-side active regions provide improved magnetic boundary conditions for models of the coronal magnetic field and solar wind. We highlight how these data connect properties of ambient structures in the low and middle corona with the PUNCH data of the outer corona and solar wind. Ground-based data also provide crucial information on the formation and early dynamics of CMEs and related solar activity.

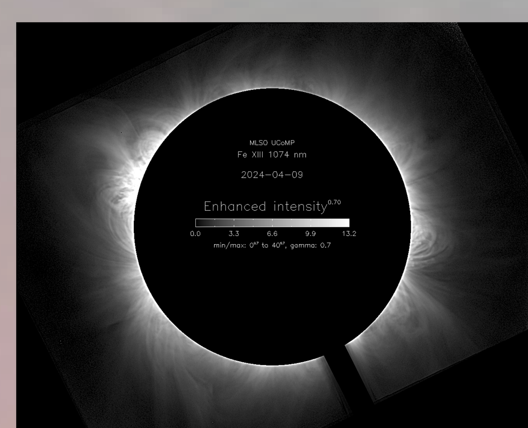
GROUND-BASED DATA CONNECT SOLAR SOURCE REGIONS TO OUTER CORONA and SOLAR WIND

NCAR/HAO Mauna Loa coronagraphs:

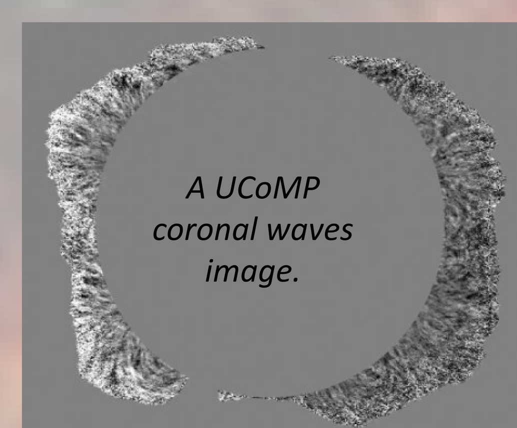
- **UCoMP:** Coronal spectropolarimetry: Full Stokes polarimetry (I, Q, U, V), 9 coronal emission lines, field-of-view: 1.03 to ~2 solar radii; Provides magnetic field diagnostics; MHD wave diagnostics; plane-of-sky magnetic field maps; line-of-sight Doppler velocities, line width, and density; and temperature maps.
- **K-Cor:** White light, 1.05 to 3 $R_\odot$ at 15 sec cadence, 2.5 min data latency ideal for tracking CMEs from onset, polarization to derive line-of-sight coronal density and mass, provides near-real-time CME alerts to NASA CCMC and users



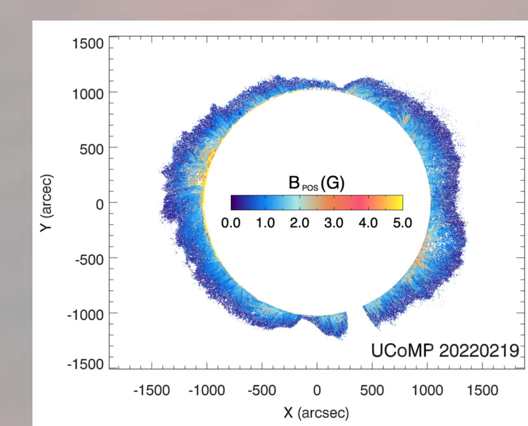
K-Cor + LASCO on April 9, 2024. K-Cor fills observing gap below LASCO occulter. Will fill in 1/2 of gap for PUNCH NFI.



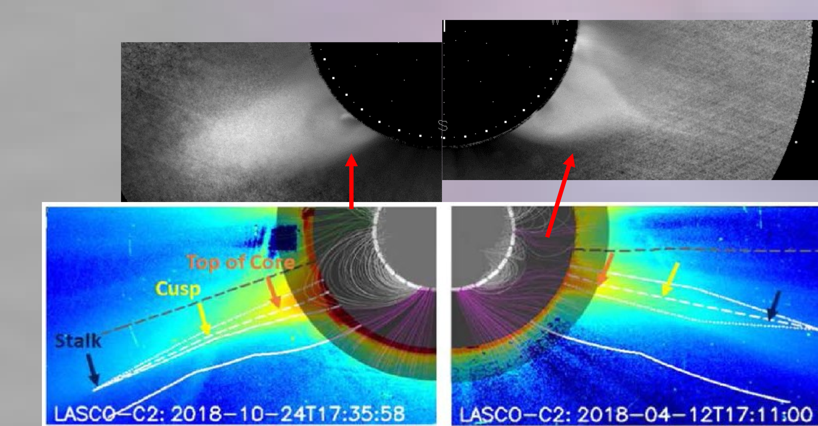
UCoMP Fe XIII 1074 nm on April 9, 2024. UCoMP provides a wealth of plasma and magnetic field diagnostics out to $2R_\odot$



Many papers suggest MHD wave energy is sufficient to heat the solar corona, but the majority of energy is 'hidden' in nonthermal line widths. **UCoMP provides unique information on MHD wave properties of the global corona on open and closed field lines** *(not possible with spectrographs)* to connect wave properties between corona and in-situ data. *See Sharma and Morton 2023:* https://doi.org/10.1038/s41550-023-02070-1

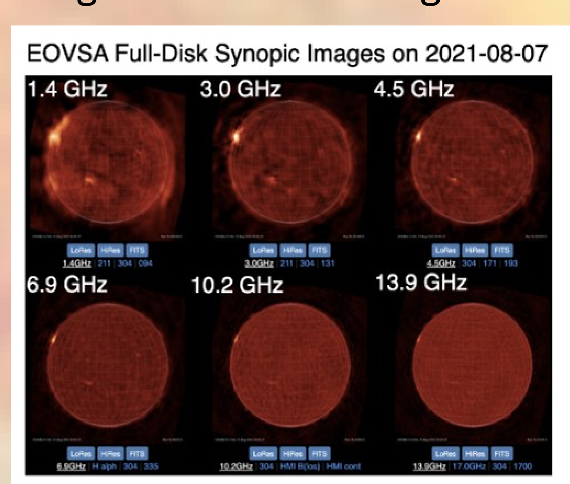


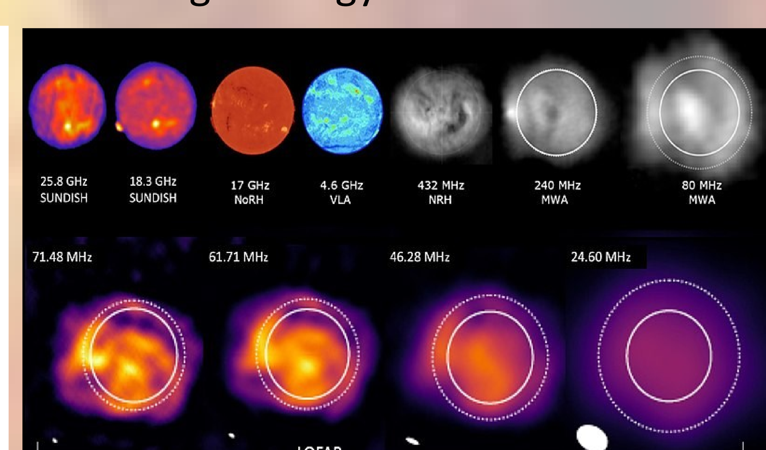
UCoMP Fe XIII 1074 nm phase speeds from UCoMP waves data combined with density from UCoMP Fe XIII emission lines are used to construct plane-of-sky POS coronal magnetic field maps. These maps can constrain and validate coronal models that connect the photosphere to PUNCH data. Zihao Yang, has made 114 days of magnetic field maps from UCoMP data between Feb and mid-October 2022.



Connecting Magnetic Structures in Corona to Parker Solar Probe (PSP). Lee et al. 2021 used K-Cor to identify different types of coronal streamers, i.e. pseudo-streamers and helmet streamers. They estimated solar wind speeds from these structures by tracking blobs above these streamers in K-Cor and LASCO. They found slower wind above helmet streamers, and faster wind above pseudo-streamers. https://doi.org/10.3847/2041-8213/ac2422

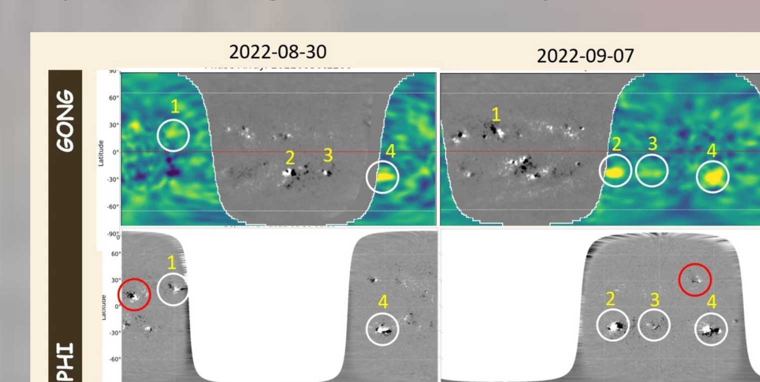
NJIT: Radio Observations: Observations from chromosphere through the middle corona provide unique diagnostics of the magnetic field and high-energy electrons to connect to PUNCH. As a rough guideline,





Decreasing frequency corresponds to higher heights in the solar atmosphere (figures at left). NJIT is developing is developing real-time radio burst detection capability at the Expanded Owens Valley Solar Array (EOVSA) for space weather forecasting. Radio images are also available in real-time from the Owens Valley Radio Observatory (OVRO).

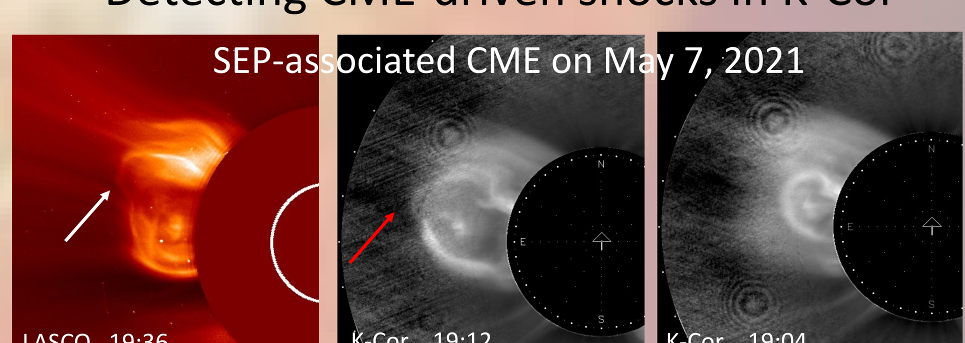
NSO GONG/SOLIS/DKIST: Uses combined observations of vector and line-of-sight magnetic fields from photosphere and chromosphere (plus coronal magnetic fields from DKIST), far-side imaging of active regions, and updated magnetic field maps for better boundary conditions to models. Boundary conditions are improved using



SOLIS/VSM photospheric and chromospheric vector and line-of-sight magnetic field measurements and GONG far-side imaging using helioseismology. NSO is developing new data products including synoptic maps of uncertainties in modeling of coronal structures, and including Solar Orbiter magnetic field measurements from the PHI instruments to create synoptic maps from multiple vantage points to further improve boundary conditions.

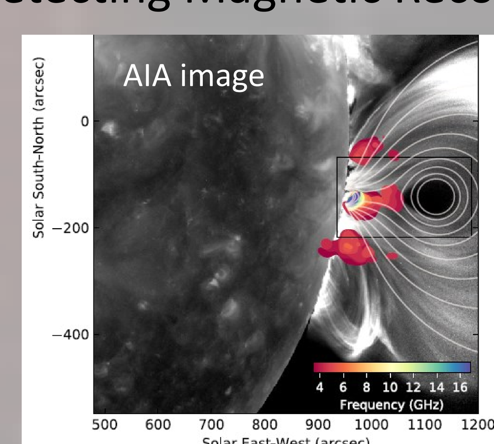
GROUND-BASED DATA PROVIDE DIAGOSTICS OF CME ONSET, SHOCKS, RECONNECTION SITES

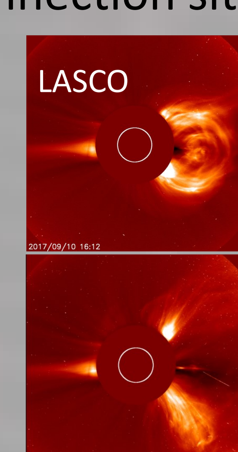
Detecting CME-driven shocks in K-Cor

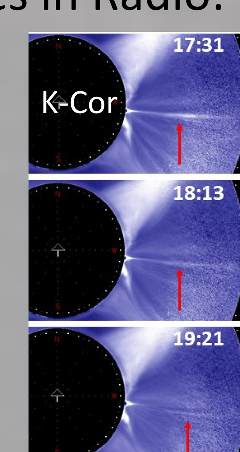


May 7, 2021 solar energetic particle (SEP)-associated CME had an acceleration of 510 m/s^2 in K-Cor. The CME front changed shape as it approached 2 $R_\odot$. The warped front was clearly visible in LASCO and will be tracked in PUNCH. A warping CME front suggests shock formation. 59% of all K-Cor CMEs with SEPs have CME fronts that warp as described in Steinolfson and Hundhausen 1990. https://doi.org/10.1029/JA095iA09p15251

Detecting Magnetic Reconnection sites in Radio: EOVSA

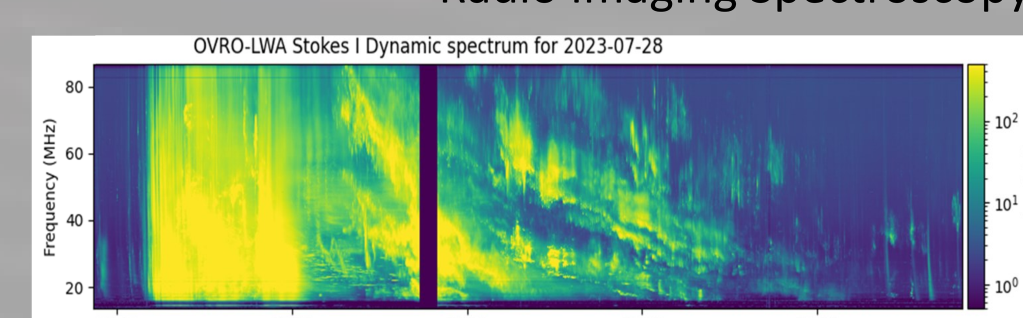


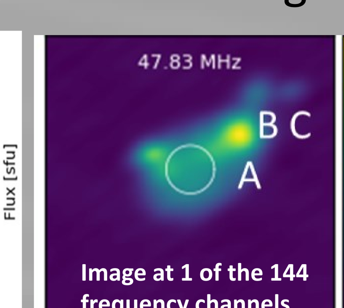


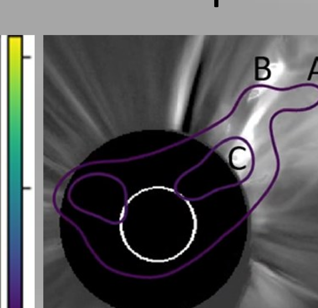


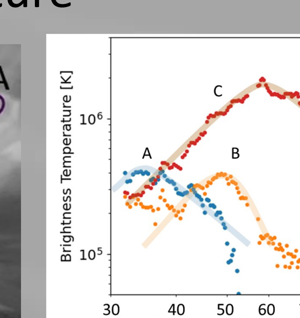
Above left: Radio emission detected from Expanded Owens Valley Array (colored contours in left image) shows the sites of magnetic reconnection within the CME on Sep 10, 2017 moving over 3000 km/s in LASCO. Far right are reconnection blobs detected in K-Cor.

Radio Imaging Spectroscopy to obtain Brightness Temperature



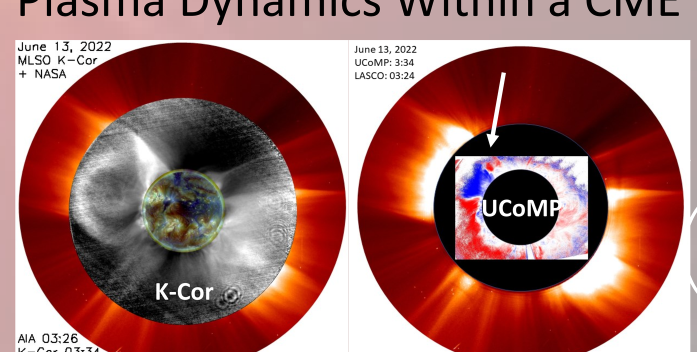


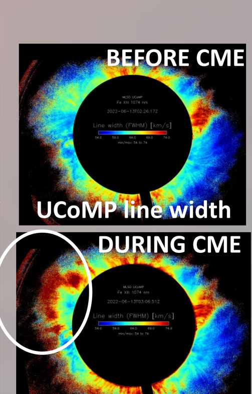




NJIT can now do ***imaging spectroscopy****, i.e.* imaging at very high time and frequency resolution over a wide range of frequencies. It can determine brightness temperatures of sources. NJIT has a **real-time pipeline** that produces **spectrogram data with 1 min latency** and **images at 144 frequency channels and 1 min cadence with 10 min latency.**

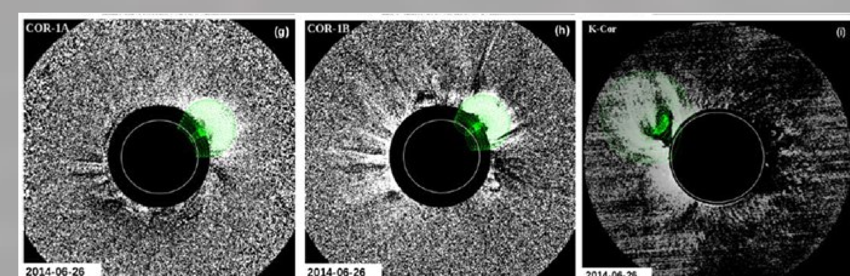
Plasma Dynamics Within a CME





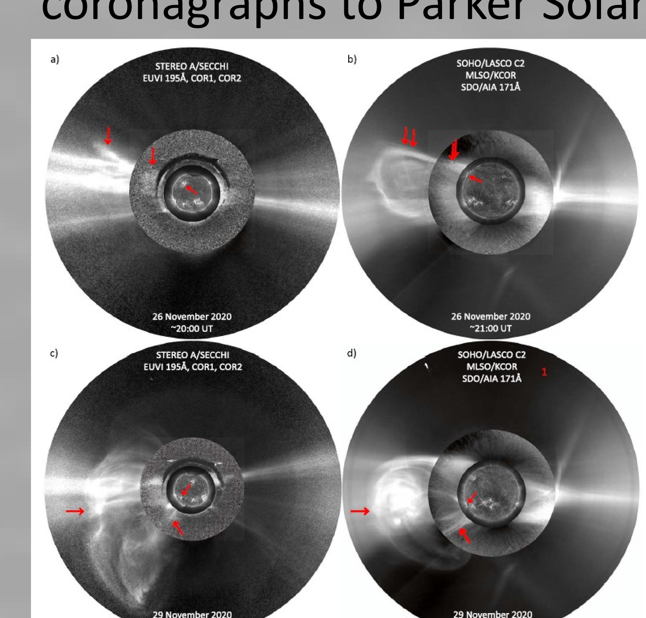
June 13, 2022 CME associated with an SEP event seen in K-Cor and UCoMP. Dramatic changes in plasma conditions in the CME core are visible in UCoMP Doppler and line width data. Line width increases are consistent with increase in turbulent flows.

Evolution of CMEs from low to outer corona



Majumdar et al. 2022 modified the Graduated Cylindrical Shell model to work with K-Cor and STEREO COR1. Using these data with COR2 and LASCO data they found the volumetric evolution of CMEs varied with height, with rapid expansion occurring at lower heights. https://doi.org/10.3847/1538-4357/ac5909

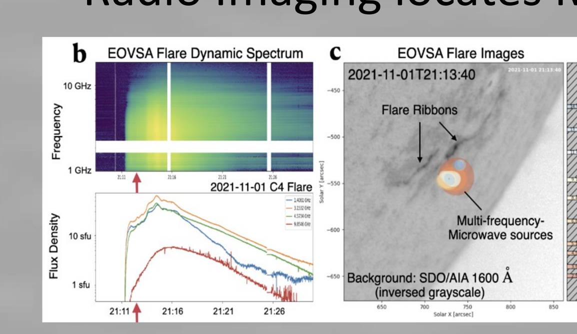
Connect space- and ground-based coronagraphs to Parker Solar Probe (PSP)

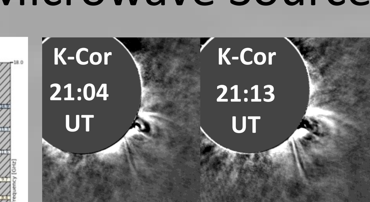


Nieves-Chinchilla et al. 2022 demonstrated that two CMEs were interacting at PSP. They used STEREO, MLSO K-Cor, AIA, and LASCO data with forward modeling and numerical propagation models. ***This work sheds light on PSP observations of the internal structure of CMEs and their physical characteristics.***

https://doi.org/10.3847/1538-4357/ac590b

Radio Imaging locates Microwave Sources





Above: K-Cor images of this CME on Nov 1, 2021.

Above are examples of some of the imaging spectroscopy data products from EOVSA and OVRO-Long Wavelength Array (LWA). These data provide unique information on locations of accelerating electrons, magnetic field diagnostics, and magnetic reconnection sites associated with CMEs and solar flares to better understand the processes driving CMEs.