Synergies of ground-based coronal observations with PUNCH

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ABSTRACT

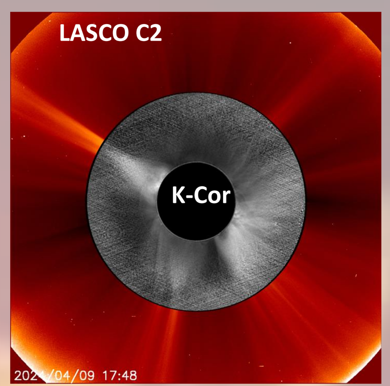
PUNCH will deliver the first observations of polarized brightness of the heliosphere over a nearly full field-of-view from the base of the outer corona to nearly 1 AU.

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 coronal magnetic field measurements provide crucial constraints on coronal and solar wind models and play a key role in the validation and improvement of these models, ultimately providing a more accurate connection of PUNCH observations to their coronal sources. We highlight how ground-based coronal data connect properties of ambient structures in the low and middle corona with 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, that connect CME observations by PUNCH to their solar sources to form a more complete picture of CME interactions with the surrounding corona and solar wind.

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

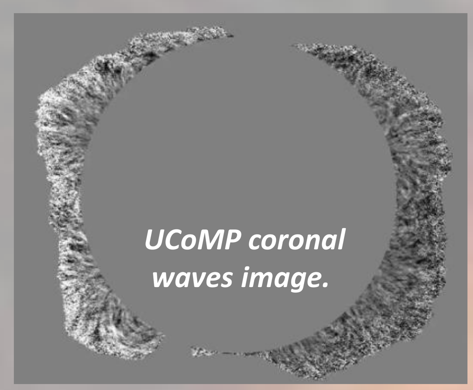
NCAR/HAO Mauna Loa coronagraphs:

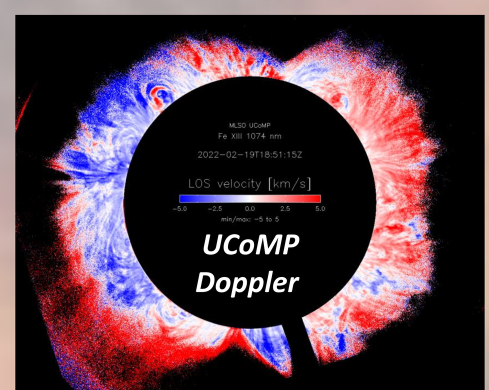
- **UCoMP:** Full Stokes polarimetry; 9 coronal emission lines; 1.03 to ~2 $R_\odot$; Magnetic field diagnostics and plane-of-sky magnetic field maps; MHD wave diagnostics; Line-of-sight Doppler velocities, line width, density, and temperature maps
- **K-Cor:** Polarized white light; 1.05 to 3 $R_\odot$; 15 sec cadence; 2.5 min data latency; Ideal for tracking CMEs from onset; Derive line-of-sight coronal density and mass; Provides near-real-time CME alerts to NASA CCMC and users



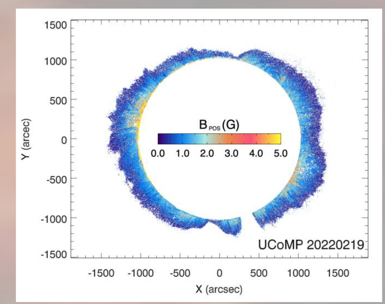
K-Cor + LASCO on April 9, 2024. K-Cor fills observing gap below LASCO occulter and will fill in part of the gap for PUNCH NFI.

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

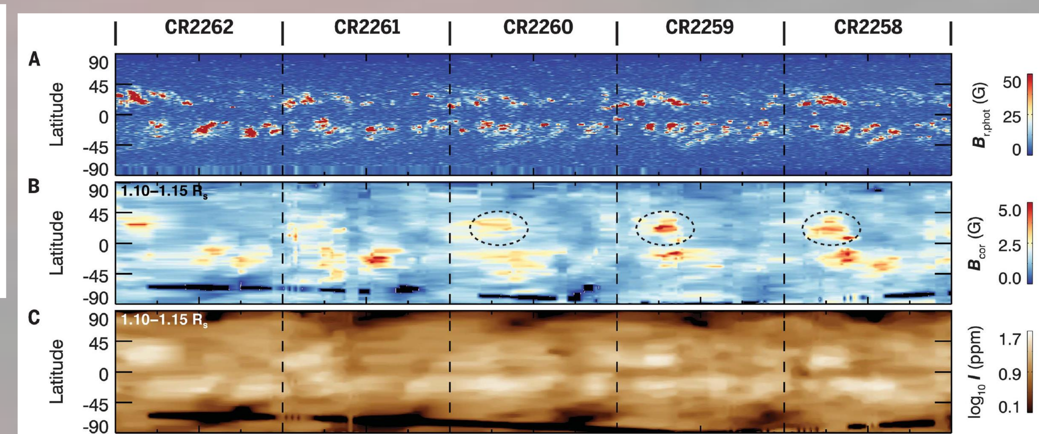




CORONAL MHD WAVES. Many papers suggest MHD wave energy is sufficient to heat the solar corona, but the majority of energy is 'hidden' in nonthermal line widths. **UCoMP provides unique information on MHD wave properties of the global corona on open and closed field lines** *(not possible with spectrographs)*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

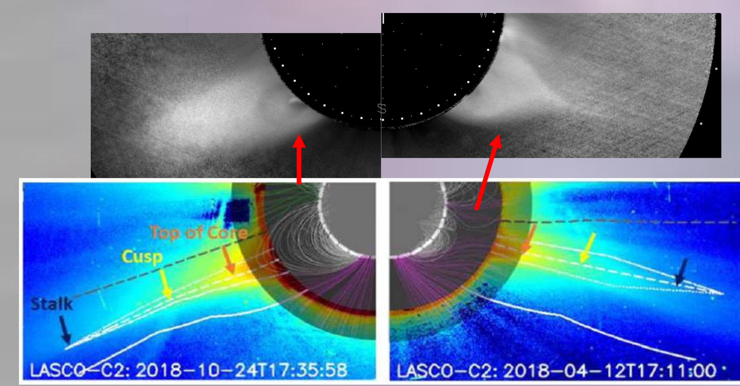


B-FIELD (Plane-of-Sky)



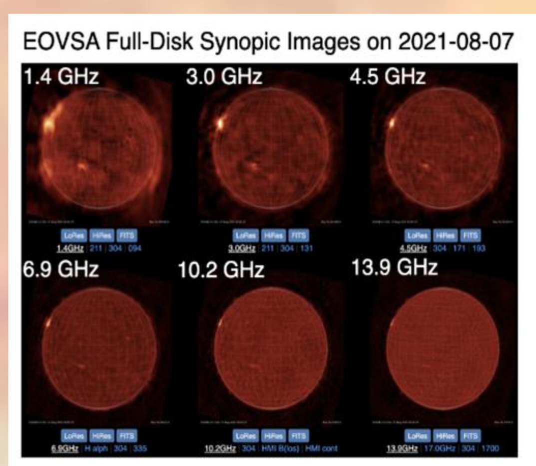
Right: Carrington rotations of: (A) B-field in photosphere, (B) POS coronal field UCoMP, (C) AIA 193 [from Yang et al. 2024]. Above left: POS B-field from UCoMP on Feb 19, 2022

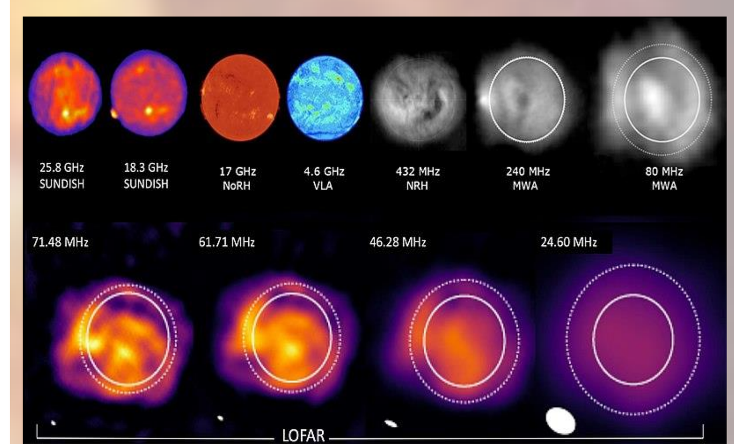
UCoMP Fe XIII 1074 nm phase speeds from UCoMP waves data are combined with density from two UCoMP Fe XIII lines to construct plane-of-sky (POS) coronal magnetic field maps. The maps constrain and validate coronal models that connect the photosphere to outer corona and solar wind structures seen by PUNCH. Yang et al., 10.1126/science.ado2993



Connecting Coronal Magnetic Structures to PUNCH and Parker Solar Probe (PSP). Lee et al. 2021 used K-Cor to identify types of coronal streamers, i.e. pseudo-streamers and helmet streamers. They estimated solar wind speeds 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

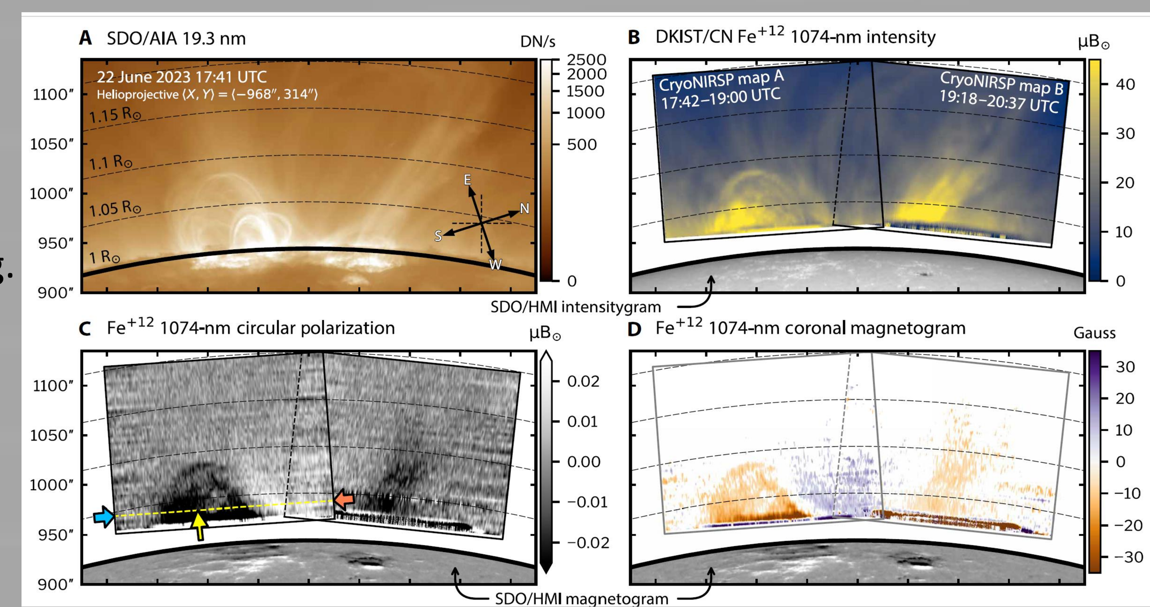
NJIT: Radio Observations: Observations from chromosphere through the middle corona provide unique diagnostics of the magnetic field and high-energy electrons to connect to PUNCH. As a rough guideline, decreasing frequency corresponds to higher heights in the solar atmosphere (figures at left). NJIT is developing near 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).





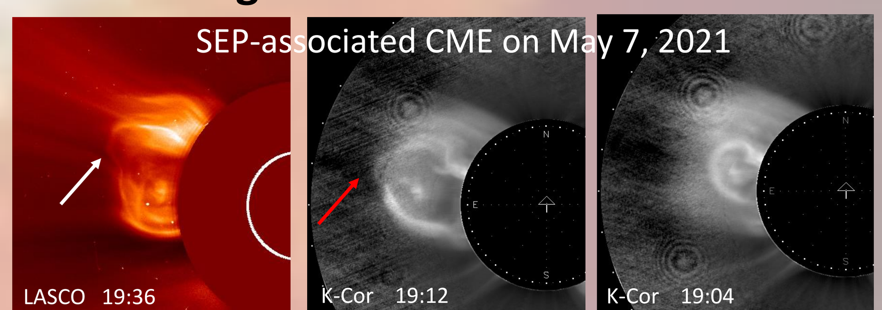
NSO DKIST CryoNRSP Coronal Magnetic Field

The CryoNRSP instrument on DKIST, the largest solar telescope, provides unprecedented views of the Sun's corona. The first coronal magnetogram from CryoNRSP was reported by Schad et al. 2024. **AT RIGHT**: Images from Fig. 1 of that paper. Upper left (A) coronal intensity from AIA; (B) CryoNRSP Fe XIII 1074 nm intensity; (C) CryoNRSP Fe XIII circular polarization; (D) First coronal magnetogram from CryoNRSP. These magnetic field maps provide important constraints on, and validation of models that will provide better modeling of the corona and solar wind. (Schad et al. 2024) 10.1126/sciadv.adq1604



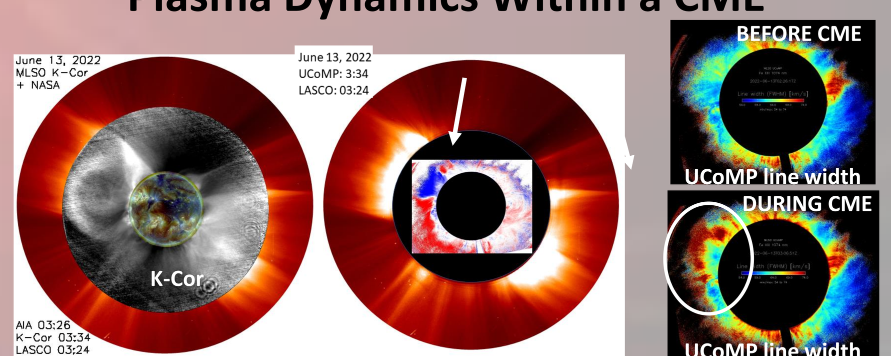
GROUND-BASED DATA PROVIDE DIAGOSTICS OF CME ONSET, SHOCKS, RECONNECTION SITES

Detecting CME-driven shocks in K-Cor



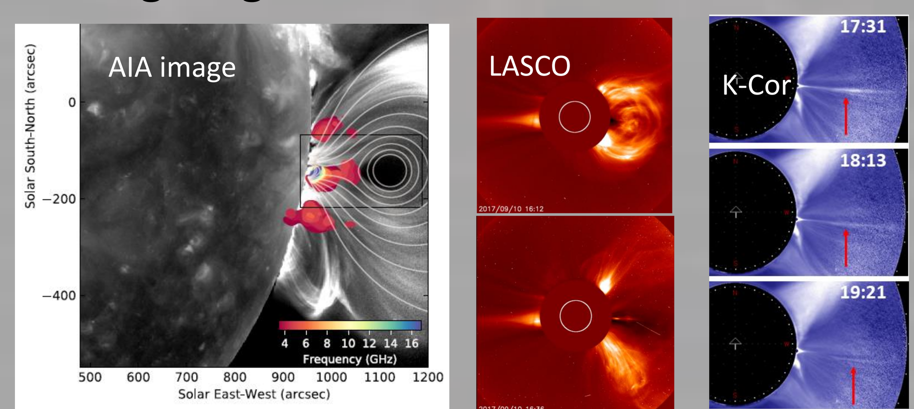
May 7, 2021 solar energetic particle (SEP)-associated CME had an acceleration of 510 m/s^2 in K-Cor. The CME front changed shape as it approached 2 $R_\odot$. The warped front was clearly visible in LASCO and will be tracked in PUNCH. A warping CME front suggests shock formation. 59% of all K-Cor CMEs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

Plasma Dynamics Within a CME



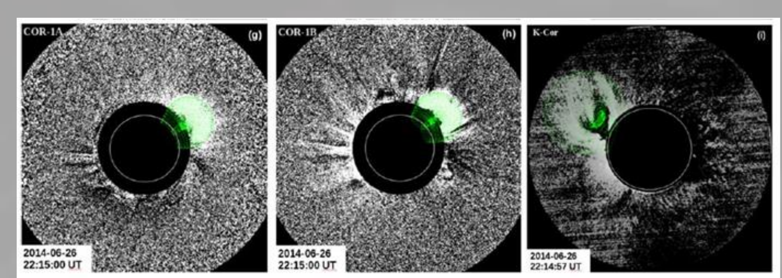
June 13, 2022 CME associated with an SEP event seen in K-Cor and UCoMP. Dramatic changes in plasma conditions in the CME core are visible in UCoMP Doppler and line width data. Line width increases are consistent with increase in turbulent flows.

Detecting Magnetic Reconnection sites in Radio: EOVSA



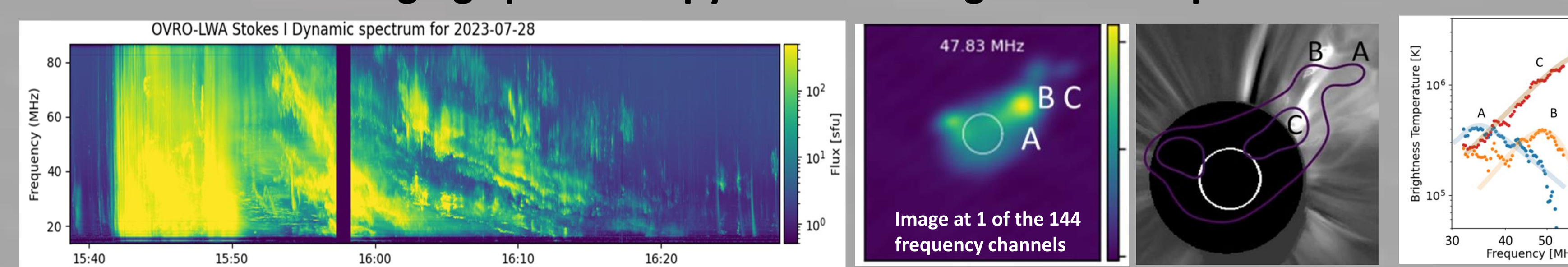
Above left: Radio emission detected from Expanded Owens Valley Array (colored contours in left image) shows the sites of magnetic reconnection within the CME on Sep 10, 2017 moving over 3000 km/s in LASCO. Far right are reconnection blobs detected in K-Cor.

Evolution of CMEs from low to outer corona



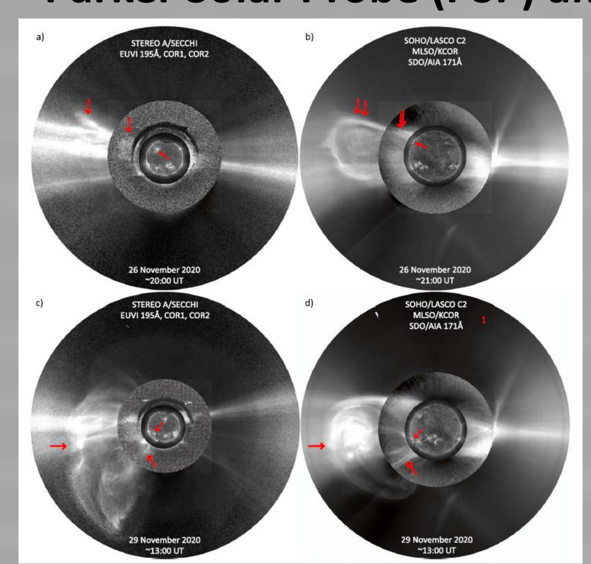
Majumdar et al. 2022 modified the Graduated Cylindrical Shell model to work with K-Cor and STEREO COR1. Using these data with COR2 and LASCO they found the volumetric evolution of CMEs varied with height, with rapid expansion occurring at lower heights. https://doi.org/10.3847/1538-4357/ac5909

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.**

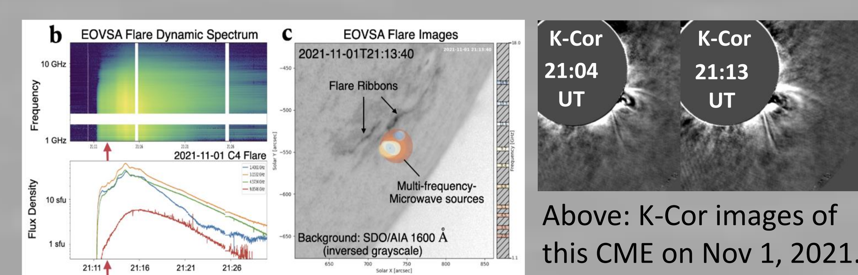
Connect space- and ground-based coronagraphs to Parker Solar Probe (PSP) and PUNCH



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

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.***

Radio Imaging locates accelerating electrons



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.