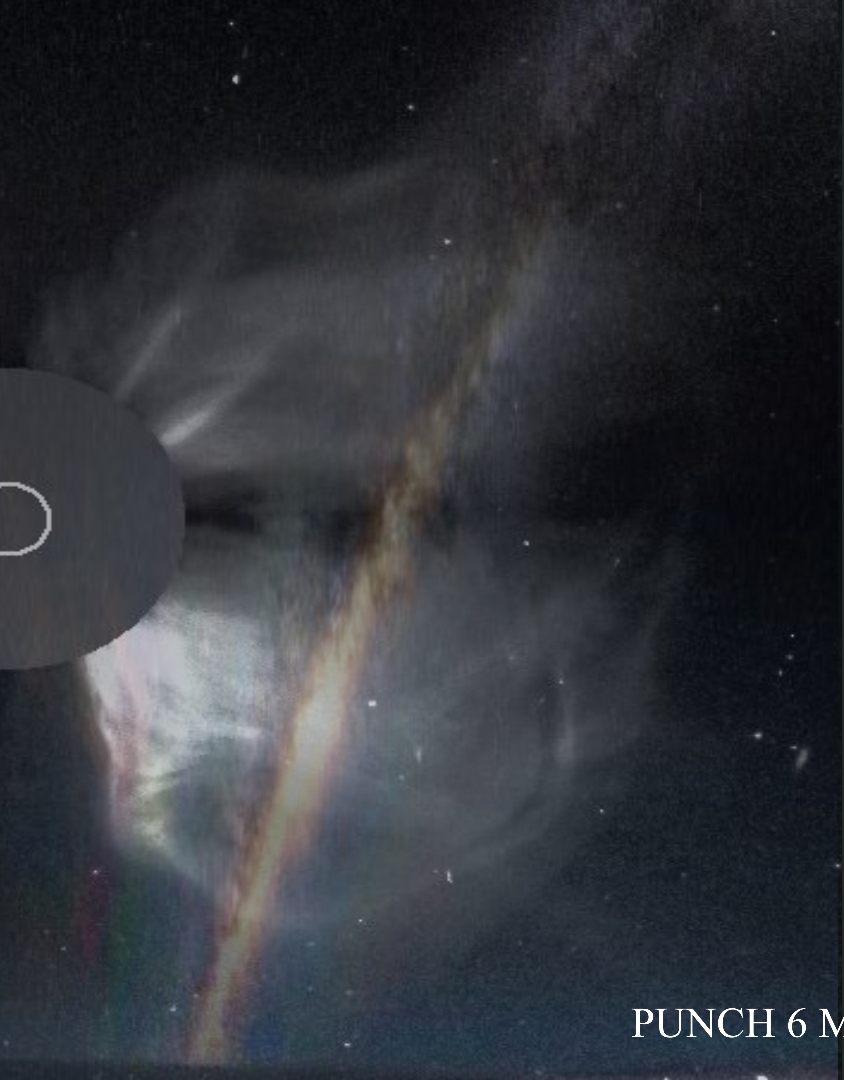

Remote Sensing of CME Magnetic Field Using Coordinated Wide Field of View Radio and PUNCH Observations

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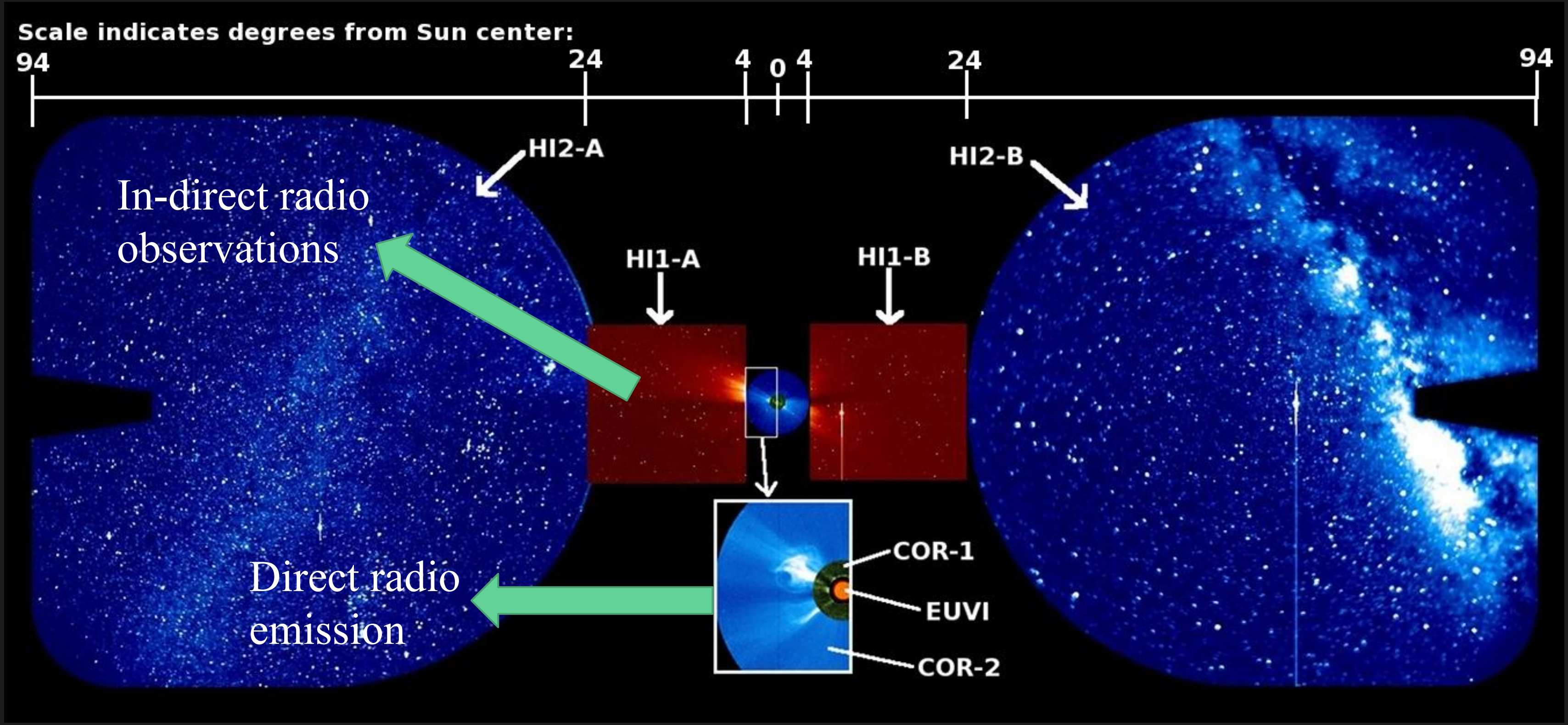
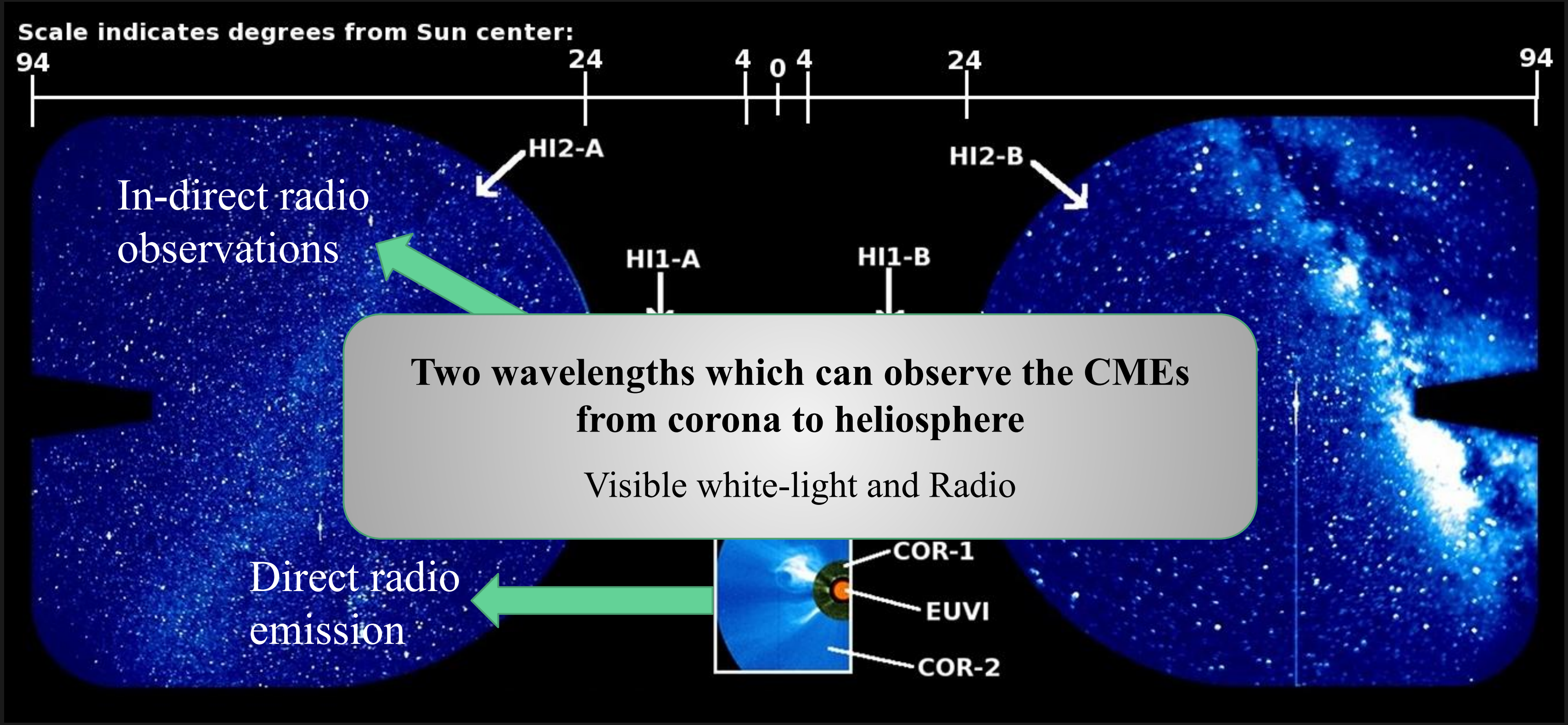
[3] CSIRO, Australia, [4] SARAO, South Africa, [5]Observatoire de Paris, France

PUNCH 6 Meeting, February 25, 2025

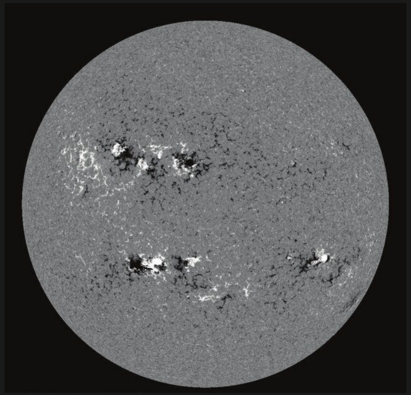
Observing CMEs in Corona and Heliosphere

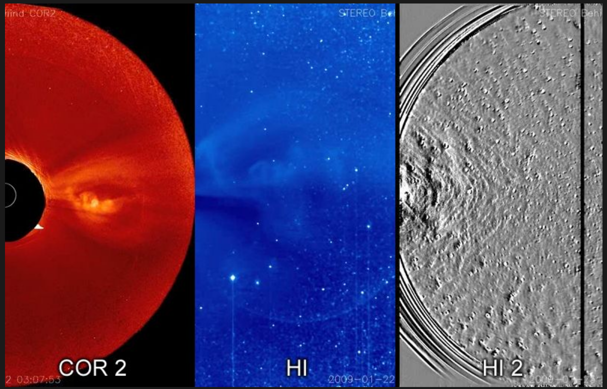


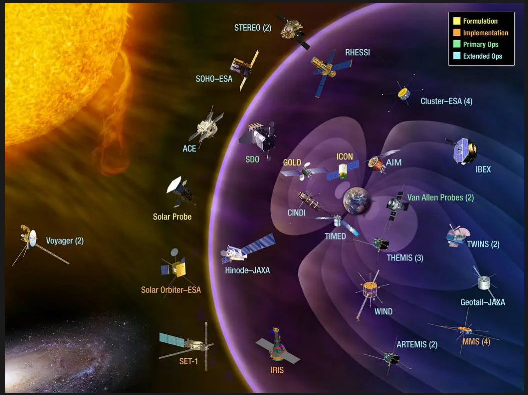
Observing CMEs in Corona and Heliosphere



Current Approach of Space-Weather Research/ Prediction







Magnetic field measurements

Geometry and dynamics of

No observational magnetic field constraints

In-situ magnetic field measurements

Empirical or numerical models

Radio observations fill this observational gap

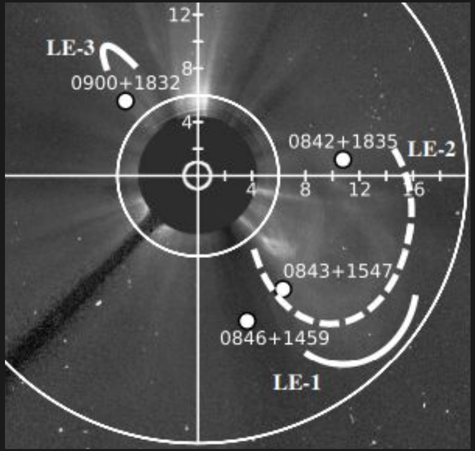
1. Direct imaging – coronal regime
2. In-direct observations – outer corona and heliospheric regime

Filling Missing Observational Gap of Magnetic Field Measurements

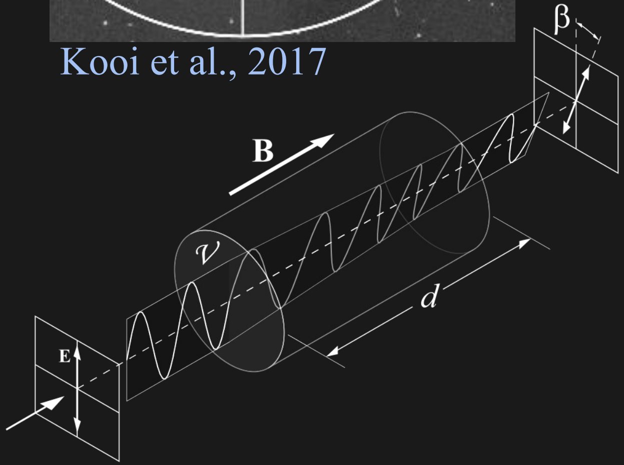
Radio Heliopolarimetry:

(Measuring magnetic fields in the heliosphere using radio polarimetry observation)

- Polarization angle of linearly polarized emission rotates as it propagates through a magnetized plasma, which is called **Faraday Rotation (FR).**
- This rotation is proportional to, $\lambda^2 \int n_e \mathbf{B}.d\mathbf{S}$
- A CME occultes a linearly polarized sources, due to CME electron density and magnetic fields, an additional FR is introduced.
- Measuring this relative FR enables determination of LoS-averaged magnetic fields, separating electron density contributions via white-light observations.
- Measured in terms of a frequency independent quantity, rotation measure (RM) = $0.81 \times \int n_e \mathbf{B}.d\mathbf{S}$ rad/m^2



Kooi et al., 2017



Filling Missing Observational Gap of Magnetic Field Measurements

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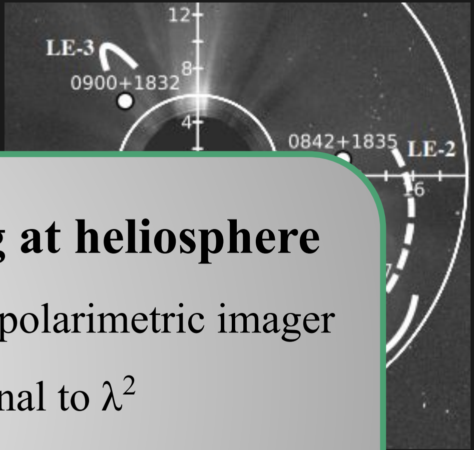
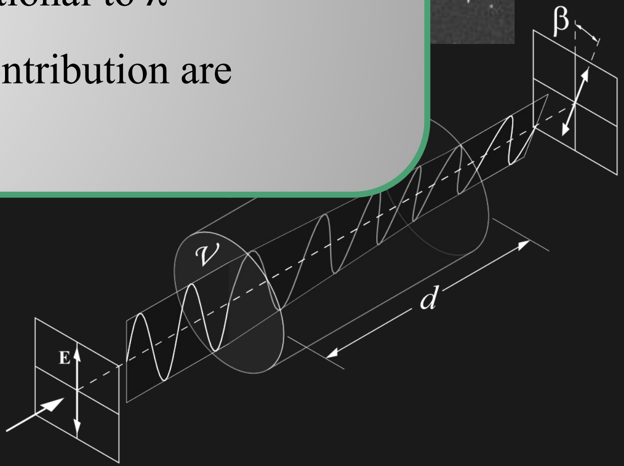
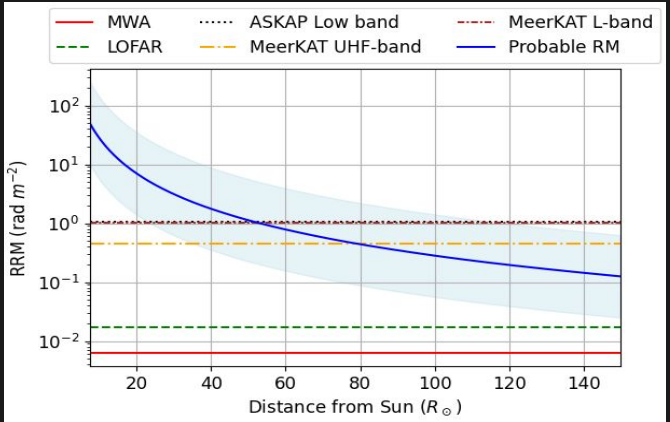


What limits the community for not doing at heliosphere

1. Need wide FoV instrument and sensitive radio polarimetric imager
2. Low-frequency observation, as FR is proportional to λ^2
3. Ionospheric contribution and heliospheric contribution are comparable



Precise Separation of Ionospheric FR – A Critical Step



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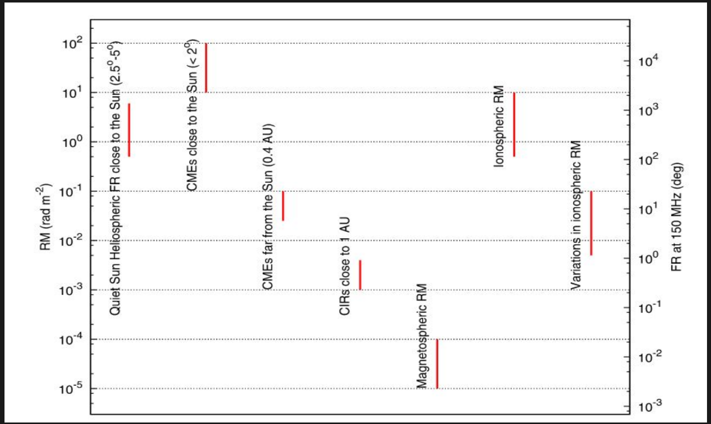

Oberoi et al., 2012

- Current ionospheric RM prediction models depend on spatially and temporally sparse GPS/GNSS based measurements.
- RM accuracy obtained over a year timescale using this available method is ~0.1 rad/m^2.
- For heliopolarimrtry, accuracy in separation of ionospheric RM should be better than these values over small timescale.

Precise Separation of Ionospheric FR – A Critical Step

A new technique is formulated to separate ionospheric FR

1. Main assumptions–
   a. Entire array is looking through the same ionospheric patch towards a certain LoS
   b. Geomagnetic field is not changing significantly within few hours
   c. TEC gradient perpendicular to LoS varies smoothly
2. Tested on night time observations
3. RMS accuracy of RM over 4-minutes of observation ~0.01 rad/m^2

Kansaban … , 2012

- Cu … parse GP …
- RM a … .1 rad/m^2.
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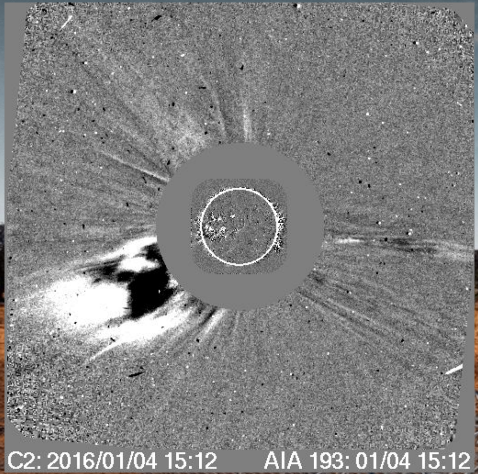
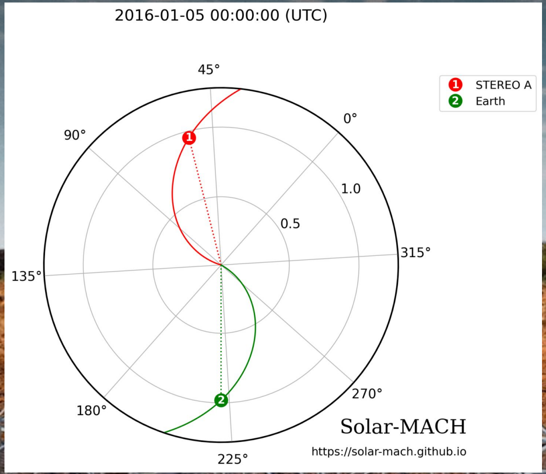
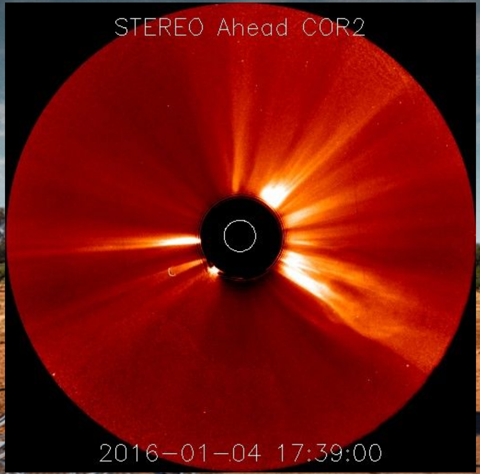
Preliminary Result – First Heliospheric RM Measurements

SKAO-Low Precursor – Murchison Widefield Array (MWA)

128 (currently 144) antenna tiles, 80 - 300 MHz, 30.72 MHz bandwidth, 40 (10) kHz, 0.5 (0.25) s







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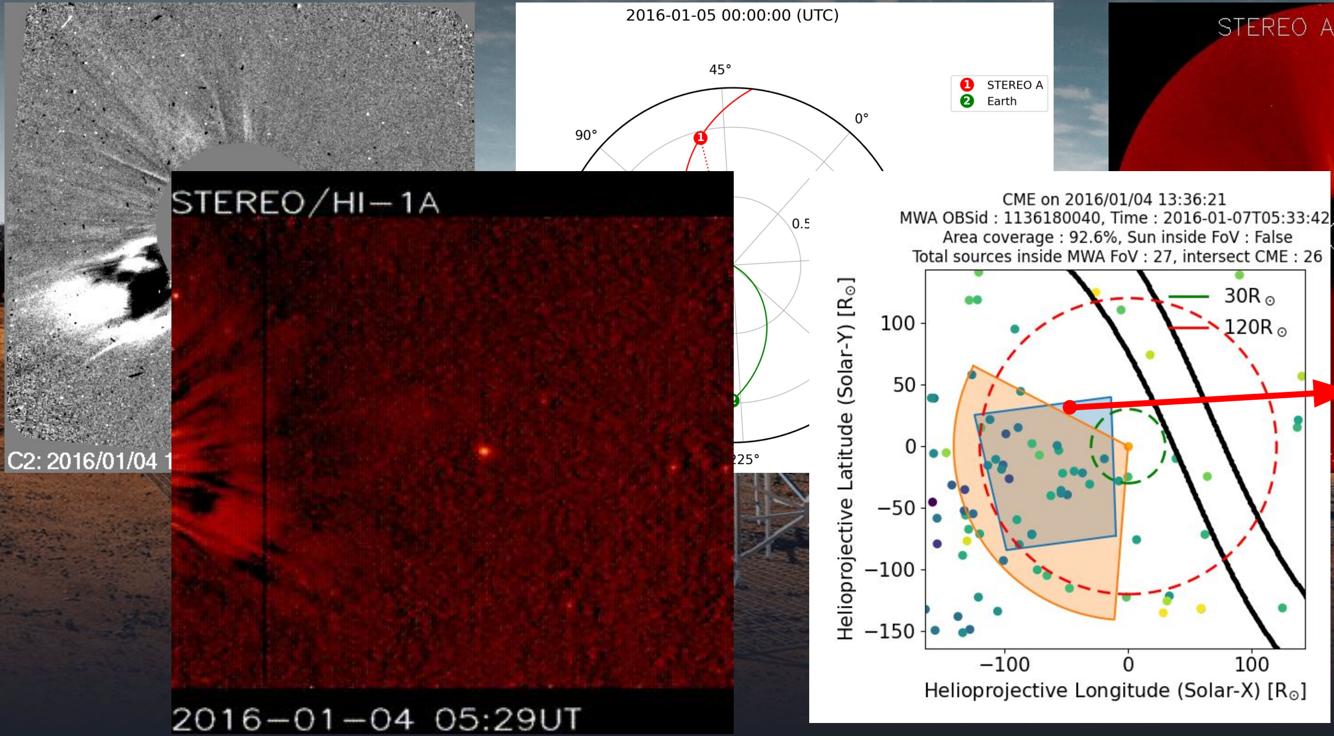
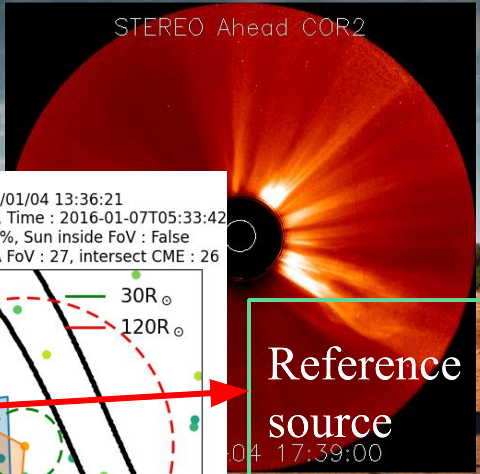




Reference source

Maximum

$\Delta RM = 0.56 \pm 0.04$ rad/m^2

$\Delta RM = -0.21 \pm 0.01$ rad/m^2

$<|\Delta RM|> = 0.13$ rad/m^2

Need Synergy with PUNCH : Complementary Observation

- Radio Heliopolarimetry provides is the rotation measure, RM $\propto \int n_e \mathbf{B}.d\mathbf{S}$
- How to separate electron density contribution?
- White-light observation can help here to provide n_e or $\int n_e dS$ estimation.
- Having that, one can estimate LoS averaged magnetic field, $\langle B \rangle = \int n_e B.dS / \int n_e dS$
- Currently limited to one direction in the ecliptic plane due to only availability one STEREO HI

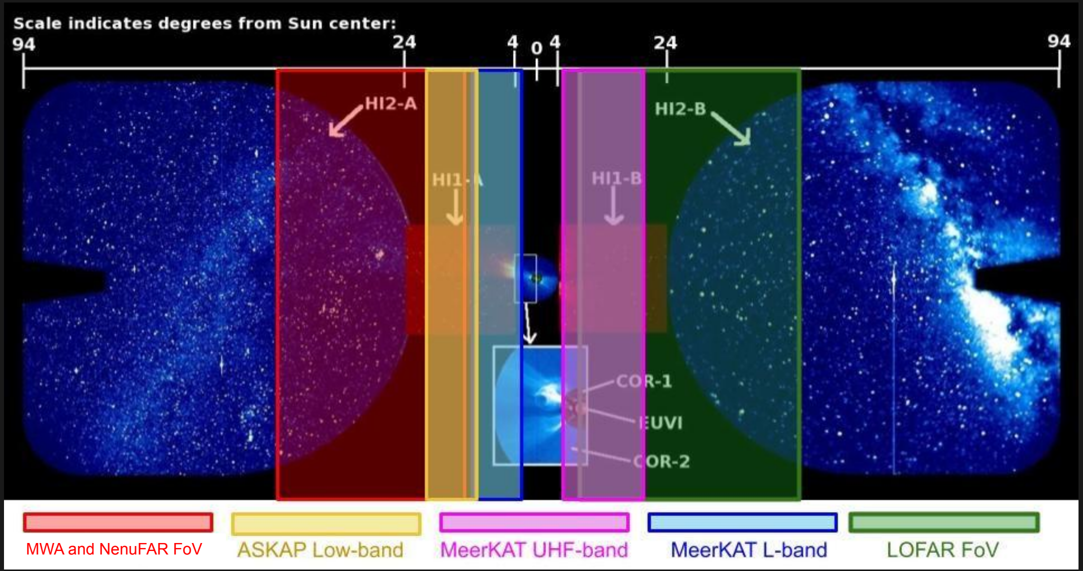
Radio Heliopolarimetry

- Sensitive to magnetic field strength along the LoS
- But combined with electron density contribution
- Need complementary observation to separate n_e contribution

PUNCH White-light data

- Sensitive to density structure
- Not directly sensitive to magnetic field strength
- Provide a way to separate density contribution in FR – 360 deg around the Sun

Preparation for of A Global Heliopolarimtery Network



- Fairly new field – almost no dedicated observation and result were available a year ago.
- New generation large radio interferometric arrays are suitable for these observations.
- Combining these instruments as a global observing network – continuous observations over a large heliocentric distances

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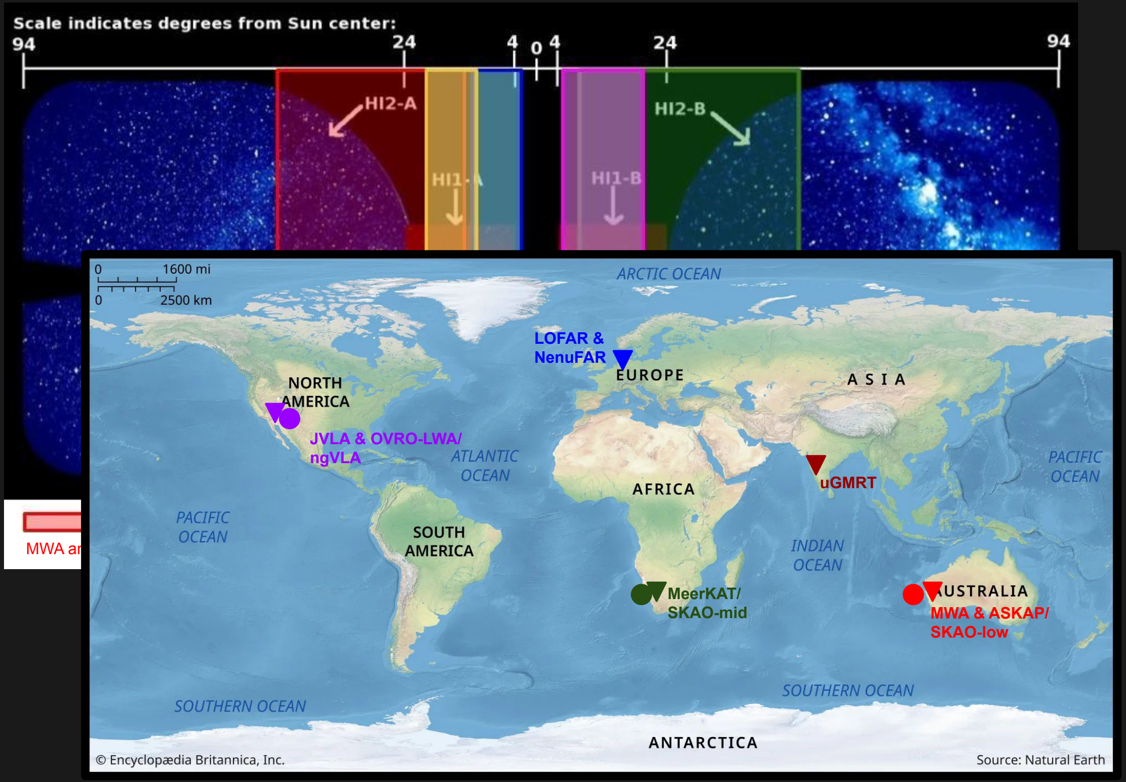

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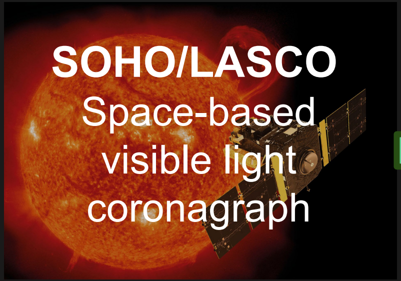
Helioschedule – Automated Triggered Heliospheric Observation

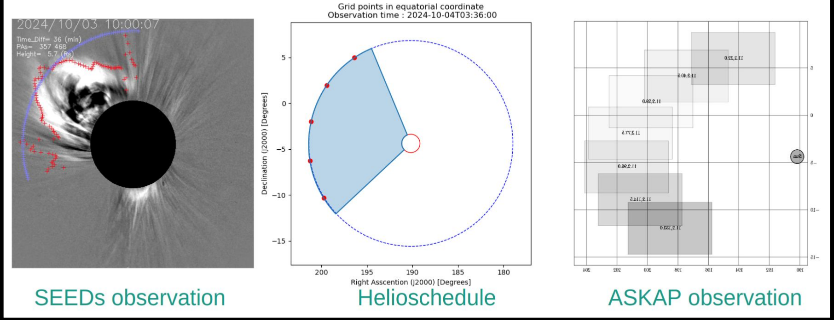


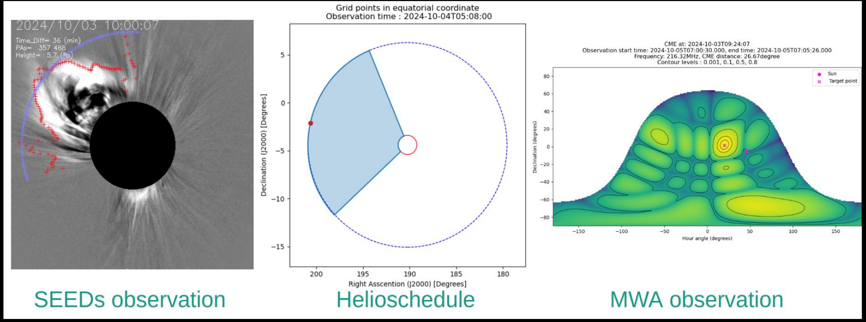
SEEDS
Near real-time (1-5 hr latency) CME catalog provides CME propagation information

Helioschedule
Determines telescope pointing and observation timing based on propagation information and a drag-based heliospheric model

Telescope Helioschedule
Determines pointings, observational configuration and trigger telescope for observation

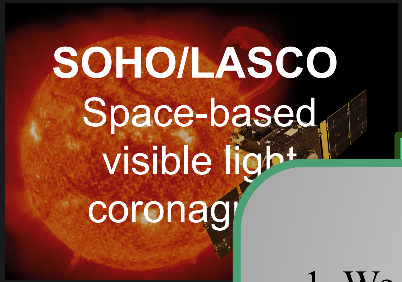
Helioschedule is operational for the MWA and ASKAP from August 2024





Kansabanik, Vourlidas & Morgan, in prep.

Helioschedule – Automated Triggered Heliospheric Observation



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Determines telescope pointing and observation timing based on

Telescope Helioschedule
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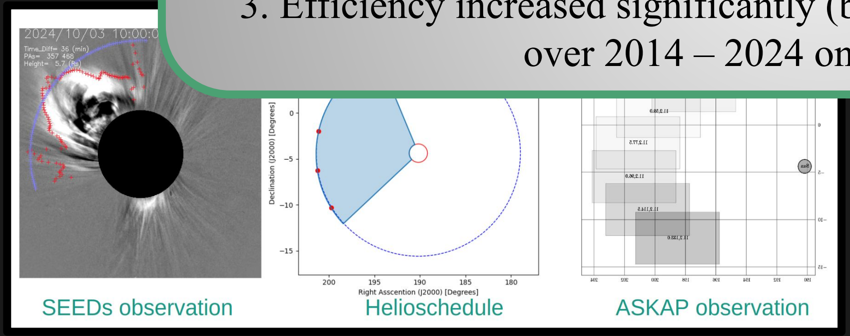
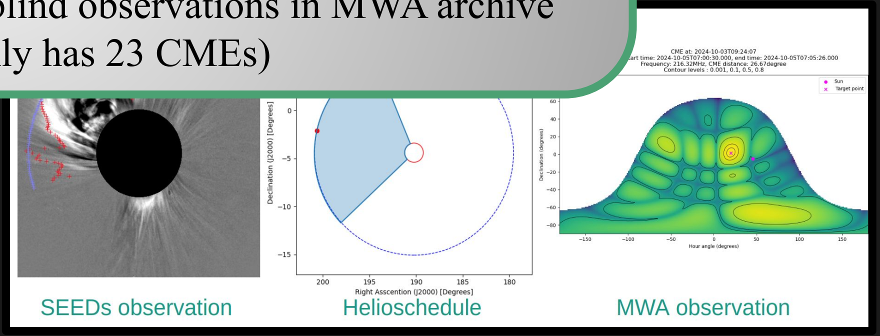
Optimal use of observing time

1. We had 60 hours of MWA observations and 10 hours ASKAP observing time in the last cycle
2. More than 60 CMEs observed with the MWA and 10 CMEs with ASKAP
3. Efficiency increased significantly (blind observations in MWA archive over 2014 – 2024 only has 23 CMEs)

He t 2024



SEEDs observation | Helioschedule | ASKAP observation



SEEDs observation | Helioschedule | MWA observation

Kansabanik, Vourlidas & Morgan, in prep.

Conclusions

- Radio Heliopolarimetry : a new way to provide remote sensing estimates of CME magnetic fields in the heliosphere
- Only possible using new-generation large FoV radio polarimetric imagers – non solar-dedicated instruments
- Precise ionospheric RM separation is necessary – obtained accuracy of 0.01 rad/m^2 over minute to hour timescale
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- An fully automated triggering is necessary and successfully operational on two of these instruments – MWA and ASKAP
- Heliospheric imager with 360 degree position angle views are necessary to separate electron density contribution in measured RM – PUNCH and Heliopolarimetry network will provide complementary informations.

Thank You

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