Tracking CME substructure evolution through the solar wind

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ABSTRACT

Future coronagraphs and heliospheric imagers, in particular those to be launched on the PUNCH mission, will have the capability to track the evolution of CME substructures as it moves through and interacts with the solar wind. We present analyses using polarization data obtained from forward modeling simulations of CMEs in the corona and inner heliosphere. We use these data to track the evolution of CMEs in three dimensions and consider the diagnostic potential of polarization data. We find this method reproduces 3D position well for structures at small elongation, whereas higher elongations are more impacted by multiple features along the line of sight. We demonstrate that front-back ambiguities may be resolved by observing time evolution of structures, and explore capabilities for extracting information about the chirality of CME magnetic flux ropes from polarization data.
ANALYZING FLUX ROPE CHIRALITY

Polarization diagnostics on MHD model with background solar wind: GAMERA

- GAMERA is a reimplementation of LFM model (Zhang et al. 2019)
- GAMERA-Hallo is driven by Wang-Shueley-Arga (WSA) model of the corona (Wang & Sheeley, 1990; Arge and Pizzo, 2000; WSA model is driven by ADAPT global photospheric magnetic field maps (Arge et al., 2010; Henney et al. 2012)
- GAMERA-Hallo-GL incorporates the Gibson & Low (1998) CME, allowing multiple possible topologies (Malanushenko et al., 2020; Provenzale et al. in preparation)

Polarization diagnostics on MHD model with background solar wind: GAMERA

Gamera CME simulation: Away from Earth

Even without subtracting off the background, the Back solution captures the 3D position of the CME substructure well

Simulation is counterclockwise rotation front to back (blue to red), left-handed flux rope. Although it is possible to see features consistent with this in the polarization analysis, ambiguities remain.
USING POLARIZATION TO DEDUCE 3D POSITION

Front-back ambiguity about the Thomson surface (TS) may be largely resolved, e.g., if CME source is identified on solar limb, implying \( +X \) trajectory. Time variation can also be used to eliminate Ghost solutions and establish direction of CME.

Assume a croissant type CME (Themeli, 2011; Hutton and Morgan, 2015, 2016) with a trajectory 65° to the Sun-Earth line.

Synthesize polarization ratio. The CROISSANT model has been incorporated into FORWARD Solarsoft package (Gibson et al., 2016).

Lines of sight pass through the near and far sides of the shell of the croissant. The polarization ratio can diagnose the center of mass between these localized structures (DeForest et al., 2017).
DISTINGUISHING CME DIRECTION

Polarization measurements vs. time can distinguish between Earth-towards and Earth-away

Case 1: Earth-towards
Clues:
- Front solution LOS position stays positive and all points get more positive with time
- Back solution starts negative but parts get more positive with time, ultimately transitioning to positive X (blue)

Case 2: Earth-away
Clues:
- Back solution LOS position stays negative the whole time and all points get more negative with time
- Front solution LOS position stays positive the whole time and all points get more positive with time
CONCLUSIONS

- The 3D position of the CME front is well captured using polarization analysis for small elongations.

- Analysis gets more complex for higher elongations especially if there are multiple localized structures along the line of sight with differing proximities to the Thomson Surface.

- Ambiguity of whether Front vs Back solutions apply can be dealt with by observing time series.

- Polarization presents a tool for distinguishing between left-handed and right-handed CME flux ropes. However, the oblique view (perpendicular to the axis) can be ambiguous. 3D realization of the feature allows rotation to a viewing angle along the axis, ultimately required for establishing chirality.

- Future work: Consider effect of noise

References

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- Matlanunshenko, A., Flyer, N. and Gibson, S. E., FRASS, accepted 2020
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