Lessons from 10 years of STEREO results and applications for future heliospheric missions

Wednesday, 10:15 – 1:10 pm

Organizers:
Barbara Thompson (GSFC/NASA), Teresa Nieves-Chi. (GSFC/CUA), Noé Lugaz (UNH), Gang Li (UAH)
Scene Setting Talks:
LEILA MAYS (GSFC/NASA)

Lan Jian – CIR/SIR
Brian Wood – ICMEs
Ian Richardson – SEPs
Bernie Jackson – IPS as inputs of inner boundary to global solar wind MHD modelling
Lessons learned during the STEREO era:

What have we learned about the 3-dimensional nature of solar wind and inner heliospheric structures (such as CMEs or CIRs) and the extent and variability of solar energetic particles (SEPs) and radio emissions?

Which limitations of 2-D/single-viewpoint observations do we now recognize?

Facing the Future

How have we improved our ability to investigate and understand the initiation, evolution, propagation and morphology of CMEs and the acceleration and propagation of energetic particles with only one or two viewpoints, and with adapted models and analysis techniques?

What are the essential characteristics (orbit, instrument, etc.) that future heliospheric missions must have in light of past heliospheric missions (STEREO, Ulysses, ACE, Helios)?
Better Identification of CME source locations using STEREO EUV

Pre-STEREO era: poor identification of CME source locations when multiple events occur close in time

• STEREO greatly removes unambiguity (not fully).

• Supports TWIN-CME scenario.

Patsourakos et al. 2016
ApJ

Colaninno et al. 2015
ApJ
Better Estimation of CME direction and speed and arrival time

rough error bar estimates at 0.1 AU

<table>
<thead>
<tr>
<th>1 spacecraft</th>
<th>2 spacecraft</th>
<th>3 spacecraft</th>
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<tbody>
<tr>
<td>±30° longitude</td>
<td>±15° longitude</td>
<td>±5-10° longitude</td>
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<tr>
<td>±15° latitude</td>
<td>±10° latitude</td>
<td>±5° latitude</td>
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<tr>
<td>±30° width</td>
<td>±20° width</td>
<td>±10° full width</td>
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<tr>
<td>30-40% speed</td>
<td>20-30% speed</td>
<td>10-20% speed</td>
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Limited 2 spacecraft period shows reduction in skill:

1.7±2.9 hrs (95% confidence)
1.7±1.2 hrs (60% confidence)

Multi-view coronagraph observations have a quantitative impact on CME arrival time forecast accuracy at 60% confidence.

Wold et al. 2017, JSWSC, submitted
Better Estimation of CME Mass and Kinematics

CME mass (e.g. Colaninno & Vourlidas 2009 ApJ)
• Before STEREO CME mass was underestimated by a factor of 2
• STEREO COR2 allows the true CME mass to be determined

Gilbert et al. 2013
ApJL
Better MHD modeling

- STEREO observations can provide the inner boundary for solar wind modelling
- validate and improve models by comparison with synthetic images
Combining with Interplanetary Scintillation

IPS Iteratively Updated Model Density

CME on 2011/09/09 03 UT

Kinematic Model Meridional Cut

3-D MHD Model Meridional Cut

UCSD Model

ENLIL Model

Kinematic Model Time Series

3-D MHD Model Time Series
Better Determination of CIRs and SIRs

Corotating Interaction Regions (CIRs) + transient SIRs (~17%) which do not recur in one or more Carrington rotations (CRs)

Better Identification of shock drivers

~14% of shocks without a clear local driver, possibly due to a distant or disappeared CME

Updated after Jian et al. (2013)
Better Correlation studies of CIRs/SIRs

237 pristine SIRs at STA and 239 at STB.

Among the 156 SIR pairs, 50 (32%) were observed when STA and STB were separated by less than 60 in longitude.

For the 156 SIRs observed by both STA and STB, the maximum speed is best correlated between two s/c, while the maximum Np is least correlated.
Better Flux rope reconstruction and continuous 3D tracking of CMEs

2012 Feb. 24 CME
Better CME classifications from kinematics

Group 1: Flare-associated CMEs
Group 2: CMEs with prominence eruptions (but no flare)
Group 3: No surface activity

Distribution of distance where CME reaches peak speed
Distribution of distance where CME reaches terminal speed

Kinematics of Event #24

Dashed lines are five extra geoeffective events from Wood et al. (2016, JGR, 121, 4938).

Kinematics of Event #24

Distribution of distance where CME reaches peak speed

Distribution of distance where CME reaches terminal speed
Comparing Imaging and In-situ Data

Comparing force-free and non force-free MC solutions

Comparing MC solutions with image-based FR orientation:
- Force-free MC solution
- Non force-free MC solution

- Comparison between MC reconstructed from imaging and that measured from in-situ
- Conclusion: Image-based FR reconstructions are not in good agreement with MC durations and orientations.
Multi-point observation of the SAME SEP made possible

**STEREO A**

Prompt onset at STA, well connected to the flare @W55°

**Earth**

Recent 25 MeV Proton Event at STEREO A and Earth: April 18, 2017 C5.5 Flare at E84°

**SOHO/EPHIN**

Slower onset, more extended event at Earth (SOHO/EPHIN observations); Flare is at E84°

**ENLIL model of ICME at 00 UT, April 21 (from the DONKI database)**
New constraints on topology of magnetic field near the source and/or (cross-field) diffusion of SEPs

August 18 (DOY 230), 2010

STEREO A 0.7-4 MeV e-, 14-24 MeV, 24-41 MeV protons

SOHO EPHIN 0.7-3 MeV e-; ERNE 14-24 MeV, 24-41 MeV protons

STEREO B 0.7-4 MeV e-, 14-24 MeV, 24-41 MeV protons

CME: 0548 UT, 184°, 1471 km/s (CDAW)

Flare location wrt:
STEREO B: W172°  Earth: W100°  STEREO A: W20°
New constraints on topology of magnetic field near the source and/or (cross-field) diffusion of SEPs

Different estimates of onset times using different methods:
Blue lines=uncertainty “by eye”; green dots=Poisson-CUSUM; orange dots=Fixed onset level method.

Different coronal fields obtained using different models/magnetograms:
a)PFSS+HMI; b)PFSS+GONG; c)MAS+HMI

Evolving magnetic connection to an expanding ellipsoidal model shock front assuming a PFSS+GONG coronal field

A particle transport model including cross field diffusion may also account for the particle profiles, in particular the onset at STEREO A which does not connect to a fast section of the shock.

Lario et al., 2017
The Future – more STEREOS