

The Science Case for a 4 π Perspective: A Polar/Global View on Space Weather Origins

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One of the fundamental inputs to space-weather forecasting is information about the origins of coronal mass ejection (CMEs). This includes knowledge of the CME source region, and of the CME's size, morphology, trajectory and acceleration.

Space Weather Magnetic Origins: Current State

Substantial uncertainties remain about the solar photospheric magnetic boundary (Riley+ 2014), affecting not just global heliospheric models¹ but also magnetic models of CME precursors. In addition to center-to-limb foreshortening issues, vector magnetic measurements from a single viewpoint possess intrinsic ambiguities (Semel & Skumanich, 1998). These introduce uncertainties in magnetic field extrapolations (De Rosa+ 2009) and so hamper investigations of the roles of stored magnetic energy, magnetic helicity, and topology of the magnetic field in solar eruptions. Coronal plasma and polarimetric measurements can be used to address such limitations by providing independent measurements for validation and/or optimization of coronal magnetic models (Savcheva+ 2013; Malanushenko+ 2014; Gibson+ 2016; Dalmasse+ 2019). However, modeling limb structures is fundamentally limited because the underlying on-disk magnetic boundary cannot be co-temporally observed.

One of the most tantalizing findings of multi viewpoint imaging is the evidence for long-range interactions between eruptive events occurring over the span of hours to days across a full solar hemisphere (Schrijver & Title 2011). The subject of 'sympathetic' flaring and remote triggering of flares or eruptions has been discussed for decades, but is seriously hampered by a single viewing angle, so that we depend largely on models for our current understanding of global interactions (Török+ 2011; Titov+ 2011, 2012, 2017). Relatedly, although we know CMEs exhibit rotation, deflection, and reconnection during eruption², we cannot observe longitudinal structure and dynamics from the ecliptic, limiting our understanding of the CME's initial evolution.

Space Weather Magnetic Origins: Desired State

Ultimately, improving space-weather forecasts requires observations from off the Sun-Earth line (SEL) and in particular, observations from the solar poles (Table 1). Before eruption, non-SEL observations enhance predictive capability for impending SEL-directed CMEs: for example, the presence of a teardrop morphology in coronal cavities seen at the limb indicates near-term eruption (Forland+ 2013)--but these must be observed in quadrature to the CME direction to be useful for space-weather prediction. Non-SEL viewpoints also more accurately measure speed and mass (and hence, kinetic energy) of SEL-directed CMEs. For example, the accuracy of the CME time of arrival at Earth is now ± 10 hours, compared to ± 24 hours in the pre-STEREO era (Vourlidas+ 2019). There are early indications that the momentum

¹ See submitted WP "The Science Case for a 4 π Perspective: A Polar/Global View of the Heliosphere", Gibson et al.

² See submitted WP "The Science Case for a 4 π Perspective: A Polar/Global View on Studying the Evolution & Propagation of the Solar Wind and Solar Transients", Vourlidas et al.

flux of the Earth-directed part of a CME front, measured from a non-SEL coronagraph and extrapolated to 1 AU, can be used to predict Dst variations (Savani+ 2013). In general, non-SEL measurements are the best means for monitoring evolution of Earth-intersecting CMEs (and CIRs) via coronal and heliospheric imaging. **The longitudinal “sunny-side-up” coverage from a spacecraft positioned near the solar rotation axis is particularly useful, uniquely providing space-weather monitoring for all the planets and spacecraft in the inner heliosphere, not just the Earth-Moon system and L1.** This will become increasingly important as human exploration takes us out into the heliosphere.

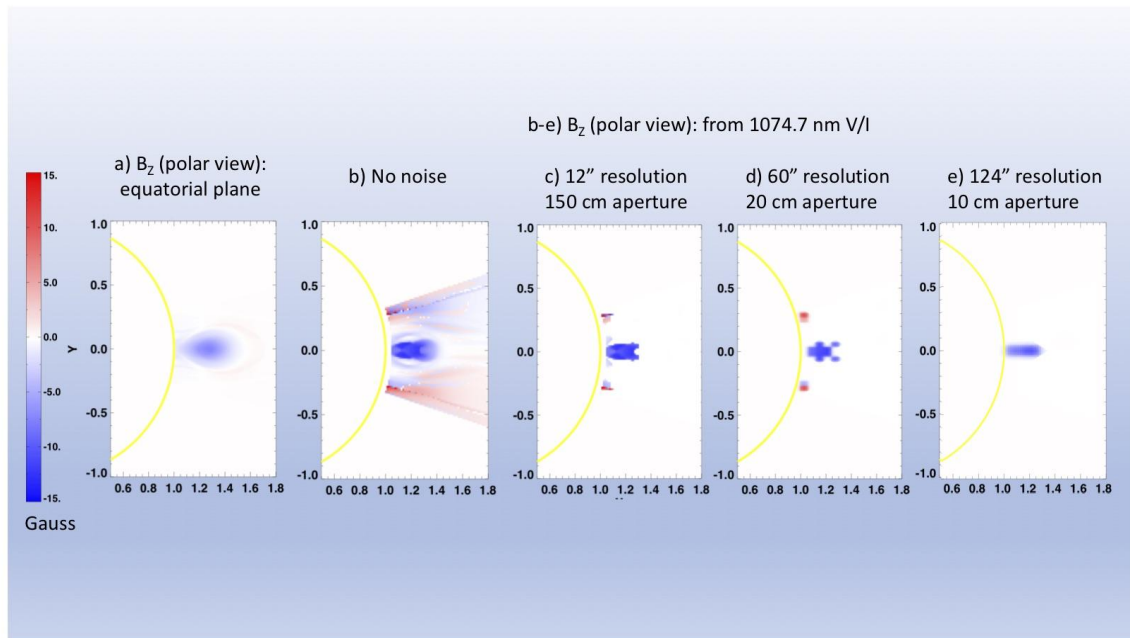


Fig. 1. B_z for a simulated, erupting CME (Fan+ 2018) viewed from the North pole. a) Simulation ground truth B_z in equatorial plane. b) B_z inverted from ratio of forward-modeled (Gibson+ 2016) Stokes circular polarization V and intensity I . c) B_z values with signal-to-noise ratio >3 , based on a 1.5 m telescope, 12'' spatial resolution, and 5 minute integration. d) Same but 20 cm; 60'' resolution. e) 10 cm; 124'' resolution. Note that the sign and strength of the pre-eruptive core field is captured in all cases. From Gibson+ 2018.

Of utmost importance, non-SEL line configurations may be our best option for quantifying the magnetic field entrained in the CME. A 4π multi-longitude view enables monitoring of the birth-to-death evolution of solar active regions, critical since most CMEs occur in the 24 to 48 hours after new flux emerges. Multiple viewpoints also help vector magnetic field disambiguation and enable comprehensive tomographic and/or stereoscopic methods (Kramar+ 2006; 2016; Aschwanden+ 2015), yielding key information about magnetic energy, helicity, and topology. **Moreover, we note that from near the poles, the line-of-sight magnetic field is close to B_z , the southward component, known to greatly impact geoeffectiveness.** B_z could also potentially be obtained, even mapped, via Faraday rotation measured from beacon signals sent from spacecraft distributed in and away from the ecliptic (e.g., Jensen+ 2013). Or, as a recent CME simulation has demonstrated, coronal IR spectropolarimetry could measure line-of-sight magnetic field strength at the core of an erupting CME (Fig. 1; Fan+ 2018).

Table 1. Space-weather science enabled by non-SEL observations (Adapted from Gibson+2018³)

Open science questions: How is magnetic energy stored in the corona, how is it released in eruption, and what is the role of helicity/topology? How do local and global coronal magnetic fields interact? What will the impact of a given CME be at the Earth and other planets?			
Measurements needed: (1) Full-disk photospheric Doppler magnetographs; (2) Chromospheric spectropolarimeters; (3) Full-Sun multi- λ EUV coronal imagers; (4) Multi- λ coronal spectrometers; (5) Polarimetric coronagraphs; (6) White-light/multi- λ coronagraphic imagers; (7) Heliographic imagers with polarizing filters; (8) In-situ heliospheric measurements; (9) Faraday rotation measurements			
Benefits from non-SEL vantage (assumes existence of complementary SEL observations)	Polar	Quadrature (Ecliptic)	Far-side
Magnetic vector boundary disambiguated	yes (1),(2)	yes (1),(2)	no
Simultaneous view of magnetic boundary/limb structures	yes (1)-(7)	yes (1)-(7)	no
Line-of-sight measurements of B_z	yes (5),(9)	no	no
Global interactions comprehensively observed	yes (1)-(7)	yes (1)-(7)	no
Improved observations of Earth/planet intersect. transients	yes (1)-(9)	sometimes (1)-(9)	sometimes (1)-(9)
Notional timeline for reaching science closure			
<2030	Preliminary exploration of Solar Orbiter high latitude data (2027+)		
>2030	First polar (>60°) investigations (e.g., Solaris mission currently in Phase A)		
2050	4 π coverage of the corona/inner heliosphere		

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³ Note, some portions of white paper text also modified from Gibson+, 2018