

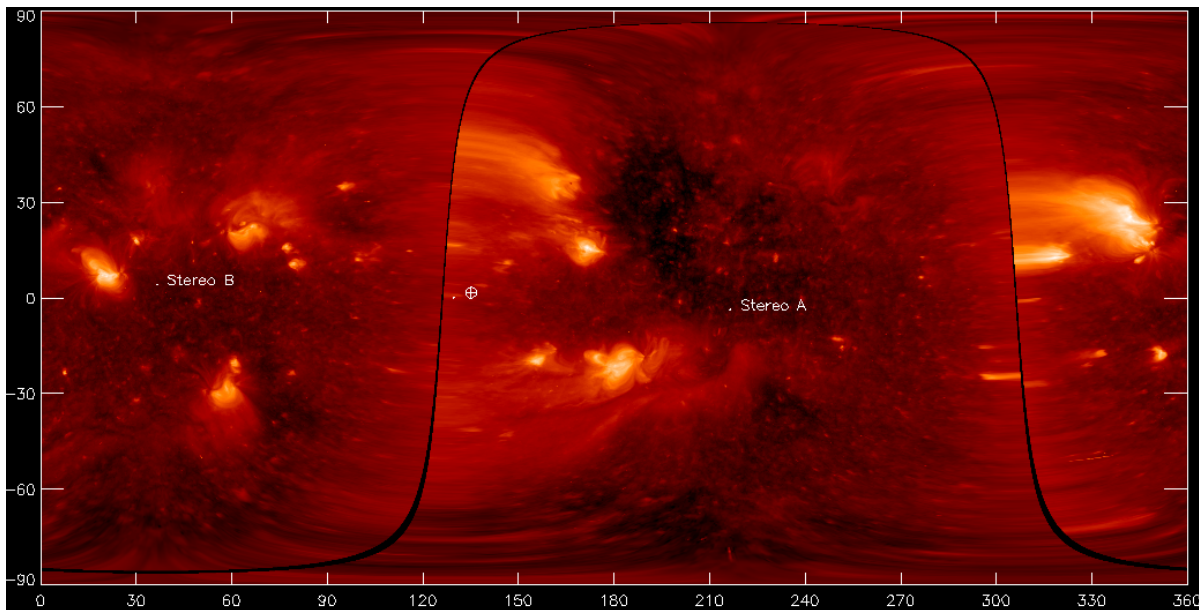
## The Science Case for a $4\pi$ Perspective: A Polar/Global View of the Heliosphere

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The heliosphere is a network of magnetically connected systems, from Sun, through solar wind, to the planets. Understanding the global heliosphere is central to the field of heliophysics.

### **Global Heliosphere: Current State**

Photospheric magnetographs provide a lower boundary constraint on the heliosphere<sup>1</sup>. Global models, ranging from potential-field-source-surface extrapolations (Wang & Sheeley 1990; Arge+ 2003) to magnetohydrodynamic simulations (Toth+ 2005; Riley+ 2012) use photospheric observations to simulate the magnetic fields of the solar corona and heliosphere.



**Fig. 1.** A Carrington map of EUV synchronic observations of the full  $360^\circ$  sun, made possible by far-side imaging provided by the twin STEREO spacecraft.  $284 \text{ \AA}$  images were taken on February 6, 2011 at 18:00 UT while the STEREO spacecraft were in exact opposition. From Gibson+, 2018.<sup>2</sup>

However, current magnetographs are mostly limited to a single Sun-Earth Line (SEL) vantage. Foreshortening affects both the poles and the East/West limbs. Magnetic fields on the far-side of the Sun are not seen at all. As a result, global magnetic boundary conditions on models cannot represent any single time as they incorporate measurements taken over multiple days or even weeks. Standard synoptic maps are made up of an average in which each longitude is weighted towards observations taken when that longitude is at disk center (Hoeksema & Scherrer, 1986). Alternatively, “synchronic” methods weight the entire map towards a single time, making use of flux-transport models and data assimilation (Worden & Harvey, 2000; Schrijver & De Rosa,

<sup>1</sup> And an upper boundary on the solar interior: see also submitted white paper “The Science Case for a  $4\pi$  perspective: A Polar/Global View for Understanding the Solar Cycle”, Hoeksema+

<sup>2</sup> Note, some portions of white paper text also modified from Gibson+, 2018

2003; Arge+ 2010; Hickmann+ 2015). A true synchronic observation of the photospheric magnetic field, e.g., as shown in **Fig. 1** for [EUV STEREO observations](#), is not currently possible.

Although the approximately 7° inclination of the Sun's rotational axis with respect to the ecliptic plane means that observations from the Earth catch a glimpse of each solar pole once per year, they are still viewed from a very large angle, making accurate measurements of the polar photospheric magnetic fields extremely difficult (Petrie, 2015). High-resolution spectro-polarimetric observations from Hinode during a time of maximum polar inclination relative to the Earth found concentrated patches of strong field at high latitudes (Tsuneta+ 2008). The polar magnetic flux implied by these high-resolution measurements suggest that the current photospheric magnetic synoptic/synhronic maps may underestimate the flux in the polar region. This could help explain why comparisons of coronal and interplanetary open flux find inconsistencies of a factor of two or more (Linker+ 2017; Wallace+ 2019). Current models of the heliosphere are thus poorly constrained due to lack of solar polar magnetic field observations.

Recent deep-field imaging of the mid to outer corona (DeForest et al. 2018) reveals faint moving structures and inhomogeneities at all latitudes and solar wind speeds. The observed structural variations can arise from three sources: 1) discrete, but steady solar sources rotating through different longitudes (Borovsky 2008; Burkholder+ 2019); 2) magnetic reconnection driven flows (Antiochos et al. 2011); and 3) evolution *en route* such as turbulence (Bruno and Carbone 2013). It is currently not possible to distinguish between sources because structures from rotation can only be identified from a viewpoint near parallel to the solar rotation axis.

### **Global Heliosphere: Desired State**

***Ultimately, obtaining a global understanding of the heliosphere requires observations from off the Sun-Earth line (SEL) and in particular, observations from the solar poles (Table 1).*** The addition of magnetograph measurements from non-SEL viewpoints is expected to significantly improve global magnetic simulations (Mackay+ 2016) and to generally improve modeling of the heliosphere (Pevtsov+ 2016). A polar view (i.e., >60° latitude) is critical to removing uncertainty in polar magnetic field strength and would also enable direct measurements--both on-disk and in-situ--of fast solar wind sources and structures free from the effects of foreshortening inherent in observations to date (McIntosh+ 2006), and capable of decoupling rotational vs evolutionary effects. Non-SEL views also enable simultaneous limb and disk multiwavelength spectroscopic observations, which with complementary in-situ solar-wind observations (e.g., matched composition measurements) clearly connects solar wind to source regions. ***To make progress on open questions on the globally connected heliosphere, non-SEL observations are needed for better coverage of the photospheric magnetic boundary and for multi-vantage observations of optically-thin structures. The polar vantage is particularly important to resolve uncertainty in the magnetic boundary on the global solar wind, with implications for open magnetic flux in the heliosphere.***

**Table 1. Global heliospheric studies enabled by non-SEL observations** (Adapted from Gibson+2018)

<b>Open science questions:</b> What is the structure of the global coronal/heliospheric magnetic field? What are the source regions of the global solar wind?
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<b>Measurements needed:</b>			
(1) Full-disk photospheric Doppler magnetographs	(5) Polarimetric coronagraphs		
(2) Chromospheric spectropolarimeters	(6) White-light/multi- $\lambda$ coronagraphic imagers		
(3) Full-Sun multiwavelength coronal imagers	(7) Heliographic imagers w/ polarizing filters		
(4) Multiwavelength coronal spectrometers	(8) In-situ heliospheric measurements		
<b>Benefits from non-SEL vantage</b> (assumes existence of complementary SEL observations)	<b>Polar</b>	<b>Quadrature (Ecliptic)</b>	<b>Far-side</b>
Better coverage of global magnetic boundary	yes (1)	yes (1)	yes (1)
Better constraints on polar fields/heliospheric open flux	yes (1),(8)	no	no
Simultaneous view of magnetic boundary and limb structures	yes (1)-(7)	yes (1)-(7)	no
Solar-wind source regions connected to in-situ measurements	yes (1)-(7)	yes (1)-(7)	no
Decoupling of rotation vs transient effects	Yes (6-7)	no	no
<b>Notional timeline for reaching science closure</b>			
<2030	Preliminary exploration of Solar Orbiter high latitude data (2027+) and PSP coronal meas.		
>2030	First polar (>60°) investigations (e.g., Solaris mission currently in Phase A)		
2050	4 $\pi$ coverage of the corona/inner heliosphere		

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