The Science Case for a Polar Perspective: Discovery Space

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Opportunities for discoveries abound for spacecraft out of the ecliptic plane. New observations from new places or new vantage points inevitably lead to discoveries and insight. Even in the ecliptic, but away from the Sun-Earth line (SEL), previous experience illustrates the power of non-SEL vantage points to offer unique ways to find and observe celestial objects such as comets and asteroids: Ulysses, for example, crossed through the tail of one of the comets that was imaged -- and detected in-situ -- by STEREO (Fulle et al., 2007; Neugebauer et al., 2007). Non-SEL viewpoints also can also extend observations of variable stars and improve the rate of discovery of exoplanets (Wraight et al., 2011).

The polar view of the Sun offers unprecedented opportunities for discovery in the field of Heliophysics. The Solaris mission, currently undergoing Phase A study, will be a pathfinder for discovery, imaging the Sun's poles from heliolatitudes >60° for months at a time. Multiple fundamental problems will be addressed as never before, including the solar dynamo[1], the origins of coronal mass ejections[2], the global heliosphere[3], and transient evolution and interaction with the solar wind[4]. There are several reasons that the solar polar vantage is so necessary for progress. In particular,

- **The poles are very poorly and sporadically observed.** In addition to seasonal obscuration, observational difficulties include foreshortening, resolution degradation, center-to-limb effects, reduced sensitivity, and small signals. These make it difficult to use ecliptic-viewed high-latitude observations for model validation and incorporation.

- **High latitudes may have different flow patterns than those observed near the Sun's equator, with implications for solar cycle evolution**. The solar interior is largely unexplored for subsurface regions above 60°, and tracking of surface features is complicated by solar rotation. Much of our current knowledge essentially extrapolates ecliptic-viewed information to the polar "zone of the unknown". But, for example, we don't know what happens to converging poleward flows.

- **The magnetic field appears to be different in the polar regions** (e.g. largely unipolar, small flux concentrations with no active regions, structured by surges from low latitudes),

[1] See submitted white paper "The Science Case for a 4π perspective: A Polar/Global View for Understanding the Solar Cycle", Hoeksema et al.
[2] See submitted white paper "The Science Case for a 4π perspective: A Polar/Global View on Space Weather Origins", Gibson et al.
[3] See submitted white paper "The Science Case for a 4π perspective: A Polar/Global View of the Heliosphere", Gibson et al.
[4] See submitted white paper "The Science Case for a 4π perspective: A Polar/Global View for Studying the Evolution & Propagation of the Solar Wind and Solar Transients", Vourlidas et al.

which is particularly difficult to measure due to line-of-sight projection, and potentially important for addressing solar cycle poloidal 'flux deficit' concerns (Cameron and Schussler, 2015) as well as the 'heliospheric open flux mystery' (Linker et al., 2017).

- **We cannot easily observe longitudinal coronal structure and variability from the ecliptic.** The polar view is the *only* way to view the heliospheric current sheet "sunny-side-up" *from the solar rotational axis*. As a result, transient longitudinal structure and interactions with the surrounding heliosphere can be observed, confirming or falsifying current models of their dynamic evolution.

- **There is a fundamental mismatch between high-resolution imaging of the surface and of the plane-of-sky above the limbs**. The only way to link highest-resolution observations at disk center from Earth with high-definition plane-of-sky (PoS) images is to view the Sun away from the SEL. STEREO has provided PoS images that show latitudinal structure relevant to Earth. A polar vantage point is the only way to reveal how the structure of the corona and heliosphere vary with longitude in the ecliptic.

These represent "known unknowns", but we also expect this first extended view of the Sun's poles to present us with new mysteries, impossible to anticipate. We have never observed the solar poles with imagers. What do we expect to see? The semi-annual view of high latitudes arising from the tilt of the Earth's orbit provides us with some sense of what we might expect in polar flow patterns, as does SEL observations of high-latitude large-scale magnetic features structures (**Figure 1 a-b**). However, based on recent images from planetary missions, such as Juno and Cassini (**Figure 1 c-d**), direct observations of the poles are likely to reveal far more complex and beautiful structure than anything we have been able to piece together to date.

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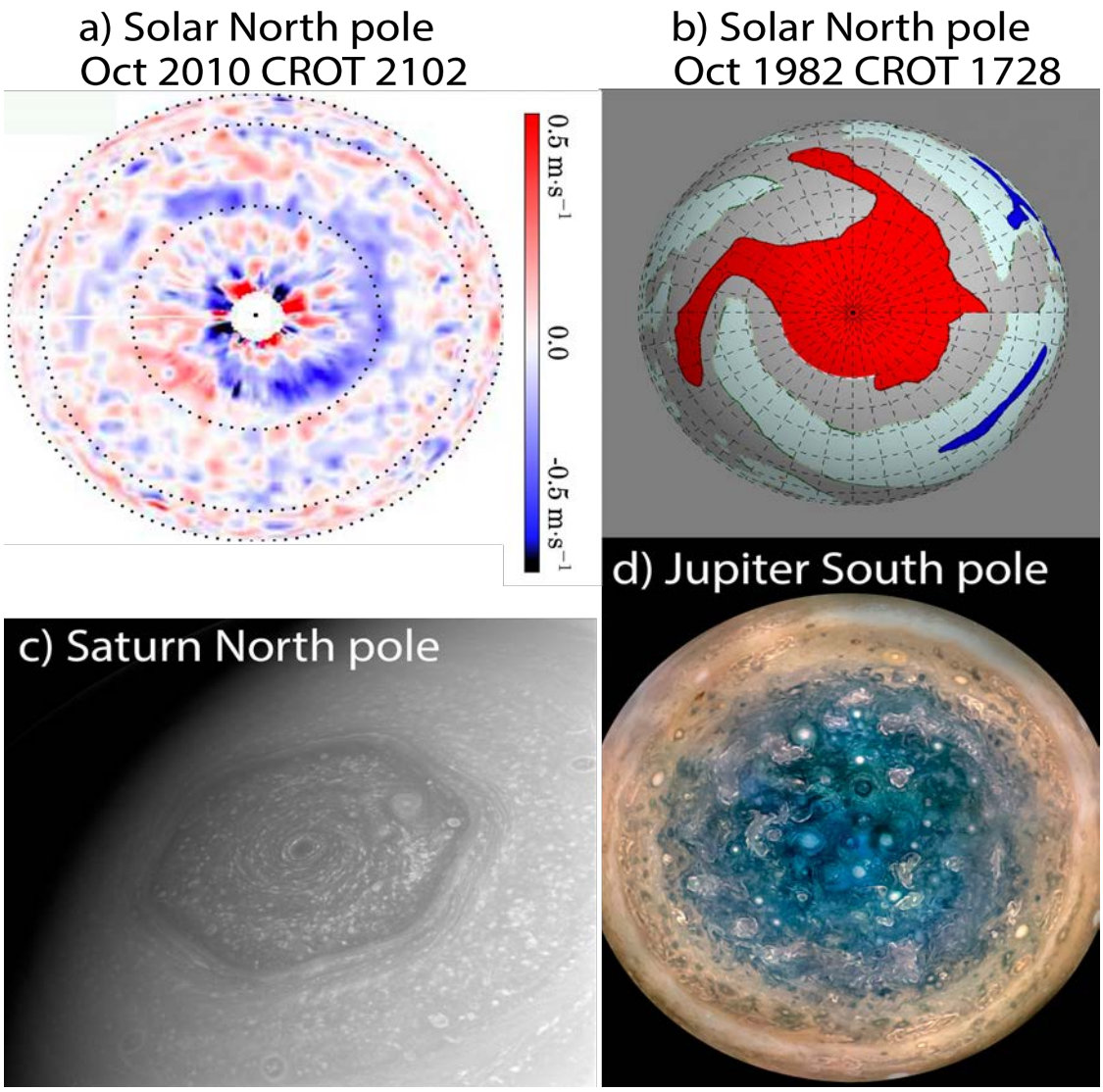

Figure 1. *(a) Ring-diagram analysis of near-surface flow anomalies indicate spiral flow patterns at the poles (Bogart et al., 2015). (b) Observations of large-scale, high-latitude magnetic features spanning multiple decades (McIntosh 1979; 2003) similarly demonstrate spiral structure at the poles (Webb et al., 2018; red=negative coronal hole, blue=positive coronal hole, grey = negative polarity quiet Sun, light blue = positive polarity quiet Sun, dark green=filaments). (c) A view centered on Saturn's north pole. North is up and rotated 33 degrees to the left. The image was taken with the Cassini spacecraft wide-angle camera on June 14, 2013 using a spectral filter sensitive to wavelengths of near-infrared light centered at 752 nanometers. (Source: NASA JPL) (d) Multiple images combined show Jupiter's south pole, as seen by NASA's Juno spacecraft from an altitude of 32,000 miles. The oval features are cyclones. (Credit: NASA/JPL - Caltech/SwRI/MSSS/Betsy Asher Hall/Gervasio Robles). (Figure and some portions of text from Gibson+, 2018)*