

Our Global Heliosphere: Toward Understanding Astrospheres Around Other Stars

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Recommendation:

- ***New measurements at the heliospheric boundary and in the local interstellar medium (ISM) are required in the near-term to resolve the fundamental questions about the nature of the global heliosphere. Understanding this region is necessary to enable future longer-term investigations at the intersection of the Heliophysics and Astrophysics fields, aimed at exploring the structure and evolution of other astrospheres and their role in habitability of the exoplanets that they host.***
- Our heliosphere is the only astrosphere accessible to us to explore in detail how a star's wind interacts with its interstellar neighborhood, and what interplanetary environment such interaction creates for star system planets.
- The Voyager mission discovered that our heliosphere shields solar system planets from galactic cosmic rays (GCR). Modulation of GCR flux in other astrospheres is a fundamental, open question and critical to assess the habitability of exoplanets.
- Understanding how dust flows through the heliosphere is the key for using observed dust traces in other astrospheres to unravel interactions between stellar winds and ISM.

I. Current Knowledge: The Nature of the Heliosphere remains a mystery

Our heliosphere, a plasma bubble around the Sun, is formed in a complex interaction of magnetized space plasmas of different origin, solar and galactic. Understanding the global nature of the heliosphere and physical processes involving the varying solar wind plasma and solar magnetic field, ISM plasma and magnetic field, ISM neutral particles, energetic particles and galactic cosmic rays is one of the major science goals of NASA Heliophysics.

The first theoretical concepts of the global heliosphere were introduced by the pioneering work of Parker (1961), but relatively recently in 2004 the first observational evidence of a heliosphere boundary came from Voyager 1[1]. At 94 astronomical units (AU) from the Sun, the spacecraft detected in-situ the heliospheric termination shock (TS), the first frontier of the new region where the solar wind interacts with local interstellar space. Later, in 2007, Voyager 2 confirmed the TS, and also revealed an unexpected asymmetry in its global structure [2]. As the two Voyagers traversed through the heliosheath, the outermost region of the heliosphere, and exited into interstellar space, they made a number of fascinating discoveries which completely changed our view of this region and made the science community seek new explanations. Remote observations on IBEX [3], Cassini [4], SOHO/SWAN [5] and the Hubble Space Telescope[6] revealed the global three-dimensional dynamic structure of the heliosphere and its interaction with the interstellar medium but many discoveries still challenge our understanding. The following fundamental science questions (top-level) on the nature of the heliosphere remain open:

- *How are galactic cosmic rays modulated in the heliosphere?*
- *What pressure components uphold the heliosphere boundary?*
- *Does the heliosphere have an open or closed tail?*
- *How is interstellar dust filtered through the interaction region at the heliosphere boundary?*

- *How do shock waves propagate through the heliospheric boundary, and what is their role in particle acceleration?*
- *What is the structure of the hydrogen wall, and how does it relate to similar structures in other astrospheres?*
- *What are the properties of the local interstellar medium?*

To answer these questions and fill the gaps in our understanding requires the near-term (2030-2050) investigation of the heliospheric boundary and local ISM¹ by making new both in-situ measurements of charged and neutral particles, magnetic fields and dust, and remote observations in energetic neutral atoms (ENAs)² and backscattered hydrogen Lyman- α emission³.

Like our heliosphere, the interaction of stellar winds with the surrounding interstellar medium results in the formation of *astrospheres*. Many astrospheres, representing more extreme cases than our heliosphere, were observed with appearances ranging from a bright bubble to crescent and comet-like shapes. Understanding our heliosphere is vital to enable future longer-term investigations (≥ 2050) at the intersection of the Heliophysics and Astrophysics fields toward exploring the structure and evolution of other astrospheres and their role in the habitability of exoplanets that they host.

II. From our Heliosphere to Astrospheres Around Other Stars

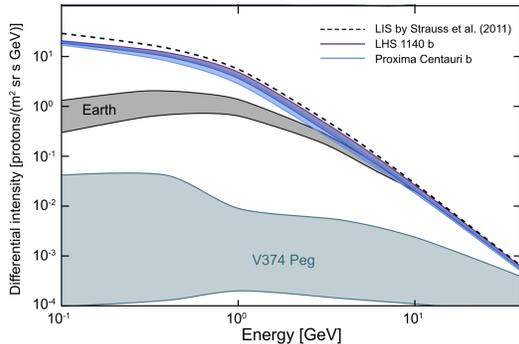


Figure 1. *GCR flux at the location of potentially terrestrial-like planets may significantly vary between astrospheres [9]*

How are Galactic Cosmic Rays modulated in astrospheres? The heliosphere represents an ideal 'test case', from which valuable lessons can be learned as to the transport of cosmic rays (CRs) and the various processes that influence their modulation [7]. These lessons can, and to a degree have, been applied to study CR transport in other, sometimes vastly different, astrospheres [8,9]. These studies show that large stellar wind cavities can act as sinks for the galactic CR flux and give rise to small-scale anisotropies, and the impact of GCRs on potentially Earth-like exoplanets like, e.g., Proxima Centauri b and LHS 1140 b cannot be neglected in the context of exoplanetary habitability

(Fig. 1). However, ***meaningful extrapolation of what we have learned in the heliosphere to the study of astrospheres requires a more profound understanding of the transport of CRs in a heliospheric context.***

Recent advances in our understanding of significant factors in the heliospheric transport of CRs have mainly been based on an improved understanding of their diffusion in heliospheric magnetic field [10], as well as their drift due to gradients and curvatures of this field, and along with the heliospheric current sheet [11]. These advances have gone hand-in-hand with similarly novel insights as to the so-called microphysics of the heliosphere, in the theoretical and observational study of turbulence in the solar wind, which plays a significant role in scattering and transport of charged particles [12,13,14]. In turn, such insights have been mostly gleaned from observations confined to the very inner heliosphere [15]. This has driven a continuous improvement in our understanding of CR transport and modulation, accompanied by significant

¹ Helio 2050 white paper by Brandt et al.

² Helio 2050 white paper by R. Demajistre et al.

³ Helio 2050 white paper by M. Mayyasi et al.

refinements in the complexity and capacity of numerical CR modulation models to yield CR intensities in good agreement with spacecraft observations [16,17].

Much, however, remains unknown. The *Voyager* spacecraft have provided tantalizing hints as to plasma conditions in the heliosheath, a region where, in fact, most CR modulation occurs [18], but much more data is required. This will stimulate advances in heliospheric simulations, turbulence transport modeling, and the development of theories to describe the scattering of CRs in this unique plasma environment. These advances will provide the foundation upon which the next generation of CR modulation codes will be developed. Due to their first-principle approach, these codes would be directly transferable to the study of CR modulation in astrospheres. Such advances are of vital importance to properly consider the large variety of potential astrospheres out there and provide a more nuanced understanding of the transport of CRs in such astrospheres, allowing one to study their influence in these environments quantitatively.

How does interstellar dust interact with an astrosphere boundary? Measurements of the infra-red light from the interstellar dust represent a unique and effective way to observe and study astrospheres. Charged interstellar dust particles interact with stellar and interstellar radiation, magnetic fields and plasma within the astrosphere. Therefore, the dust distribution may reflect a structure of the interaction region between the stellar wind and surrounding ISM [19,20,21]. Many astrospheres with different shapes have been revealed recently by Spitzer Space Telescope, Wide-field Infrared Survey Explorer and Herschel Space Observatory [22]. Analysis of the observed structures using physics-based models may help to obtain constraints for parameters of these stellar winds and the ISM, as well as local properties of the dust around certain astrospheres. Analysis of these data requires an understanding of the physical processes which affect the dust dynamics and distribution in an astrosphere. The heliosphere is the only accessible example where the interstellar dust has been measured in-situ [23]. Despite a number of studies of the interstellar dust filtration and deflection in the vicinity of the heliosphere [24-28], the distribution of dust and the physical processes acting between the dust and magnetic fields at the heliospheric boundary remains unknown. *Understanding mechanisms of propagation and filtration of interstellar dust through the heliosphere is required to interpret astrosphere images and unravel the structure of the interaction of the stellar wind with the ISM.*

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