Interplanetary Hydrogen Properties as Probes into the Heliospheric Interface

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Abstract

A NASA sponsored study conducted at John Hopkins University Applied Physics Lab culminated in a community-inspired heliospheric mission concept called the Interstellar Probe (ISP). The ISP's science goals include understanding our habitable astrosphere by investigating its interactions with the interstellar medium, and determining the structure, composition, and variability of its constituents. A suite of instruments were proposed to achieve these and other science objectives. The instruments include a Lyman-a spectrograph for velocity-resolved measurements of neutral H atoms. The capability to address key components of the ISP's science objectives by utilizing high spectral resolution Lyman-a measurements are described in this presentation. These findings have been submitted as a community White Paper to the recent Heliophysics decadal survey.

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1- Brief Background

The heliosphere is comprised of multiple regions and boundaries (Figure 1). At the interface region between the heliosphere and the LISM, neutral H atoms of interstellar origin can: directly penetrate into the heliosphere, charge exchange with interstellar neutral H atoms before entering the heliosphere, or charge exchange throughout the heliosphere. Such different populations of solar & interstellar originating H atoms comprise the interplanetary hydrogen (IPH) flow and each have different dynamical and thermal properties, determined by their formation mechanisms [1]. When monitored over a solar cycle, the differentiation of properties from each population can be used to identify variations in local (solar) processes as well as to determine dynamics of external (interstellar) interactions [e.g., 2, 3].

2- Knowledge Gap

V1 observations showed a perplexing region of near-zero radial plasma velocity upstream of the heliopause within 10-15 AU where the solar wind slows [4], reaching a 'stagnation region'. Explanations for this region include: momentum loss due to charge-exchange reactions of ions with interstellar H atoms that collectively decelerate the inner heliosheath solar wind [6], or solar wind magnetic field reversal that alters the flow as the radial velocity of solar wind dwindles [7]. However, these theories do not reconcile with data, highlighting our lack of understanding of the nature of the heliosheath [8].

3- Mitigation

The inconsistencies around the heliospheric interface can be observationally constrained by new approaches with high spectral resolution UV measurements [9]. These measurements would be capable of resolving the momentum exchange in the reactions between the solar wind and Energetic Neutral Atoms that are key to identifying the most important processes and how solar wind flow is modified. This can be done by measuring the velocity spectrum of IPH atoms in the Lyman-α emission spectral profile, shown in Figure 2. Inflowing ISM neutral atoms can be observed through resonant scattering of solar H Lyman-α emission to determine both the line of sight speed and the velocity distribution of the inflowing atoms after modification by charge exchange in the interface region [10]. An IPH emission in the range of 800-1000 R at 1 AU (lower near solar minimum), would include multiple spectral components corresponding to: a primary interstellar population, with a bulk velocity of 26 km/s and a temperature close to 7000 K; a secondary population created by charge exchange in the outer heliosheath, with a bulk velocity of 22 km/s and a temperature around 12,000 K; and a tertiary component red-shifted from the main line with a brightness of 25 R. These observable characteristics have been used to measure the flow speed of H and He atoms, and to identify line broadening associated with charge exchange reactions in the interface region [11]. The ISP mission would be optimal for obtaining the most reliable and revealing signal from IPH emissions.

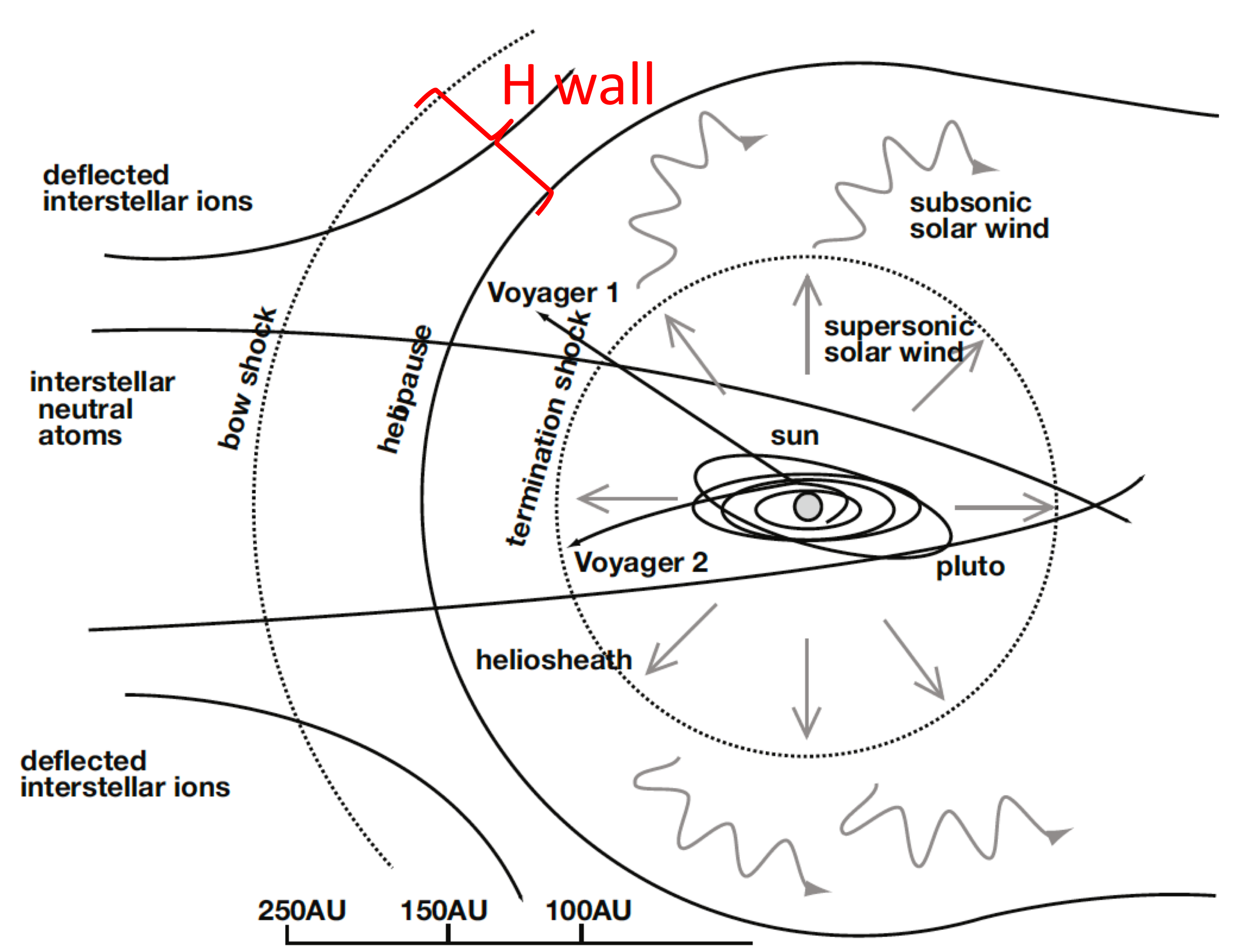

Figure 1: Basic heliospheric structure and IPH Flow, adapted from [5].

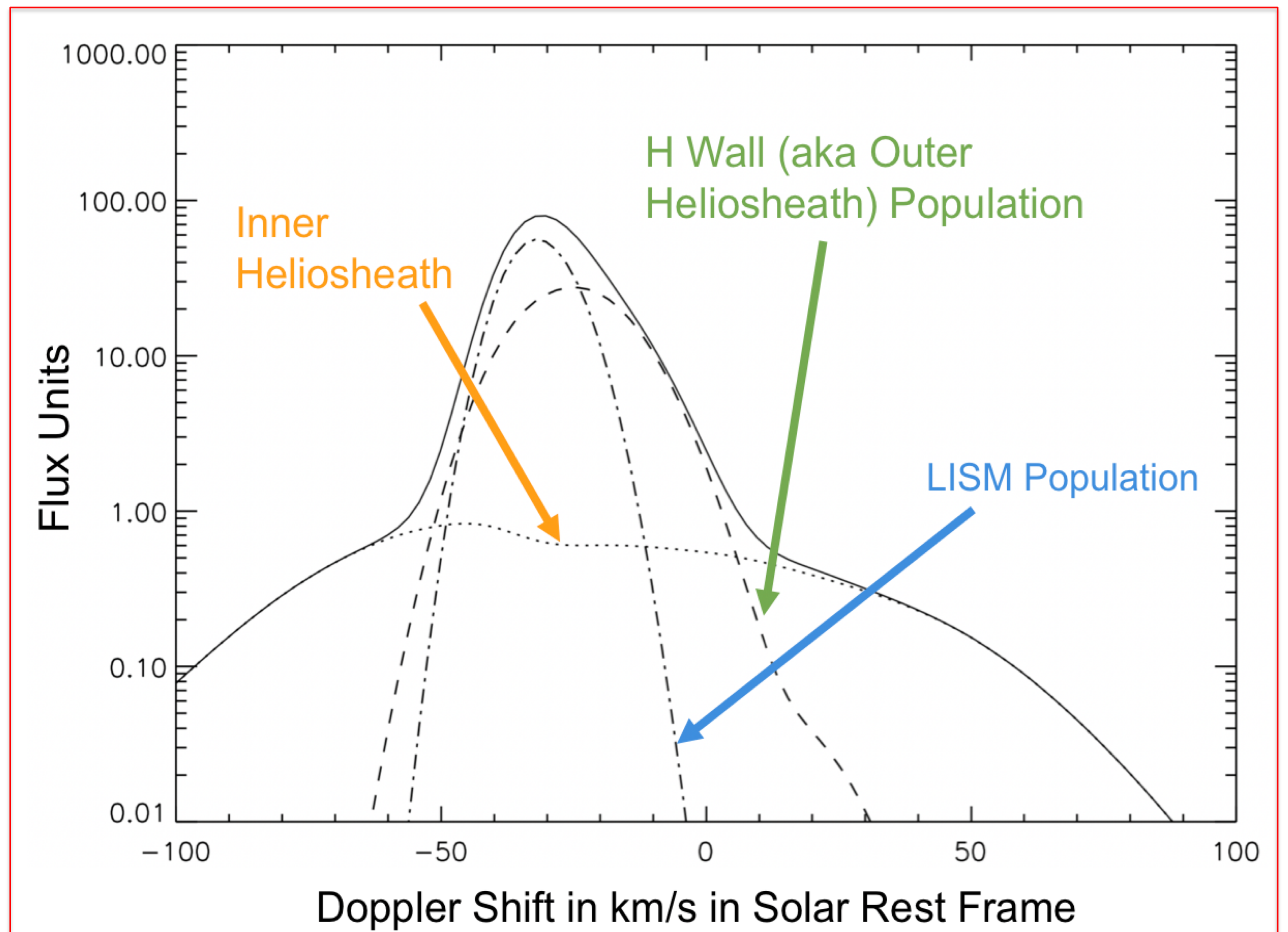

Figure 2: Theoretical spectra for LOS upwind of IPH (adapted from [1]).

References

[1] Quémerais and Izmodenov, 2002
[2] Izmodenov, 2007
[3] Vincent et al., 2014
[4] Krimigis et al. 2011
[5] Nakagawa et al., 2008
[6] Lallement et al., 2014
[7] Opher et al., 2012
[8] Opher et al., 2015
[9] Quémerais et al., 2003
[10] Lallement et al. 1993
[11] Clarke et al., 1995

4- Science Questions

What is the Hydrogen atom number density in the Local Interstellar Medium?
What is the Hydrogen velocity distribution in the outer heliosheath?
What is the Hydrogen secondary (hot) population number density in the inner heliosheath?
What is the Hydrogen hot population velocity distribution in the inner heliosheath?
How is momentum exchanged between these populations?
What do these properties tell us about the interactional dynamics of the individual populations?

5- Science Recommendations

Placement of a high-resolution spectrograph on ISP will allow for measurements that distinguish the different populations of H atoms directly interacting at the heliosheath interface, where the solar wind is subsonic. A resolution of 3 – 10 km/s at H Lyman-α would suffice for spectrally resolving line emissions from the LISM, inner and outer heliosheath populations, and enable characterization of these populations and their interactions from 1 – 1000 AU.