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Modeling the Lyman-alpha backscatter observed by Voyager 1 and 2 in the outer heliosphere and the structure of the heliospheric bow shock

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1) Observations made by ultraviolet (UV) detectors on board Pioneer 10 , Voyager 1 , and Voyager 2 can be used to analyze the distribution of neutral hydrogen throughout the heliosphere, including the interaction regions of the solar wind and local interstellar medium. We use state-of-the art three-dimensional (3D) magnetohydrodynamic (MHD) – kinetic neutral H models to simulate Lyman-alpha backscatter as would be seen by the three spacecraft, exploiting a new 3D Monte Carlo radiative transfer code under solar minimum conditions (Fayock et al., 2013) . Both observations and simulations of the UV backscatter intensity are normalized for each spacecraft flight path at 15 AU, and we compare simulations with Voyager 1 and 2 and Pioneer 10 Lyman-alpha data results, finding a very close match with the Voyager data. Our results predict a large increase in the Lyman-alpha intensity as the hydrogen wall is approached.

2) Recent IBEX observations indicate that the local interstellar medium (LISM) flow speed is less than previously thought (23.2 km/s rather than 26 km/s), indicating that the LISM flow may be either marginally super-fast magnetosonic or sub-fast magnetosonic. This raises two questions: (A) Can a LISM model that is barely super-fast or sub-fast magnetosonic account for Ly-alpha observations that rely critically on the additional absorption provided by the hydrogen wall (H-wall)? and (B) If the LISM flow is weakly super-fast magnetosonic, does the transition assume the form of a traditional shock or does neutral hydrogen (H) mediate shock dissipation and hence structure through charge exchange? Both questions are addressed using three-dimensional self-consistently coupled magnetohydrodynamic plasma – kinetic neutral H models with different LISM magnetic field strengths (2, 3, and 4mG) as well as plasma and neutral H number densities. The 2 and 3mG models are fast magnetosonic far upwind of the heliopause whereas the 4μ G model is fully subsonic. The 2mG model admits a broad (~50–75 AU) bow-shock-like structure. The 3mG model has a smooth super-fast–sub-fast magnetosonic transition that resembles a very broad, ~200 AU thick, bow wave. A theoretical analysis shows that the transition from a super-fast to a sub-fast magnetosonic downstream state is due to the charge exchange of fast neutral H and hot neutral H created in the supersonic solar wind and hot inner heliosheath, respectively. For both the 2mG and the 3mG models, the super-fast magnetosonic LISM flow passes through a critical point. Because the Mach number is only barely super-fast magnetosonic in the 3mG case, the hot and fast neutral H can completely mediate the transition and impose a charge exchange length scale on the structure, making the solar-wind–LISM interaction effectively bow-shock-free. The charge exchange of fast and hot heliospheric neutral H therefore provides a primary dissipation mechanism at the weak heliospheric bow shock. Both super-fast magnetosonic models produce a sizeable H-wall. We find that (1) a sub-fast magnetosonic LISM flow cannot model the observed Ly-alpha absorption profiles along four sightlines corresponding to upwind, sidewind, and downwind; and (2) both the super-fast magnetosonic models can account for the Ly-alpha observations, with possibly the bow-shock-free 3μ G model being slightly favored.

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