HELIOSPHERIC STRUCTURE: THE BOW WAVE AND THE HYDROGEN WALL

G. P. Zank, J. Heerikhuisen, B. E. Wood, N. V. Pogorelov, E. Zirnstein, and D. J. McComas

University of Alabama in Huntsville

Recent IBEX observations indicate that the local interstellar medium (LISM) flow speed is less than previously thought (23.2 km s\(^{-1}\) rather than 26 km s\(^{-1}\)). Reasonable LISM plasma parameters indicate that the LISM flow may be either marginally super-fast magnetosonic or sub-fast magnetosonic. This raises two challenging questions: (1) 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 (2) 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 three-dimensional self-consistently coupled magnetohydrodynamic plasma—kinetic H models with different LISM magnetic field strengths (2, 3, and 4 \(\mu\)G) as well as plasma and neutral H number densities. The 2 and 3 \(\mu\)G models are fast magnetosonic far upwind of the heliopause whereas the 4 \(\mu\)G model is fully subsonic. The 2 \(\mu\)G model admits a broad (~50–75 AU) bow-shock-like structure. The 3 \(\mu\)G 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 2 \(\mu\)G and the 3 \(\mu\)G models, the super-fast magnetosonic LISM flow passes through a critical point located where the fast magnetosonic Mach number \(M = 1\) and \(Q_e = \gamma / (\gamma - 1) U Q_m\), where \(Q_e\) and \(Q_m\) are the plasma energy and momentum source terms due to charge exchange, \(U\) is the LISM flow speed, and \(\gamma\) is the plasma adiabatic index. Because the Mach number is only barely super-fast magnetosonic in the 3 \(\mu\)G 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, in some cases effectively creating a one-shock heliosphere (i.e., a heliospheric termination shock only). 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 the four sightlines considered (\(\alpha\) Cen, 36 Oph, DK UMa, and \(\chi^1\) Ori—upwind, sidewind, and downwind respectively); (2) both the super-fast magnetosonic models can account for the Ly\(\alpha\) observations, with possibly the bow-shock-free 3 \(\mu\)G model being slightly favored. Subject to further modeling and comparison against further lines of sight, we conclude with the tantalizing possibility that IBEX may have discovered a class of interstellar shocks mediated by neutral H.