Inverse Energy Cascade of Fast Magnetosonic Turbulence in the Heliosheath

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The solar wind in the heliosheath beyond the termination shock (TS) is a non-equilibrium collisionless plasma consisting of thermal solar wind ions, suprathermal pickup ions (PUI) and electrons. In such multi-ion plasma, two fast magnetosonic wave modes exist: the low-frequency fast mode that propagates in the thermal ion component and the high-frequency fast mode that propagates in the suprathermal PUI component [Zieger et al., 2015]. Both fast modes are dispersive on fluid and ion scales, which results in nonlinear dispersive shock waves. In this talk, we briefly review the theory of dispersive shock waves in multi-ion collisionless plasma. We present high-resolution three-fluid simulations of the TS and the heliosheath up to 2.2 AU downstream of the TS. We show that downstream propagating nonlinear magnetosonic waves grow until they steepen into shocklets (thin current sheets), overturn, and start to propagate backward in the frame of the downstream propagating wave, as predicted by theory [McKenzie et al., 1993; Dubinin et al., 2006]. The counter-propagating nonlinear waves result in fast magnetosonic turbulence far downstream of the shock. Since the high-frequency fast mode is positive dispersive on fluid scale, energy is transferred from small scales to large scales (inverse energy cascade). Thermal solar wind ions are preferentially heated by the turbulence. Forward and reverse shocklets in the heliosheath can efficiently accelerate both ions and electrons to high energies through the shock drift acceleration mechanism. We validate our three-fluid simulations with in-situ high-resolution Voyager 2 magnetic field and plasma observations at the TS and in the heliosheath. Our simulations reproduce the magnetic turbulence spectrum with a spectral slope of -5/3 observed by Voyager 2 in frequency domain [Fraternale et al., 2019]. However, since Taylor's hypothesis is not true for fast magnetosonic perturbations in the heliosheath, the inertial range of the turbulence spectrum is not a Kolmogorov spectrum in wave number domain.