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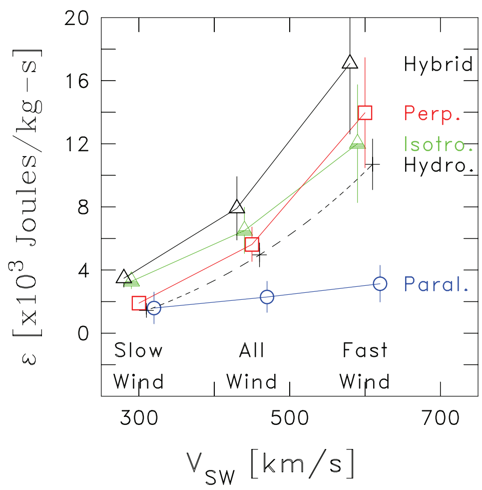
Energy Cascade in the Solar Wind

The ACE spacecraft provides a merged data product of magnetic field and thermal solar-wind proton moments from the MAG and SWEPAM instruments. The merged data has a 64-s cadence consistent with the normal operations of the SWEPAM instrument. This data has proven useful to many research topics. In a recent effort using the merged data, we measure the rate of energy cascade through the turbulent inertial range from the large-scale structures that drive the turbulence to the small-scale fluctuations where dissipation mechanisms set in and convert energy into heat.



In both hydrodynamic and magnetohydrodynamic (MHD) turbulence theory there is the concept that energy at the largest scales of the flow (which in the solar wind means stream structures and ejecta of solar origin) cascade energy to smaller scales in an energy-conserving fashion so as to form an "inertial range" between the energy-containing large-scale fluctuations and the dissipative small-scale fluctuations. In this way the large-scale structures drive dissipation and the heating of the background plasma. It has been shown that this model produces good agreement with the rate of *in situ* solar wind heating.

While there are heuristic predictions for the form of the inertial range power spectrum in MHD turbulence and each prediction contains an implied rate of energy transfer, variations in the spectrum are observed in solar wind measurements. These heuristic predictions have not produced reliable estimates for the rate of energy transfer through the inertial range. However, a rigorous result from hydrodynamics sometimes called "Kolmogorov's 4/5 Law" has been generalized to MHD by Politano and Pouquet (1998) in a manner that is independent of the form taken by the inertial range spectrum, and we have applied extensions of this formalism to 8 years of observations by the ACE spacecraft. In so doing, we can reliably and objectively measure the flow of energy through the inertial range as it is passed from the energy-containing range to the dissipation range. Our results agree with local heating rates as inferred from local gradients in the proton temperature (variation of proton temperature with distance from the Sun).

The figure shows the computed energy cascade rate (ε) for low-speed winds, all the data, and high-speed winds and separately measures the cascade parallel and perpendicular to the mean magnetic field. The isotropic MHD and hydrodynamic formalisms are also examined and the total cascade rate of this model is represented by the "hybrid" curve. In a result that is consistent with theory and simulation, we find that the perpendicular cascade dominates the parallel cascade and that energy is moving away from the field-aligned wave vectors toward a 2D state. This holds for all orientations of the IMF and is especially true of fast wind conditions where we believe the bulk of the energy resides in the field-aligned wave vectors. The trend toward a 2D state with energy residing in the wave vectors perpendicular to the mean field is unmistakable and the overall energy cascade rate agrees with the local heating rate (which itself depends on wind speed).

We believe that this proves most clearly that the fluctuations in the interplanetary medium are fundamentally turbulent, that they are not merely waves imparted with a turbulent spectral signature at the acceleration region, and that the 2D state is the ultimate fate of the turbulent evolution.

Contributed by Benjamin T. MacBride and Charles W. Smith of the University of New Hampshire and Miriam A. Forman of the State University of New York at Stony Brook. Benjamin MacBride completed this work while an undergraduate physics major at the University of New Hampshire. He is now a graduate student in the physics program at UC/Berkeley.

Address comments and questions to Charles.Smith@unh.edu. For an archive of earlier ACE News items, see http://www.srl.caltech.edu/ACE/ACENews_Archives.html.