The dissipation of solar wind turbulence: A progress report

Shine 2011

John Podesta and Bill Matthaeus
We discussed how low frequency turbulence with mostly oblique wavevectors can produce strong perpendicular heating of ions through stochastic heating when $\beta << 1$. In this regime the stochastic heating mechanism is very effective for heavy ions and it is self limiting (Chandran).

Ben Chandran did a great job of highlighting some of the important physics issues that need to be addressed going forward.
Discussed recent observations of scaling laws beyond the spectral break and how the interpretation in terms of a KAW cascade is probably just one aspect of a more complex physical picture. Ion cyclotron interactions and other processes may also play a role. It is important for all of us to acknowledge the wide range of possibilities so we do not limit the directions for future research.

We debated whether it is feasible that propagation angles of KAWs are between 89 and 90 degrees in the dissipation range as some theories propose. One problem is that the ambient magnetic field in the solar wind is not straight over the relevant wavelengths.
We discussed the properties of KAWs and whistler waves in the spacecraft frame when the Doppler shift is taken into account and how these different wave modes can be discerned in solar wind data. In principle they are discernable, sometimes with large differences, but the task is challenging. It is less clear how to distinguish other possibilities (e.g., current sheets).

We discussed the very real possibility that the linear theory of Landau damping for KAWs may not work in the solar wind, i.e., it may not give the correct Landau damping rate for various reasons (Borovsky).
We discussed how energy spectra in simulations of Incompressible MHD turbulence can successfully reproduce the Inertial range scaling seen in the solar wind including the $3/2$ scaling of velocity fluctuations and the $5/3$ scaling of magnetic field fluctuations. The excess of magnetic energy over kinetic energy is called the residual energy which simulations show is generated spontaneously in MHD turbulence (Perez and Boldyrev).
Discussed first results from hybrid simulations spanning MHD to kinetic scales that show strong damping of the fluctuations near the spectral break, i.e., at the proton inertial length scale (Krauss-Varban).

Dissipation of solar wind turbulence
We had a debate about some interesting new measurements of compressible fluctuations in the solar wind and whether the interpretation in terms of the MHD slow mode is unique. Other possibilities such as pressure balanced structures were discussed. It was also pointed out that the measurements are probably insensitive to nearly parallel propagating magnetosonic/whistler modes which may have gone undetected.
We discussed some of the inherent limitations of gyrokinetic theory for the description of dissipation scale processes. The theory cannot describe ion cyclotron interactions or high frequency whistler modes. Gyrokinetics also requires that the fluctuations at kinetic scales are highly anisotropic, $k_{\perp} \gg k_{\parallel}$, so as not to violate one of the principal assumptions of the theory $\omega \ll \Omega_p$. There were questions whether such high anisotropies are practically realizable in the solar wind.
Issue of turbulence versus waves. The turbulence viewpoint that emphasizes nonlinear structures and interactions is difficult to reconcile with the wave viewpoint that emphasizes dispersion relations. Is it correct to cast the discussion in terms of waves? Is the wave description meaningful when the dispersion relation is violated? Can waves and turbulence coexist, say, for example, at different scales?
Things that many of us agree on

• Solar wind protons are heated in-situ but the mechanisms responsible for energization of the perpendicular degrees of freedom (perpendicular heating) remain a mystery.

• The analysis of dissipation range processes requires many different tools in order to elucidate proton and electron heating mechanisms including but not limited to particle orbit calculations, hybrid simulations, gyrokinetic simulations, and more.

• Different physical processes may operate under different plasma regimes: $\beta << 1$ and $\beta > 1$. 
The dissipation range probably contains fluctuations with both parallel and perpendicular wavevectors (Smith; Podesta) and, consequently, the level of anisotropy may be limited. This also depends on how anisotropy is defined.

A number of groups are achieving success in various types of comparisons between nonlinear simulations and observed statistical properties of the solar wind.
Progress is being made in understanding the role of plasma instabilities in the regulation of particle distribution functions in the solar wind.

But how nonlinear evolution and structure figure into this picture is not yet clear.

Distribution of $T_p$ in ($\beta_p$, $T_p / T_\perp$) plane

"mirror"

"firehose"

From Kasper, Maruca & Bale, 2011
Have a good day!