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Compressive nature of space plasma turbulence: state-of-the-art

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The majority of research on plasma turbulence has used magnetic field data. In the solar wind, magnetic fluctuations' power is predominantly transverse to the magnetic field at large fluid scales, with very little power in the compressive (along the mean field direction) components. At smaller scales where kinetic effects of ions and electrons become important, the relative power of the compressive component becomes approximately a third of the power.

Measuring the compressive magnetic component is not straightforward, requiring a mean magnetic field direction to be defined. The mean field may not necessarily be well-defined for a turbulent medium. An alternative to measuring compressive magnetic fluctuations is to use density fluctuations. The drawback with measuring the density is that plasma instruments often do not have the necessary time resolution to resolve ion kinetic scales and below. This is due to the finite integration time necessary for a sufficient number of counts in the detector or that the detector scans azimuthally using the spacecraft spin. To overcome these issues, a different approach is required: calibrating the spacecraft potential.

A spacecraft embedded in a plasma will charge to a particular value determined by the currents to and from the spacecraft. Typically in the solar wind, two currents dominate, the photoelectron current and the electron thermal current from the ambient plasma. Sunlit surfaces of the spacecraft emit the photoelectron current and can be assumed to be constant on short timescales. The electron thermal current is proportional to the density and the square root of the electron temperature. Using a lower-resolution measurement of the density, we can calibrate the potential measurement to obtain a density measurement.

The principal advantages of this method are the higher time resolution and signal-to-noise ratio. The potential measurement is made using electric field probes, which have much higher time resolutions than particle measurements. Furthermore, instead of having a very small collecting area (as in a plasma instrument), the entire body of the spacecraft is used as a collecting surface. This method allows us to probe compressive fluctuations down to sub-ion scales.

Using the spacecraft potential methodology on the Magnetospheric MultiScale (MMS) mission, we can measure the electron density at 8 kHz in burst mode and 32 Hz in fast survey mode. This allows us to probe deep into the sub-ion range where the power of compressible fluctuations becomes much more important in comparison to fluid scales. An example of the turbulent density power spectrum is shown in Figure 1. This is from a one hour interval of solar wind plasma.

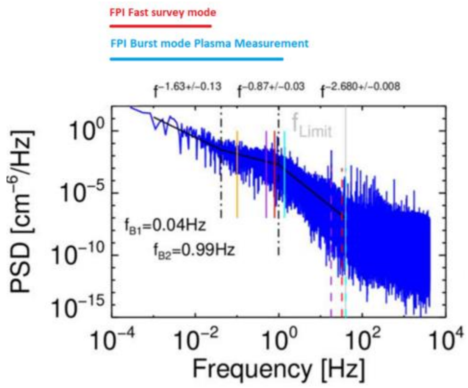

Figure 1. Power spectral density of density fluctuations obtained from the spacecraft potential measurement. The red and blue bars above denote the frequency ranges accessible from the Fast Plasma Investigation (FPI) measurement. Adapted from Roberts et al. (2020)

The exceptional time resolution available from MMS gives a unique way to study compressive fluctuations. Furthermore, the multi-point capabilities of MMS allow several multi-point methods to be used, such as the wave-telescope (Roberts et al. (2020a)) and multi-spacecraft structure functions (Roberts et al. (2020b)) so that we are also able to make measurements of compressible plasma turbulence fully in three dimensions. Making this data set truly state-of-the-art.

References

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