Imperial College London

Science & Technology Facilities Council

Measuring Anisotropy of Turbulence in the Solar Wind using Multi-Spacecraft Data

C. H. K. Chen,[1] T. S. Horbury[1] and A. A. Schekochihin[2]

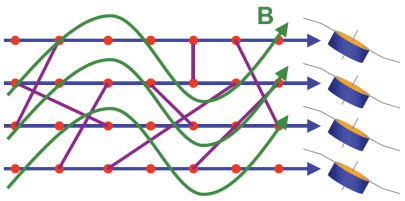
[1]Space and Atmospheric Physics Group, Blackett Laboratory, Imperial College London
[2]Rudolf Peierls Centre for Theoretical Physics, University of Oxford

Summary

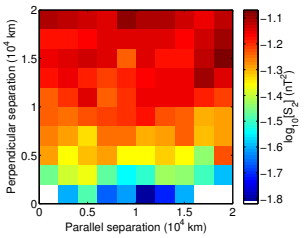
- Multi-spacecraft data was used to measure properties of solar wind turbulence through the use of structure functions.
- Eddy anisotropy was measured to be $C_{\parallel}/C_{\perp} = 7 \pm 1$.
- Power anisotropy measurements suggest fluctuations with $k_{\perp} >> k_{\parallel}$.
- Spectral index is ≈ -2 parallel to the magnetic field and becomes shallower for perpendicular directions.

Multi-Spacecraft Structure Functions

- The four Cluster spacecraft move through the solar wind.
- They measure the magnetic field at a set of points (red dots).
- Taylor's hypothesis ⇒ spatial map of the magnetic field:



- A variety of spatial separations are possible (purple lines).
- From these separations, 2nd order structure functions, $S_2 = \langle \delta B_x^2 \rangle$, for each field component can be calculated.
- Values of S_2 for the perpendicular components were binned according to their parallel and perpendicular separations, e.g.:



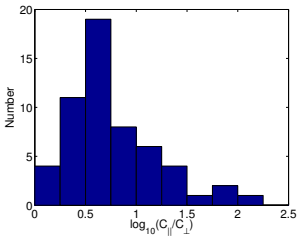
- These separations are with respect to the local mean field seen by the eddy since this is what is important for the turbulent fluctuations.
- A set of 66 1 hour intervals were found in the 2006 Cluster data.

Eddy Anisotropy

- A model was used to fit to the 66 structure functions.
- The model structure function contours are ellipses with different parallel and perpendicular scalings:

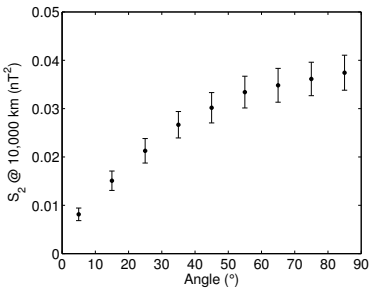
$$S = S_0 \sqrt{\left(\frac{1}{C_{\parallel}}\left(\frac{r_{\parallel}}{r_0}\right)^{(\alpha_{\parallel}-1)}\right)^2 + \left(\frac{1}{C_{\perp}}\left(\frac{r_{\perp}}{r_0}\right)^{(\alpha_{\perp}-1)}\right)^2}$$

- A least squares fit of this model was performed on each interval.
- The mean eddy anisotropy is $C_{\parallel}/C_{\perp} = 7 \pm 1$.



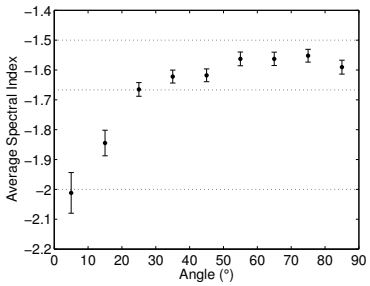
Power Anisotropy

- The interpolated structure function value at 10,000 km was found for each angle.
- Results show a clear increase with angle, consistent with previous measurements [1,2] ⇒ fluctuations with $k_{\perp} >> k_{\parallel}$.
- Average plot for the 66 intervals:



Spectral Index Anisotropy

- Structure function scaling, g, is related to spectral index, $-\alpha$, by $\alpha = g + 1$.
- Scaling in different directions to the magnetic field was measured from the structure functions and converted to spectral index.
- Similar results to previous measurements [2,3] with a parallel spectral index ≈ -2 and a perpendicular spectral index between -5/3 and -3/2.
- Results are sensitive to certain aspects of the analysis ⇒ further work needed.



Future Work

- Refine multi-spacecraft analysis method.
- Investigate variability of anisotropy with respect to plasma parameters.
- Measure anisotropy at small scales – dissipation range.
- Apply analysis to other fields (velocity, density, electric).
- Higher order structure functions – anisotropic intermittency.

Acknowledgements

Thanks to the FGM and CIS teams and the CAA for providing data.

References

[1] Bieber et al., Dominant two-dimensional solar wind turbulence with implications for cosmic ray transport, JGR, 1996.

[2] Horbury et al., Anisotropic scaling of magnetohydrodynamic turbulence, PRL, 2008.

[3] Podesta, Dependence of solar wind power spectra on the direction of the local magnetic field, submitted to ApJ, 2009.