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Compressible MHD Turbulence and Cosmic Ray Transport

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The interstellar medium is turbulent on scales ranging from AUs to kpc (Armstrong et al. 1995). Both the spectra of CRs and the ISM turbulence show big power laws, suggesting a strong interrelation of the two.

A new chapter of CR propagation research has begun when studies of particle transport and interstellar turbulence can confront each other. Our recent analysis of Magnetospheric Multiscale (MMS) MMS data confirms the scale dependent anisotropy of Alfvenic turbulence (Zhao et al. 2022, Fig.1), which makes it completely ineffective for scattering particles (Goldreich & Sridhar 1995, Yan & Lazarian 2002). As proposed by our earlier work (Yan & Lazarian 2004, 2008, henceforth YL04, YL08), the solution rests on thorough understanding of compressible turbulence from both theoretical studies and first-hand knowledge of turbulence in space.

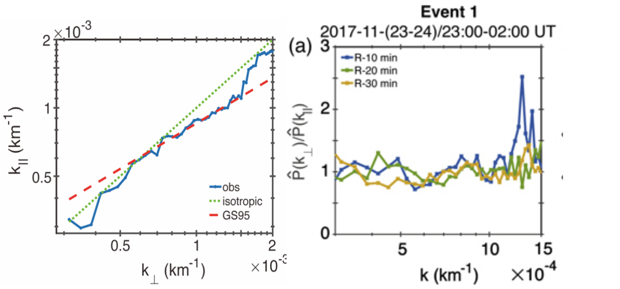

Fig.1 Analysis of MMS turbulence data at 1Au. a) The variation of $l_{\|}$ versus $l_{\perp}$ for magnetic power of $Alfvenic$ fluctuations. b) The ratio $\hat{P}(k_{\perp})$ to $\hat{P}(k_{\|})$ of fluctuations within $\hat{k}\hat{b}_0$ plane. $\hat{P}(k_{\perp})$ and $\hat{P}(k_{\|})$ represent the normalized perpendicular wavenumber spectrum, and parallel wavenumber spectrum.

Plasma turbulence is primarily shaped by the forcing on large scales and damping on small scales. The multiphase nature of ISM and diversity of driving mechanisms give rise to spatial variation of turbulence properties. We find that the proportion of magnetosonic modes increases with increasing compressive forcing from turbulence simulations (Makwana & Yan 2020, Fig.2a).

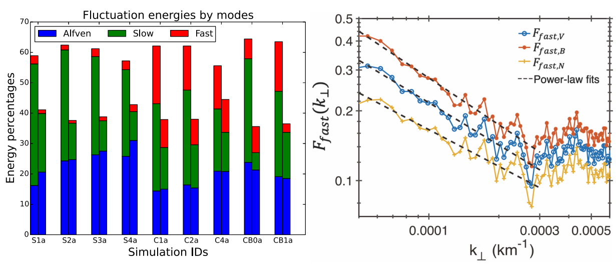

Fig.2 a) The time-averaged fractions of mode energies in different modes in different simulations. Each simulation has two bars, the left and right ones represent the percentages of kinetic and magnetic energies, respectively. b) Fast-mode energy fractions in the total energy of compressible modes analyzed from Cluster observations of magnetosheath.

With the advanced techniques we developed for radio polarization data, it is found that Alfven and compressible modes are distinguishable from observations (Malik 2023). On small scales, compressible turbulence is much influenced by damping. demonstrated a strong propagation angle dependence in collisionless and viscous damping, influencing the three-dimensional (3D) energy distributions (YL04, YL08). Based on an improved compressible MHD decomposition algorithm, our observational analysis demonstrates that collisionless damping enhances the anisotropy of compressible MHD modes due to their strong pitch angle dependence, consistent with theoretical expectations (Zhao et al. 2023, Fig. 2b)

Different regimes of particle transport, e.g., diffusion vs. superdiffusion, isotropic vs. anisotropic diffusion, will be discussed in relation to turbulence properties (see Fig.3).

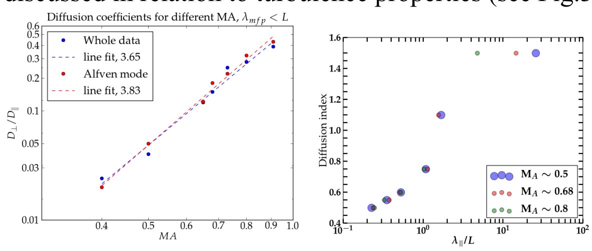

Fig.3 a) Cross field diffusion vs. M_A. b) Diffusion index vs. the ratio of particles' mean free path and turbulence coherence scale (Maiti et al. 2022).

References

[1] Siqi Zhao, H. Yan, T. Z. Liu, et al. 2022, ApJ, 937, 102

[2] P. Goldreich, A. Sridhar, 1995, ApJ, 438, 763

[3] Siqi Zhao, H. Yan, T. Z. Liu, et al. 2023, under review; arxiv: 2305.12507

[4] H. Yan, A. Lazarian, 2002, PRL, 937, 102

[5] H. Yan, A. Lazarian, 2004, ApJ, 937, 102

[6] H. Yan, A. Lazarian 2008, ApJ, 937, 102

[7] K. Makwana & H. Yan 2020, PRX, 10, 031021

[8] S. Malik, KH Yuen, H. Yan 2023, under review, arXiv:2303.17282

[9] S. Maiti, K. Makwana, H. Zhang, H. Yan 2022, ApJ., 926, 94