Modelling plasma turbulence observed by Parker Solar Probe during its first two orbits with hybrid-kinetic simulations

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We employ 2D and 3D high-resolution hybrid kinetic simulations of plasma turbulence to explore the physical conditions encountered by the Parker Solar Probe (PSP) spacecraft during its first two orbits, modelling the turbulent cascade self-consistently from large fluid scales down to kinetic scales.

By varying key parameters (e.g., the ion and electron plasma beta, the level of fluctuations with respect to the ambient magnetic field, the injection scale), we explore different plasma conditions. We identify a new kinetic-scale regime with respect to what has previously been found in both hybrid simulations and spacecraft observations of the solar wind and of the near-Earth environment, characterized among other things by a steeper magnetic field spectrum. Our simulations reproduce PSP observations and thus offer the opportunity to investigate the physical mechanism(s) behind such change in the turbulent cascade properties. We discuss our results in the framework of theoretical models of the nonlinear interaction of dispersive wave modes, field-particle interactions, and magnetic reconnection in low-beta plasmas.

We also analyse intermittency, magnetic compressibility, polarization of wave-like fluctuations, and statistics of magnetic reconnection events by means of iterative filters, a new method for the analysis of nonlinear nonstationary signals.

Together with our previous numerical results in quantitative agreement with MMS observations in the Earth’s magnetosheath, our new findings confirm the ability of the hybrid approach to model in-situ observations, which is fundamental for interpreting observational results and for planning future spacecraft missions.