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High-resolution hybrid simulations of turbulence from inertial to sub-proton scales

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We investigate properties of turbulence from MHD scales to ion scales by means of two-dimensional, large-scale, high-resolution hybrid particle-in-cell simulations, which to our knowledge constitute the most accurate hybrid simulations of ion scale turbulence ever presented so far. We impose an initial ambient magnetic field perpendicular to the simulation box, and we add a spectrum of large-scale, linearly polarized Alfvén waves, balanced and Alfvénically equipartitioned, on average. When turbulence is fully developed, we observe an inertial range which is characterized by the power spectrum of perpendicular magnetic field fluctuations following a Kolmogorov law with spectral index close to -5/3, while the proton bulk velocity fluctuations exhibit a less steeper slope with index close to -3/2. Both these trends hold over a full decade. A definite transition is observed at a scale of the order of the proton inertial length, above which both spectra steepen, with the perpendicular magnetic field still exhibiting a power law with spectral index about -3 over another full decade. The spectrum of perpendicular electric fluctuations follows the one of the proton bulk velocity at MHD scales and reaches a sort of plateau at small scales. The turbulent nature of our data is also supported by the presence of intermittency. This is revealed by the non-Gaussianity of the probability distribution functions of MHD primitive variables increasing as approaching kinetic scales. All these features are in good agreement with solar wind observations.