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Generation and evolution of anisotropic turbulence and related energy transfer in a multi-species solar wind

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The electromagnetic fluctuations in the solar wind represent a zoo of plasma waves with different properties, whose wavelengths range from largest fluid scales to the smallest dissipation scales. By nature the power spectrum of the magnetic fluctuations is anisotropic with different spectral slopes in parallel and perpendicular directions with respect to the background magnetic field. Furthermore, the magnetic field power spectra steepen as one moves from the inertial to the dissipation range and we observe multiple spectral breaks with different slopes in parallel and perpendicular direction at the ion scales and beyond. The turbulent dissipation of magnetic field fluctuations at the sub-ion scales is believed to go into local ion heating and acceleration, so that the spectral breaks are typically associated with particle energization. The gained energy can be in the form of anisotropic heating, formation of non-thermal features in the particle velocity distributions functions, and redistribution of the differential acceleration between the different ion populations. To study the relation between the evolution of the anisotropic turbulent spectra and the particle heating at the ion and sub-ion scales we perform a series of 2.5D hybrid simulations in a collisionless drifting proton-alpha plasma. We neglect the fast electron dynamics and treat the electrons as an isothermal fluid electrons, whereas the protons and a minor population of alpha particles are evolved in a fully kinetic manner. We start with a given wave spectrum and study the evolution of the magnetic field spectral slopes as a function of the parallel and perpendicular wave¬numbers. Simultaneously, we track the particle response and the energy exchange between the parallel and perpendicular scales. We observe anisotropic behavior of the turbulent power spectra with steeper slopes along the dominant energy-containing direction. This means that for parallel and quasi-parallel waves we have steeper spectral slope in parallel direction, whereas for highly oblique waves the dissipation occurs predominantly in perpendicular direction and the spectral slopes are steeper across the background magnetic field. The value of the spectral slopes depends on the angle of propagation, the spectral range, as well as the plasma properties. In general the dissipation is stronger at small scales and the corresponding spectral slopes there are steeper. For parallel and quasi-parallel propagation the prevailing energy cascade remains along the magnetic field, whereas for initially isotropic oblique turbulence the cascade develops mainly in perpendicular direction.