Kinetic Modeling of Sub-Proton Scale Turbulence

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Turbulent energy in the solar wind is injected at large scales and cascaded through an inertial range, which is well described by a variety of fluid models. As the turbulent cascade approaches ion kinetic scales, a variety of kinetic effects become important, only some of which are captured by typical fluid descriptions. Notably, the mechanisms responsible for damping the electromagnetic energy in the cascade and transferring it to particle energy are missing from the majority of fluid descriptions. Without capturing these mechanisms, fluid models may underestimate the spectral energy exponents and are unable to make predictions concerning particle heating, nor are they capable of identifying which mechanisms are responsible for the heating. The three primary numerical approaches for studying turbulence at kinetic scales are Vlasov-Maxwell, particle-in-cell, and gyrokinetics, each of which shall be introduced and results pertaining to the models reviewed. Focus will be given to describing the kinetic effects that these modeling approaches have revealed.