Abstract

I will describe the first three-dimensional (3-D) dispersion relations and wavenumber spectra of magnetic turbulence in the solar wind at sub-proton scales. The analysis takes advantage of the short separations of the Cluster spacecraft ($d/sim 200$~km) to apply the {\it k}-filtering technique to the frequency range where the transition to sub-proton scales occurs. The dispersion diagrams show unambiguously that the cascade is carried by highly oblique Kinetic Alfv\'en Wave with $\omega\leq 0.1\omega_{ci}$ in the plasma rest frame down to $k_\perp\rho_i \sim 2$. The wavenumber spectra in the direction perpendicular to the mean magnetic field consists of two ranges of scales separated by a breakpoint in the interval $[0.4,1] k_\perp \rho_i$. Above the breakpoint, the spectra follow the Kolmogorov scaling $k_\perp^{-1.7}$, consistent with existing theoretical predictions. Below the breakpoint, the spectra steepen to $\sim k_\perp^{-4.5}$. We conjecture that the turbulence undergoes a {\it transition-range}, where part of energy is dissipated into proton heating via Landau damping, and the remaining energy cascades down to electron scales where electron Landau damping may predominate.