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Multi-scale coupling and intermittency in solar wind turbulence

M. P. Leubner (1) and Z. Voros (2)

(1) Institute for Astrophysics, University of Innsbruck, Austria (manfred.leubner@uibk.ac.at),
(2) Space Research Institute, Austrian Academy of Sciences, Graz, Austria
(zoltan.voeroes@oeaw.ac.at)

The analysis of probability distribution functions (PDFs) is of considerable interest to study intermittency and cross-scale statistical properties in fully developed turbulence of the solar wind plasma and interplanetary magnetic field fluctuations. The presence of long-range forces in turbulence imply direct nonlocal interactions between large and small scales, indicating that small-scale fluctuations in each time/space point depend on the large scale motions in the whole domain and vice versa. The associated, observed global leptokurtic non-Gaussian shape of the increment PDFs of characteristic solar wind variables requires theoretically a corresponding unique global distribution function, where nonlocality is controlled via a multi-scale coupling parameter. We relate nonlocality in turbulent flows to the presence of long-range forces in nonextensive systems and demonstrate in the context of pseudo-additive entropy generalization the consistency of a theoretically derived bi-kappa distribution with in situ observations. The scale dependence of density, velocity and magnetic field variables of observed WIND and ACE PDFs are accurately reproduced for different time lags by the bi-kappa functional, where the parameter kappa measures the degree of multi-scale coupling in the system. Gradual decoupling is obtained by enhancing the spatial separation scale, corresponding to increasing kappa values, where a Gaussian is approached for infinite kappa. The relative increase of the coupling parameter for best fitting theoretical PDFs depends non-linearly on the spatial scale, indicating the presence of a transitional dynamical element between small and large scales. Consequently, cross-scale coupling, introduced on the fundamental level of entropy generalization, provides physically the source of the observed scale dependence of the turbulent fluctuations in the intermittent interplanetary medium.