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Non-Extensive Entropy Approach to Space Plasma Turbulence

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Spatial intermittency in fully developed turbulence is an established feature of astrophysical plasma fluctuations and in particular apparent in the interplanetary medium by in situ observations. In this situation the classical Boltzmann-Gibbs extensive thermo-statistics, applicable when microscopic interactions and memory are short ranged and the environment is a continuous and differentiable manifold, fails. We are dealing with systems generally subject to spatial or temporal nonlocal interactions evolving in a non-Euclidean, multi-fractal space-time that makes their behavior non-extensive. Upon generalization of the entropy function accounting for long-range interactions and thus for correlations in the system, it is demonstrated that the corresponding probability distributions (PDFs) are members of a family of specific power-law distributions. In particular, the resulting theoretical bi-kappa functional reproduces accurately the observed global leptokurtic, non-Gaussian shape of the increment PDFs of characteristic solar wind variables on all scales, where nonlocality in turbulence is controlled via a multi-scale coupling parameter. Gradual decoupling is obtained by enhancing the spatial separation scale, which corresponds to increasing kappa-values and a Gaussian is approached in the limit of large scales. The PDFs of solar wind scalar field differences are computed from WIND and ACE data for different time-lags and bulk speeds and analyzed within the non-extensive theory, where also a particular nonlinear dependence of the coupling parameter with scale, for best fitting theoretical PDFs, arises. Consequently, nonlocality in turbulence should be related to long-range interactions in the context of non-extensive entropy generalization, providing fundamentally the physical background of the observed scale dependence of fluctuations in intermittent space plasmas.