Heavy-tailed distributions from superstatistics: Recent applications for power grids, air pollution statistics, and water quality time series

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The superstatistics concept, introduced 20 years ago [1], is a useful general method borrowed from statistical physics to describe driven nonequilibrium systems in spatio-temporally inhomogeneous environments that exhibit fluctuations of one or several intensive parameters. The method can be quite generally applied to heterogeneous complex systems if there is time scale separation of the underlying dynamics. This approach generates heavy-tailed probability densities in quite a natural way. After a brief introduction to the basic ideas, I will concentrate onto three examples of useful recent applications, namely the statistics of frequency fluctuations in power grid networks [2,6], the dynamics of air pollution [3,4], as well as measured time series of water quality indicators in rivers [5].

Air pollution concentration time series, as measured at a variety of measuring stations in Europe, exhibit a very heterogeneous spectrum of power-law PDFs with a wide spectrum of observed exponents, depending on location. The spectrum depends on the kind of pollution particles that are investigated. I will describe observed patterns of best-fitting parameters and the high degree of spatial heterogeneity associated with that [4]. For water quality indicators we also find that the deviations around the mean behaviour are well described by some generalized form of superstatistics [5]. In addition, non-Gaussian fluctuations can be enhanced by correlations in the system, for example in [6] different households are not statistically independent in their time-dependent electricity consumption but strongly correlated, thus leading to non-Gaussian behaviour as the ordinary Central Limit Theorem is not valid.

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