Suprathermal Particle Distributions in Space Physics: The origin of Kappa Distributions and the Role of the Tsallis Entropy

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The energy distributions functions of different species (electrons, protons and heavy ions) determined by instruments aboard satellites in different physical environments in space are found to be far from equilibrium and thus non-Maxwellian. The occurrence of such non-equilibrium distributions in these almost collisionless environments is very common. It has been found empirically that these distributions can be well fitted by a Kappa distribution defined by

$$f_\kappa(x) = C(\kappa)\left[\frac{1}{1+\frac{x^2}{\kappa+1}}\right]^{\kappa+1}$$

where $x = v/v_t$ is a reduced speed, $v_t = \sqrt{mv^2/2k_BT}$ is a thermal velocity, κ is a parameter and $C(\kappa)$ is a normalization such that $4\pi\int_0^\infty f_\kappa(v)v^2dv = 1$. For large arguments, the Kappa distribution is a power law and in the limit $\kappa \to \infty$, the Kappa distribution goes over to a Maxwellian. Kappa distributions have been used to fit the energy distributions of energetic particles in the vicinity of the Earth, Jupiter and the Sun.

Owing to the success of the Kappa distribution as a fitting procedure it has become popular to provide some fundamental justification for the Kappa distribution from statistical mechanics. There have been discussions that the Kappa distributions arise from some new statistical mechanics based on either Levy distributions and/or nonextensive entropy or Tsallis statistics.

The heating mechanisms that produce steady energetic particle distributions are generally believed to be wave-particle interactions in competition with Coulomb collisions. A model based on a Fokker-Planck equation will be presented and compared with discussions in recent papers. The implications of this work to a variety of fundamental problems in space physics such as the heating of the solar corona, the solar wind and the heating of minor ions in the solar wind will be summarized.

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