Kappa distributions: Theory and applications in plasmas

G. Livadiotis

Southwest Research Institute

Statistical Mechanics is frequently used to determine the average behavior of a particle system when it resides at thermal equilibrium - the concept that any flow of heat (thermal conduction, thermal radiation) is in balance. When a particle system is at thermal equilibrium (typical behavior of earthy gases, e.g., the air), the particles are distributed in a specific way: There are many particles with small velocities and very few with large velocities. It is possible to write a mathematical equation describing how many particles are found at each velocity; this mathematical expression is called a Maxwellian distribution. However, space plasmas are particle systems distributed such that there are more high velocity particles than there should be if the space plasma were in equilibrium. The mathematical equation used to describe the space plasma is called a kappa distribution [Livadiotis, G., 2017, Kappa distribution: Theory & Applications in plasmas (Elsevier; Netherlands, UK, US; ISBN:9780128046388); https://www.elsevier.com/books/kappa-distributions/livadiotis/978-0-12-804638-8].
Empirical kappa distributions have become increasingly widespread across space and plasma physics. Space plasmas from the solar wind to planetary magnetospheres and the outer heliosphere are systems out of thermal equilibrium, described by kappa distributions. A breakthrough in the field came with the connection of kappa distributions to the solid background of non-extensive statistical mechanics. Understanding the statistical origin of kappa distributions was the cornerstone of further developments of these distributions, by means of the (i) Foundation theory, (ii) Plasma formalism, and (iii) Space plasma applications. some of which will be presented in this talk: (1) The physical meaning of thermal parameters, e.g., temperature and kappa index; (2) the N-particle description of kappa distributions; (3) the generalization to phase-space kappa distribution of a Hamiltonian with non-zero potential; (4) the Sackur-Tetrode entropy for kappa distributions, and (5) the existence of a large-scale phase-space cell in collisionless space plasmas, indicating a possible large-scale quantization constant 12 orders of magnitude larger than the Planck constant.

[l] G. Livadiotis, EPL **113**, 10003 (2016).
[2] G. Livadiotis, JGR **120**, 1607 (2015).
[3] G. Livadiotis, JGR **120**, 880 (2015).