

Monte Carlo Generation of Kappa Distributions in Kinetic Plasma Simulations

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In space physics, the Kappa distribution is arguably the most important velocity distribution function (VDF) after the Maxwell distribution. Driven by spacecraft observations and theoretical motivations, kinetic modeling of Kappa-distributed plasmas is growing in its importance. At the initialization phase of kinetic plasma simulations, we need to generate VDFs of particles by using random numbers. However, until recently, numerical procedures for Kappa distribution families are not well known.

In this presentation, we overview recent advances in numerical procedures for generating Kappa-type VDFs in kinetic plasma simulations [1-4]. The standard Kappa distribution can be obtained by Student's t-generator [1], but there may be cases where other options are needed. We propose two new methods: a rejection method based on the Pareto distribution Type II and an inverse transform method from an approximate cumulative distribution function of the Kappa distribution [4]. We further present numerical procedures for other Kappa distributions such as the relativistic Kappa distribution and Kappa Loss-cone (KLC) distributions. The relativistic Kappa distribution is obtained by the rejection method, with help from the beta-prime distribution [1]. To date, three variants of the KLC distributions are known: the Summers/Dory-type KLC distribution, the pitch-angle-type KLC distribution, and the recently proposed subtracted Kappa distribution. We provide numerical recipes for all of them [2,3].

References:

- [1] Zenitani & Nakano, PoP 29, 113904 (2022)
- [2] Zenitani & Nakano, JGR 128, e2023JA031983 (2023)
- [3] Zenitani, Usami, Matsukiyo, JGR 131, e2025JA034669 (2026)
- [4] Zenitani & Umeda, arXiv:2602.05606 (2026)