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In search of universality: towards a statistical mechanics of collisionless plasma

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This talk is a piece of light but relevant theoretical-physicsy entertainment in the midst of serious astro content. Much of existing plasma (astro)physics (and indeed much of the rest of kinetic physics) is done hovering in the vicinity of a Maxwellian equilibrium, which is the maximum point of the standard Gibbs entropy and is achieved dynamically by means of two-particle collisions. In this talk, I would like to discuss what I believe to be the next frontier for plasma theoreticians—and, hopefully, also observers—and attempt to grapple with the fact that many astrophysical plasmas (solar wind being the most accessible of them, and ICM the grandest) are too collisionless to be Maxwellian (in the sense that they have dynamics that occur on shorter timescales than interparticle collisions). The central question is then whether there exist universal collisionless equilibria, or classes thereof, and what they are. What is the meaning of entropy in a collisionless plasma? (Similar questions are asked in galactic dynamics, where the collisionless particles are stars.) I will discuss some simple ideas, going back to the work of Lynden-Bell in the 1960s, about the statistical mechanics of a collisionless plasma, leading to a class of universal collisionless equilibria—these are reminiscent of the equilibria of Fermi gases, with phase-volume conservation in a collisionless plasma imposing (an infinite set of) constraints that are analogous to the Pauli exclusion principle. I will then outline a programme for how one might do to this statistical mechanics what Boltzmann did to Gibbs: derive a "collisionless collision integral"that describes the dynamical relaxation of a plasma towards the Lynden-Bell equilibria. It turns out that in order to make progress in this task, one must understand the structure of chaotic fluctuations in phase space. Lynden-Bell-like equilibria are recoverable under some very restrictive assumptions—roughly speaking, when these fluctuations are treated as structurally similar to a thermal noise. In fact, they are more likely to behave like fully-fledged turbulence—with phase mixing ("Landau damping") and stochastic echoes conspiring to process a constant flux of energy. What universal equilibria (if any) exist against such a background is a topic of ongoing research.

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