Non-equilibrium statistical mechanics of dilute astrophysical plasmas

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The transport of energy and momentum and the heating of plasma particles by waves and turbulence are key ingredients in many problems at the frontiers of heliospheric and astrophysics research. This includes the heating and acceleration of the solar wind; the observational appearance of black-hole accretion flows on event-horizon scales; and the properties of the hot, diffuse plasmas that fill dark-matter halos. All of these plasmas are magnetized and weakly collisional, with plasma beta parameters of order unity or even much larger. In this regime, deviations from local thermodynamic equilibrium (LTE) and the kinetic instabilities they excite can dramatically change the material properties of such plasmas and thereby influence the macroscopic evolution of their host systems. Departing from the astronomical tradition of abstracting these physics into crude, sub-grid prescriptions, this talk outlines an ongoing programme of kinetic calculations aimed at elucidating from first principles the multi-scale physics of waves, turbulence, instability, and transport in magnetized, weakly collisional astrophysical plasmas. Effective "collision operators" describing the interaction between plasma particles and microscale kinetic instabilities driven by departures from LTE will be presented, alongside a witches' brew of self-defeating Alfvén waves, self-sustaining sound waves, and microphysically modified magnetosonic modes.