The Outer Heliosphere: Revolutionary Observations and Non-Maxwellian Plasmas

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Space physics offers the ultimate laboratory for modern thermodynamics, pushing its principles to extremes and revealing their fundamental limits far beyond the reach of any human-made experiment. In this natural setting, the solar system moves through the partially ionized and magnetized very local interstellar medium (VLISM) with a relative speed of ~26 km/s. The Sun is constantly emitting supersonic and magnetized solar wind in all directions at typically 300-800 km/s, which inflates a "bubble" in the VLISM and produces a complicated interaction that defines the boundary of our heliosphere. Almost all space plasmas are non-Maxwellian and well characterized by kappa distributions (equivalently q-Gaussians). Kappa distributions arise from thermodynamic states with intrinsic correlations and originate from the entropy defect, a concept that is of fundamental importance and governs how entropy is partitioned among a system's constituents; in this framework, $1/\kappa$ quantifies the magnitude of this difference. Interestingly, the solar wind becomes increasingly non-Maxwellian (lower kappa) with increasing distance from the Sun. We now understand this to be because some interstellar neutral atoms entering the heliosphere are ionized and become Pickup Ions (PUIs) that are carried out in the solar wind flow; the PUIs are initially distributed in a ring distribution with low dimensionality (highly ordered) that gets shared with the bulk solar wind, reducing its kappa. This talk briefly summarizes some of the fascinating things that we have been learning recently from in situ measurements on the Voyager and New Horizons spacecraft and remote observations of the plasma environment from the Interstellar Boundary Explorer (IBEX) and recently launched Interstellar Mapping and Acceleration Probe (IMAP) NASA missions.