# Stochastic thermodynamics for investigating Solar Wind Turbulence

S. Benella[1], M. Stumpo[1], T. Alberti[2], O. Pezzi[3], E. Papini[1], G. Consolini[1]

[1] *INAF - Institute for Space Astrophysics and Planetology, Rome, Italy*

[2] *National Institute for Geophysics, Rome, Italy*

[3] *CNR - Institute for Plasma Science and Technology, Bari, Italy*

Turbulence is ubiquitous in space plasmas and arise from nonlinear dynamics and emergence of collective phenomena, from the largest scales of the energy injection to the smallest scales where dissipation occur. The turbulent dynamics of velocity and magnetic field fluctuations in nearly collisionless plasmas, such as solar wind, can be envisioned as a scale-to-scale Langevin process. This allows us to embed the statistics of magnetic field fluctuations in the framework of stochastic process theory, and then to resort to fundamental concepts of the recent theory of stochastic thermodynamics [1].

We investigated magnetic field fluctuations of pristine solar wind by using Parker Solar Probe measurements gathered by the FIELD suite during the first perihelion, on 2018 November 6. Magnetic field increments as a function of the scale define the cascade trajectories in which we have calculated the stochastic entropy variation. The total stochastic entropy produced along a trajectory expresses in average the imbalance of forward with respect to backward processes, which, in the case of turbulence, are proxies for direct and inverse cascades.

By using the stochastic entropy, we can identify two different regimes where fluctuations exhibit contrasting statistical properties [2]. In the inertial range a net production of entropy production is linked to an increase of the kurtosis, thus indicating the occurrence of intermittency in the sample of fluctuations. On the other hand, cascade trajectories associated with a decrease of entropy are assimilated to a global scale invariance. In the transition region between inertial and ion scales the scenario reverses: trajectories characterized by $\Delta S < 0$ exhibit a sudden increase of the kurtosis due to small-scale intermittency, whereas trajectories with $\Delta S > 0$ show a constant flatness. Results are interpreted in terms of physical processes consistent with an accumulation of energy at ion scales.

**References:**

[1] U. Seifert, Physical review letters, 95(4), 040602, 2005.

[2] M. Stumpo, S. Benella, T. Alberti, et al., ApJL, 959(2), L20, 2023.