Interplay of Turbulence and Reconnection for Particle Acceleration in Astrophysical Systems

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Turbulence and particle acceleration are two of the most important open problems in astrophysics, as well as in many other fields: from fusion reactors, to regular fluids on Earth, like air or water. Astrophysical plasmas are found to behave in a turbulent way, developing vorticose motions over a broad range of scales. Turbulence exchanges energy across different scales and in the process highly energetic particles are produced. Great minds have devoted their attention to this problem, such as the famous Fermi mechanism for turbulence-induced particle acceleration. But now the attention is dominated by the new mission of exploration Parker Solar Probe that measures in situ the turbulence in the solar corona at distances closer to the Sun than ever before.

Due to the mathematical complexity of turbulence, the progress possible with purely analytical means is limited, despite the great success of the past (as, for example, the Kolmogorov scaling). Numerical simulations are required to arrive where pure theory cannot go. The simulations of turbulence and acceleration are among the most challenging of all the high-performance computing tasks. The difficult part of them lies on the need of resolving numerically a broad range of scales that all together constitute the phenomenology of turbulence.

In our work we deployed cutting edge numerical simulations of plasma turbulence using the implicit particle in cell method [1] that overcome several limitations in the description of plasma motions from large to small scales. The approach has been implemented in a highly efficient massively parallel implementation [2] suitable for Tier-0 supercomputers, with proven scaling up to 50,000 processors.

Our approach allowed us to address still open questions on this topic with an unprecedented realism of the model and precision of the description. We focused especially on the study of the kinetic range of plasma turbulence, a more recent history with respect to its large-scale fluid counterpart. We addressed several of the questions that remain open on the nature of the kinetic range:

1. What are the mechanism which allows the conversion of electromagnetic energy into particle kinetic energy in the kinetic range of plasma turbulence?
2. What is the effect of turbulence in particle transport?
3. How does turbulence shape proton and electron distribution function?

The results of our study especially focused on the role of reconnection as part of the turbulent mechanism. Reconnection is a process where magnetic energy is converted into kinetic energy via the formation of very localised regions of dissipation where particles and fields exchange their energy. This mechanism is a powerful mean for the turbulence to release energy and in particular to produce highly energetic particles. The results of the investigations supported by a recent Tier-0 allocation will be reported, updating our recently published work [3,4]

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[3] Pecora, F., Pucci, F., Lapenta, G., Burgess, D., & Servidio, S. (2019). Statistical analysis of ions in two-dimensional plasma turbulence. *Solar Physics*, *294*(9), 114.
[4] Lapenta, G., Pucci, F., Goldman, M. V., & Newman, D. L. (2019). Local regimes of turbulence in 3D magnetic reconnection. *To appear on Astrophys. J.*