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Transport of particles in a turbulent solar corona

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I will discuss the transport of charged particles in energy- and position-space inside a convection zone-driven 3D turbulent solar corona. It is important to address the formation of the small- and large-scale 3D Current Sheets, the 3D turbulence, and the 3D large scale magnetic disturbances (let us call this environment "3D turbulent reconnection") in the solar corona before addressing the transport of charged particles in energy (heating and acceleration) and space. The transport in space is an important parameter since the volume where the energy is released during turbulent reconnection is finite and defines the time particles remain trapped (escape time). The energization time (or acceleration time) of the particles is limited by the escape of particles from the fragmented energy release volume towards the heliosphere and/or the solar chromosphere. Numerous observations, especially in radio (groups of type III bursts, millisecond radio spikes, fast drifting radio bursts) and X-rays suggest that the energy dissipation in the low solar corona is fragmented.

Fermi proposed two mechanisms for particle acceleration (1949,1952). One is the stochastic scattering of charged particles off magnetic clouds and the other the systematic scattering off converging turbulent flows (as it appears in turbulent shocks). Adopting the methodology proposed by Fermi for the transport (scattering) of particles in a 3D turbulent reconnection environment, we have discovered that both mechanisms operate simultaneously. One controls the heating of the plasma (stochastic) and the other the acceleration of the nonthermal tail (systematic). The 3D turbulent reconnection environment inside a finite volume is a relatively new concept and many of the assumptions adopted by Fermi in his original analysis need revisions. We encounter turbulent reconnection environments in many places in the heliosphere (solar corona, solar wind, downstream of shocks, magnetosheath, magnetotail, termination shock) and laboratory plasmas (Edge Localized Modes). The transport of particles in energy and space are anomalous for the mildly relativistic particles in 3D finite volumes the high energy particles execute complicated trajectories (Levy walks) in a large-scale fragmented energy release volume, suggesting that in both, energy and space, respectively, Fractional Transport Equations are needed to analyze their behavior. On the other hand, the low energy particles are executing classical random walks in energy and remain still an open question for their transport in space, leading to their heating, which can be analyzed by the well-known Fokker Planck equation.

In summary, three fundamental questions are open, and we hope to settle them with the help of modern observational and modeling tools over the next decade: (1) How the complex magnetic topologies in the solar corona set up and maintain a turbulent reconnection environment? Several suggestions have been proposed, e.g. random shuffling of the magnetic filaments (loops) by the photospheric motions, emerging of new magnetic flux, 3D magnetic eruptions of unstable filaments, etc. (2) How the charged particles are transported in energy and space inside a finite turbulent reconnection environment? (3) What are the radiation signatures of the heated and accelerated particles inside the 3D turbulent reconnection and what are the observational signatures needed to test the above ideas?

The analysis proposed in this talk suggests a new vision for our models and observations for the next decade. We should find ways to approach the complex 3D global time-dependent connection of the photosphere with corona using an interacting systems method. The convection zone drives the emerged complex extrapolated fields forming millions of current sheets and other large-scale disturbances. The emerging magnetic flux interacting with the complex emerged magnetic fields leads the solar eruptions. Global eruption starts on large scales but quickly forms complex multi-scale environments where turbulent reconnection sets in. Large research consortia are needed to integrate the processes of turbulence, reconnection, radiation, and observations to understand the coupling of the convection zone, solar atmosphere, and the base of the solar wind.

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