Magnetic reconnection driven by merging of magnetic flux ropes/tubes in space plasma turbulence

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The interaction of coherent structures such as magnetic flux ropes/tubes and current sheets can lead to the generation of turbulence in cosmic and laboratory plasmas. Magnetic reconnection and magnetic merging involving the interaction of magnetic flux ropes/tubes plays a key role in space plasma turbulence, e.g., in solar wind and in solar photosphere.

The interplanetary medium is a natural laboratory for probing the link between magnetic reconnection and turbulence. Recently there has been a growing interest in the study of the interaction of multiple magnetic flux ropes/tubes in plasmas and multiple coronal mass ejections in space and astrophysics. We report the observation of magnetic reconnection at the interface region of two interplanetary magnetic flux ropes (Chian *et al.* 2016, 2022). Our analysis is based on *in situ* data of *ACE*, *Wind*, and *Cluster* on 2002 February 1-2 when *ACE* and *Wind* were located in the vicinity of the L1 point and *Cluster* was upstream of the Earth's bow shock. During this interval, the front and rear boundary layers of three interplanetary magnetic flux ropes are identified. Evidence of magnetic reconnection between two magnetic flux ropes and the associated bifurcated current sheet is obtained. The structures of magnetic flux ropes are reconstructed by the Grad-Shafranov method. The relation between current sheet, magnetic reconnection, dynamic pressure pulse and turbulence in the region of rope-rope magnetic reconnection is investigated. A quantitative analysis of the reconnection condition and the degree of intermittency by comparing kurtosis, phase coherence index, and scaling exponent of five different regions in this triple magnetic flux rope event reveals that rope-rope magnetic reconnection is the most likely site for genesis of interplanetary intermittency turbulence in this event, as confirmed by the kurtosis-skewness and complexity-entropy relations (Miranda *et al.* 2018, 2021). The dynamic pressure pulse resulting from this magnetic reconnection triggers the onset of a geomagnetic storm. Our results render support for recent studies showing that turbulence can be self-generated by magnetic reconnection resulting from the instability of a current sheet.

The network magnetic fields at solar supergranular junctions are organized into predominantly vertical kilogauss flux tubes and form patches of intense magnetic flux concentrations that can persist for hours and even days. Magnetic switchbacks observed by *Parker Solar Probe* in the near-Sun solar wind may be driven by interchange magnetic reconnection events, with the footpoints of merging closed and open magnetic flux ropes rooted at supergranular junctions, just above the solar transition region and the spacecraft measurements represent the extended regions of a turbulent outflow of magnetic reconnection exhaust. Switchbacks are likely formed in the low corona and modulated by the solar surface convection patterns of supergranulation and granulation; the large scales detected for switchback patches are compatible with supergranulation scales and the smaller scales are compatible with granulation scales. We study the spatiotemporal dynamics of vorticity and magnetic field in the region of a persistent photospheric vortex at a supergranular junction of the quiet Sun using *Hinode* observation on 2010 November 2 by showing that in a 30-min interval during the vortex lifetime, the magnetic field is intensified at the centers of two merging magnetic flux tubes trapped inside the vortex boundary (Chian *et al*. 2023; Rempel *et al*. 2023). Moreover, we show that the electric current density is intensified at the interface boundary boundary layers of merging tubes, resulting from strong vortical downflows in a supergranular vertex. Evidence of Lagrangian chaos and vortex stretching in the photospheric plasma turbulence responsible for driving the intensification of magnetic fields is analyzed. In particular, we report the first solar observation of the intensification of electromagnetic energy flux resulting from the merger of magnetic flux tubes.

References

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