Intensification of magnetic field by turbulent vortical flows

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The solar network magnetic fields are one of the most distinct structures of the photosphere. They outline the supergranular (SG) junctions in the quiet and active Sun, where the diverging flows from nearby SG cells collide and turn into converging downdrafts with strong shear where cold plasma returns to the solar interior, leading to complex interactions between turbulent convective flows and magnetic fields. The network magnetic fields are organized into predominantly vertical kG magnetic flux tubes (MFTs) and form patches of intense magnetic flux concentrations that can persist for hours and even days.

Vorticity plays an important role in the evolution of network magnetic fields. MFTs are coherent structures that contain strong concentrations of magnetic fluxes and electromagnetic field energy fluxes bounded by closed convex surfaces of electric current density. Innes et al. [1] observed micro-flares and mini-coronal mass ejections at SG junctions in the quiet Sun in association with brightenings seen on EUV images. These activities are activated by converging vortical photospheric flows which appear to twist small concentrations of mixed-polarity magnetic fields in shear flow regions. Intensification of magnetic field by merging of magnetic elements has been detected by observations and numerical simulations, which show that two magnetic bright points move towards each other before merging with the magnetic field rising and peaking as they coalesce [2].

We have shown in a series of papers that Lagrangian coherent structures provide a powerful tool to unravel the complex nature of supergranular turbulence in active and quiet Sun. In [3], we established the correspondence of the high network magnetic flux concentrations to the ridges of attracting Lagrangian coherent structures and demonstrated that the boundaries of SG cells are given by the maxima of the backward finite-time Lypapunov exponent of the horizontal plasma velocity which expose the location of the sinks of photospheric flows at SG junctions. In [4], we showed that the centre of a SG cell is given by the local maximum of forward finite-time Lyapunov exponent and the repelling Lagrangian coherent structures interconnect the Lagrangian centres of neighbouring SG cells. In [5], we presented observational evidence of Lagrangian chaotic saddles in plasmas given by the intersections of finite-time unstable and stable manifolds, and showed that the persistent objective vortices are formed in the gap regions of Lagrangian chaotic saddles at SG junctions. current densities in two merging magnetic flux tubes trapped by a persistent objective vortex.

In this talk we will discuss the relation between vorticity and magnetic field in the SG turbulence by investigating the intensification of magnetic field and electromagnetic field energy flux at the centres of two merging MFTs and the intensification of electric current densities at their interface boundary layers driven by a persistent objective kinematic vortex at a SG vertex of the quiet-Sun disc centre [6]. First, we analyse the spatiotemporal dynamics of Hinode's line-of-sight magnetic field, horizontal velocity field, horizontal electric current density derived from the line-of-sight magnetic field, and compute the Local Current Deviation in the SG region of a persistent objective kinematic vortex detected by the Instantaneous Vorticity Deviation. Second, we study the spatiotemporal dynamics of the horizontal electric current density, the temporal growth of the maxima of line-of-sight magnetic fields at the centres of two merging MFTs trapped in the interior of the vortex boundary, and the temporal growth of the maxima of the Local Current Deviation at the interface boundary layers of two merging MFTs. Third, we present the observational evidence of stretching-twisting-folding in the Lagrangian chaotic dynamics of turbulent vortical flows. Fourth, we apply the horizontal electromagnetic field energy flux given by the Poynting vector to investigate tube-tube merging and the temporal growth of core electromagnetic field energy fluxes in the merging MFTs. Fifth, we discuss the physical mechanisms responsible for the intensification of magnetic fields, electric current densities, and electromagnetic field energy fluxes in multiple MFTs undergoing merging trapped by SG vortical flows.

Our novel approach can be applied to the study of turbulent dynamo and magnetic reconnection of merging magnetic flux tubes in astrophysical and laboratory plasmas.

References

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