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Lagrangian Coherent Structures in Solar Plasmas

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Abstract:

Dynamical systems theory is concerned with the identification of the basic building blocks of the system under investigation and how they interact with each other to produce the observable dynamics. Examples of those building blocks are unstable equilibrium and periodic solutions, and nonattracting chaotic sets and their manifolds, which are special surfaces in the phase space that basically control the observable dynamics, guiding solutions in preferred directions. In this talk, we show that the dynamical systems approach can be employed to investigate solar plasmas by adopting a Lagrangian reference frame, where the phase space for each fluid element is studied and the building blocks of the turbulence can be efficiently extracted by appropriate numerical tools. We reveal how finite-time Lyapunov exponents, a traditional measure of chaos, can be used to detect attracting and repelling time-dependent manifolds that divide the plasma in regions with different behavior. In addition, stagnation points and vortices detected as elliptical Lagrangian coherent structures (LCS) complete the set of building blocks of the photospheric turbulence. Such structures are crucial for the trapping and transport of magnetic elements, mass and energy in the solar plasma. The elliptical LCS are computed with the Lagrangian Averaged Vorticity Deviation (LAVD) operator. Our data analysis is based on the continuum intensity images at the quiet-Sun disc centre captured by the NFI onboard the Hinode satellite on 2010 November 2, with a cadence of 90 s. The horizontal velocity fields are extracted using the local correlation tracking (LCT) method. We show that the boundary of supergranular cells in the photosphere can be clearly defined from the backward-time Finite-Time Lyapunov exponent (FTLE) field. Similarly, the Lagrangian centres of the supergranules are found as local maxima in the forward-time FTLE field. The magnetic elements are transported along the repelling LCS toward the intergranular boundary, where there is a strong concentration of magnetic field. This region is dominated by vortices with a wide range of temporal and spatial scales. These structures tend to trap patches of magnetic elements, causing the magnetic field intensity to increase locally. Overall, we show that LCS provide a powerful tool to determine the transport properties of photospheric flows and the complex dynamics of solar magnetic fields.

References:

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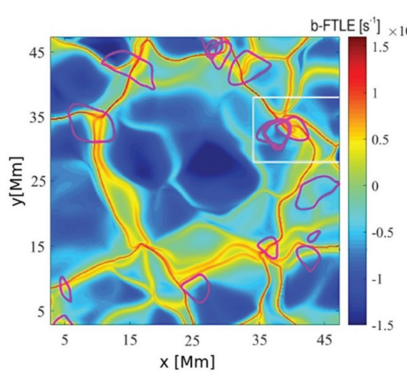

Figure 1. Lagrangian view of photospheric turbulence at disk center of the quiet Sun. The vortex boundary (magenta lines) of persistent objective vortices detected from 08:31:15 UT to 19:25:29 UT on 2010 November 2, superposed on the backward-time finite-time Lyapunov exponent field.