Role of Parallel Solenoidal Electric Field on Energy Conversion in 2.5D Decaying Turbulence with a Guide Magnetic Field

บทบาทของสนามไฟฟ้าแบบโซเลนอยดัลในทิศขนานต่อการแปรรูปพลังงานในความปั่นป่วนที่สลายตัวใน 2.5 มิติพร้อมสนามแม่เหล็กนำ

(P. Pongkitiwanichakul*, **D. Ruffolo,** F. Guo, S. Du, P. Suetrong, C. Yannawa, K. Makwana, and K. Malakit, Astrophys. J., 923, 182)

Turbulence is a random swirling motion in fluids moving at relatively high speeds, as can be seen when water comes out of a faucet and impacts a basin, or from the swirling of milk in a coffee cup. Turbulence is ubiquitous in space plasmas (where a plasma is an ionized gas) and plays a major role in the conversion of energy from the large-scale astrophysical magnetic field **B** to heating of the plasma. Here we study such energy conversion in a particle-in-cell (PIC) simulation of decaying turbulence in 2.5 dimensions, which means that the simulation domain is two-dimensional (with periodic boundary conditions) but all vector quantities are expressed in three dimensions.

A key physical process for such energy conversion, which occurs in small-scale turbulence, is magnetic reconnection, in which magnetic field lines reconnect and magnetic energy is converted to bulk flow energy and heat energy of the plasma particles. We address the role of this process and evaluate various possible indicators of where this is taking place, which could assist in the identification of this process in data from spacecraft observations. Another innovative aspect of this work is to perform the "Helmholtz decomposition" of the electric field **E** into a solenoidal component (with zero divergence) and an irrotational component (with zero curl). Physically, an irrotational electric field relates to charge separation and a solenoidal field relates to the plasma motion **u** (as the electron and ion motions tend to cancel any electric field in the rest frame, in a fixed frame there is an electric field of -**u x B**).

First, we consider a mathematical and conceptual framework for energy conversion. Based on Maxwell's equations, magnetic field energy must first convert to solenoidal electric field energy. Then electric field energy converts to particle energy (bulk + thermal) via **J . E**, where **J** is the plasma current. In our simulations, the electric field does not accumulate energy, so these two energy conversion rates are approximately equal and relate to the solenoidal component. Furthermore, we find that the parallel solenoidal component $J_{\parallel}E_{so,\parallel}$ dominates the energy conversion. Its spatial distribution is shown in Figure (a). We show that the contributions within magnetic islands cancel, leaving the contribution from reconnection sites outside the islands. Of the various indicators we tried, only $|E_y|/|B_{xz}|$, inspired by the work of Lapenta (2021), succeeds in identifying the sites of energy conversion (see Figure below).

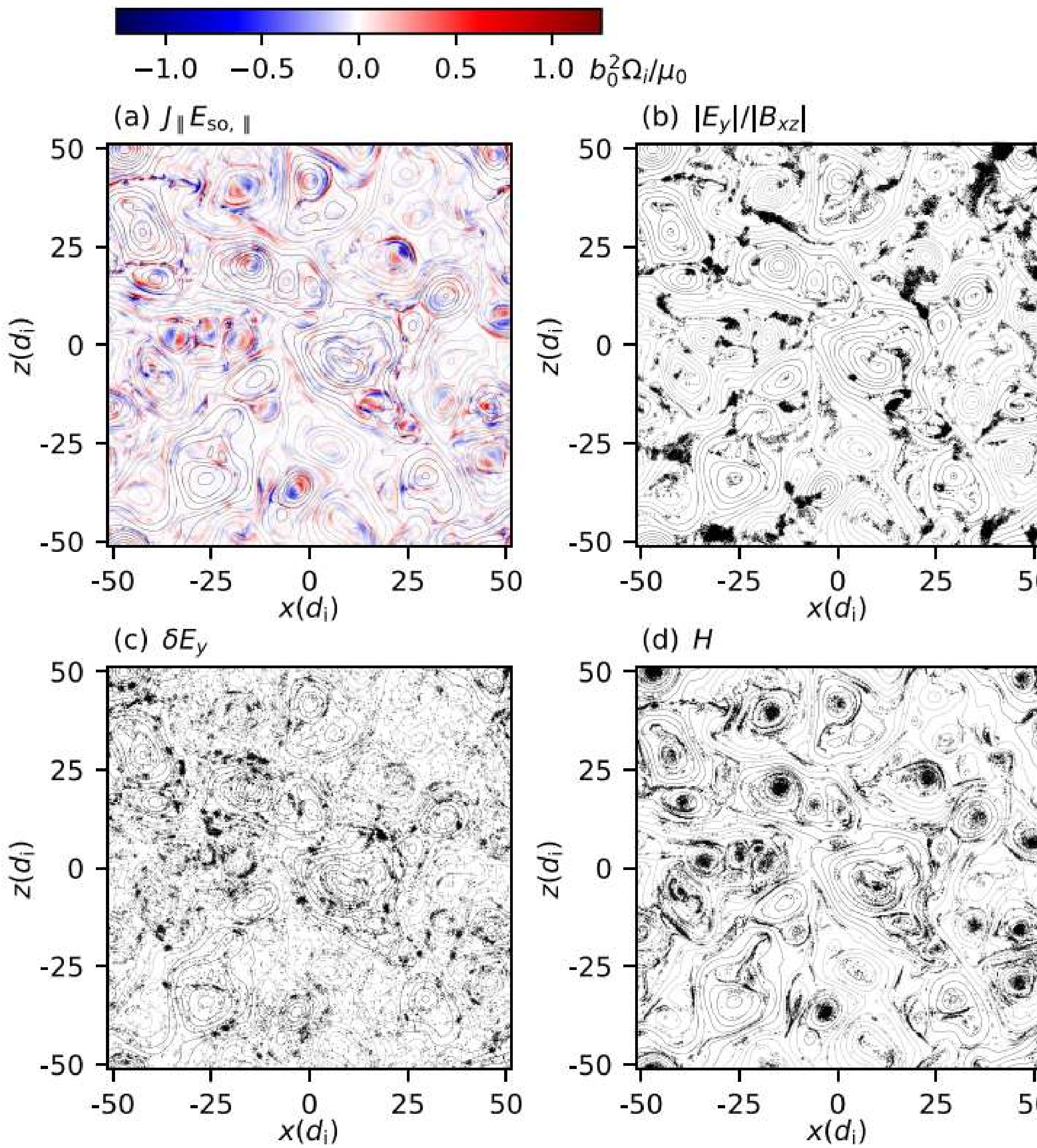

Figure: (a) 2D color plot of $J_\parallel E_{so,\parallel}$ from a 2.5D simulation of decaying turbulence in a collisionless plasma, in comparison with the predictions of various indicators: (b)–(d) Spatial regions (black) where the indicator is (b) $|E_y|/|B_{xz}|$ less than its 10th percentile, or (c) δE_y or (d) H greater than its 90th percentile.