The Structure of Dissipating and Quiescent Magnetic Fields

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We discuss the nature of reconnection and dissipation in magnetically dominated astrophysical plasmas (such as the solar corona, accretion disc coronae, galactic coronae, astrophysical jets, etc.), in particular the question how reconnection and near force-free conditions can exist hand in hand.

A magnetically dominated plasma driven by motions on boundaries at which magnetic field lines are anchored is forced to dissipate the work being done upon it, no matter how small the electrical resistivity. Numerical experiments have clarified the mechanisms through which balance between the boundary work and the dissipation in the interior is obtained. Dissipation is achieved through the formation of a hierarchy of electrical current sheets, which form as a result of the topological interlocking of individual strands of magnetic field. The probability distribution function of the "local winding number" is nearly Gaussian, with a width of the order unity. The dissipation is highly irregular in space as well as in time, but the average level of dissipation is well described by a scaling law that is independent of the electrical resistivity [1, 2].

Magnetic dissipation in astrophysical plasmas often occurs under conditions where the level of boundary driving varies considerably, both in space at any given time, and also with time at any given location. It is therefore of interest to study the response to variations in the level of boundary driving.

If the boundary driving is suspended for a period of time the magnetic dissipation rapidly drops to insignificant levels, leaving the magnetic field in a nearly force-free, yet spatially complex state, with significant amounts of free magnetic energy but no dissipating current sheets. In this state the probability distribution function of the "local winding number" has contracted somewhat, but its width remains of the order unity.

Renewed boundary driving leads to a quick return to dissipation levels compatible with the rate of boundary work, with dissipation starting much more rapidly than when starting from idealized initial conditions with a uniform magnetic field (see the Figure).

We thus conjecture that even "quiescent" astrophysical plasmas are characterized by a considerable spatial complexity, and that a hierarchy of current sheets, capable of dissipating an arbitrary level of driving, rapidly forms when such a plasma is subjected to boundary work.

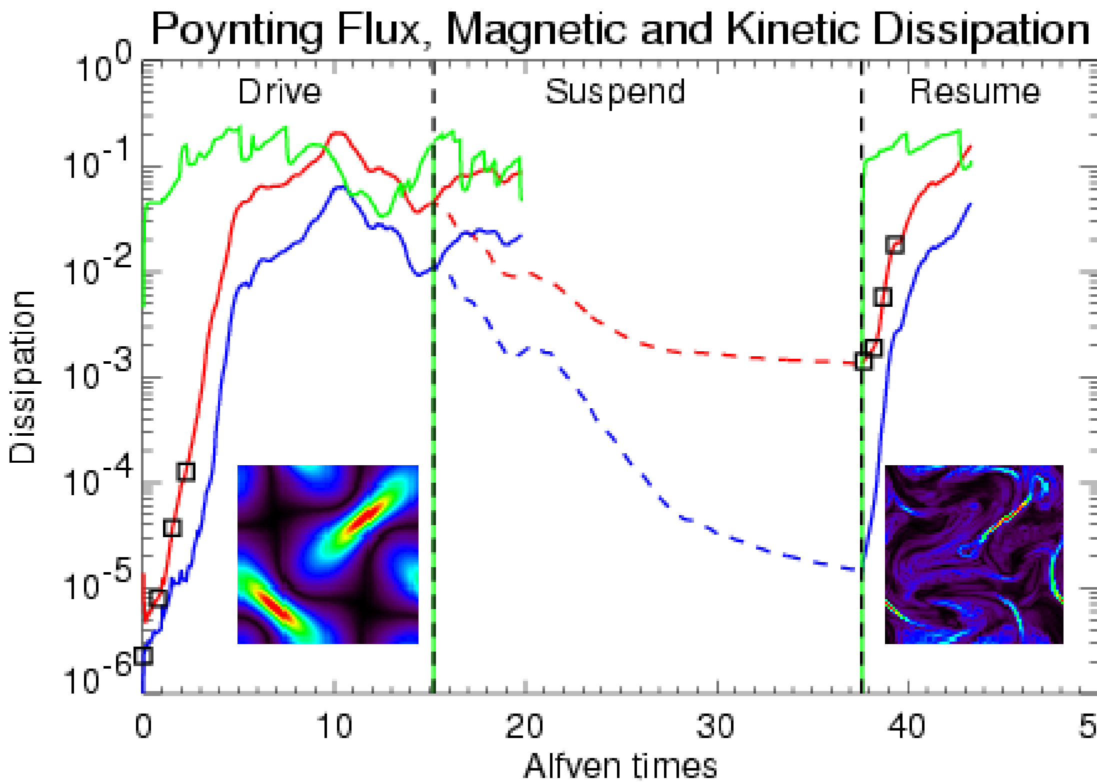

Figure 1: The boundary work (green), the magnetic dissipation (red), and the kinetic energy dissipation (blue) in a 3-D numerical experiment where a magnetically dominated plasma is driven by boundary work at two opposing boundaries. The boundary work occurs because magnetic field lines are anchored in boundaries that are subjected to a sinusoidal, incompressible velocity field, with phase and amplitude varying randomly in time. At $t \sim 15$ the boundary work is turned off and the system is allowed to relax until $t \sim 38$, where the initial velocity pattern is repeated again. The two insets show the electric current density in a cross section half-way between the two driving boundaries, approximately two Alfvén crossing times after the driving has started and resumed, respectively. Note that, even though exactly the same velocity field is applied for exactly the same time, there are much sharper current concentrations (current sheets) in the right-most panel, illustrating that the quiescent but spatially complex magnetic field in the suspended state is "ripe" for quickly producing current sheets. The system thus reaches balance between driving and dissipation much more rapidly from the suspended driving state than from the (idealized) initial state.

References

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[2] Nordlund, Å. and Galsgaard, K. (1997). Topologically Forced Reconnection. In 'Proc. 8th European Solar Physics Meeting', eds.: G. Simnett, C. E. Alissandrakis and L. Vlahos, *Lecture Notes in Physics* **489**, 179–200.