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Magnetic reconnection: Theory and modelling for space and astrophysical plasmas

D.I. Pontin[1], E.R. Priest[2] and L.P. Chitta[3]

[1] School of Information and Physical Sciences, University of Newcastle, Australia

[2] School of Mathematics and Statistics, University of St Andrews, UK

[3] Max Planck Institute for Solar System Research, Göttingen, Germany

e-mail (speaker): david.pontin@newcastle.edu.au

Magnetic reconnection is a fundamental astrophysical process: it plays a key role in the dynamics of the Sun's atmosphere and planetary magnetospheres, as well as other astrophysical objects. It facilitates the rapid conversion of stored magnetic energy into other forms such as kinetic and thermal energy. This drives phenomena such as flares, eruptions and jets in the Sun, stars, and beyond, as well as contributing to coronal heating. In the magnetosphere it is involved in flux transfer events and substorms. This talk will begin with a review of the fundamental theory of three-dimensional magnetic reconnection [e.g. 1].

In a highly-conducting plasma the *magnetic topology* is preserved as the plasma evolves, an idea encapsulated by Alfvén's frozen flux theorem [2]. Magnetic topology conservation therefore means that magnetic field lines cannot break or merge with one another, but instead evolve via smooth deformations. Here "magnetic topology" refers to the connectivity and mutual linkage of magnetic field lines within the domain of interest, as well as field line connectivity between points on the domain boundary. Real plasmas have finite conductivity with the result that the magnetic topology is not preserved everywhere for all time: field lines break and recombine in small sub-domains by the process of *magnetic reconnection*, permitting a reconfiguration of the magnetic field and often a rapid conversion of stored magnetic energy to other forms. A significant challenge for our understanding of reconnection is how the dynamics on global length scales are coupled with the micro-scale (kinetic) processes that take place in the dissipation region within which the reconnection takes place.

Recent observations from the Solar Orbiter and Parker Solar Probe missions have shed new light on the important role of small-scale magnetic reconnection (involving flux domains on the scale of granules) in coronal heating and in the generation of the solar wind [e.g. 3]. In the second part of this talk I will briefly introduce a new model [4] that suggests that interchange magnetic reconnection induced by photospheric flux cancellation may play a leading role. I will show that through two phases of atmospheric energy release -- pre-cancellation and cancellation -- the cancellation of photospheric magnetic flux fragments may provide a significant contribution to coronal heating and solar wind generation, depending on the global field geometry (see Figure 1).

References

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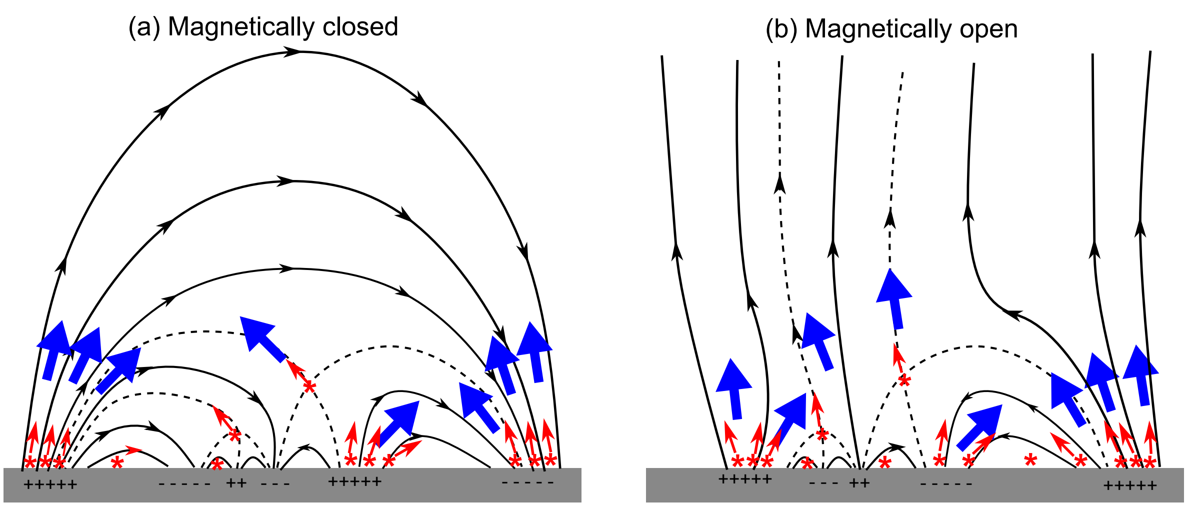

Figure 1. From [4], a unified model for coronal heating and solar wind acceleration in regions above supergranules that are (a) magnetically closed and (b) magnetically open. Stars indicate reconnection sites in the lower atmosphere that generate flows (red arrows) as well as fast particles, waves and heat flux (blue arrows).