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Frontiers of Magnetic Reconnection Research and FLARE Project

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Magnetic reconnection - the topological rearrangement of magnetic fields - underlies many explosive phenomena across a wide range of natural and laboratory plasmas. It plays a pivotal role in electron and ion heating, particle acceleration to high energies, energy transport, and self-organization. The frontiers of magnetic reconnection are highlighted by the following 10 major scientific challenges or problems [1]: (1) The multiple scale problem, (2) The 3D problem, (3) Energy conversion problem, (4) Boundary condition problem, (5) Onset problem, (6) Partial ionization problem, (7) Flow-driven problem, (8) Extreme condition problem, (9) Turbulence, shock and reconnection, and (10) related explosive phenomena. I will summarize these challenges and describe a new laboratory experiment called FLARE (Facility for Laboratory Reconnection Experiments) as a collaborative research facility at Princeton Plasma Physics Laboratory. The goal of the FLARE project is to provide a platform for experimental access of new multiple X-line regimes of magnetic reconnection shown a magnetic reconnection phase diagram (Figure 1) to solve a majority of these problems, in collaboration with users across multiple communities on basic plasma physics, space plasma physics, solar physics, astrophysics and fusion plasma physics.

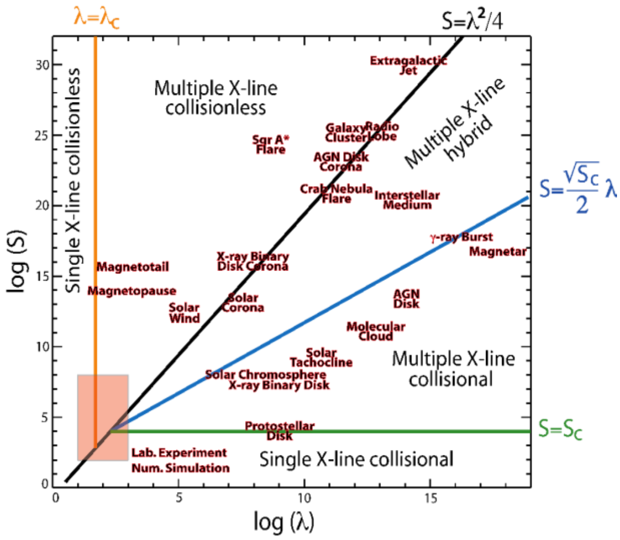

Figure 1. A phase diagram for magnetic reconnection. If either Lundquist number S or the normalized size λ (to ion kinetic scales), is small, reconnection with a single X-line occurs in collisional or in collisionless phases. When both S and λ are sufficiently large, three new multiple X-line phases appear through plasmoid instabilities. Global MHD physics can effectively couple to local dissipation scales, which can be either collisionless or collisional, depending on parameters. There are some updates on this diagram by including effects such as electron pressure anisotropy. Various heliophysical and astrophysical cases are also shown in their approximate locations in the diagram. Numerical simulations and laboratory experiments can already, or are poised to, access all reconnection phases directly relevant to heliophysical and astrophysical plasmas. An particularly important question that should be addressed by these studies is how does this simplified 2D reconnection diagram extend into more realistic 3D. Figure adapted from Ref.[2].

References

[1] "Major Scientific Challenges and Opportunities in Understanding Magnetic Reconnection and Related Explosive Phenomena in Magnetized Plasmas", H. Ji et al. (2020). https://arxiv.org/abs/2004.00079

[2] "Phase diagram for magnetic reconnection in heliophysical, astrophysical, and laboratory plasmas", H. Ji and W. Daughton, Phys. Plasmas **18**, 111207 (2011). https://w3.pppl.gov/~hji/paper/Ji11.pdf