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Studying the fluctuation dynamo and magnetized turbulence with the TDYNO laser-plasma experiments

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Magnetic-field amplification due to the motion of turbulent plasma – the so-called small-scale turbulent dynamo – plausibly accounts for the dynamically significant magnetic fields that are present in a myriad of astrophysical environments, including stars and the intracluster medium of galaxy clusters. The small-scale turbulent dynamo was first proposed over half a century ago, but confirming its viability (as well as testing theoretical and numerical predictions of its key properties) in a laboratory setting has been an outstanding challenge.

Significant steps towards addressing this challenge have been made by the 'TDYNO' series of experiments. These have been carried out during the last eight years at several different high-energy laser facilities including the Central Laser Facility [1], the Omega Laser Facility [2-5, 8], the Laser Mégajoule [6], and the National Ignition Facility [7]. Plasma jets driven by intense laser irradiation are passed through asymmetric grids, and then collided head on, leading to developed subsonic turbulence (see Figure 1). Specialized laser-plasma diagnostics including Thomson scattering, soft-X-ray-imaging and proton imaging have allowed for a thorough characterization of the turbulent plasma state, including measurements of temperatures, densities, flow velocities, turbulent kinetic-energy spectra, and magnetic fields.

Our key finding is that at sufficiently large magnetic Reynolds numbers, magnetic fields are amplified very efficiently, attaining dynamical strengths [1, 2]. The robustness of this conclusion has been confirmed subsequently via several extensions of the original experimental configuration, including time-resolved measurements [5], and experiments with different seed-field strengths [8]. The viability of magnetic-field amplification in supersonic turbulence has also been investigated, confirming expectations that it can occur, but is less efficient in several regards [6]. Finally, the stochastic magnetic fields produced by the TDYNO platform have been used to characterize the transport of both high-energy particles and heat in astrophysically relevant magnetized plasma turbulence [4,7].

References

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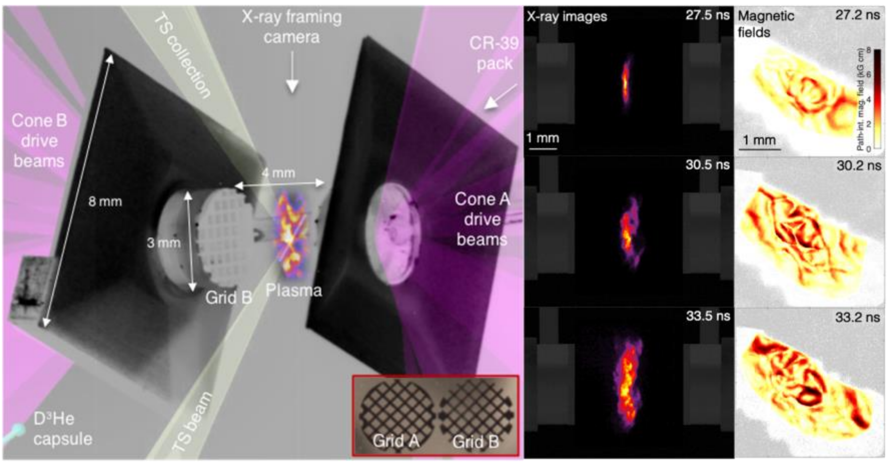

Figure 1: TDYNO platform for investigating the small-scale turbulent plasma dynamo (adapted from [5]). Left panel: annotated photograph of experimental target. Central panels: time series of self-emitted X-rays from the turbulent plasma. Right panels: path-integrated magnetic fields in the turbulent plasma, reconstructed from proton radiography data generated using a D^3He fusion capsule.