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Studying the Astrophysical Turbulent Dynamo using the OMEGA-EP Lasers

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Magnetic fields are ubiquitously observed or inferred in a variety of astrophysical systems. These wide-spread magnetic fields are believed to have come from a dynamo process, during which a fraction of the flow kinetic energy is converted to the magnetic energy. Most dynamo theories and experiments have emphasized the important role of flow turbulence, In the so-called small-scale dynamo regime, significant magnetic fields are produced at scales comparable to or smaller than that of the flow. Theory and extensive numerical simulations have mapped out the parameter space near magnetic Prandtl number Pm $\sim 0.01 - 100$ and Mach number M $\sim 0.01 - 100$ for exciting small-scale dynamo [1]. For example, for Pm ~ 1 plasmas, the critical Rm required for dynamo is ~ 100, which is likely accessible with high-energy density plasmas made by powerful lasers [2].

We describe our experiments on the OMEGA-EP wherein the turbulent small-scale dynamo was observed in the Pm > 1, high Rm > 100, and transonic turbulent regime. Extensive numerical simulations have suggested its feasibility [3]. As shown in Figure 1, a ~mm^3-scale volume of turbulent, magnetized plasma is produced using the OMEGA-EP laser. Using diagnostics including a 4ω laser beamline for angular filter refractometry and a sheath-accelerated proton beamline for deflectometry, we were able to reliably measure the hydrodynamics and magnetic field of the target plasma and observe the turbulent dynamo over a few nanoseconds of activity across two orders of magnitude in spatial scale, $10 < k < 1000$ cm^{-1}.

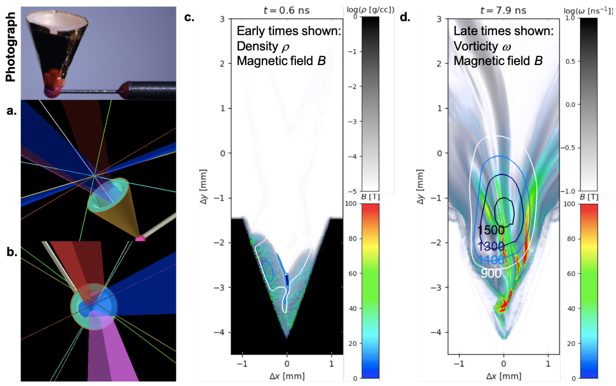

FIG. 1. Drawings and simulations show hardware and plasma as designed in our turbulent dynamo experiment: a. Main target, laser beams, and diagnostics' lines of sight are shown in relief. b. Elements in (a) are shown with the target oriented face-on for detail of laser paths. c. Magnetic field distributions are shown together with density based on our 3-D FLASH simulation at early times. d. Both vorticity and magnetic field distributions at late times, during turbulent dynamo [3].

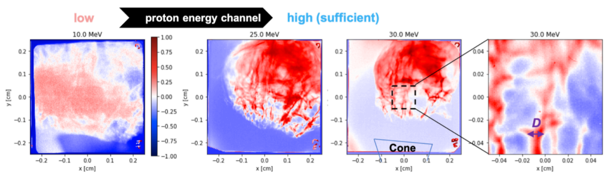

Fig. 2. Experimental fluence contrast maps reveal the proton energy dependence of imaging regimes. With sufficiently high proton energy, the underlying filamentary structure of the target plasma magnetic field is revealed and can be quantified. Evolution of magnetic energy spectra derived from our highest-quality proton deflectometry data reveal fast turbulent dynamo activity in its exponential growth stage, lasting until 8 ns.

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