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Magnetogenesis in collisionless plasma

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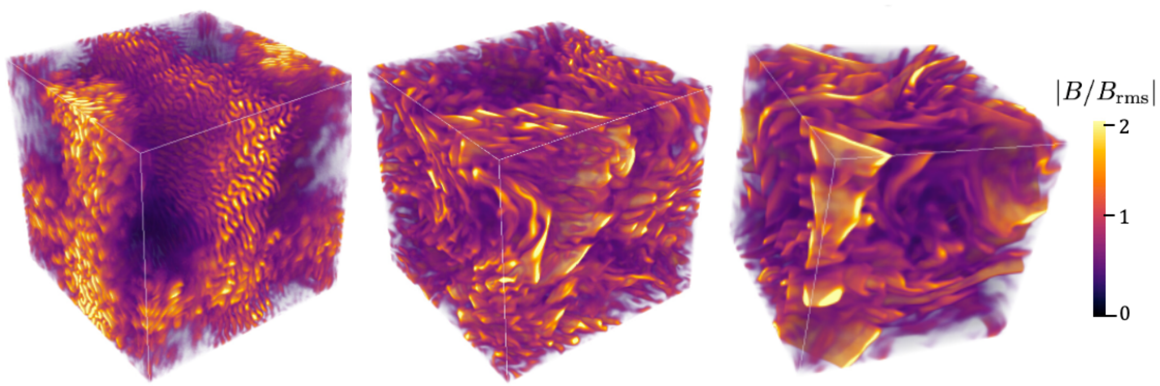
Astronomical observations suggest pervasive, dynamically important magnetic fields in our Galaxy and the intracluster medium. Their origin remains a long-standing question in astrophysics and cosmology. It is widely believed that such fields first arose as weak 'seeds' generated by cosmic batteries, and were subsequently amplified by the turbulent plasma flows to current levels via the 'dynamo' process. However, a complete understanding of these processes in a weakly collisional plasma is still lacking. Our first-principles numerical and theoretical study provides a unified paradigm for understanding the origin and evolution of cosmic magnetism by taking into account the effects of nonequilibrium micro-physics of collisionless plasmas on macroscopic astrophysical processes. We apply an external mechanical force to a weakly collisional, initially unmagnetized plasma. The driven large-scale motions are subject to strong phase mixing, which leads to the development of thermal pressure anisotropy. This anisotropy triggers the Weibel instability, which produces filamentary 'seed' magnetic fields on plasma-kinetic scales. The plasma is thereby magnetized, enabling efficient stretching and folding of the fields by the plasma motions and the development of Larmor-scale kinetic instabilities such as the firehose and mirror. The scattering of particles off the associated microscale magnetic fluctuations provides an effective viscosity, regulating the field morphology and turbulence. During this process, the seed field is further amplified by the fluctuation dynamo until energy equipartition with the turbulent flow is reached. By demonstrating that equipartition magnetic fields can be generated from an initially unmagnetized plasma through generic large-scale turbulent flows, this work has important implications for the origin and amplification of magnetic fields in the intracluster and intergalactic mediums.



Visualization of (normalized) magnetic-field magnitude at peak Weibel growth (left), after one large-scale turnover time (middle), and in the saturated state of the dynamo (right).