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From Weibel seed generation to saturated dynamo in collisionless plasmas with finite mass ratio

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The magnetic fields permeating the universe have a profound effect on the development of astrophysical systems, from stellar to cosmological scales. Yet the origin and evolution of these fields remains a major open question. Observed magnetic field strengths in the intracluster medium are consistent with being a result of turbulent dynamo. However, unlike in stellar or planetary interiors, the dynamo in the intracluster medium is weakly collisional, relying on small scale kinetic processes. While magnetohydrodynamics remains the standard framework for dynamo studies, it does not capture such kinetic processes. On the other hand, a fully kinetic treatment of this multi-scale inherently 3D process can be prohibitively expensive. Capturing the spatio-temporal scales of the seed generation through Weibel instability and the subsequent dynamo field amplification through saturation poses an extreme numerical challenge, and it has only been achieved very recently in pair-plasmas [1].

Using the 10-moment collisionless fluid solver of Gkeyll [2] that retains the full pressure tensor for all species, and thus the pressure anisotropy driving the electron Weibel instability, allows us to perform simulations including both the seed generation and the subsequent dynamo at finite mass ratio.

Lacking a collisional resistivity and an explicit viscosity in our collisionless fluid system motivates a generalization of the fluid and the magnetic Reynolds numbers, which play essential roles in dynamo theory [3]. To this end we consider the effects of the employed heat flux closure on a scale-dependent magnetic and fluid kinetic energy dissipation. This study also confirms that the electron and ion physics are sufficiently decoupled at the mass-ratio we use; this allows exploring physics beyond what is possible in pair-plasmas. Then we study the effect of our effective magnetic Reynolds number on the dynamics of the magnetic field generation process, finding qualitatively different evolution patterns for different strengths of the electron heat flux closure that drives the system towards pressure isotropy.

References
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