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Long-term consistent evolution of electron and ion currents generated via the Weibel instability in a plasma with temperature anisotropy

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We carry out 2D3V numerical simulations of the nonlinear stage of the Weibel instability of a two-component collisionless plasma with strong temperature anisotropy ($T_{\|}/T_{\perp} \sim 10$) and comparable energies of the electron and ion fractions. Calculations are done for a number of plasma parameters sets and based on the PIC-code DARWIN [1–3]. Spatio-temporal and spectral dynamics of the current filaments and the magnetic field created first by electrons, and then by the electron and ion fractions together is analyzed. The laws of growth of different spatial current modes are determined for the first time.

Small-scale magnetic field modes saturate earlier, magnetizing fractions of low energy electrons and decreasing the growth rate of large-scale modes. The value of the saturating field remains constant for a long period of time, since the growth of large-scale modes is compensated by the decay of small-scale ones.

The magnetic field resulting from the electron instability leads to the scattering of ions, slightly decreases the degree of their momentum distribution anisotropy. Magnetized electrons have energy comparable to that of ions, preventing the growth of the magnetic field and inhibiting the ion Weibel instability, which could develop since ions remain unmagnetized.

However, we found that after the saturation of the Weibel instability ion currents are still growing for some time due to inductive electric fields, associated with the decay of small-scale electron ones and their magnetic fields. We show that the long-term maintenance and the slow dynamics of a large-scale magnetic field are due to those ion currents, which eventually start to dominate over the electron ones and keep electrons magnetized for a long period of time.

Thus, the long-term evolution of the magnetic field and its scale distribution almost do not depend on the ion anisotropy degree which retains the order of initial one. This slowly evolving field also produces inductive electric fields, making the spatial pattern of remaining large-scale electron currents resemble the ion's one.

We discuss how the considered scenario can be implemented in experiments with laser-produced plasmas. We also compare it with the proposed earlier scenario [4], in which the ion Weibel instability plays the leading part in the process of the magnetic field generation and results in completely different spatio-temporal dynamics of currents.

References

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