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Self – Organization of photoionized plasmas via kinetic instabilities

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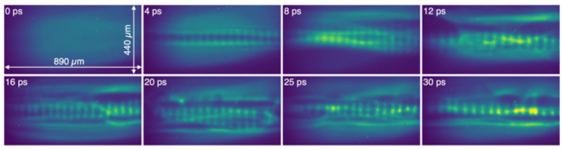
Self-organization mechanism transforms energy stored or otherwise existing in the system into a collective response. A common example is the wave produced by spectators at a sports event . A more complex but well known example in plasma physics is that of kinetic effects leading to the spontaneous appearance of waves and echoes in collisionless plasmas. Theory predicts a whole host of kinetic instabilities arising from nonthermal or anisotropic distribution functions. The thermalization of the distribution functions is accompanied by the spontaneous growth of electrostatic, electromagnetic or both electrostatic and magnetostatic response by the plasma. However, it was not known how to initialize plasma with such known electron distribution functions and how to measure the growth, saturation and damping of such instabilities before e-e collisions thermalize the distribution. I will show that high field ionization by ultrashort laser pulses allows one to design the electron distribution functions and Thomson scattering and relativistic electron beam probing enables movies to be obtained, with sub 100fs frame duration, of the resulting hierarchy of self-oraganization effects such as streaming (electrostatic), oblique current filamentation (both electrostatic and magnetostatic) and the electron Weibel instabilities (electromagnetic).

As an example of self-organization we show here the example of the self-generation of magnetic fields in the plasma due to the Weibel instability. The Weibel instability driven by temperature anisotropy was proposed over six decades ago as a possible mechanism for self-magnetization that occurs in many laboratory and astrophysical plasma scenarios that leads to collisionless thermalization of the electron distribution function. Weibel instability is one of several kinetic instabilities that occurs in collisionless plasmas. Yet its unambiguous demonstration remains a challenge. This is because it has been impossible to initialize a known anisotropic electron velocity distribution from which it can rapidly grow and to diagnose its growth on a few plasma period timescale. We have recently demonstrated an experimental platform suitable for understanding Weibel instability, which allows one to “design” electron velocity distribution functions using optical-field/tunnel ionization and measure the magnetic fields which arise as the thermal energy is converted into magnetic field energy with unprecedented spatiotemporal resolution using relativistic electron probing. We have provided the first visualization of the self-organization of magnetic fields and plasma currents driven by Weibel instability, which have validated kinetic theory predictions. We demonstrate that a up to 1% of the electron energy is converted into magnetic energy as the initially anisotropic plasma becomes thermalized , which supports the hypothesis of spontaneous magnetization of collisionless astrophysical plasmas by Weibel instability.

The self-generated magnetic fields in a hydrogen plasma produced by a plane polarized intense CO_2 laser are shown in the figure above. The growth rate , saturation level and the decay time of the magnetic field is consistent with the electron Weibel instability. The other two kinetic instabilities we have quantitatively documented are the electron streaming instability and the current filamentation instability. Since these instabilities have an electrostatic component we can probe these instabilities with ultrafast resolution Thomson scattering diagnostic using a femtosecond probe beam.

Figure 1



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