FINAL TECHNICAL REPORT

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Generation and Control of Self-Organized Nonlinear Kinetic Structures in High Energy Density Plasmas in the Presence of Intense Magnetic Fields and Ultrashort Laser Pulses

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(1) What are the major goals of the project?

Goals were to study the interplay between electron plasma waves (EPW), KEEN waves and externally generated magnetic fields. In particular, the Weibel instability B field generation process and its interrelationship with the existence of nonlinear EPWs in high energy density plasmas. We focused on a number of models of how Kinetic, Nonlinear Electron Plasma Waves, KNL-EPW and KEEN waves create anisotropic electron velocity distribution functions, e- VDF, and how these anisotropic e- VDFs in turn drive the Weibel instability and generate B fields. Our goal is to control the SRS and SKEENS processes that generate the KNL-EPW, control the anisotropy, and thus also control the dynamics of the resulting B fields, their influence on the transport coefficients and heat transport that results, their modification of SRS itself and the reinforced anisotropy driven loop gain.

(2) ***What was accomplished under these goals?***

We undertook a systematic study of anistropic e- VDF generation due to the existence of KNL-EPW and KEEN waves. This comes in three mathematical forms. In early evolution of such waves, the flattened e- VDF is expected. This is a Maxwellian in the axial direction modified in a velocity strip, called the active strip around the phase velocity of the driven KNL-EPW or KEEN wave where the slope is far flatter than that of a Maxwellian, including zero slope. At a later stage of evolution of SRS or SKEENS, a hot tail is expected or a double Maxwellian, a cold and a hot component. Any further SRS insuch a system would trigger a flattened strip in a double Maxwellian. These are the three main scenarios we have studied. By varying the phase velocity of the driven wave, the width of the active strip, the hot tail scaling with the square of that phase velocity, the density of hot electrons, and a possible drift between Maxwellian components, we constructed a series of anisotropic e- VDFs with a Maxwellian transverse VDF, monitoring the effective axial temperature (second velocity moment) vs the transverse temperature. We identified the extent to which shape of VDF affects Weibel vs mere temperature ratio between axial and transverse directions. We also included DLM VDFs, which are the super-Gaussian variety with an exponent between 2 and 5. The K distribution familiar from space plasma physics, and power law fat tails (typically with 1/v2 scaling). We also conducted simulations with SRS and Weibel acting together in collaboration with the Portuguese group who had started such studies independently. We found this out at APS DPP by accident! We decided to join forces and work together moving forward since November of 2018.

(3) How have the results been disseminated to communities of interest?

Besides numerous conferences and seminars, we have two papers published with our colleagues at Lisbon on this topic of SRS interacting with self-generated B fields and modified theory of Weibel instability showing the unexpected result that even when T_parallel = T_perpendicular, Weibel can still be unstable. A result that flies in the face of all that has been published about Weibel prior to our work.

Weibel instability beyond bi-Maxwellian anisotropy, T. Silva, B. Afeyan, and L. O. Silva, Phys. Rev. E **104**, 035201, 2021.

Anisotropic heating and magnetic field generation due to Raman scattering in laser-plasma interactions, T. Silva, et al. Phys. Rev. Research **2**, 023080, 2020.

(4) Inventions and new horizons opened-up by this work

The main thrust remaining to be accomplished by this pioneering work is to close the loop with STUD pulses. That is to control SRS's nonlinear evolution in the first place and to control Weibel as well in 2D geometry of single laser hot spots. If the goal is to generate the largest stable plasma waves we can in a high energy density plasma, and moreover, to generate a series of them like a picket fence, arranged transversally, so that they can function together as a distributed Bragg mirror for XUV or X-Ray radiation, it is necessary to be able to squeeze these nonlinear plasma waves into tight configurations. The idea is to create them via optical mixing of counterpropagating waves and the Raman process, to control their transverse localization via Weibel self-generated fields, and to squeeze them together by combinations of ES and EM interactions in an overall trapping field. The aim is to finally be able to create a cavity for XUV or X ray lasers using high energy density disposable nonlinear kinetic plasma structures.

We are still in early stages of this work. The control with STUD pulses is in progress. Adding Weibel to that picture is still work for future studies.