S8-6

# Control of the Weibel instability and structure formation by a strong magnetic field

# 強磁場によるワイベル不安定性の制御と構造形成


Toshihiro Taguchi, Thomas M. Antonsen, Jr. [1)] and Kunioki Mima [2)]

田口俊弘, T. M. Antonsen, Jr. [1)], 三間圀興[2)]

*Setsunan University, University of Maryland [1)], The Graduate School for the Creation of New Photonics Industries [2)]*

*摂南大学理工学部, メリーランド大学 [1)], 光創成大学院大学 [2)]*



The magnetized beam instability has been investigated in linear and nonlinear regimes. According to a linear analysis of the Vlasov equation in two dimensional wave number space, it is found that the transversely unstable mode (the Weibel instability) is suppressed under a strong magnetic field. The nonlinear analysis is performed using a hybrid simulation code. When a sufficiently strong magnetic field is applied along the beam direction, the instabilities are well suppressed and the electron stream becomes laminar. When the magnetic field strength is not large enough, however, electron flow stagnates and a shock-like structure is formed.


## 1. Introduction

When a ultra-intense laser is irradiated on a solid target, a large amount of relativistic electrons are generated at the critical surface and propagate into the overdense region. When such a large electron flow penetrates the plasma, a return electric current is induced in the background plasma in order to maintain current neutrality. Such a two-stream state is unstable to two kinds of perturbation. One is longitudinal, in which the wave number is parallel to the beam propagation direction. For this mode, an electrostatic field grows as well as a density modulation. The other mode is transverse, in which the wave number is perpendicular to the beam propagation direction. For this mode, known as the Weibel instability, current separation takes place and a quasi-static magnetic field grows. The magnetic field deflects the electrons broadening their spread in angles.

In order to suppress the broadening of the angular spread, a group at the Institute of Laser Engineering [1] proposed the application of a strong magnetic field. In their experiments, a large magnetic field, which is on order of 1 kT, has been successfully generated. When such a large magnetic field is applied along the beam propagation direction, the angular spread can be suppressed in two ways. One is by guiding the electrons along the magnetic field. The strong magnetic field restricts transverse motion, and the beam propagates along the magnetic field lines.

The other mechanism is suppression of the Weibel instability. The dispersion relation of a two-stream plasma is modified by a strong magnetic field, and unstable modes may be stabilized.

## 2. Linear dispersion relation of two stream instability in a strong magnetic field

In order to investigate the stability of the two-stream state in a strong magnetic field, we calculate the linear dispersion relation using the Vlasov theory. In the weak instability regime, kinetic effects are an important factor of the analysis [2].

Figures 1 show the growth rates in two-dimensional wave vector space including both longitudinal and transverse components. In these results, beam electron temperature (10 keV), background electron temperature (5 keV) and the density ratio between beam and background electron (1:9) are fixed. The drift velocity of the beam is set to be 0.9*c*, so the initial beam energy is 0.66MeV. Figures 1 (a), (b) and (c) are for different external magnetic field strengths, which are denoted by the normalized value $\omega_c/\omega_{pe}$ (cyclotron frequency/plasma frequency). In these figures, $k_x$ is the longitudinal wave number component and $k_y$ is the transverse wave number component.

As shown in the figures, the growth rate of the transverse modes depends on the strength of the external magnetic field, while the longitudinal modes are not affected as much by the field. When the external field is weak, the transverse mode grows as well as the longitudinal modes. As the strength of the field increases, the transverse modes are stabilized but the longitudinal modes are still unstable for the parameters considered.

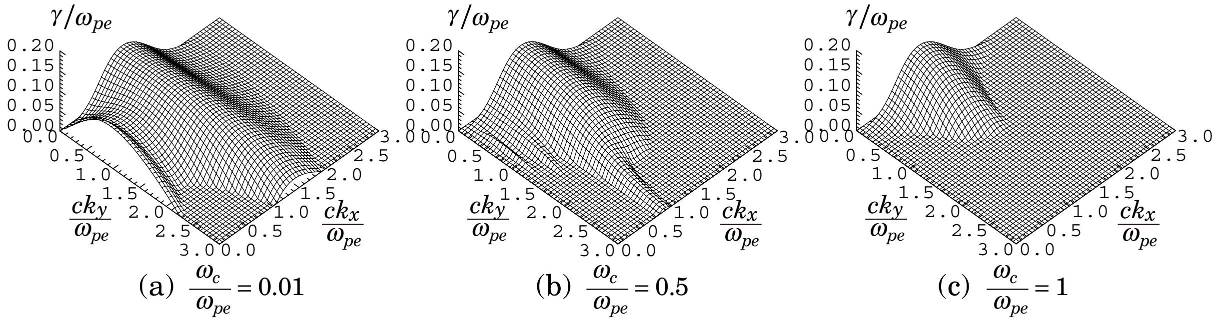


**Figure 1. Growth rate of magnetized two-stream instability**

## 2. Nonlinear hybrid simulation

In order to analyze the nonlinear evolution of the beam instability, we performed several runs of a hybrid simulation, which treats the background plasma as a fluid and the beam electrons as particles as in a PIC simulation. Typical results are shown in Figs. 2, which are two dimensional false color images displaying the beam electron density. Figures 2 (a), (b) and (c) correspond to the cases of the normalized magnetic field $\omega_c/\omega_{pe}$=0, 0.5 and 1, respectively.

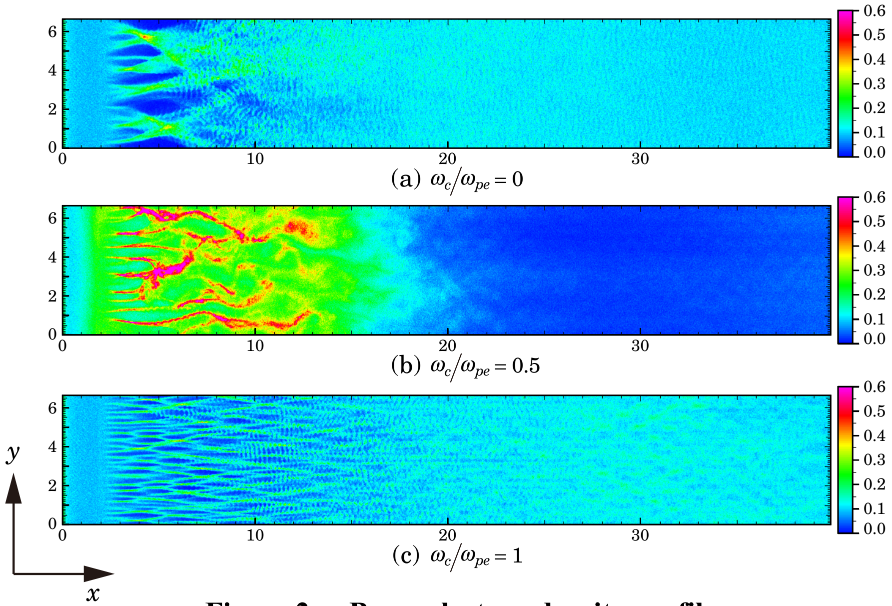


**Figure 2. Beam electron density profile**

The beam velocity is 0.99*c* and the initial beam temperature is 150keV. The left and right boundaries are open, while the top and the bottom boundaries are periodic. The beam electrons are continuously injected in the vicinity of the left boundary as their density is set to be 1/10 of the background plasma density. The length is scaled in μm and the background plasma density is taken to be $10^{22}$ 1/cm$^3$.

When there is no magnetic field (Fig.2(a)), the growth rate is large and the beam breaks up into filaments due to the Weibel instability. Each filament carries net electric current as the background electrons evacuate the filaments to maintain charge neutrality. The current filaments then attract each other due to the magnetic force and they tend to collide with each other. As a result, the current filaments change direction randomly, and this behavior results in the large angular spread of the electrons.

On the other hand, when the magnetic field is strong enough (Fig.2(c)), the beam flows quasi-laminarly, although fine filament structures still remain. One reason for the quasi-laminar flow is the guiding effect on the filament of the strong magnetic field. As a result, a sufficiently strong magnetic field has the capability to suppress the increase of the angular spread.

However, electron flow stagnates for a medium strength magnetic field. As shown in Fig.2(b) ($\omega_c/\omega_{pe}$ =0.5), the electrons accumulate near x=10μm and form a shock-like structure. Our analysis shows that this structure is sustained by an electromagnetic field. More details will be shown in the talk.

**References**

[1] S. Fujioka et al., Sci. Rep., **3**, 01170 (2013).

[2] B. Hao et al., Phys. Rev. E,**80**, 006402 (2009).