Collisional effects on the relativistic electromagnetic modes for beam-plasma interactions in the whole *k* space

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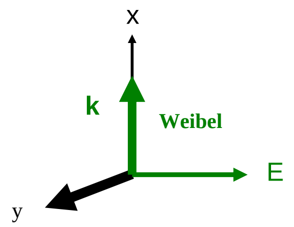
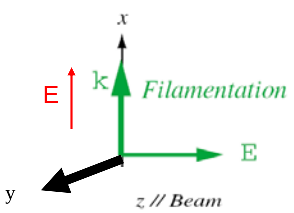
1. Introduction

- ***The*** transportation of a large flux of laser generated mildly relativistic electrons in a cold dense plasma is one of the most important problems for the fast ignition scenario (FIS) of laser inertial confinement fusion (Tabak *et al.*, POP **1** 1626 1994). When the beam propagates in the plasma, it will induce a return current to keep current neutralization of the beam-plasma system, resulting in the well known three instabilities: the two-stream (TS), current-filamentation (CF) and the two-stream filamentation (TSF) instabilities. These instabilities can affect the collimation of the beam and result in anomalous heating. However, the collisions between ambient particles are supposed to alter these instabilities in the FIS since the plasma density ranges from 10^{21}cm^{-3} to 10^{26}cm^{-3}. Thus it is very important to investigate whether the collisional effects can stabilize the instabilities in a dense cold plasma.

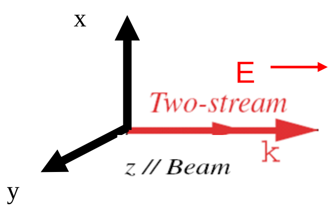
2.1. Polarizations of different modes



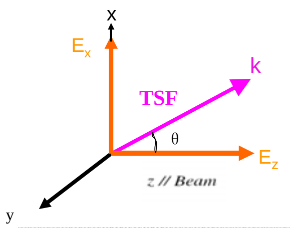
Weibel mode



Current-filamentation mode



two-stream mode



two-stream filamentation mode

2.2. Physical model of our investigation

- **Infinite unmagnetized uniform plasma (Hao *et al*., POP 15 082112 2008);**
- **Charge and current neutralization condition (Bell *et al*, PPCF 39 653 1997):**

$$n_b v_{db} + n_p v_{dp} = 0$$

- **Vlasov-Krook-Maxwell equations;**
- **Simplified relativistic drift Maxwellian distribution function (Watson *et al*, Phys. Fluids 3, 741 1960):**

$$f_{0\alpha}\left(\vec{P}_\alpha\right) = \frac{n_{0\alpha}}{2\pi m\gamma_\alpha^2\left(T_{t\alpha}T_{l\alpha}\right)^{1/2}} e^{-P_x^2/2m\gamma_\alpha T_{tb}} e^{-\left(P_z-P_{d\alpha}\right)^2/2m\gamma_\alpha^3 T_{lb}},$$

where $\gamma_\alpha, m, T_{t\alpha}, T_{l\alpha}, P_{d\alpha}$ are the Lorentz factor, electron mass, transverse thermal temperatrue, longitudinal temperatrue and drift momentum, correspondingly.

3. General Dispersion relations

Dispersion relations: $$\det\left|\frac{\omega^2}{c^2}\varepsilon_{ij} + k_i k_j - k^2\delta_{ij}\right| = 0,$$

where

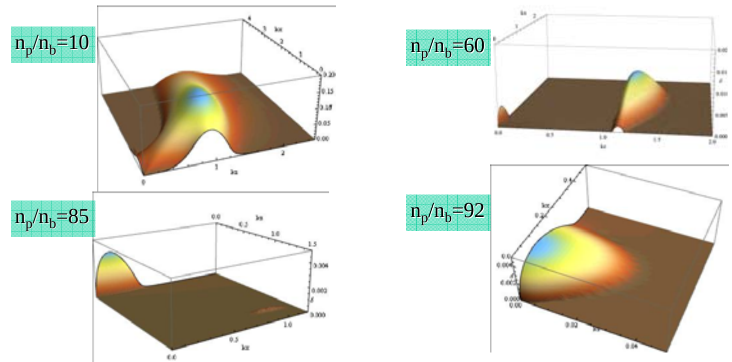
$$\varepsilon_{ij} = \delta_{ij} + \sum_\alpha \frac{\omega_{p\alpha}^2}{n_\alpha\omega^2}\int d^3\vec{p}_\alpha \frac{\left[m_\alpha\gamma_\alpha^*\omega - \vec{k}\cdot\vec{p}_\alpha\right]\delta_{lj} + k_l p_{\alpha j}}{\gamma_\alpha^*\left[m_\alpha\gamma_\alpha^*\left(\omega + i\nu_\alpha\right) - \vec{k}\cdot\vec{p}_\alpha\right]} p_{\alpha i}\frac{\partial f_\alpha\left(\vec{p}_\alpha\right)}{\partial p_{\alpha l}}.$$

For two-stream filamentation mode

$$\left(\omega^2\varepsilon_{zz} - k_x^2c^2\right)\left(\omega^2\varepsilon_{xx} - k_z^2c^2\right) = \left(\omega^2\varepsilon_{xz} - k_xk_zc^2\right)\left(\omega^2\varepsilon_{zx} - k_xk_zc^2\right).$$

4.1. Collisional effects: momentum isotropic case

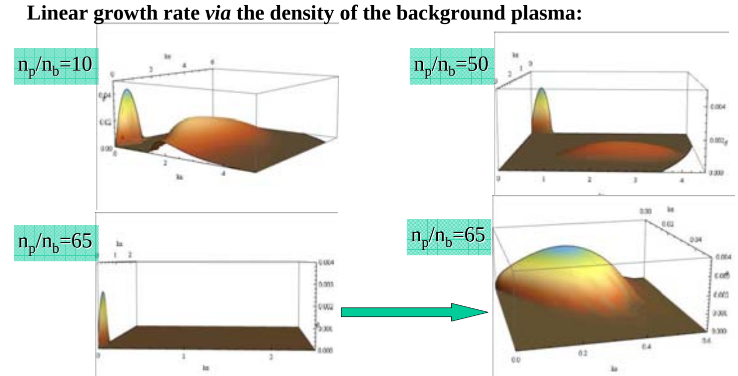
Linear growth rate *via* the density of the background plasma:



The other parameters: T_{tb}=30Kev, E_b=1Mev, n_b=10^{21} cm^{-3}, T_{lp}=T_{tp} =250ev.

4.2. Collisional effects: temperature isotropic case

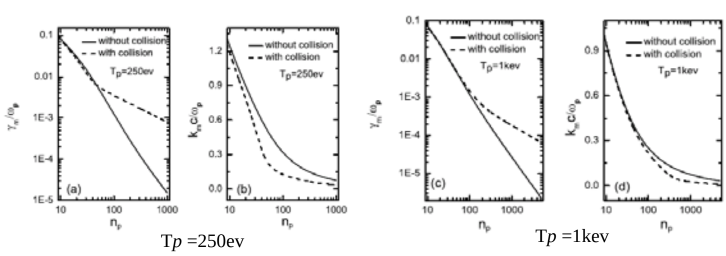
Linear growth rate *via* the density of the background plasma:



The other parameters are similar except that, T_{lp}=T_{tp} =1kev.

4.3. Collisional effects on the CF mode

The maximum growth rate and the wave number *via* the density of the ambient plasma, correspondingly (Hao *et al*., PRE **79** 046409 2009) **.**



The other parameters: T_{tb}=30Kev, E_b=1Mev, n_b=10^{21} cm^{-3}.

5. Conclusions

1. The TSF mode can be approximately divided into electrostatic part and the electromagnetic part. The former is attenuated but the later is enhanced by collisional effects. In the FIS, the electrostatic part is fully stabilized when the plasma reaches solid density.
2. The TS mode is attenuated by collision and finally stabilized when the plasma reaches solid density.
3. The CF mode is enhanced by collision and becomes the dominant mode. In the dense region the CF mode can be enhanced up to one order of magnitude. Meanwhile, the most unstable CF mode is shifted to the long wavelength region, resulting in larger filaments.
4. Since the growth rate of the CF mode is comparable to the collision frequency between the beam electron and the plasma, it suggests that the beam potentially will break into small filaments and anomalous heating may take place even in the dense core (Hao *et al*., PRE **79** 046409 2009).

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