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by

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and Ronald C. Davidson

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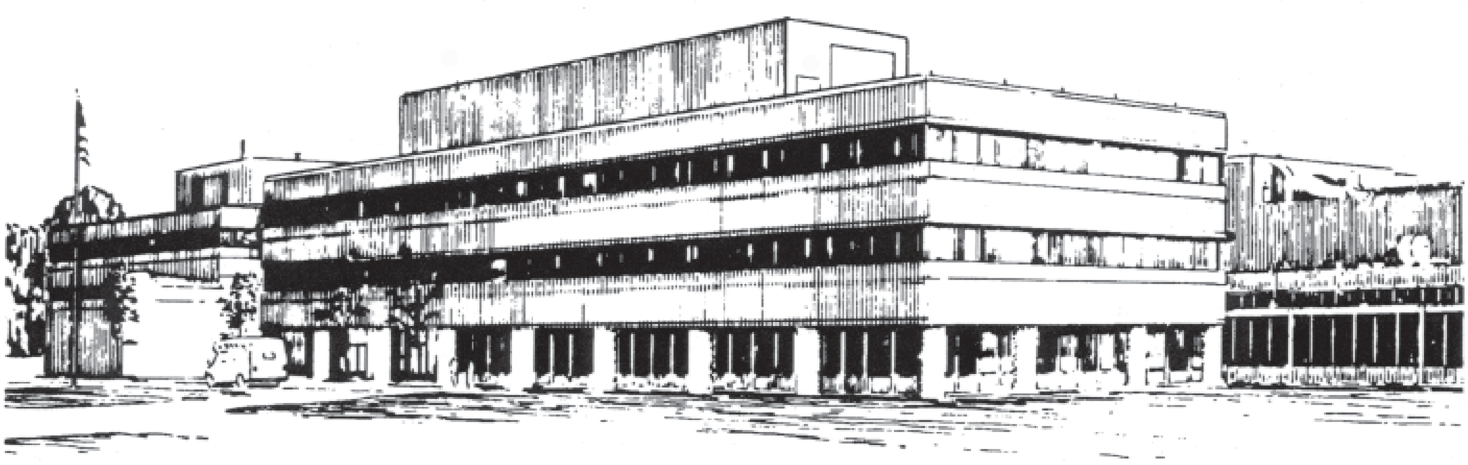

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Images of Complex Interactions of an Intense Ion Beam with Plasma Electrons

Igor D. Kaganovich, Edward Startsev, and Ronald C. Davidson

***Abstract* - Ion beam propagation in a background plasma is an important scientific issue for many practical applications. The process of ion beam charge and current neutralization is complex because plasma electrons move in strong electric and magnetic fields of the beam. Computer simulation images of plasma interaction with an intense ion beam pulse are presented.**

Plasma neutralization of an intense ion beam pulse is of interest for many applications, including plasma lenses, heavy ion fusion, high energy physics, etc. Comprehensive analytical, numerical and experimental studies are underway to investigate the complex interaction of a fast ion beam with a background plasma [1-5]. The positively charged ion beam attracts plasma electrons, and as a result, the plasma electrons have a tendency to neutralize the beam charge and current. An analytical electron fluid model has been developed to describe the plasma response to a propagating non-relativistic ion beam [1]. The model predicts very good charge neutralization during quasi-steady-state propagation, provided the beam pulse duration is much longer than the electron plasma period. In the opposite limit, the beam pulse excites large-amplitude plasma waves [3]. If the beam density is larger than plasma background density, the plasma waves break. Theoretical predictions are compared with the results of calculations utilizing a particle-in-cell (PIC) code. A suite of particle-in-cell codes has been developed to study the propagation of an ion beam pulse through the background plasma. The cold electron fluid results agree well with the PIC simulations for ion beam propagation through a background plasma. The reduced fluid description can provide an important benchmark for numerical codes and yield scaling relations for different beam and plasma parameters [3].

The movies produced by visualization of numerical simulation data show complex collective phenomena during beam entry and exit from the plasma [3,4] and during beam propagation along a solenoidal magnetic field [5]. Note that movies of these results are available online [3,4].

Figure 1 shows the electron density perturbation during beam entry into the uniform background plasma in the presence of a solenoidal magnetic field along the beam propagation. Without solenoidal magnetic field the wake in the electron density is produced by the ion beam head and lags the ion beam density [1,4,7]. A presence of the external solenoidal magnetic field leads to the electron density perturbations propagation ahead of the beam. This makes the moving window computational approach applied for simulations inadequate after certain time when perturbation reach the front boundary (see Fig.1d), as it assumes unperturbed plasma ahead of the beam. The complete study of this phenomena is still in progress and shall be reported elsewhere.

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Figure captions

Fig.1 Neutralization of an ion beam pulse during its propagation through a cold, uniform, background plasma in planar geometry with an external uniform magnetic field. The beam propagates in the y-direction. The beam velocity is $V_b=0.5c$, the beam density is $n_b=0.5n_p$, where n_p is the background density, and the ion beam charge state is $Z_b=1$. The beam pulse dimensions are: the beam radius is equal to 1.5 of the skin depth (c/ω_{ep}) and half length is $7.5c/\omega_{ep}$. Here, ω_{ep} is the electron plasma frequency, c is the speed of light in vacuum. The external magnetic field corresponds to the electron cyclotron frequency $\omega_{ec}=5\omega_{ep}$. Shown in the figure are color plots of the normalized density (n/n_p) obtained in particle-in-cell simulations in ($\omega_{ep}x/c$, $\omega_{ep}y/c$) space, (a) the beam pulse density (b)-(d) the electron density after beam enters plasma at times: (b) $132/\omega_{ep}$, (c) $172/\omega_{ep}$, and (d) $200/\omega_{ep}$. Figure 1(e) shows the photo of the trilobite [6].

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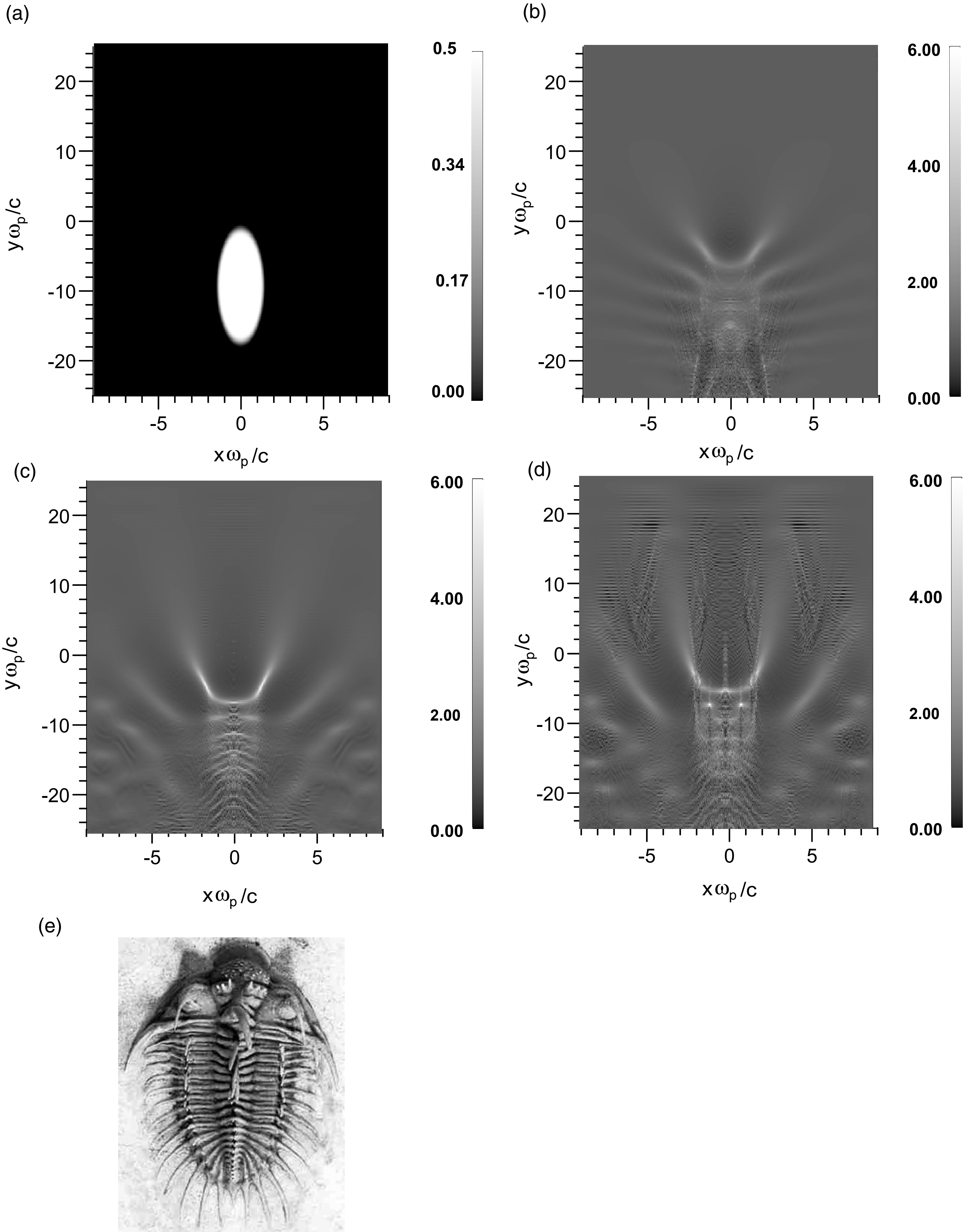

(a)
20
10
0
-10
-20
yωp/c
-5
0
5
xωp/c
0.5
0.34
0.17
0.00
(b)
20
10
0
-10
-20
yωp/c
-5
0
5
xωp/c
6.00
4.00
2.00
0.00
(c)
20
10
0
-10
-20
yωp/c
-5
0
5
xωp/c
6.00
4.00
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(d)
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yωp/c
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(e)

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