A VLASOV CODE SIMULATION OF THE AMPLIFICATION OF SEED PULSES BY BRILLOUIN BACKSCATTERING IN PLASMAS

M. Shoucri[1], J-P. Matte[2], F. Vidal[2]

1-Institut de recherche d'Hydro-Québec (IREQ), Varennes, Québec, Canada, J3X-1S1

2-INRS-Energie, Matériaux et Télécommunications, Université du Québec, Varennes, Québec, Canada J3X-1S2

We use an Eulerian Vlasov code to study the problem of the amplification of seed pulses by Brillouin backscattering in the strong-coupling regime. In this process, there is an energy transfer, mediated by a resonant ion wave, from a long, high energy pump electromagnetic wave, to an initially counter-propagating ultra-short seed pulse. The code solves the one-dimensional Vlasov-Maxwell set of equations, and has been previously used to study the problem of the plasma-based backward Raman amplification of seed pulses in underdense plasmas [1], and the problem of the Brillouin backscattering amplification of seed pulses in overdense plasma in the strong coupling regime [2]. In the example we present here, we use the parameters which have been used in [2], but we increase the plasma amplifier length from the value of $1000c/\omega_{pe}$ to $1600c/\omega_{pe}$, which is the length used in the PIC simulations reported in [3], where essentially the same parameters were used for the same problem. For such a length of interaction, in the PIC simulations [3] the pump becomes depleted due to scattering from numerical noise. Here, the noiseless Vlasov code allows to follow the amplification of the seed pulses by Brillouin backscattering until the formation of steep gradients of the amplified pulses. We present simulation results in the plateau of a high density ($n/n_{cr}=0.3$) uniform plasma. This corresponds to a ratio of the pump frequency to the plasma frequency $\omega_{0p}/\omega_{pe}=1.826$. The normalized vector potential or quiver momentum a_0 verify $a_0^2 = I\lambda_0^2/1.368\text{x}10^{18}$, where I is the laser intensity in W/cm^2 and λ_0 the wavelength in microns. For the chosen pump beam intensity $I_p=10^{16}$ W/cm^2, and wavelength $\lambda_{0p}=1.0\mu m$, the pump normalized vector potential is $a_{0p}=0.0855$, assumed constant during the simulation. The normalized time ω_{pe}^{-1} and length $c\omega_{pe}^{-1}$ units correspond to 0.97 fs and 0.29 μm, respectively. Hydrogen plasma is assumed, with electron and ion temperatures T_e=500eV and T_i=50eV. The Debye length is $\lambda_D=0.0313$. With N=50000 grid points in space, we have for the mesh-size $\Delta x = 0.032$, which is of the order of the Debye length. We use for the seed pulse an intensity of $I_s = 10^{15}\,\mathrm{W/cm^2}$ at the same wavelength as the pump pulse, which leads to $a_{0s} = 0.027$. The seed frequency ω_{0s} is equal to the pump frequency $\omega_{0s} = \omega_{0p} = \omega_0$. From the dispersion relation $\omega_{0p}^2 = 1 + k_{0p}^2$ we have for the corresponding wavenumber $k_{0p} = 1.528$. In a similar simulation presented in [4], the length of the initially uniform plasma system was restricted to $273c/\omega_{pe}$ because of the noise level in the PIC simulation. In the simulation results presented here, the length is $L_p = 1600c/\omega_{pe}$, about 6 times the length used in [4].

The forward propagating linearly polarized pump laser beam penetrates the plasma at *x*=0, with a value $E^+ = 2E_{0p}\cos(\omega_0 t)$. Figure (1) show the time evolution of the pump (full curve), and of the seed pulse (broken curve). In the right of Fig.(1a), at *t*=1600, the precursor of the pump, which propagates at the speed of light, has just reached the boundary at *x*=1600, while the seed pulse has just penetrated (see the small bump at the right, in the Fig.(1a)). At time *t*=1600-2τ_s ,where $\tau_s = 100$ is the duration of the seed pulse, the backward seed wave $E^- = -2E_{0s}P_r(t)\cos(\omega_0\tau)$ is injected at the right boundary at *x*=1600, where $\tau = t - 1400$. The seed pulse has a temporal shape: $P_r(t) = \sin^2(\pi\tau/2\tau_s)$, 1400<*t*<1600 and zero otherwise. In our normalized units $E_{0p,s} = \omega_0 a_{0p,s}$. We present in Figs.(1b-1d) a sequence showing the growth of the seed pulse which is propagating towards the left (broken curve). Behind the seed peak, the pump (full curve) is slowly depleted, while in front of the growing seed pulse, the incident pump has a constant amplitude. The simulation is stopped at *t*=2816 in Fig.(1d), due to the formation of a very steep gradient behind the seed front, which is followed by a numerical instability. At that time, the seed amplitude reached a factor about 6 times higher than that of the pump, or about 20 times the initial seed peak amplitude. So we have been able to push the calculations a little bit further in time compared to the results presented in [2]. Comparing Fig.(1b) and Fig.(1d), we see that the front edge of the seed pulse has compressed, and detached from the tail. Figs.(2) and (3) present the electron density and ion density profiles at three different times, while Fig.(4) presents the longitudinal electric field. Figs.(5) and (6) present the phase-space contour plots at different positions for the electrons and the ions. More details on the phase-space plots can be found in [2].

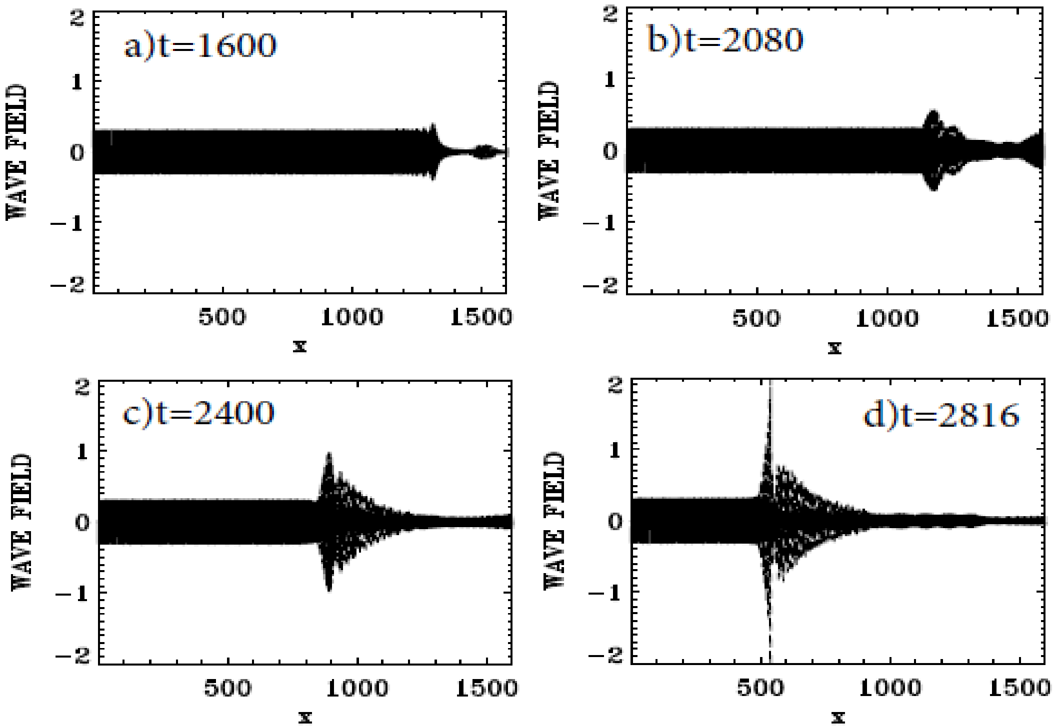

Figure 1. Incident pump wave E^+ (full curve) and backward seed wave E^- at different times

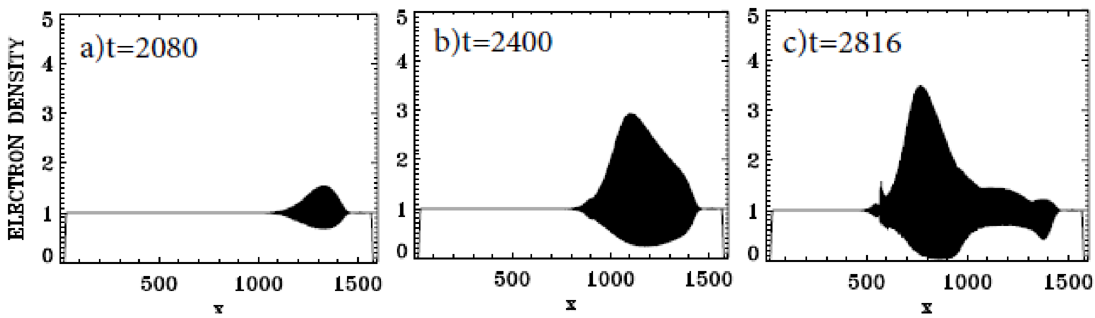

Figure 2. Electron density profiles at different times.

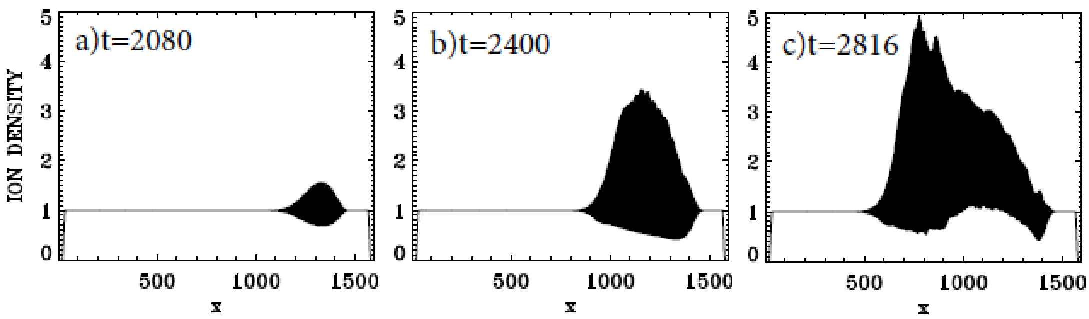

Figure3. Ion density profiles at different times

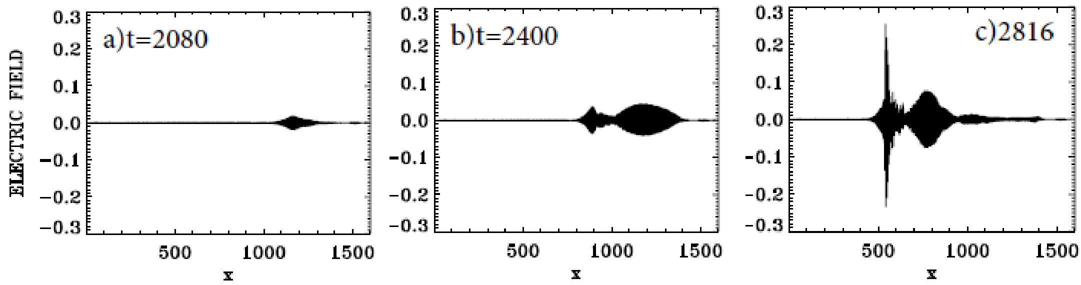

Figure 4. Longitudinal electric field at different times.

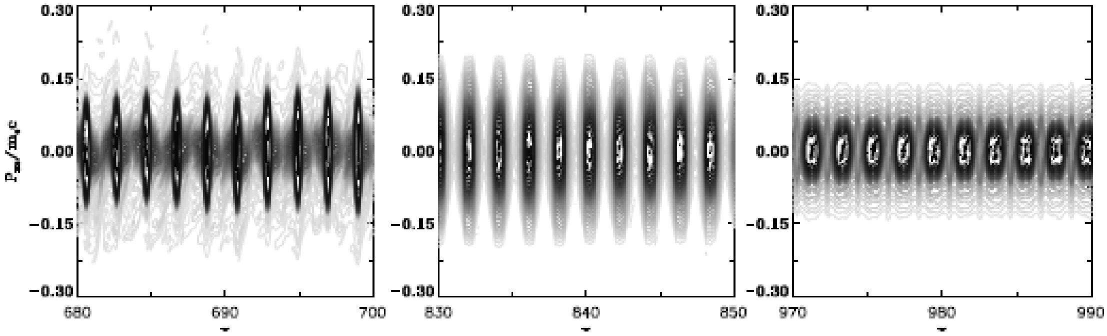

Figure 5. Phase-space contour plots of the electron distribution function at *t*=2816.

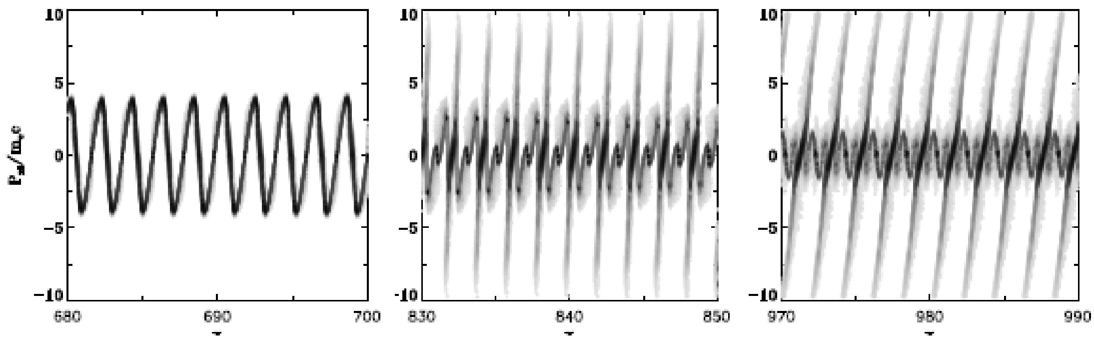

Figure 6. Phase-space contour plots of the ion distribution function at *t*=2816.

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References

[1] M. Shoucri, J.-P. Matte, F. Vidal Proc. 41rst EPS Conf., Berlin (2014)

[2] M. Shoucri, J.-P. Matte, F. Vidal Phys. Plasmas 22, 053101 (2015),

[3] K.A. Humphrey, R.M.G.M. Trines, F. Fiuza, D.C. Speirs et al. , Phys. Plasmas 20, 102114, (2013)

[4] A. Andreev, C. Riconda, V. Tichonchuk, S. Weber Phys. Plasmas 13, 053110 (2006)