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Ion soliton observation with laser induced fluorescence.

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1 Introduction

Many theoretical and experimental studies of solitons in plasma have been performed [1, 2, 3, 4] and most of the properties such as the relation between the amplitude, the velocity and the width, for soliton or soliton-dust interaction, have been obtained. The agreement between experiment and theoretical model is not always good [5, 6, 7]. The experimental observations typically involve Langmuir probes. However, the ion acoustic soliton propagation can be observed by laser induced fluorescence (LIF) in double plasma device. This direct observation of ion perturbation with LIF points out the importance of the optical pumping effect [8] in the measurement of fast velocity propagation of ion phenomena like solitons are. With the LIF we discovered that a train of soliton propagates easier in the device if a weak backward ion flux plasma, having a drift velocity in the range of 200 m/s is present; as faster the ion flux is, as close to the grid the solitons separation occurs; the precursors ions is in fact a collective phenomenon.

2 Pumping effect during soliton propagation

Experiments were performed using a multipolar unmagnetized, collisionless, ArII double plasma device described elsewhere [9].
When ion acoustic solitons are excited, the recorded fluorescence signal shows a huge amplitude increase of about 400%. This is shown in Figure 1 which represents the superposed fluorescence signal observed at 9 cm from the grid and normalized to the maximum amplitude of steady state ion velocity distribution function. One can easily see a global velocity shift due to the electric field associated with soliton propagation. It also can be observed that the ion metastable thermal velocity is not changed. Therefore the velocity integration of this signal, which can be thought as the ion metastable density perturbation, is increased in the same proportion and is in complete disagreement with the electronic density perturbation of roughly 12% obtained with a one sided Langmuir probe biased at $+9V$. The signal increase is due to phenomenon exploited in the non linear optical tagging diagnostic [8].
This large discrepancy comes from the optical pumping effect. During soliton propagation the electric field produced a rapid shift of the ion velocity. For a laser frequency Doppler tuned to a given velocity class of metastable ions, this shift brings new metastables in to resonance with the laser causing the fluorescence signal to increase. However, because optical pumping does not depend on absolute ion velocity, the first moment $V_i(t)$ derives from the distribution in Figure 1 is negligibly affected by optical pumping. This allows an analysis based on the continuity equation to determine the actual ion density variations [10].
From the continuity equation in the ionic acoustic velocity reference frame in a stationary state:

$$n_i' - \frac{n_i' V_i + n_i V_i'}{cs} = 0 \tag{1}$$

the density perturbation can then be computed, $\delta n_i = \frac{n_i}{n0} = exp(\frac{-V_i'}{cs - V_i})$, where $'$ denotes the derivative respectively to $\xi = t - \frac{x}{c_s}$, c_s the ionic acoustic velocity which can be determined from the experimental dispersion relation measured by interferometry. In the experimental conditions : $c_s = 2.1\ km/s$.

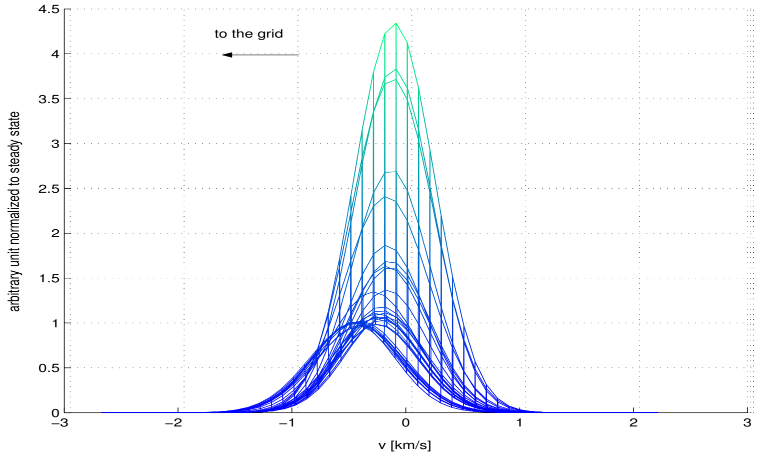

Figure 1: 2D representation of the fluorescence signal, f at 9 cm from the grid.

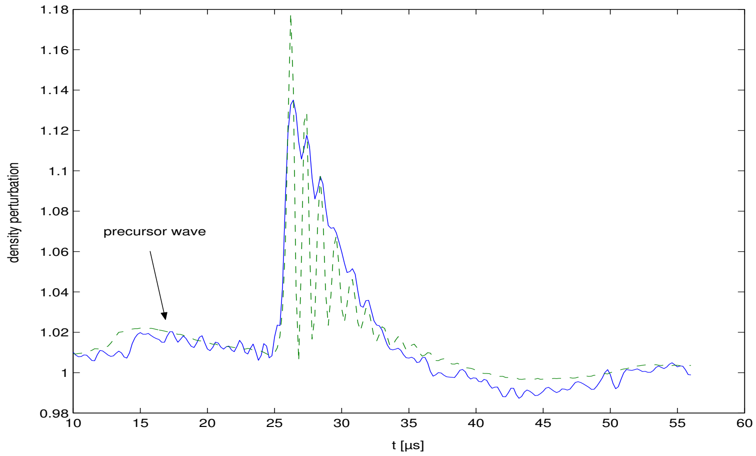

Figure 2: Ionic (solid line, LIF) and electronic (dashed line, Langmuir probe) density perturbation in the Honzawa configuration at 9 cm.

From the Navier Stokes equation:

$$V_i' - \frac{V_i V_i'}{cs} = \frac{e}{M} E \tag{2}$$

the electric field E can be deduced.
To have a good signal to noise ratio we use the laser induced fluorescence with a finite spatial resolution, 1 mm for this experiment in the direction of propagation; with a time resolution not limited by the natural life time of the upper state (10 ns) but by the photon count rate, a window of 200 ns was used; and the recorded data are also smoothed. Therefore the observed fluorescence signal is in fact convoluted by an apparatus function which limits the temporal resolution. The sample spacing time corresponding to the Langmuir probe (40 ns) signal is also smaller than the one used for the LIF signal (200 ns).
We have used the same configuration as Honzawa [4] but with only one plasma lightened in the target chamber. Figure 2 compares δn_i obtained from the fluid model and δn_e as given by the Langmuir probe, at 9 cm from the grid.
It is easier to see the separation of the trailing oscillations with fluorescence and agreement between LIF and Langmuir probe is convincing. A better signal to noise ratio in the Honzawa configuration is the only difference noticed between the results obtained with the two configurations. In fact, as we observe a precursor in the fluid velocity with no ballistic ions in the distributions functions present, these precursors ions are an Argon ion precursor wave independent on the ion drift and not impurity

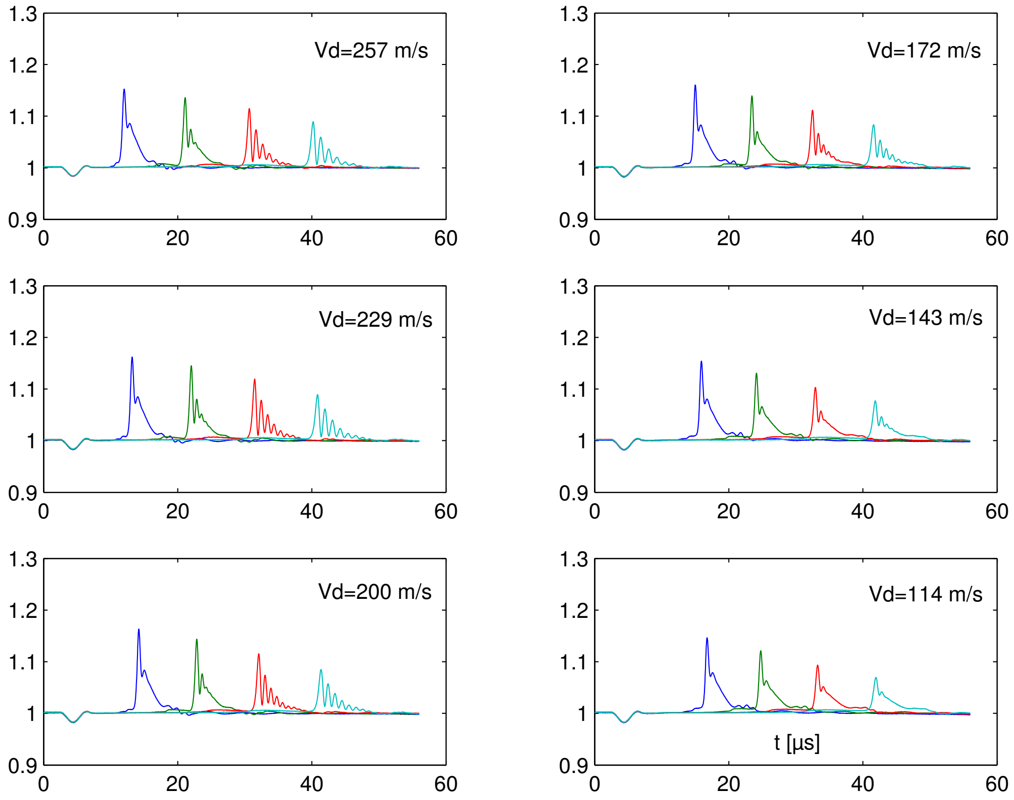

Figure 3: Electronic density perturbation from 2 cm to 8 cm from the grid with a step of 2 cm for 6 different velocity drifts. The time unit is μs.

as it has been thought [11].
The qualitative and quantitative agreement between ionic and electronic observation demonstrate that the fluid velocity, calculated from the first moment of the LIF distribution function, is not strongly affected by optical pumping. These are the first LIF observation of soliton propagation and its direct comparison to a Langmuir probe. The LIF data indicates that to obtain a propagation of a train of solitons in either configuration, the target plasma must drift $V_d > 200\ m/s$ in the backward direction.

3 Inverse ion flux

Since the agreement between LIF and Langmuir probe is good, we will present now experiment done only with Langmuir probe, in the double plasma configuration (in simple plasma configuration the results are equivalent), the plasma drift being measured by LIF. Figure 3 presents the plasma electronic behavior from 2 cm to 9 cm from the grid for different plasma drift velocity $|V_d|$. One can see the propagation of a train of solitons for a backward drift velocity of $V_d = 257\ m/s$, for $V_d = 114\ m/s$ the train of solitons is no longer observable. We find that as $|V_d|$ increases soliton separation begins closer to the grid. However for $|V_d|$ below a value depending of the density, no train of solitons propagates. In the case of no soliton separation, ions in the neighbourhood of c_s but bellow it are present, Figure 4 shows the perturbated ion phase space in this case. Reflected or deflected ions are able to interact with the potential structure and determine the existence of a soliton. Nevertheless that these ions have velocities below c_s is not understood for the moment.

4 Conclusion

The first comparison between the electronic perturbation, measured by a Langmuir probe, and the ionic perturbation, given by LIF measurement, when solitons propagate through a plasma shows the

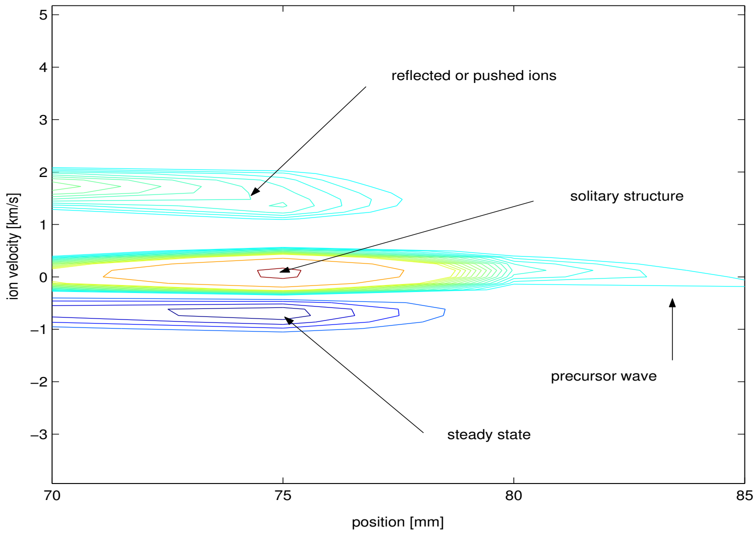

Figure 4: Perturbed ion phase space. One can see the solitary structure (not a soliton structure), the precursor wave and the background ions.

importance of the pumping effect, depending on the intensity of the laser excitation and of collision frequencies, on the data recorded by laser induced fluorescence in a situation were fast ion velocity shift occurs. Because the measurement of the fluid velocity is, in a first approximation, not affected by the optical pumping, the data can be corrected by using a classical fluid model.
The LIF diagnostic lets us show that a necessary plasma conditions for soliton propagation is to have a global velocity drift of the target plasma of about $V_d \approx 200m/s$ in the direction opposite to the soliton propagation. Below this velocity, no soliton can be observed and as $\mid V_d \mid$ increases the distance between the grid and soliton separation decreases. It may be that this flux allows the solitary structure to reflect or deflect ions near the resonant velocity c_s. The precursors, which can be now observed by LIF, are definitively an Argon ion precursor wave and not impurity as has been previously suggested.

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