

Particle in cell simulation of a Tonks-Langmuir model

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Polytropic constants are frequently used in plasma analysis. However, under realistic conditions, e.g. in the presence of different atomic processes, the plasma transport can not be properly described by using well known “global” polytropic law $Tn^{1-\gamma} = \text{constant}$ (where γ is the the global polytropic coefficient, T is the temperature and n is the density of the gass). A typical example is the plasma edge in fusion devices [1]. Recently ([2] - [6]) we propose a new approach, namely we consider a “local” or “pseudo-polytropic” coefficient $\gamma(n, T) = 1 + \frac{n}{T} \frac{dT}{dn}$ which depends on local coordinate rather than to be a constant.

Kuhn et all [6] performed a detailed analysys on pseudo-polytropic coefficient based on general analytical model of Riemann [7] which covers both collision-free Tonks-Langmuir [8] and collision-dominated by charge-exchange Riemann models of plasmas. In both cases the ions are assumed to be born by unspecified ionization mechanisms as “cold” (i.e., with zero innitial velocity) but the resulting ion velocity distributions are very different in shape. Nevertheless the quantities averaged over velocity space turn out to be very similar to each other independently on velocity distribution shape details. The pseudo-polytropic coefficient has attained very high negative values in the plasma with its maximum positive value (of the order of $\gamma \approx 7$) appearing at the plasma-sheath boundary (and relaxing to $\gamma = 3$ due to acceleration in the sheath). However, it can be argued that for the increased ion temperatures the pseudo-polytropic coefficient at the plasma sheath boundary in both models should tend to $\gamma = 1$. In addition the PIC simulations under complex collisional plasmas ([3] - [5]) indicate that these arguments indeed might be valid.

The aim of this work is to demonstrate the results of kinetic simulations of Tonks-Langmuir model via Particle-in-Cell code BIT1 [9], (developed on the basis of the XPDP1 code [10]). The central quantity of interest is the local ion velocity distribution function and its dependence on local potential profile. Once we know the distribution function we are able to calculate all its local velocity-averaged, i.e., hydrodynamic quantities and look for some generalizations as proposed in [6]. In this paper we deal only with colision-free cases with

Tonks-Langmuir cold-ion source in order to reproduce the analytical results for this rather transparent physical model by means of high resolution PIC simulations.

In the Tonks-Langmuir one-dimensional model a plasma source, which produces cold ions and Maxwellian distributed electrons is distributed between two infinite floating electrodes. In our simulations we reconstruct this model by assuming that plasma is produced via electron impact ionization collisions with neutrals. The neutrals are assumed to be cold with the uniform density profile. Both, the electron and the ion motions are fully resolved in space and in time. In order to keep electron distribution near to Maxwellian the ionization energy is assumed to be zero and Maxwellizing pseudo-collisions between the electrons is switched on [9]. The results of simulation are compared with the analytical model in Fig 1.

It can be seen that there is a fair *qualitative* agreement between the theoretical calculation (which are exact) and simulation results. Namely, both results show that γ_i is a local parameter which can take arbitrary negative and positive values, depending on local coordinate. However, *quantitative* agreement is apparently bad. This is because a simulation is inherently like a real experiment in which some of accompanying effects are extremely difficult to damp. Basically there can be two sources of such influences, namely numerical and physical ones, the last being the main subject of our present analysis. In order to exclude numerical oscillations we performed runs with different resolutions, showing independence of results. The highest resolution was 600 particles per cell and 3 spatial grids per Debye length. In Fig 2 we see the ion velocity distribution and the spectrum of the oscillations emerging from the plasma simulations. The amplitude of the oscillations is several percent of the electron temperature. These oscillations are probably physical ones and correspond to ion and electron plasma oscillations, ion sound waves and physical noise. Due to this oscillations each new-born charged particle is imposed not only to the static electric field (which accelerates ions) but also to a random fluctuating electric field, which can either "trap" or accelerate some ions and electrons. Therefore these oscillations are concerned to be a source of smoothing the ion distribution function in the whole spectrum of velocities and being responsible for the accumulation of low energy ions near the zero velocity (see Fig. 2a). It is a rather difficult task how to remove mentioned effects and to reproduce analytical results exactly. We intend to prepare soon the BIT1 code for dealing with these problems much more efficiently.

Finally, we have to point out that with warm ions we have much less problems to reproduce the results of the velocity distribution, e.g. according to Bisell and Johnson model [11]. A systematic investigation for finite ion temperature is already in progress.

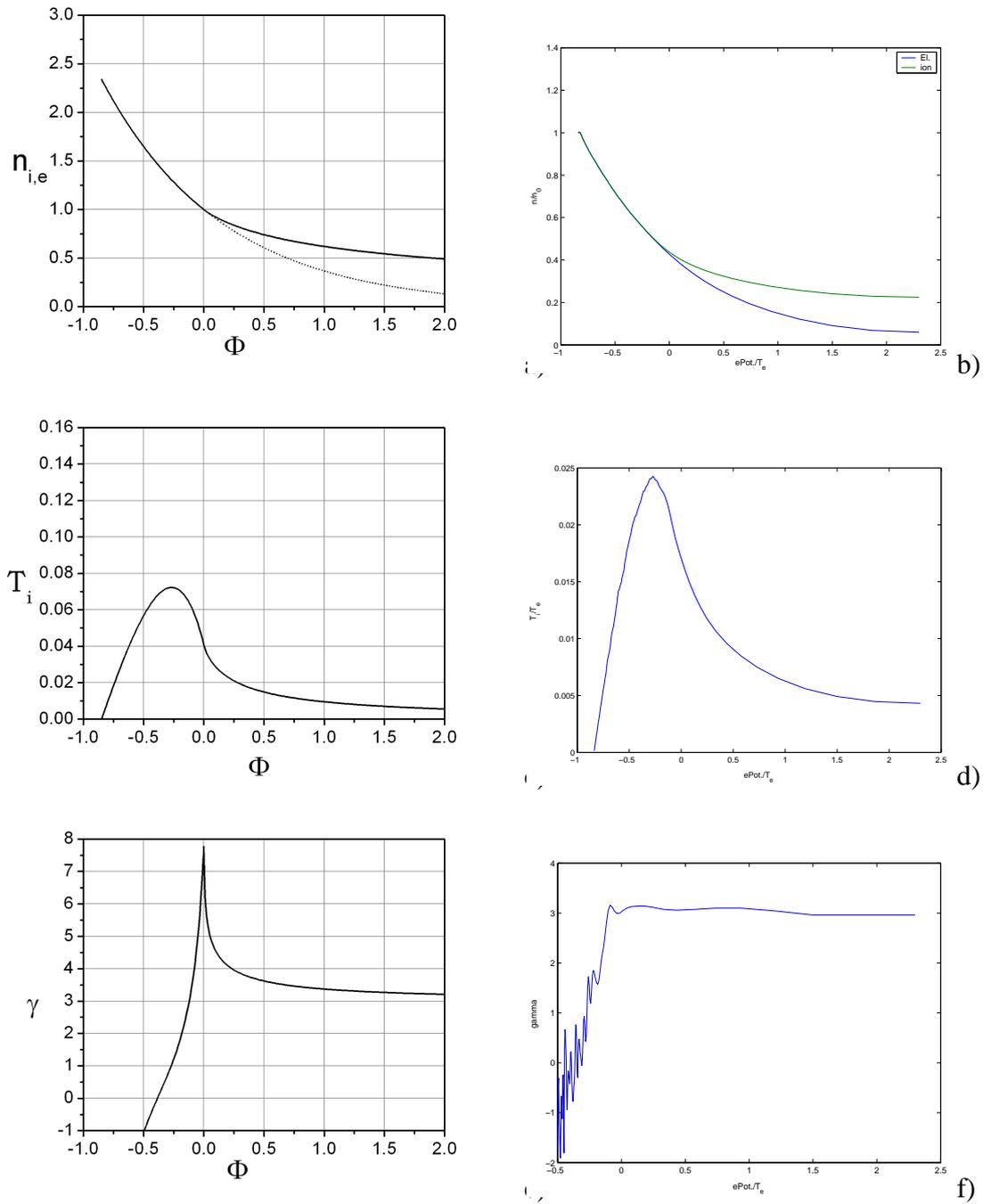


Figure 1: Ion and electron densities (a, b) ion temperature (c, d) and pseudo-polytropic coefficient (e, f) in the presheath and the sheath region for pure theoretical (left hand side column) and PIC simulation (right-hand side column) cases

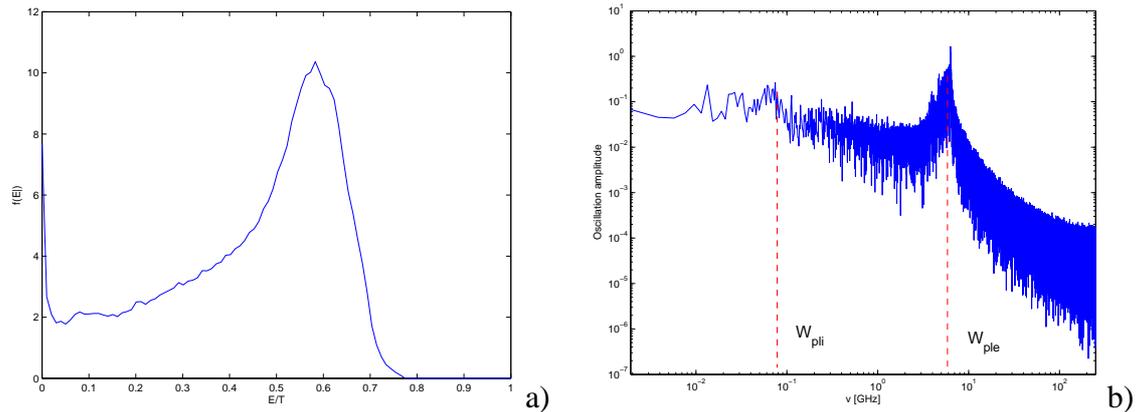


Figure 2: Ion distribution function at the sheath entrance and potential oscillation spectrum

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