

A ionization instability in weakly ionized unmagnetized plasmas with negatively charged dust grains

L. Conde, C. Ferro Fontán and N. Franco

Dpto. Física Aplicada, E.T.S.I Aeronáuticos

Universidad Politécnica de Madrid

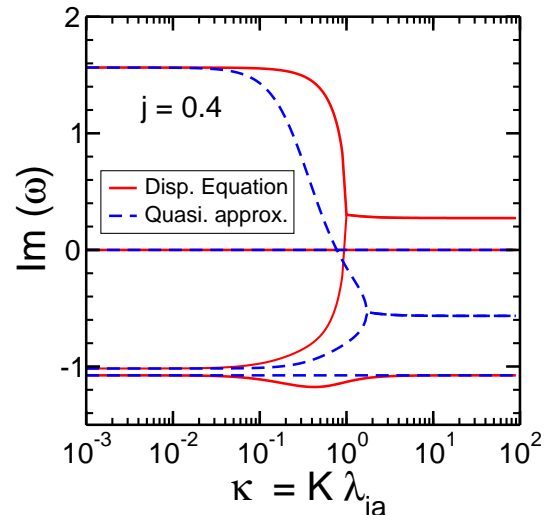
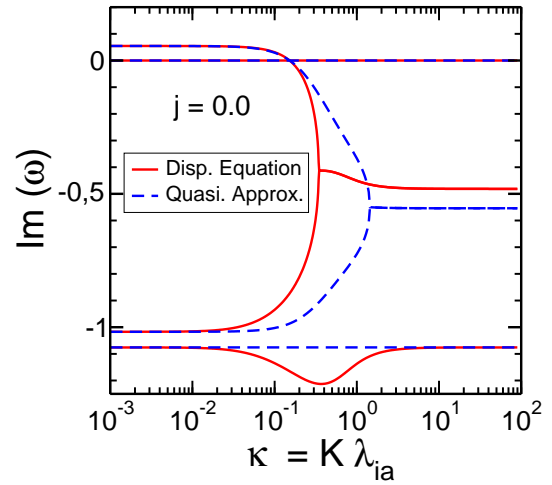
28040 Madrid, Spain

The investigation of ionization instabilities in weakly ionized dusty plasmas using multifluid formulations is a subject current interest [1, 2, 4]. Small carbon particles in fusion devices have been also detected at the edge of tokamaks by Thomson scattering where additionally high energy electrons are present [3]. In dust free plasmas the injection of a suprathermal electron current density $J_{eb} = -e\Gamma_{eb}(E_b)$ with energy over the ionization threshold $E_I < E_b$ of the neutral gas may unstabilize the equilibrium state. The charge production by thermal $v_I n_{eo}$ electron population and by energized electrons $G_o = v_I n_{eo} + n_a \sigma_{eb} \Gamma_{eb}$ is balanced by loss rate $R_o = v_L n_{io}$ [5].

$$n_a \Gamma_{eb}(E_b) \sigma_{Ib} + v_I n_{eo} = v_L n_{io} \quad (1)$$

In present model the equations are essentially those of Ref. [4] with an additional charge source term for the high energy electron beam. The electron impact ionization cross section is approximated by $\sigma_I(E) \cong \sigma_{eb} + C(E - E_b)$ and the cross section σ_{ia} for elastic collisions between ions and neutrals is considered as constant, as well as the corresponding frequency $\nu_{ia} = \sigma_{ia} n_{io}$.

The plasma potential fluctuations are related with charged particle densities by means of the more involved Poisson equation instead of the



currently used quasineutral approximation.

The dimensionless multifluid equations [2a-f] are obtained using the characteristic time $\tau = 1/\nu_{ia}$ and length $s = z/\lambda_{ia}$ scales for elastic collisions between ions and neutral atoms. The electric potential ϕ is scaled as $\phi = e\varphi/K_B T_e$ and the charged particle densities are normalized with respect to their equilibrium values $N_\alpha = n_\alpha/n_{\alpha o}$ ($\alpha = i, e, d$). Finally, the ion and dust speeds are scaled with respect to ion sound speed $V_i = u_i/c_{is}$, $V_d = u_d/c_{is}$ in order to preserve the same time scale and is introduced the ratio $\rho = \lambda_D/\lambda_{ia}$.

Thus, in these scaled transport equations the relevance of the different terms could be calculated according to the values of collision frequencies ($\nu_{ia}, \nu_{id}, \nu_{di}, \nu_{da}$ and ν_{ad}) between all heavy species in the plasma.

The dimensionless equations respectively for dust grains, ions and thermal electrons are,

$$\frac{\partial N_d}{\partial \tau} + \frac{\partial}{\partial s}(N_d V_d) = 0 \tag{2a}$$

$$N_d \left(\frac{\partial V_d}{\partial \tau} + V_d \frac{\partial V_d}{\partial s} \right) - Z_d \left(\frac{m_i}{m_d} \right) N_d \frac{\partial \phi}{\partial s} + \left(\frac{\nu_{da}}{\nu_{ia}} \right) V_d N_d + \left(\frac{\nu_{di}}{\nu_{ia}} \right) N_d (V_d - V_i) = 0 \tag{2b}$$

$$\frac{\partial N_i}{\partial \tau} + \frac{\partial}{\partial s}(N_i V_i) = F_o \tag{2c}$$

$$N_i \left(\frac{\partial V_i}{\partial \tau} + V_i \frac{\partial V_i}{\partial s} \right) + N_i \frac{\partial \phi}{\partial s} + \left(\frac{T_i}{T_e} \right) \frac{\partial N_i}{\partial s} + N_i V_i + F_o V_i + \left(\frac{\nu_{id}}{\nu_{ia}} \right) N_i (V_i - V_d) = 0 \tag{2d}$$

$$N_e = \exp(\phi) \tag{2e}$$

$$\rho^2 \frac{\partial^2 \phi}{\partial s^2} = N_e + Z_d \frac{\nu_{do}}{\nu_{eo}} N_d - \frac{\nu_{io}}{\nu_{eo}} N_i \tag{2f}$$

where the right term in Eq. [2c] $F_o = (G - R_o)/\nu_{ia} n_{io}$ is,

$$F_o = \frac{\nu_{eo}}{\nu_{io}} \left(\frac{\nu_I}{\nu_{ia}} N_e + h_o(j) + h_1(j) \phi \right) - \frac{\nu_L}{\nu_{ia}} N_i \tag{3}$$

The following dimensionless parameters are related with the ionizations produced by the electron beam,

$$h_o(j) = \frac{\sigma_{Ib}}{\sigma_{ia}} \sqrt{\frac{2m_i}{m_e}} \frac{J_{eb}}{J_{eT}} \quad h_1(j) = \frac{CK_B T_e}{\sigma_{ia}} \sqrt{\frac{2m_i}{m_e}} \frac{J_{eb}}{J_{eT}}$$

where J_{eT} is the electron thermal current density.

$J_{eb} > 0$ an unstable growing amplitude wave is found for large wavenumbers.

In Figure 3 it may be appreciated the effect of the dust charge Z_d in the cutoff unstable wavenumbers holding the equilibrium ion n_{io} and dust n_{do} densities constant. The increments in the negative charge of dust increases the instability growth rates and reduce maximum unstable wavenumber.

References

- [1] J.C. Johnson, N. D'Angelo and R.L. Merlino, J. Phys. D, Appl. Phys, **23**, 682, (1990). N. D'Angelo, Phys. Plasmas, **4**, (9), 3422, (1997) and Phys. Plasmas, **5**, (9), 3155, (1998).
- [2] P.K. Shukla and G. Morfill, Phys. Lett. A, **216**, 153 (1996).
- [3] S.I. Krashenninikov, Y. Tomita, R.D. Smirnov and R.K. Janev, Phys. Plasmas, **11**, (6), 3141, (2004). approximation
- [4] X. Wang, A. Bhattacharjee, S.K. Gou and J. Goree, Phys. Plasmas, **8**, (11), 5018, (2001). and D. Samsonov and J. Goree. Phys. Rev. E, **59**, 1047, (1999).
- [5] L. Conde, Phys. Plasmas, **11**, (5), 1955, (2004).
- [6] D.B. Graves and K.F. Jensen, IEEE Trans. Plasma Sci, **PS-14**, 78 (1986).
- [7] Y.P. Raizer, Gas Discharge Physics (Springer Verlag, Berlin, 1991), Chaps. 2 and 4.