Effect of Dust Grains on the parametric coupling of neutral beam driven ion cyclotron instability of lower hybrid wave in a plasma

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NUMERICAL ANALYSIS OF INSTABILITY

Assumed a neutral beam launched inside a tokamak at an angle to the applied magnetic field. The neutral beam gets ionized by emitting electrons and generating a gyrating ion beam having density n^{0b}. The tokamak consists of deuterium, tritium ions, electrons, negatively charged dust grains and a static magnetic field which is applied along z direction, $B_s\hat{z}$. The density, mass, charge and temperature of electrons, tritium and deuterium ions are $(n^{0e}, m^e, -e, T^e)$, (n^{0T}, m^T, e, T^T), (n^{0D}, m^D, e, T^D), respectively, whereas n^{0d}, m^d and Q_d represent the density, mass and charge of dust grains. The solution of Vlasov equations (1) to (36) will provide the gyrating ion beam response.

$$\frac{\partial F}{\partial t} + V.\nabla F - \frac{eE}{m^b}.\left(\frac{\partial F}{\partial V}\right) - \frac{e}{m^b}\frac{V}{c} \times B.\left(\frac{\partial F}{\partial V}\right) = 0, \qquad (1)$$

Using the linearization procedure, we obtain the value of equilibrium distribution function as

$$f_{0b} = \frac{n^{0b}}{2\pi v_{0\perp}} \delta(v_\perp - v_{0\perp})(v_\parallel - v_{0\parallel}). \qquad (2)$$

A large amplitude lower hybrid wave (LHW) is also propagating through this complex plasma

having potential ,

$$\phi_1 = A_1 \exp^{-i(\omega_1 t - \vec{k}_1 . \vec{r})}, \qquad (3)$$

$$\omega_1^2 = \omega_{LH}^2 \left(1 + \frac{m^i}{m^e} \frac{k_{1z}^2}{k_1^2} \right),$$

Now, the pump wave having large amplitude decays into an ion cyclotron wave of potential

$$\phi = A \exp^{-i(\omega t - \vec{k}.\vec{r})}, \tag{4}$$

and two lower hybrid side bands of potential

$$\phi_j = A_j \exp^{-i(\omega_j t - \vec{k}_j.\vec{r})}, \text{ j= 2, 3,} \tag{5}$$

where, the phase matching condition are $\omega_2 = \omega - \omega_1$, $\omega_3 = \omega + \omega_1$, $\vec{k}_2 = \vec{k} - \vec{k}_1$, and $\vec{k}_3 = \vec{k} + \vec{k}_1$. The lower and upper side bands cannot satisfy phase matching condition simultaneously, when one sideband satisfies the phase matching condition neglects the other sidebands and the parametric decay process is known as resonant three-wave decay process.

The perturbed velocity of electrons at the two lower hybrid side band $(\omega_j, \vec{k}_j)$ is written as

$$\vec{v}_{j\perp} = -\frac{ie\phi_j}{m^e\,\omega_{ce}^2}(\vec{k}_{j\perp} \times \vec{\omega}_{ce} + i\omega_j \vec{k}_{j\perp}). \qquad v_{jz} = -\frac{e\,k_{jz}\phi_j}{m^e\,\omega_j}$$

The linear perturbed density response of beam, deuterium and tritium ions can be written as

$$n^{1b} = -\left(\frac{k^2}{4\pi e}\right)\chi_{1b}\,\phi\,, \qquad (6)$$

$$n^{1D} = -\left(\frac{k^2}{4\pi e}\right)\chi_{1D}\,\phi \quad \text{and} \quad n^{1T} = -\left(\frac{k^2}{4\pi e}\right)\chi_{1T}\,\phi\,, \qquad (7)$$

where $\chi_{1b} = -\dfrac{\omega_{pb}^2}{\omega_{cb}^2}\left[\dfrac{k_\perp^2}{k^2}\dfrac{\omega_{cb}J_0^2(k_\perp\rho_b) - J_z^2(k_\perp\rho_b)}{2(\omega - k_z v_{0\|} - \omega_{cb})} + \dfrac{k_\|^2}{k^2}\dfrac{\omega_{cb}^2 J_1^2(k_\perp\rho_b)}{(\omega - k_z v_{0\|} - \omega_{cb})^2} + \dfrac{k_\|^2}{k^2}\dfrac{\omega_{cb}^2 J_0^2(k_\perp\rho_b)}{(\omega - k_z v_{0\|})^2}\right]$,

is the beam susceptibility and $\omega_{pb} = \left(\dfrac{4\pi n^{0b} e^2}{m^b}\right)^{1/2}$, $\omega_{cb} = \dfrac{eB_s}{m^b c}$ represent the plasma and cyclotron frequency of beams, respectively. The ions susceptibility for deuterium and tritium ions can be written as $\chi_{1i} = \dfrac{2\omega_{pi}^2}{k^2 v_{thi}^2}\left[1 + \dfrac{\omega}{k v_{thi}}\sum_n Z\left(\dfrac{\omega - n\omega_{ci}}{k_z v_{thi}}\right) I_n(b_i) e^{-b_i}\right]$, i= D, (8) The perturbed density of dust grains may be written as

$$n^{1d} = \frac{k^2}{4\pi Q_{0d}} \chi_{1d}\phi, \tag{9}$$

$$Q_{1d} = -\frac{i\left(\dfrac{|I_{0e}|k^2}{4\pi n^{0e} e}\right)}{(\omega + i\eta)}\left[\chi_e(\phi+\phi_p) + \chi_{1D}\frac{n^{0e}}{n^{0i}} + \chi_{1T}\frac{n^{0e}}{n^{0i}}\right]. \tag{10}$$

Substituting the values from Eqs. in Poisson's equation we obtain

$$\nabla^2\phi = 4\pi(ne - n^{1D}e - n^{1T}e - n^{0d}Q_{1d} - Q_{0d}n^{1d} - n^{1b}), \tag{11}$$

After simplifying the above Eq. (12) we get

$$\left[1+\chi_e\left(1+\frac{i\beta}{(\omega+i\eta)}\right)+\chi_{1D}\left(1+\frac{i\beta}{(\omega+i\eta)}\frac{n^{0e}}{n^{0i}}\right)+\chi_{1T}\left(1+\frac{i\beta}{(\omega+i\eta)}\frac{n^{0e}}{n^{0i}}\right)+\chi_{1d}+\chi_{1b}\right]\phi = -\chi_e\left(1+\frac{i\beta}{(\omega+i\eta)}\right)\phi_p \quad ,$$

$$\varepsilon\ \phi = -\chi_e\left(1+\frac{i\beta}{(\omega+i\eta)}\right)\phi_p. \tag{12}$$

In the Poisson's equation, after using ion and electron perturbed density, we have

$$\nabla^2 \phi_2 = 4\pi \left(n_j e - n^{jD} e - n^{jT} e \right). \tag{13}$$

After simplifying the above equation, we get

$$\varepsilon_j \phi_j = \frac{k^2}{k_j^2} (\varepsilon - \chi_e) \frac{\vec{k}_j . \vec{v}_1^{\,*}}{2\omega_j} \phi \quad , j=2,3 \tag{14}$$

Corresponding to the upper hybrid side band wave and ion cyclotron mode, the linear dispersion relation has been obtained in the absence of the pump wave. We can obtain the growth rate as

The value of growth rate can be determined after substituting the value. We get,

$$\gamma = \left[\frac{\chi_e \left(1 + \dfrac{i\beta}{\omega + i\eta} \right) (\varepsilon - \chi_e) \dfrac{k^2 U^2}{k_3^2\, 4\, \omega_3^2} \mathrm{Sin}^2 \delta \left(1 - \dfrac{\omega \quad k_{1z}}{\omega_1 \quad k_z} \right)}{M \quad N} \right]^{1/2}, \tag{15}$$

$$M = \frac{2}{\omega_3}\left(1 + \frac{\omega_{pe}^2}{\omega_{ce}^2}\right)$$ and

$$N = \frac{2\omega_{pd}^2}{\omega^3} - \chi_e\left(\frac{i\beta}{(\omega+i\eta)^2}\right) + \frac{2\omega_{pD}^2}{k^2 v_{thD}^2}\left[\frac{\omega_{cD} I_1(b_D) e^{-b_D}}{(\omega-\omega_{cD})^2}\right]\left[1 + \frac{i\beta}{(\omega+i\eta)}\frac{1}{\delta}\right]$$

$$-\frac{2\omega_{pD}^2}{k^2 v_{thD}^2}\left[1 - I_0(b_D)e^{-b_D} - \frac{\omega I_1(b_D)e^{-b_D}}{(\omega-\omega_{cD})}\right]\left[\frac{i\beta}{(\omega+i\eta)^2}\frac{1}{\delta}\right] + \frac{2\omega_{pb}^2}{\omega_{cb}^2}\left[\frac{k_\parallel^2}{k^2}\frac{\omega_{cb}^2 J_0^2(k_\perp \rho_b)}{(\omega - k_z v_{0\parallel})^3}\right]. \quad (16)$$

Here, the coupling between plasma and negatively charged dust grains is defined by a coupling parameter $\beta = \frac{|I_{0e}|\, n^{0d}}{e\; n^{0e}}$.

Results and Conclusion

In the numerical calculations, we have used typical plasma parameters of the experimental paper Singh &*Tripathi 1.*

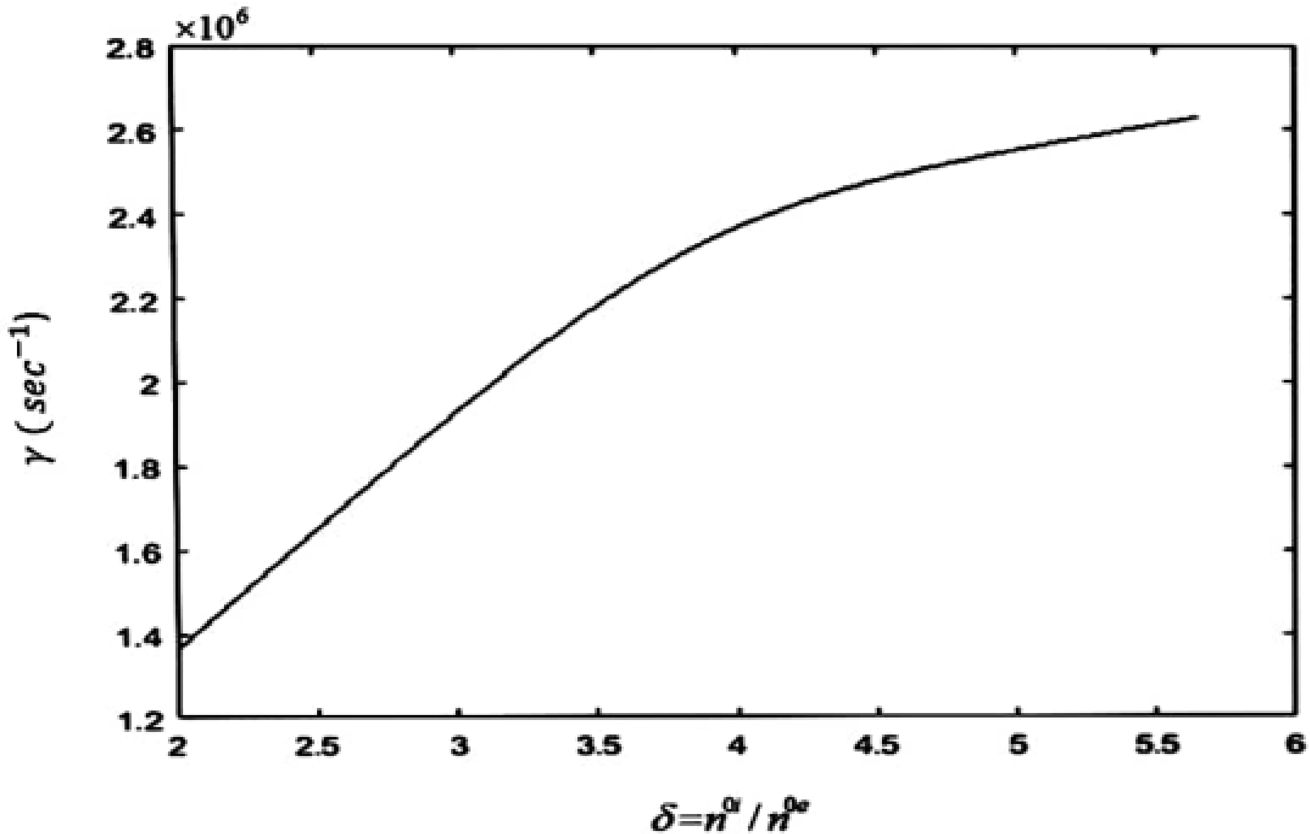

Fig. 1. Growth rate $\gamma(\sec^{-1})$ as a function of relative density $d(= n^{0i} / n^{0e})$ of negatively charged dust grains.

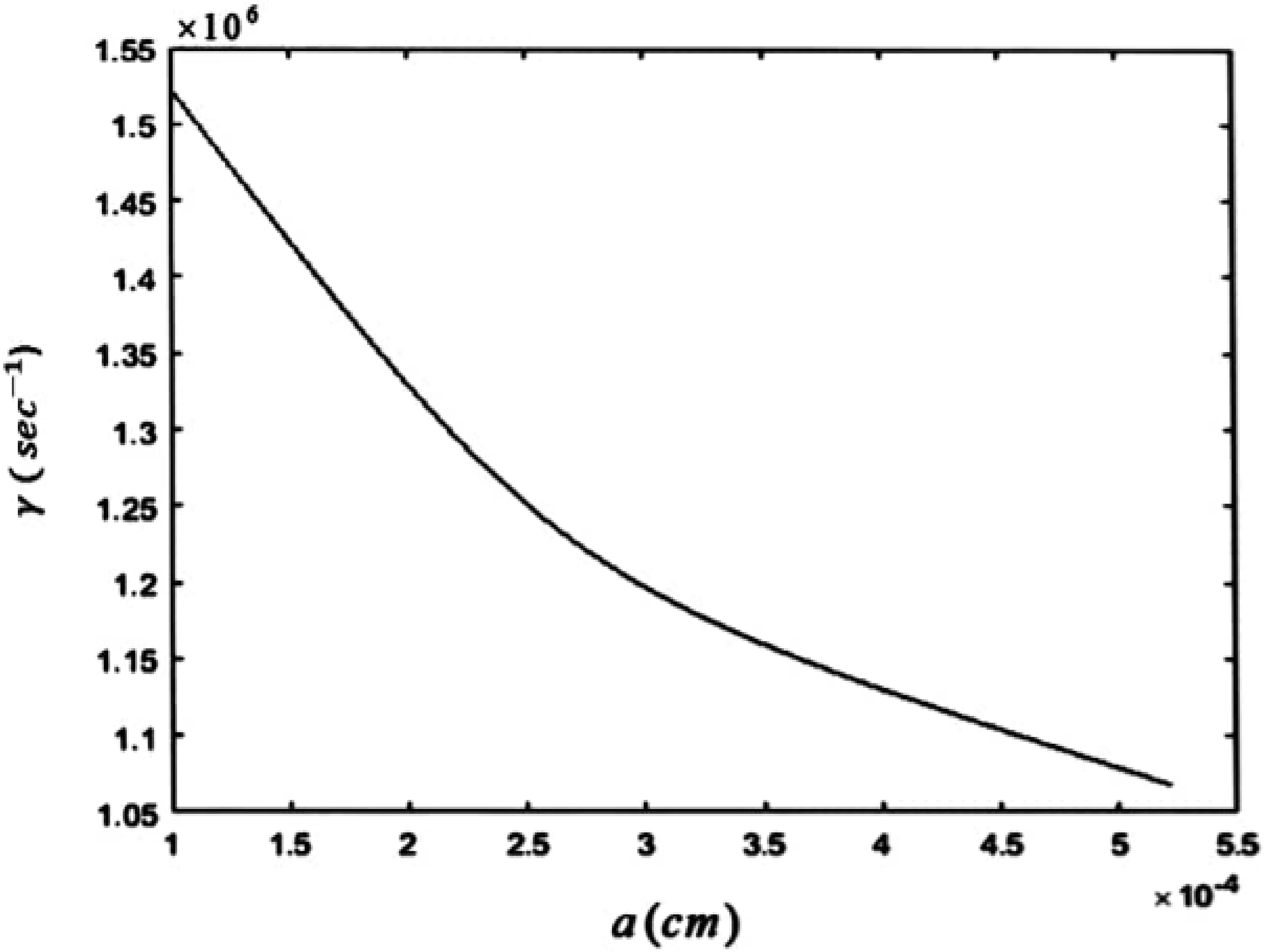

Fig. 2. Growth rate $\gamma(\sec^{-1})$ as a function of dust grain size $a(cm)$.

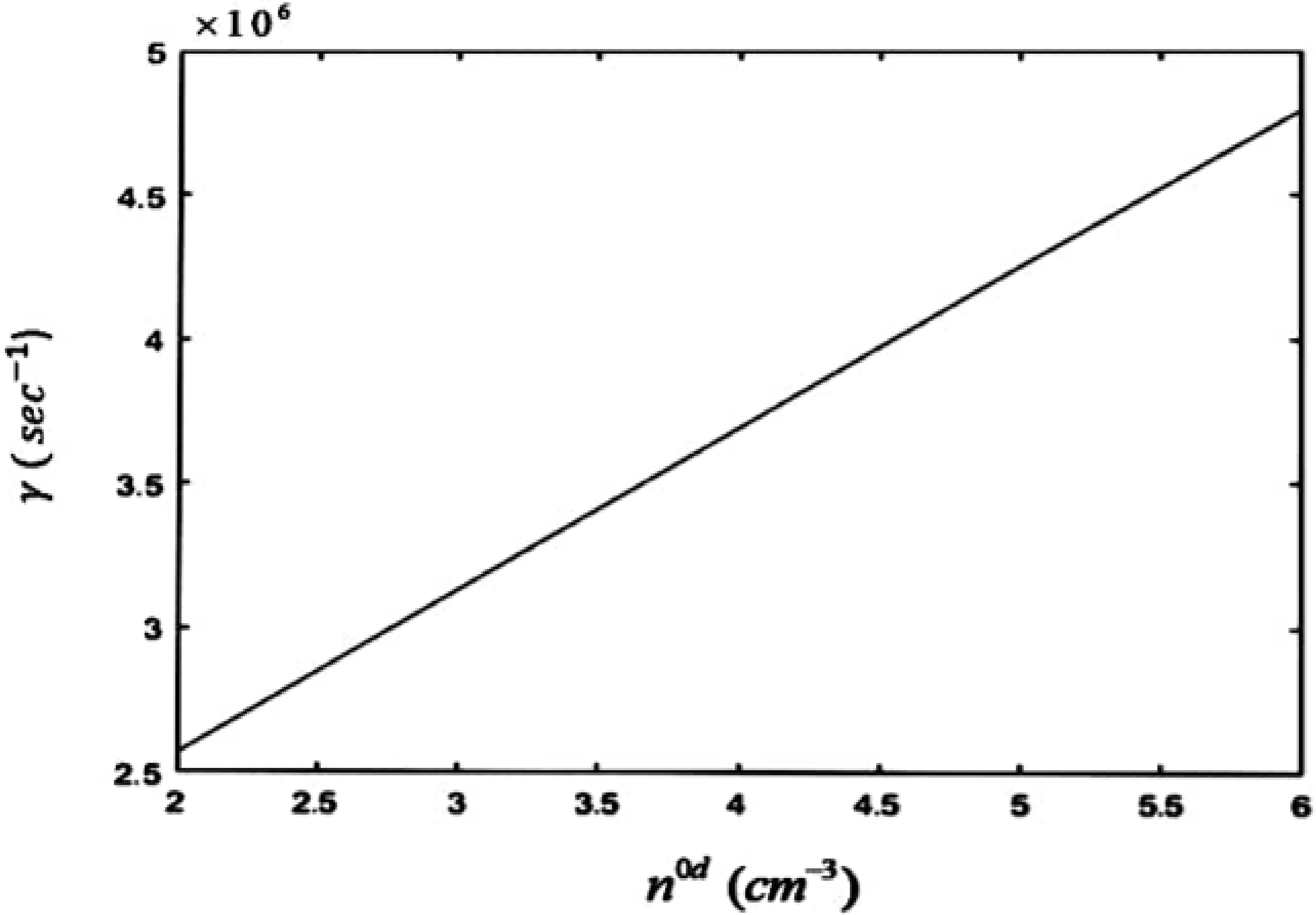

Fig. 3. Growth rate $\gamma(\sec^{-1})$ with number density of dust grains $n^{0d}(cm^{-3})$.

- **Conclusion**
- In the present manuscript, the parametric coupling of large amplitude lower hybrid waves **(LHWs)** with **gyrating ion beam driven ion cyclotron instability** in two-ion (D-T) species complex plasma is described. LHW is parametrically unstable and decays into **ion cyclotron mode** and an **upper side band wave**. The growth rate of the unstable mode has a significant influence on the **presence of dust into plasma.** With an increment in the relative density of grains and number density of dust grains, an increment in growth rate is resulted. However, with increasing dust grain size, a reduction in growth rate is reported.

APPLICATIONS

- The study about the causes and role of dust particles and their sizes is useful for fusion community to increase the tokamak efficiency. Our theoretical results may find applications in laboratory plasma, fusion plasma as well as in burn phase of tokamak

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Thank you