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Theoretical study of dust grain parameters on electrostatic ion cyclotron waves in a magnetized plasma

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ABSTRACT

The theoretical model for electrostatic ion cyclotron (EIC) wave is proposed in this present paper. Analytical analysis and numerical calculations using the kinetic theory model have been used to find out the growth rate and unstable mode frequency of EIC waves for current experimental settings. The dispersion relation for the same has been inferred. The dust grain parameters are studied in our proposed theoretical model and it was found that it affects the properties of waves. The consequence of density and size of dust particles on EIC wave is examined. It was observed with the rise in dust density, the growth rate of the wave decreases. The results obtained are analogous to the experimental observations.

INTRODUCTION

The most prevalent state of matter in the cosmos is plasma, with dust being another widespread occurrence. As a result, it's not astonishing that a study of "dusty plasmas" is recommended in several astrophysical settings[1,2]. Dust is present in the plasma environment, therefore affecting the overall charge neutrality condition. The Electrostatic Ion-Cyclotron Instability (EICI) is one of the fundamental modes when the plasma is magnetized, and the electrons drift along magnetic field lines. The EIC wave propagates approximately perpendicular to the magnetic field B. The EIC is a field-aligned current-driven instability with one of the lowest threshold drift velocities among current-driven instabilities[4].

MODEL

- We have considered a system in which magnetized dusty plasma is immersed in a static uniform magnetic field B_0 in the z-direction. This system comprises three species, i.e., ions, electrons and negatively charged dust grains with equilibrium densities n_i^0, n_e^0 and n_d^0 and their respective velocities v_i, v_e and v_d. The mass, charge and temperature of ions, electrons and dust grains are denoted by $(m_i, e$ and $T_i)$, $(m_e, -e$ and $T_e)$ and , $(m_d, Q_d$ and $T_d)$ respectively.
- An electrostatic potential perturbation is defined by

$$\phi_1 = \phi_0 \exp\left[-i\left(\omega t - k_y y - k_z z\right)\right]$$

- The density perturbation response can be governed by

$$n_\alpha^1 = \frac{m_\alpha^2}{\omega_{c\alpha}} \iiint f_\alpha^0 d^3\vec{v}$$

- The EIC wave linear dispersion relation is given by

$$\varepsilon(\omega,k) = 1 + \chi_\alpha$$

Where $\alpha = e, i$ and dust grains.

$$\varepsilon(\omega,k) = 1 + \frac{2\omega_{pe}^2}{k^2 v_{te}^2}\left[1 + i\sqrt{\pi}\frac{\omega_1}{k_z v_{te}}\right] + \frac{2\omega_{pi}^2}{k^2 v_{ti}^2}\left[1 - \Gamma_1^i \frac{\omega}{\omega - \omega_{ci}} - \frac{1-\Gamma_0^i}{b_i} + i\sqrt{\pi}\frac{\omega}{k_z v_{ti}}\Gamma_0^i e^{-\xi_i^2}\right]$$

Where $\omega_1 = \omega - k_z u_{de}$

- The real frequency is given as $\omega_r = \omega_{ci}(1+\Delta)$

Where

$$\Delta = \frac{\Gamma_1^i}{1 - \Gamma_1^i - \frac{1-\Gamma_0^i}{b_i} + \frac{T_i}{T_e}\left(1 + \frac{k^2 T_e}{4\pi n_i e^2}\right)}$$

The growth rate expression is as follows

$$\omega_i = -\sqrt{\pi}\left[\frac{\frac{2\omega_{pe}^2}{k^2 v_{te}^2}\frac{(\omega_r - k_z u_{de})}{k_z v_{te}} + \frac{2\omega_{pi}^2}{k^2 v_{ti}^2}\frac{(\omega_r)}{k_z v_{ti}}\Gamma_o^i e^{(-\xi^2)}}{\frac{2\omega_{pi}^2}{k^2 v_{ti}^2}\Gamma_1^i \frac{\omega_{ci}}{(\omega_r - \omega_{ci})^2} + \frac{2\omega_{pd}^2}{\omega_r^3}}\right]$$

RESULTS

As the number of dust particles increases, the number of accessible electrons per dust grain falls, implying that the dust particles collectively have a huge demand for electrons. The average dust grain charge decrease, and as a result, the growth rate decreased.

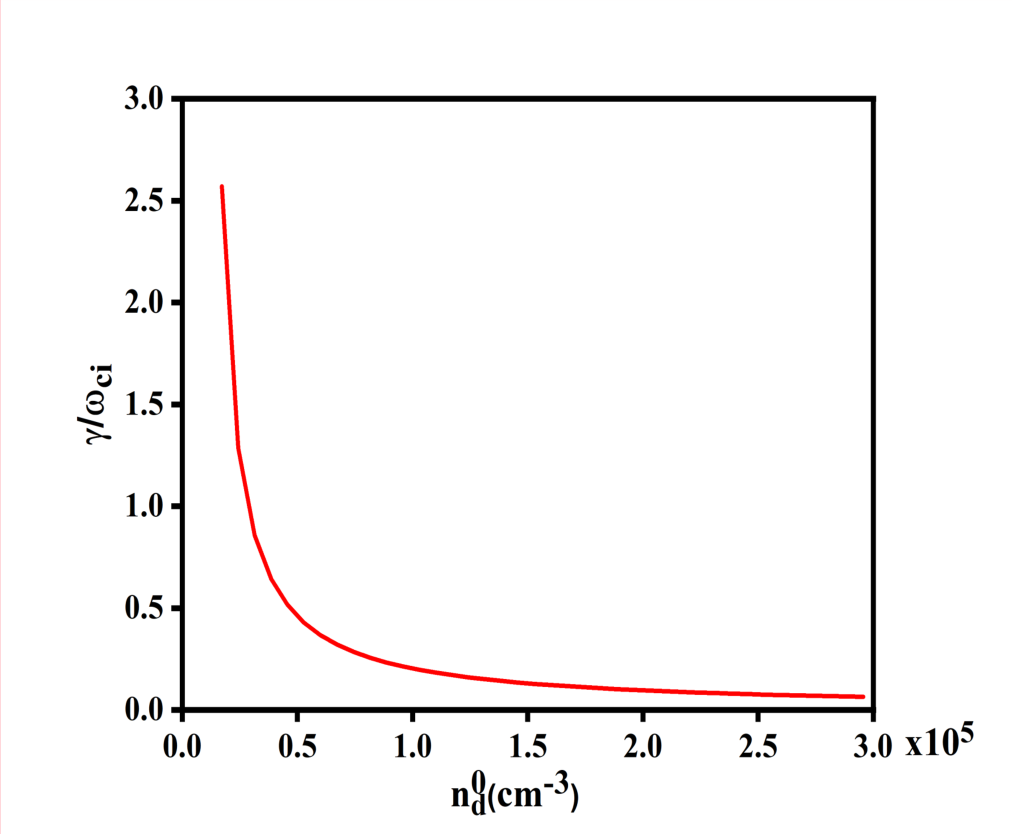


Fig.1: The normalized growth rate variation with the dust grain number density of the EIC wave.

It could be explained that when relative density ratio grows, the electron plasma density falls in comparison to the ion plasma density. The effective mass $m_{ieff} = \frac{m_i}{\delta}$ of an ion is smaller than m_i for greater values of δ, and as a result of their greater movement, wave generation gets enhanced.

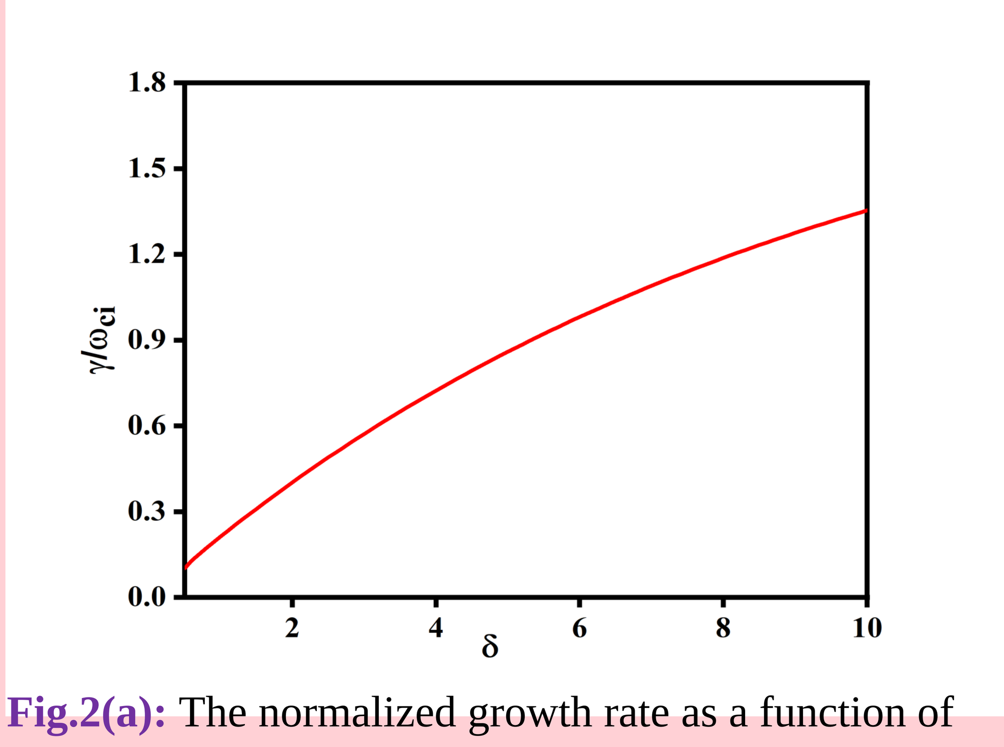
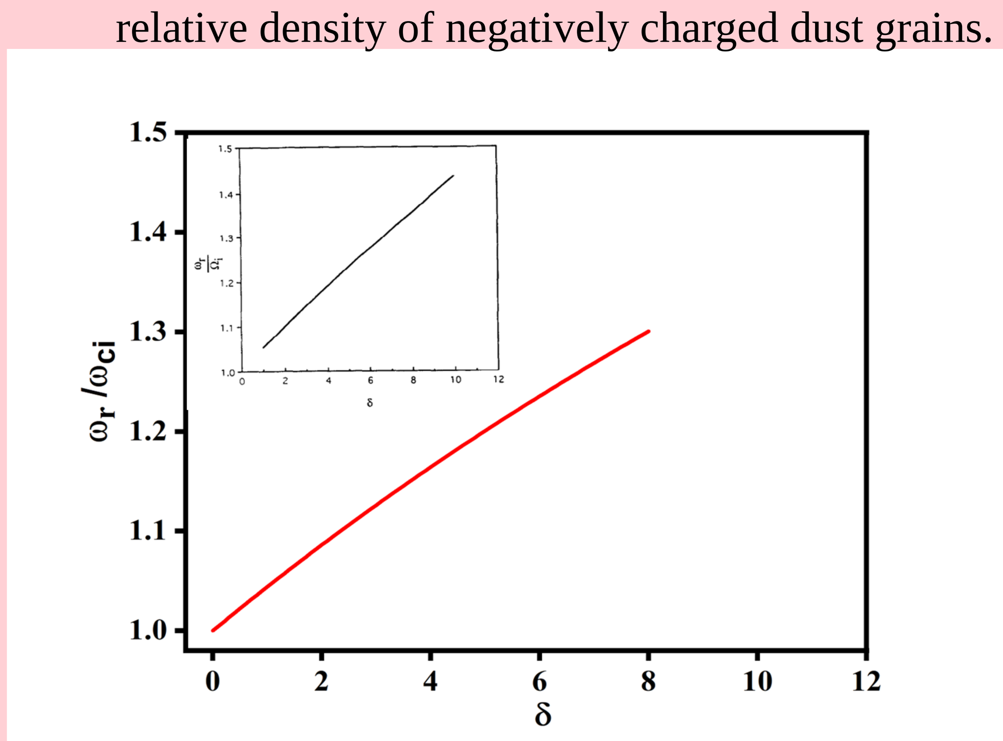


Fig.2(a): The normalized growth rate as a function of relative density of negatively charged dust grains.

Our results are in good agreement with the Chow and Rosenberg[4] results.

Fig.2(b): Variation of the normalized real frequency with respect to the relative density of negatively charged dust grains and the inset of Fig. 2(b) shows the results of Chow and Rosenberg in the absence of an electric field.



CONCLUSION

- An analytical model has been developed to study the excitation of current-driven EIC waves in a magnetized dusty plasma; the frequency and growth rate of the with different parameters have been investigated.
- The growth rate of the wave decreases as the dust grains number density increases.
- The growth rate and frequency of the EIC mode increase with the increase in relative density of negatively charged dust grains.

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