Kinetic Theory of quasi-electrostatic waves in non-gyrotropic plasmas

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Abstract

The kinetic theory of twisted wave instability is developed for the nonthermal dusty plasmas in the presence of helical electric field carrying orbital angular momentum (OAM). The Laguerre Gaussian (LG) mode function is employed to decompose the mode into its longitudinal and azimuthal components. The longitudinal component illustrates the spatial while the azimuthal component describes the phasor variation of the wave. The dielectric functions of quasi-electrostatic dust ion acoustic (DIA) and dust acoustic (DA) twisted modes are obtained and solved analytically to calculate the growth rates. The numerical results are also shown pictorially.

Kinetic Theory of Quasi-electrostatic waves in non-gyrotropic plasmas

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ABSTRACT

The kinetic theory of twisted wave instability is developed for the nonthermal dusty plasmas in the presence of helical electric field carrying orbital angular momentum (OAM).

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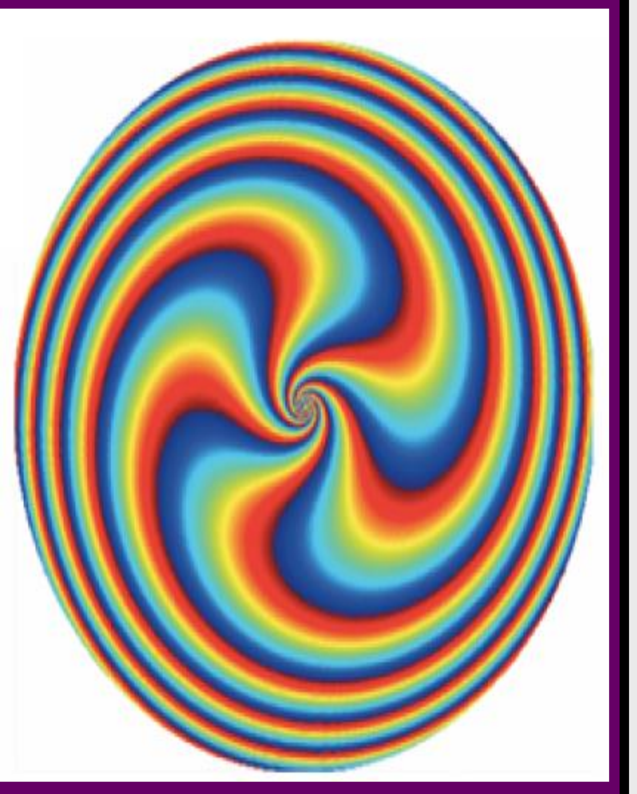


INTRODUCTION

The helical waves carry orbital angular momentum. Allen et al., 2003 predicted the orbital angular momentum of the laser beams in the optical range.
Later the study of orbital angular momentum is observed in many fields like microscopy and imaging, ultra fast optical communication, quantum computing, ionospheric radar facility, quantum entanglement of two photons, photonic crystal fibre, twisted gravitational waves, ultra intense laser pulses, astrophysics.

After the seminal predictions of Alfvenic and magnetic tornadoes like helical structures, the plasma community can not resists the study of orbital angular momentum. This brings the era of twisted waves in plasma physics.

Therefore the kinetic theory of twisted waves is developed by considering the realistic distribution of plasma species. In particular, Landau damping rates of Langmuir and ion acoustic twisted waves and growth rates of quasi-electrostatic twisted waves in nonthermal dusty plasmas are obtained by using non-gyrotropic Kappa distribution function.

The dielectric function for the quasi-electrostatic twisted waves in nonthermal dusty plasma can be written as,

$$\epsilon(\omega,k,lq_\theta) = 1 + \sum_{\alpha=e,i,d} \frac{\omega_{p\alpha}^2}{k^2} \int \frac{\mathbf{q}_{eff} \cdot \partial_{\mathbf{v}} f_{0\alpha}}{(\omega - \mathbf{q}_{eff} \cdot \mathbf{v})} d\mathbf{v}$$

The isotropic non-gyrotropic Kappa distribution function is given by the following expression;

$$f_0 = \frac{1}{\pi^{3/2}\theta^3\kappa^{3/2}} \frac{\Gamma(\kappa+1)}{\Gamma(\kappa-1/2)} \times \left[1 + \frac{v_r^2 + v_\theta^2}{\kappa\theta^2} + \frac{(v_z - v_d)^2}{\kappa\theta^2}\right]^{-\kappa-1}.$$

By using the above non-gyrotropic distribution function, we obtain the modified plasma dispersion for the twisted waves in the presence of helical electric field;

$$Z_{\kappa,lq_\theta}(\xi_z,\xi_\theta) = \frac{2}{\theta^2}\left[\frac{2(\kappa-1)}{\kappa} + \xi_z Z^*(\xi_z) + \xi_\theta Z^*(\xi_\theta)\right]$$

DIA AND DA TWISTED MODES

The dielectric function of dust ion acoustic and dust acoustic twisted modes can be expressed as;

$$\epsilon(\omega,k,lq_\theta) = 1 + \frac{2\omega_{pe}^2}{k^2\theta_e^2}\left[\frac{2\kappa_e - 1}{\kappa_e} + \xi_{z_e} Z(\xi_{z_e}) + \xi_{\theta_e} Z(\xi_{\theta_e})\right] + \frac{2\omega_{p_i}^2}{k^2\theta_i^2} \times \left[\frac{2\kappa_i - 1}{\kappa_i} + \xi_{z_i} Z(\xi_{z_i}) + \xi_{\theta_i} Z(\xi_{\theta_i})\right],$$

and

$$\epsilon(\omega,k,lq_\theta) = 1 + \frac{2\omega_{pe}^2}{k^2\theta_e^2}\left[\frac{2\kappa_e - 1}{\kappa_e} + \xi_{z_e} Z(\xi_{z_e}) + \xi_{\theta_e} Z(\xi_{\theta_e})\right] + \frac{2\omega_{pi}^2}{k^2\theta_i^2}\left[\frac{2\kappa_i - 1}{\kappa_i} + \xi_{z_i} Z(\xi_{z_i}) + \xi_{\theta_i} Z(\xi_{\theta_i})\right] + \frac{2\omega_{pd}^2}{k^2\theta_d^2}\left[\frac{2\kappa_d - 1}{\kappa_d} + \xi_{z_d} Z(\xi_{z_d}) + \xi_{\theta_d} Z(\xi_{\theta_d})\right]$$

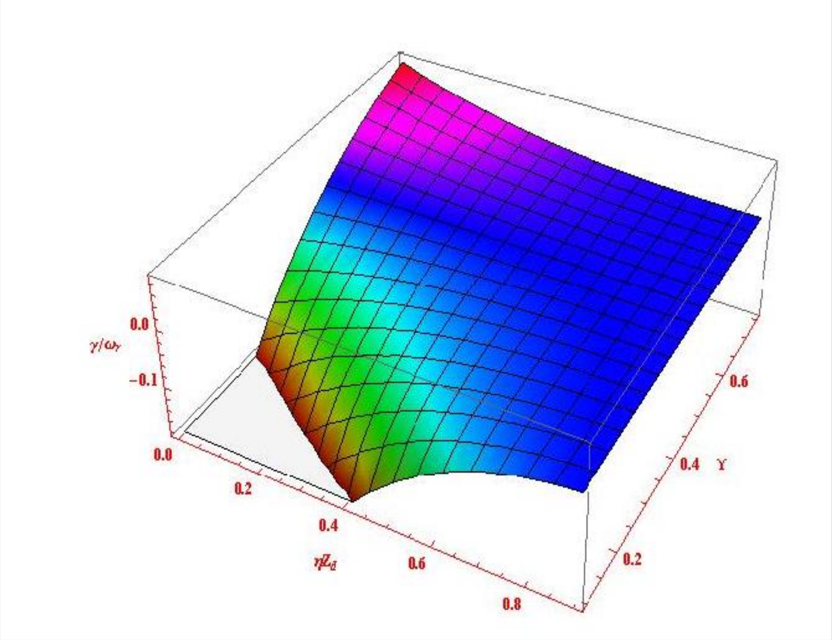


Figure 3. Three dimensional surface plots of the growth rates of DIA twisted mode.

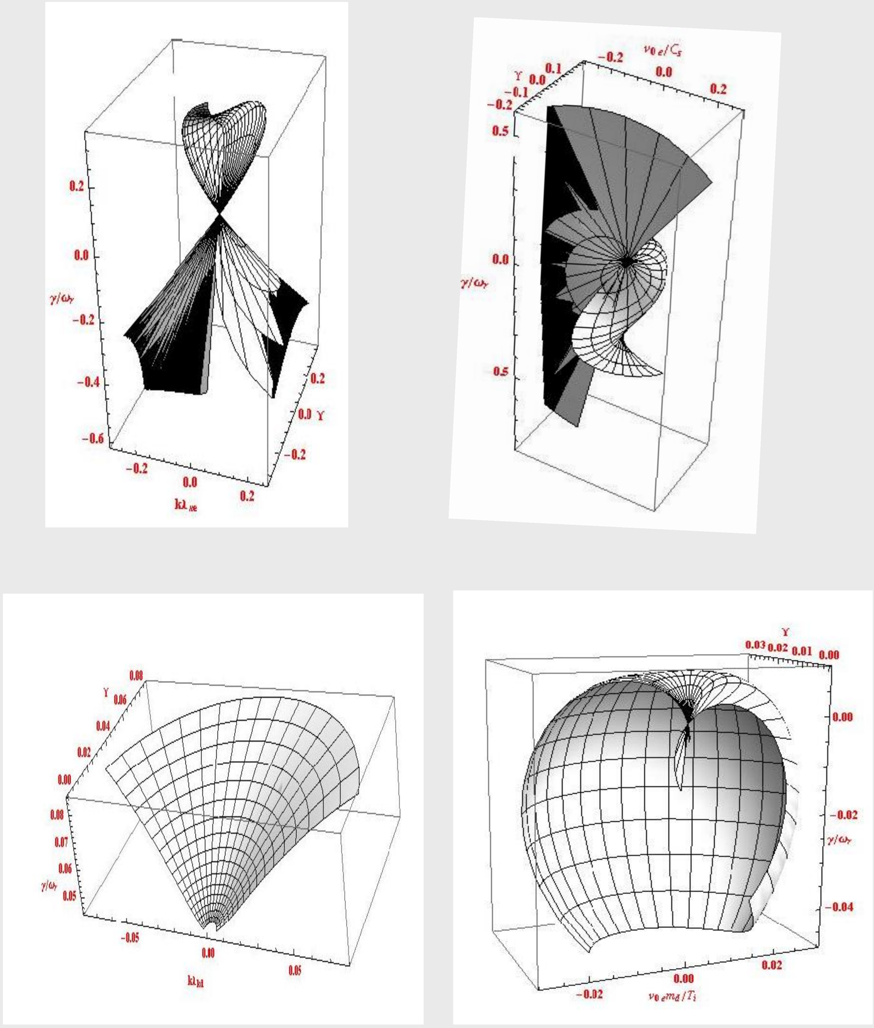


Figure 5. Three dimensional spherical plots of the growth rates of DA twisted mode.

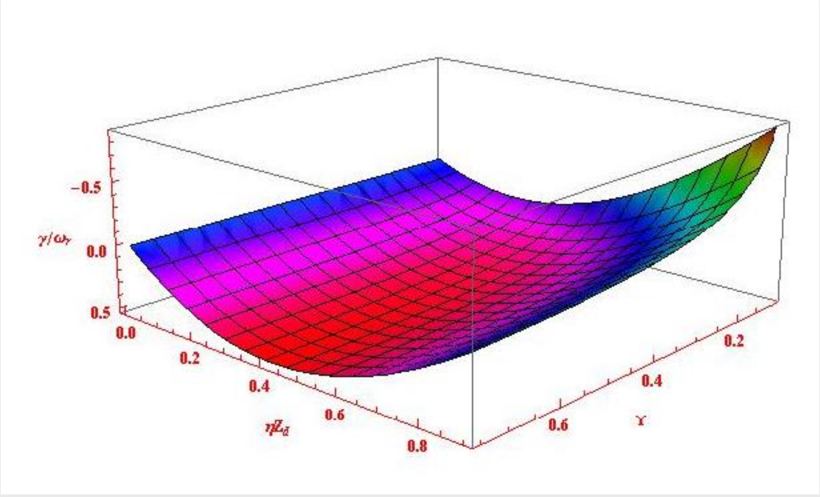


Figure 6. Three dimensional surface plots of the growth rates of DIA twisted mode.

APPLICATIONS IN ASTROPHYSICAL ENVIRONMENT

The twisted waves or vortex like structures are observed in many astrophysical environments. Few examples are given below;

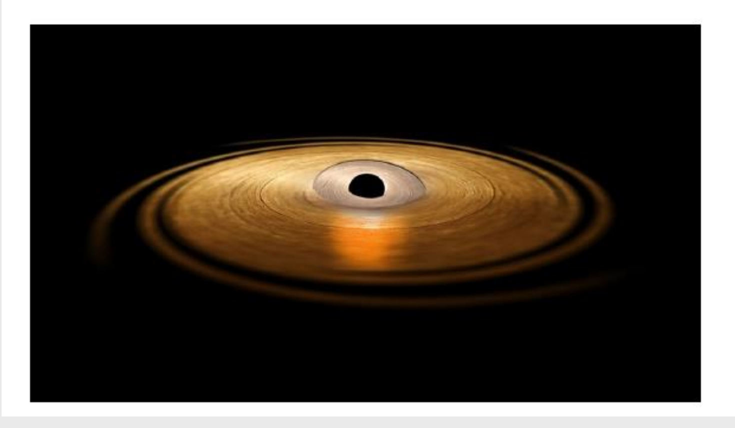


Figure 1. Gravitational vortex around a rotating black hole.

Figure 2. The discovery of giant solar twist resolve the mystery, why solar corona is hotter than the Sun's visible surface,

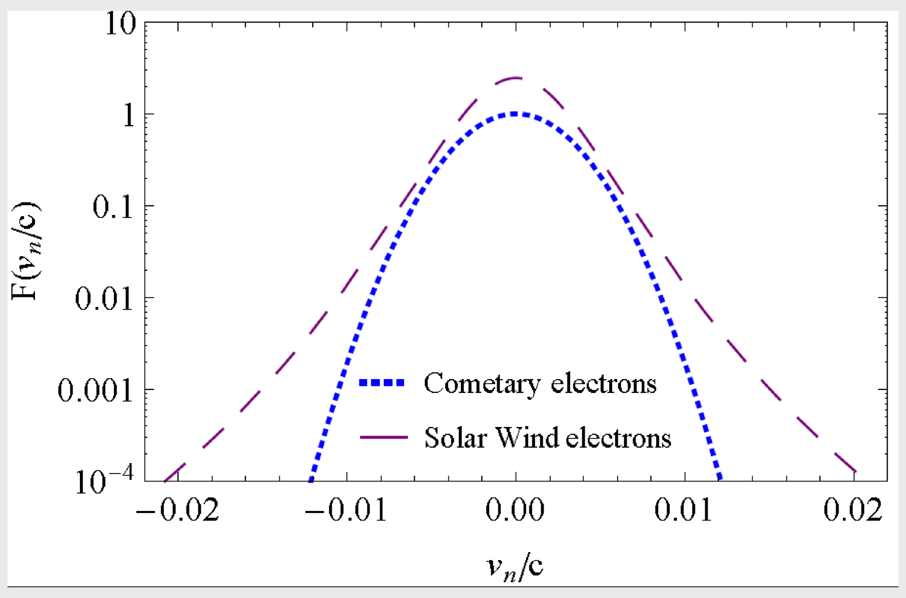
COMETARY TAILS GENERATED BY SOLAR WIND

Comets develop tails when they approach perihelion (the place where their orbits are closer to Sun). The Sun's heat vaporizes some of the Cometary ice and releasing ionized gases and dust , that were trapped in the ice.
A combination of solar radiation pressure and solar wind blow away gases from the Comet's nucleus in the form of tail of ions and dust particles, collectively called as Cometary tail.

$$\epsilon(\omega,k,lq_\theta) = 1 + \frac{2\omega_{p_{we}}^2}{k^2\theta_{we}^2}\left[\frac{2\kappa_{we} - 1}{\kappa_{we}} + \xi_{z_{we}} Z(\xi_{z_{we}}) + \xi_{\theta_{we}} Z(\xi_{\theta_{we}})\right] + \frac{2\omega_{p_{wi}}^2}{k^2\theta_{wi}^2}\left[\frac{2\kappa_{wi} - 1}{\kappa_{wi}} + \xi_{z_{wi}} Z(\xi_{z_{wi}}) + \xi_{\theta_{wi}} Z(\xi_{\theta_{wi}})\right] + \frac{2\omega_{p_{ce}}^2}{k^2\theta_{ce}^2}\left[2 + \xi_{z_{ce}} Z(\xi_{z_{ce}}) + \xi_{\theta_{ce}} Z(\xi_{\theta_{ce}})\right] + \frac{2\omega_{p_{ci}}^2}{k^2\theta_{ci}^2}\left[2 + \xi_{z_{ci}} Z(\xi_{z_{ci}}) + \xi_{\theta_{ci}} Z(\xi_{\theta_{ci}})\right]$$

Figure 4 . Comet approaches perihelion near Sun

DISTRIBUTION FUNCTIONS



CONCLUSIONS

This is an advance kinetic theory of space plasmas in the presence of helical electric field carrying orbital angular momentum.

We have studied the nonthermal Langmuir, ion acoustic and quasi-electrostatic dusty plasma twisted modes. The Landau damping and growth rates are highly modified in the presence of orbital angular momentum.

We have started to investigate the relevant modes in magnetized plasmas typically encounter in corona, solar wind, planetary magnetosphere and preliminary results show similar major modifications.

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