



# ANOMALOUS ELECTRON BERNSTEIN WAVE ASSISTED LASER BEAM ABSORPTION IN PLASMA

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## Abstract

**In this study, we explore the absorption of a cosh-Gaussian laser beam in a plasma with a static magnetic field, facilitated by the electron Bernstein wave. The oscillatory velocity induced by the laser interacts with the density perturbation caused by the electron Bernstein waves, generating a nonlinear current density that drives the electromagnetic sideband wave. An analytical expression for the absorption coefficient is derived under the condition that the nonlinear current density is in phase with the cosh-Gaussian laser field. The graphical analysis indicates that absorption in the plasma can be enhanced by adjusting parameters such as the laser beam's decentred parameter, beam width, laser frequency, electron cyclotron frequency, parameter  $b$ , and the frequency of the electron Bernstein wave. The decentred parameter of the laser beam is identified as a highly sensitive factor. The absorption process remains robust even with minimal variations in the frequency of the electron Bernstein wave relative to the laser frequency. This adaptable and effective absorption theory may have applications in plasma heating.**

**Keywords:** Beam decentred parameter, Current density, Electron Bernstein wave, Electron cyclotron frequency, Absorption, Oscillatory velocity, Beat wave, cosh-Gaussian laser beam

## 1. Introduction

In last few years, the interaction of laser beam with plasmas attracts the researcher for studying the nonlinear phenomena such as anomalous absorption [1], terahertz radiation generation [2], stimulated Raman scattering [3], self-

focusing [4]. The anomalous absorption of electromagnetic and electrostatic waves in plasma, cluster, and nanoparticle is a subject of significant interest due to absorption [5-7]. Plasma behaves as a promising candidate for interacting media owing to possess large current density as compared with other media. This enables the large absorption of laser beam in plasma. The laser with various mode profile can control and optimize the nonlinear interaction phenomena. In magnetized plasma, density fluctuation is a noticeable feature. The irregularities in plasma density are occurred due to the parametric process in Q machine and mirror machine [8-9]. This density fluctuation can cause the strong absorption of high frequency intense laser beam in plasma. As the electromagnetic wave frequency is closed to the natural frequency of plasma, the resonant absorption process takes place [10].

A number of experiments, simulations, and theoretical investigations of laser beam absorption have been studied in plasma by several research groups. The anomalous resistivity is a key point of transport properties of charged particles in plasmas. Whistler mode is a kind of electromagnetic wave found in magnetized plasma and it causes the strong oscillatory velocity to the plasma electrons via Landau damping. This whistler mode possess the ultra-high anomalous absorption in magnetized plasma for 10 % rippled density plasma. Kinetic model of inverse Bremsstrahlung absorption mechanism is studied in collisional plasma and strongly coupled plasma by Cauble and Rozmus [11]. The kappa distribution is a kind of bi-Maxwellian electron distribution function. The kappa parameter associated with electron causes enhanced anomalous absorption through inverse Bremsstrahlung process in undersense plasmas compared with

Maxwellian distribution of electron. They found that absorption has possessed the noticeable peak by increasing the laser intensity and plasma density[12]. In nonuniform over-dense plasma, theoretical model of nonlinear absorption is derived by using the short laser pulse. In this model, theoretical analytic results of nonlinear absorption coefficient are in good agreement with the results obtain from PIC simulation [13]. We have studied the efficient absorption of ultra-short laser pulses in plasma and depicts the hole boring phenomena and magnetic field generation that cause the strong heating [14]. A strong laser field has potential to generate the electron positron pair in plasma and the combined effect of laser field and self-generated cascaded electromagnetic field cause the intense absorption [15].

In the present paper, we study the electron Bernstein wave aided cosh-Gaussian laser absorption in plasma with static magnetic field. Here, we assume that the electron Bernstein wave is pre-existed in plasma. A high-power cosh-Gaussian laser beam couples

$$\vec{E}(y, z) = \hat{y}E_0 \cosh\left(\frac{yd}{w_0}\right) \exp\left(-\frac{y^2}{w_0^2}\right) e^{-i(\omega_0 t - k_0 z)}, \quad (1)$$

where  $\omega_0$  and  $k_0$  is the frequency and wave number of laser beam respectively.

The laser imparts oscillatory velocity to the plasma electrons. The expression of oscillatory velocity can be written as

$$\vec{v}_{\omega_0} = e\vec{E}/mi\omega_0. \quad (2)$$

An electron Bernstein wave with frequency  $\omega$  and wavenumber  $k$  exists in plasma with electrostatic potential  $\phi = \phi_0 e^{-i(\omega t - kr)}$ . The frequency of electron Bernstein wave can be written as

$$\omega = l\omega_c \left(1 + \frac{I_l(b)e^{-b}}{1 + k^2 v_{th}^2 / 2\omega_p^2}\right),$$

absorption coefficient enhances with increase in electron Bernstein wave frequency. This depicts that in the presence of electron Bernstein wave, the coupling of laser beam with it cause the strong absorption owing to enhance of nonlinear current density. It is interesting to see that a slight change in electron Bernstein wave frequency, the nonlinear current density is enhanced as compared with laser beam frequency. In this consideration, absorption coefficient of laser aided electron Bernstein wave is enhanced by increasing the value of electron Bernstein wave frequency.

with electron Bernstein wave. The nonlinear current density and self-consistent electric field are obtained because presence of density perturbation due to electron Bernstein wave and oscillatory velocity due to the laser beam. The absorption coefficient is strongly dependent on electron Bernstein wave frequency, laser frequency, beam decentred parameter, and electron cyclotron frequency. In Sec 2, we derive the electron Bernstein mode coupling with cosh-Gaussian laser beam. An expression of absorption coefficient is analytically derived in Sec. 3. The result and discussion of this theory are given in Sec4. Finally, summary and conclusion is presented in Sec 5.

## 2. Laser Coupling with Bernstein Wave

Consider a plasma with equilibrium electron density  $n_0$  immersed in a dc magnetic field  $\vec{B}_s \parallel \hat{z}$ . Here we launch pump laser beam having cosh-Gaussian profile with polarization along y-direction and it propagates along z-direction in the plasma. The electric field profile of cosh-Gaussian laser can be written as

In Fig. 2, we have plotted the variation of normalized absorption coefficient electron Bernstein wave aided cosh-Gaussian laser as a function of normalized laser beam propagation distance from y- axis for different values of laser beam decentred parameter. The peak profile of absorption is purely Gaussian for decentred parameter  $d=0$ . The energy density of laser beam profile increases with increase in beam decentred parameter. It is noticed that the absorption increases slowly upto the range of beam decentred parameter  $0 \leq d \leq 1$ . Further, it will rapidly increase upto the range of beam decentred parameter  $1 \leq d \leq 2$ . The above results prove that the beam decentred parameter is very sensitive parameter. This implies that the amplitude of normalized absorption coefficient is much more enhanced by varying the beam decentred parameter.

Fig. 3 depicts the variation of normalized absorption coefficient of electron Bernstein wave aided cosh-Gaussian laser as a function of normalized laser beam propagation distance from y- axis for different values of

laser normalized frequency. The peak profile of absorption increases very fast with slight increase in laser pump frequency. It is observed that the absorption is maximum for normalized laser pump frequency  $\omega_0/\omega_p \sim 1$ . Further, it decreases with increase in this value of pump frequency. Therefore, one can obtain the extreme absorption via taking proper value of laser pump frequency.

The variation of normalized absorption coefficient of electron Bernstein wave aided cosh-Gaussian laser as a function of normalized laser beam frequency for different values of normalized frequency of electron Bernstein wave is shown in Fig. 4. We can see that aid of Bernstein mode with laser leads to higher absorption in plasma. The absorption coefficient attains very low value in the absence of electron Bernstein mode ( $\omega/\omega_p = 0$ ). While in the presence of electron Bernstein wave it leads to enhance the absorption coefficient in plasma with static magnetic field. It is interesting to see that with slight change in electron Bernstein wave frequency it not only cause to enhance the absorption coefficient but also needs to provide lesser value of laser beam frequency as compared to previous one. The coupling of laser with electron Bernstein mode plays an effective role for enhancement in current density. In this consideration, one can conclude that the presence of electron Bernstein wave leads to stronger absorption in plasma.

### 5. Summary and Conclusions

In this paper, electron Bernstein wave aided cosh-Gaussian laser absorption was analytically investigated in plasma with static magnetic field. The amplitude of absorption is dependent on laser beam frequency, electron cyclotron frequency, coupled wave frequency, laser beam transverse propagation distance, beam decentred parameter, laser beam width, parameter  $b$ , and electron thermal velocity. The amplitude of absorption is found maximum at laser beam transverse propagation distance from  $y$ -axis  $y/w_0 \sim 0.96$ . The laser beam decentred parameter plays an effective and sensitive role for enhancement of amplitude of absorption coefficient. The graphical analysis predicts that coupling of laser beam with electron Bernstein wave promises stronger absorption as compared to only laser beam frequency. One can control and tune the amplitude of absorption coefficient

with proper value of parameter  $b$  and laser beam width. The extreme and intense absorption is appeared at normalized coupled wave frequency  $\omega_1/\omega_p \sim 0.20$  while normal absorption is appeared at normalized laser beam frequency  $\omega_0/\omega_p \sim 1$ . This shows that better absorption is obtained for electron Bernstein wave aided cosh-Gaussian laser as compared to only laser beam.

### Acknowledgement

The authors would like thankful to Department of Physics and Principal, K. N. Govt. P. G. College, Gyanpur, Bhadohi for providing the research facilities.

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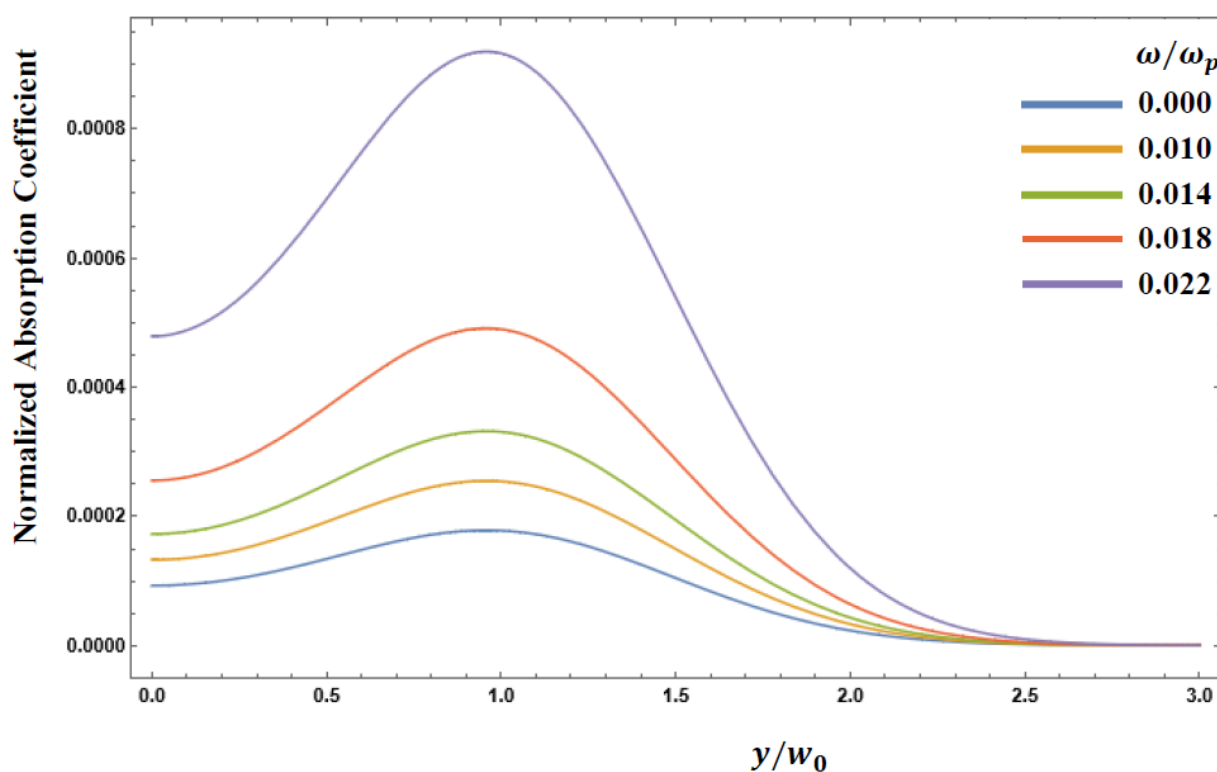


Fig. 1

Fig. 1: Variation of normalized absorption coefficient with normalized laser beam propagation distance from y-axis for different values normalized electron Bernstein wave frequency, when  $d=1$ ,  $b=1.8$ ,  $\omega_1/\omega_p = 0.5$ ,  $\omega_c/\omega_p = 0.2$ ,  $\omega/\omega_p = 0.01$ ,  $v_{th}/c = 0.2$

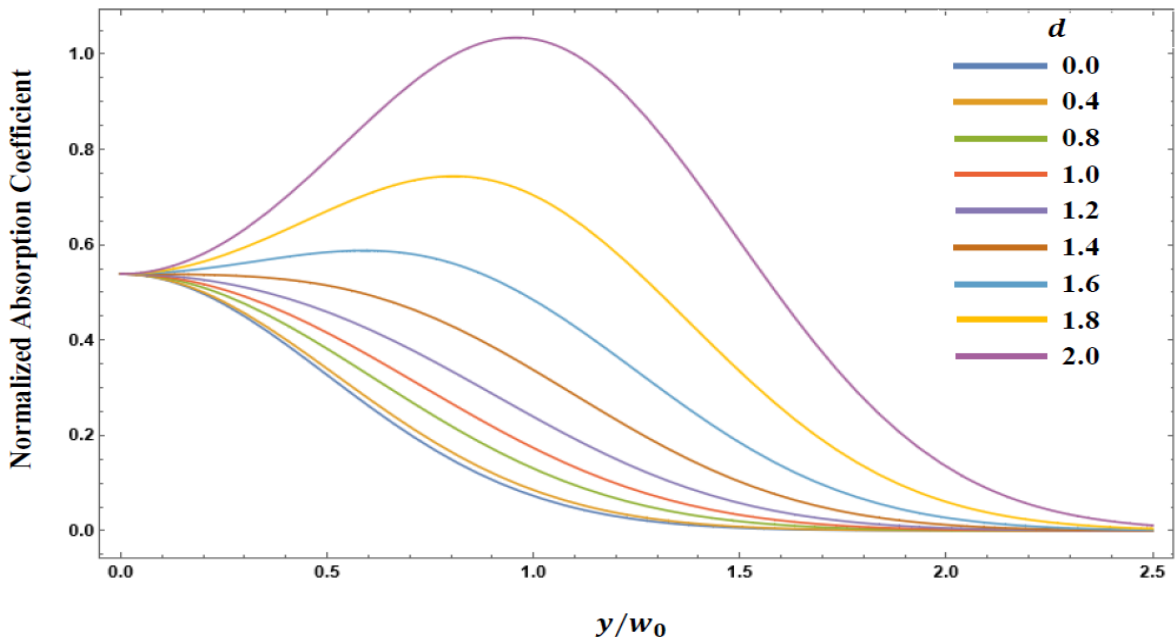


Fig. 2

Fig. 2: Variation of normalized absorption coefficient with normalized laser beam propagation distance from y-axis for different values of laser beam decentered parameter  $d$ , when  $b=1.8$ ,  $\omega_1/\omega_p = 0.5$ ,  $\omega_c/\omega_p = 0.2$ ,  $\omega/\omega_p = 0.01$ ,  $v_{th}/c = 0.2$

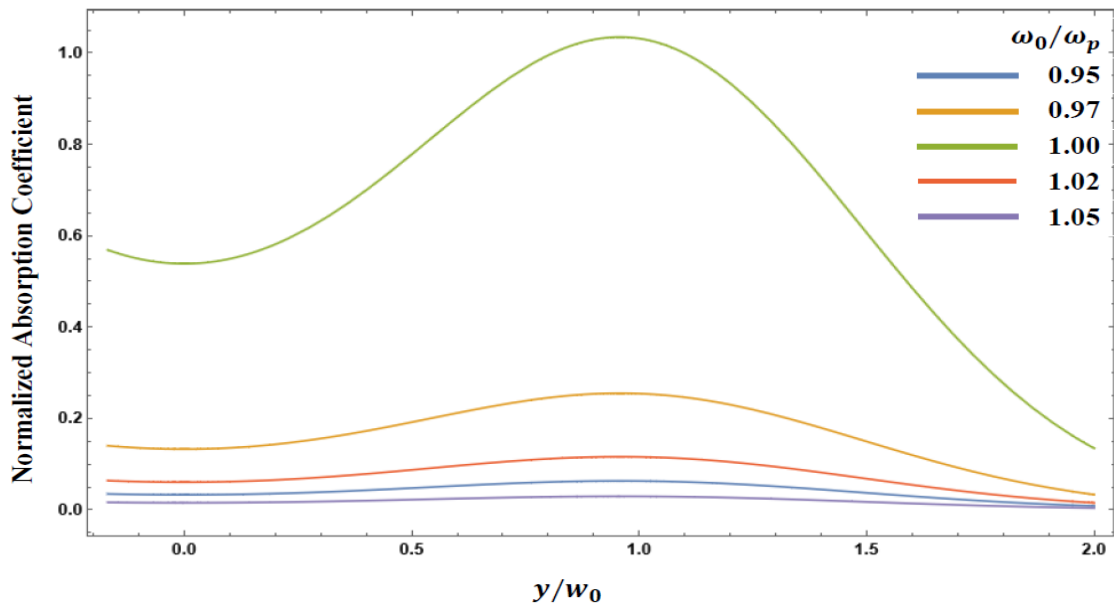


Fig. 3

Fig. 3: Variation of normalized absorption coefficient with normalized laser beam propagation distance from y-axis for different values of normalized laser beam frequency  $\omega_0/\omega_p$ , when  $d=1$ ,  $b=1.8$ ,  $\omega_c/\omega_p = 0.2$ ,  $\omega/\omega_p = 0.01$ ,  $v_{th}/c = 0.2$

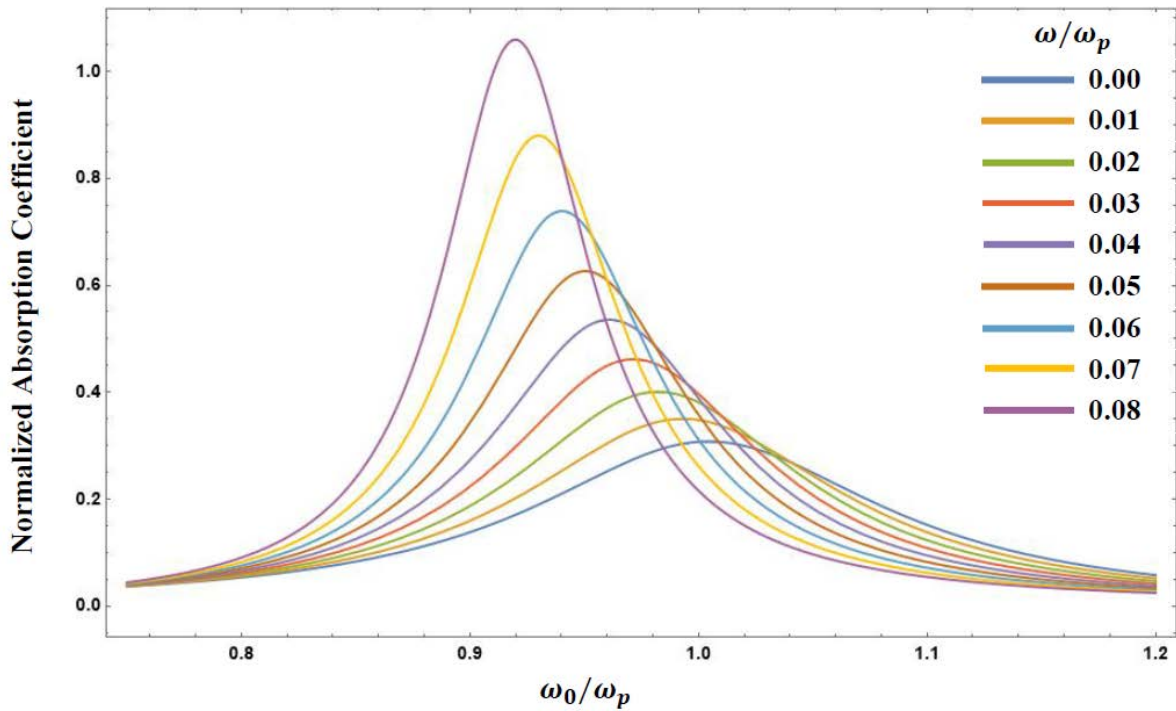
**Fig. 4**

Fig. 4: Variation of normalized absorption coefficient with normalized laser beam frequency  $\omega_0/\omega_p$  for different values of normalized electron Bernstein wave frequency  $\omega/\omega_p$ , when  $y/w_0 = 1$ ,  $d=1$ ,  $b=1.8$ ,  $\omega_c/\omega_p = 0.2$ ,  $v_{th}/c = 0.2$