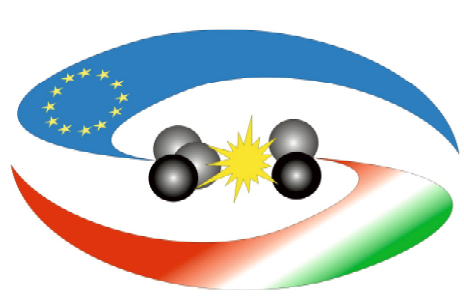




Interaction of electromagnetic waves and suprathermal electrons in the near-critical electric field limit

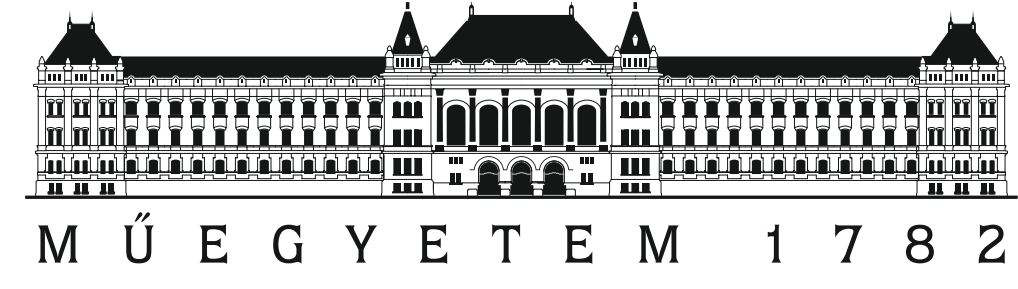


CHALMERS



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Abstract

The anisotropy of a suprathermal electron distribution can lead to destabilization of plasma waves through wave-particle resonant interaction. This work considers **electromagnetic wave instabilities driven by an anisotropic electron distribution** in near-critical field, both in super- and sub-critical cases.

If the electric field is sub-critical, suprathermal electrons do not destabilize electromagnetic waves. **If the electric field is super-critical**, both the electron-whistler and the **extraordinary electron wave** are **destabilized**, the latter more easily, requiring several order of magnitudes lower runaway density.

General dispersion of the waves

The general dispersion relation of high frequency electromagnetic waves with cold plasma approximation [1]:

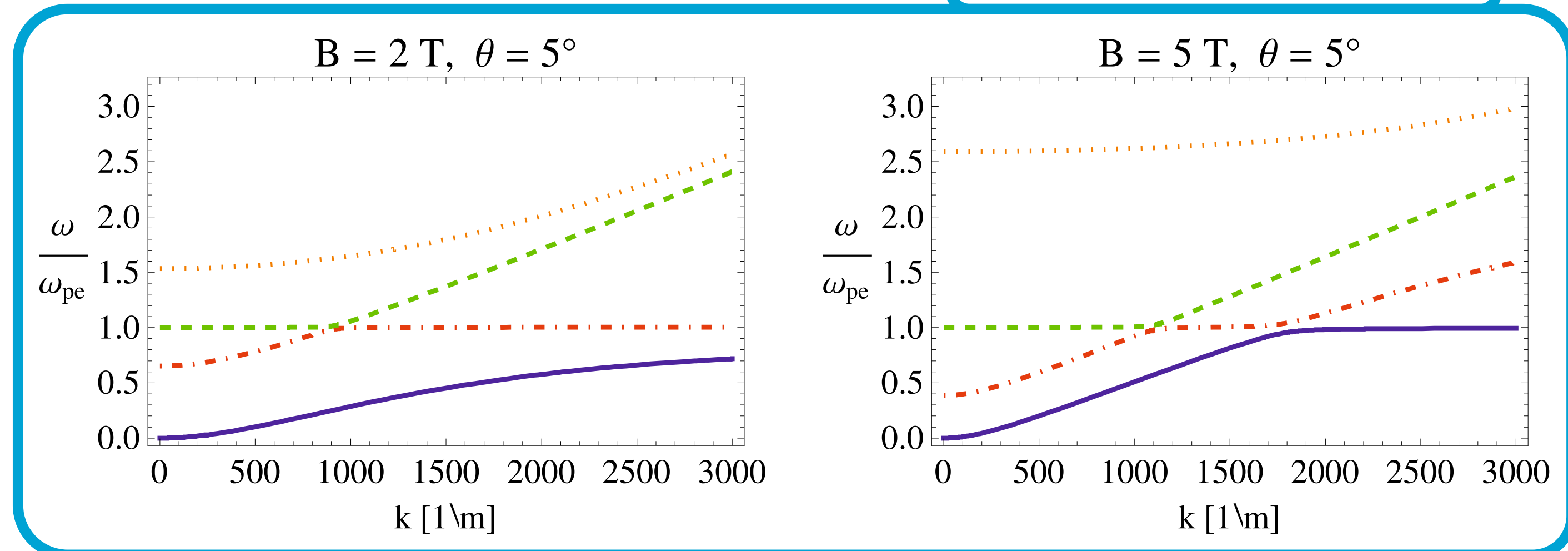
$$\left[\left(\epsilon_{11} - \frac{k_{\parallel}^2 c^2}{\omega^2} \right) \left(\epsilon_{22} - \frac{k_{\perp}^2 c^2}{\omega^2} \right) + \epsilon_{12}^2 \right] \left(\epsilon_{33} - \frac{k_{\perp}^2 c^2}{\omega^2} \right) - \frac{k_{\parallel}^2 k_{\perp}^2 c^4}{\omega^4} \left(\epsilon_{22} - \frac{k_{\perp}^2 c^2}{\omega^2} \right) = 0$$

$$\epsilon = \mathbf{1} + \chi^i + \chi^e + \chi^r$$

dielectric tensor

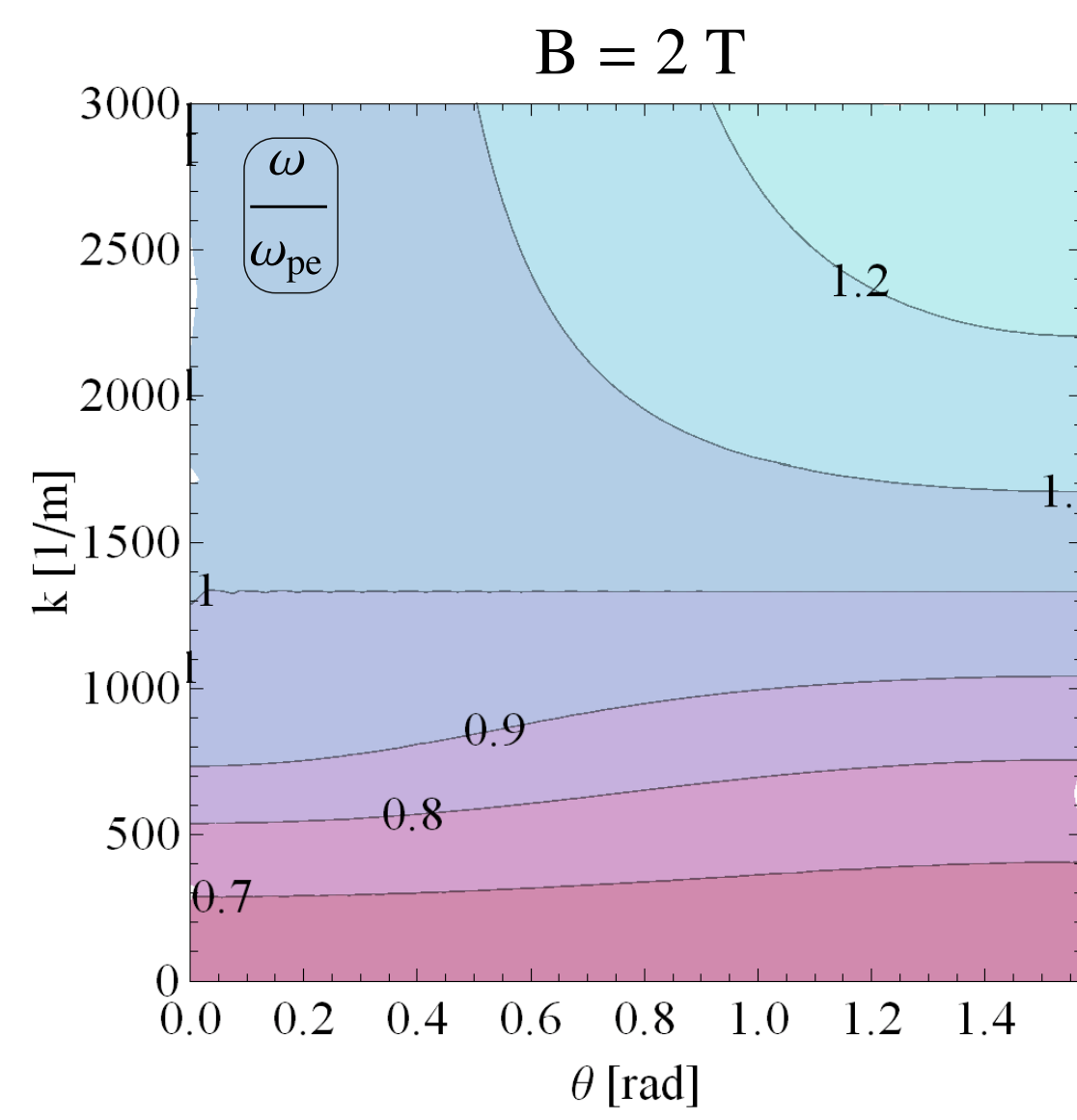
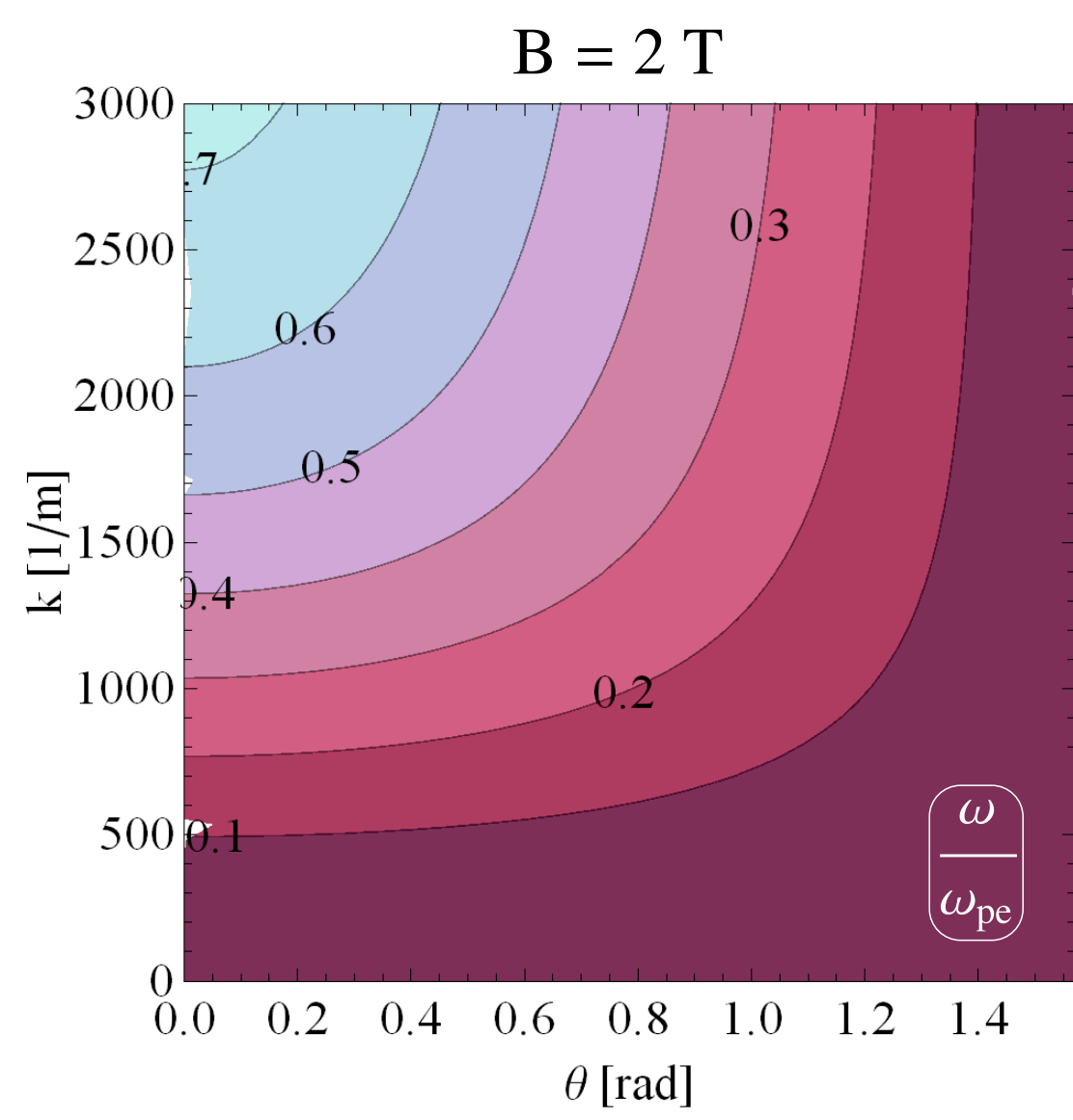
Four branches for

$$\frac{\omega_{ce}}{\sqrt{m_i/m_e}} \ll \omega \sim \omega_{ce}$$



Electron-whistler wave

Extraordinary electron wave



Suprathermal electron population

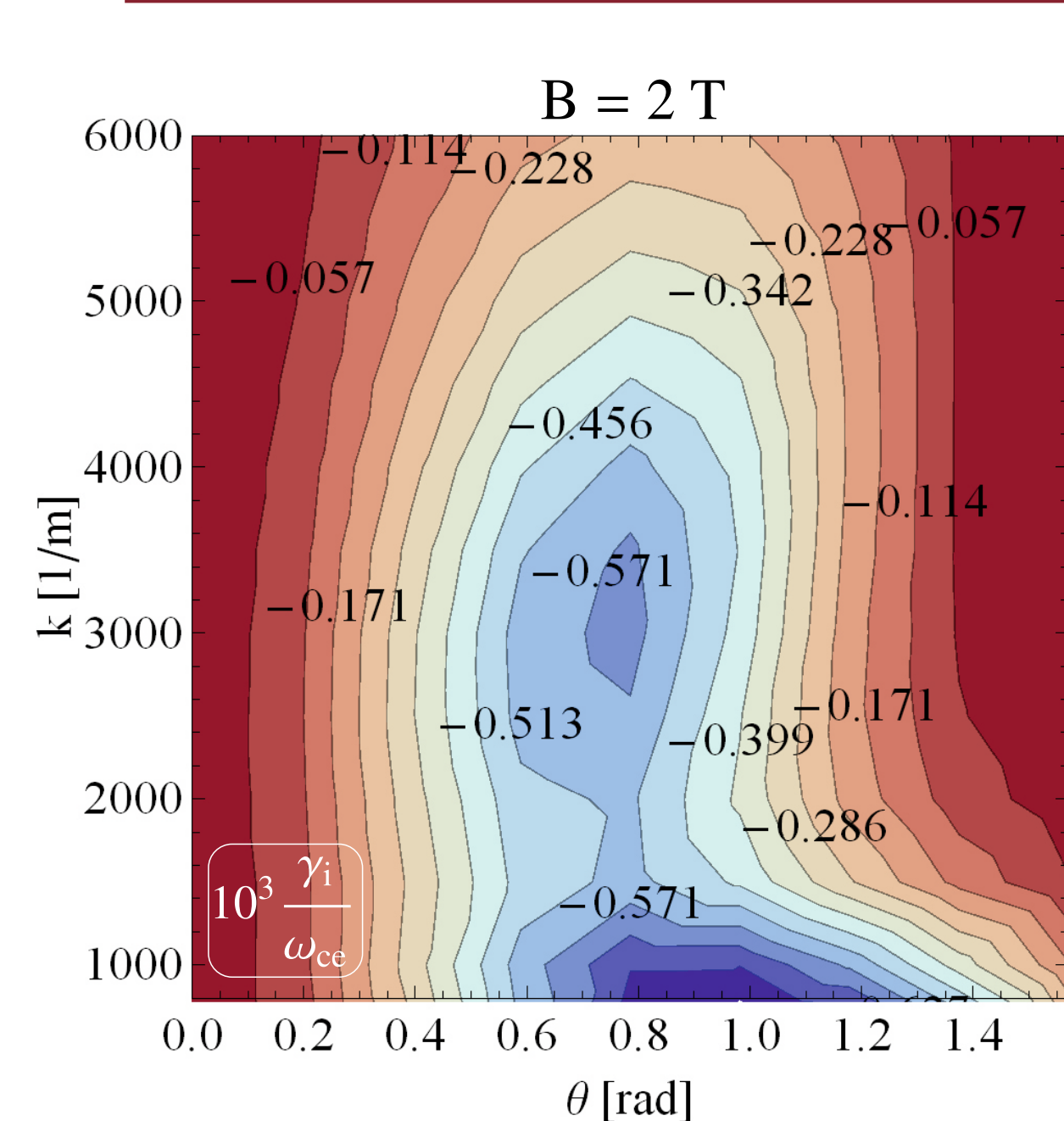
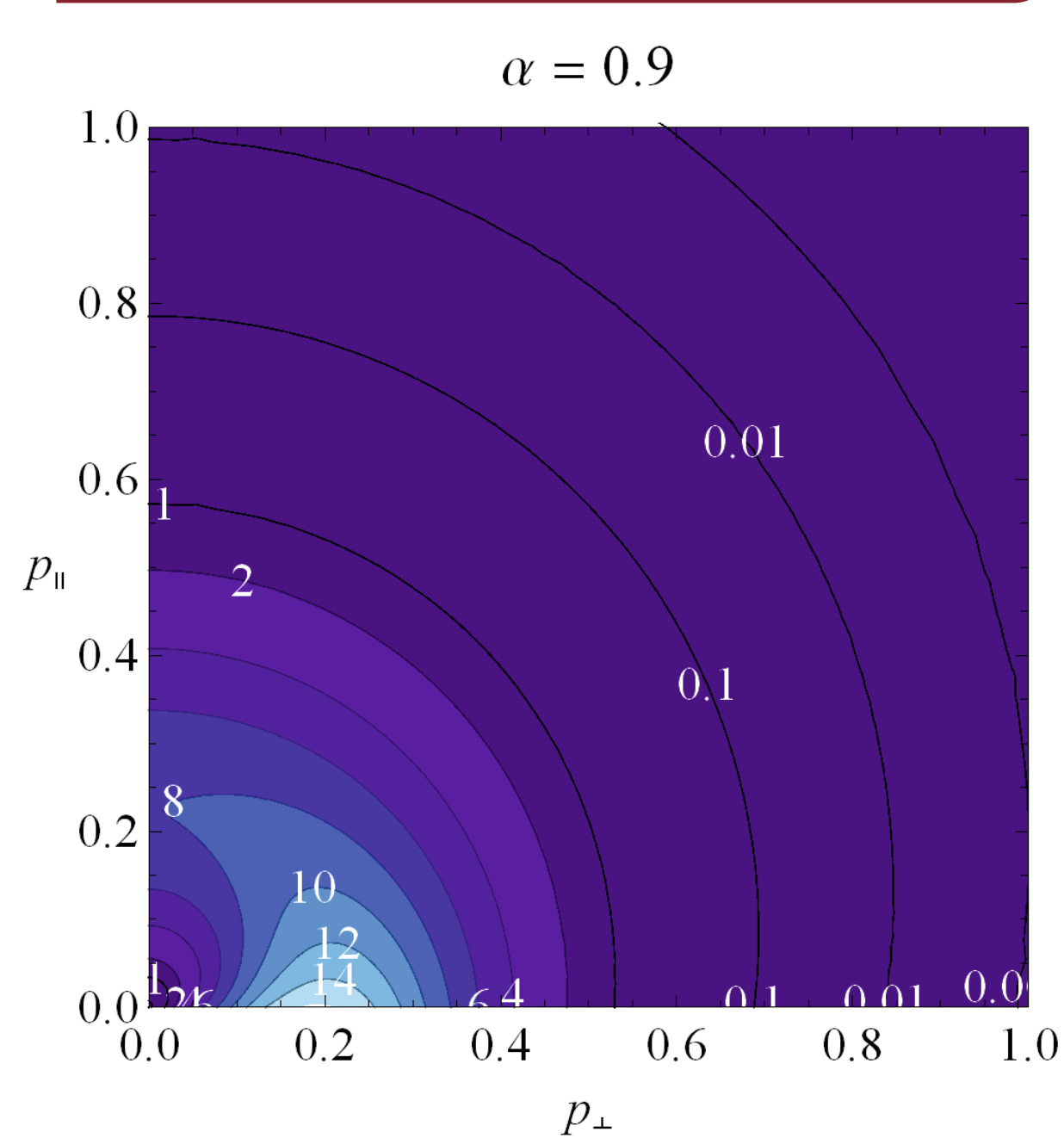
Electron population: taken into account with their susceptibility [1]
First order perturbative analysis

$$\text{Growth rate: } \gamma_i = \Im(\delta\omega) \sim \Im(\chi^r)$$

$$\Im\chi^r(\mathbf{k}, \omega) \sim \int_0^\infty dp_{\perp} \int_{-\infty}^\infty dp_{\parallel} \sum L(n) \left(\frac{\partial f_r}{\partial p_{\perp}} \frac{n\omega_{ce}}{\gamma} + \frac{\partial f_r}{\partial p_{\parallel}} \frac{k_{\parallel} c p_{\perp}}{\gamma} \right) \cdot \delta(\omega\gamma - k_{\parallel} c p_{\parallel} - n\omega_{ce})$$

Distribution function

Growth rate

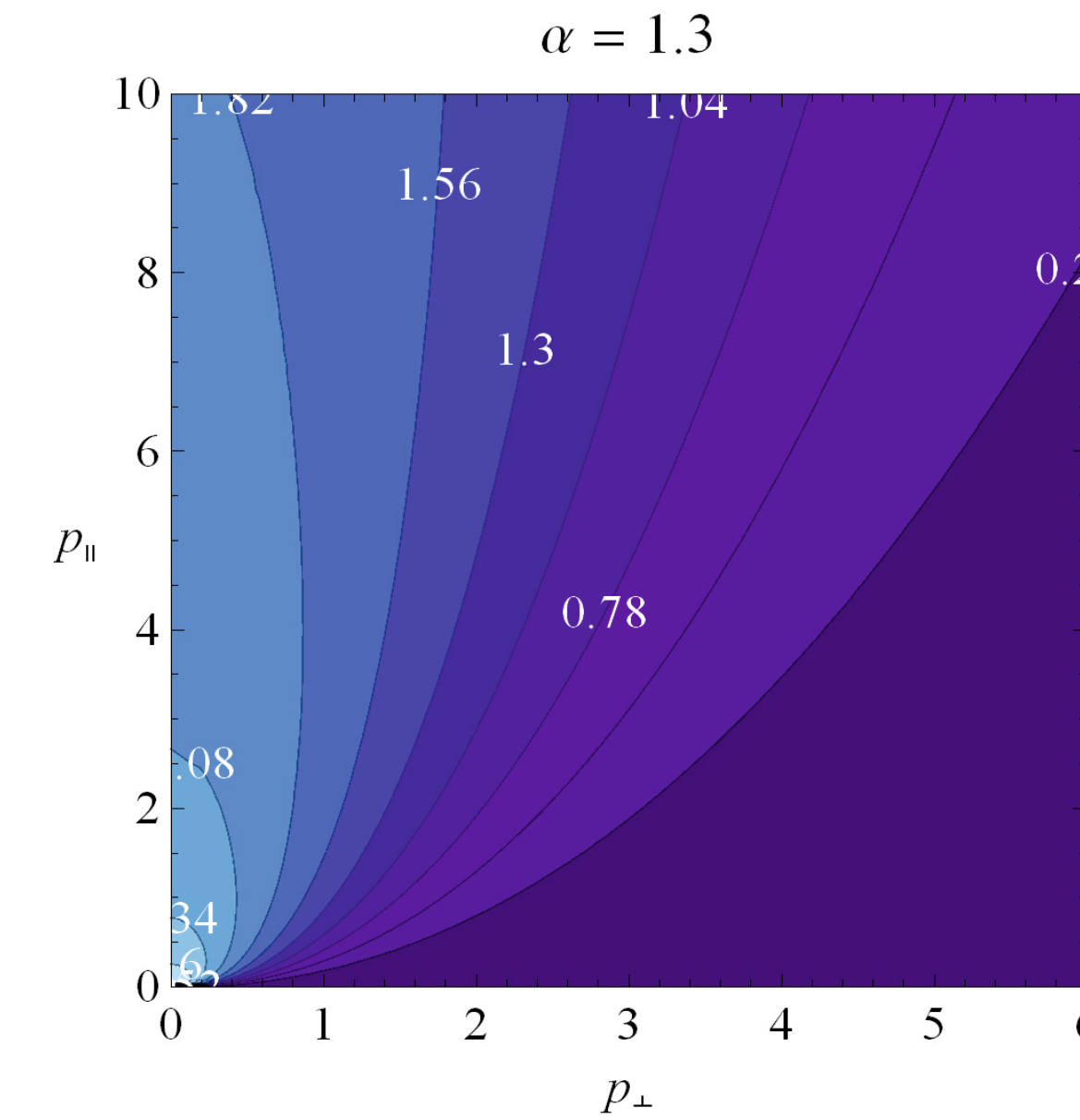


Runaway population

The runaway distribution for near-critical electric field is [2]:

$$f_r(p_{\parallel}, p_{\perp}) = \frac{A}{p_{\parallel}^{(C_s-2)/(\alpha-1)}} \exp\left(-\frac{(\alpha+1)p_{\perp}^2}{2(1+Z)p_{\parallel}}\right) {}_1F_1\left(1 - \frac{C_s}{\alpha+1}, 1; \frac{(\alpha+1)p_{\perp}^2}{2(1+Z)p_{\parallel}}\right)$$

where $\alpha = E/E_c$, Z is the effective ion charge and $C_s = \alpha - \frac{(1+Z)}{4}(\alpha-2)\sqrt{\frac{\alpha}{\alpha-1}}$



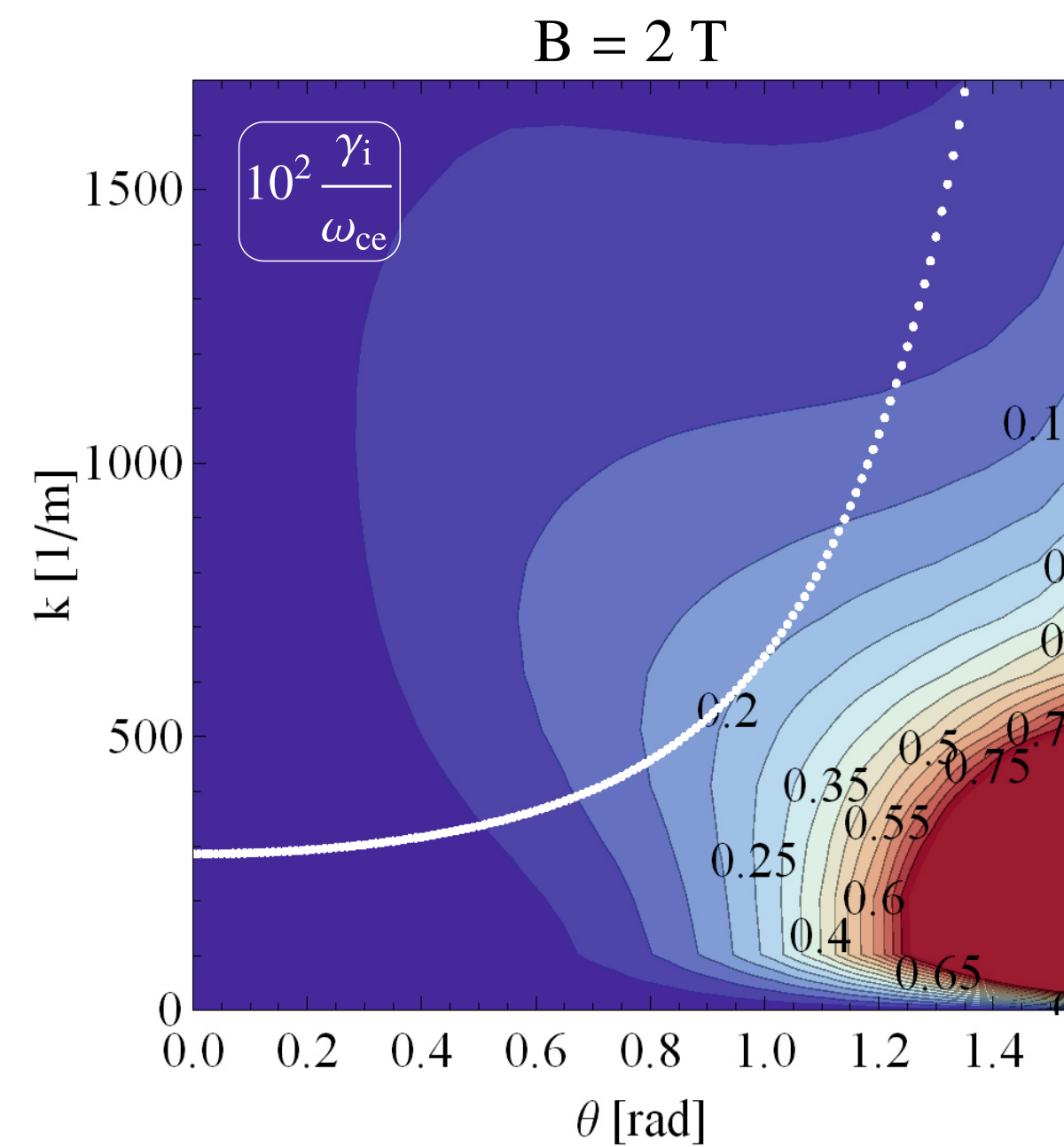
Resonance condition

$$p_{\parallel} = \frac{\omega_0 \gamma - n\omega_{ce}}{k_{\parallel} c}$$

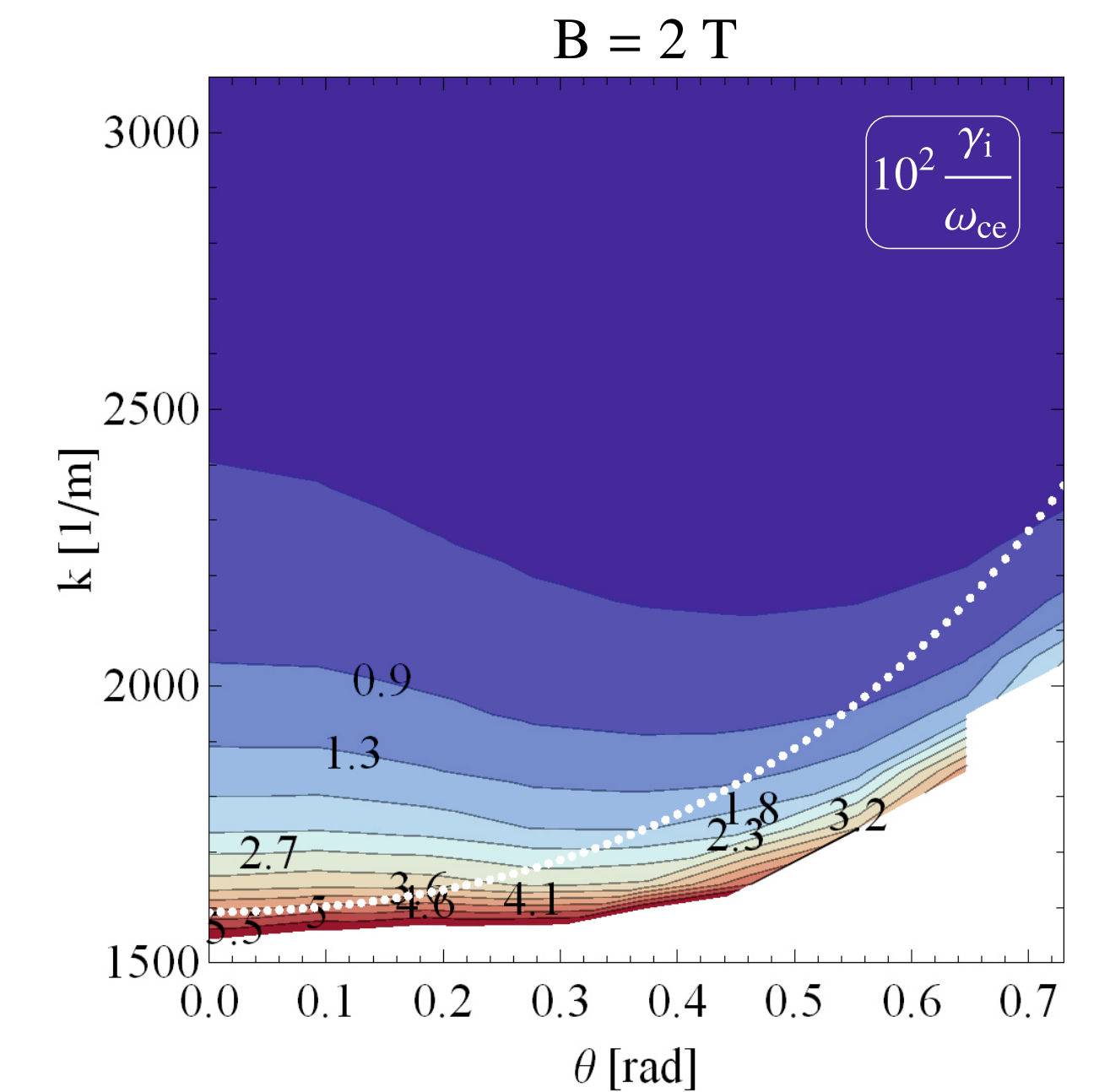
ω_0 : dispersion of the wave ω_{ce} : electron cyclotron frequency
 γ : relativistic factor c : speed of light

Most unstable wave

Electron-whistler wave



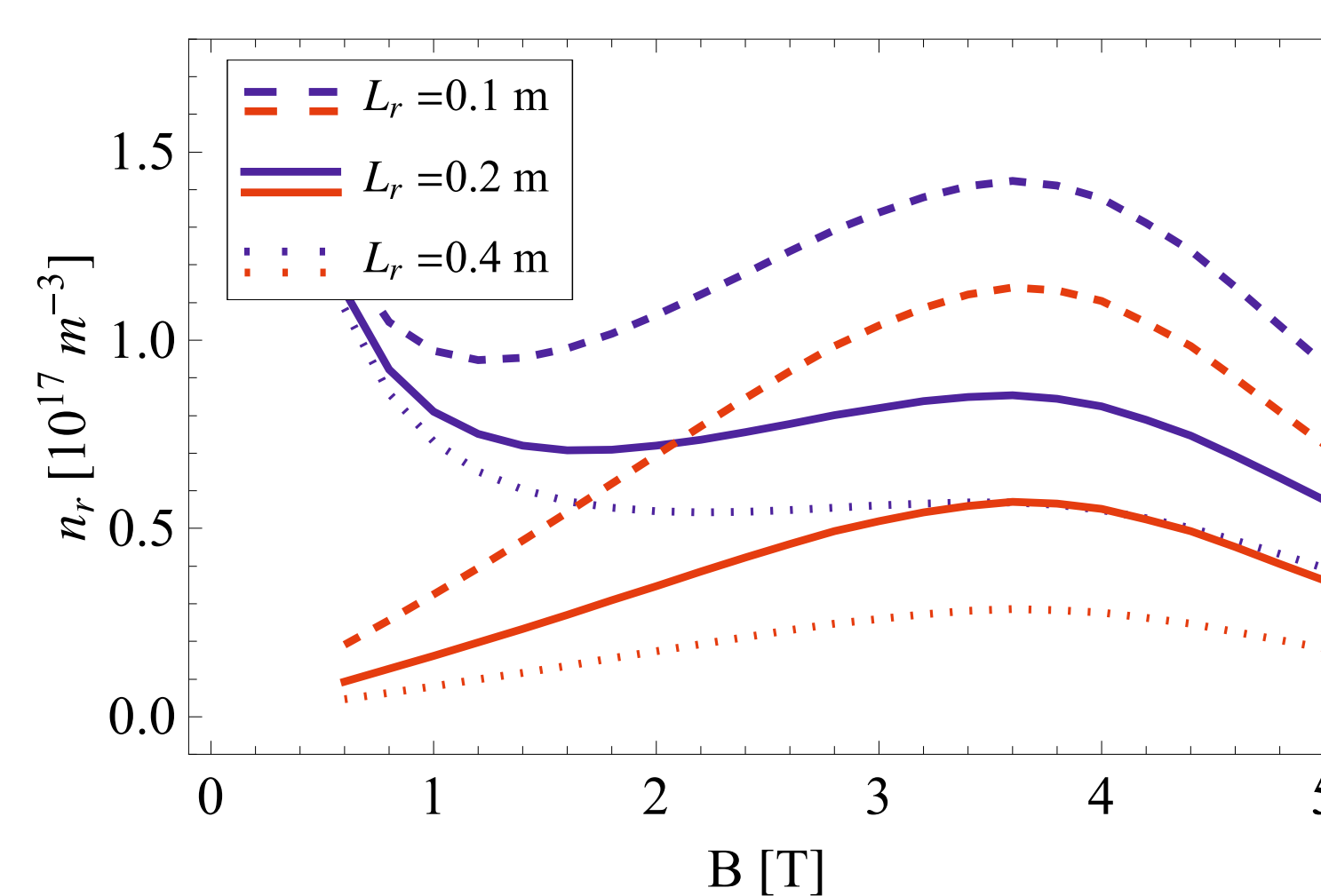
Extraordinary electron wave



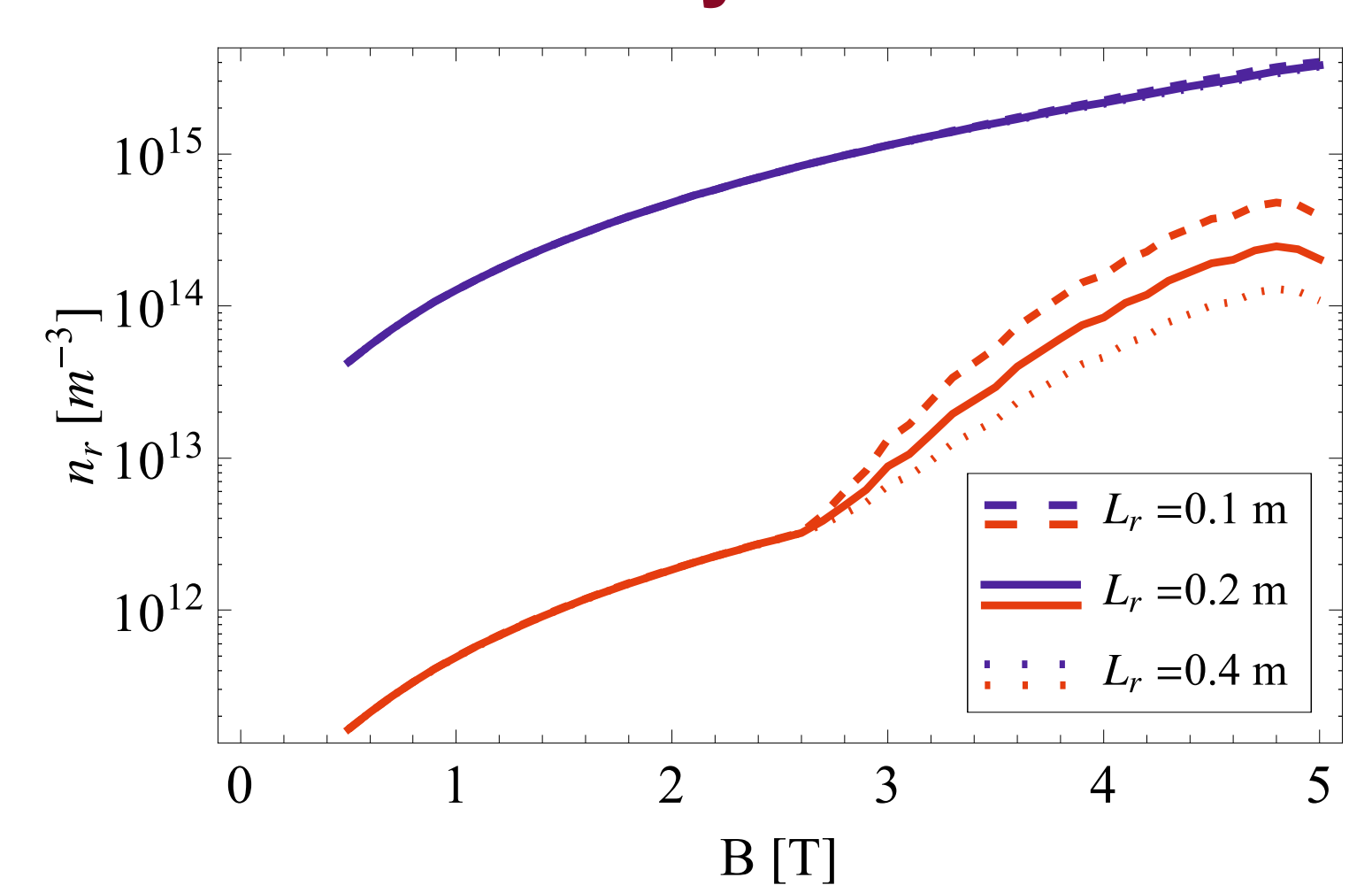
Most unstable wave: destabilized by the maximum energy runaways for both waves [3]
(white dots correspond to the energy of 2.6 MeV)

Stability: growth rate compared to the collisional and convective damping [5,7]
electron temperature: 20 eV (blue lines) and 1 keV (red lines)

Electron-whistler wave



Extraordinary electron wave



Conclusions

If the electric field is slightly lower than the critical field, the **suprathermal population** has a **stabilizing effect** on the waves.

If the electric field is slightly higher than the critical field, the **extraordinary electron wave**, arising from the general wave dispersion is **significantly more easily destabilized** than the whistler wave. For temperatures higher than 500 eV, there is a **threshold around 2.5 T**, and above this threshold the critical density is several order of magnitudes higher than below this threshold.

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