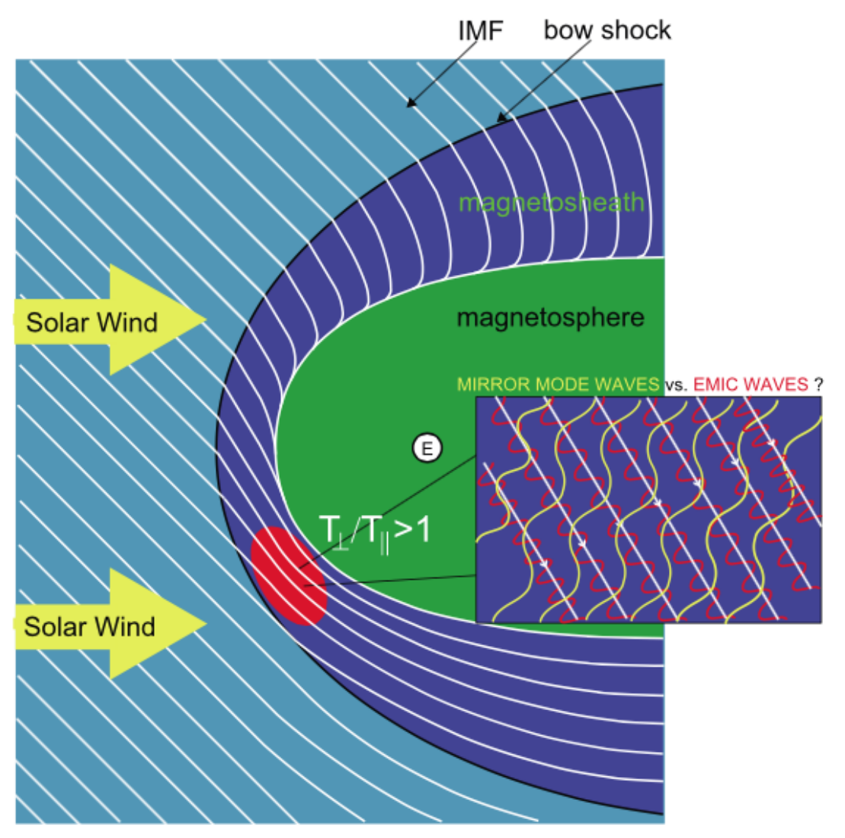
Effects of Electron Anisotropy on Mirror Instability Evolution in the Magnetosheath

Narges Ahmadi, Kai Germaschewski, Joachim Raeder
Space Science Center, University of New Hampshire, Durham, NH
University of New Hampshire

INTRODUCTION

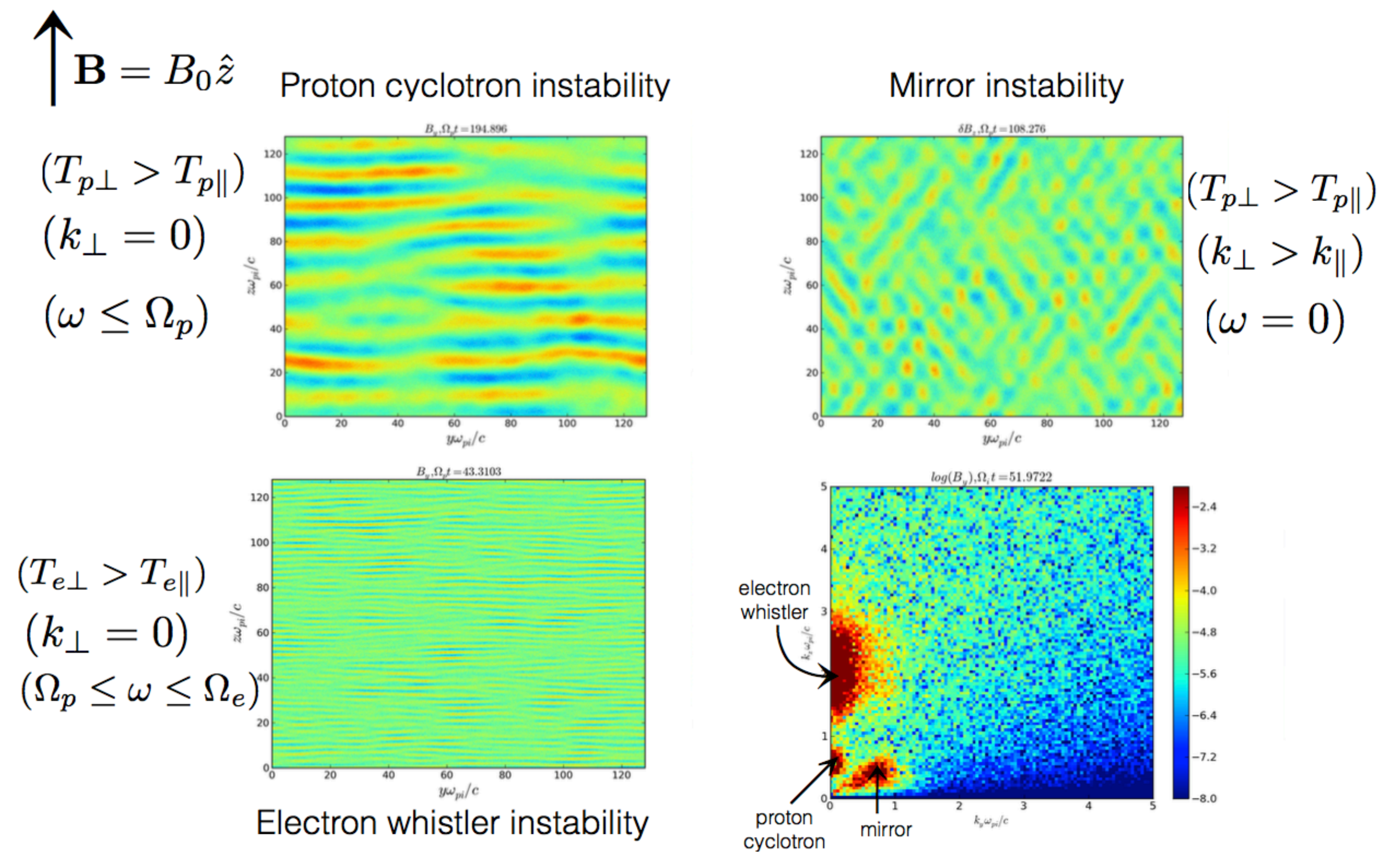
- The magnetosheath plasma, flowing around the magnetospheric cavity, exhibits large-scale inhomogeneities. These large-scale processes lead to plasma compression, expansion, depletion, velocity shear and introduces a particle temperature anisotropy. Dayside magnetosheath behind the quasi-perpendicular portion of the bow shock is characterized by $T_\perp > T_\|$ which leads to generation of low frequency waves.



After Shoji et al. (2009)

- Proton cyclotron waves are observed in low β_p regions whereas mirror waves are observed in high β_p regions. These waves are usually observed near the marginal stability of the corresponding instability in the ($\beta_{p||}$,$T_{p\perp}/T_{p||}$) parameter space.
- Proton cyclotron instability has larger growth rates compared to the mirror instability. Mirror modes are frequently observed in the magnetosheath. It is suggested that electron anisotropy can enhance the mirror instability growth rate while leaving the proton cyclotron instability unaffected, therefore, proton mirror mode can suppress the proton cyclotron mode.
- Electron anisotropy $T_{e\perp} > T_{e\|}$ creates electron whistler instability and electron mirror instability. Electron whistler instability has larger growth rate compared to the electron mirror instability in a typical magnetosheath plasma parameters.

ANISOTROPY INSTABILITIES



$\mathbf{B} = B_0\hat{z}$

Proton cyclotron instability

$(T_{p\perp} > T_{p\|})$
$(k_\perp = 0)$
$(\omega \le \Omega_p)$

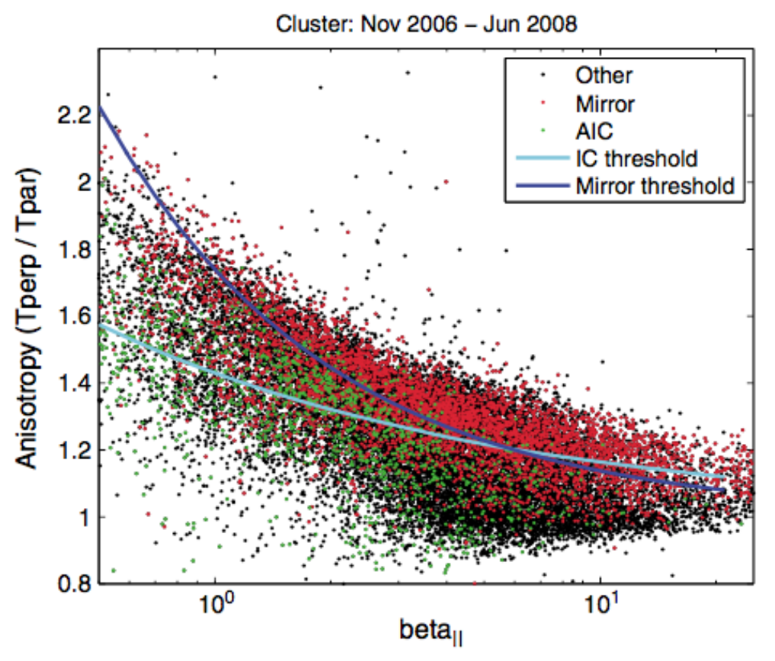
Mirror instability

$(T_{p\perp} > T_{p\|})$
$(k_\perp > k_\|)$
$(\omega = 0)$

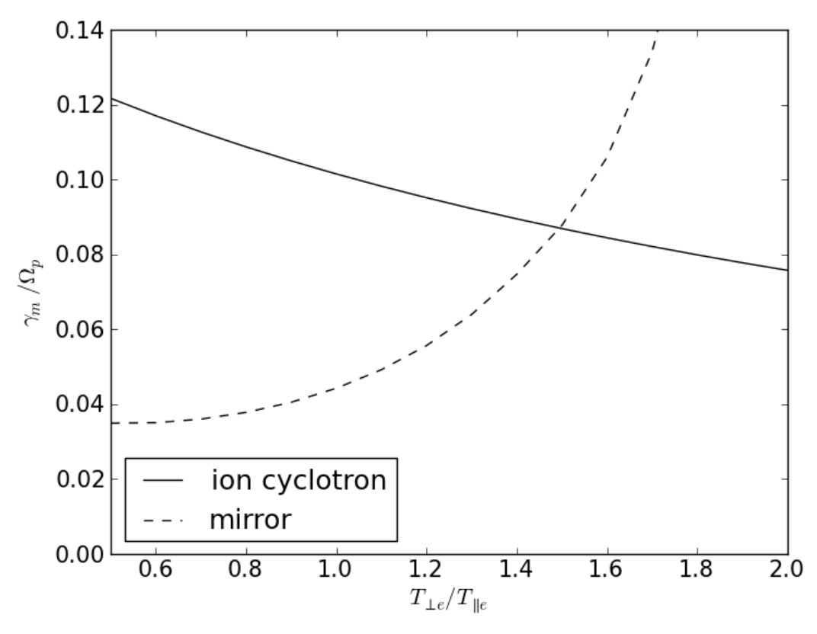
$(T_{e\perp} > T_{e\|})$
$(k_\perp = 0)$
$(\Omega_p \le \omega \le \Omega_e)$

Electron whistler instability

LINEAR DISPERSION RELATION

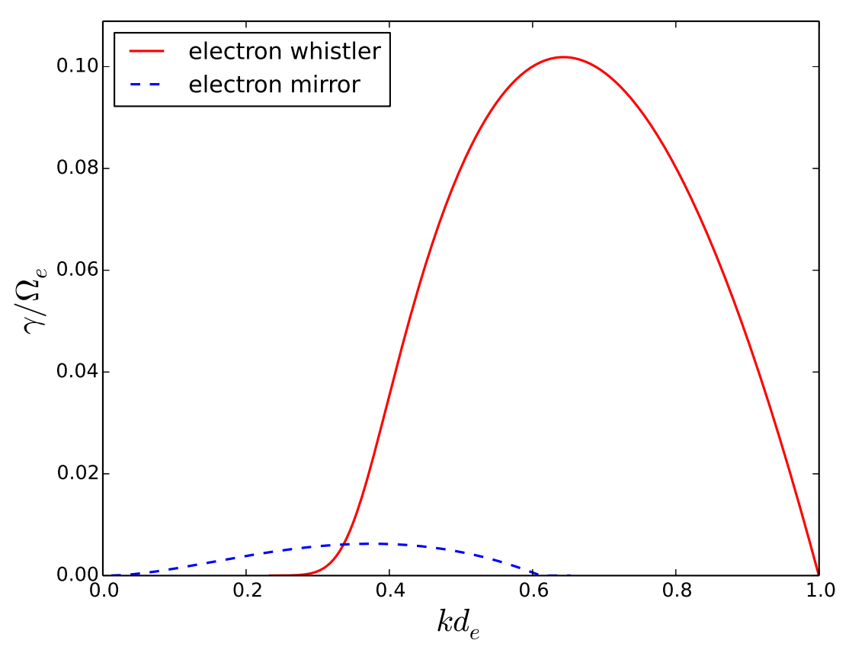


After Soucek et al. (2015)



$T_{p\perp}/T_{p\|} = 2.5, \beta_{p||} = 1.$

- Mirror instability has been observed in the magnetosheath regions that proton cyclotron instability has to be dominant based on linear dispersion relation.
- Electron anisotropy enhances the mirror instability growth rate while leaving proton cyclotron instability almost unaffected according to linear dispersion relation.



$T_{e\perp}/T_{e\|} = 2, \beta_{e||} = 1.$

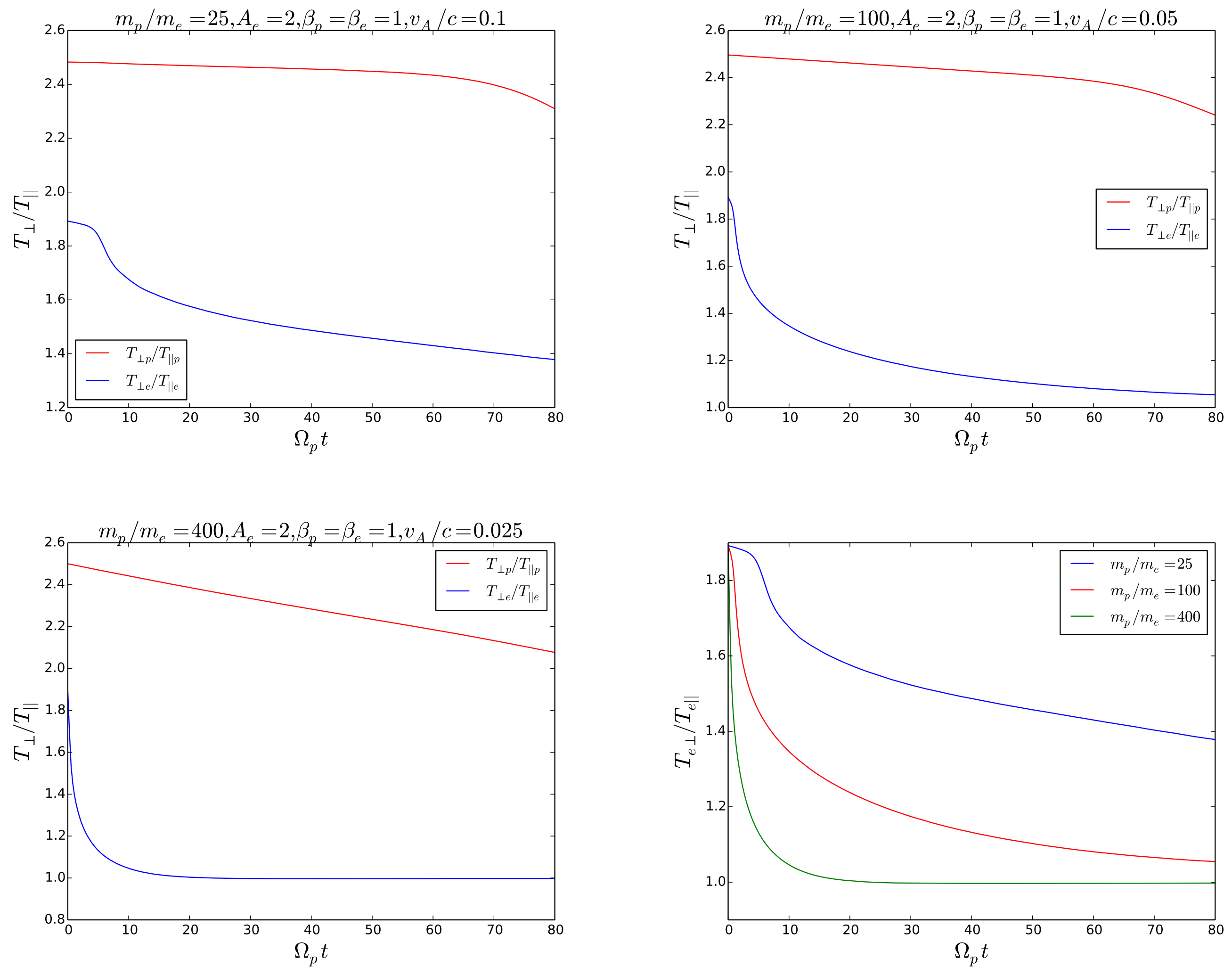
- Does electron anisotropy help the mirror instability to suppress the proton cyclotron instability?

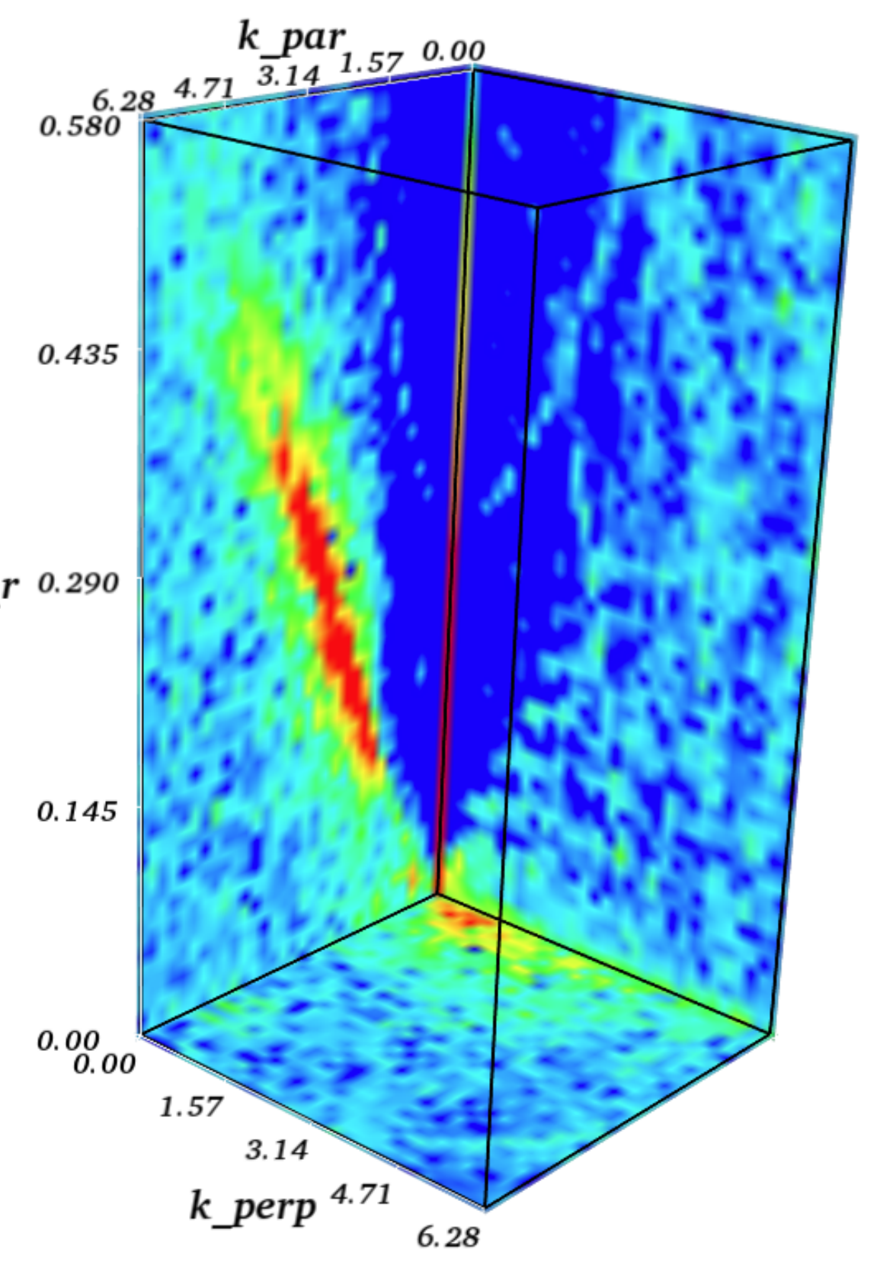
PIC SIMULATIONS

Simulation parameters are:

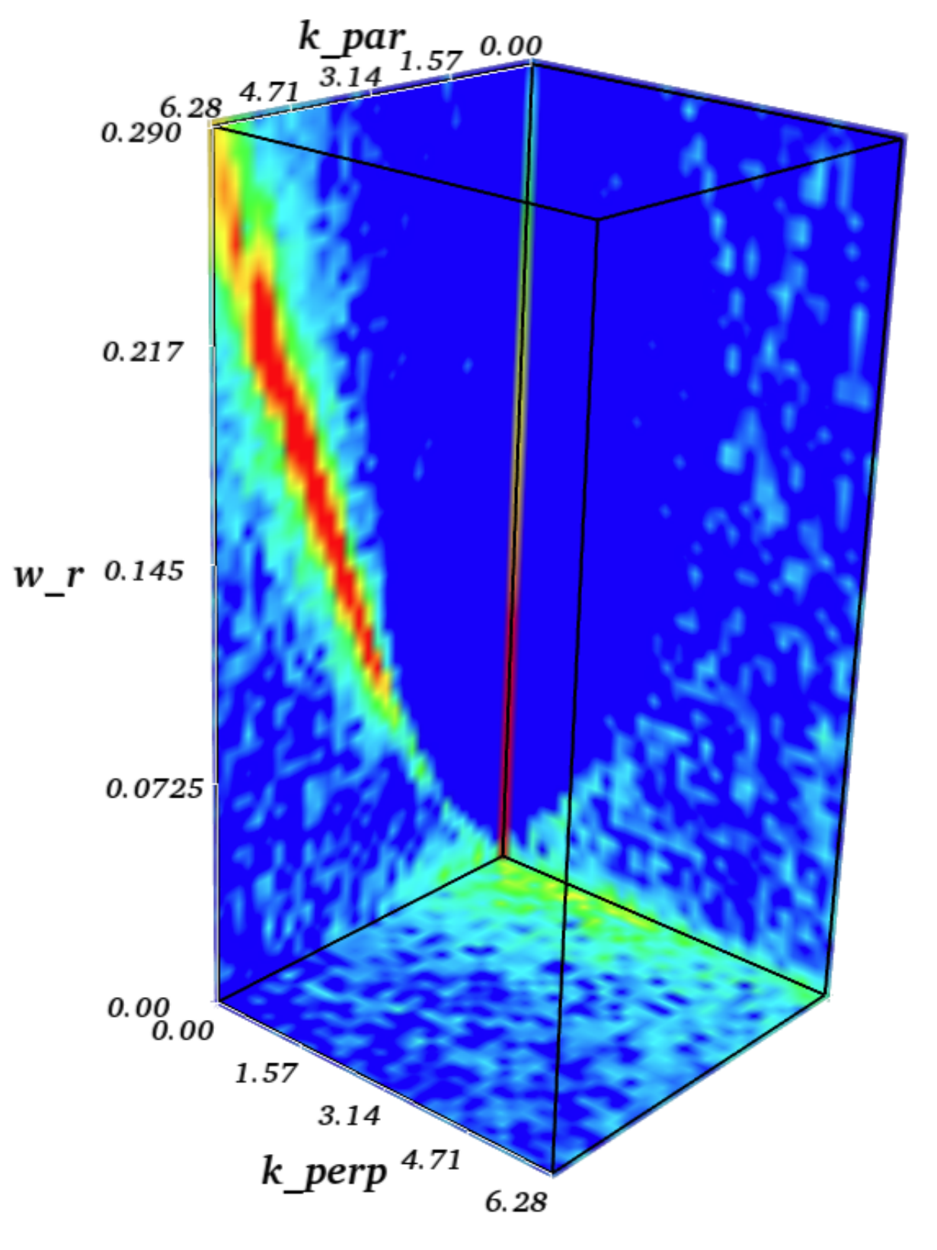
$$L_y = L_z = 32d_i, n_y = n_z = 1024, n_{cell} = 200, A_p = 2.5, A_e = 2, \beta_p = 1, \beta_e = 1$$

These results show the dependence of electron whistler instability saturation rate to mass ratio in fully kinetic simulations.



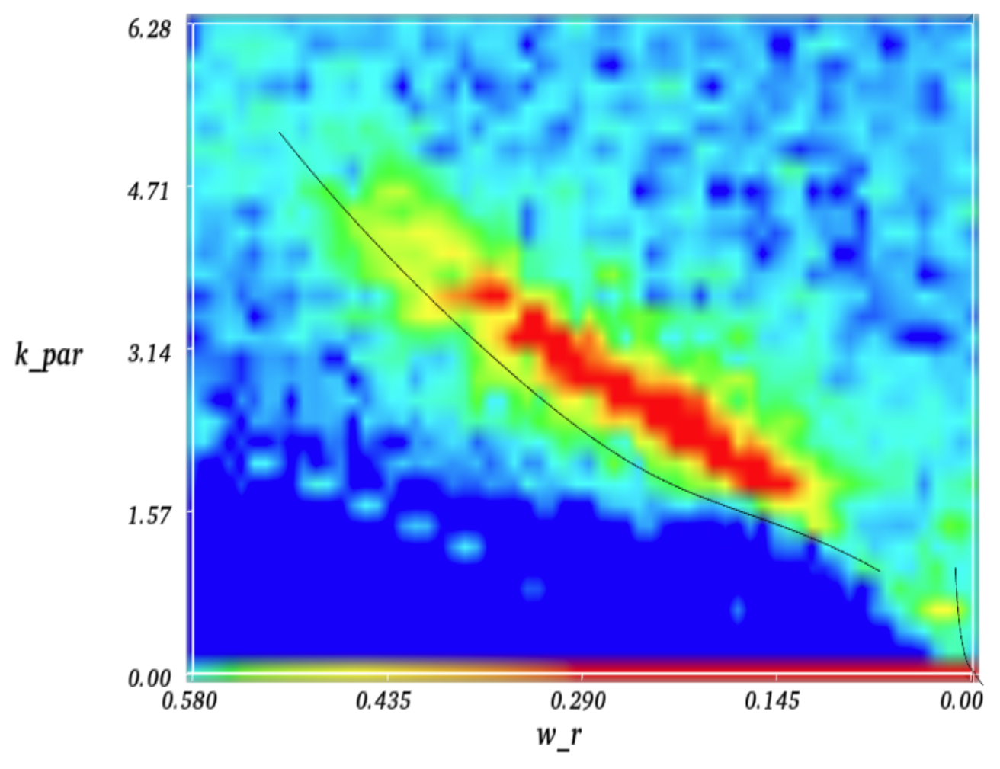


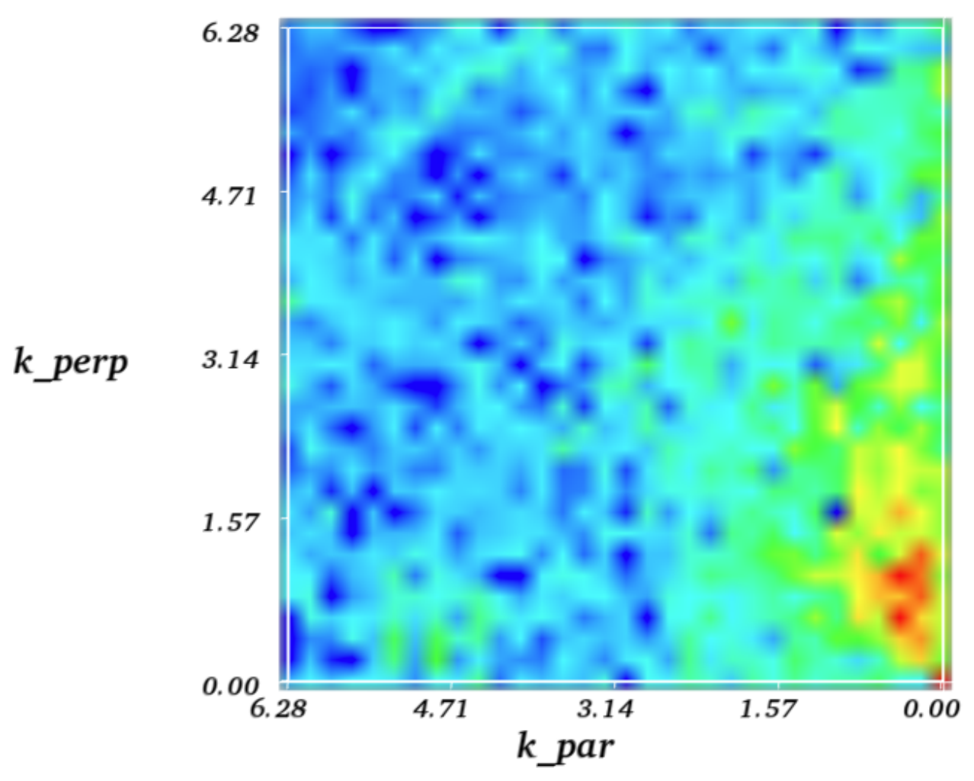
$m_p/m_e = 25$

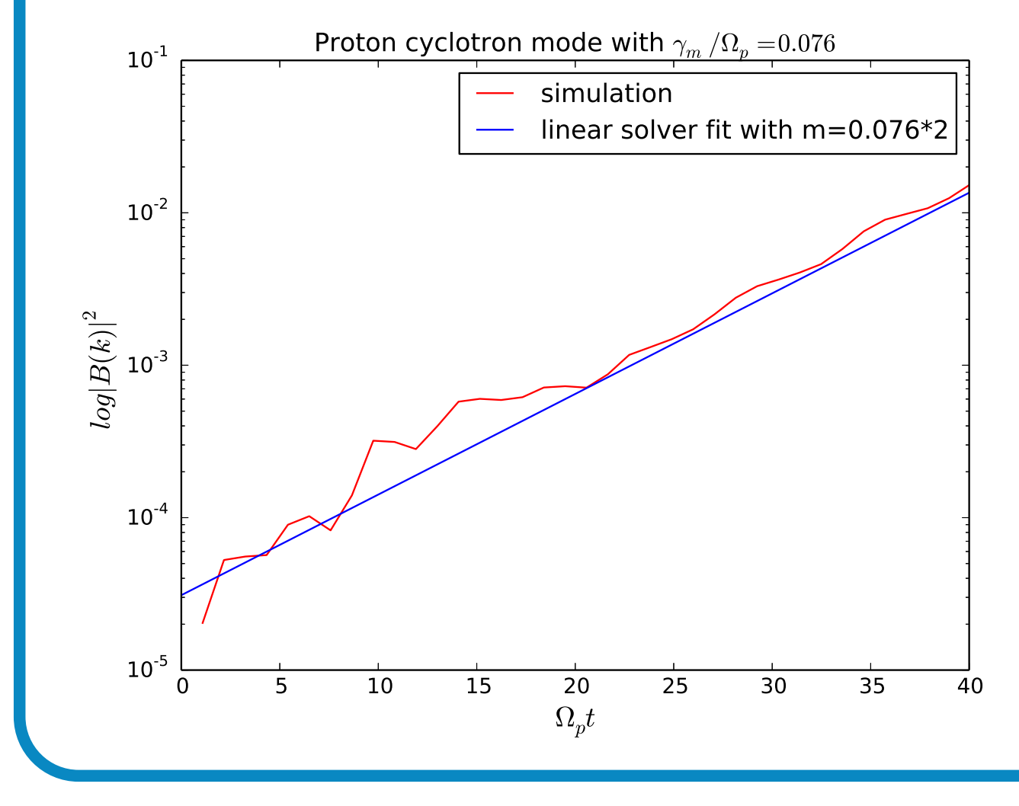


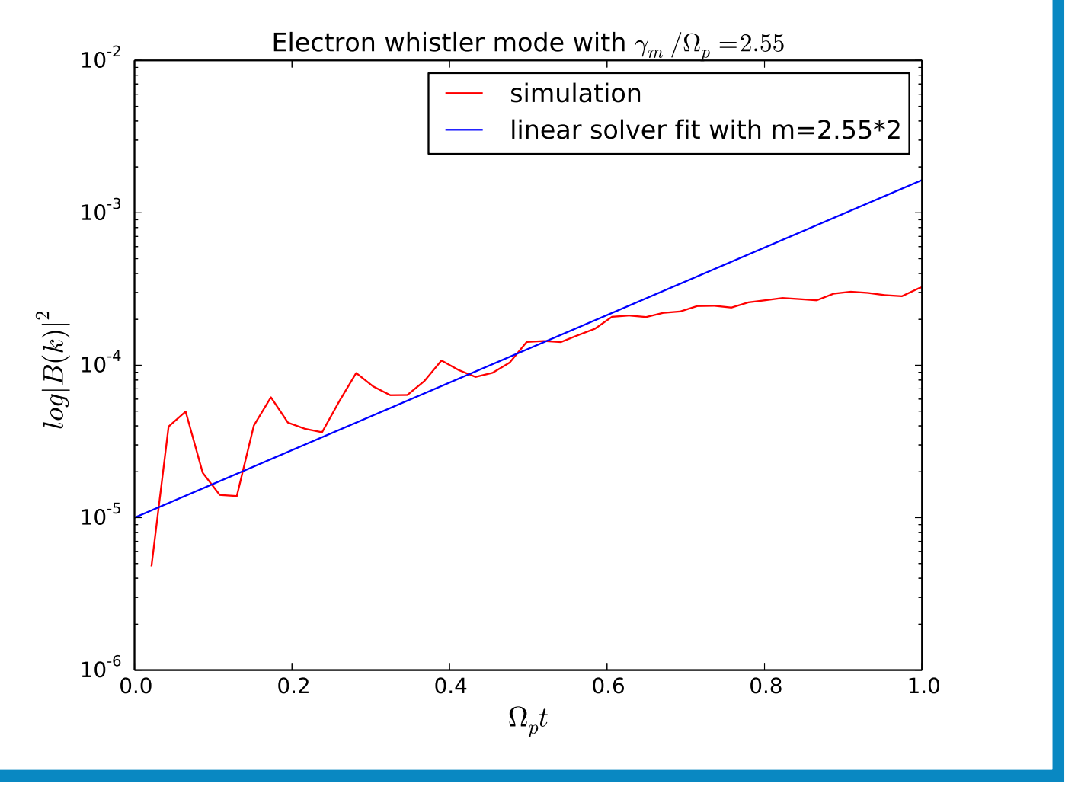
$m_p/m_e = 100$

- comparing the simulation result with linear dispersion solver:









CONTACT

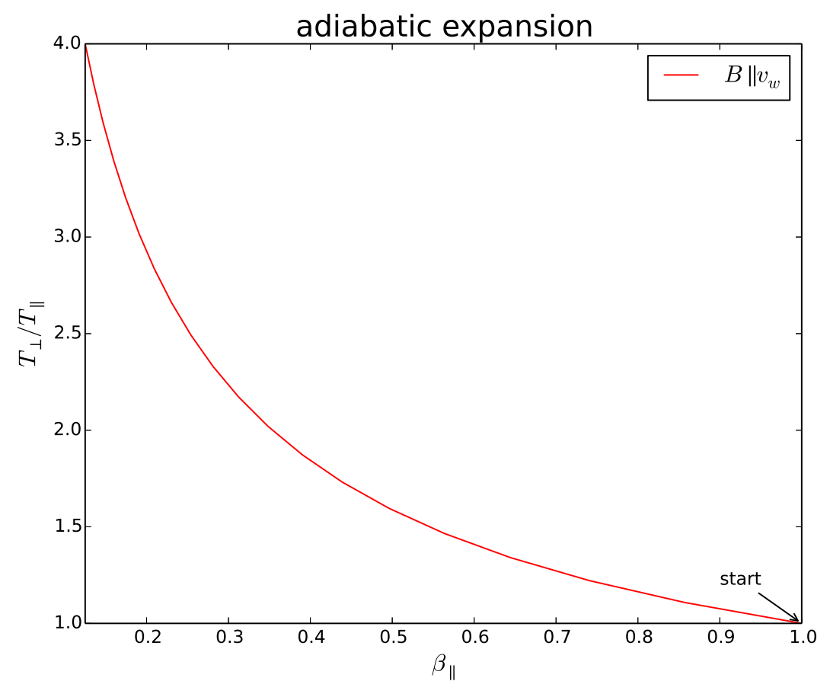
- Email: narges.ahmadi@unh.edu, University of New Hampshire, Durham, NH 03824

EXPANDING BOX SIMULATIONS

In the case of a slow expansion, when there are no waves present in the system, the first and second adiabatic invariants would be conserved, based on CGL condition,

$$\text{First adiabatic invariant:} --> \quad \frac{d}{dt}\left(\frac{p_\perp}{nB}\right) = 0 \quad --> \quad T_\perp \propto B$$

$$\text{Second adiabatic invariant:} --> \quad \frac{d}{dt}\left(\frac{p_{||}B^2}{n^3}\right) = 0 \quad --> \quad T_\| \propto \frac{n^2}{B^2}$$



$$n(t) \propto 1/L(t)$$

$$B \propto constant$$

$$T_\perp \propto constant$$

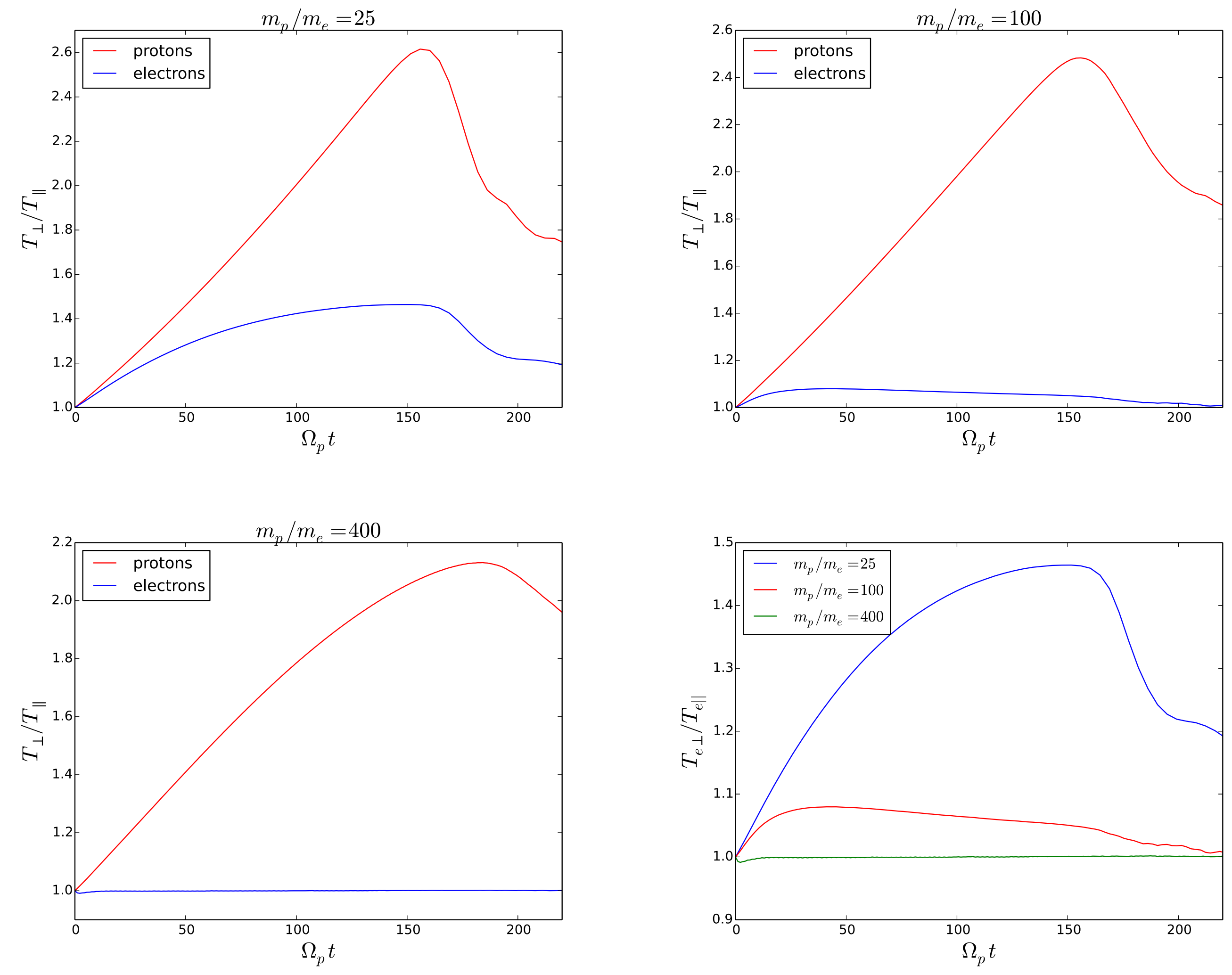
$$T_\| \propto 1/L(t)^2$$

$$\beta_\perp \propto 1/L(t)$$

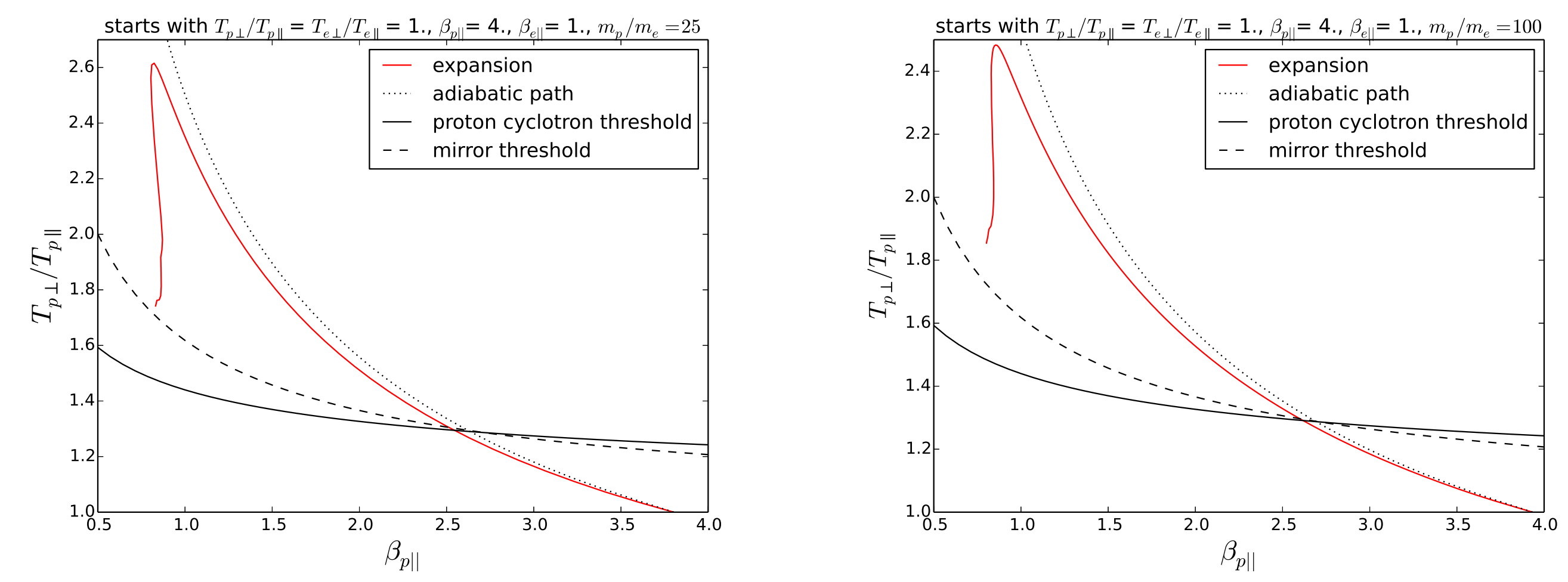
$$\beta_\| \propto 1/L(t)^3$$

MARGINAL STABILITY PATH IN PARALLEL EXPANSION

Simulations start with $L_y = 64d_i$, $L_z = 32(1 + t/t_c)d_i$, $t_c = 222\Omega_p^{-1}$, $\mathbf{B} = B_0\hat{z}$ and they end with $L_z = 64d_i$ which is 2 times larger than the initial length. Initially, the simulated system evolves almost adiabatically and becomes strongly unstable with respect to the proton cyclotron, mirror modes and electron whistler instability.



We see that electron whistler instability starts to isotropize the electrons differently for each mass ratio. In the case with $m_p/m_e = 400$, electrons become isotropic very quickly while in lower mass ratio case, electrons reach to higher anisotropy values until electron whistler instability starts growing.



Protons follow the adiabatic path until proton cyclotron and mirror instability can grow. The instability that has higher growth rate, becomes dominant and protons follow the marginal path of the stronger instability.

CONCLUSIONS

- Electron distribution becomes isotropic before proton instabilities can grow, because electron whistler instability grows much faster than proton cyclotron or proton mirror instabilities.
- In expanding box simulations, electrons become anisotropic same as protons but electron whistler instability starts growing quicker than proton instabilities and keeps electron distribution close to equilibrium.