

Collisions in PIC models

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Laser solid interaction experiment

Biermann and Weibel

Electrostatic Shocks

Transition from collisional to collisionless

Relativistic Reconnection

Effects of collisions



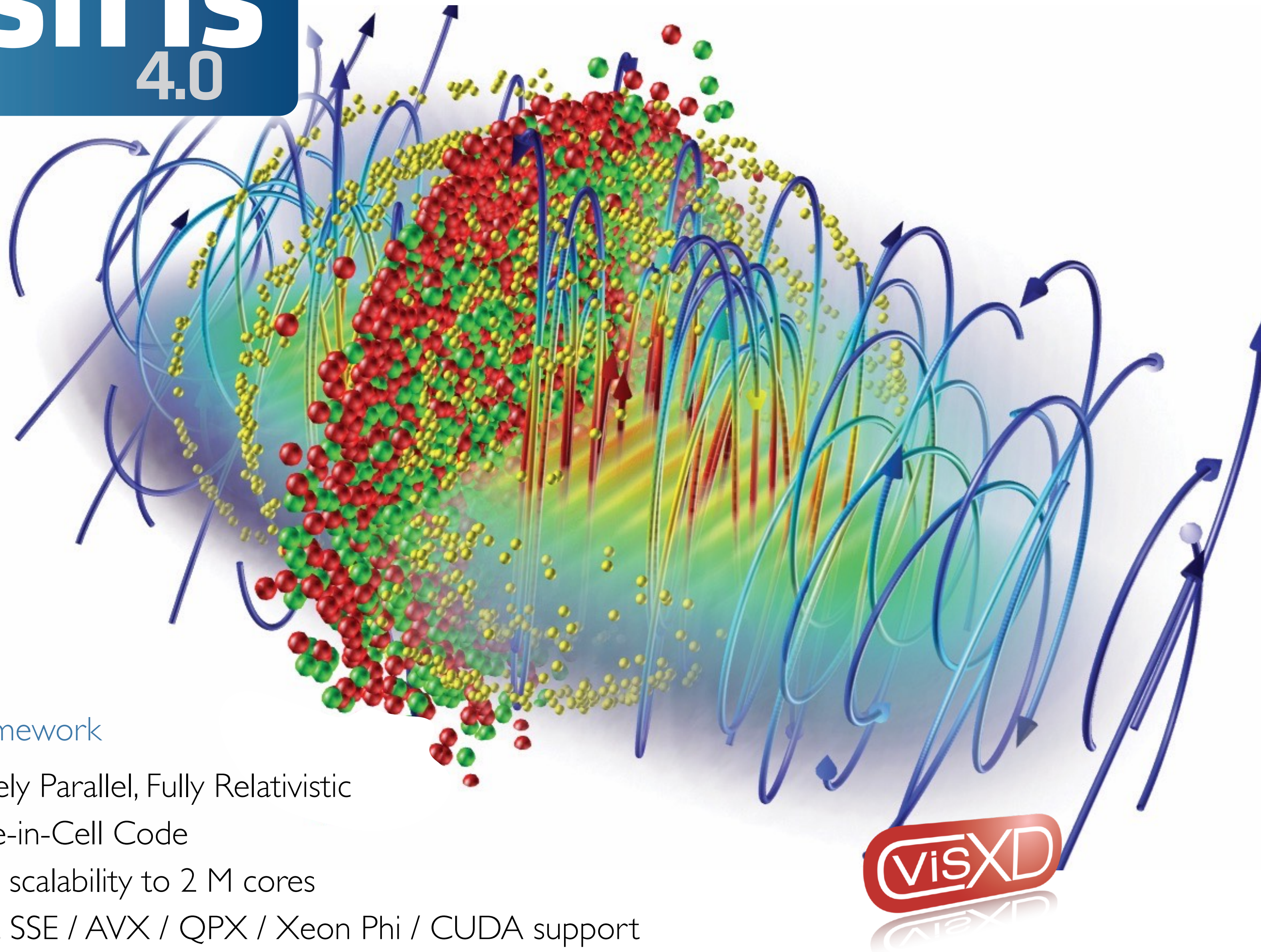
Open-source version available

Open-access model

- 40+ research groups worldwide are using OSIRIS
- 300+ publications in leading scientific journals
- Large developer and user community
- Detailed documentation and sample inputs files available

Using OSIRIS 4.0

- The code can be used freely by research institutions after signing an MoU
- Find out more at:
<http://epp.tecnico.ulisboa.pt/osiris>



OSIRIS framework

- Massively Parallel, Fully Relativistic Particle-in-Cell Code
- Parallel scalability to 2 M cores
- Explicit SSE / AVX / QPX / Xeon Phi / CUDA support
- Extended physics/simulation models - **Coulomb collision module**



Ricardo Fonseca: ricardo.fonseca@tecnico.ulisboa.pt

**Biermann
Battery**

$$\frac{dB}{dt} \sim \nabla T \times \nabla n$$

Density profile

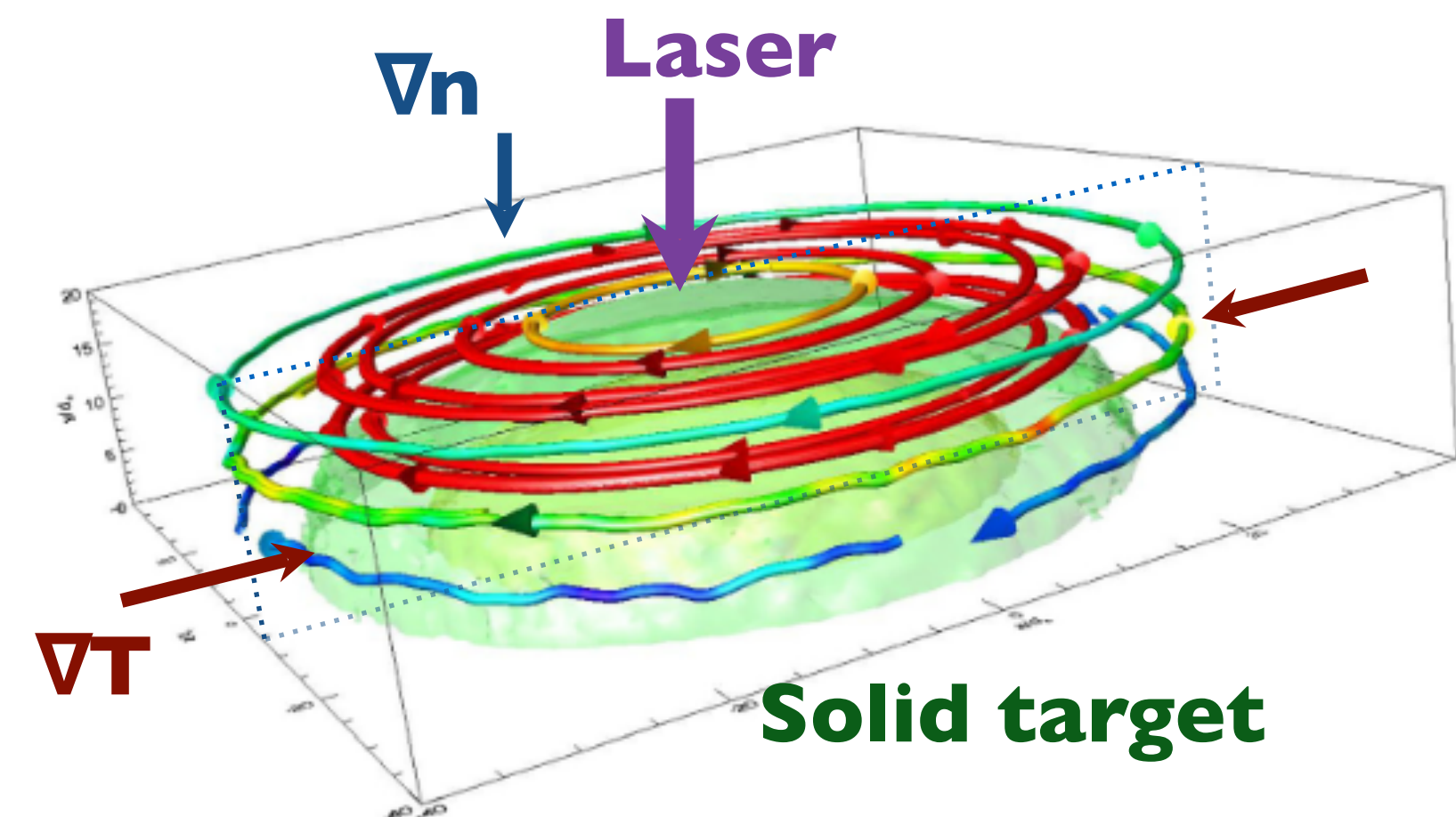
$$n = \begin{cases} (n_0 - n_b) \cos\left(\frac{\pi R_1}{2L_T}\right) + n_b, & \text{if } R_1 < L_T, \\ n_b, & \text{otherwise,} \end{cases}$$

$$R_1 = \sqrt{x^2 + (L_T/L_n y)^2}$$

Temperature profile

$$T_e = \begin{cases} T_{e0} \left[\left(1 - \frac{v_{Tb}}{v_T}\right) \cos\left(\frac{\pi R_2}{2L_T}\right) + \frac{v_{Tb}}{v_T} \right]^2 & \text{if } R_2 < L_T, \\ T_{eb}, & \text{otherwise,} \end{cases}$$

$$R_2 = |x|$$



Density profile

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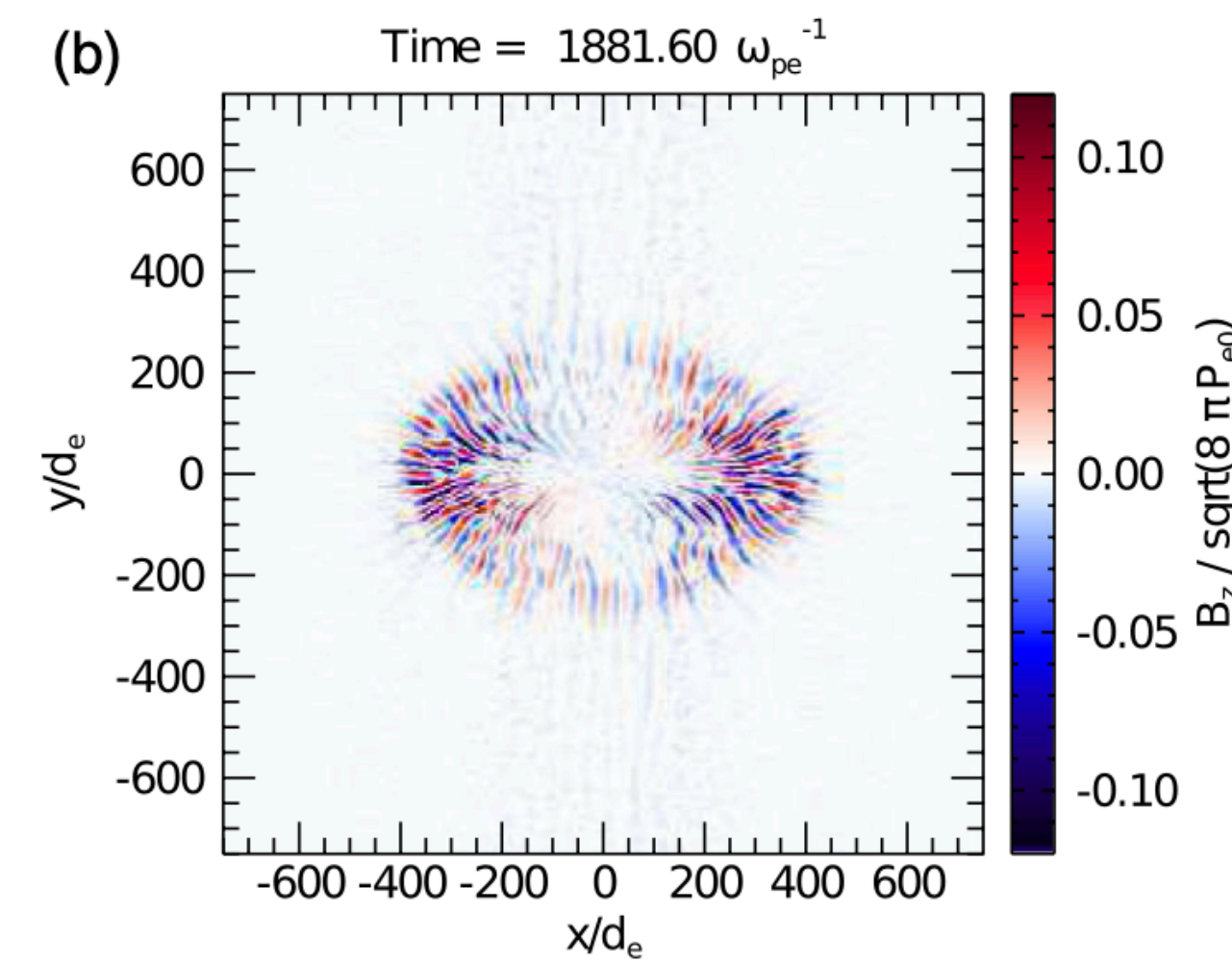
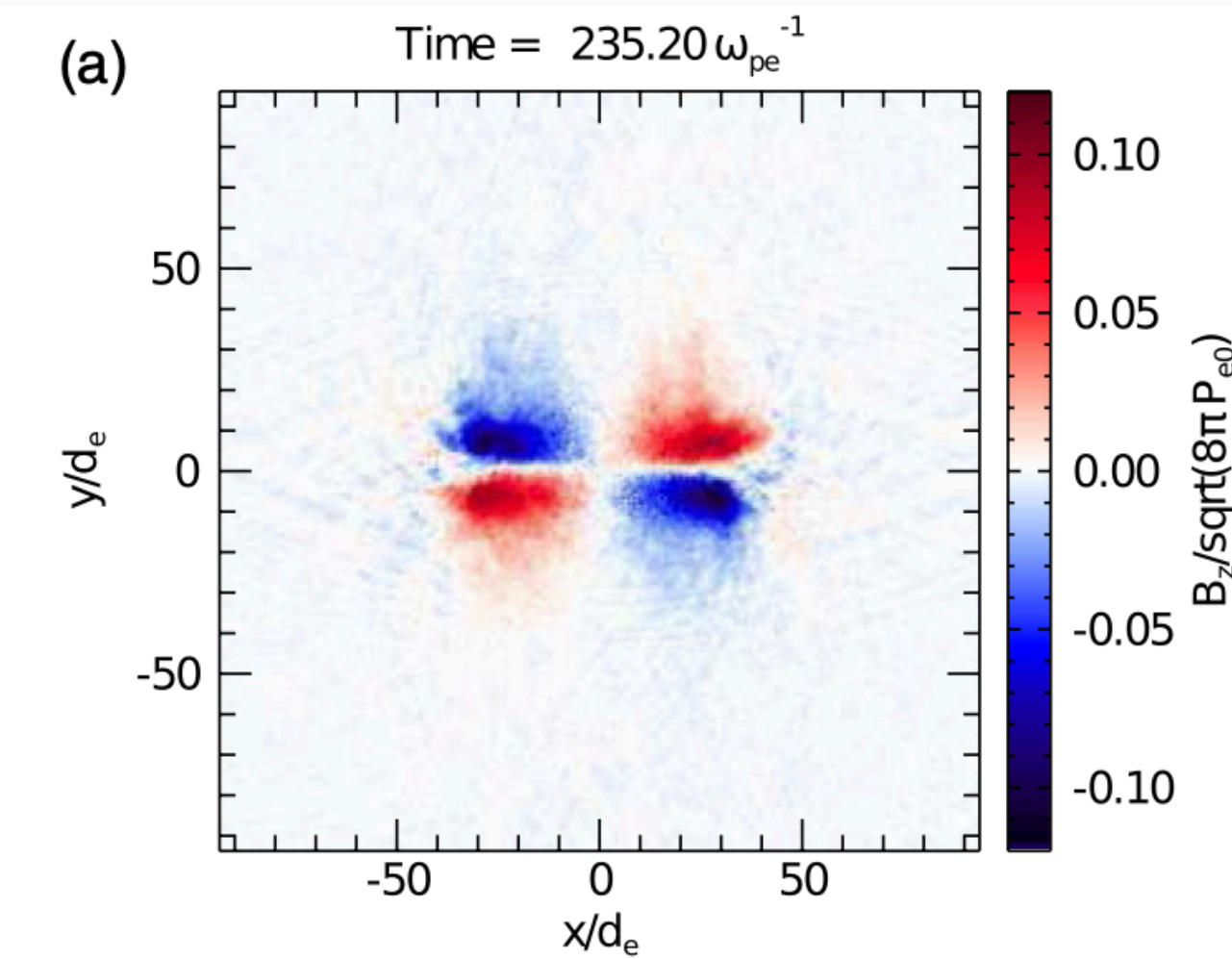
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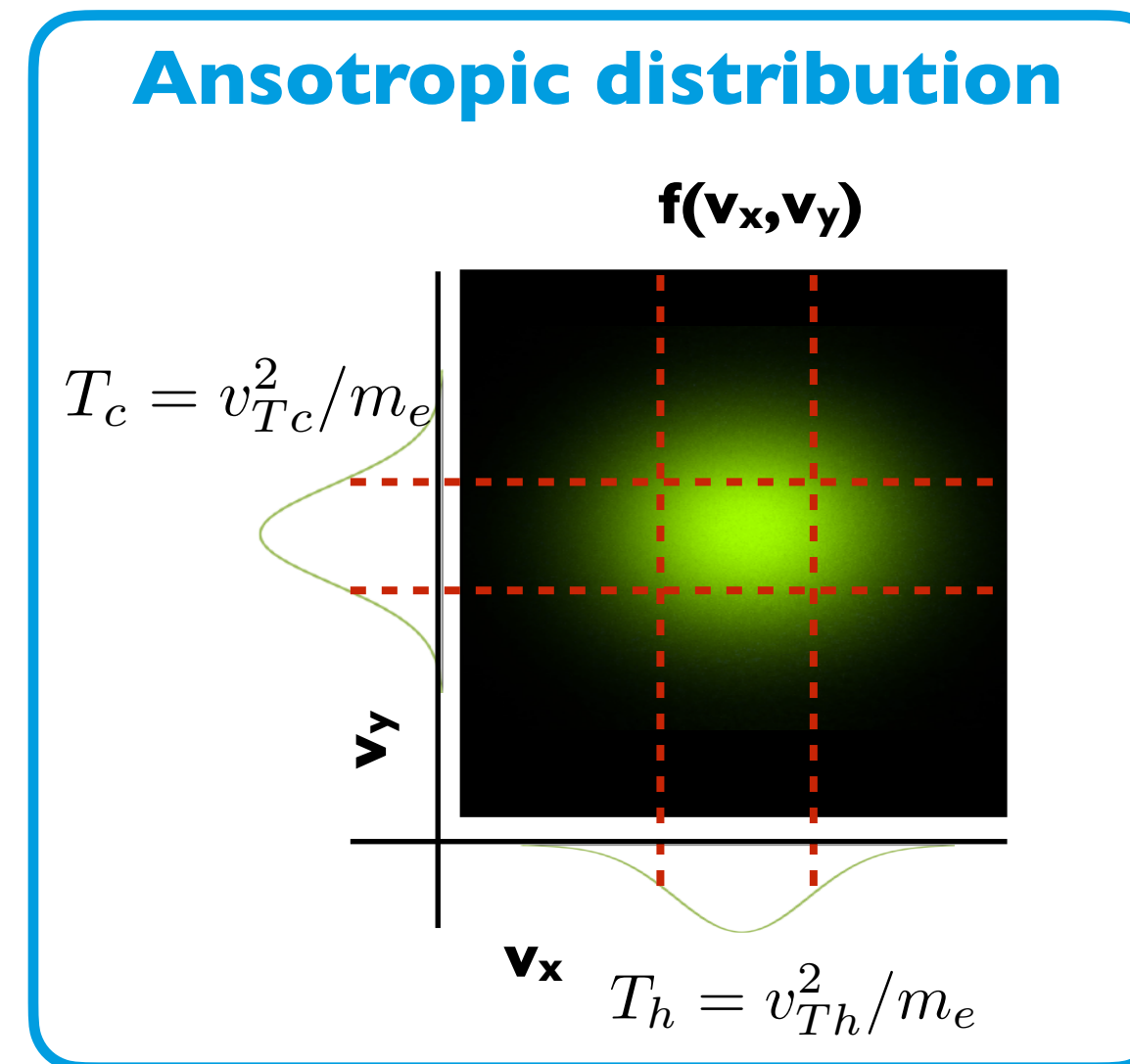
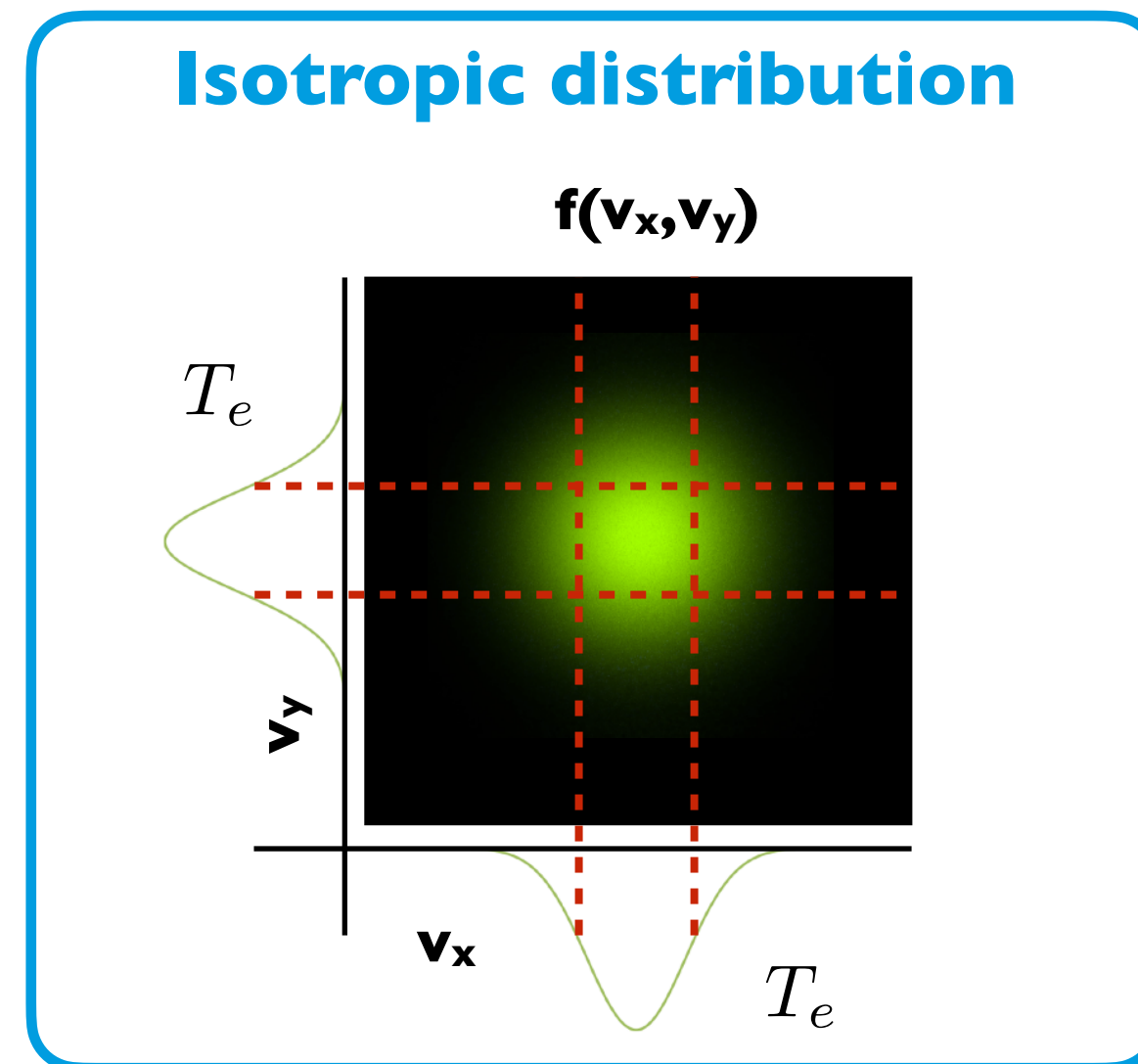
$$R_2 = |x|$$

**Biermann
dominates at small
scales**
 $L/d_e = 25$

**Weibel
dominates at large
scales**
 $L/d_e = 400$



Schoeffler, et al. (2014)



$$A = \frac{T_h}{T_c} - 1$$

Anisotropy evolution

$$\frac{1}{A} \frac{dA}{dt} = -\nu_A(\nu_0, A, Z) \sim Z\nu_0$$

Collision rate

$$\nu_0 = \sqrt{\frac{1}{m_e}} \frac{4\pi n_e e^4}{T_e^{3/2}} \ln \Lambda_C$$

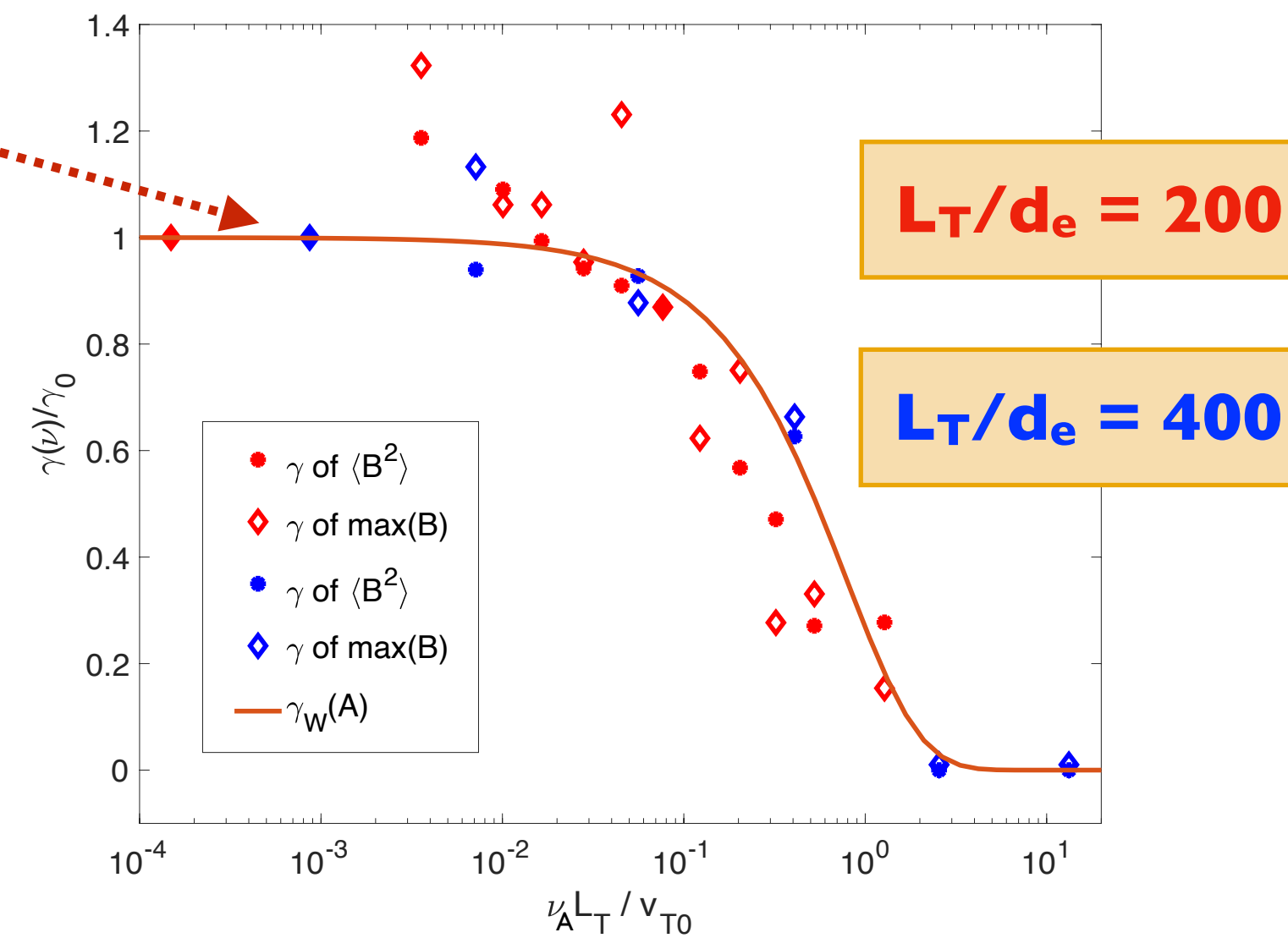
Predicted growth rate

$$A(\nu) = A(0) \exp\left(-\frac{\nu_A L_T}{v_{T0}}\right)$$

A(0) is the anisotropy measured at the onset of Weibel in the collisionless limit

$$\nu_A(\nu_0, A(0))$$

Transition to Weibel suppression occurs at $\nu_A L_T / v_{T0} \sim 1$



Schoeffler, et al. (2020)

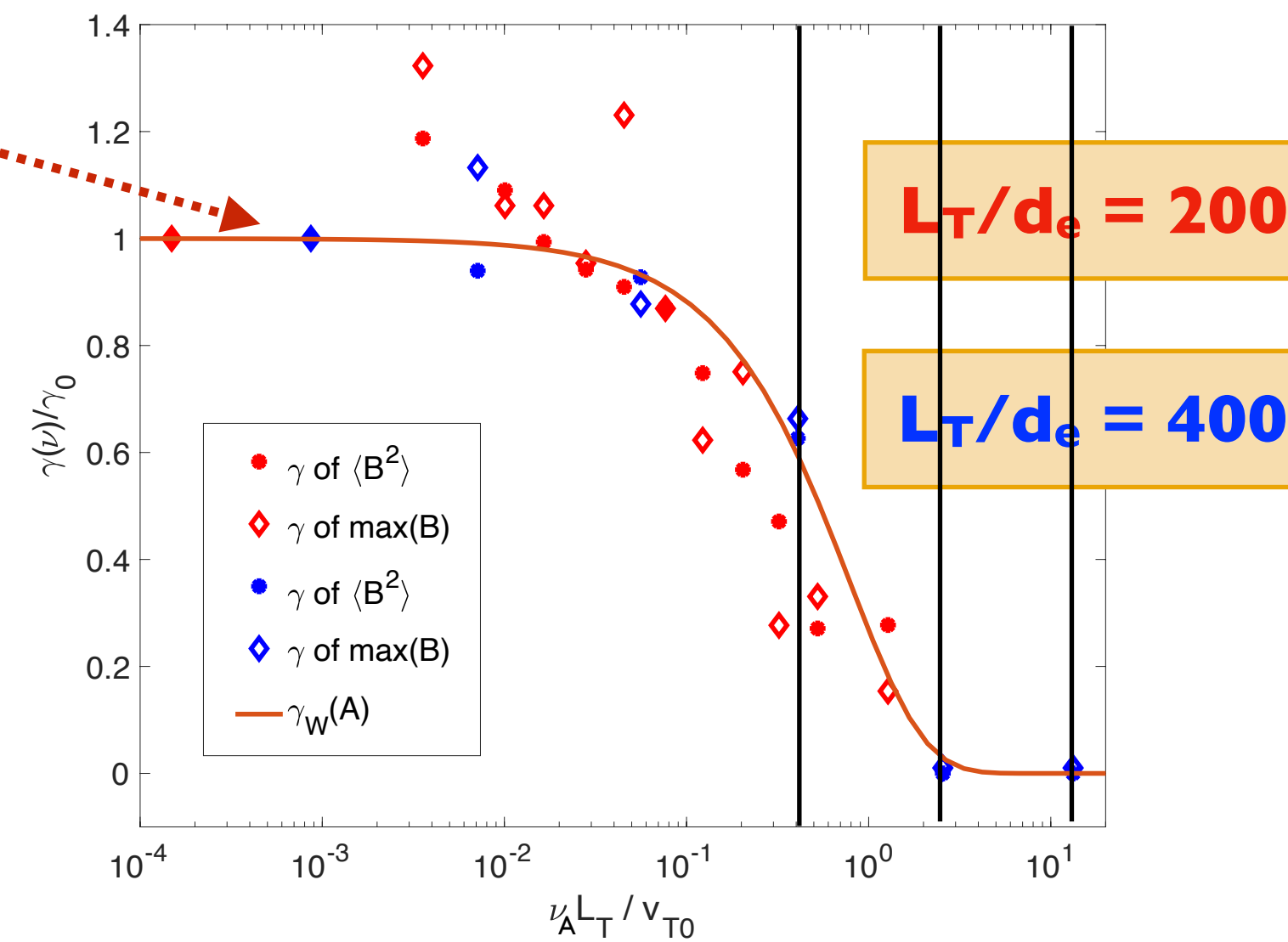
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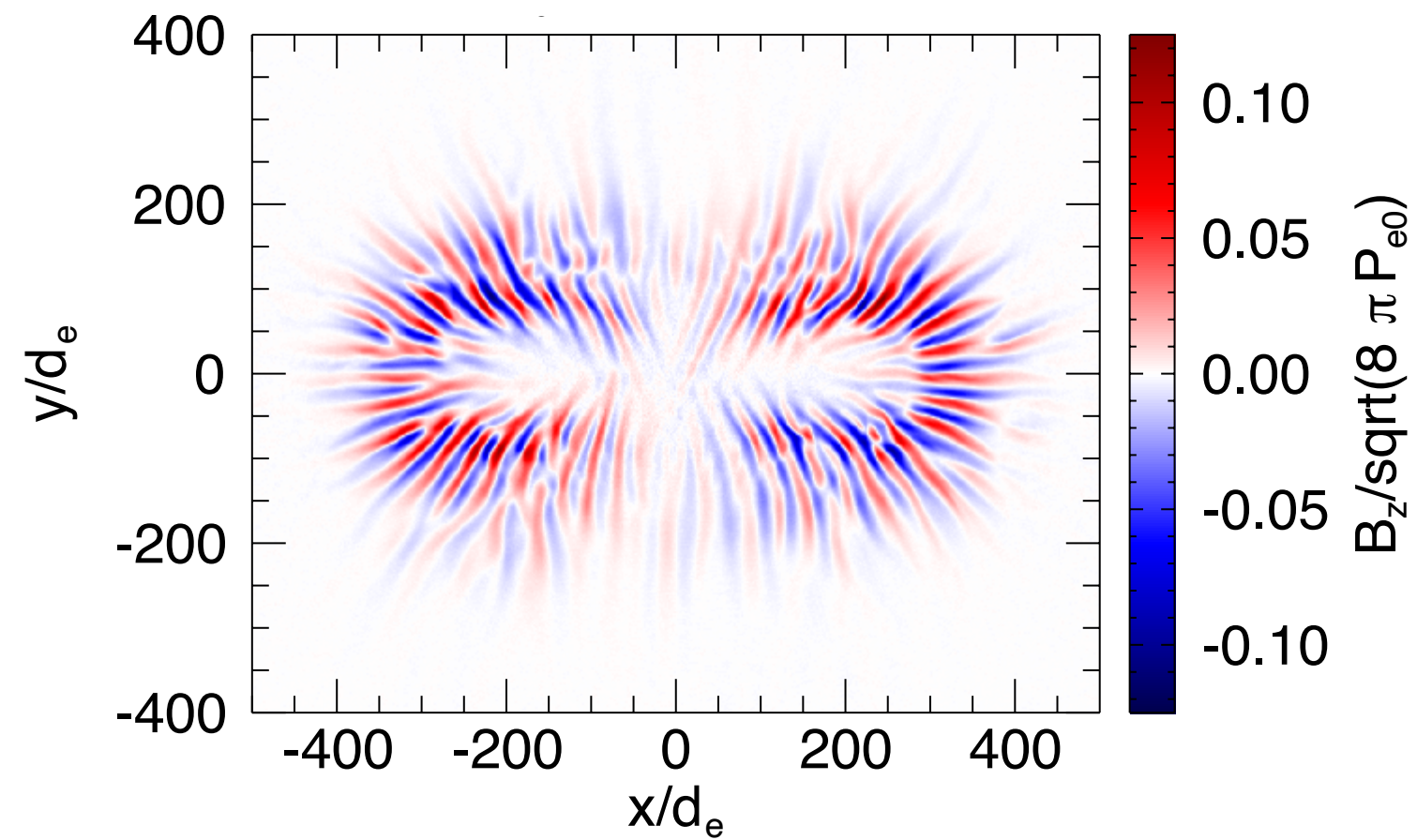
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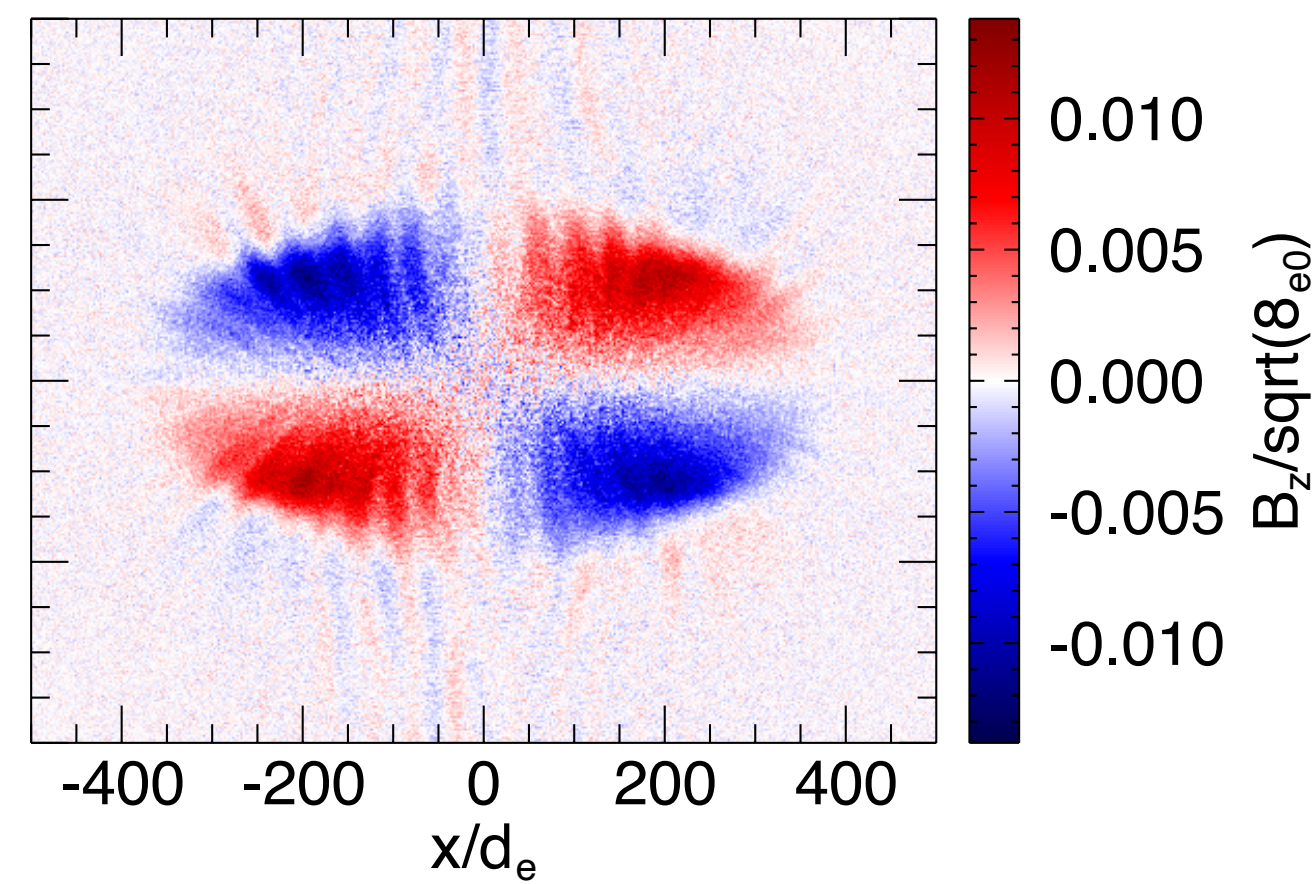
Schoeffler, et al. (2020)

$$v_{A\perp T}/v_{T0}=0.4$$



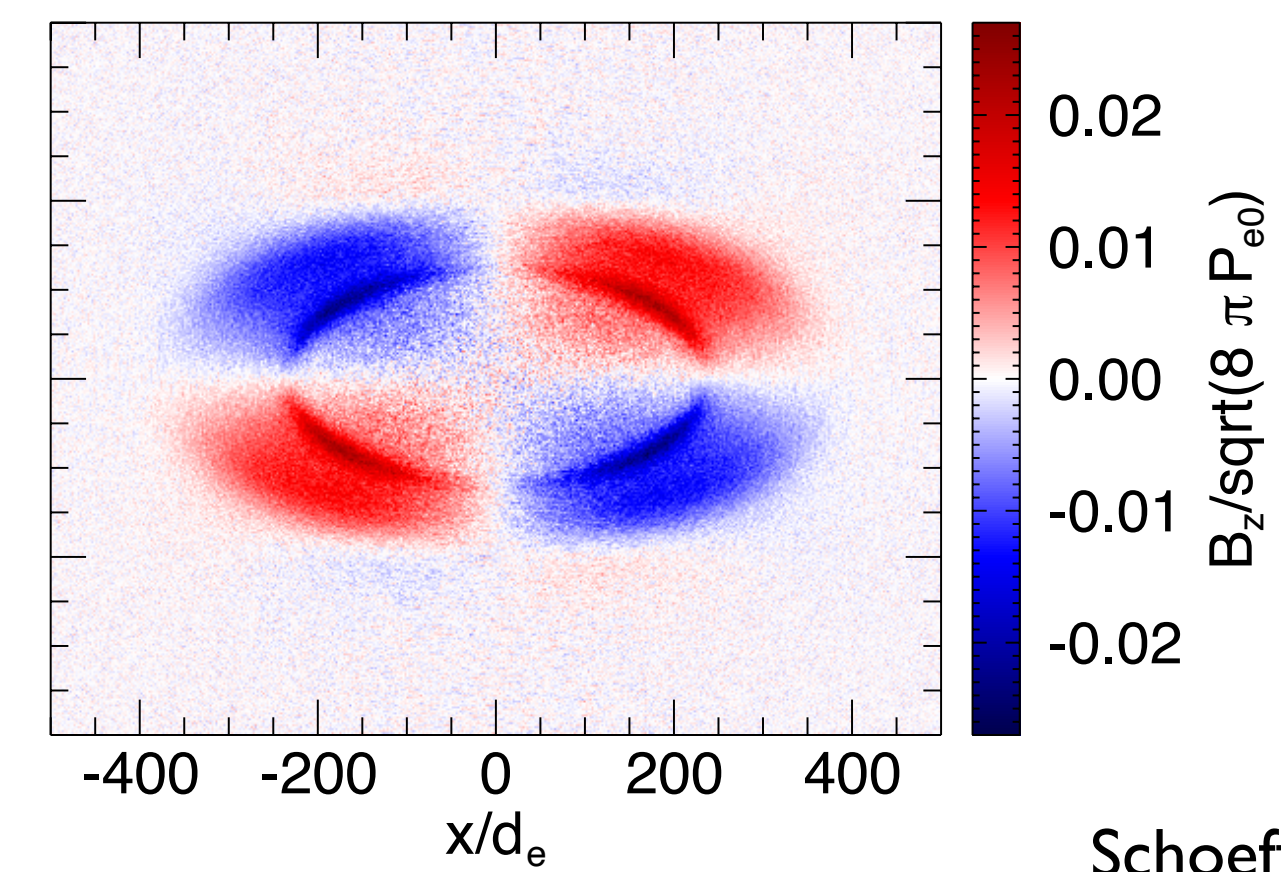
**Weibel fields
dominate**

$$v_{A\perp T}/v_{T0}=2.6$$



**Biermann fields
dominate**

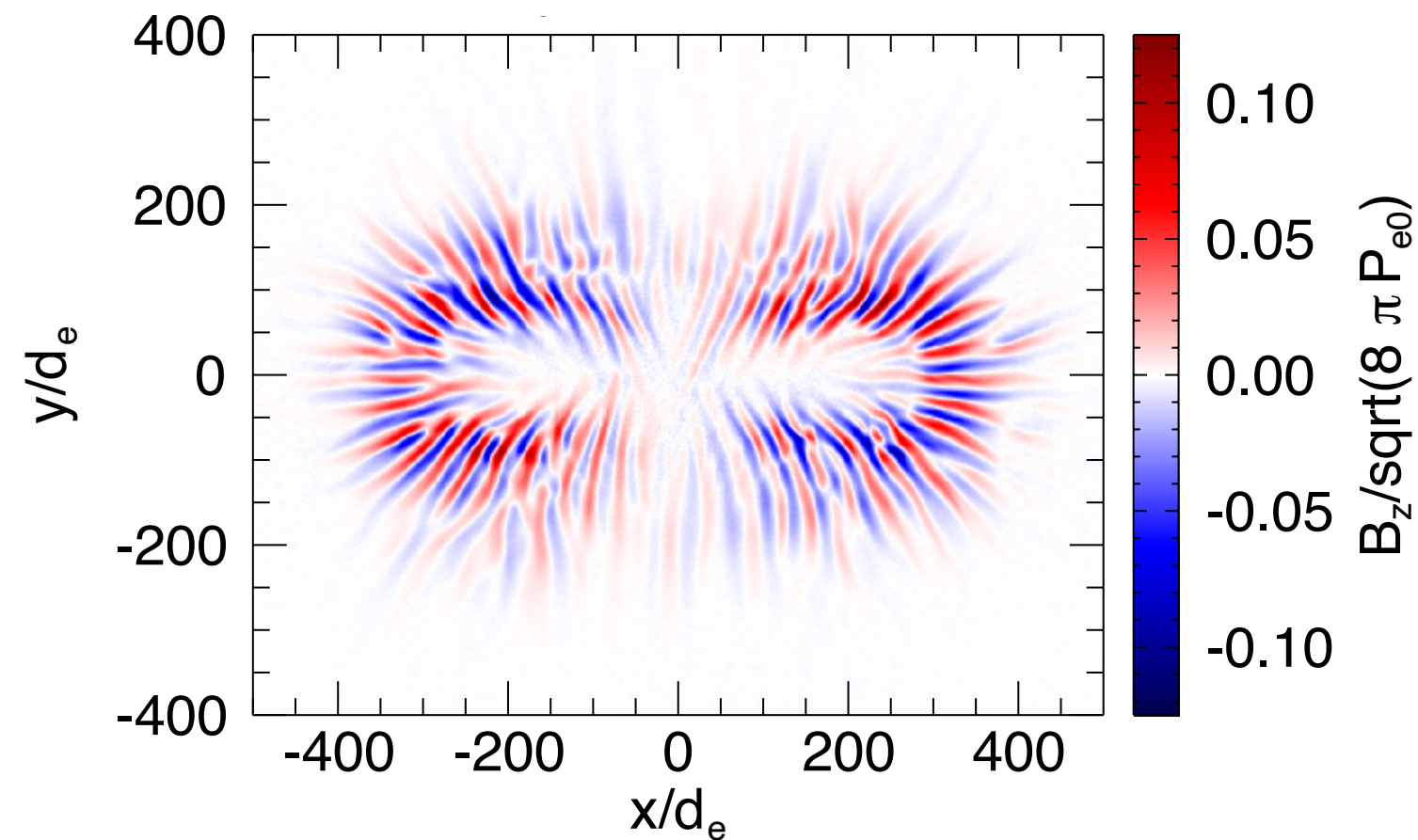
$$v_{A\perp T}/v_{T0}=13.3$$



**Nernst effect
visible**

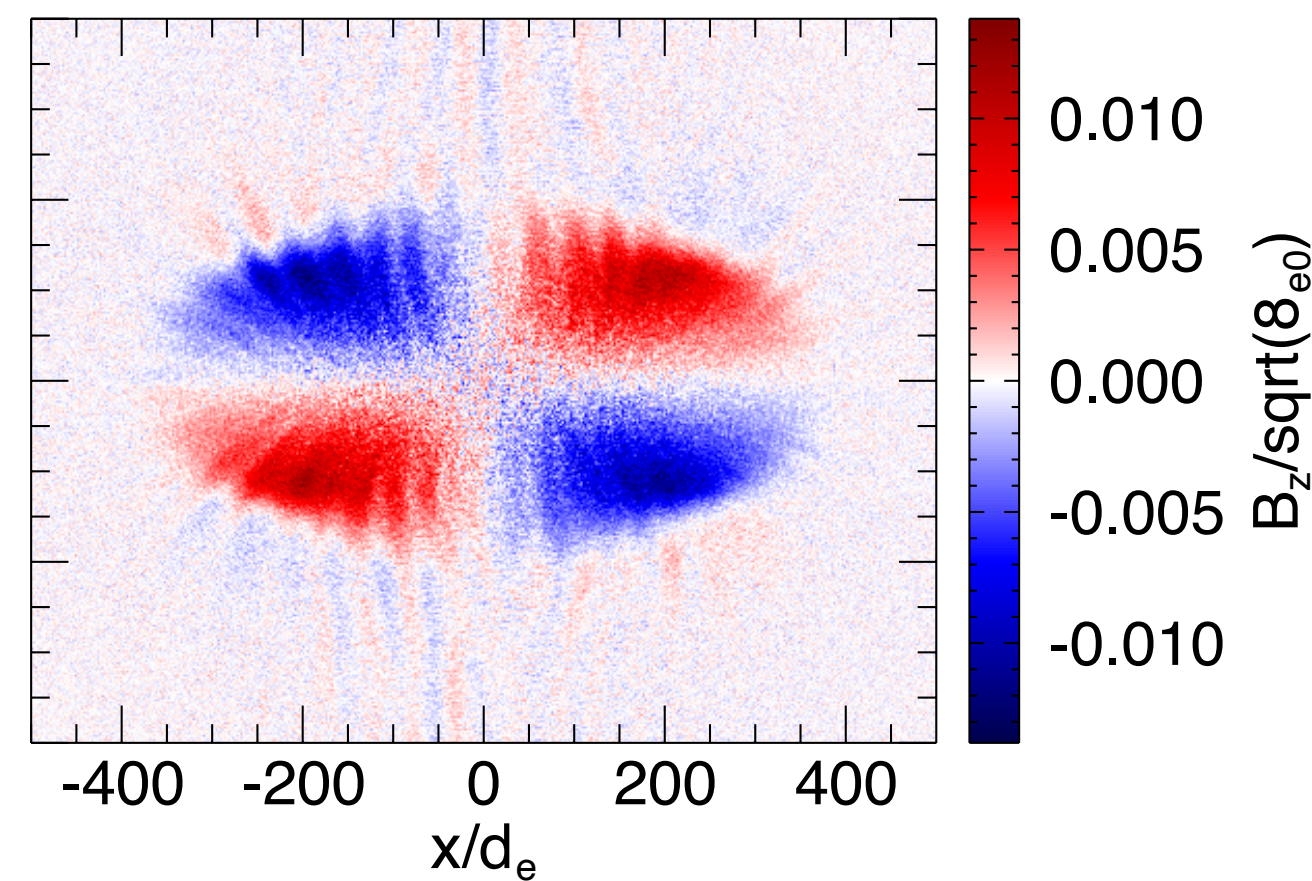
Schoeffler, et al. (2020)

$$v_{A\perp T}/v_{T0}=0.4$$



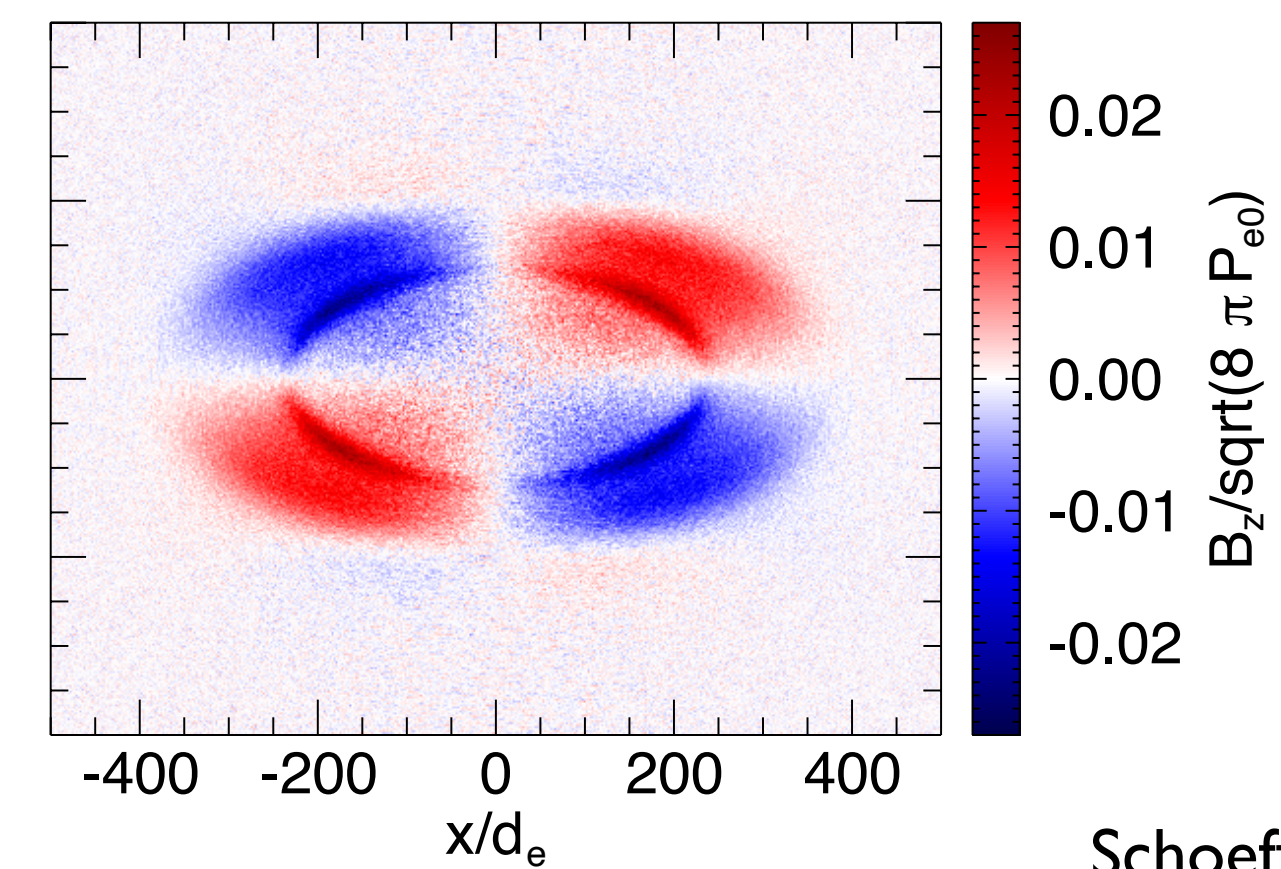
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**Nernst effect
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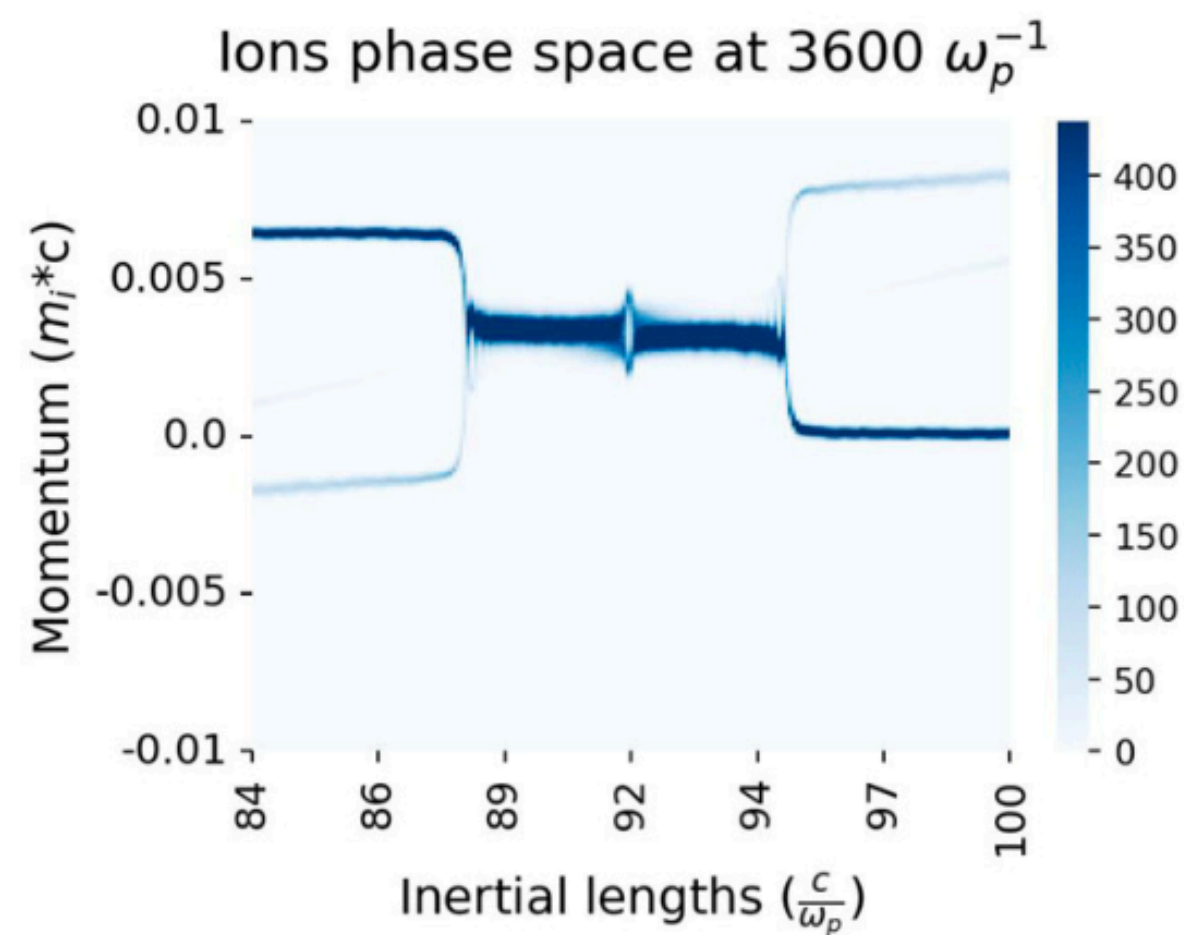
**Only energetic electrons are frozen-in
to the magnetic field, and they drag it
faster than when all of them are,
causing pile-up**

Schoeffler, et al. (2020)

Laser solid interaction experiment
Biermann and Weibel

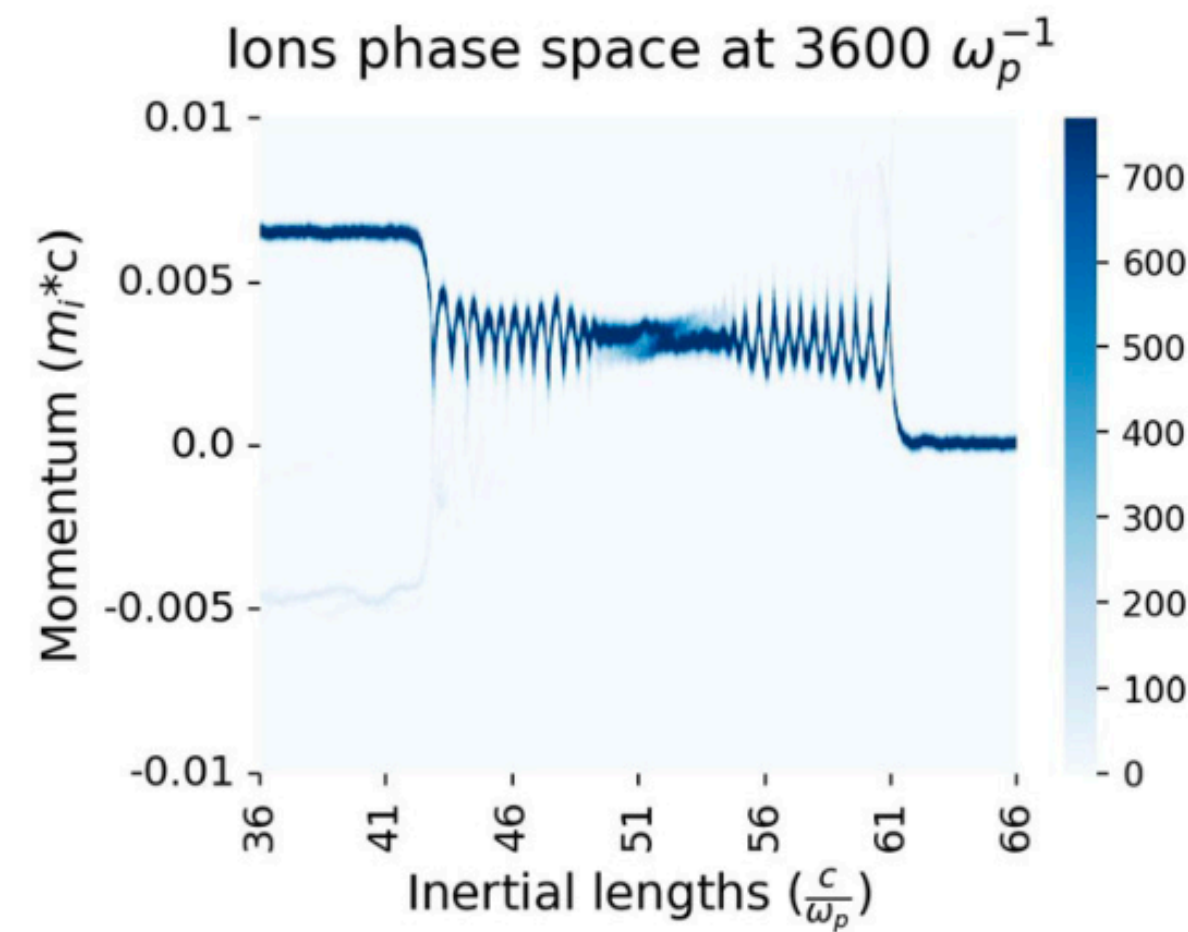
Electrostatic Shocks
Transition from collisional to collisionless

Relativistic Reconnection
Effects of collisions



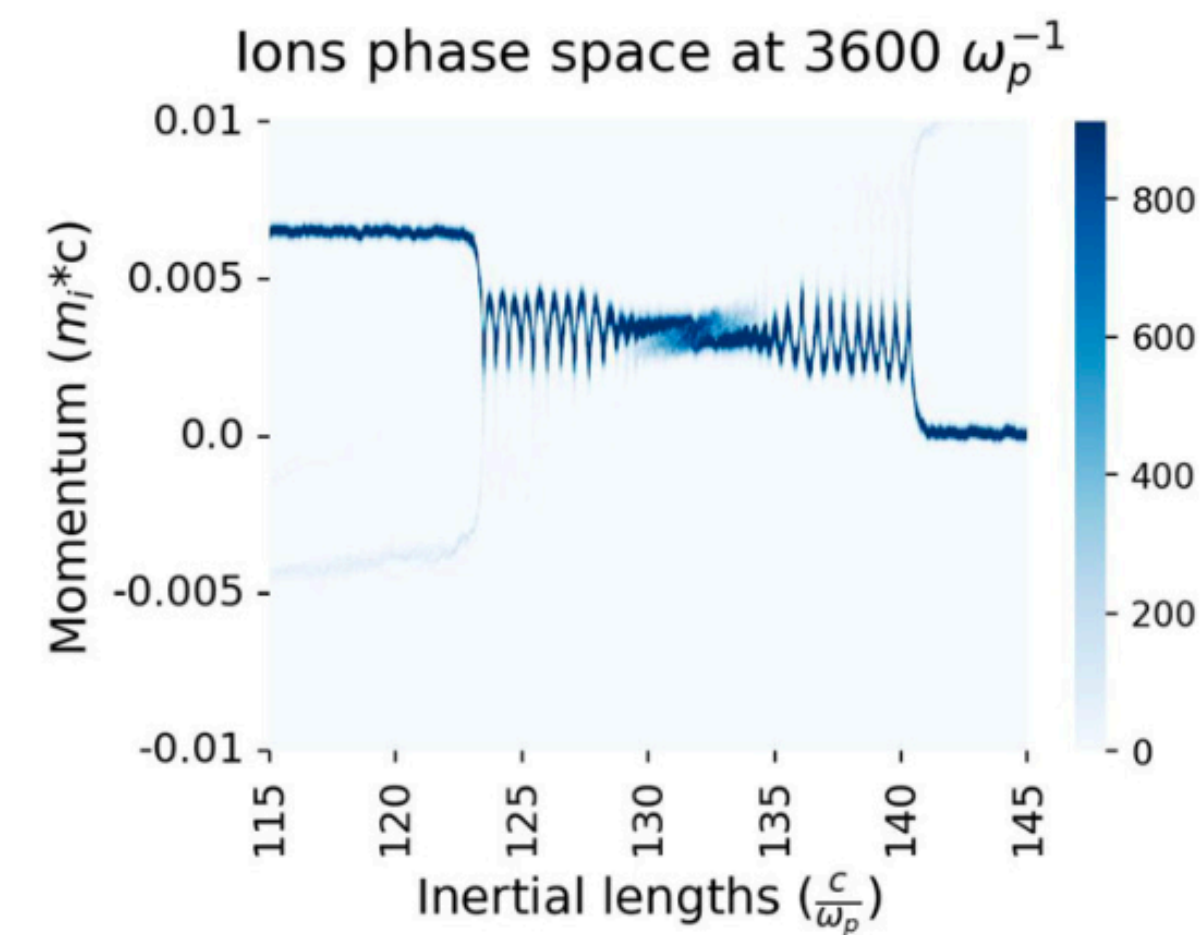
(a) Collisional ($N_D = 0.06$)

No ion acoustic waves



(b) Intermediate ($N_D = 2.78$)

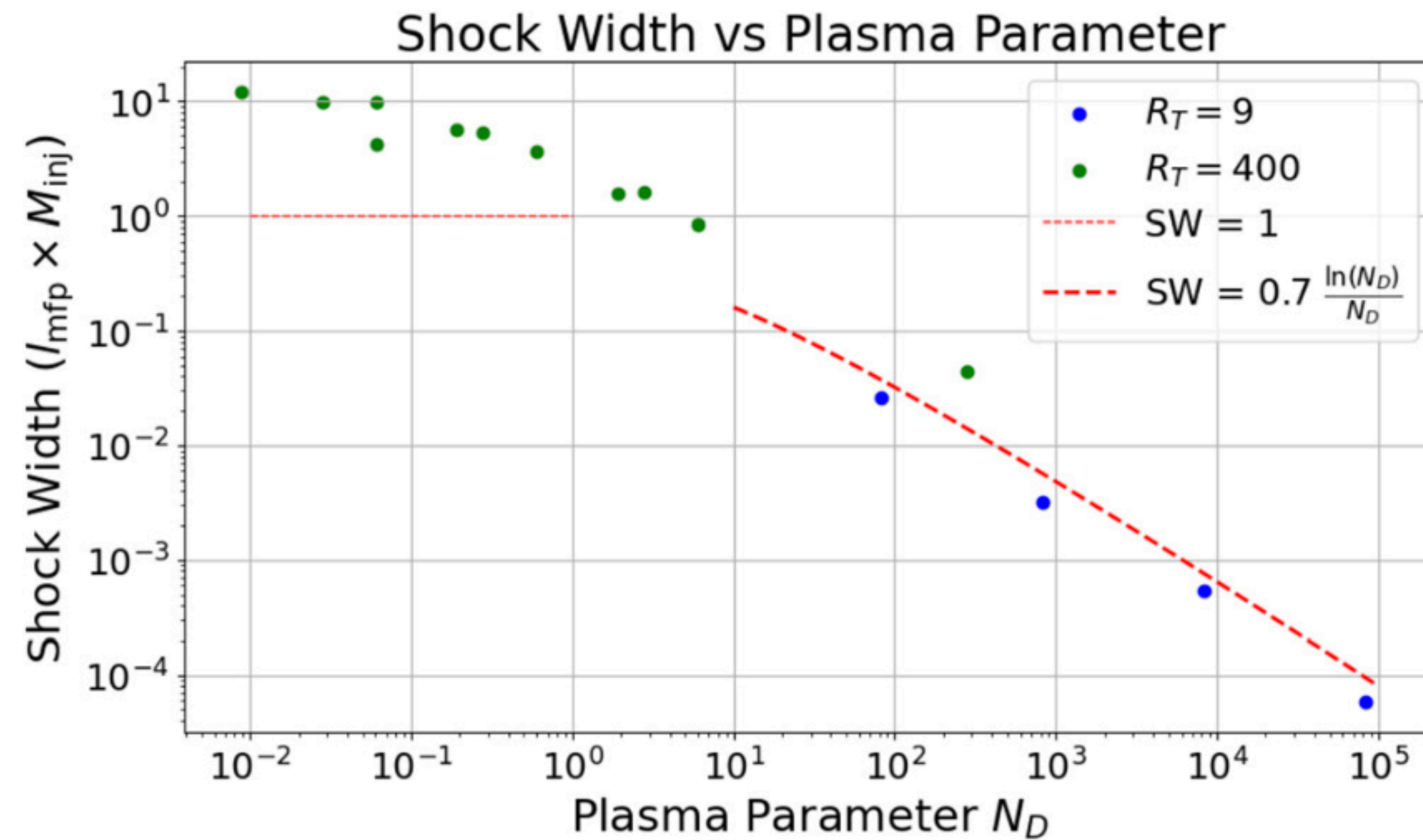
Ion acoustic wave-train



(c) Collisionless ($N_D = 278$)

Ion acoustic wave-train

Kindi, et al. (2020)



Kindi, et al. (2020)

$$N_D \equiv \frac{4\pi\lambda_{di}^3 n_0}{3} \sim \frac{T_i^{3/2}}{n_0^{1/2}}$$

Laser solid interaction experiment
Biermann and Weibel

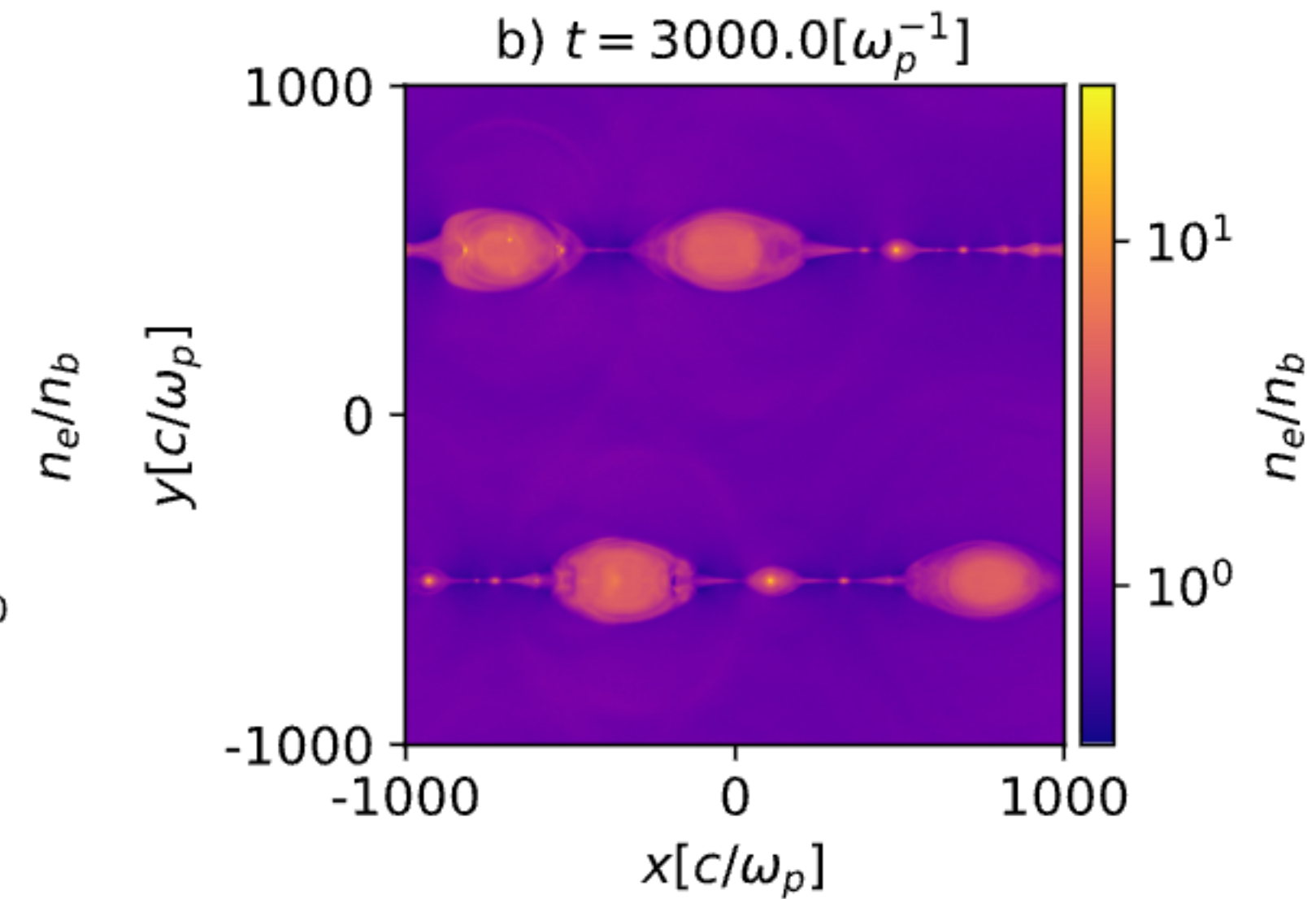
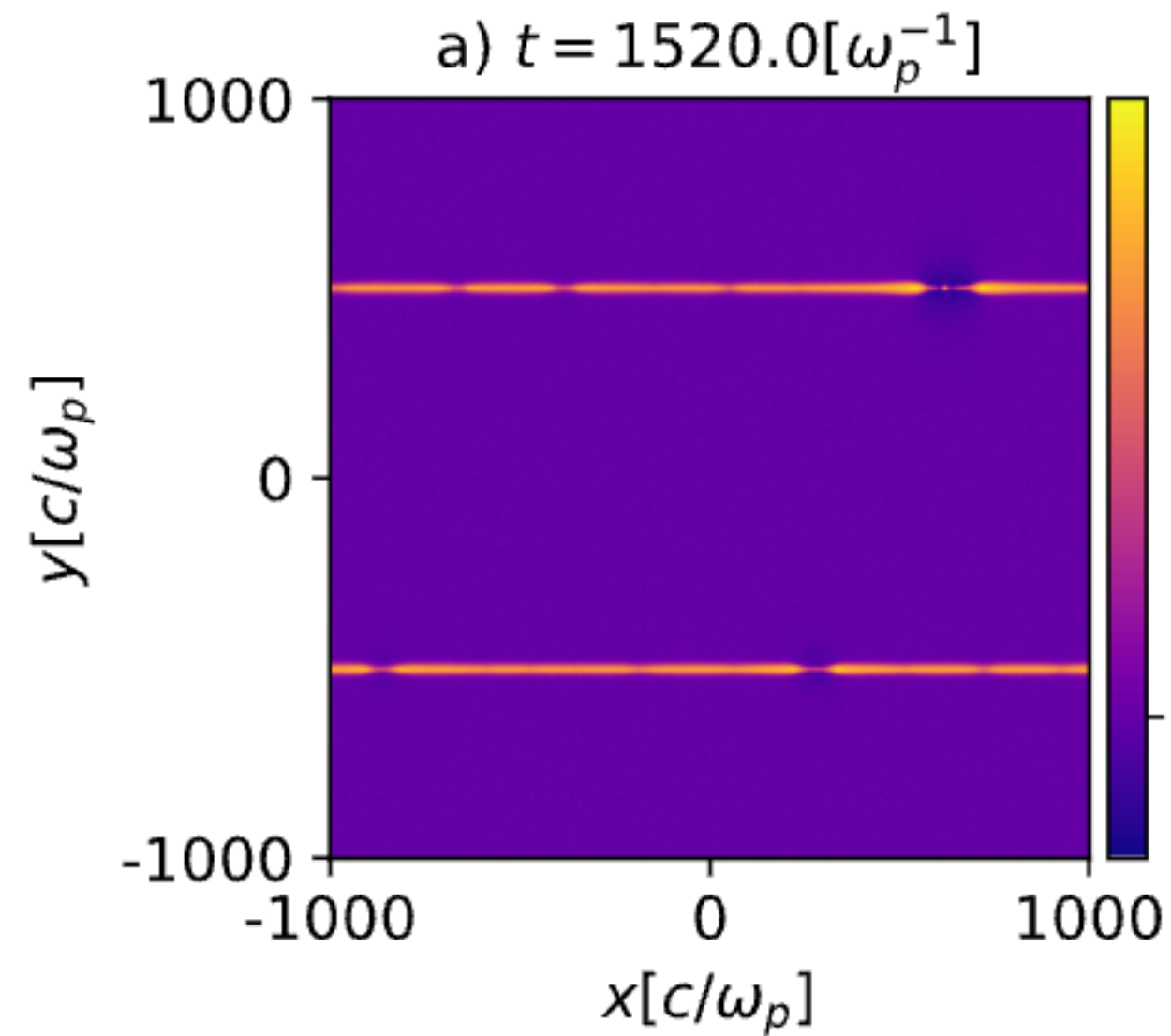
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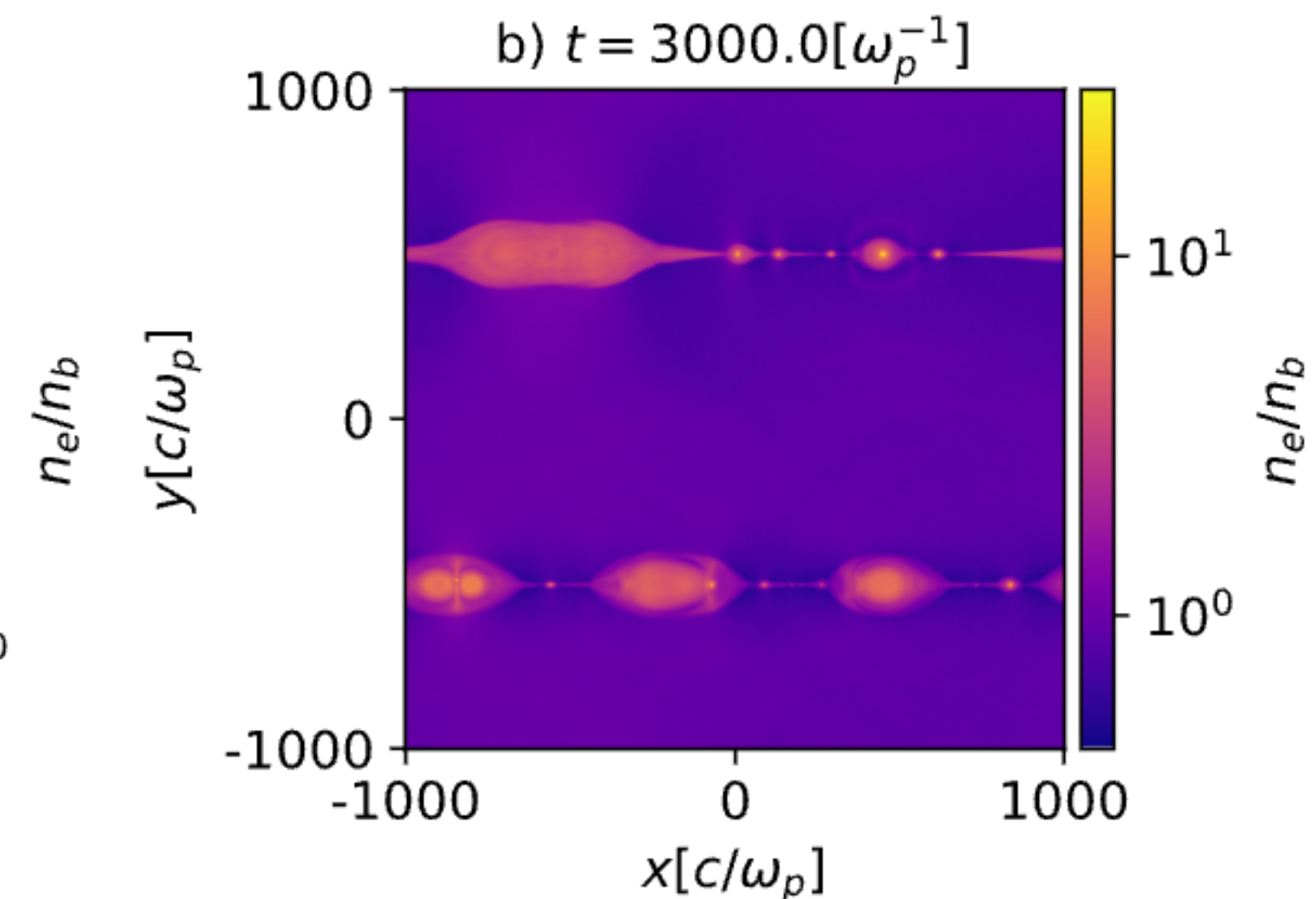
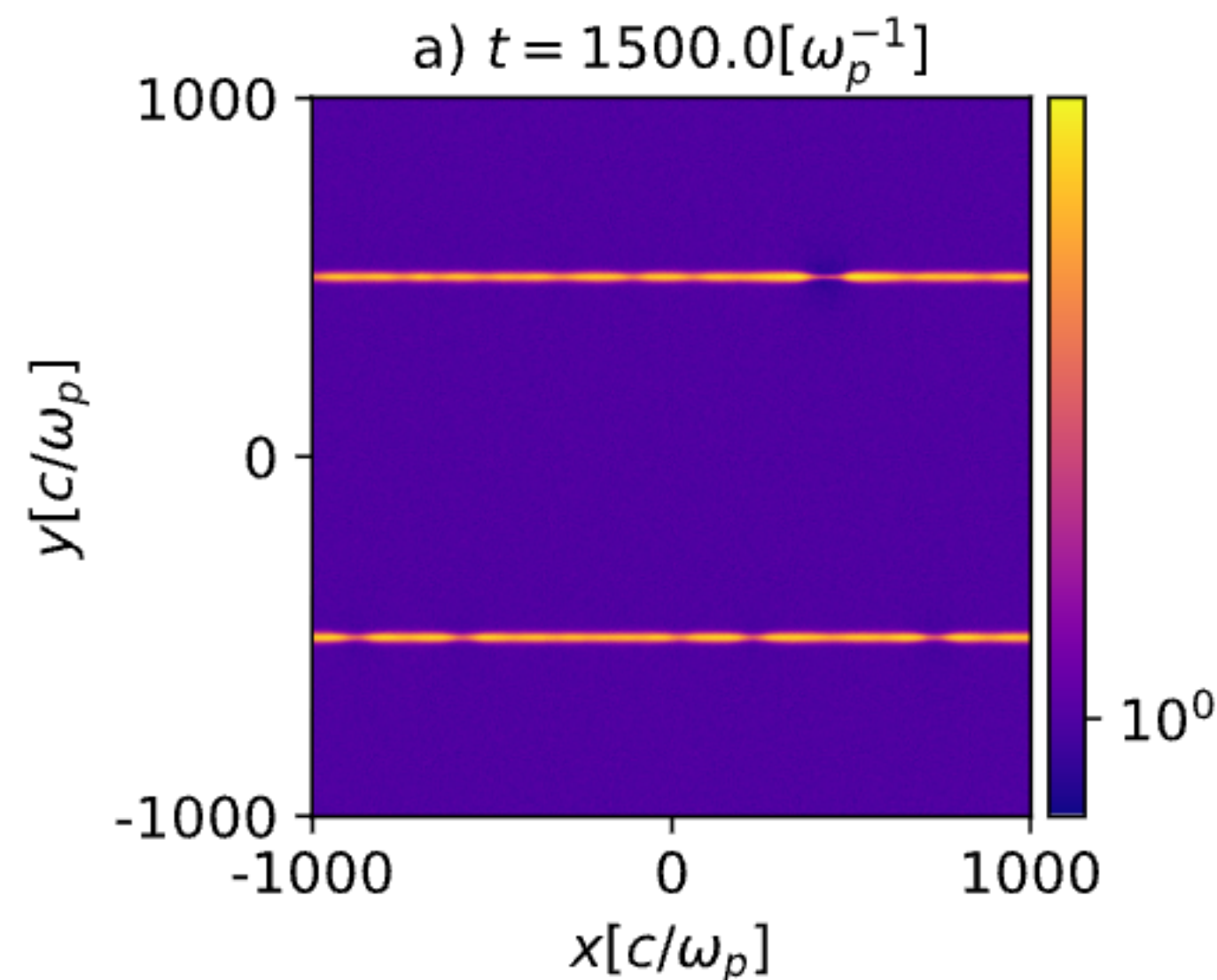
Reconnection not affected much by collisions

$$\sigma_{h,e} = \frac{B_0^2}{4\pi n_e h_e} = \frac{B_0^2}{16\pi n_e T_e} = 10000$$

Collisionless
case $\nu_c L_y / c = 0$

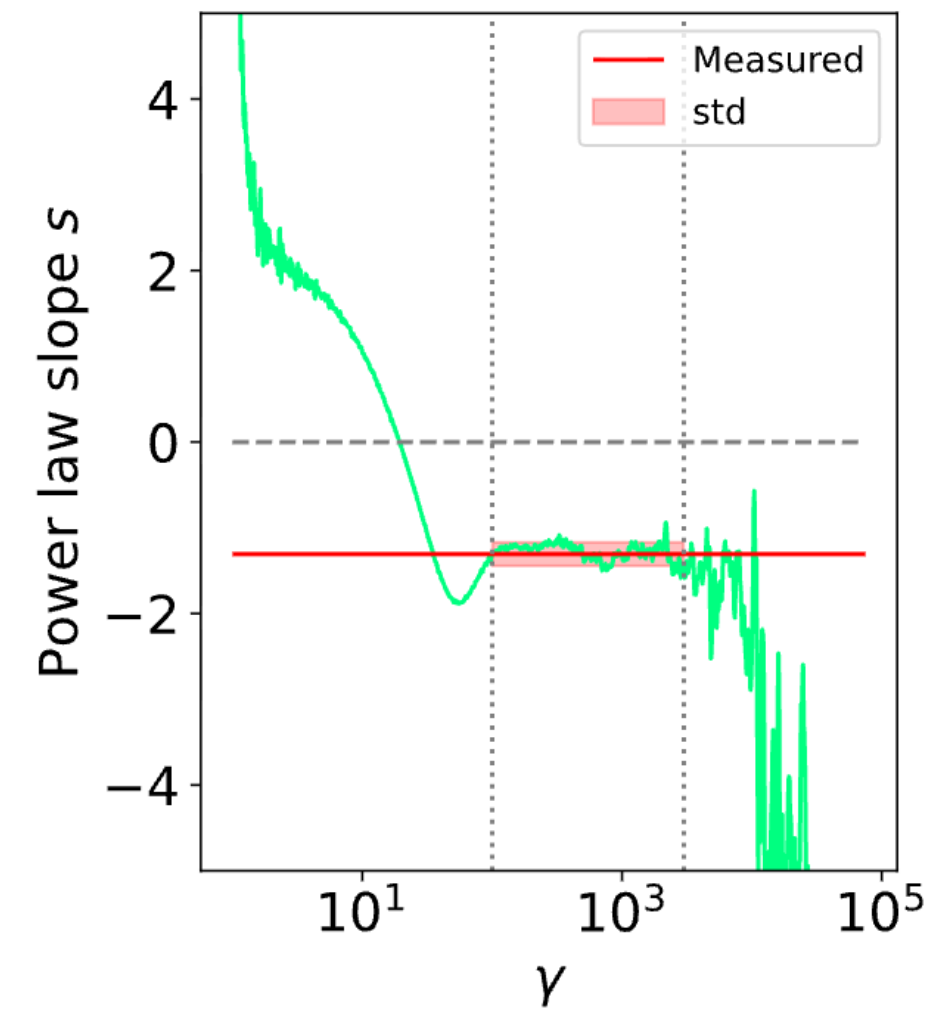
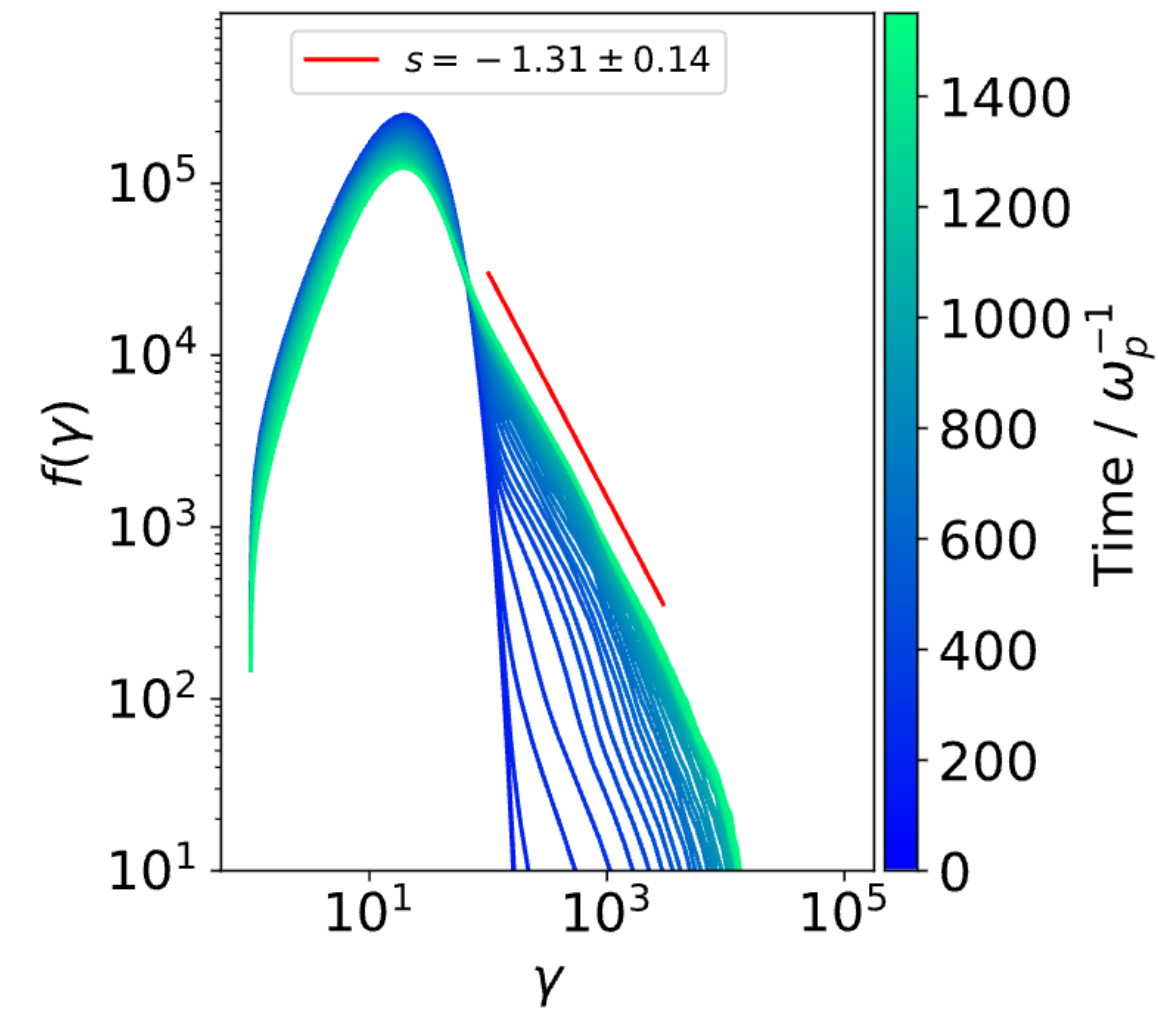


Collisional case
 $\nu_c L_y / c = 60$

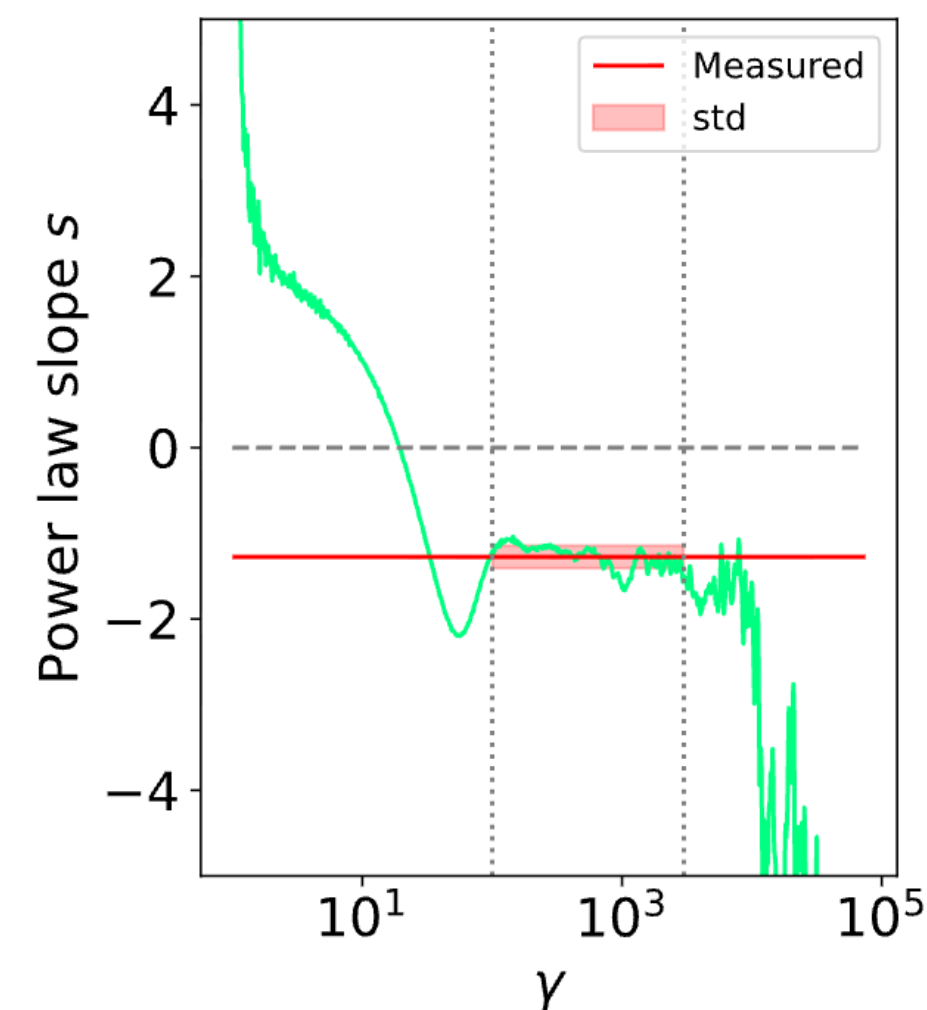
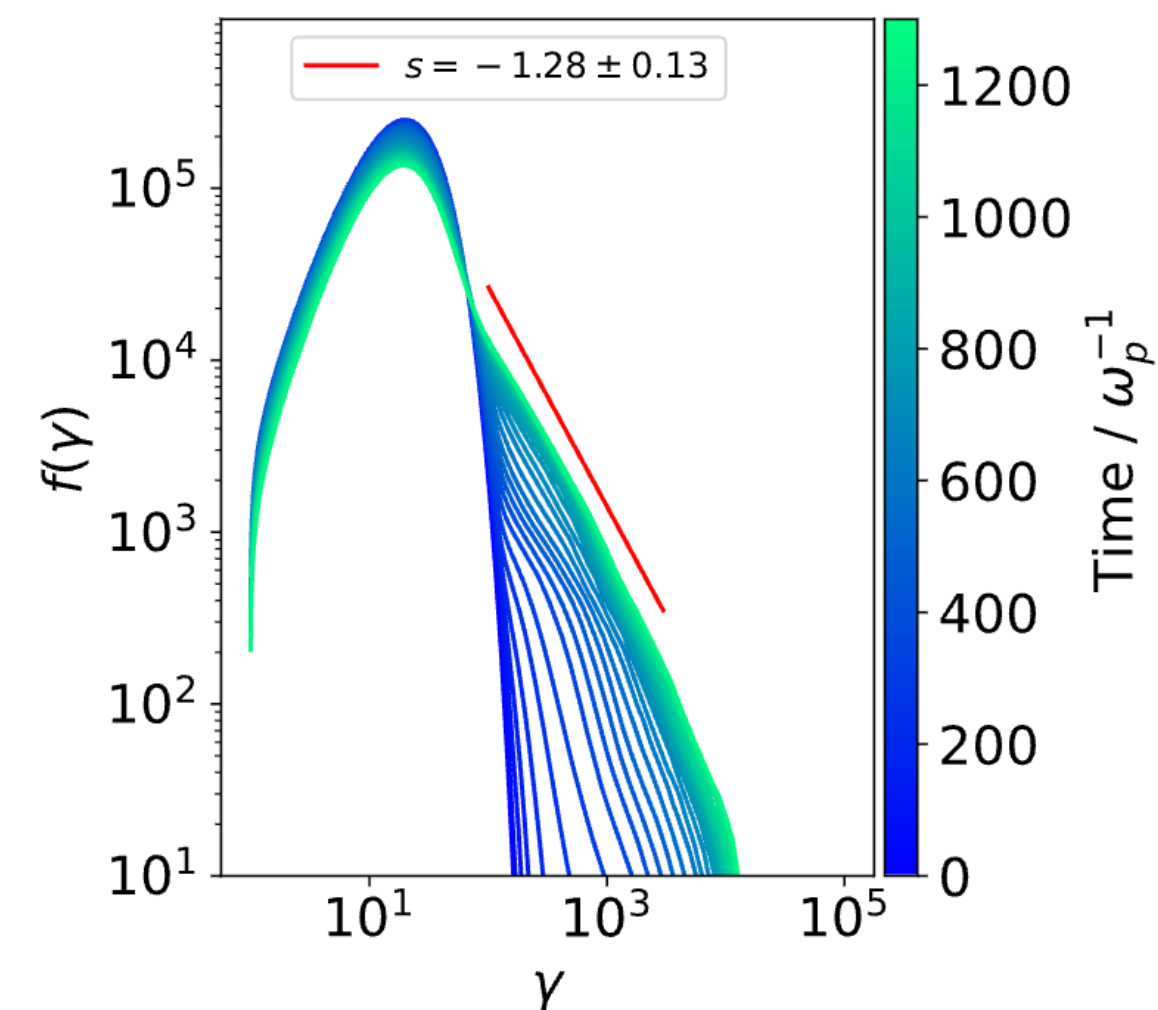


Spectra becomes only slightly harder

Collisionless
case $\nu_c L_y / c = 0$



Collisional case
 $\nu_c L_y / c = 60$



Linear growth rate not significantly affected

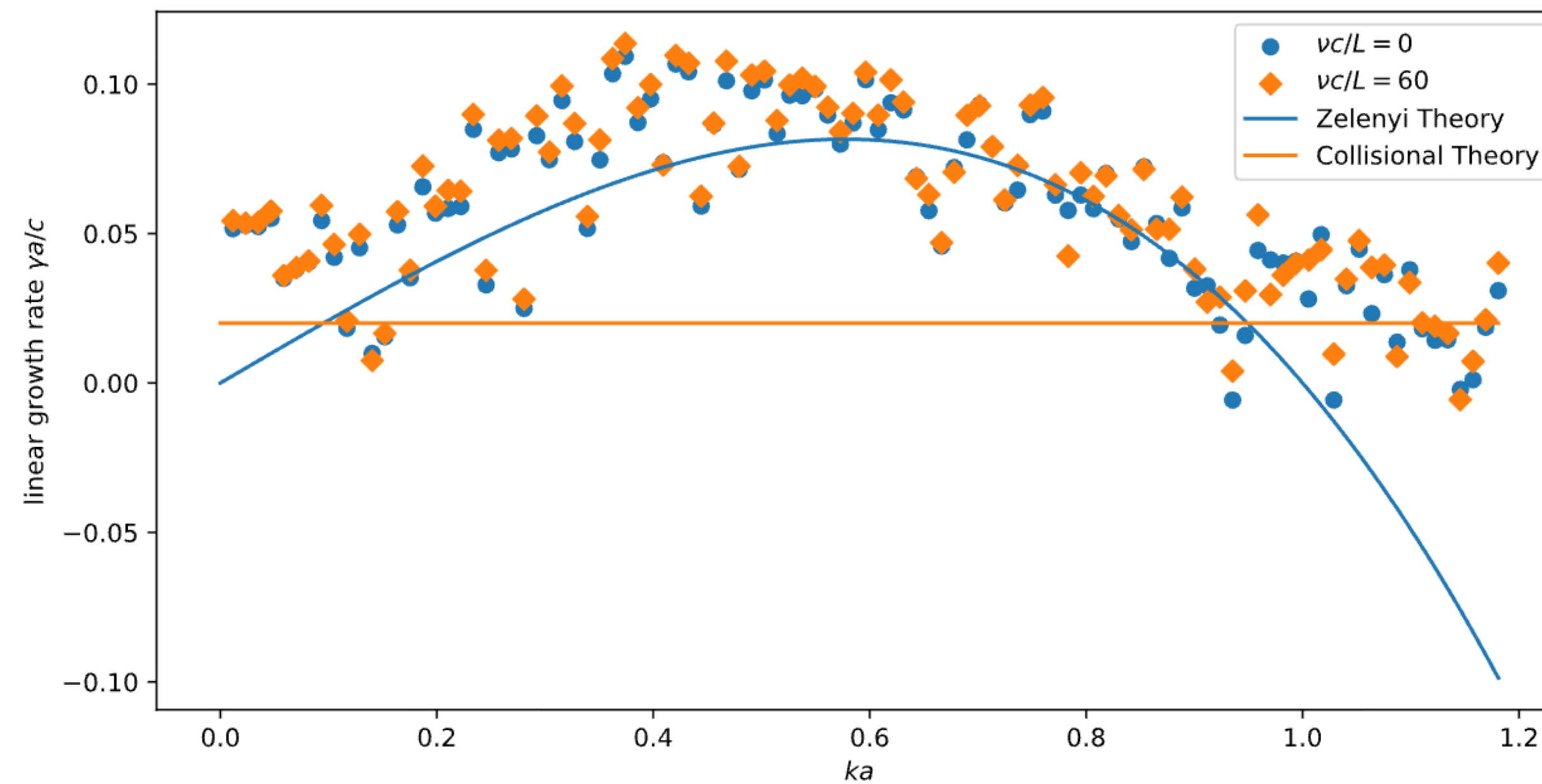
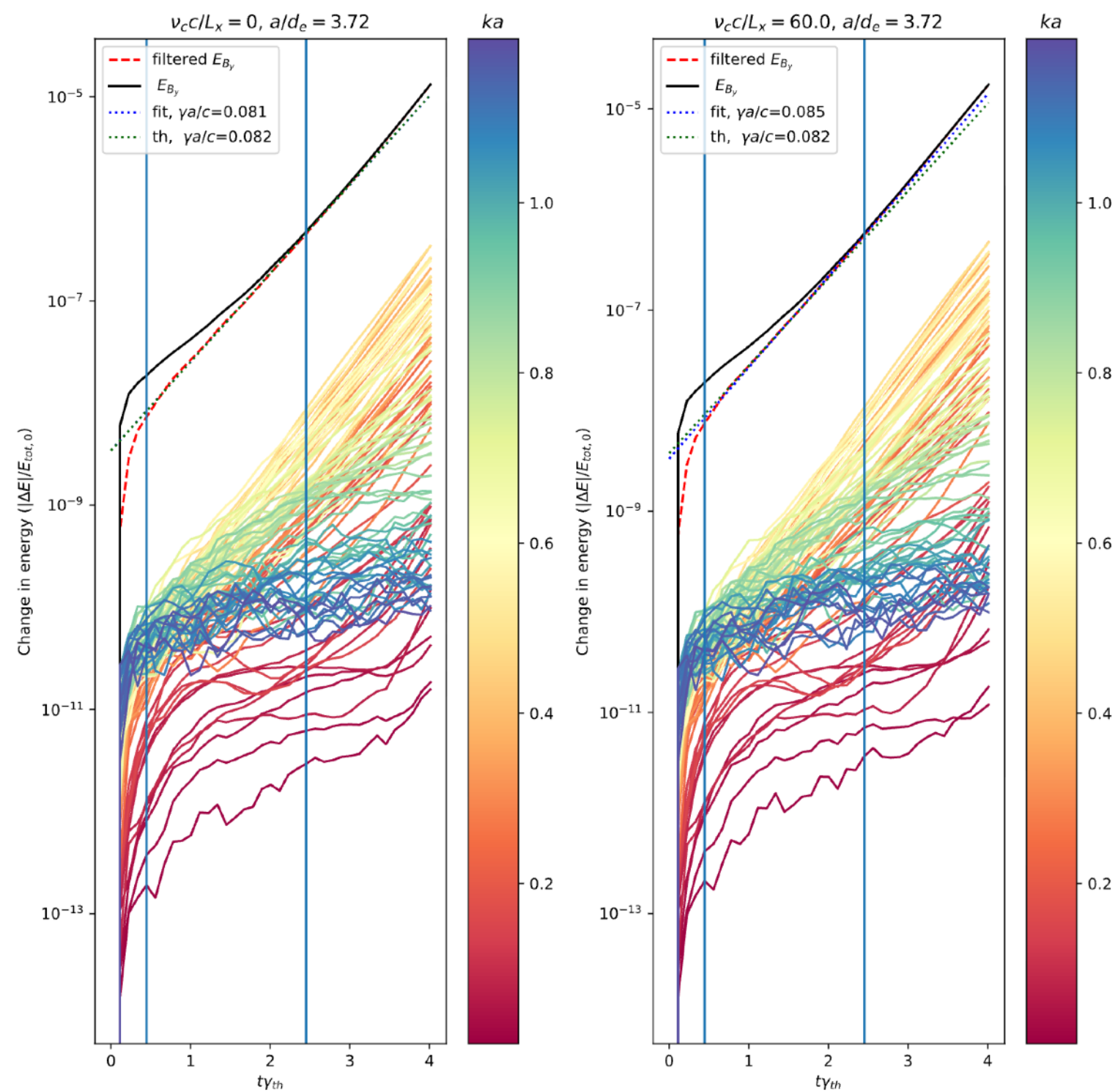
Zelenyi theory

Collisional tearing

$$\frac{\gamma a}{c} \approx \frac{2\sqrt{2}}{\pi} ka(1 - k^2 a^2) \frac{1}{\Gamma_d^{5/2}} \left(\frac{u_d}{c} \right)^{3/2}$$

$$\frac{\gamma a}{c} \approx \frac{2\sqrt{2}}{\pi} ka(1 - k^2 a^2) \frac{1}{\Gamma_d^{5/2}} \left(\frac{\rho_{L,R}}{a} \right)^{3/2}$$

$$\frac{\gamma a}{v_A} \sim S^{-1/2} \quad S \equiv \frac{av_A}{\eta}$$



Linear growth rate not significantly affected

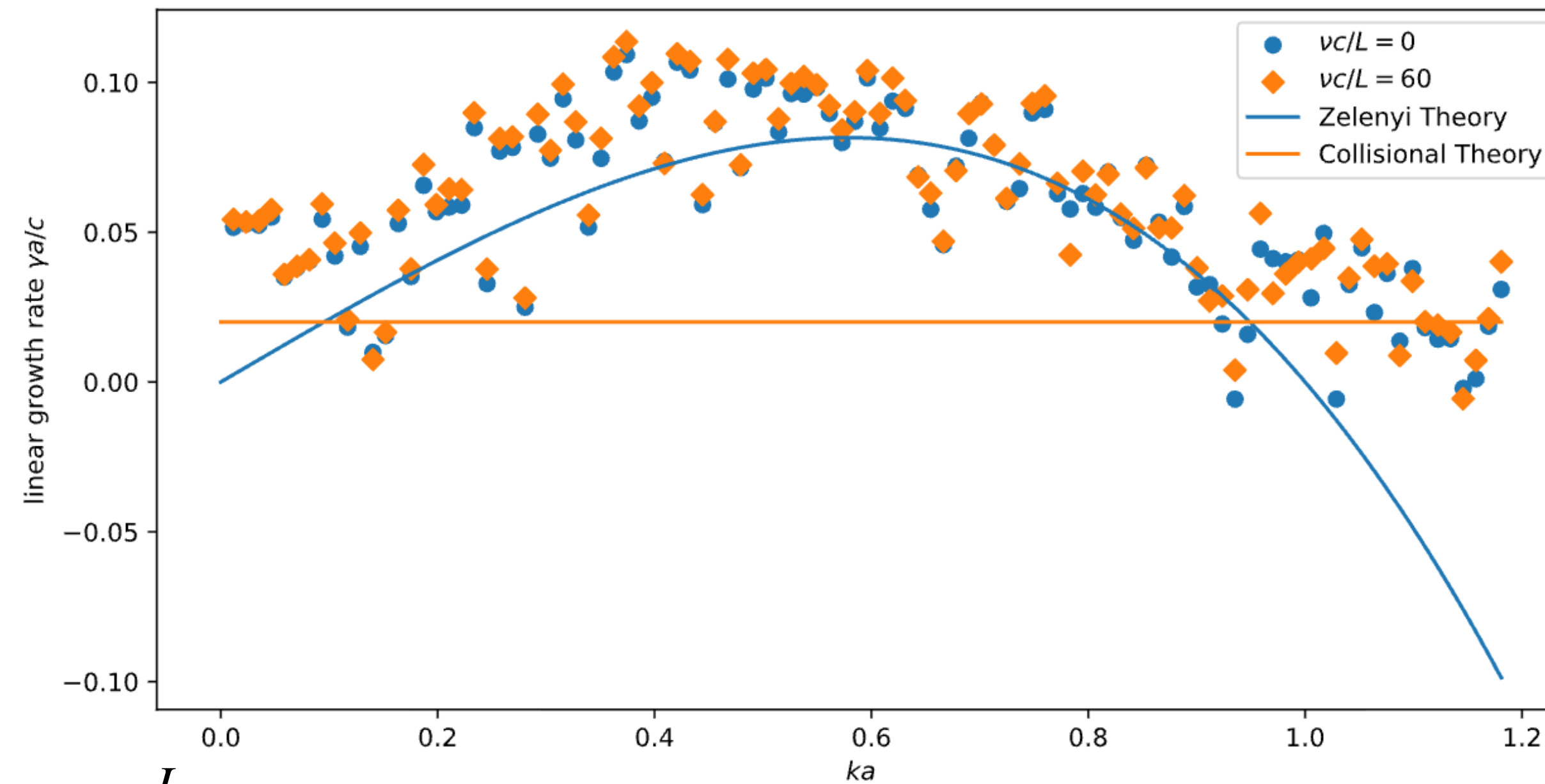
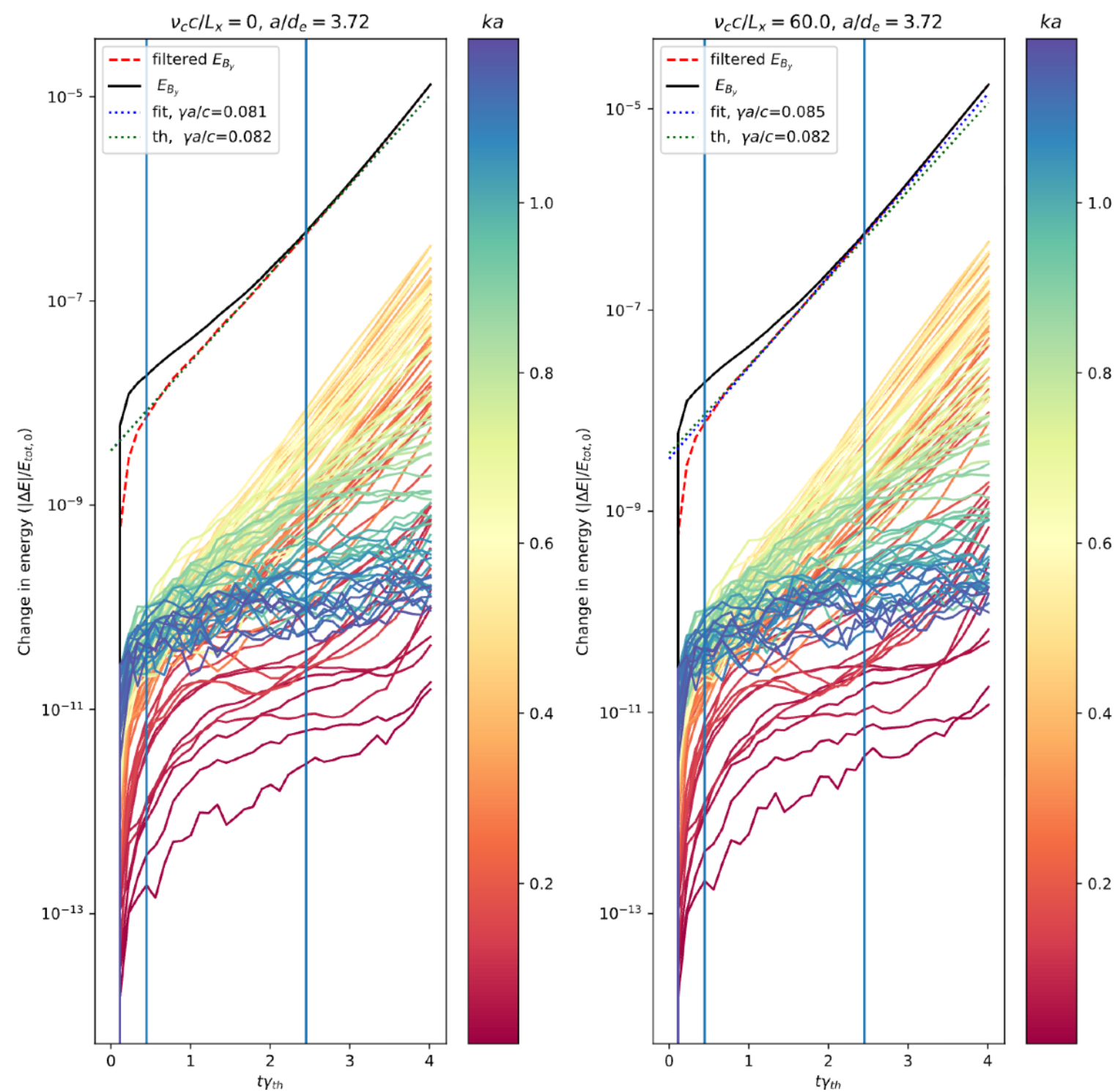
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$$\sigma_{h,e} = \frac{B_0^2}{4\pi n_e h_e} = \frac{B_0^2}{16\pi n_e T_e} = 10000$$

$$\frac{T_H}{T_b} = 26 \quad \frac{n_H}{n_b} = 27 \quad \frac{\nu_H}{\nu_b} = 0.04 \quad \frac{L_y}{d_{e0}} = 5200$$

Zelenyi theory

$$\frac{\gamma a}{c} \approx \frac{2\sqrt{2}}{\pi} ka(1 - k^2 a^2) \frac{1}{\Gamma_d^{5/2}} \left(\frac{a}{\rho_{L,R}} \right)^{-3/2}$$

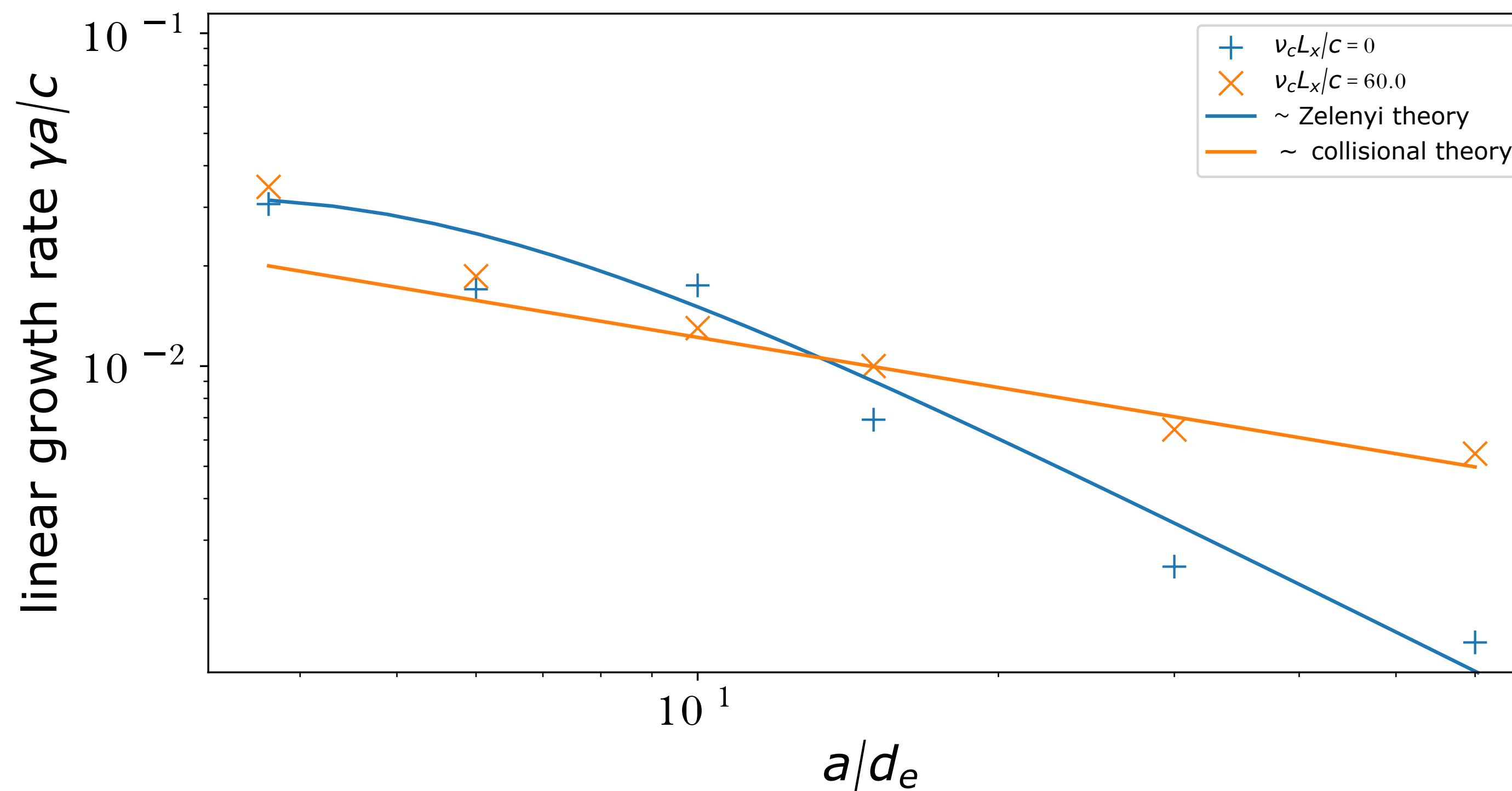
Collisional tearing

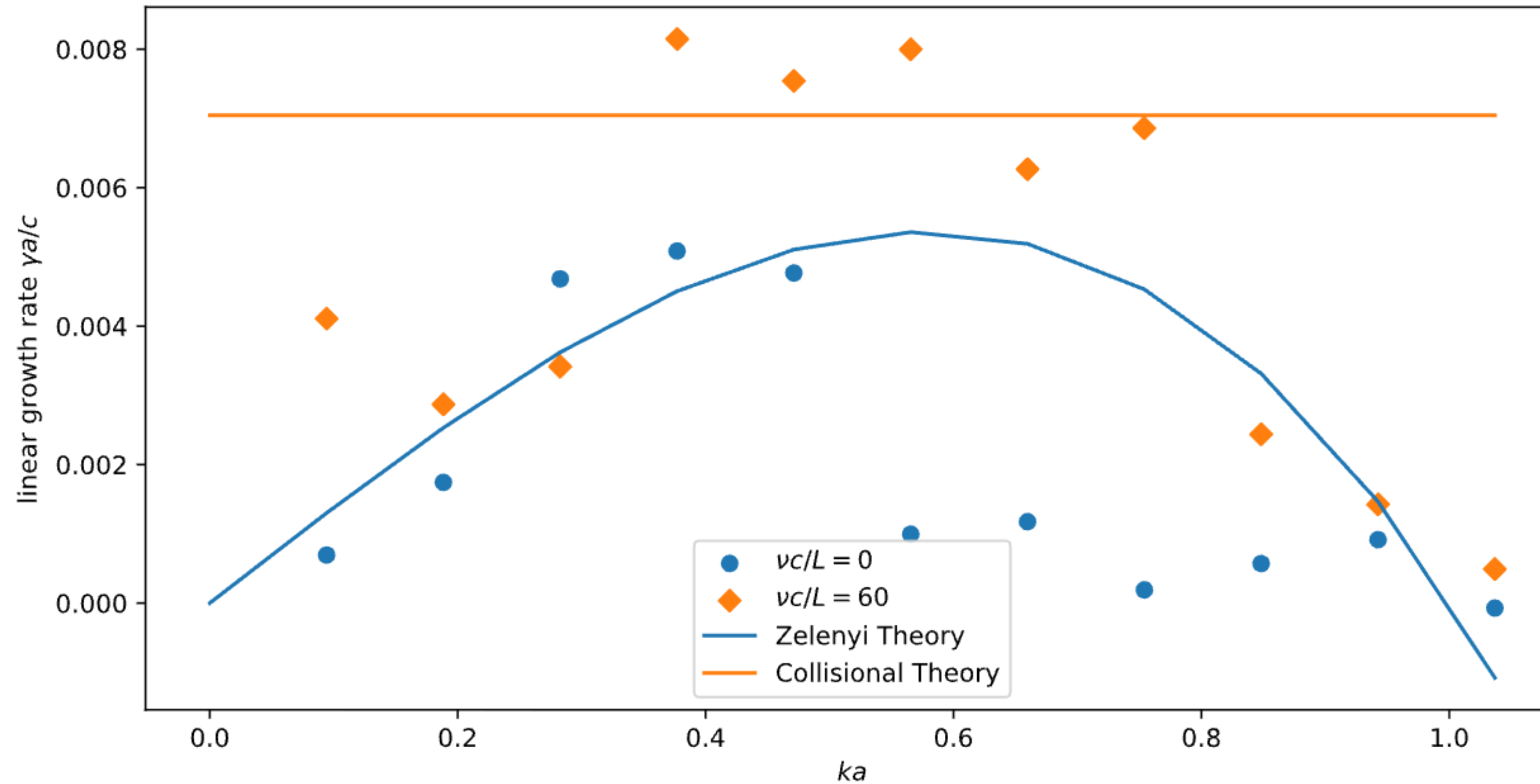
$$\frac{\gamma a}{v_A} \sim \left(\frac{av_A}{\eta} \right)^{-1/2}$$

$$\sigma_{h,e} = \frac{B_0^2}{4\pi n_e h_e} = \frac{B_0^2}{16\pi n_e T_e} = 100$$

$$\frac{T_H}{T_b} = 2.6 \quad \frac{n_H}{n_b} = 2.9$$

$$\frac{\nu_H}{\nu_b} = 0.4 \quad \frac{L_y}{d_{e0}} = 1700$$





Laser Solid interaction experiment

- Collisions kill anisotropy, driving mechanism for Weibel instability
- Biermann Battery dominates again

Electrostatic shocks

- Ion acoustic waves are suppressed with collisions
- Transition from collisional to collisionless thickness

Relativistic Reconnection

- Reconnection only weakly influenced by collisions
- Small magnetization allows for collisional influence on linear tearing stage