The Plasma Physics of TeV Blazars and Implications for the IGMF

Philip Chang (UW-Milwaukee)
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Avery Broderick (Waterloo/Perimeter)
Astrid Lamberts (Caltech)
Christoph Pfrommer (HITS-Heidelberg)
Ewald Puchwein (Cambridge)
Mohamad Shalaby (Waterloo)

Outline

- IGMF measurements from TeV Blazars

- Plasma instabilities in beam — "oblique" instability

- Minimized inverse Compton cascades — no constraints on intergalactic magnetic field from non-observation of gamma ray halos
    - Implication for the gamma-ray sky and cosmology

- Three objections
    - Nonlinear Landau damping
    - Numerical simulations
    - Inhomogeneous background

- Summary

Broderick, PC, & Pfrommer (2012) ApJ, 752, 22
PC, Broderick & Pfrommer (2012) ApJ, 752, 23
Pfrommer, PC, Broderick (2012) ApJ, 752, 24
Puchwald, Pfrommer, Springel, Broderick, & P.C. (2012) MNRAS, 423, 149
Broderick, Pfrommer, Puchwein, PC (2014a) ApJ, 790, 137
Broderick, Pfrommer, Puchwein, PC (2014b) ApJ, 796, 12
PC, Broderick, Pfrommer, Puchwein, Lamberts, Shalaby (2014) ApJ, 797, 110
Lamberts, PC, Pfrommer, Broderick, Puchwein, Shalaby (2015), ApJ, 811, 19

Propagation of TeV photons

- 10 TeV photons that meet 0.1 eV photons have a c.o.m. energy of 1 MeV

$$\gamma + \gamma \rightarrow e^+ + e^-$$

- Typical Length scale for this depends on the density of 0.1 eV photons
  - But it is typically ~100 Mpc
  - Produce pairs with energy of 10 TeV

- These pairs inverse Compton scatter off the CMB photons
  - mean free path is roughly 30 kpc.
  - Producing gamma-rays of ~100 GeV

$$E \sim \Gamma^2 E_{\rm CMB} \sim 100\,{\rm GeV}$$

- GeV halo around TeV sources BUT THIS IS NOT SEEN!

- Missing physics

Missing Physics: B-fields

• TeV beam of electrons and positions are deflected out of the line of sight reducing the GeV IC flux.

• Larmor radius: $r_{\rm L} = \dfrac{E}{eB} \sim 30 \left(\dfrac{E}{3\,{\rm TeV}}\right)\left(\dfrac{B}{10^{-16}\,{\rm G}}\right)^{-1}\ {\rm Mpc}$

• IC distance: $x_{\rm IC} \sim 0.1 \left(\dfrac{E}{3\,{\rm TeV}}\right)^{-1}\ {\rm Mpc}$

• For 10 GeV IC photons, Fermi's angular resolution is 0.2 degrees or

$$\theta \sim 3 \times 10^{-3}\,{\rm rads}$$

• $\dfrac{x_{\rm IC}}{r_{\rm L}} > \theta \rightarrow B \gtrsim 10^{-16}\,{\rm G}$

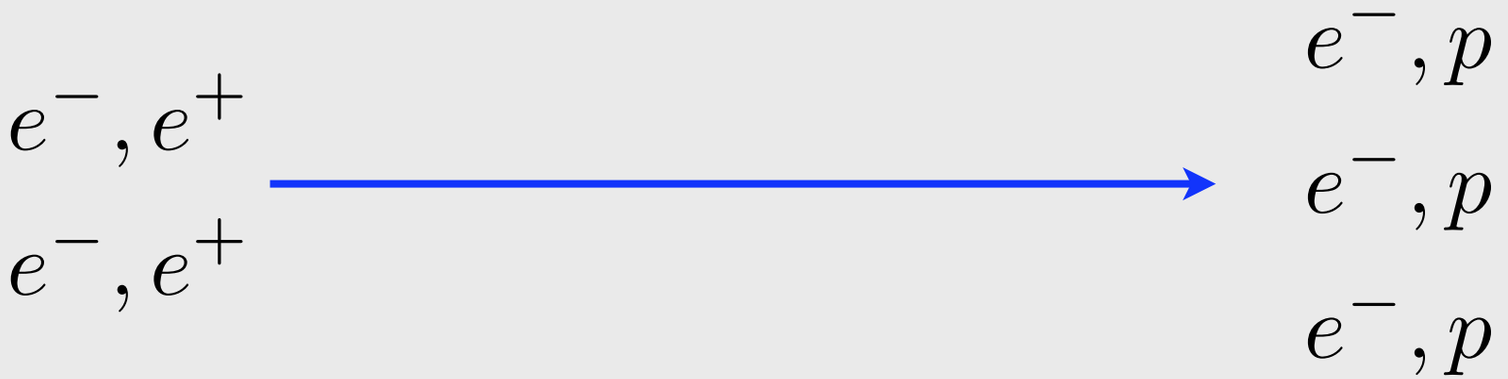
• Non-observation of GeV halos imply intergalactic magnetic field!

Missing Physics: Plasma Physics

• Plasma effects of pair beams that propagate through the IGM are important

• Interpenetrating beams of charged particles are unstable.

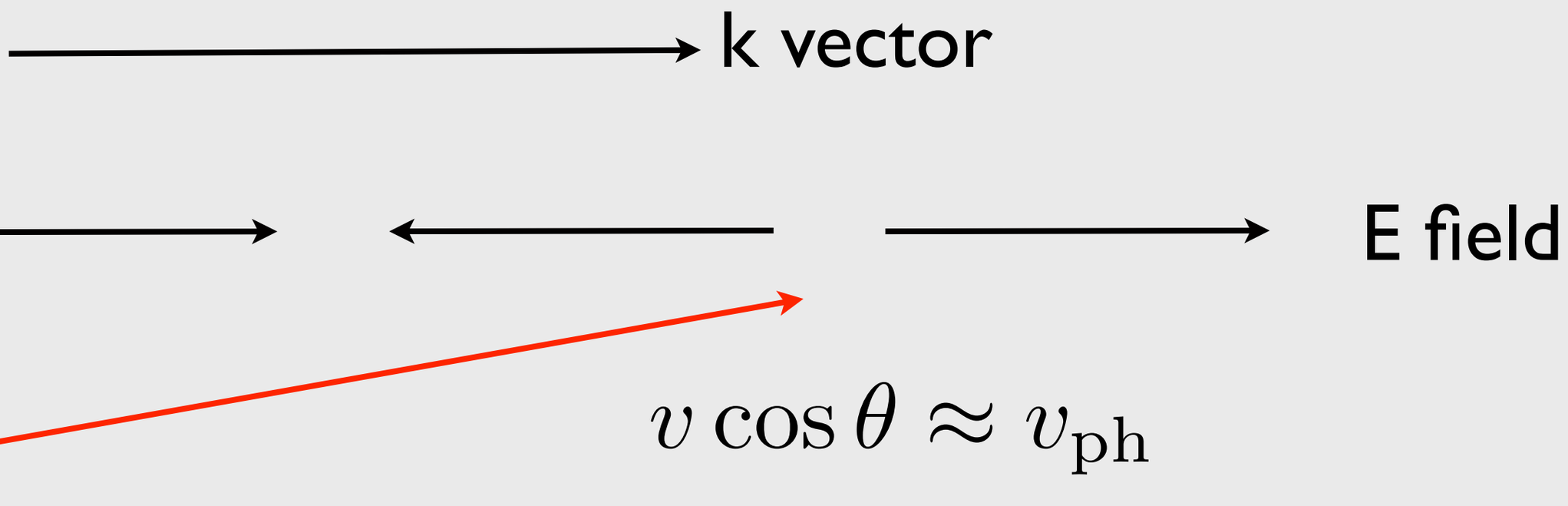
• Consider a beam of particles hitting a background plasma.



• Unstable to several plasma instabilities: beam-plasma, Weibel and oblique

Oblique Instability: Intuitive Picture

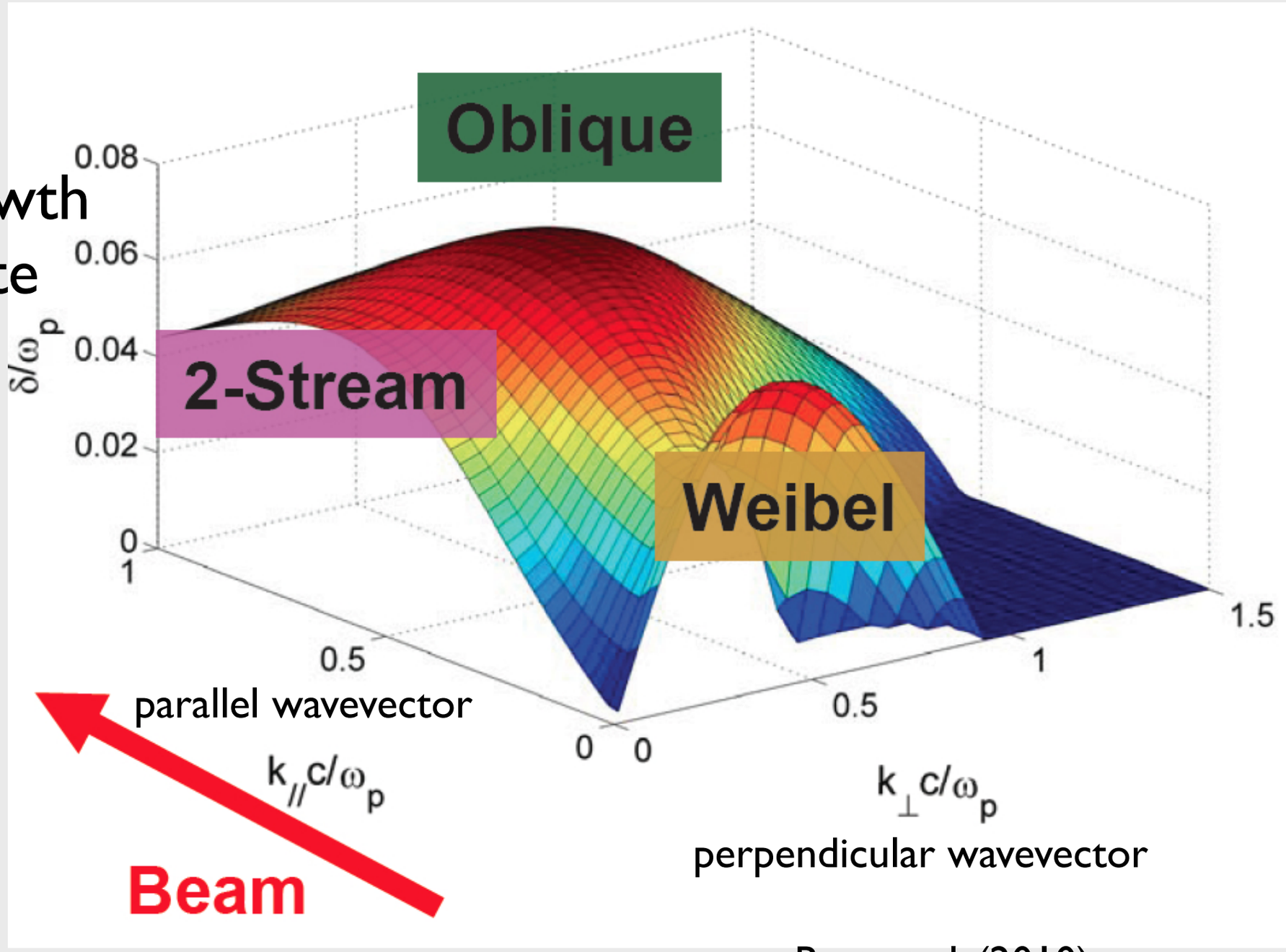
- Basically an overstable Langmuir wave (plasma oscillation)
- Move to the reference frame of the wave



- Resonant particles exchange energy with the wave.
- Deflections of particle trajectory instead of particle straight-line velocity
- Greater growth rate than two-stream because ultrarelativistic particles are easier to deflect than to change their parallel velocities (Nakar, Bret & Milosavljevic 2011).

Oblique Instability

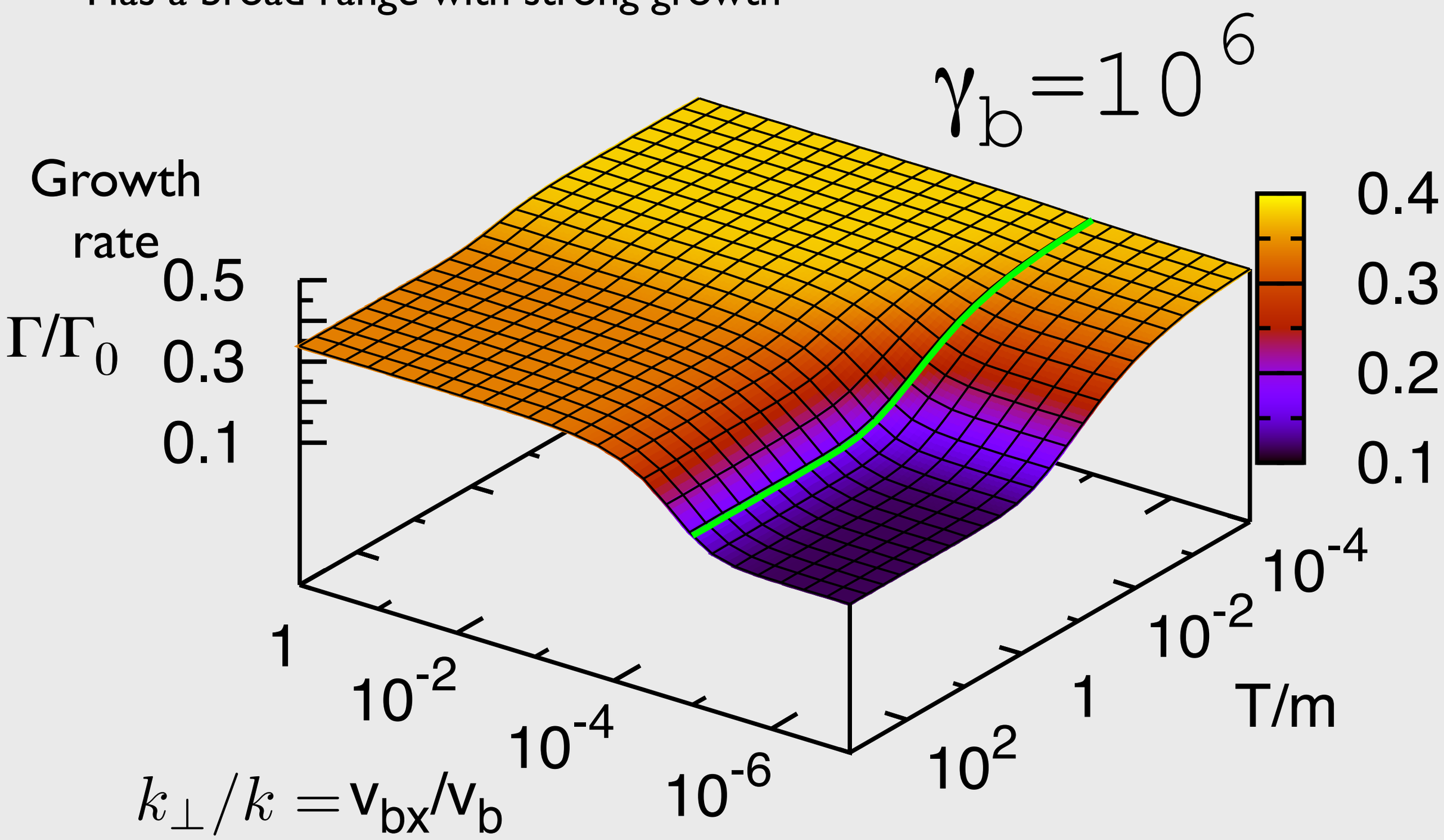
- Generalization of the classical beam plasma and Weibel instability
- Shows greatest growth for ultrarelativisitic beams $n_b/n_0 \ll 1,\ \gamma_b \gg 1$



Bret et al. (2010)

Oblique Instability

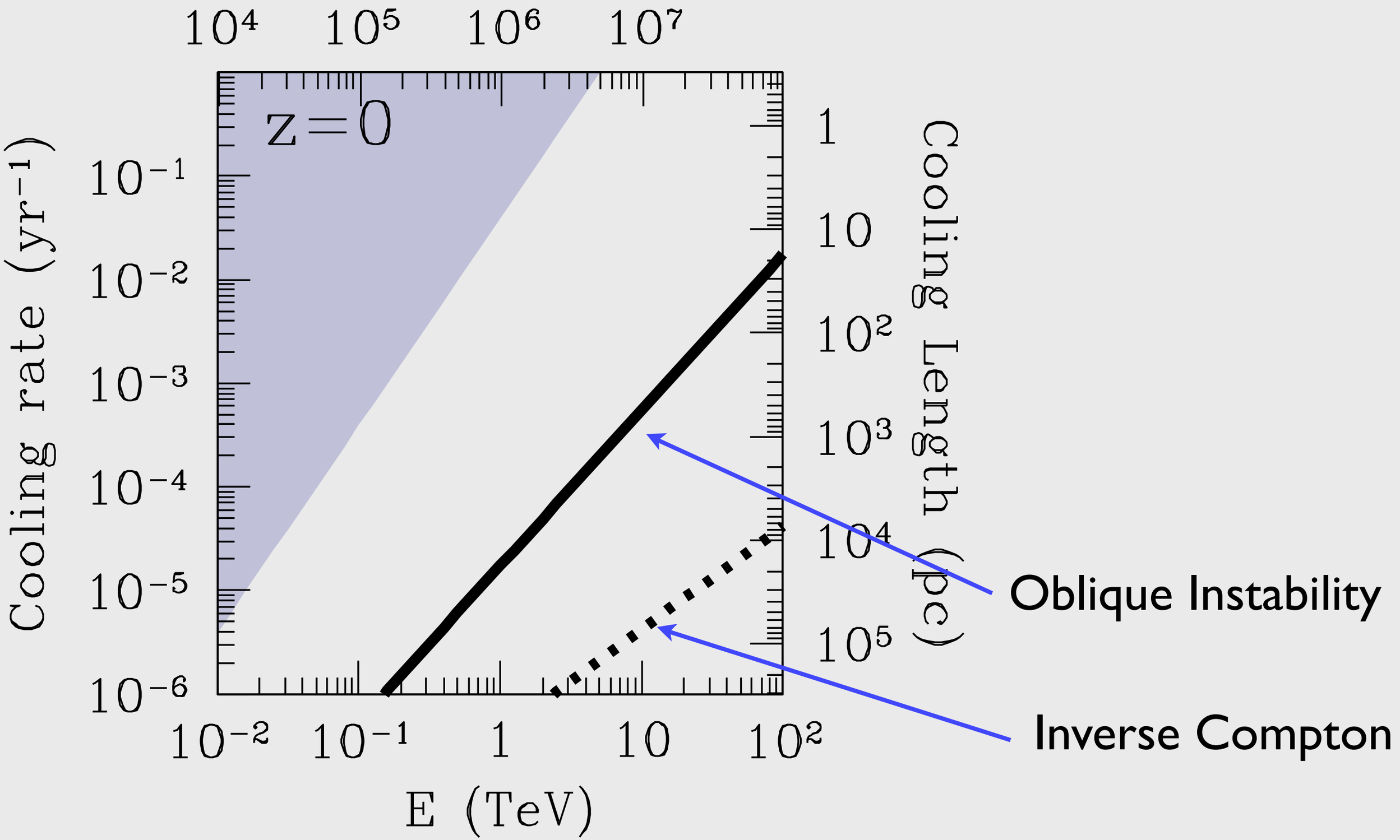
- Has a broad range with strong growth



Broderick et al. (in prep)

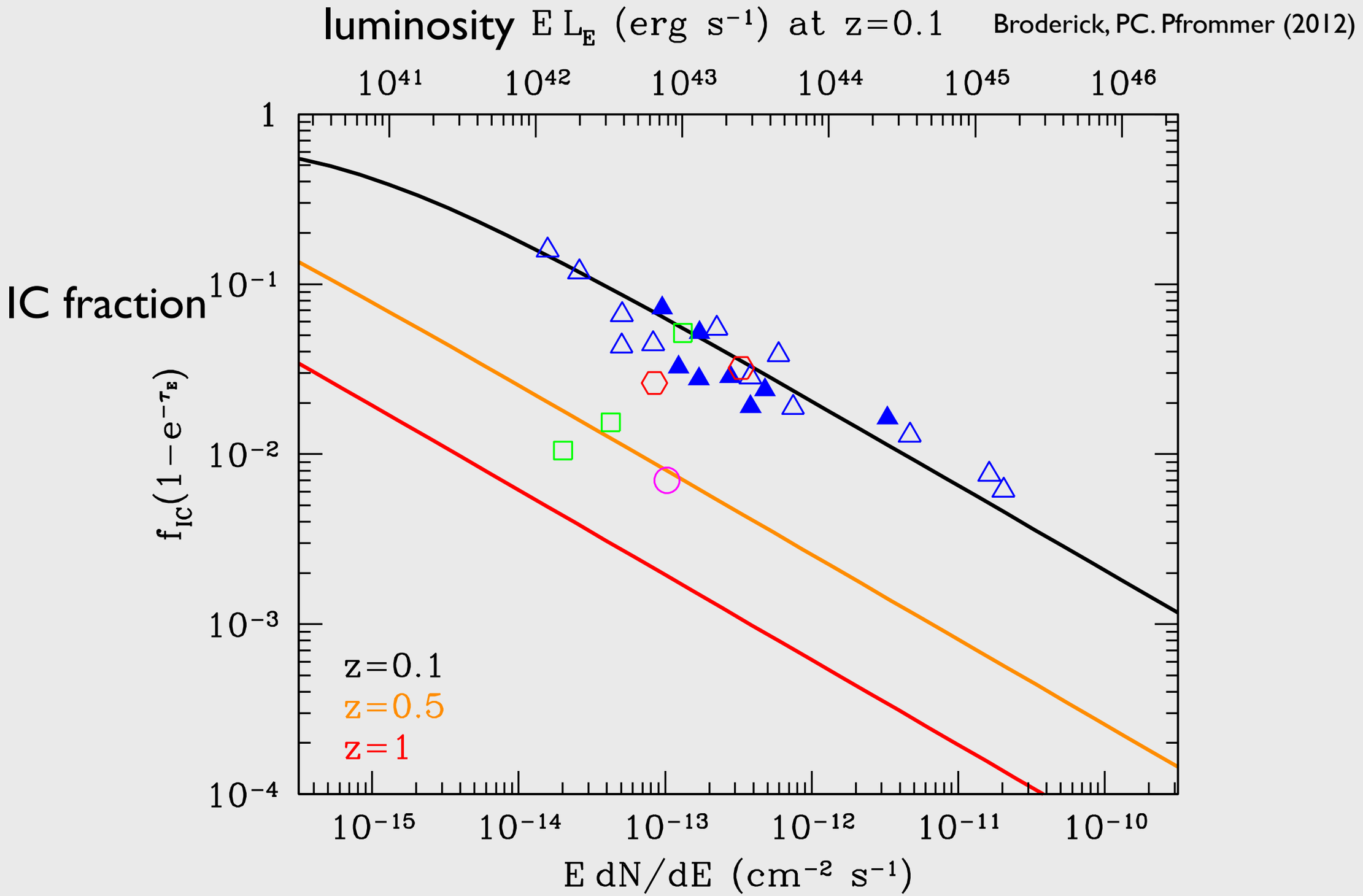
missing plasma physics?

Growth rate of Oblique instability beats inverse Compton off CMB by orders of magnitude. γ



Implications for B-field Measurements

• Minimal inverse Compton -- down an order of magnitude if beam damping rate ~ linear rate of growth



Implications beyond B-field Measurements

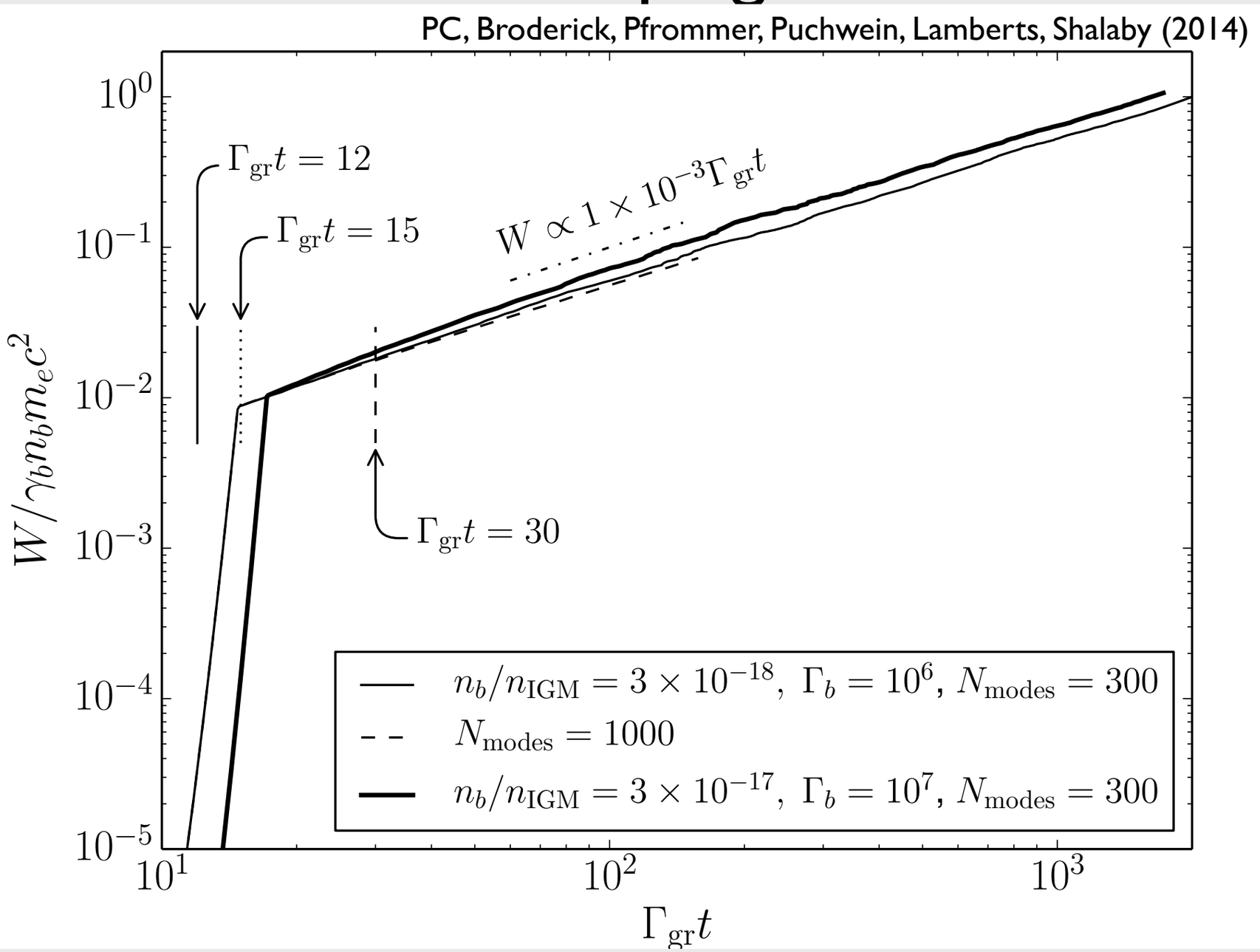
• Suppression of IC cascades allow for strong blazar evolution without violating the constraints of EGRB measurement.

• Heating from TeV blazers are the dominant heat source of the IGM post HeII deionization
    • May allow for observed invert temperature-density profile
    • May influence aspects of structure formation

Nonlinear Landau Damping

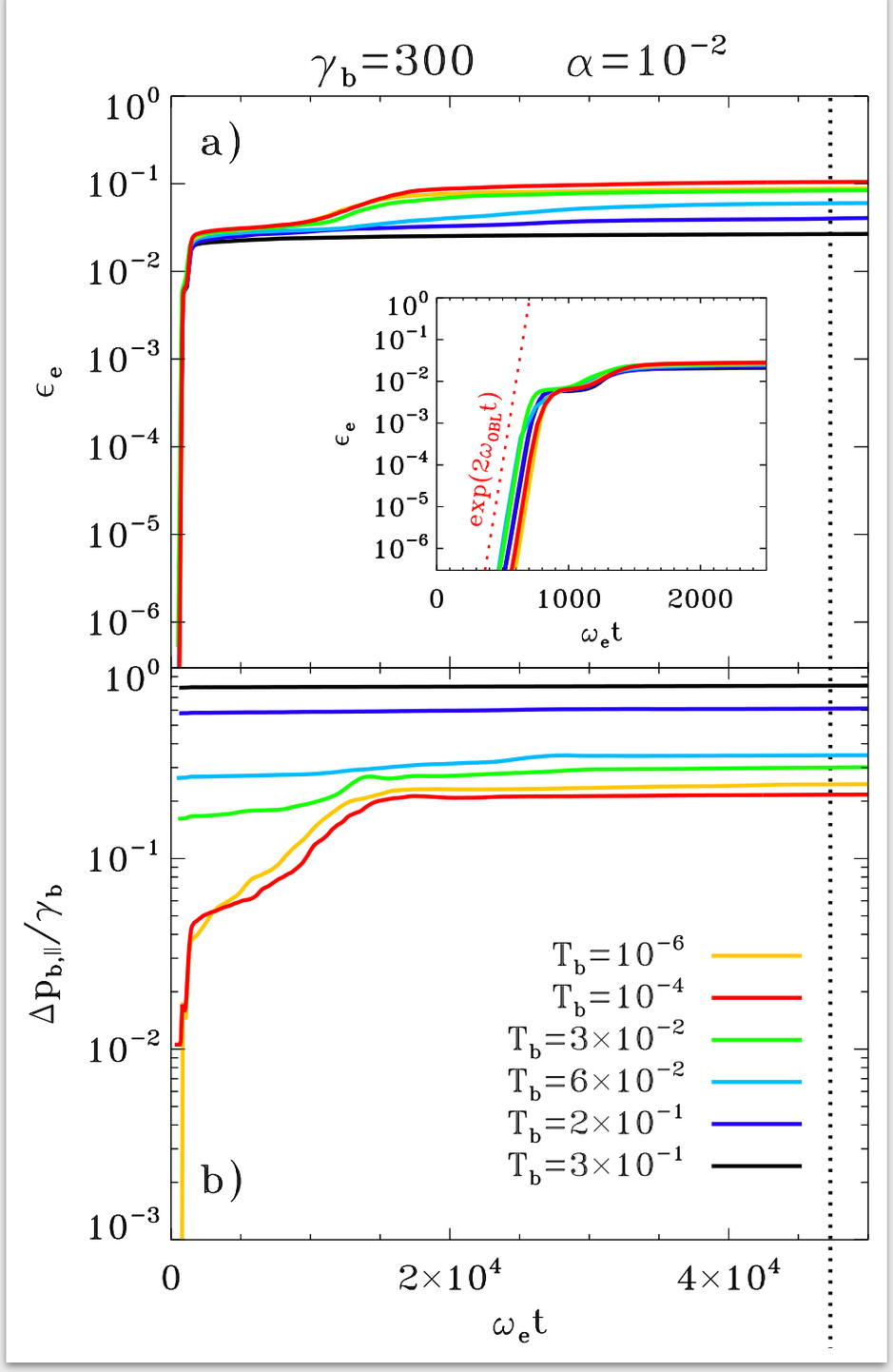
Miniati & Elyiv (2013) argued that particle-wave interaction (nonlinear Landau damping) limits the growth of the instability to exceedingly small values.

PC, Broderick, Pfrommer, Puchwein, Lamberts, Shalaby (2014)

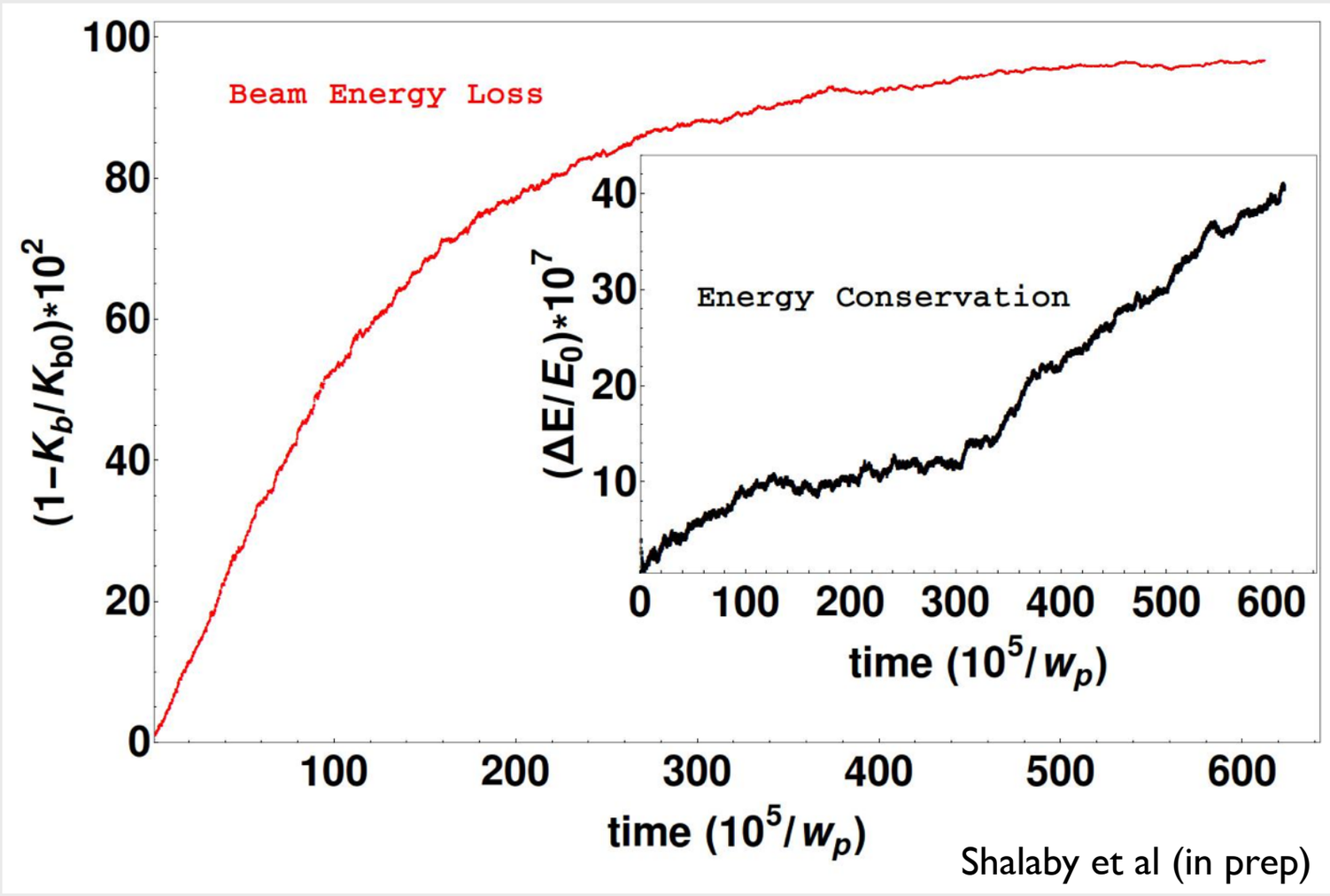


- Detailed calculations of NLD shows that 100% of the beam energy is converted to wave energy neglecting any wave damping.
- Effect cannot be captured using numerical simulations — grids are too coarse, beam to background energies are too high.
- Wave-wave calculations are needed to understand the fate of this wave energy.

Numerical Simulations



Sironi & Giannos (2013)

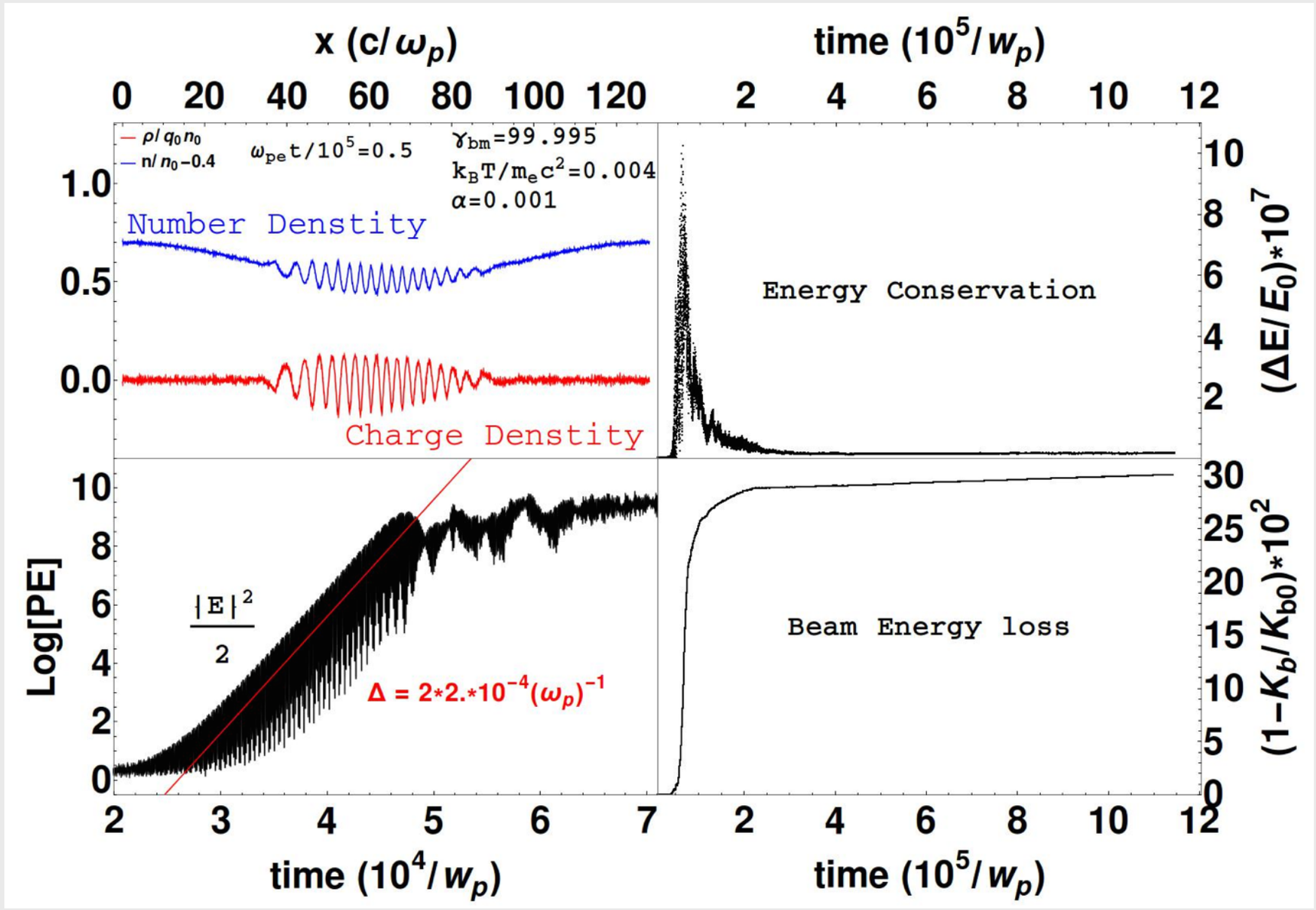


Shalaby et al (in prep)

- Sironi and Giannios (2014) used simulations to argued that the efficiency of conversion from beam energy to heat < 10%
- We have developed an improved 1-D PIC code with higher order field interpolation and superior energy conservation.
- Efficiency of conversion of beam energy is O(1)

Inhomogeneous IGM: Simulations

Shalaby et al (in prep)



- Miniati & Elyiv (2013) also argued that small gradient in the density of the IGM precludes the linear plasma instability due to a shift of the unstable wave out of resonance with the beam.
- Numerical simulations with our PIC code show that the efficiency of conversion of beam energy is O(1) when the condition in Miniati & Elyiv (2013) is applied.

Summary

- Plasma Physics are important for the propagation of TeV pair beams.
  - Beams are violently unstable to the "oblique" instability.
- Precludes constraints on the intergalactic magnetic field.
- Implications for the Gamma-ray sky and cosmology
- Objections to plasma instability effects may not be important
  - Nonlinear Landau damping
  - Numerical simulations
  - Inhomogeneous intergalactic medium
- Much work remains