Blazars-driven beam plasma instabilities in the Intergalactic Medium

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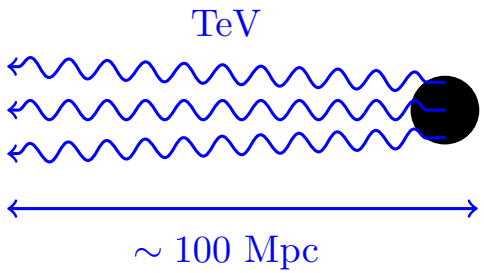
Astrid Lamberts (Caltech), Maria Werhahn (AIP-Potsdam)
Christoph Pfrommer (AIP-Potsdam), Ewald Puchwein (Cambridge/uk),

Monitoring the Non-Thermal Universe (18-21 September 2018)

Cochem, Germany

Expected GeV cascade



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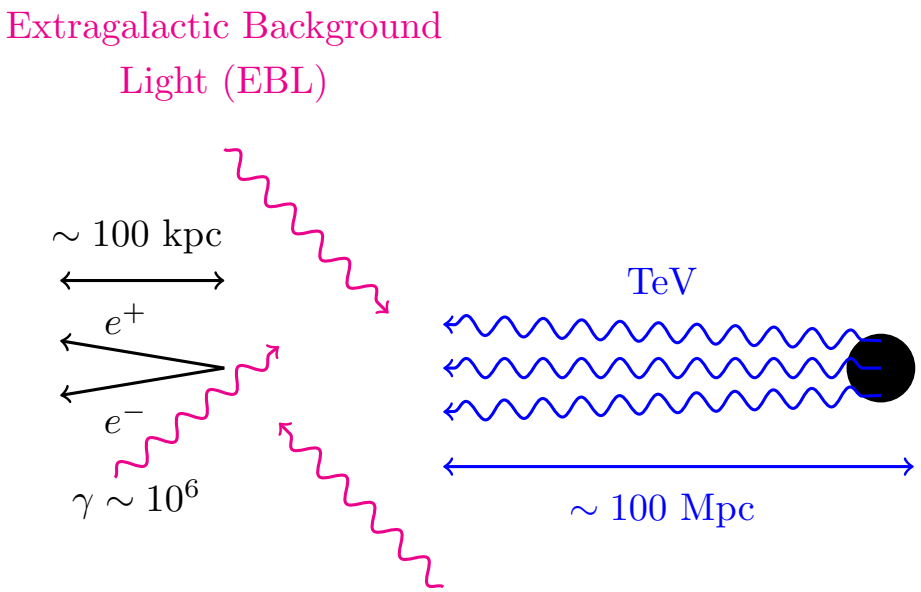

$$E_{\rm EBL}\ E_{\rm TeV}\ \ (1+\cos\theta) > 4\ m_e^2 c^4$$

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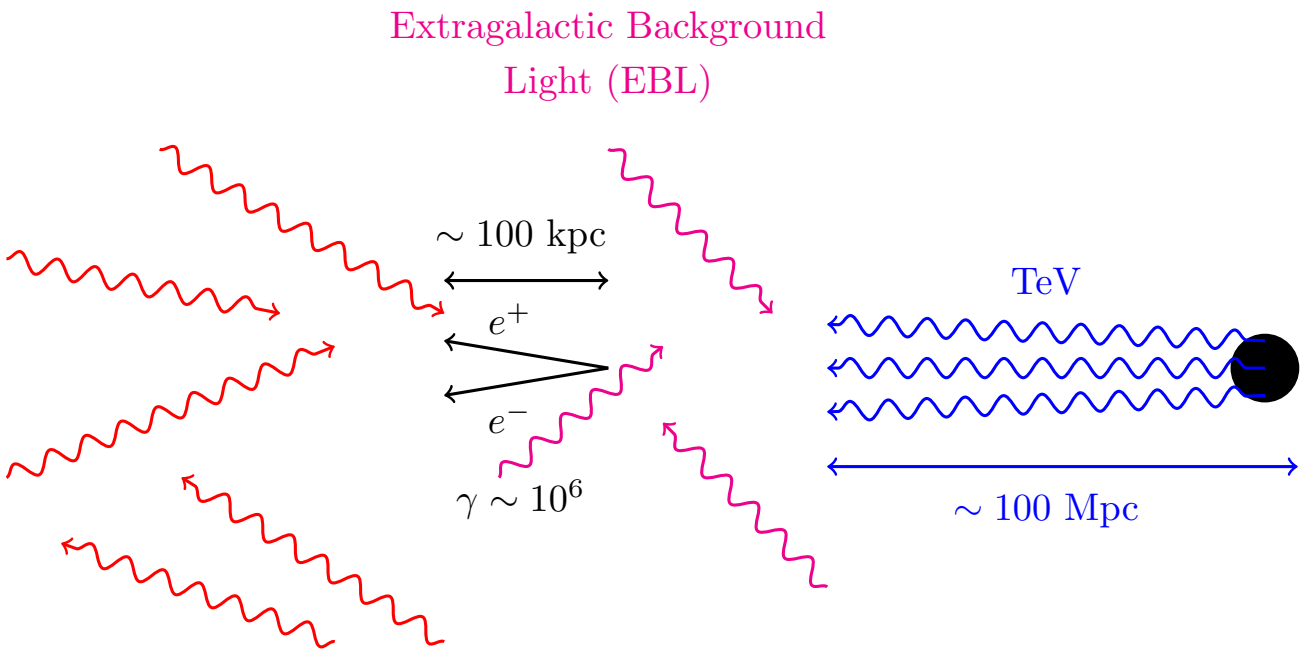

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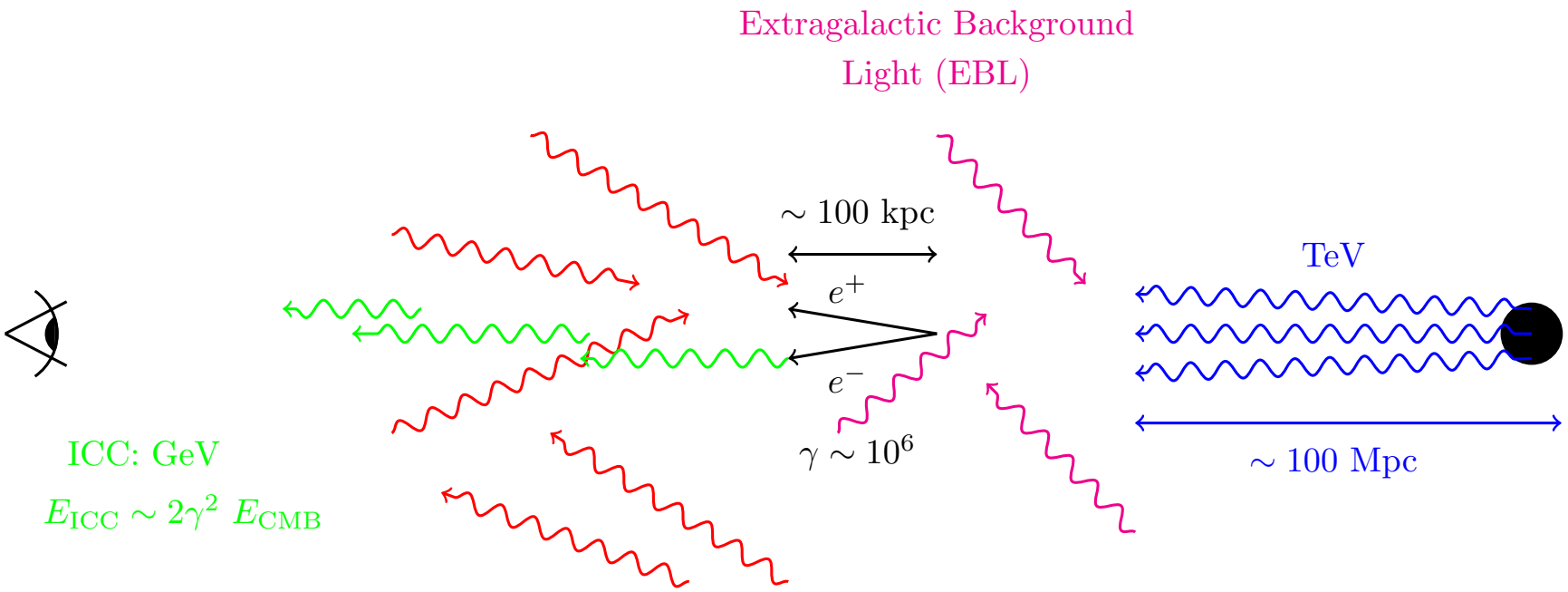

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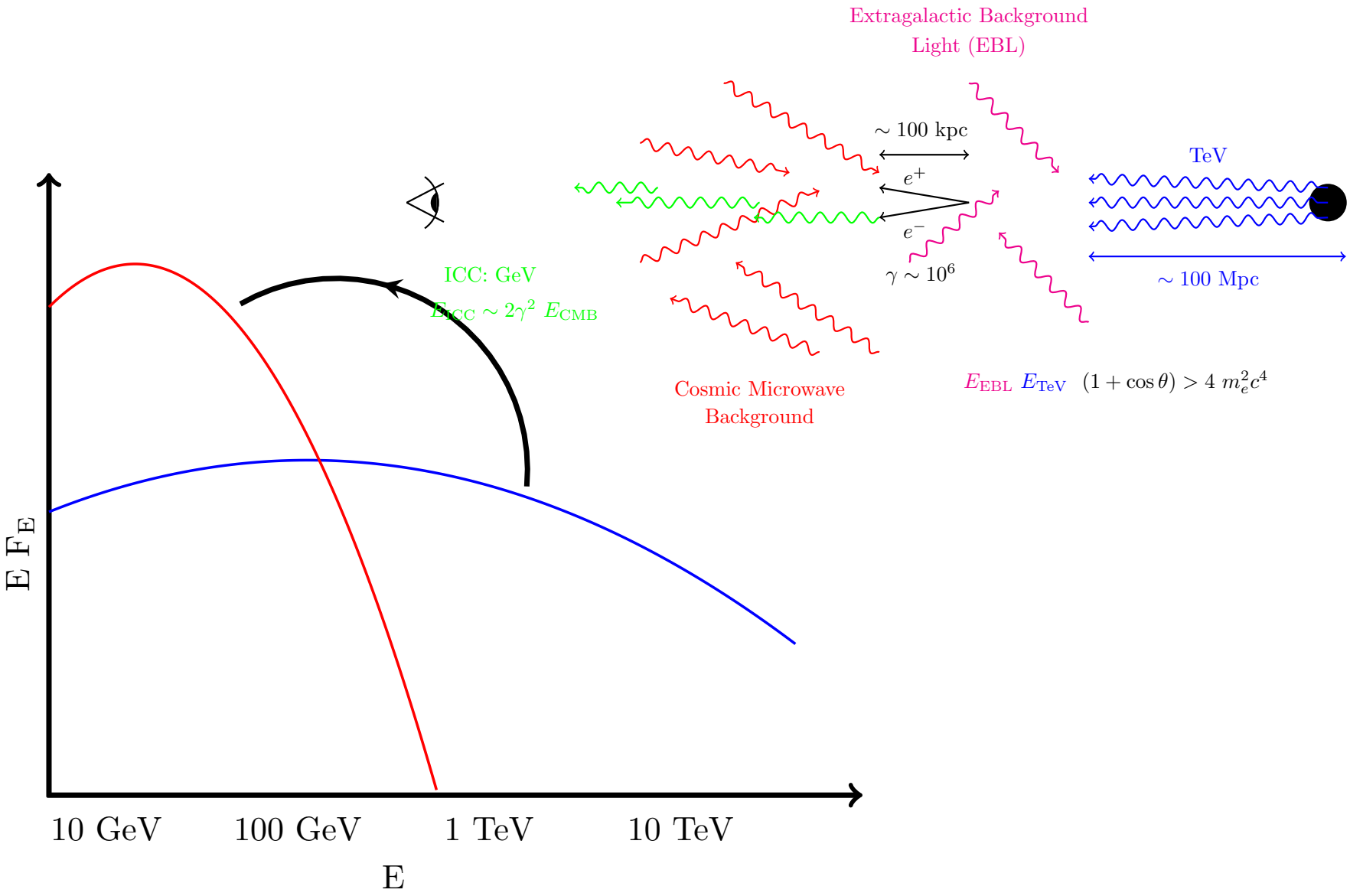

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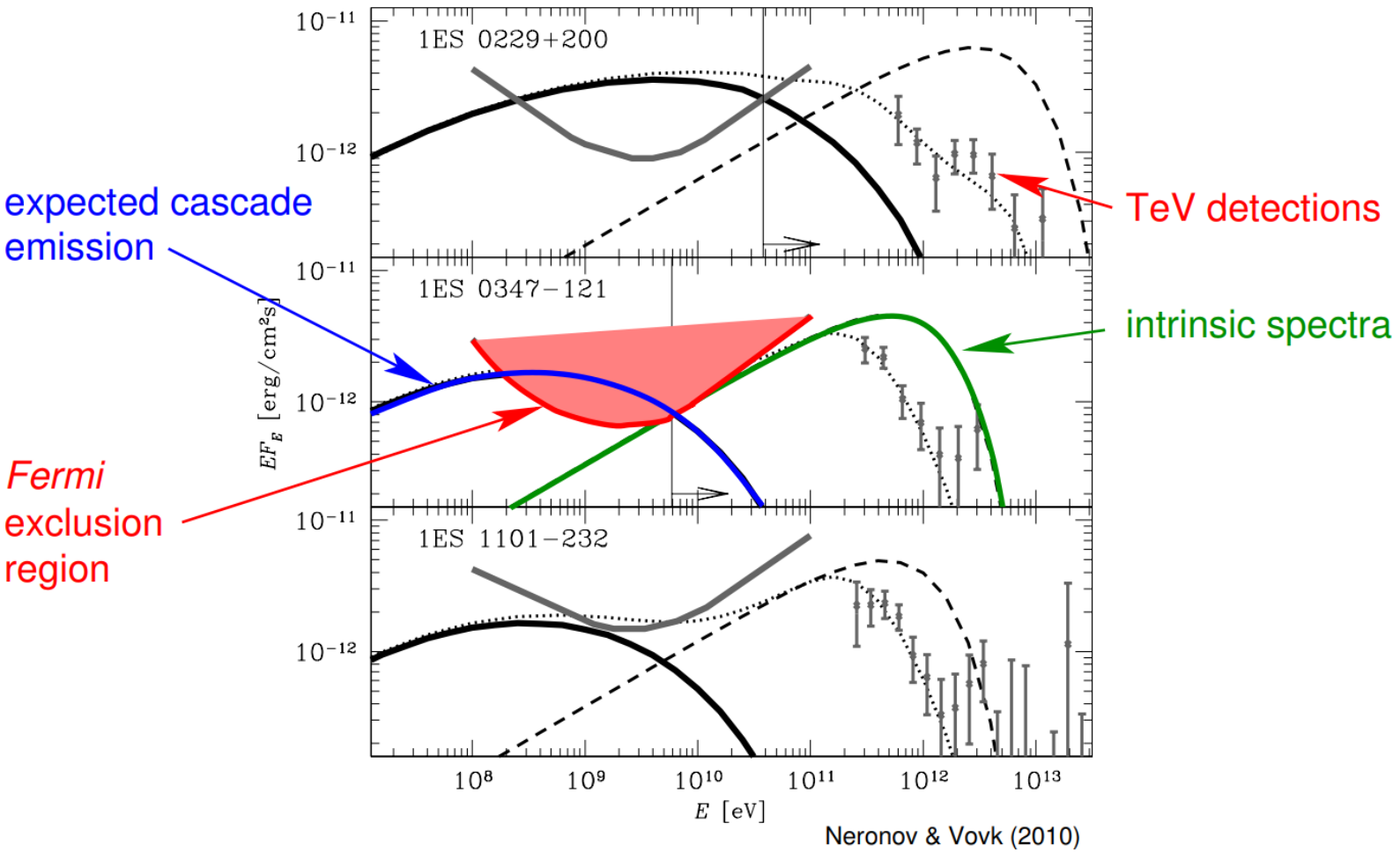
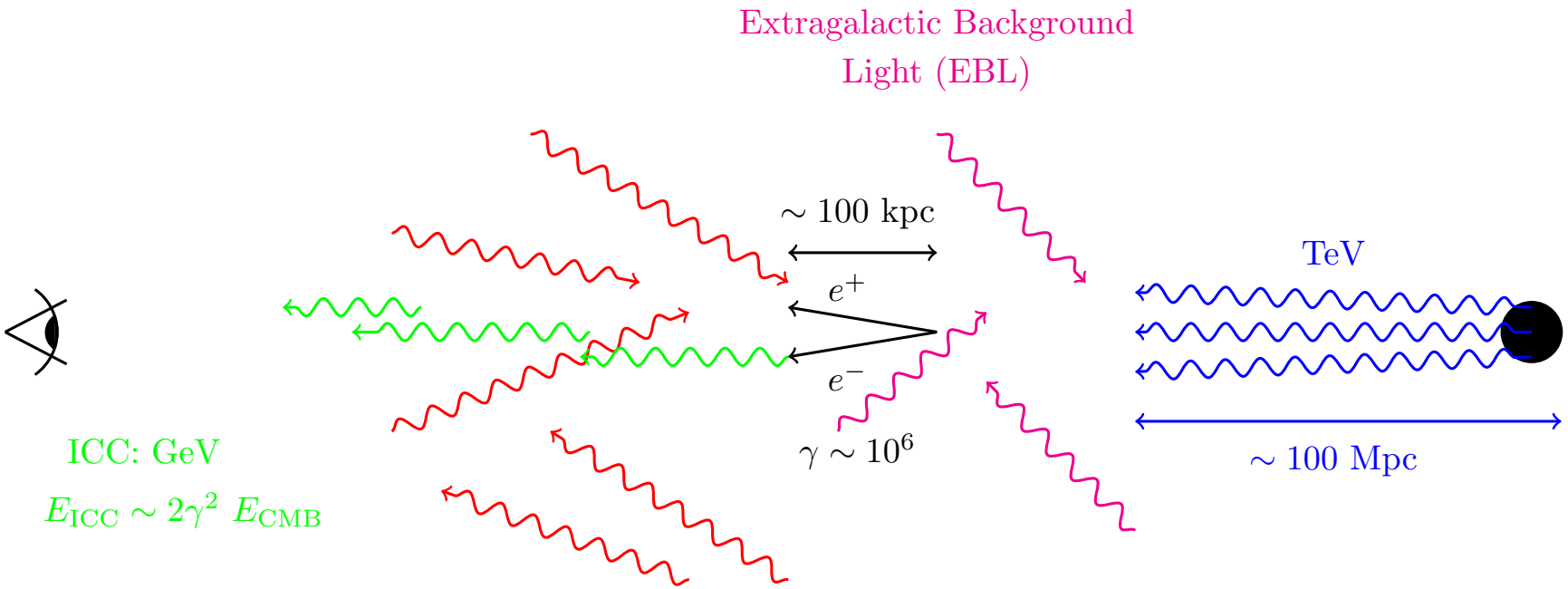


No such GeV flux seen in Fermi-LAT sources

Can IGMF explain the absence of GeV flux?



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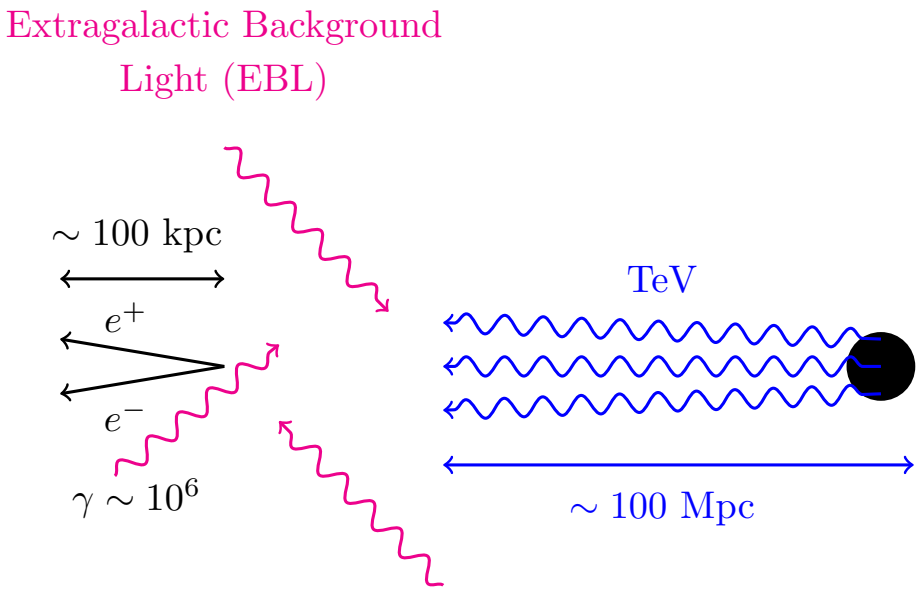

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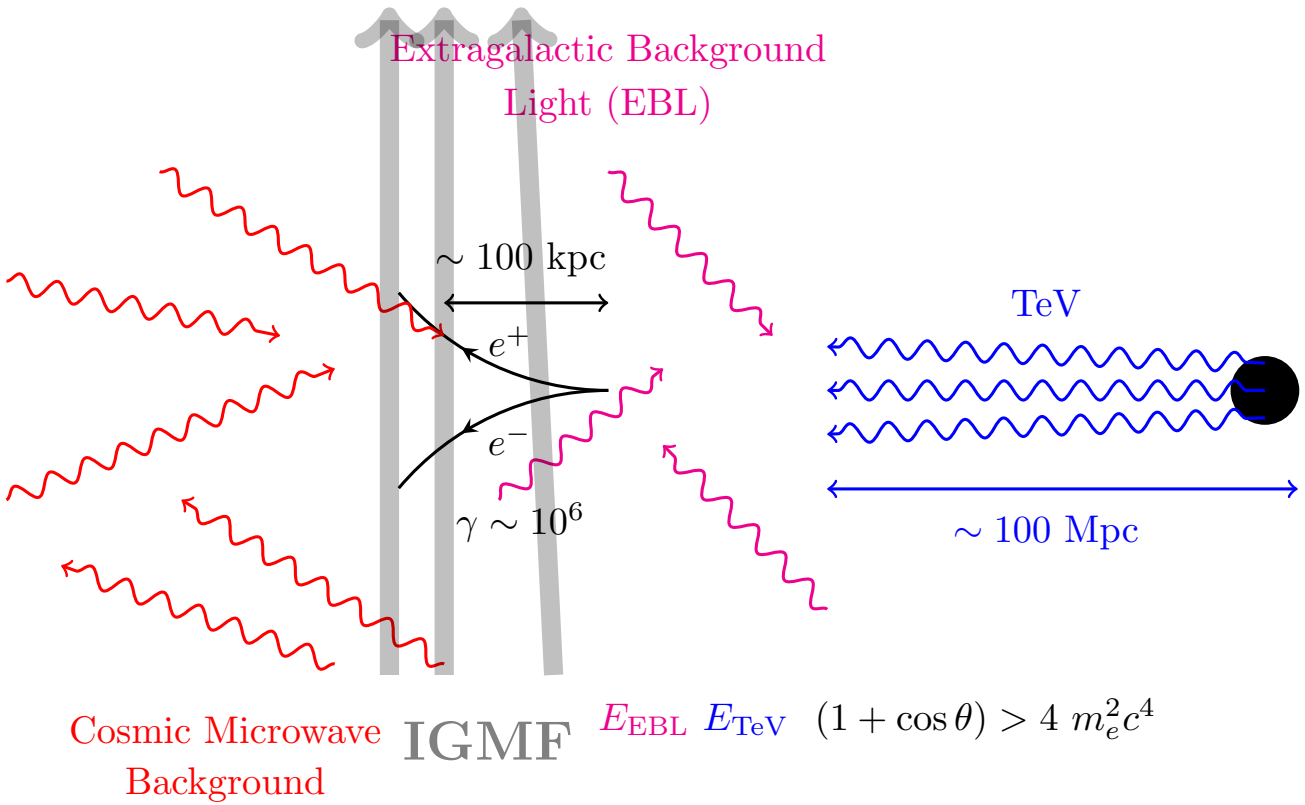

- Adding Intergalactic Magnetic Field (IGMF)

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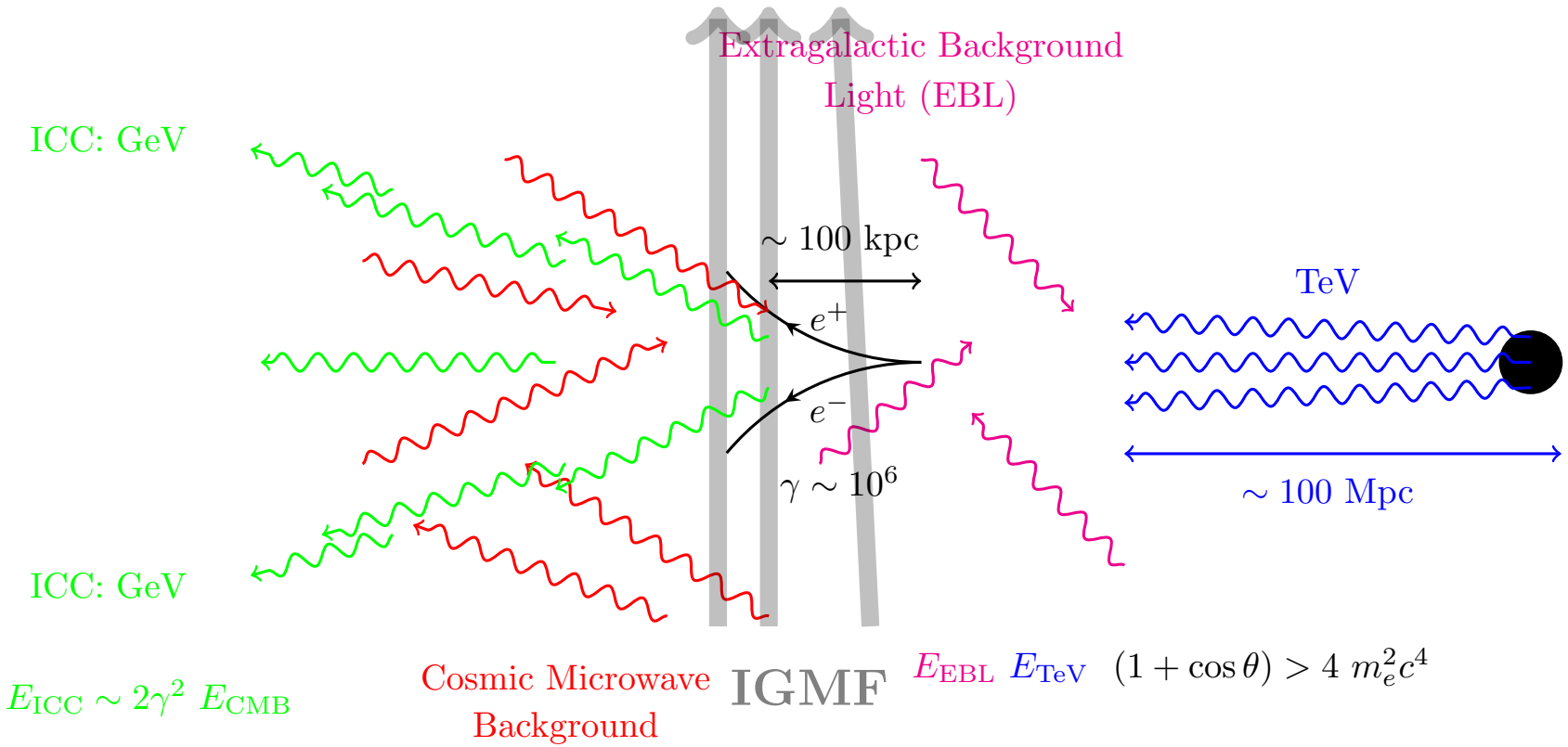

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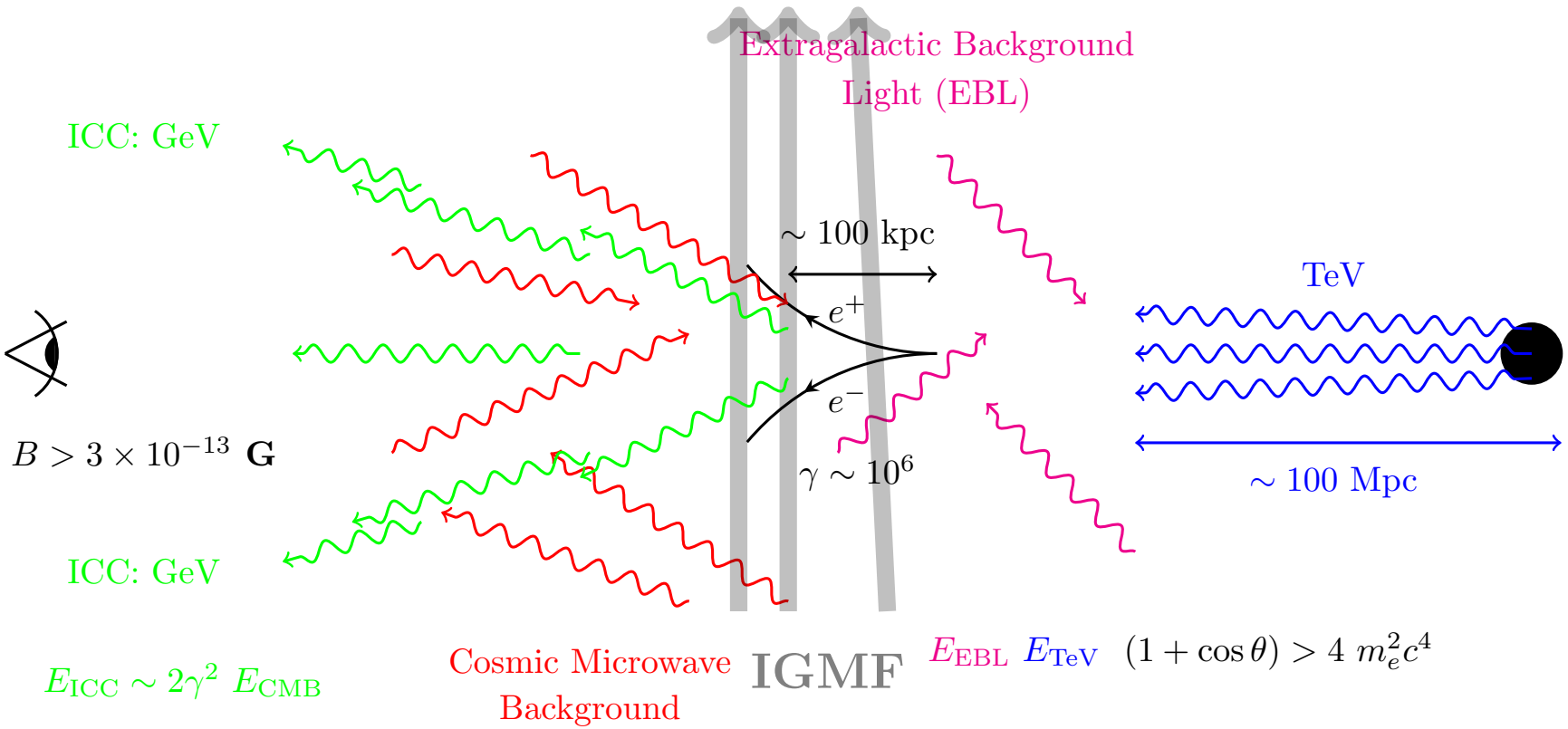
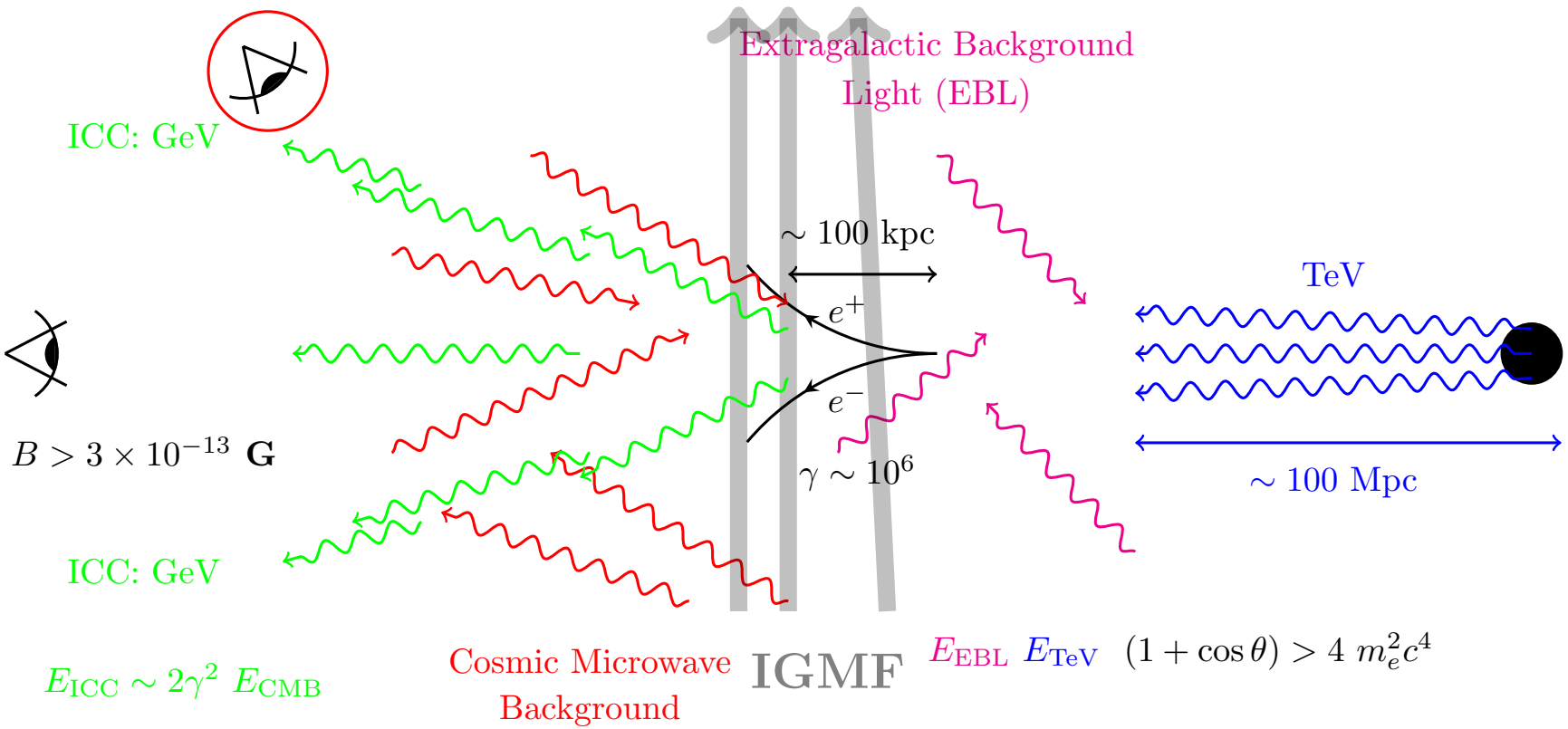


- Adding Intergalactic Magnetic Field (IGMF)
- Lower surface brightness $\xrightarrow{\text{absence of GeV flux}}$ lower limit on the IGMF

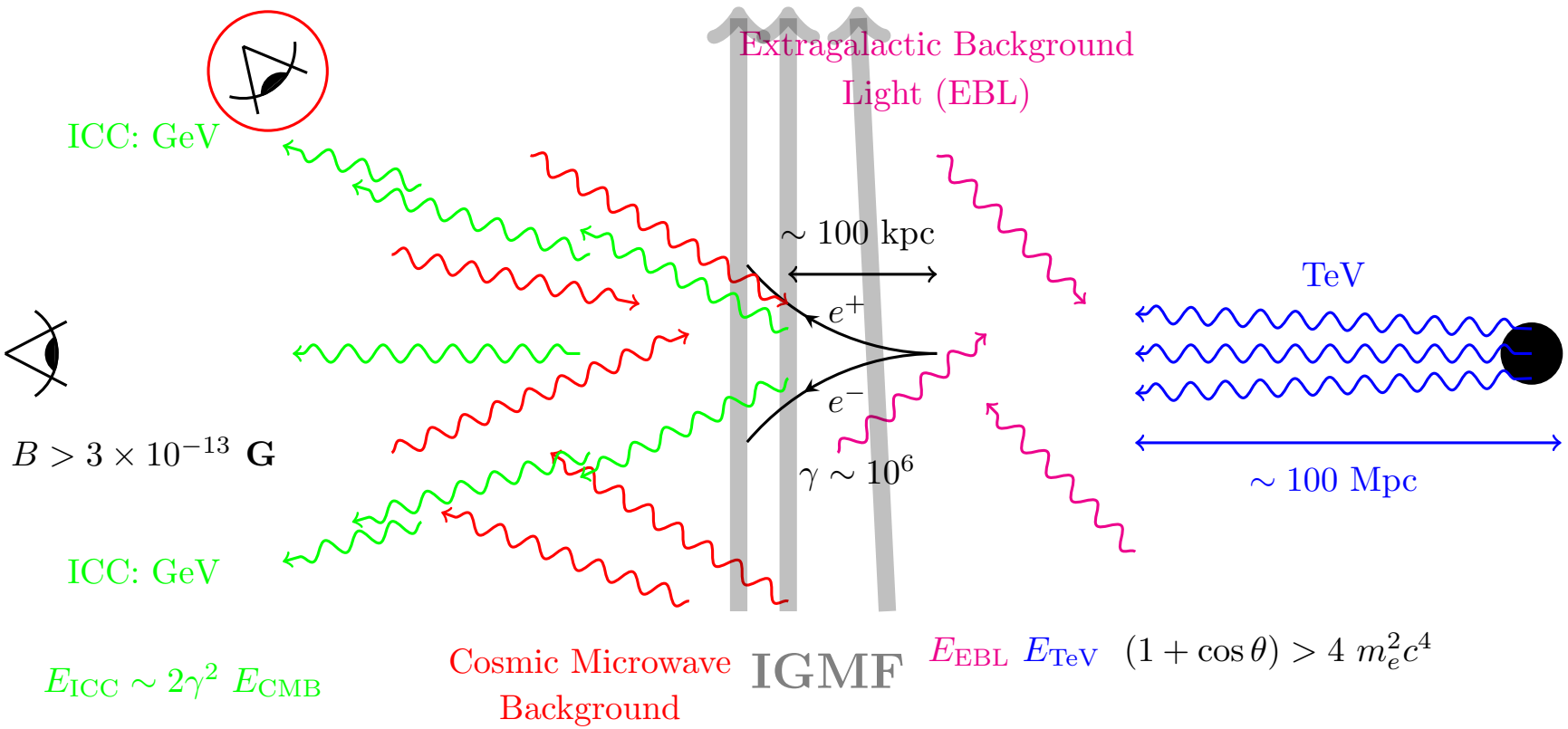
$$B > 10^{-15}\ \text{G} \xrightarrow{\text{stacking}} B > 3 \times 10^{-13}\ \text{G}\ (t_{\rm jet} \sim 10^7\ \text{years})$$

Can IGMF explain the absence of GeV flux?



Oblique observer

Can IGMF explain the absence of GeV flux?



Oblique observer $\Rightarrow$ upper limit on the IGMF

Can IGMF explain the absence of GeV flux?

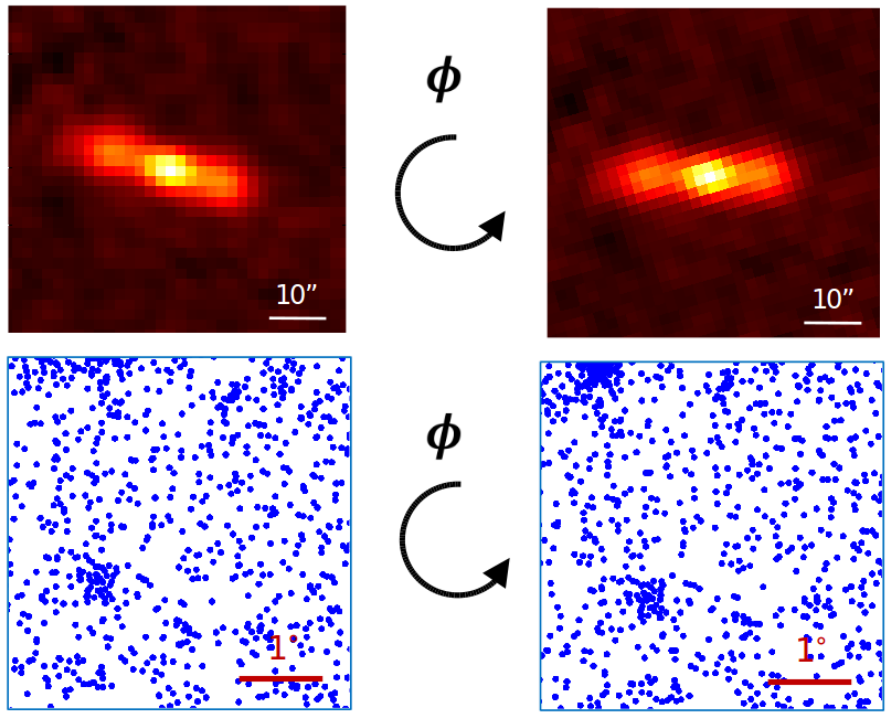
Stacking miss-aligned AGNs (Broderick et al. ApJ ??? & arXiv:1808.02959)

Observation vs expectation

- Unified AGN paradigm: strong correlation between radion and γ-ray emission (See Rocco's talk on Tuesday)
- Oblique radio sources

  [1] Remove objects with a contaminating 3FGL point source (in 2°)

  [2] Find: Position and orientation $\Rightarrow$ orient the same region in the Fermi-sky
  e.g., FRI source shown here



- Stacking the properly oriented Fermi-sky regions.

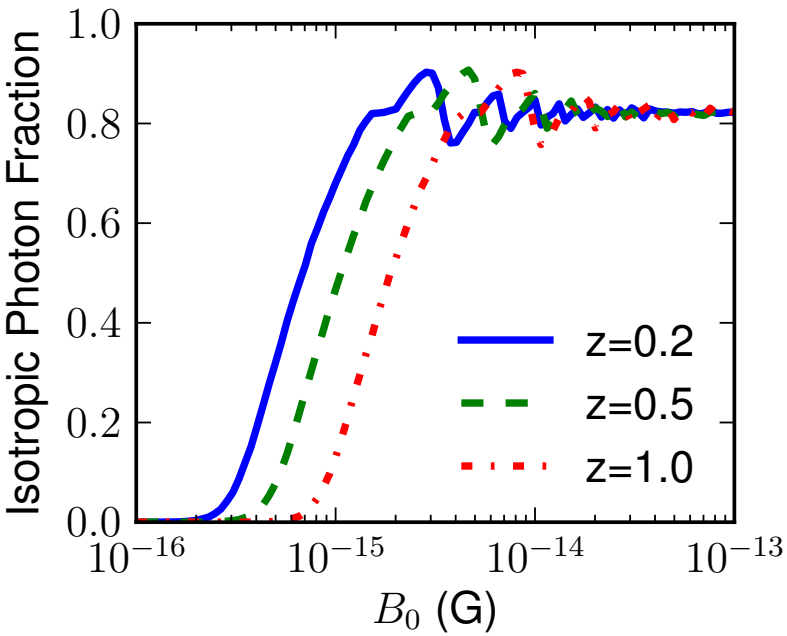
Can IGMF explain the absence of GeV flux?

Stacking miss-aligned AGNs (.Broderick et al. ApJ ??? & arXiv:1808.02959)

Observation vs expectation

Ingredients:

- Oblique Obs. ($30^\circ < \theta < 150^\circ$) see isotropic GeV photons
  $\Rightarrow \boxed{B_0 > 10^{-15}\mathrm{G}}$
- Find z and intrinsic $\mathrm{L_{TeV}}$
  TeV absorption
  Fitting intrinsic $\mathrm{L_{TeV}}$
- Generate expected GeV signal for oblique observers for each source.



- stack and repeat to estimate systematic uncertainties in the simulations.

Can IGMF explain the absence of GeV flux?

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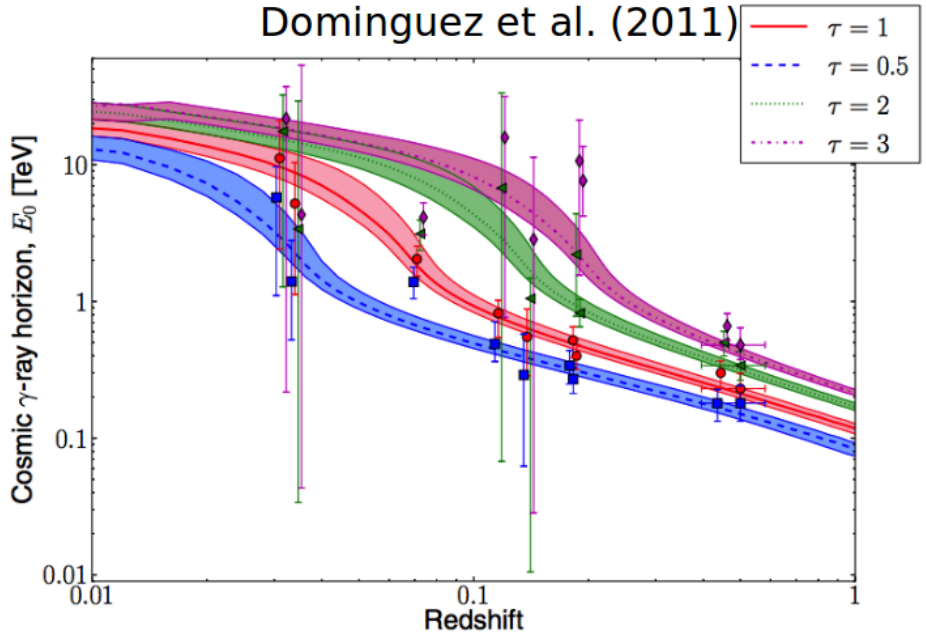

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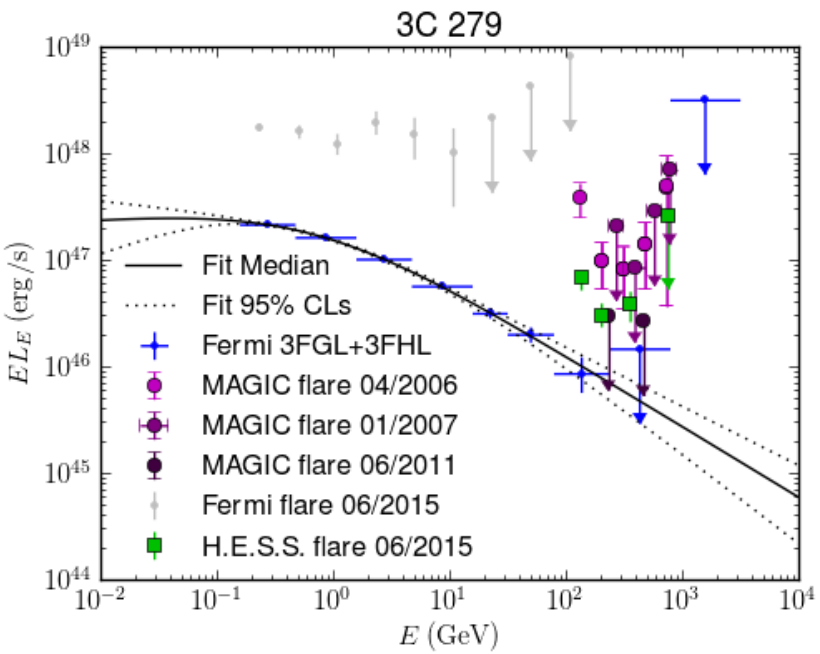

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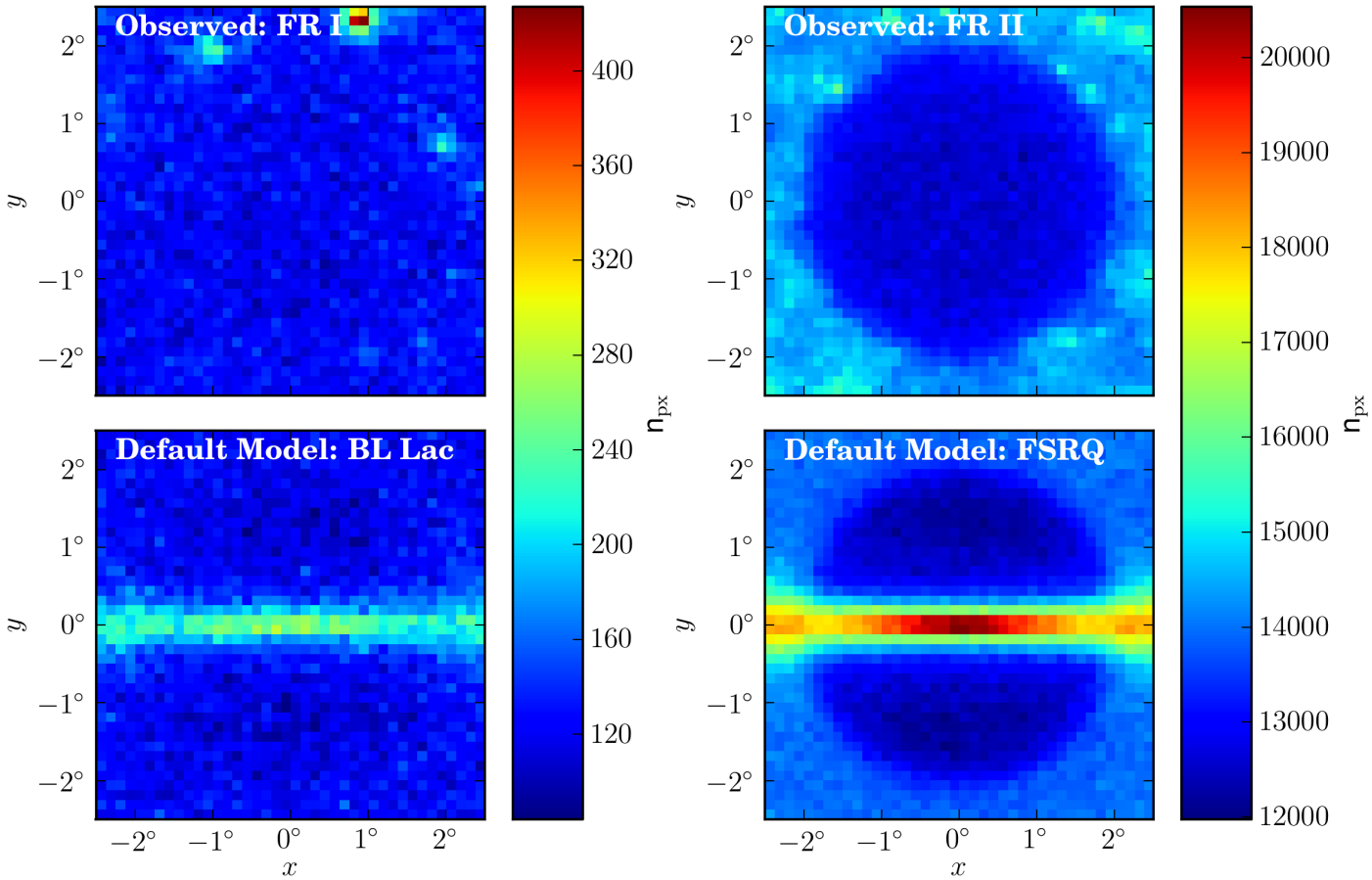
Can IGMF explain the absence of GeV flux?

Results:

FRI (~ 100) and FRII (~ 8000) radio sources separately: similar results!

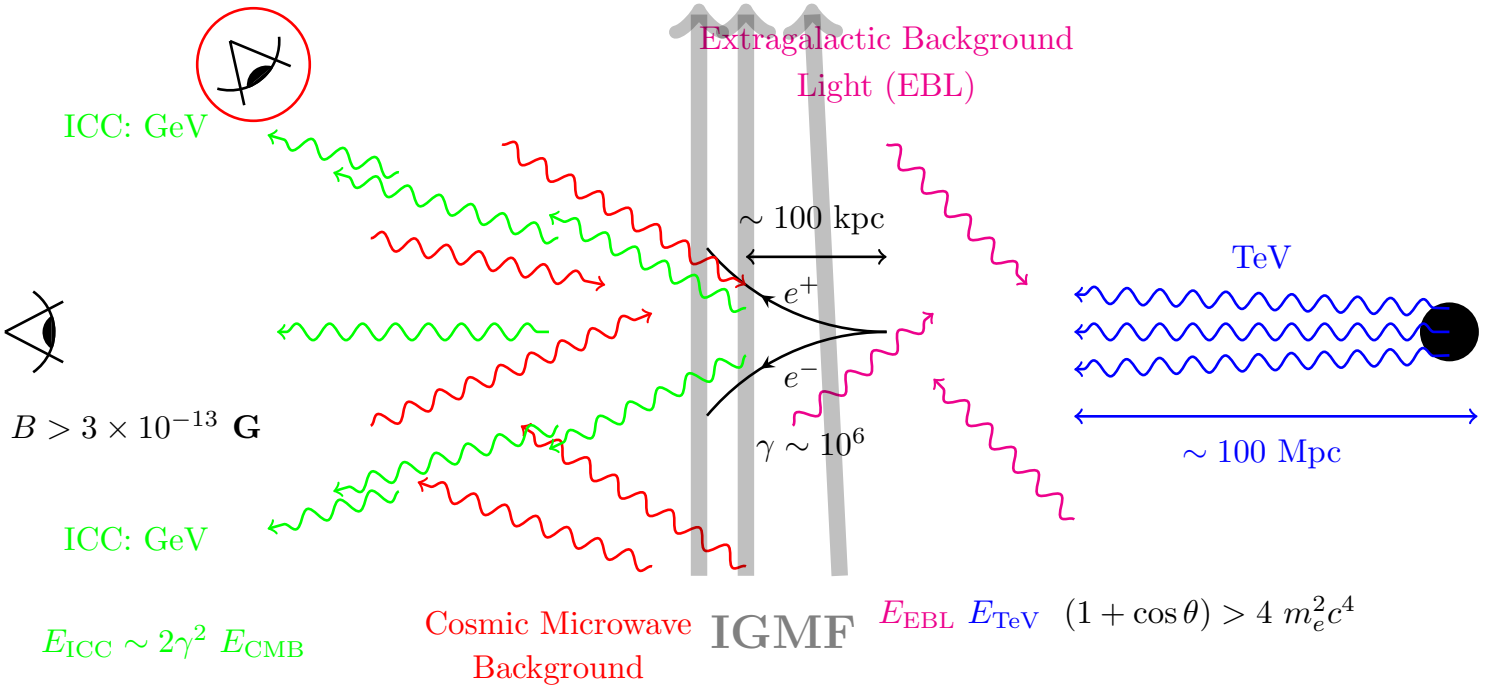
Can IGMF explain the absence of GeV flux?

Results:



To explain the absence of such signal on top panel $\Rightarrow$ B $< 10^{-15}$ G.

Can IGMF explain the absence of GeV flux?



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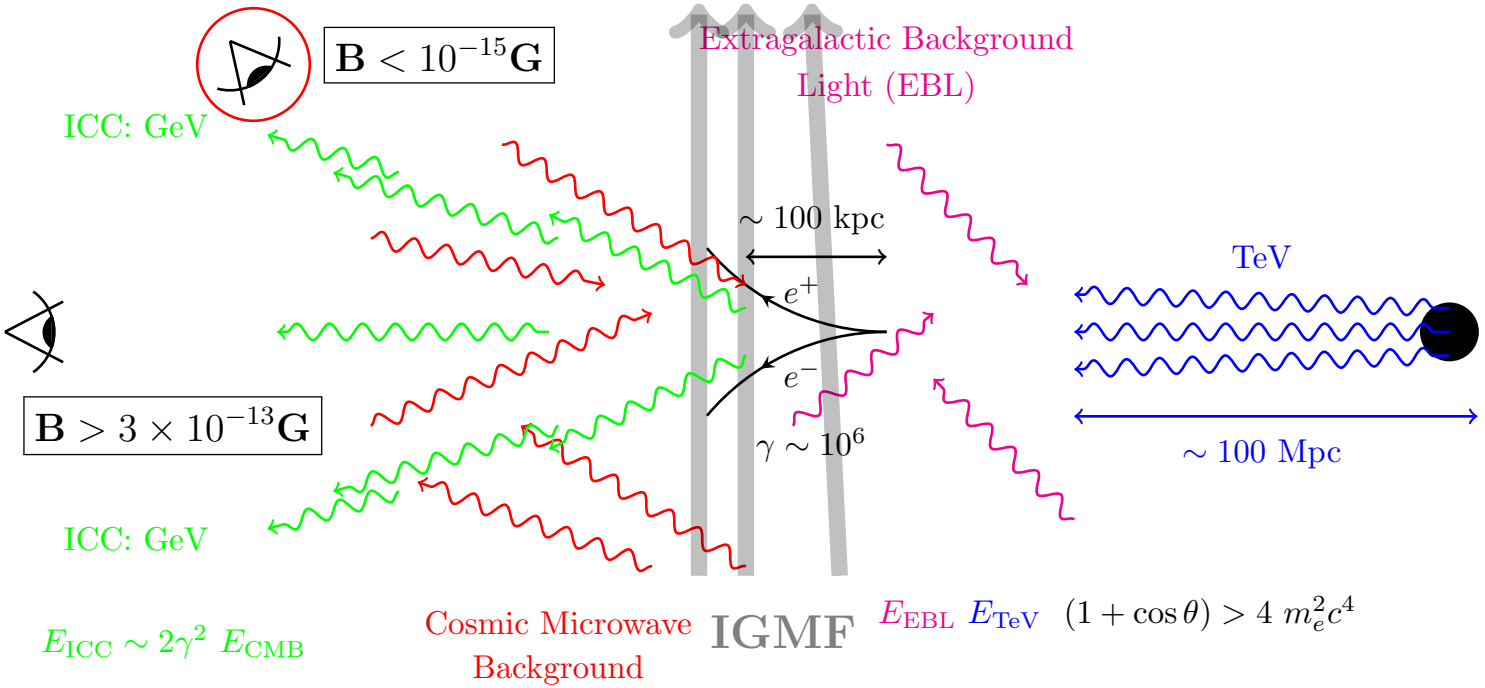
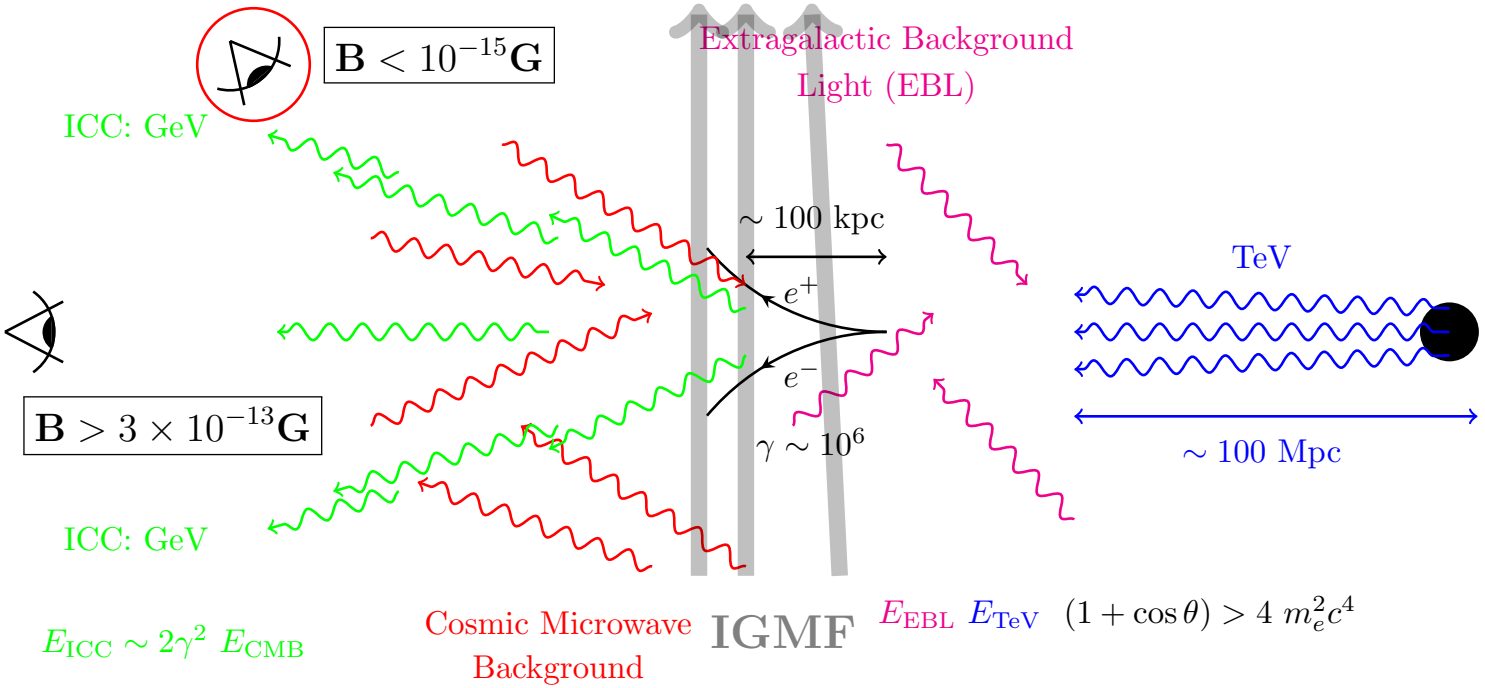


Contradiction between aligned and oblique observers.

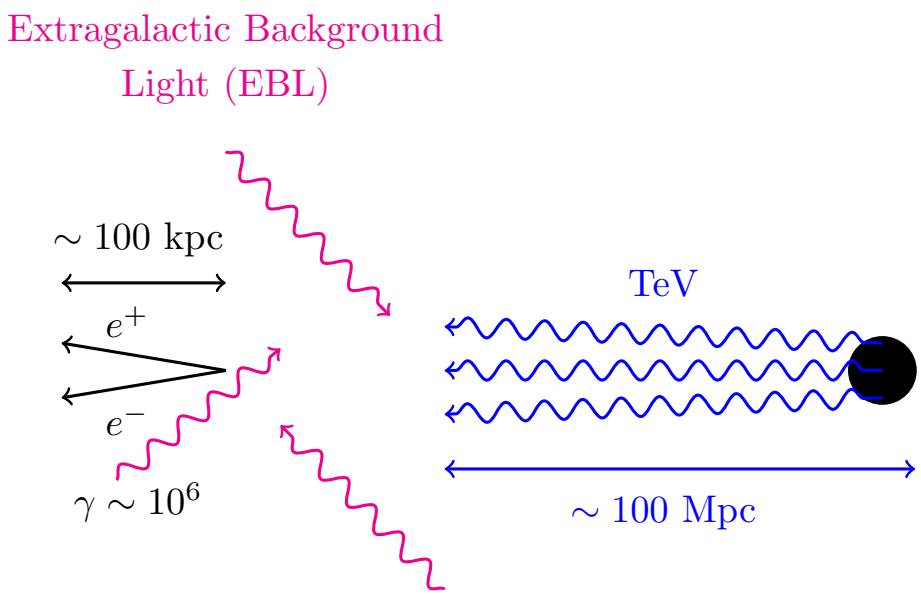
Can IGMF explain the absence of GeV flux?



Contradiction between aligned and oblique observers.

Something else must be suppressing the GeV halo emission.

New physical processes: Beam-plasma instabilities in the IGM



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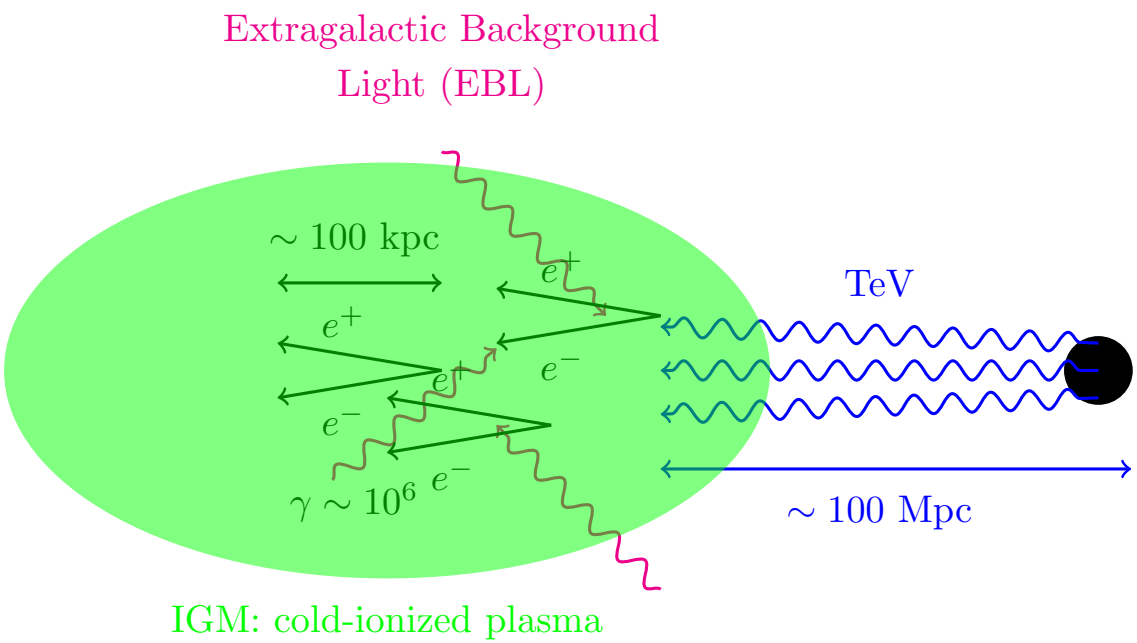


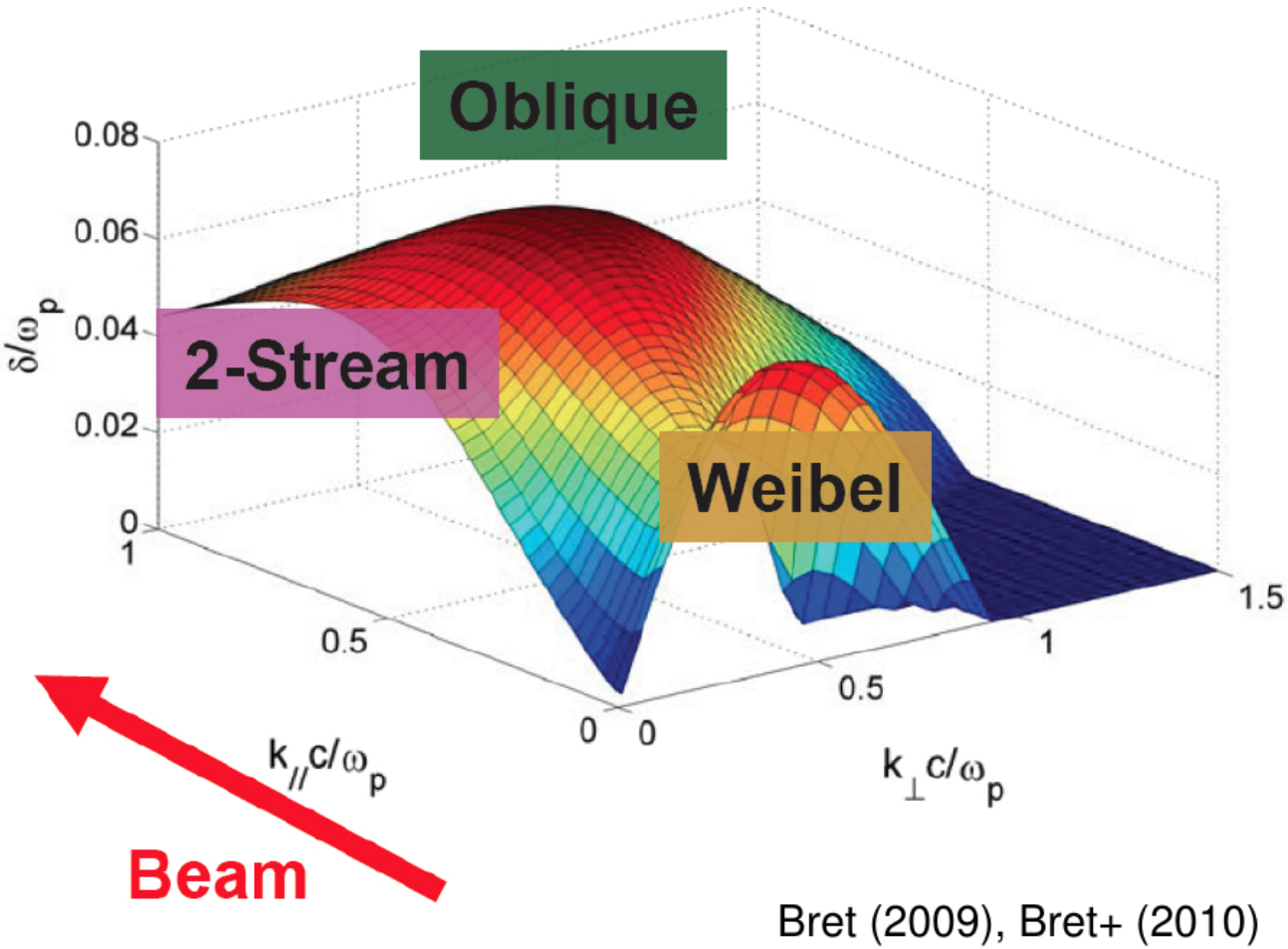
$E_{\rm EBL}\ E_{\rm TeV}\ \ (1+\cos\theta) > 4\ m_e^2 c^4$

$e^{\pm}$ pair-beams traveling through the cold-ionized IGM

$\Rightarrow$ Beam-plasma instabilities: Complicated physics problem.

$$\alpha = \frac{n_{\rm beam}}{n_{\rm IGM}} \sim 10^{-15}\ \&\ \gamma \sim 10^6$$

Inverse Compton Cascade v.s. Plasma instabilities?



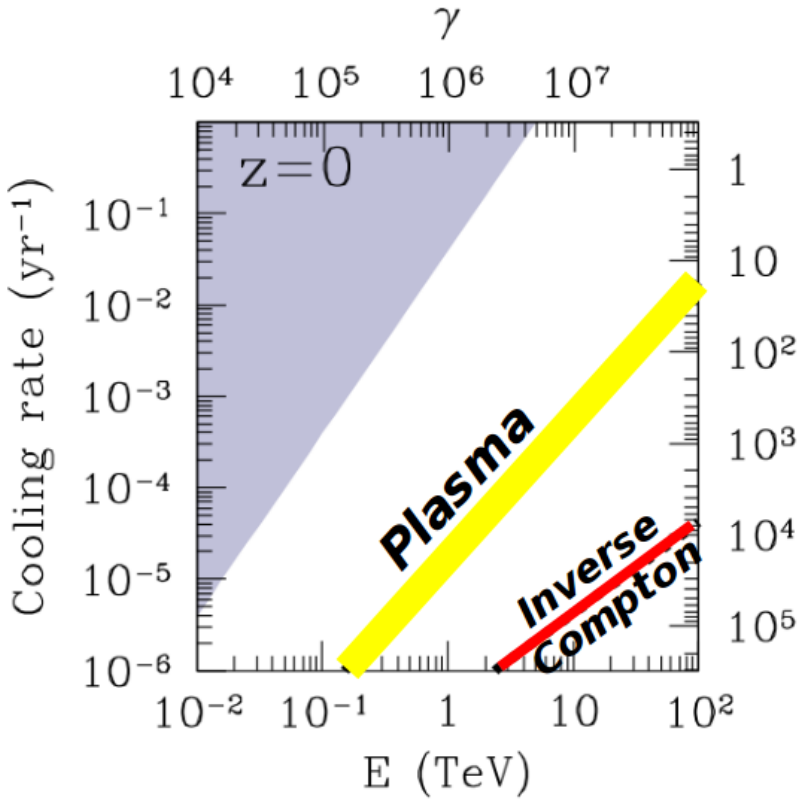
Bret (2009), Bret+ (2010)

Instabilities in the linear regime

New physical processes: Beam-plasma instabilities in the IGM

In the linear regime: **Plasma instabilities wins (z<6)**, e.g., at $z = 1$

$$\frac{\Gamma_{\rm plasma}}{\Gamma_{\rm ICC}} \sim 233 \left(\frac{E_\gamma}{1{\rm TeV}}\right)^{-1/2}$$



Broderick et al. ApJ 752 22

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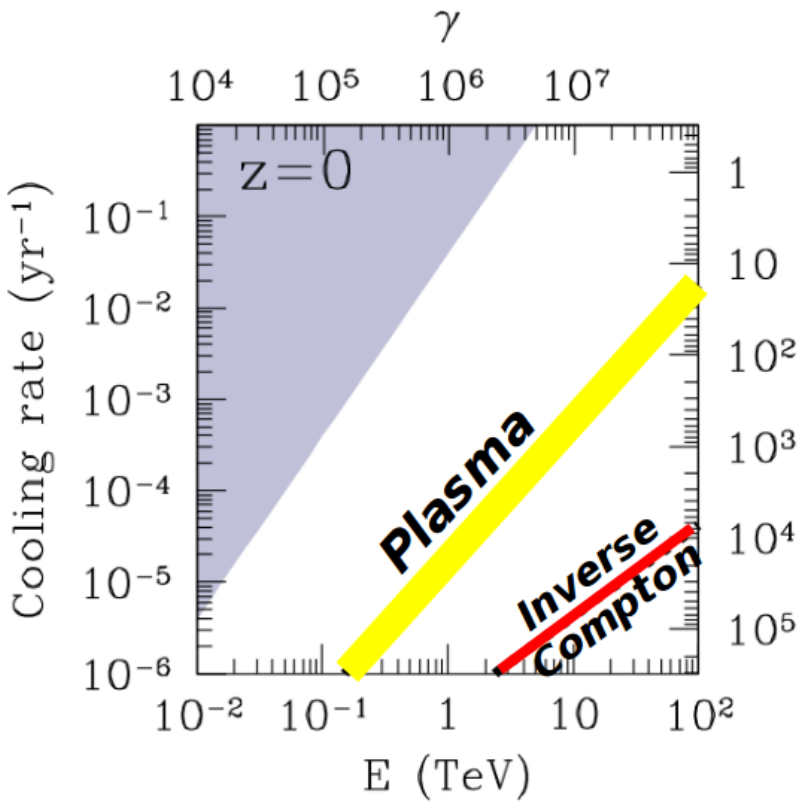


Broderick et al. ApJ 752 22

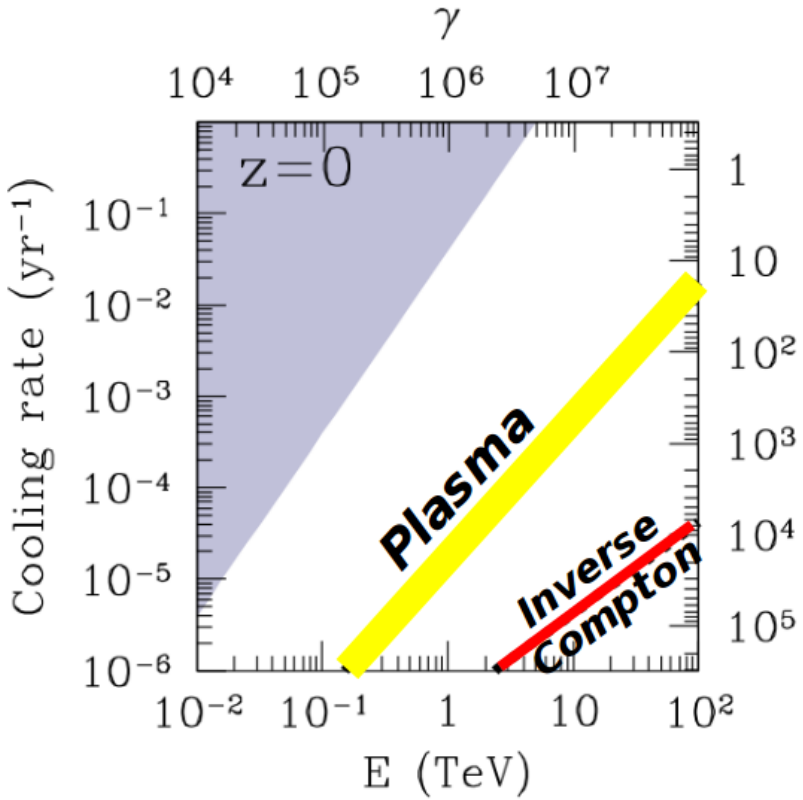
- Which process wins in reality depends on the level of saturation of the instabilities.

New physical processes: Beam-plasma instabilities in the IGM

Complications: The most extreme Plasma

$n_b/n_{\rm IGM} \sim 10^{-15}$ & $\gamma_b \sim 10^6$

- Temperature effects
- Non-linear Landau damping
- Inhomogeneities in the IGM



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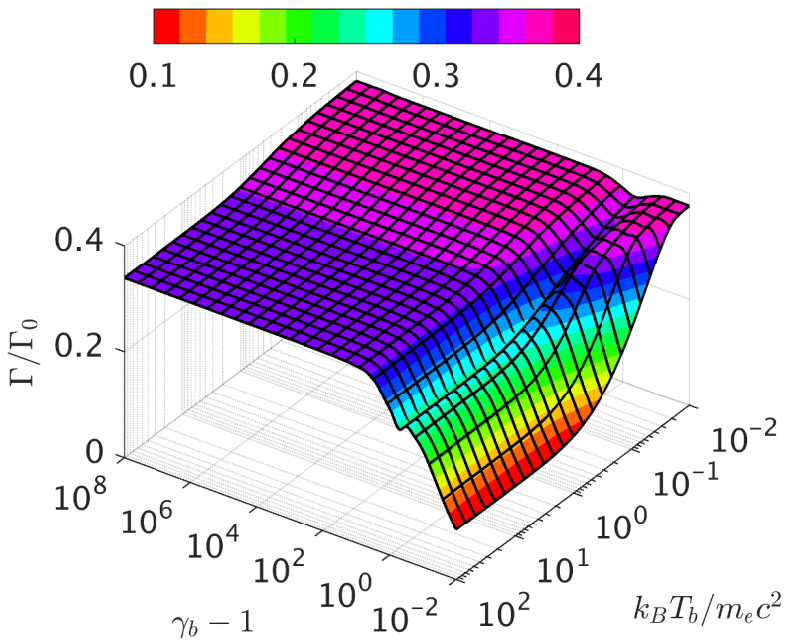
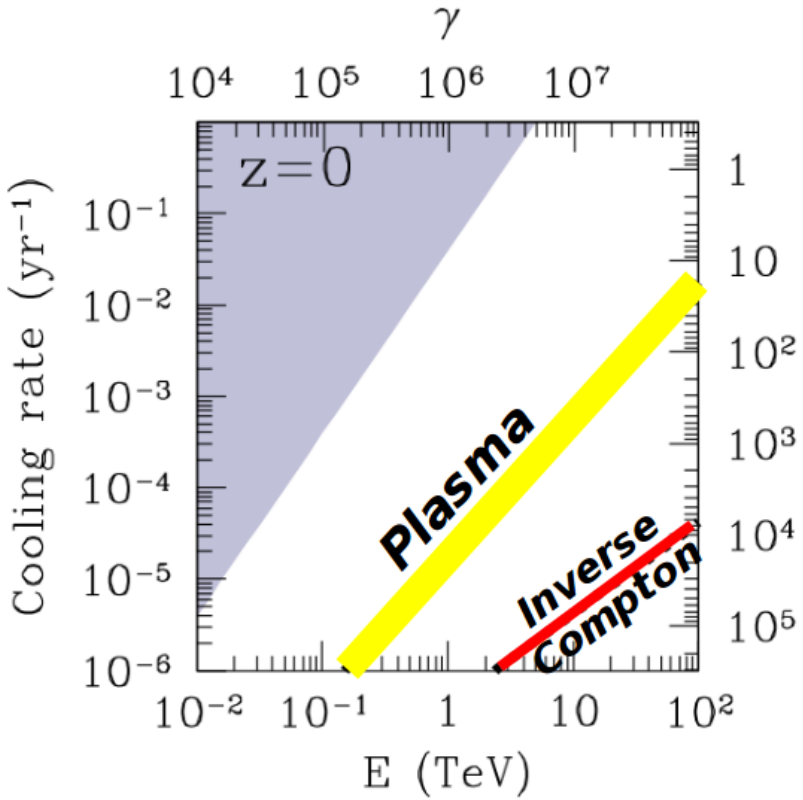


Change et al. ApJ 833, 118 (2016)



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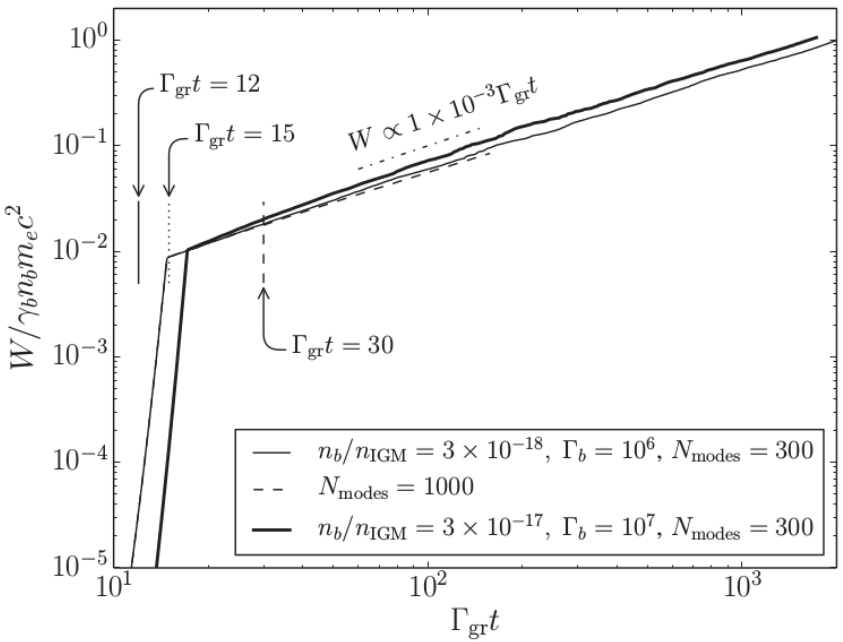
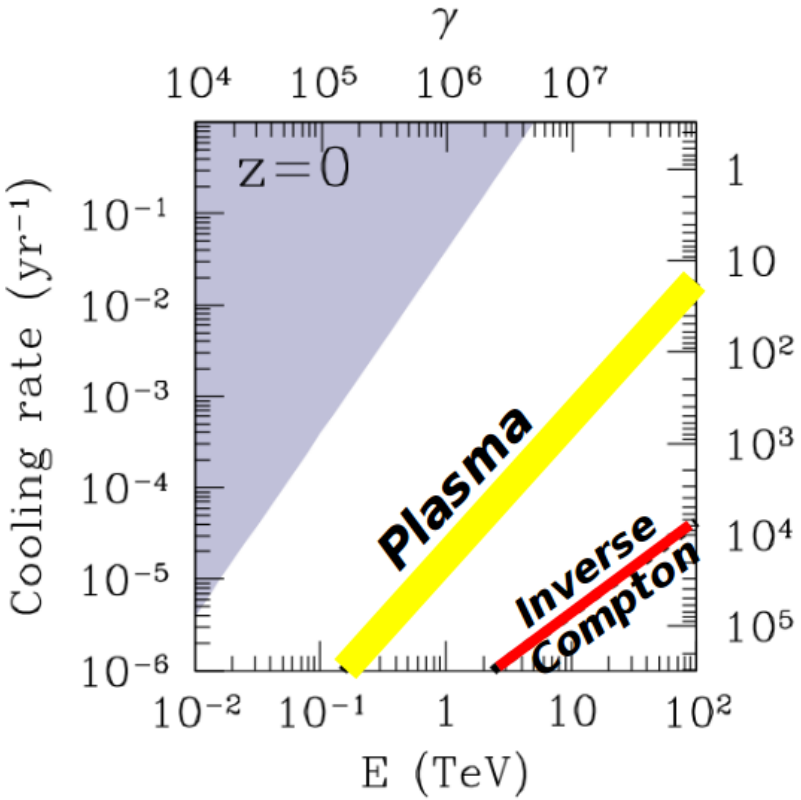


Change et al. ApJ 797 110 (2014)



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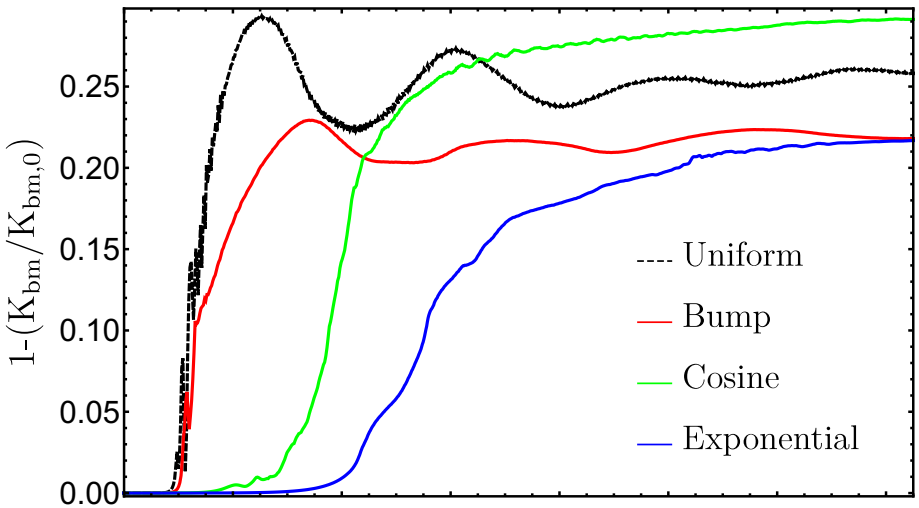
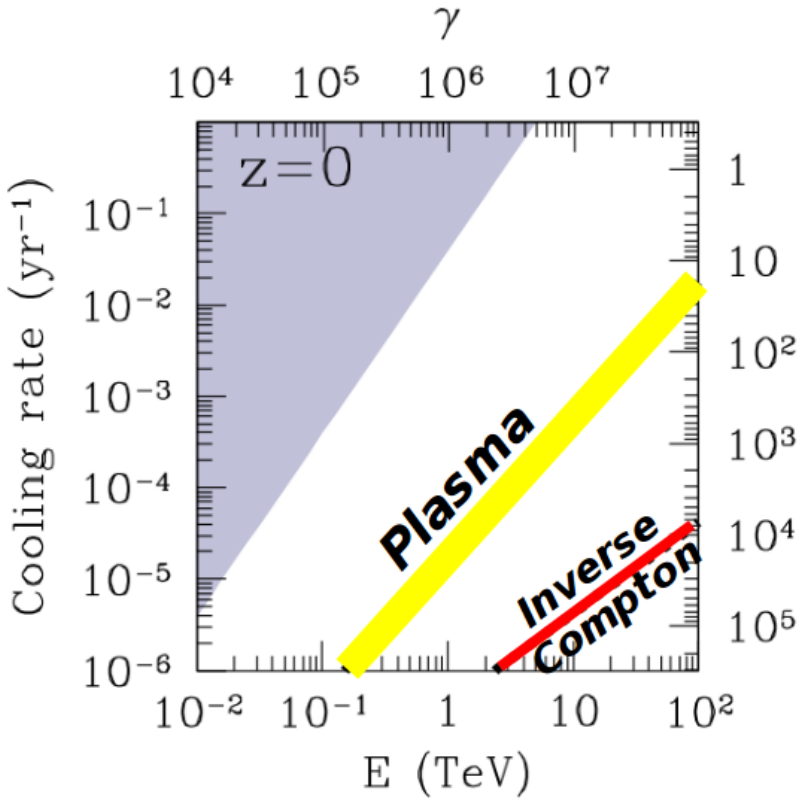


Shalaby et al. ApJ 859 45 (2018)



Broderick et al. ApJ 752 22

New physical processes: Beam-plasma instabilities in the IGM

Direct evidence for the instabilities/simulating the full non-linear evolution (another talk's highlights)

- Instabilities in Kinetic regime: Vlasov-Maxwell's equations $\Rightarrow$ PIC simulations
- Multi-scale problem: $\Gamma_{\rm obl} \sim 10^{-7}\omega_p$ even larger separation due to nonlinear effects.
- narrow spectral support $\Rightarrow$ larger boxes required
- Standard-PIC algorithm not reliable: energy, momentum non-conservation (typically also charge non-conserving)
- Recent fundamental improvement make it feasible only in asymptotic limit (XIAO et al 2018 Plasma Sci. Technol. 20 110501, Shalaby et al 2017 ApJ 841 52; 2017 ApJ 848 81)

Conclusions

- Absence of GeV excess: robust evidence of physical processes that are faster than ICC
- Beam-Plasma instabilities present a strong candidate for such process
- Standard direct simulation: not feasible (See however, Shalaby et al. ApJ 841 52)
- Quasi-linear effects does not produce saturation of the instabilities
- Energy deposited as plasma waves will eventually deposit "non-standard" heating in the IGM
- Non-standard heating $\Leftarrow$
  - ~ 10 larger $T_{\rm IGM}$ (at $z = 0$) and Modifying the Lyman-α forest at late times (z $<$ 2) – (Chang et al. 2012; Puchwein et al. 2012; Lamberts et al. 2015)
  - suppressing late time star formation in galaxies (dwarfs) (Pfrommer et al. 2012)

Thank you for attention

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