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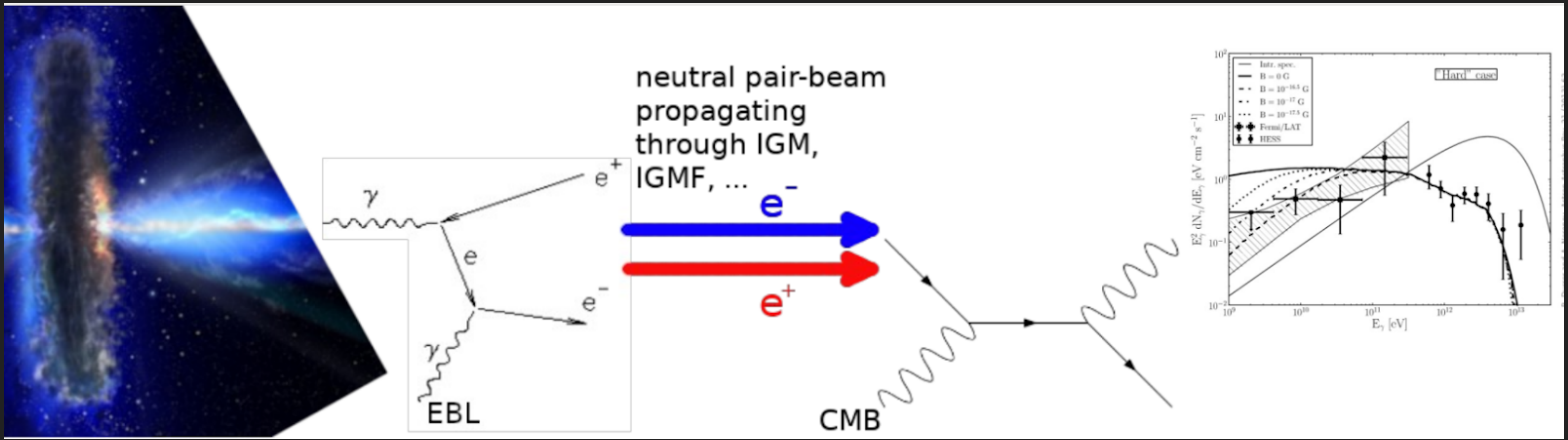
SPACE PLASMA INSTABILITIES RESOLVE GEV-TEV TENSION AND CONSTRAIN LIGHT AXIONS

EuCAPT Annual Symposium | May 31, 2023

BLAZARS: A QUICK OVERVIEW

- Active galactic nuclei ejecting ultrarelativistic jets onto large cosmological distances
- Characterised by hard power-law spectra extending up to TeV energies, e.g., BL Lacs that peak at high energies



MISSING CASCADES FROM TEV BLAZARS

- TeV emissions from blazars should be reprocessed into the GeV band through inverse-Compton cooling
- Expected GeV cascade emission suppressed in the 100 GeV-1 TeV band
- Tension seems to be a universal trend in blazars observed with γ-ray telescopes

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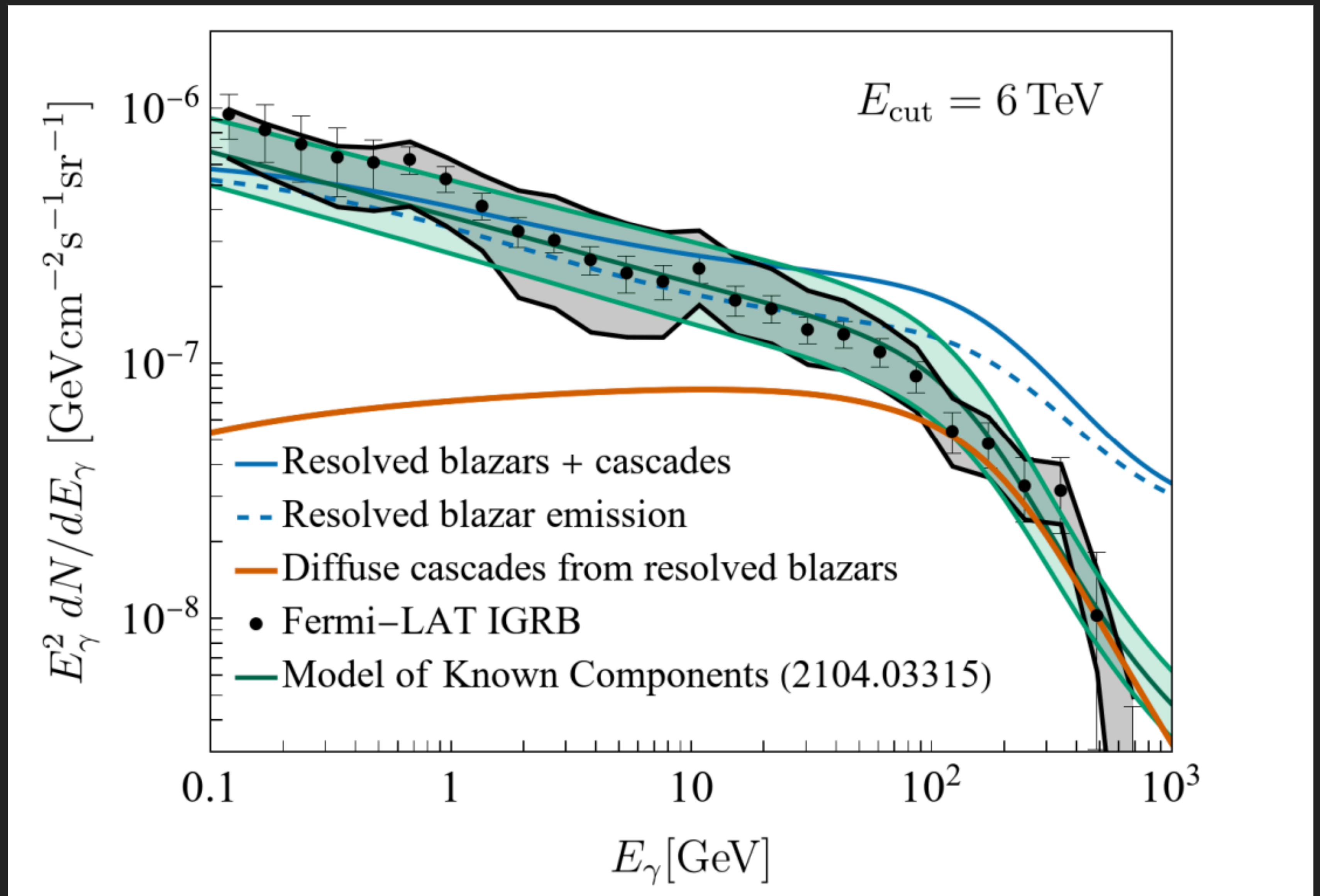
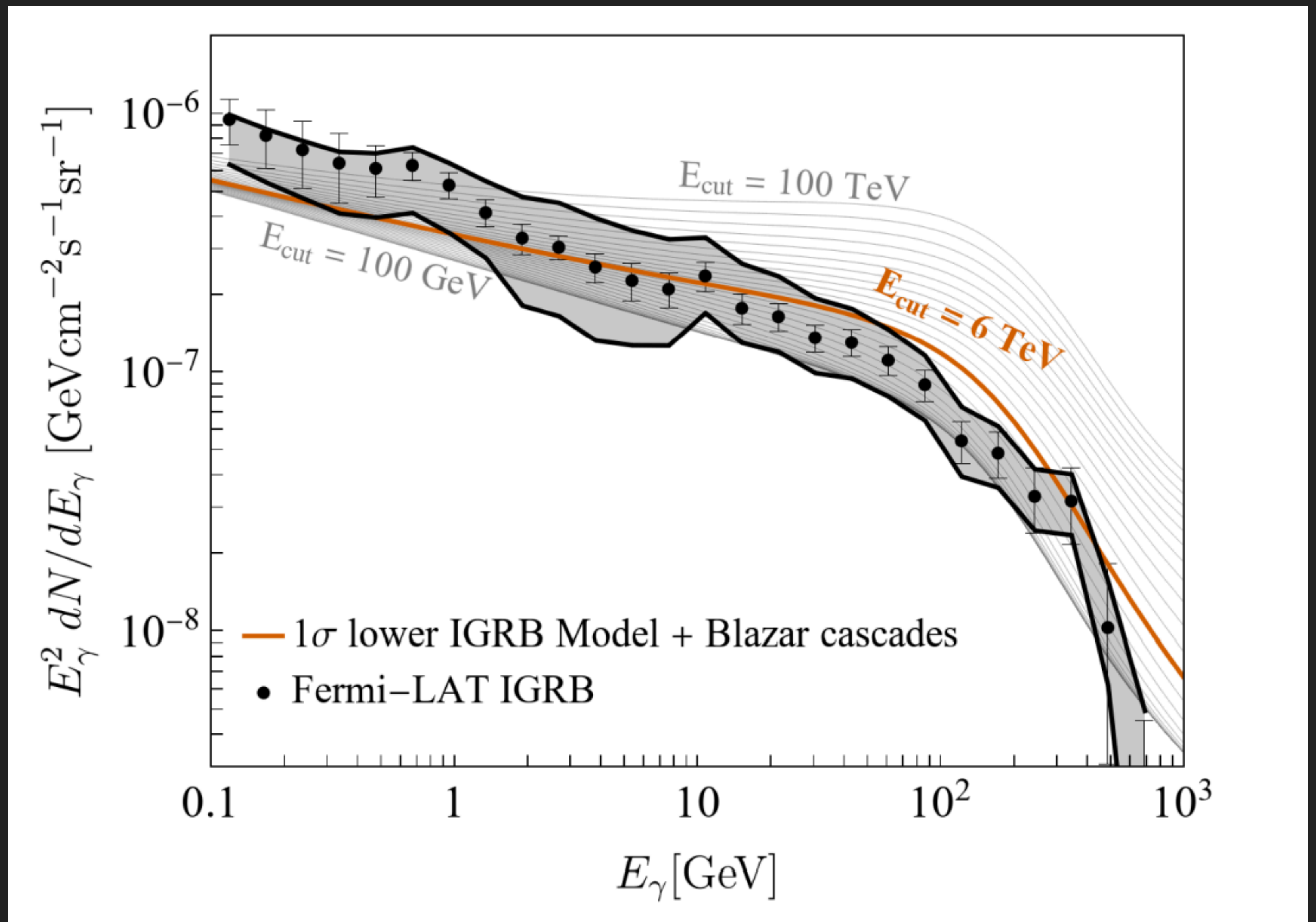
- Pair deflections off the intergalactic magnetic field (IGMF): *isotropization* or creation of *pair halo*
- If weak and tangled, IGMF induces *magnetic diffusion* and beam broadening breaking down small-angle approximation

AN EMERGING TENSION IN THE GAMMA-RAY SKY?

- Sharp spectral cutoffs at $\mathcal{O}$(TeV) energies are not observed for local blazars
- Isotropic γ-ray background (IGRB) measurements + non-observation of pair halos together imply IGMF is too feeble to prevent bright γ-ray cascade emission through ICS
- IGRB is dominated by contributions from known sources mAGN, SFG etc.
- Diffuse blazar cascade emission <10%, **in strong tension with blazar models!**

IGRB MEASUREMENTS POINT TOWARDS BEAM-PLASMA INSTABILITIES



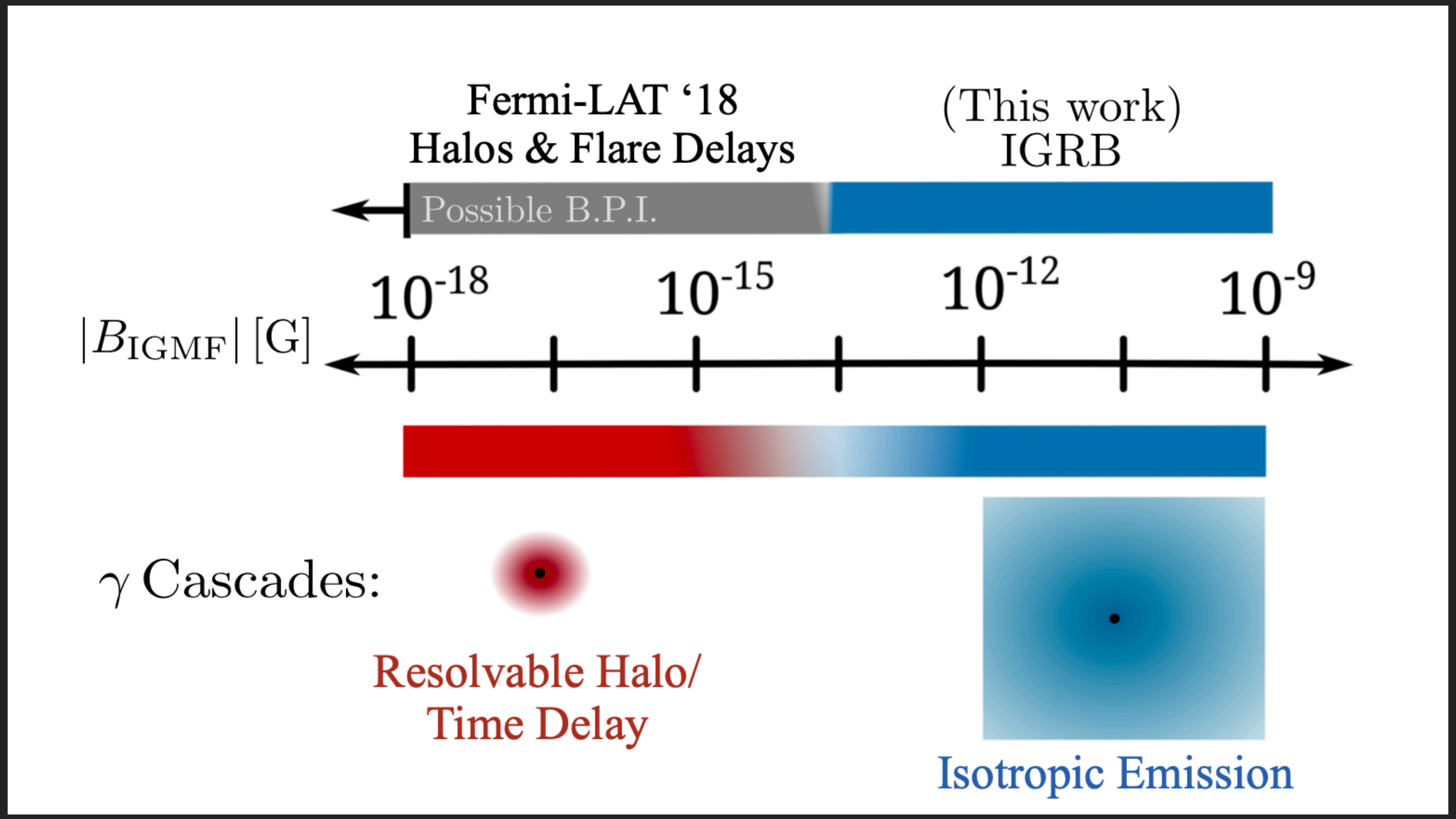


- If intrinsic cutoff $E_{cut} \gtrsim$ 5 TeV, the isotropic cascades + known components exceed the measured IGRB

Blanco, **OG**, Jacobsen, Linden (2023) arXiv: 2303.01524

COMPETING EFFECTS OF INSTABILITY GROWTH AND IGMF STRENGTH

- For more realistic beam distributions participating in cascade (e.g., Maxwell-Jüttner), IGMF stronger than 10^{-14} G required to suppress plasma instabilities
- This introduces a sliding scale in critical IGMF strength ($\lambda_B \sim 1$ kpc) in order to suppress the instabilities



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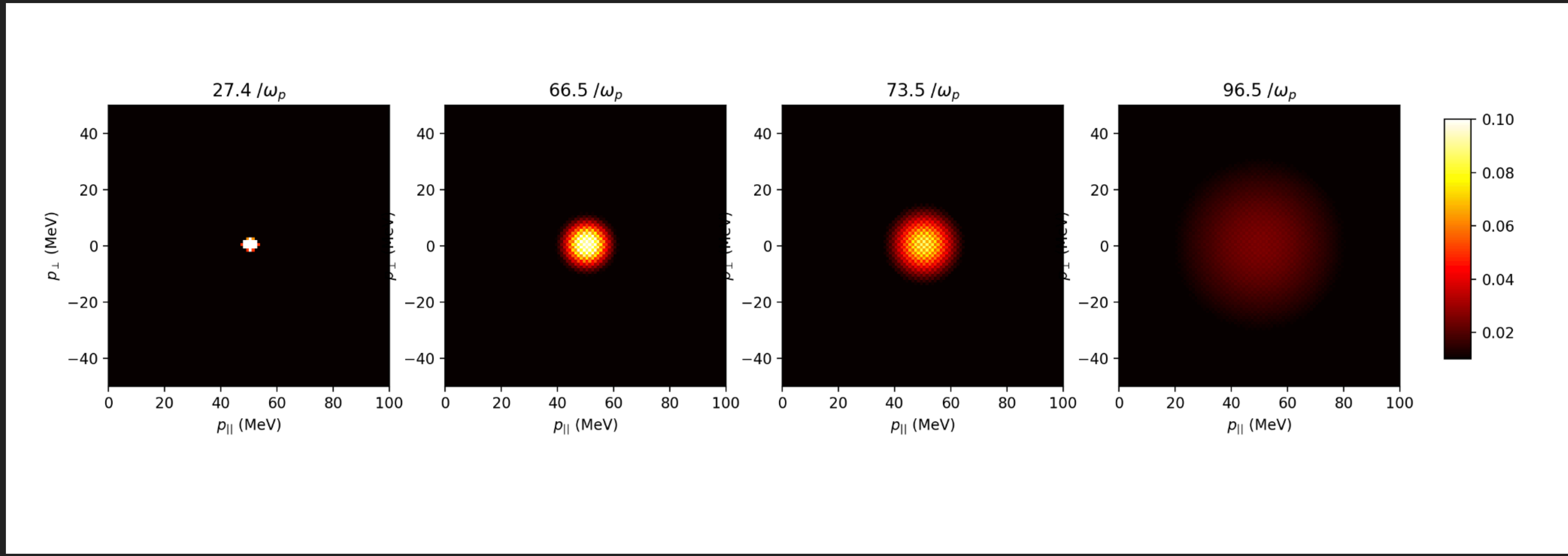
COLLECTIVE PLASMA EFFECTS: GROWTH OF UNSTABLE MODES

- Instabilities occur when the Langmuir waves undergo Cherenkov resonance $\omega = \vec{k} \cdot \vec{v}$
- Such excitations in the beam transfer energy through the resonant window
- Spectral energy density in the background of intergalactic medium (IGM) grows as $W(k) = W_0 \int_0^{\tau} e^{2\,\mathrm{Im}(\tilde{\omega})\,t} dt$ through instability losses of the beam
- Dynamics and evolution of the beam-plasma interaction is set by characteristic length scales related to the background plasma frequency $\omega_p = \sqrt{4\pi n_p e^2 / m_e}$

BEAM RELAXATION AND SELF-HEATING



- Evolution of beam-plasma system is diffusive-dissipative described best with a Fokker-Planck equation

$$\frac{\partial}{\partial t} f(\mathbf{p}, t) = -\frac{\partial}{\partial \mathbf{p}}[v(\mathbf{p}, t) f(\mathbf{p}, t)] + \frac{\partial}{\partial \mathbf{p}}\left[D(\mathbf{p}, k, t)\frac{\partial}{\partial \mathbf{p}} f(\mathbf{p}, t)\right]$$

- Consistent with results from particle-in-cell simulations for a laboratory astrophysics experiment

Beck, **OG**, Gruener, Pohl, Schroeder, Sigl, Stark, Zeitler *(appearing soon)*

BLAZAR HEATING: A MODIFIED THERMAL HISTORY

- IGM heating due to a single blazar

$$\dot{q}_{\mathrm{B}} = \int dE \frac{\Theta(E)}{D_{\mathrm{pp}}(E,z)} f\left(F_E, E, z\right) F_E$$

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- Average heating due to a population of blazars

$$\dot{Q}_{\mathrm{B}} = \int dV d\log_{10} L d\alpha' d\Omega \tilde{\phi}_B\left(z; L, \alpha', \Omega\right) \frac{\Omega}{2\pi} \dot{q}$$

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- Incorporating other heating mechanisms

$$\dot{Q}_{\rm canon} = \dot{Q}_{\rm H-I,photo} + \dot{Q}_{\rm He-I,photo} + \dot{Q}_{\rm He-II,photo} + \dot{Q}_{\rm H-II,rec} + \dot{Q}_{\rm He-III,rec} + \dot{Q}_{\rm Compton} + \dot{Q}_{\rm free-free}$$

- Total uniform volumetric heating rate

$$\dot{Q} = \dot{Q}_{\rm canon} + \dot{Q}_{\rm B}$$

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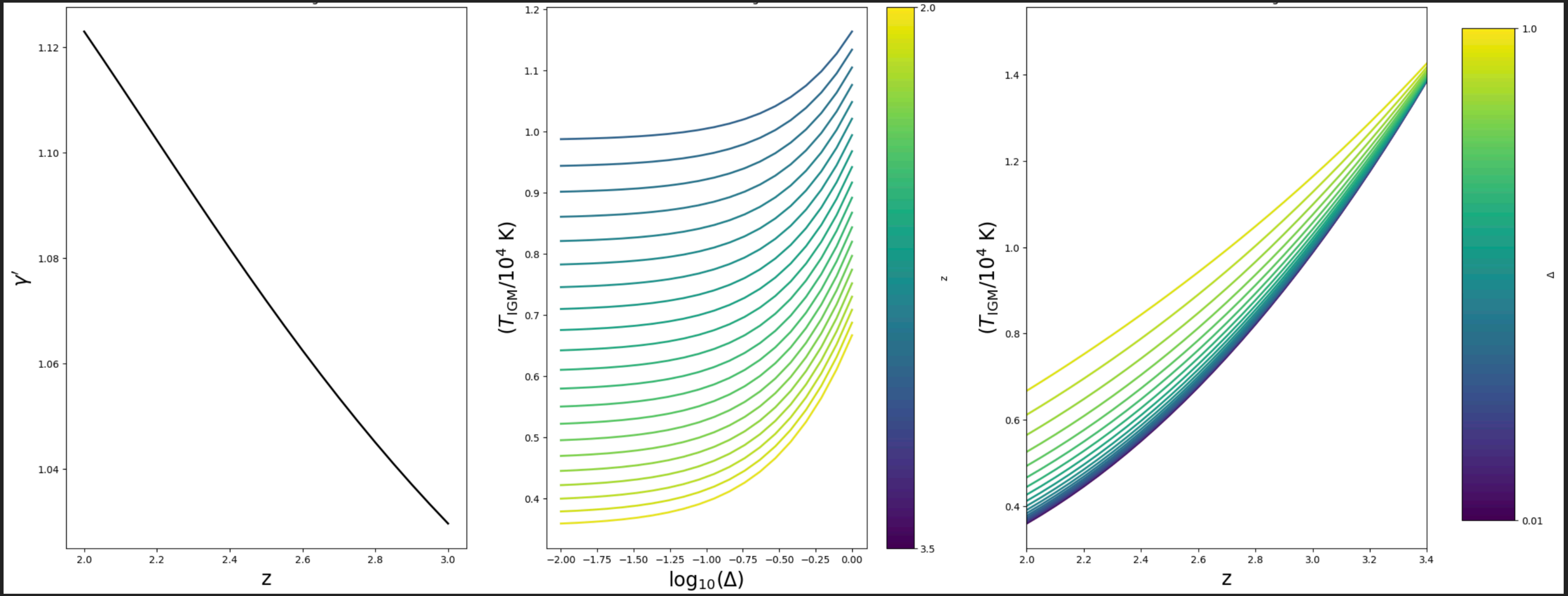
- Casting temperature-density-redshift relation during $2 < z < 3.5$ as

$$T = T_0 \Delta^{\gamma(z)' - 1}$$

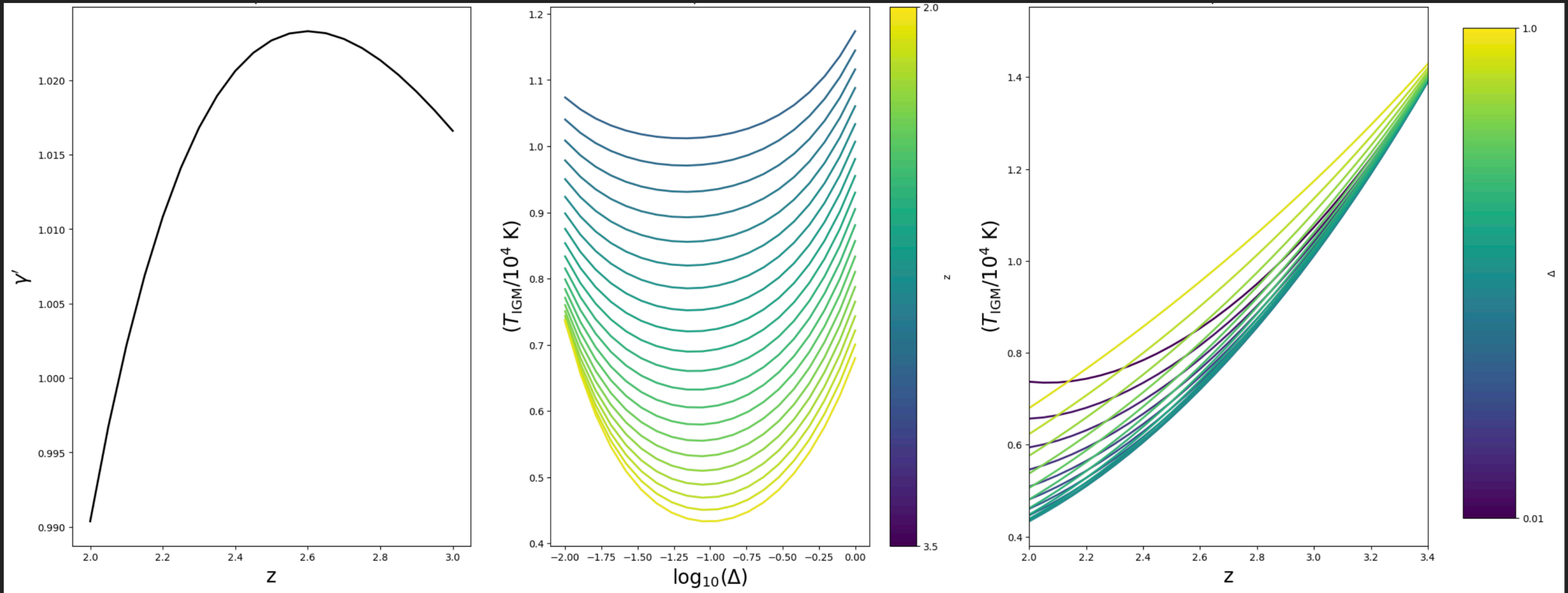
BLAZAR HEATING: A MODIFIED THERMAL HISTORY



Redshift evolution of index, temperature-density and temperature-redshift relation in absence of blazar heating

OG & Bhattacharyya *in preparation*

BLAZAR HEATING: A MODIFIED THERMAL HISTORY



Redshift evolution of index, temperature-density and temperature-redshift relation for low global blazar heating

OG & Bhattacharyya *in preparation*

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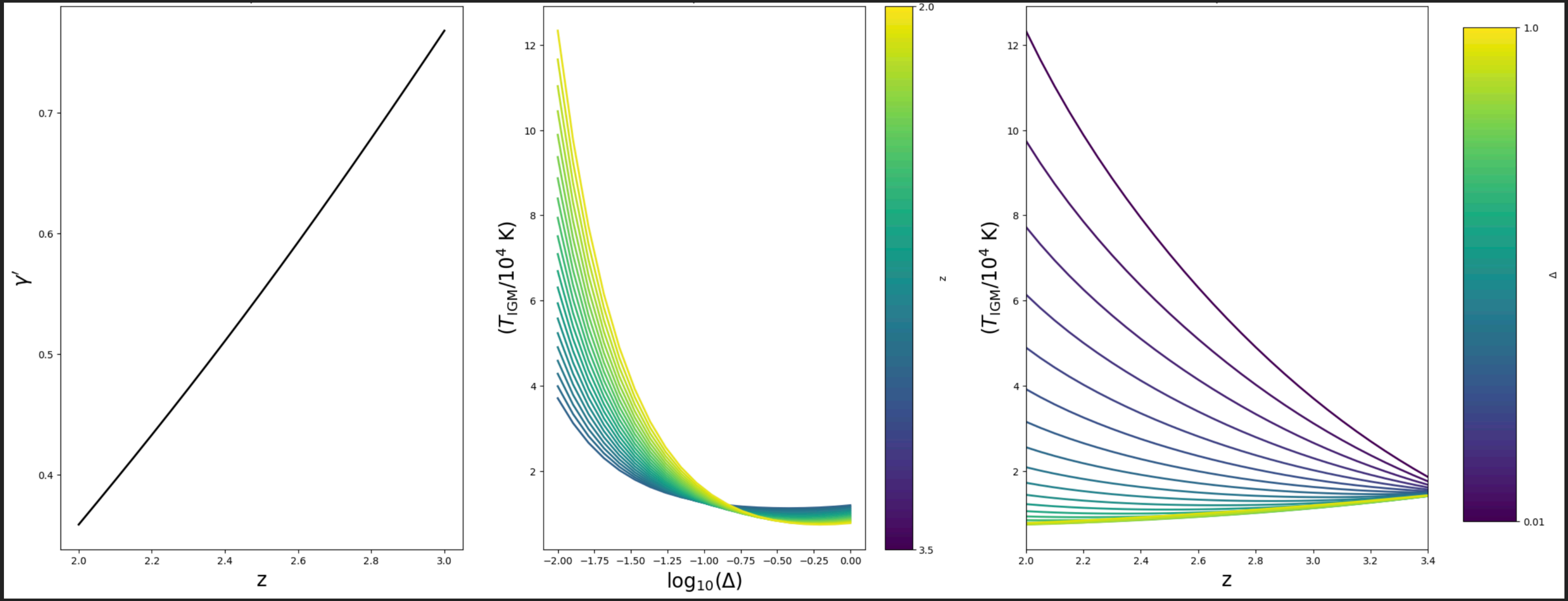
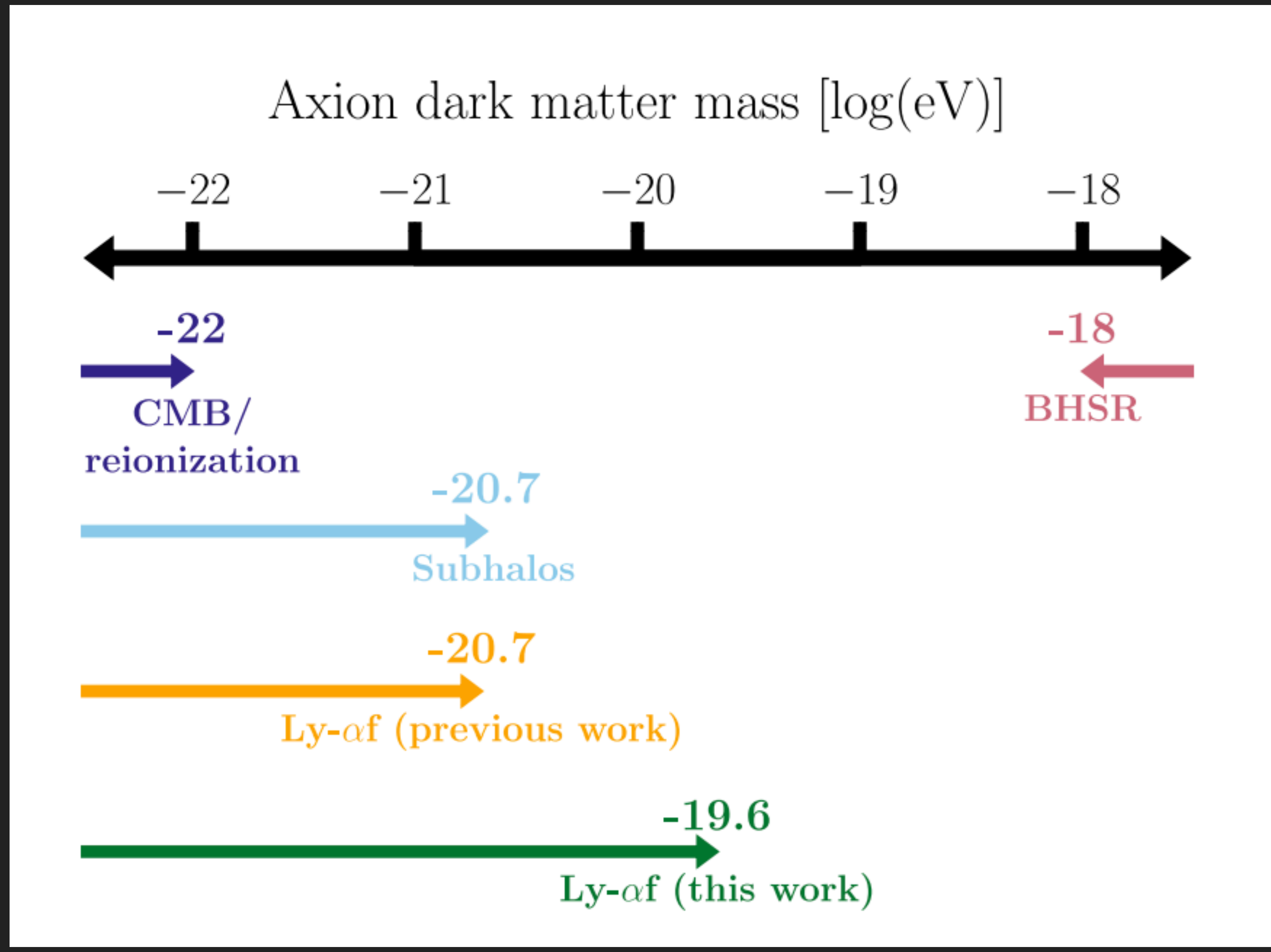


Redshift evolution of index, temperature-density and temperature-redshift relation for moderate global blazar heating

OG & Bhattacharyya *in preparation*

BLAZAR HEATING: A MODIFIED THERMAL HISTORY

- Impact of global blazar heating is most prominent in underdense regions
- Filtering mass for intermediate heating consistent with observed void dwarf galaxy masses $\sim 10^7 - 10^9 M_\odot$
- If light ALPs constitute all of dark matter, their allowed mass range is further tightened to avoid tension with Lyman-α bounds



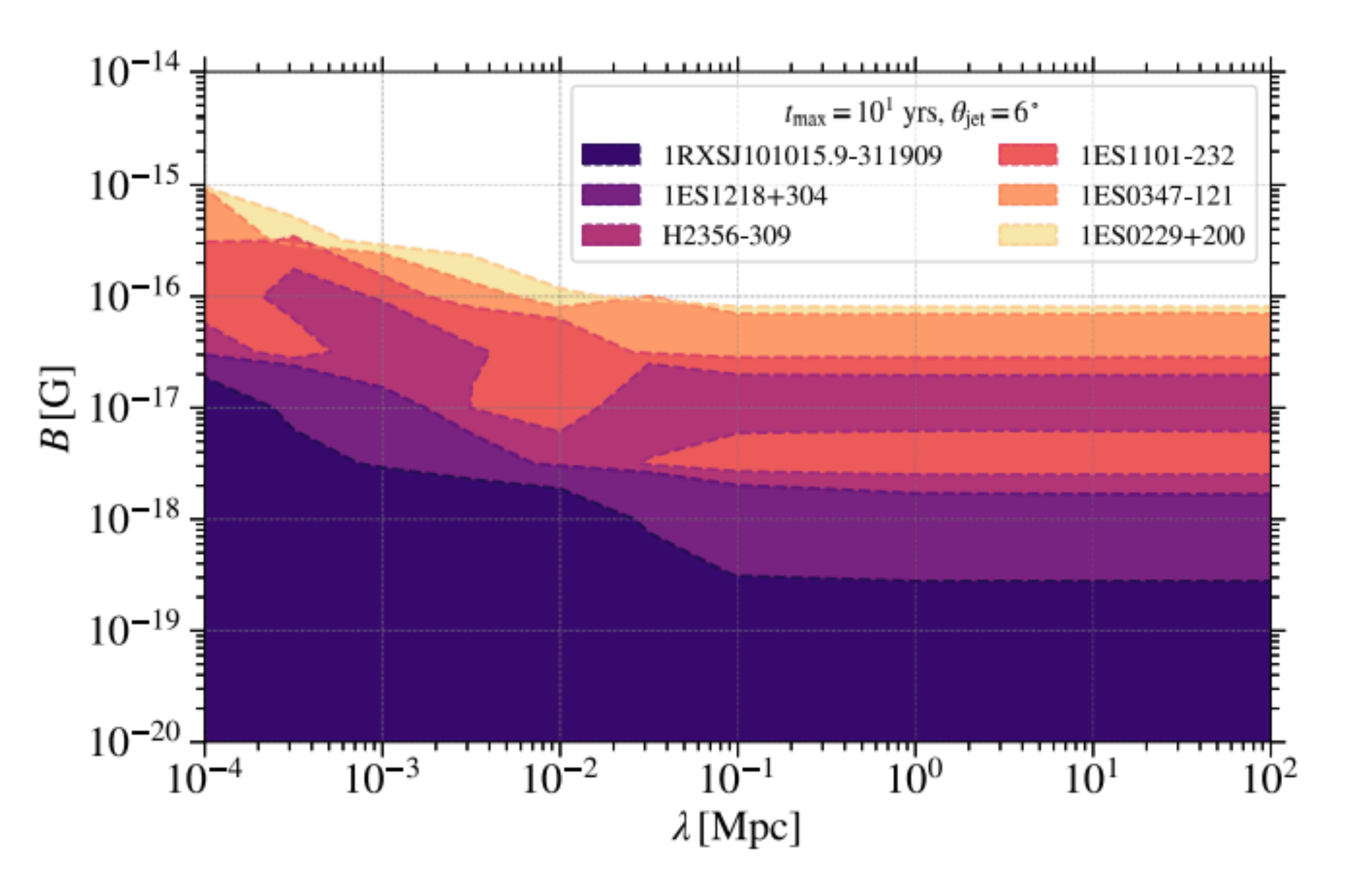
Rogers and Peiris (2021)

→ Preliminary estimates accounting for modest blazar heating

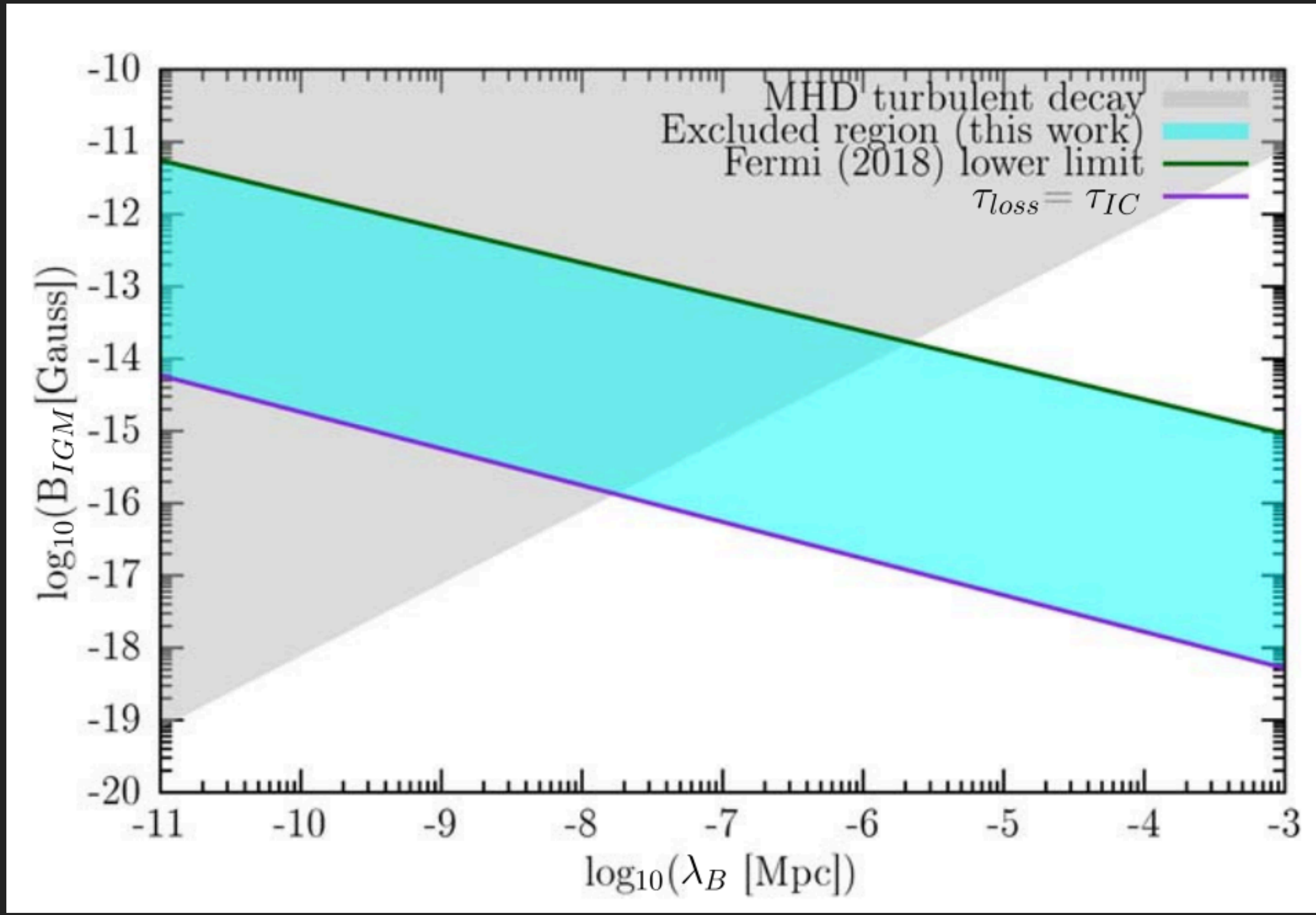
OG & Bhattacharyya *(in preparation)*

Thank you!

BACKUP SLIDE: MISSING CASCADE AS A PROBE OF IGMF



Fermi-LAT Collaboration (2018)



Alawashra & Pohl (2022)