TeV γ-RAYS AS PROBES OF NEW PHYSICS

ArXiv: **2203.04332** (S. Jacobsen, T. Linden and K. Freese)

ArXiv: **2303.01524** (C. Blanco, O. Ghosh, S. Jacobsen and T. Linden)

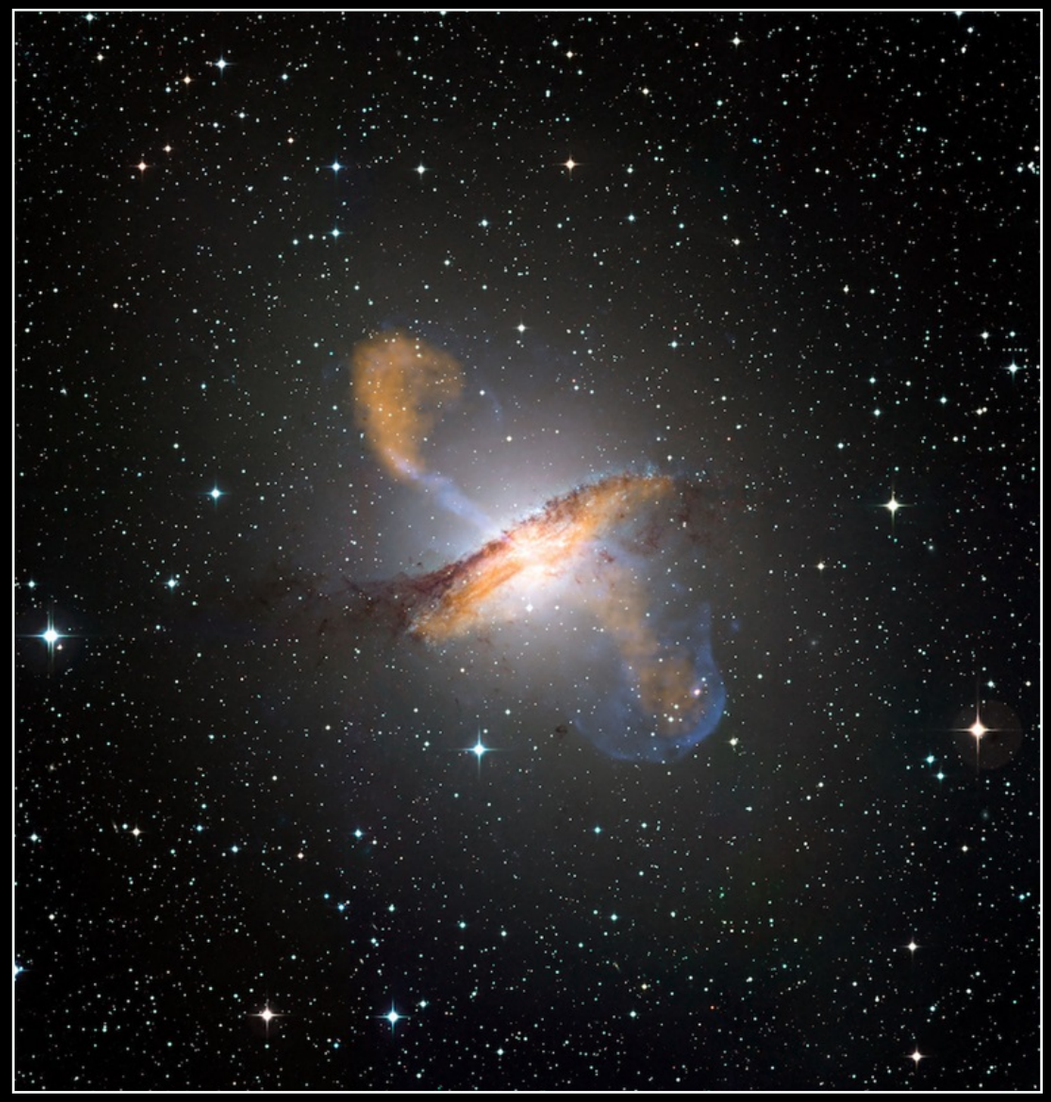
BLAZARS

Active Galactic Nuclei(AGN): Highly luminous galactic centers

10% of AGN have jets: Ionized matter and radiation are emitted as a beam along the axis of rotation

Blazars: Jet is pointed directly towards the Earth —> relativistic boosting of emission

Centaurus A (radio galaxy)



ESO/WFI (visible); MPIfR/ESO/APEX/A.Weiss et al. (microwave); NASA/CXC/CfA/R.Kraft et al. (X-ray)

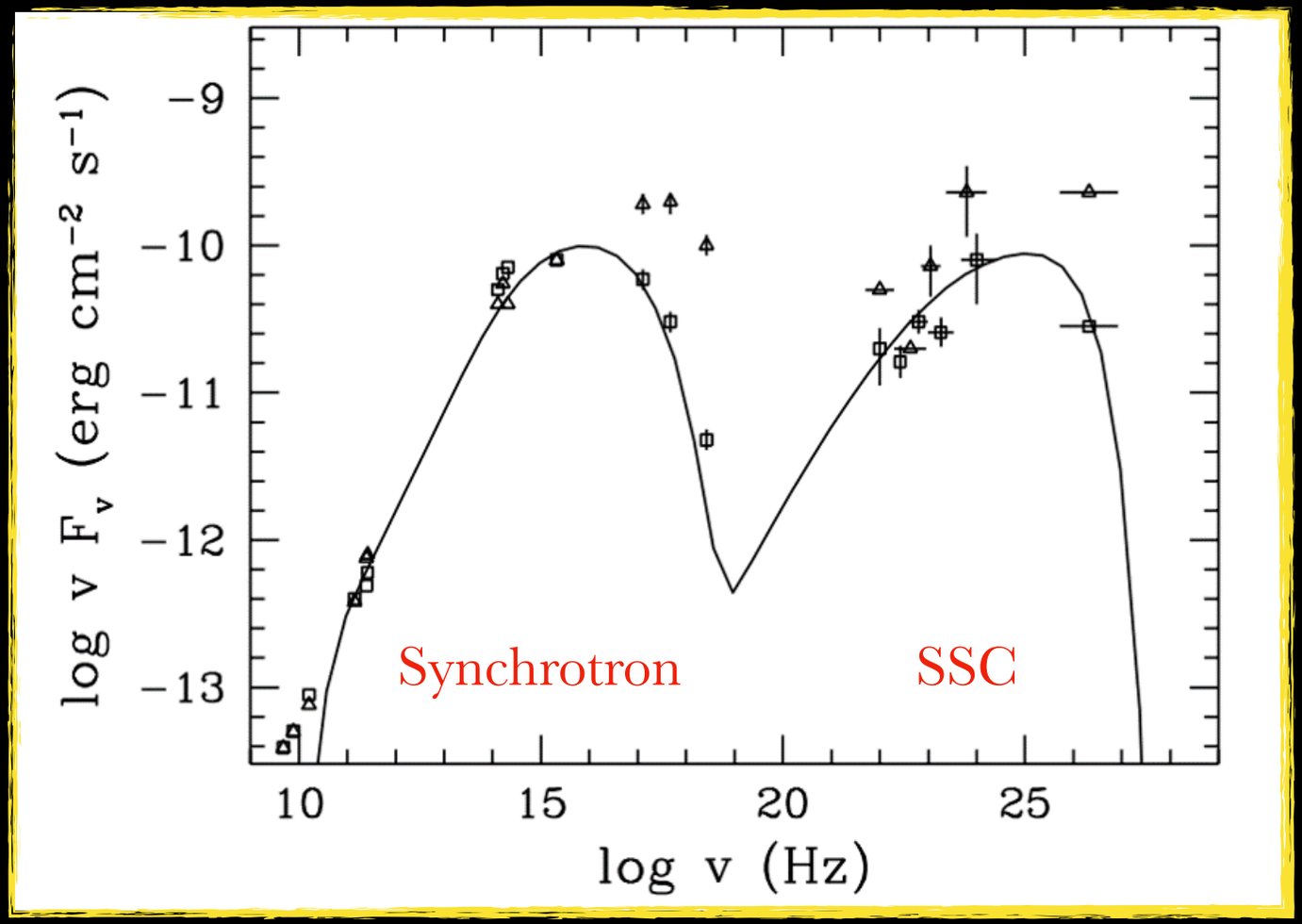
Blazars as TeV sources

Production of **synchrotron radiation** from electrons traveling in the strong jet magnetic field.

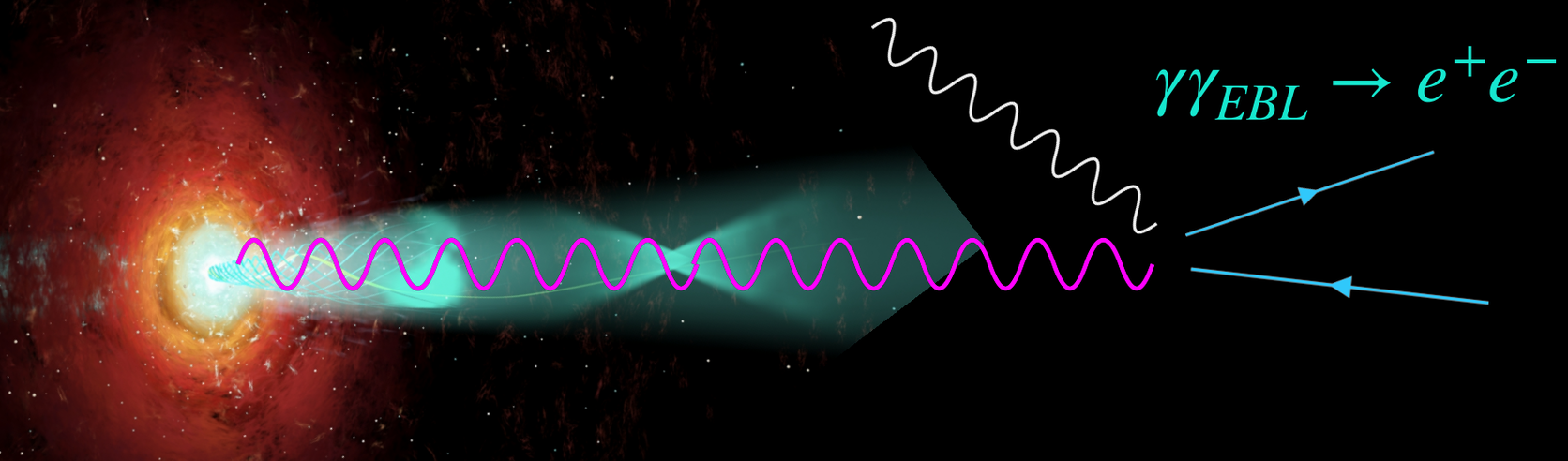
Synchrotron self-Compton: The synchrotron radiation is up-scattered by the same electrons - separate SED peak at higher energies

High-frequency synchrotron peak -> high energy emission

Spectral Energy Distribution (SED)



Attenuation in the EBL



Extragalactic Background Light: accumulated radiation from star-formation processes and active galactic nuclei

Maximal attenuation above: $\epsilon_{th}\left(E_\gamma, \theta, z\right) = \dfrac{2\left(m_e c^2\right)^2}{E_\gamma(1-\cos\theta)(1+z)}$

AXION-LIKE PARTICLES

Generalization of axions - spin-zero particles

Do not necessarily solve the strong CP problem in QCD

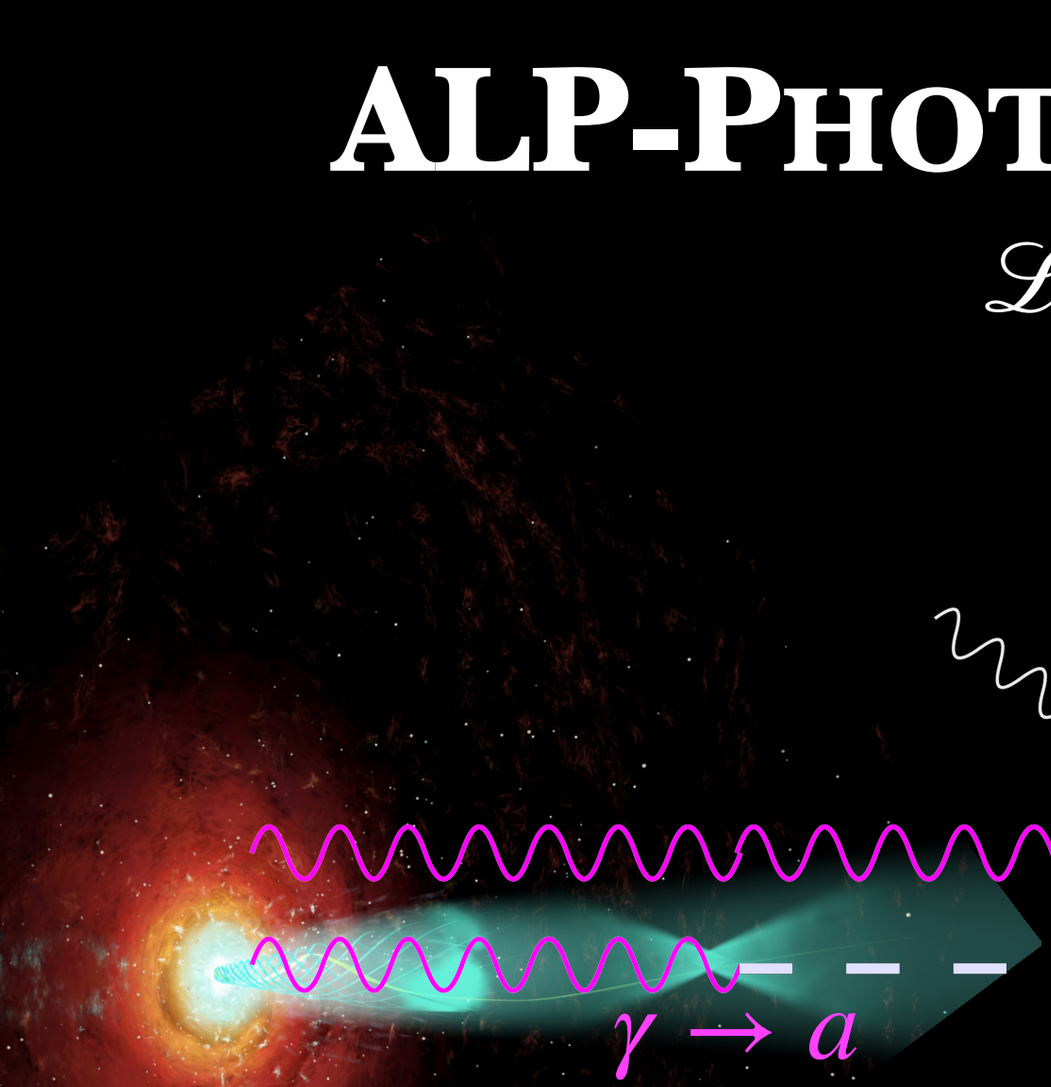
Arise naturally in several BSM models, such as supersymmetryic theories and Kaluza-Klein theories

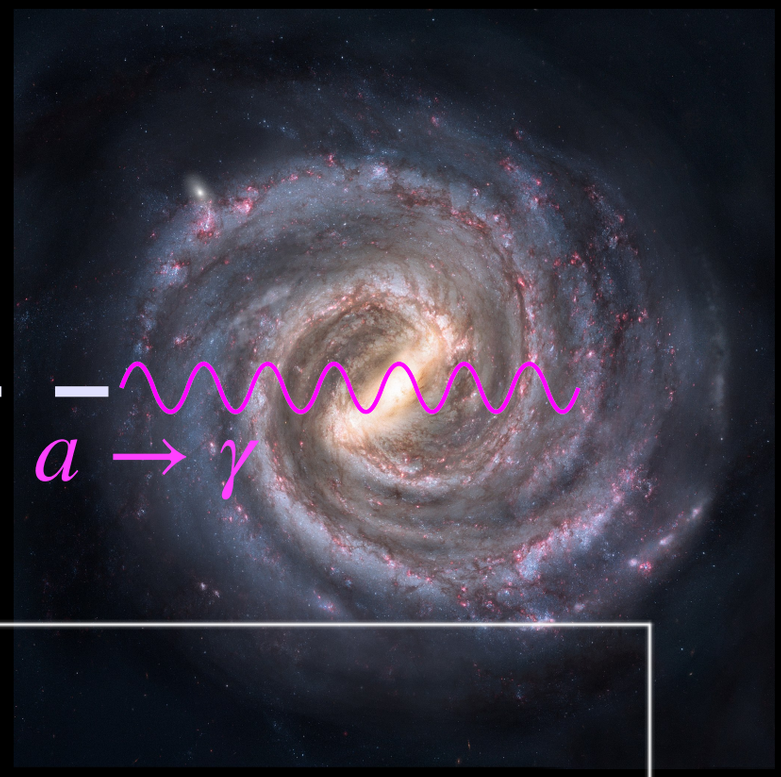
Can mix with photons, electrons and quarks.

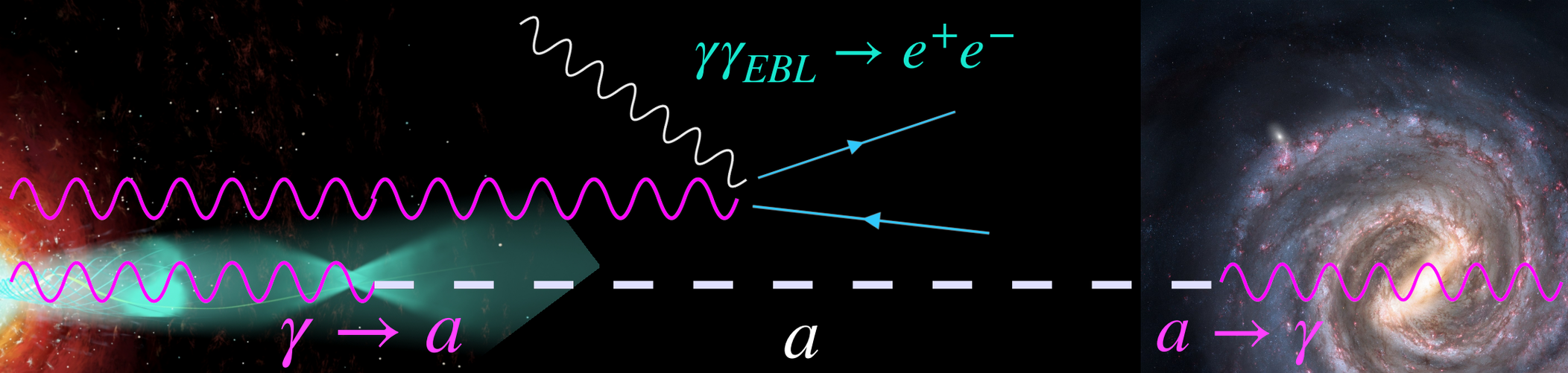
ALP parameters: Mass m_a and coupling to photons $g_{a\gamma}$

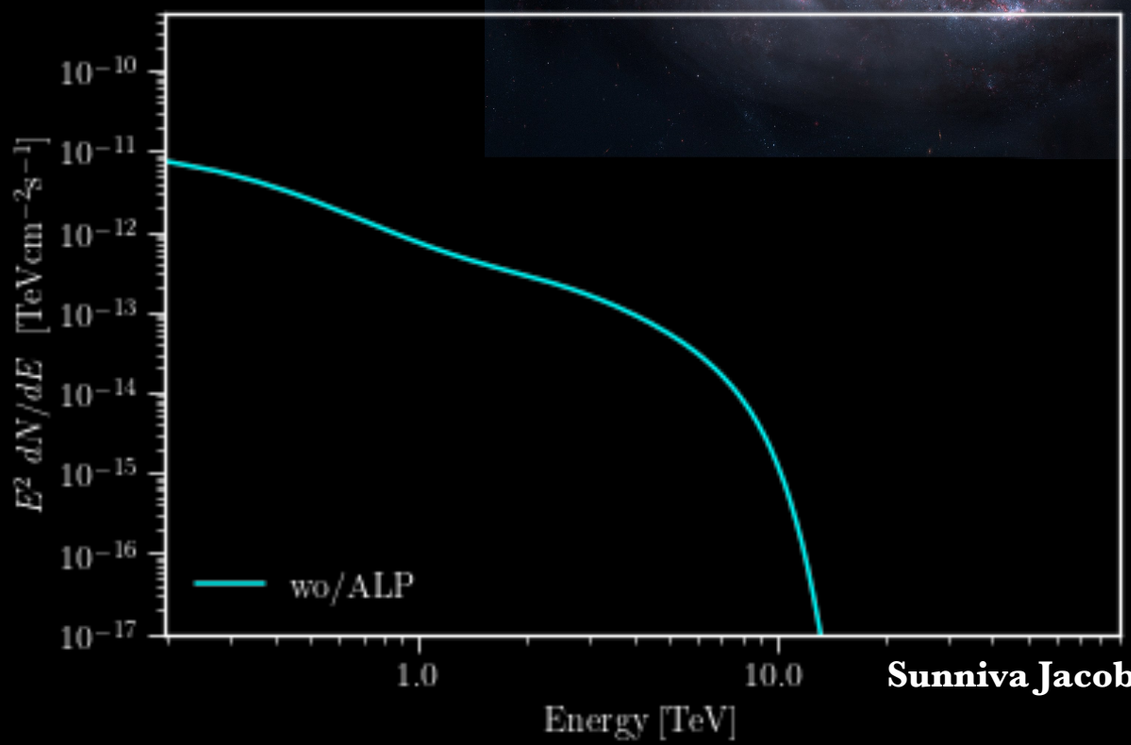
ALP-Photon Oscillations

$$\mathscr{L}_{a\gamma} = g_{a\gamma}\mathbf{E}\cdot\mathbf{B}a$$









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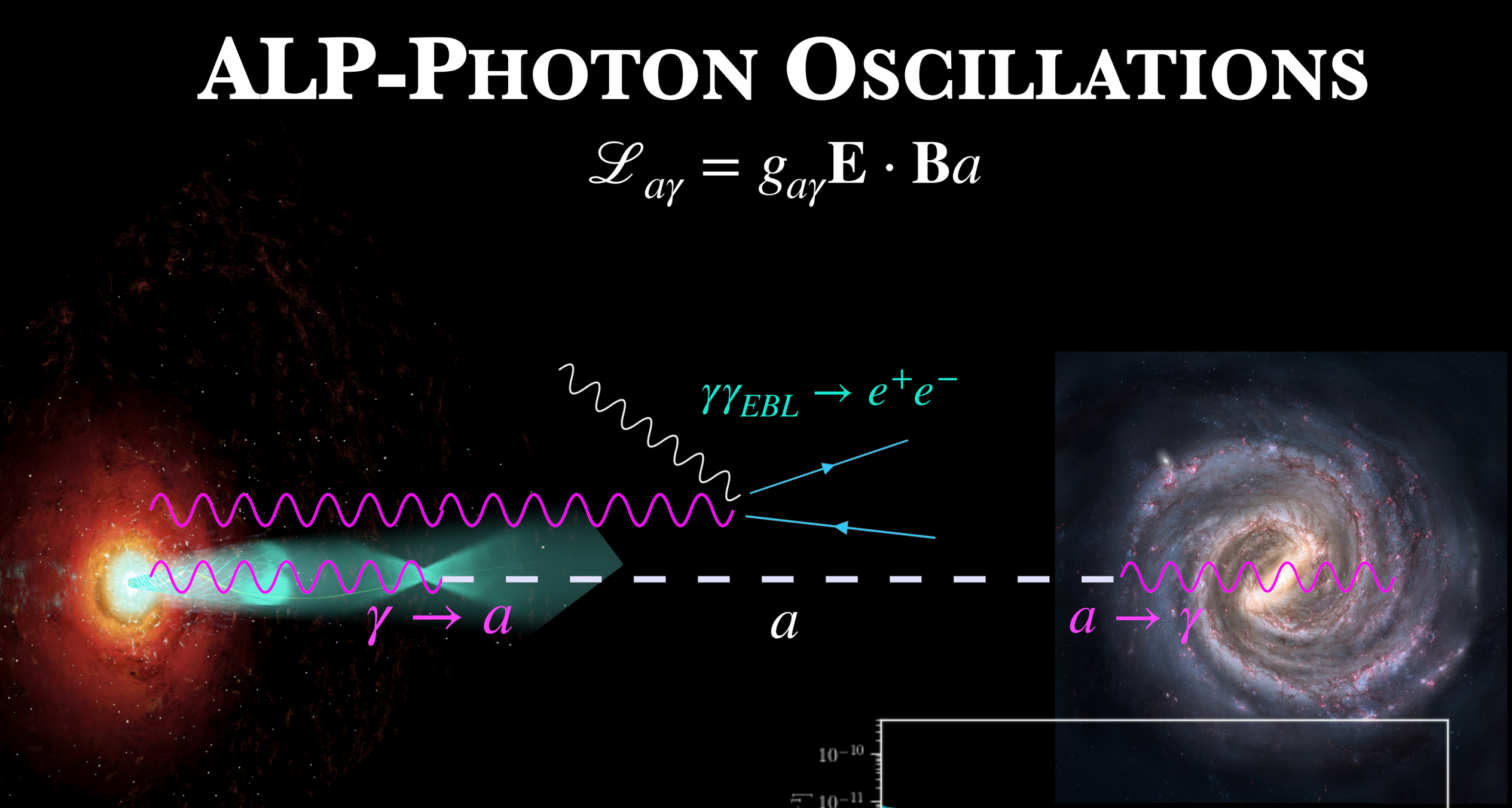
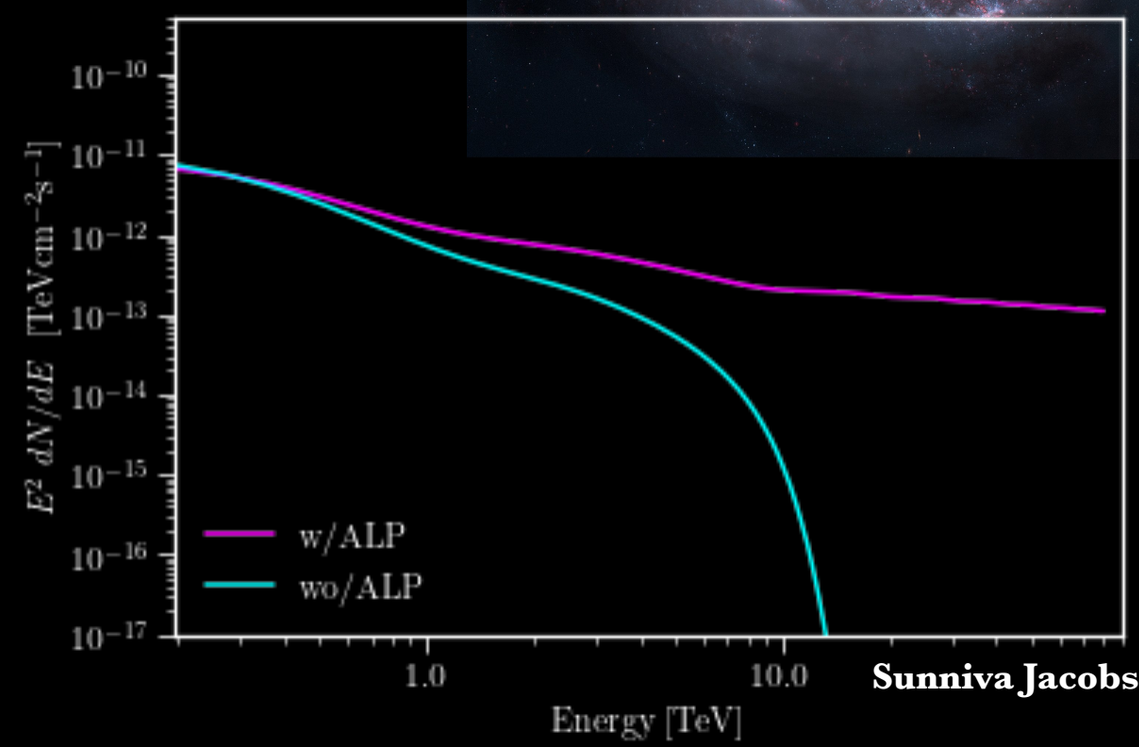




How many photons reach the Earth?

$$P_{\gamma\gamma} = \mathrm{Tr}\left[\left(\rho_{11} + \rho_{22}\right)\mathcal{T}\rho(0)\mathcal{T}^{\dagger}\right]$$

The transfer matrix can be divided into N domains:

$$\mathcal{T}\left(z_N, z_1; \psi_N, \ldots, \psi_1\right) = \prod_{i=1}^{N} \mathcal{T}\left(z_{i+1}, z_i; \psi_i; E\right)$$

Jet magnetic field

Magnetic field strength ~ G
Highly dependent on the blazar
Short distances ~pc

$$B(r) = B_0 r_{VHE} r^{-1}$$

Intra-cluster MF

Magnetic field strength ~μG
Long distances: ~100 kpc
Only for certain blazars

$$B^{\mathrm{ICM}}(r) = B_0^{\mathrm{ICM}}\left(\frac{n(r)}{n_0}\right)^{\eta}$$

Milky Way MF

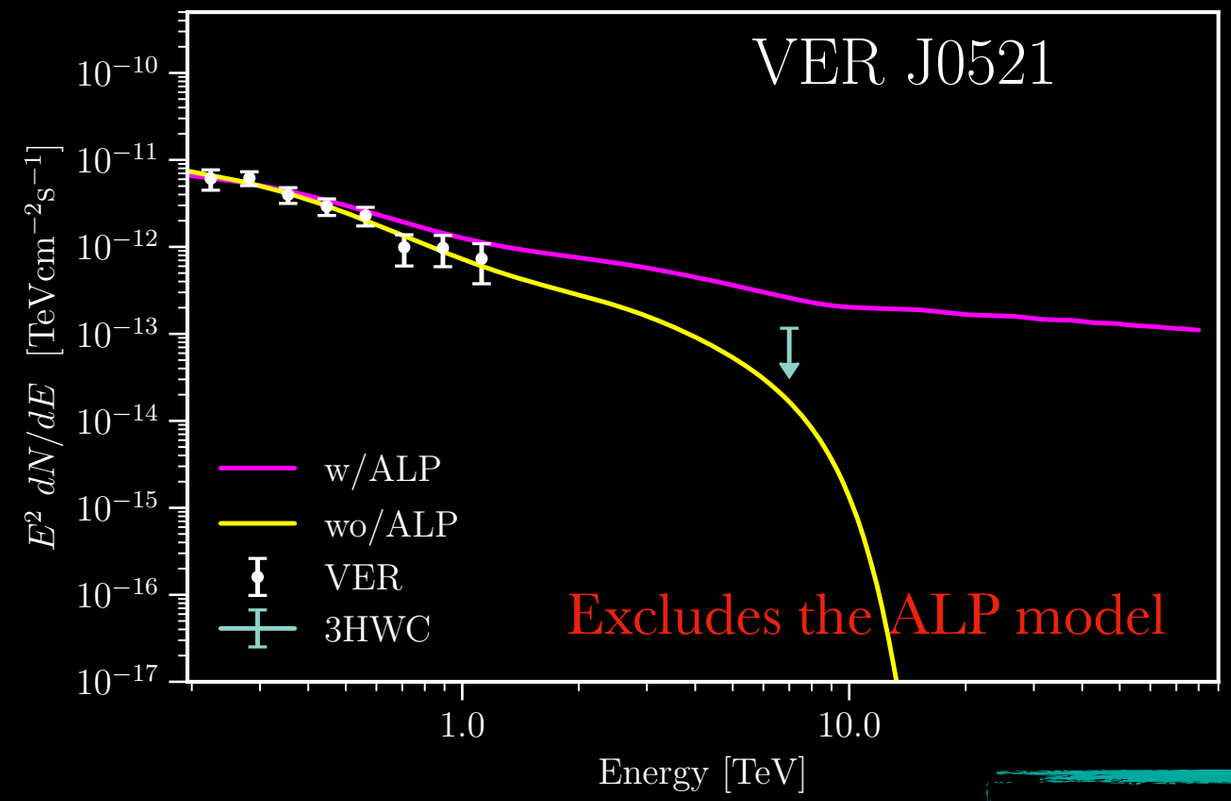
Modified Jansson & Farrar model (arXiv:1204.3662)

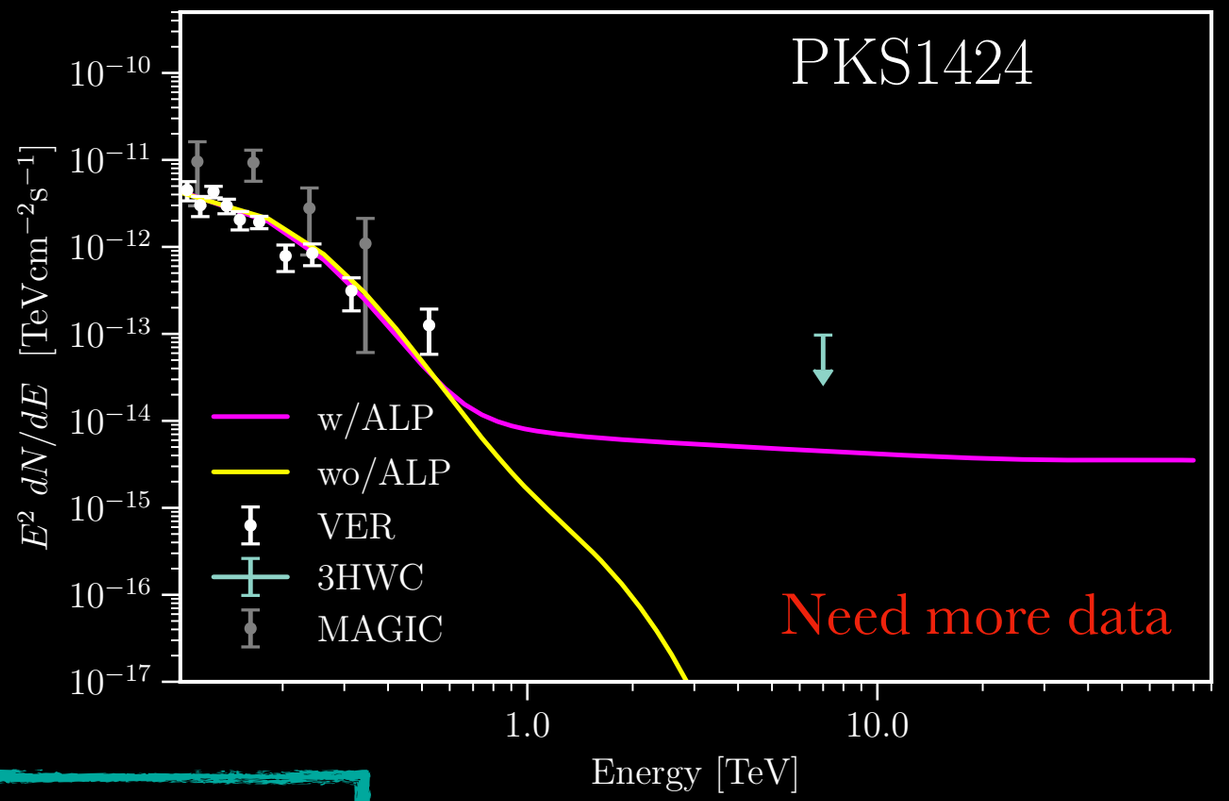
GammaALPs by Manuel Meyer
https://github.com/me-manu/gammaALPs

How do we use this to constrain ALP models?

HAWC provides an upper limit of the 7 TeV flux

Test statistic: $TS = 2\left(\mathscr{L}_{\mathrm{ALP}} - \mathscr{L}_{\mathrm{noALP}}\right)$ - in short, if the expected flux is larger than the HAWC upper limit, the ALP model is ruled out.



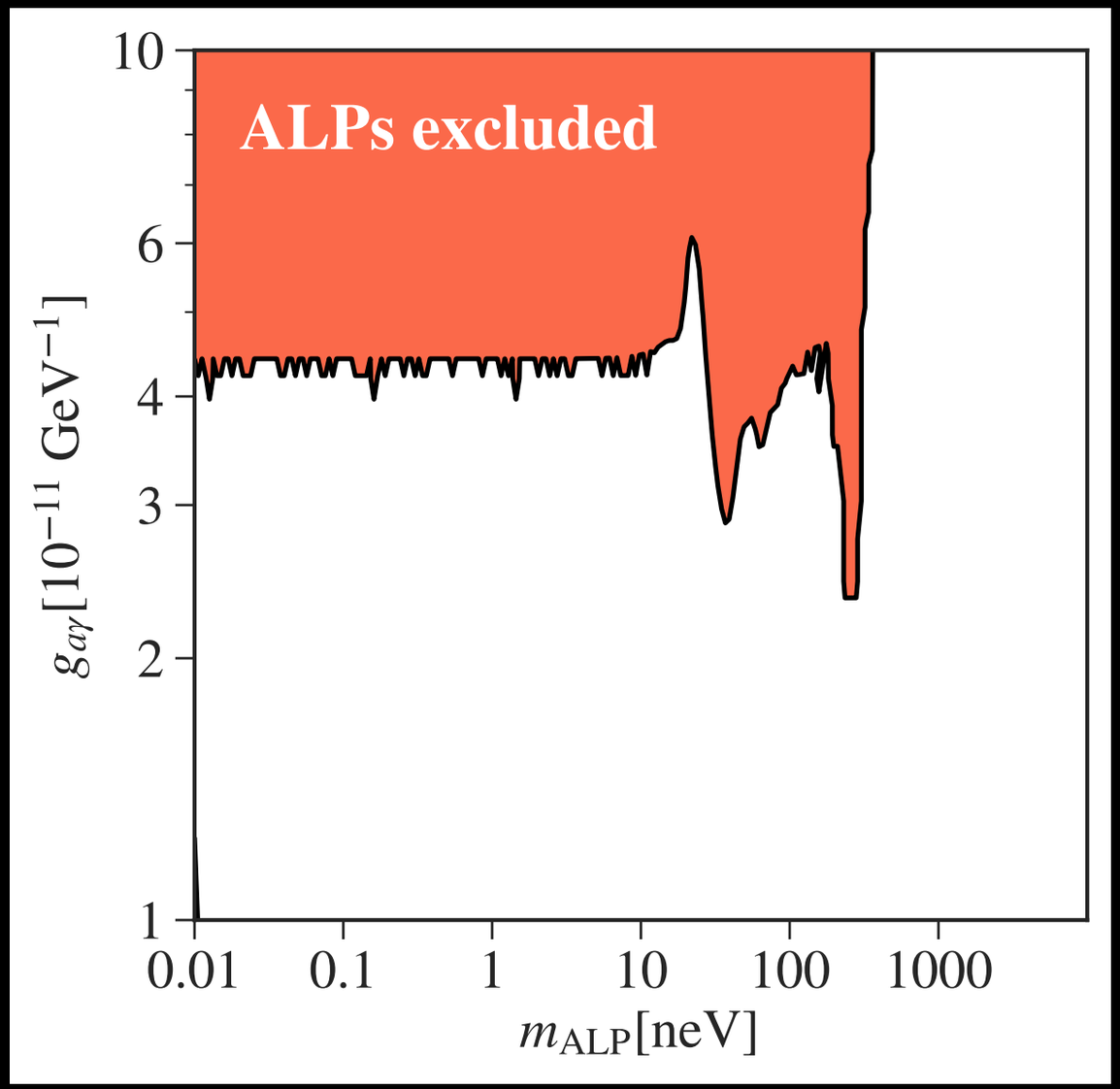


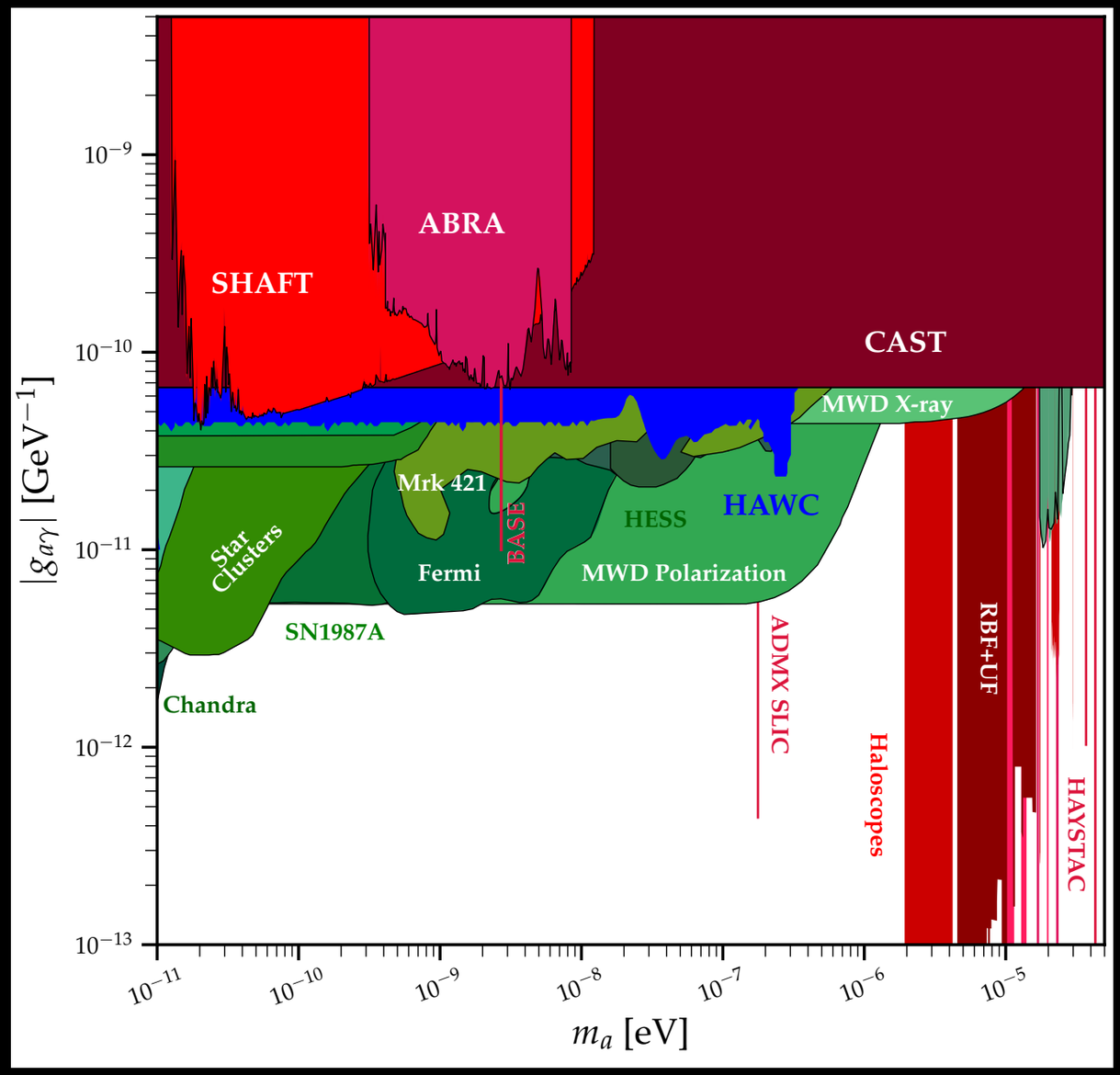
$m_{ALP} = 5 \times 10^{-9}\mathrm{eV}$

$g_{a\gamma} = 4 \times 10^{-11}\mathrm{GeV}^{-1}$

Stacked likelihood of 7 sources:
PKS 1424, PG1553, VER J0521,
1ES 1218+304, 1ES0229+200,
3C 66A and 1ES 1011

Ciaran o'Hare: AxionLimits





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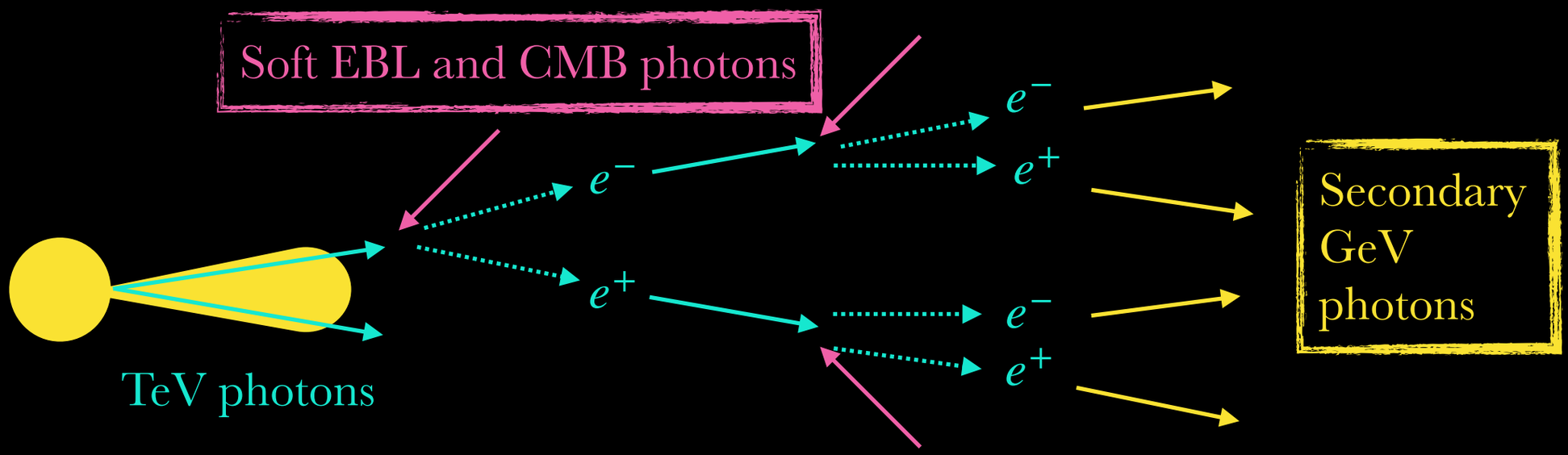
Cascades



-Electron-positron pairs produced by attenuation will inverse-Compton scatter off EBL and CMB photons

- Cycle continues and leads to an increased GeV flux

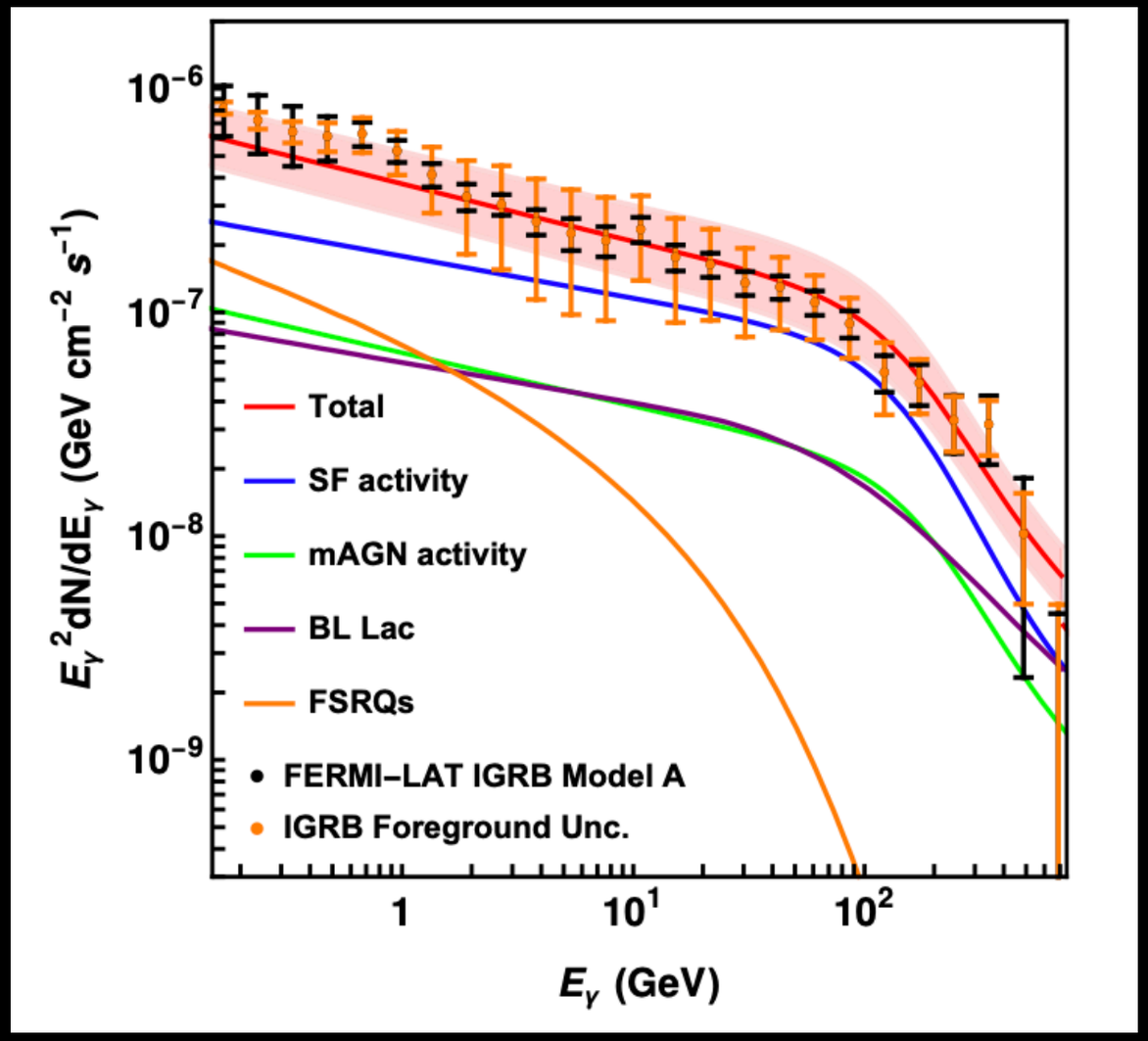
The isotropic Gamma-ray Background (IGRB)

- Photons outside the MW not attributed to a known source

- IGRB = EGRB - known sources

- γ-rays from misaligned AGN and star forming activity, plus undetected blazars

- Contribution from blazars depends on the intergalactic magnetic field (IGMF) strength



C. Blanco and T. Linden, 2104.03315

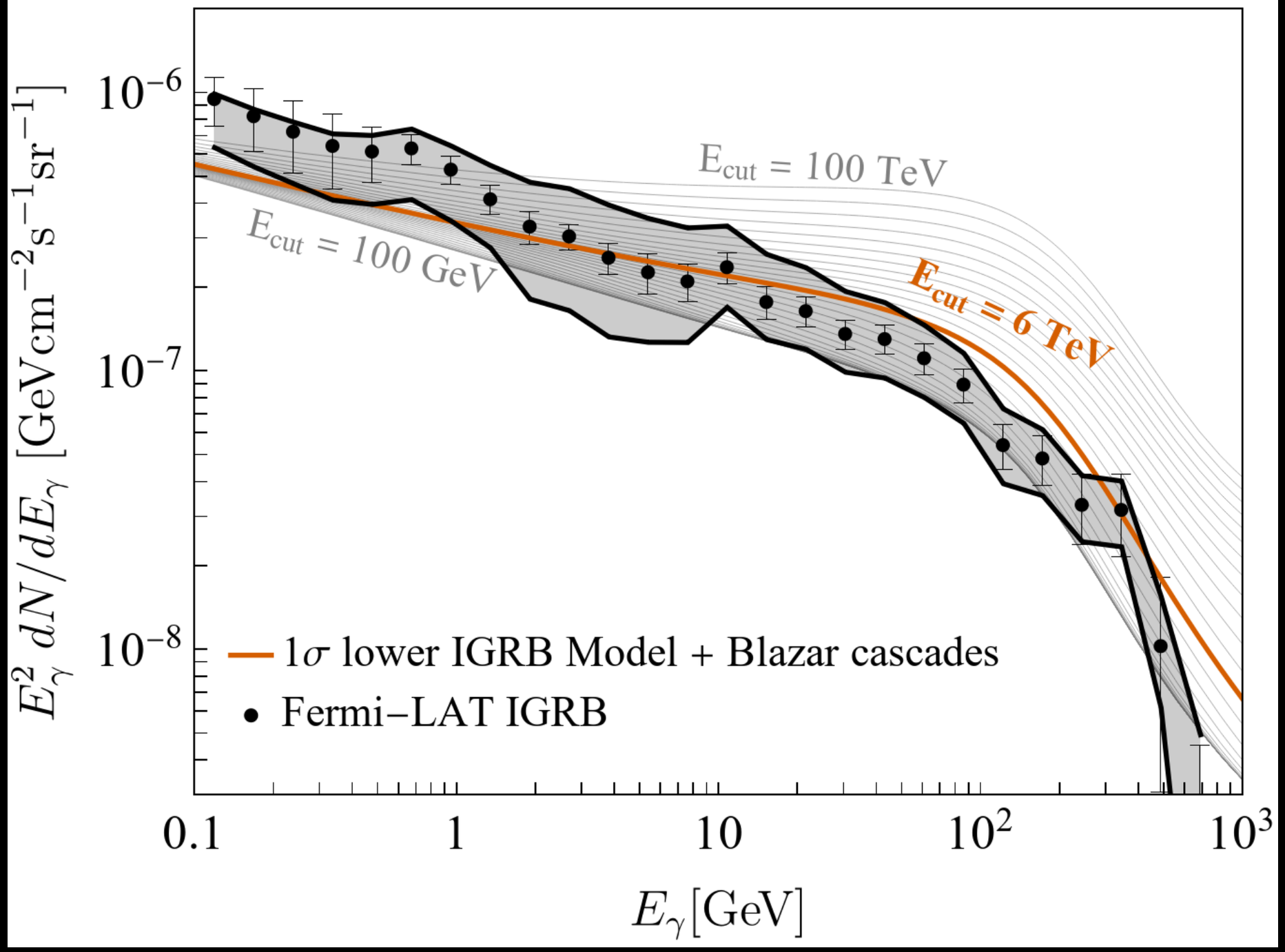
Cascaded TeV gamma-rays from blazars and the IGRB

Our paper: Calculate the contribution to the IGRB from cascades caused from blazar TeV γ-rays

Method: Calculate the intrinsic flux of 1700 Fermi blazars and compute the expected contribution to the IGRB from cascades

Intrinsic spectra: Deabsorbed spectra - after accounting for attenuation in the EBL
Spectrum types: Power-law, log-parabola or power-law with exponential cutoff

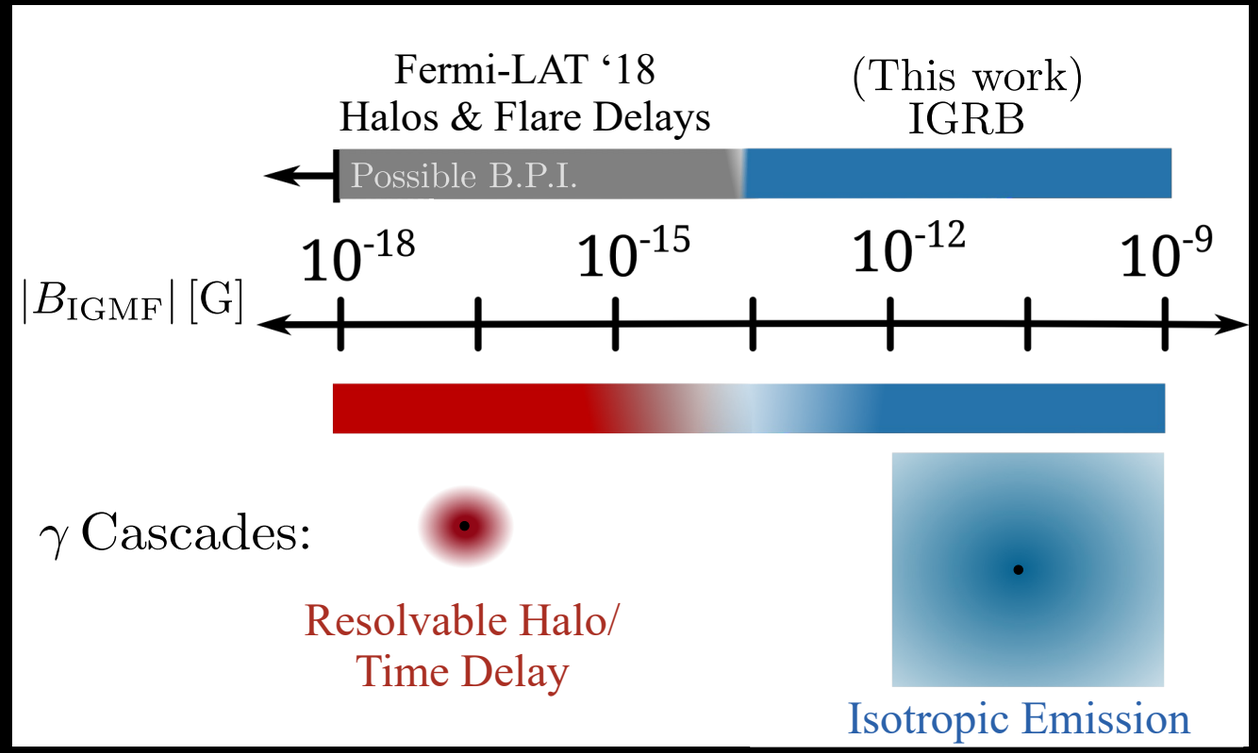
Secondary GeV flux: calculated using γ-cascade by Carlos Blanco
ArXiv: 1804.00005


$E_\gamma^2\, dN/dE_\gamma$ [GeVcm^{-2}s^{-1}sr^{-1}]
10^{-6}
10^{-7}
10^{-8}
E_{cut} = 100 TeV
E_{cut} = 100 GeV
E_{cut} = 6 TeV
1σ lower IGRB Model + Blazar cascades
Fermi−LAT IGRB
0.1
1
10
10^2
10^3
E_γ[GeV]

Beam-plasma instabilities

Instabilities in the electron-positron beam cool down the pairs before ICS occurs - no cascades.

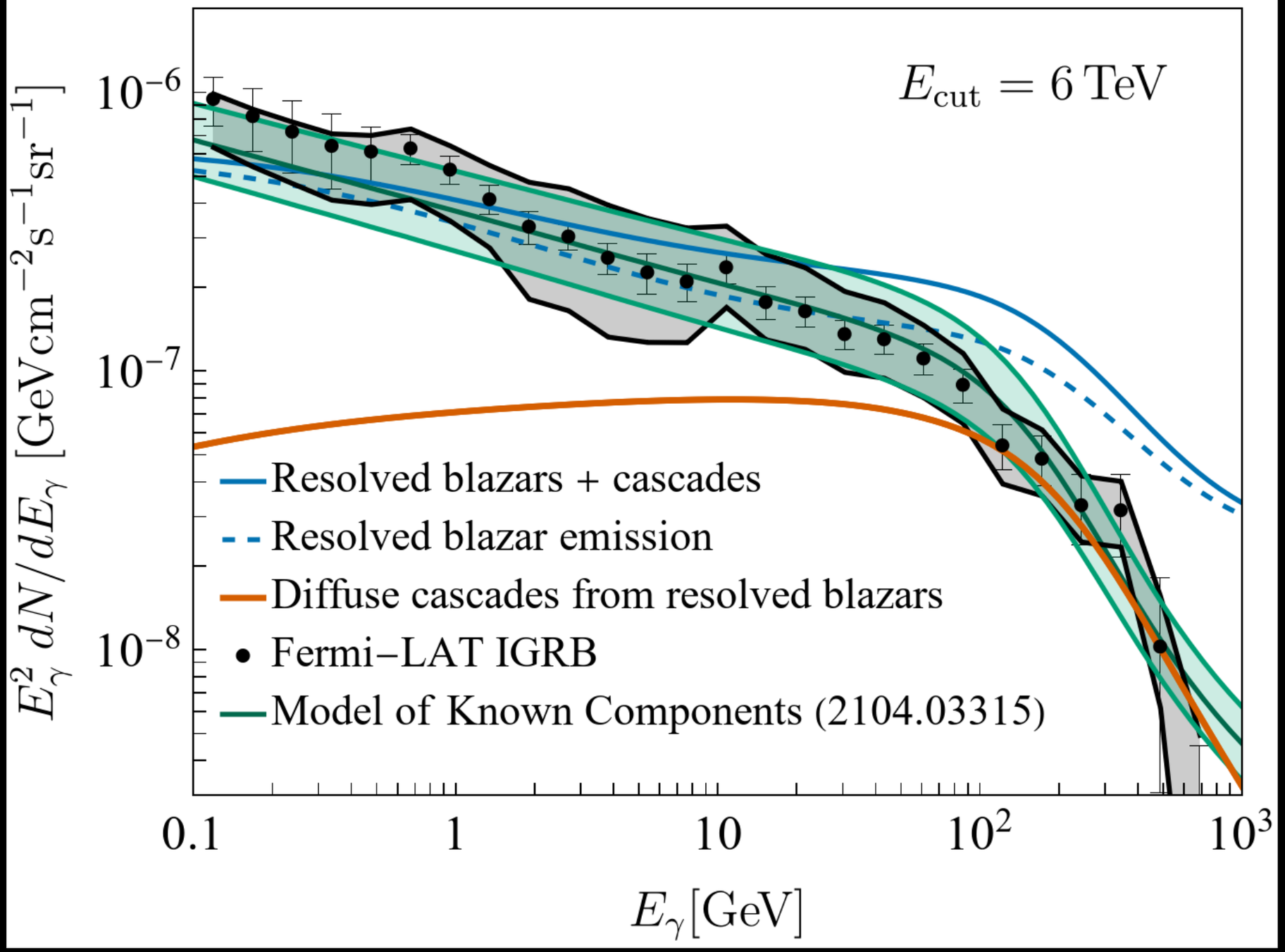
Depends on the strength of the intergalactic magnetic field: $10^{-18} - 10^{-14}$



Conclusions

Observations of TeV blazars can significantly constrain models of axion-like particles

Cascades from TeV blazars overproduce the IGRB: Blazars need strong spectral cuts in tension with local blazar observations, beam-plasma instabilities prevent cascade development or new physics?


$E_{\rm cut} = 6\,{\rm TeV}$
10^{-6}
10^{-7}
10^{-8}
$E_\gamma^2\, dN/dE_\gamma$ [GeV cm^{-2} s^{-1} sr^{-1}]
Resolved blazars + cascades
Resolved blazar emission
Diffuse cascades from resolved blazars
Fermi–LAT IGRB
Model of Known Components (2104.03315)
0.1
1
10
10^2
10^3
E_γ[GeV]