Probing the intergalactic magnetic field through gamma-ray observations with the Fermi LAT and H.E.S.S.

Manuel Meyer for the H.E.S.S. and Fermi LAT collaborations
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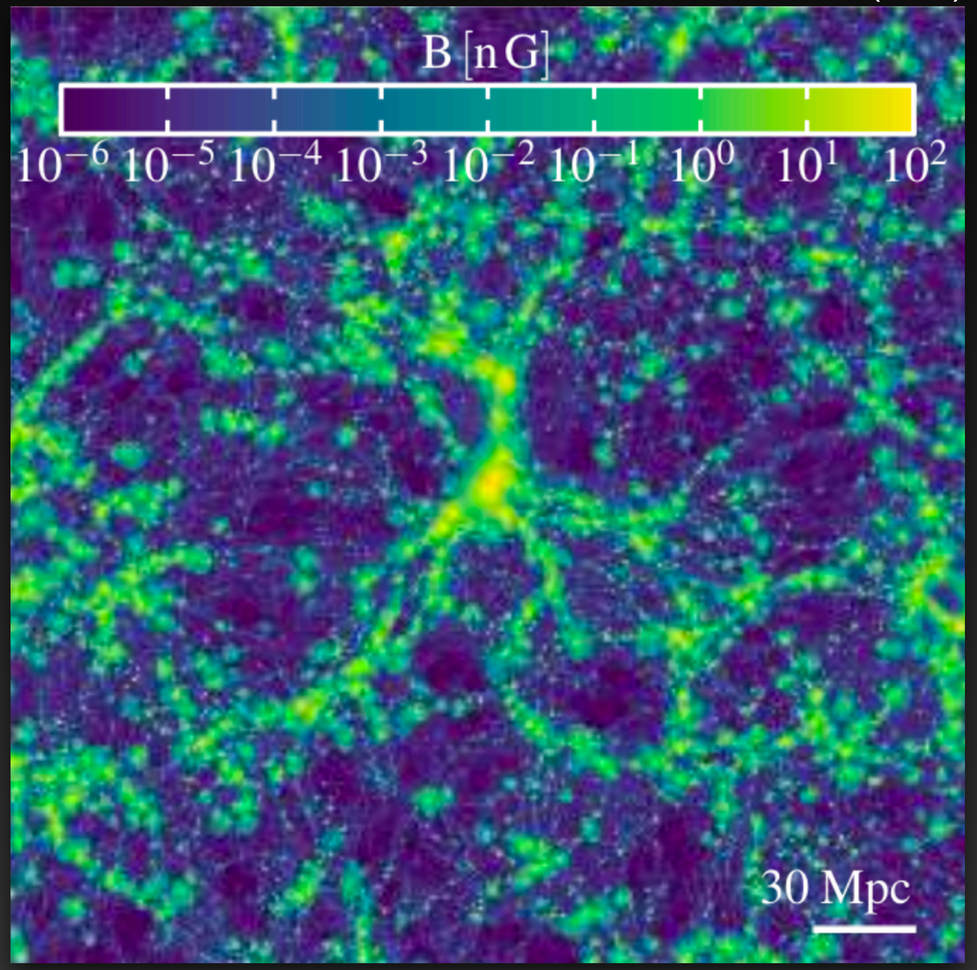
The Variable Multi-Messenger Sky — WE Heraeus Seminar, Cracow, November 8, 2022

The Intergalactic magnetic field

IllustrisTNG simulation — Marinacci et al. (2018)



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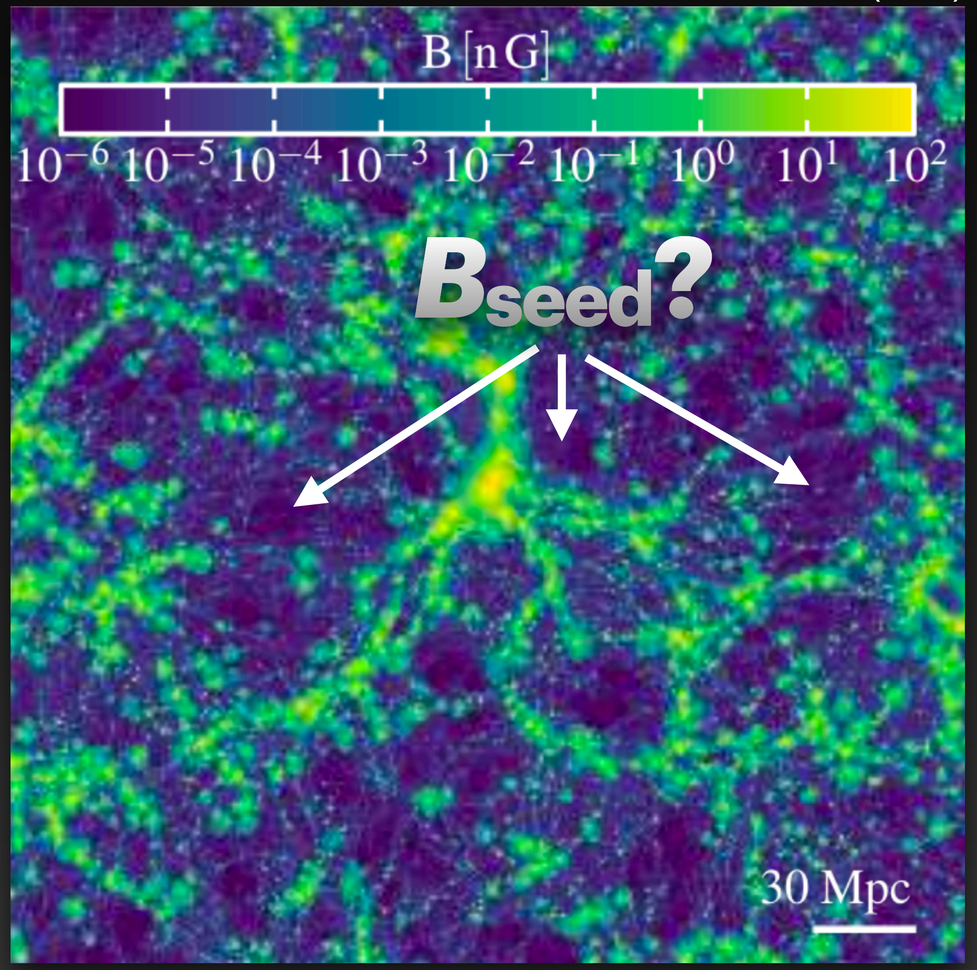

The Intergalactic magnetic field

- B-fields in galaxies and galaxy clusters originate from amplified seed field
- Origin, strength, orientation of seed fields unknown
- Extremely difficult to measure directly

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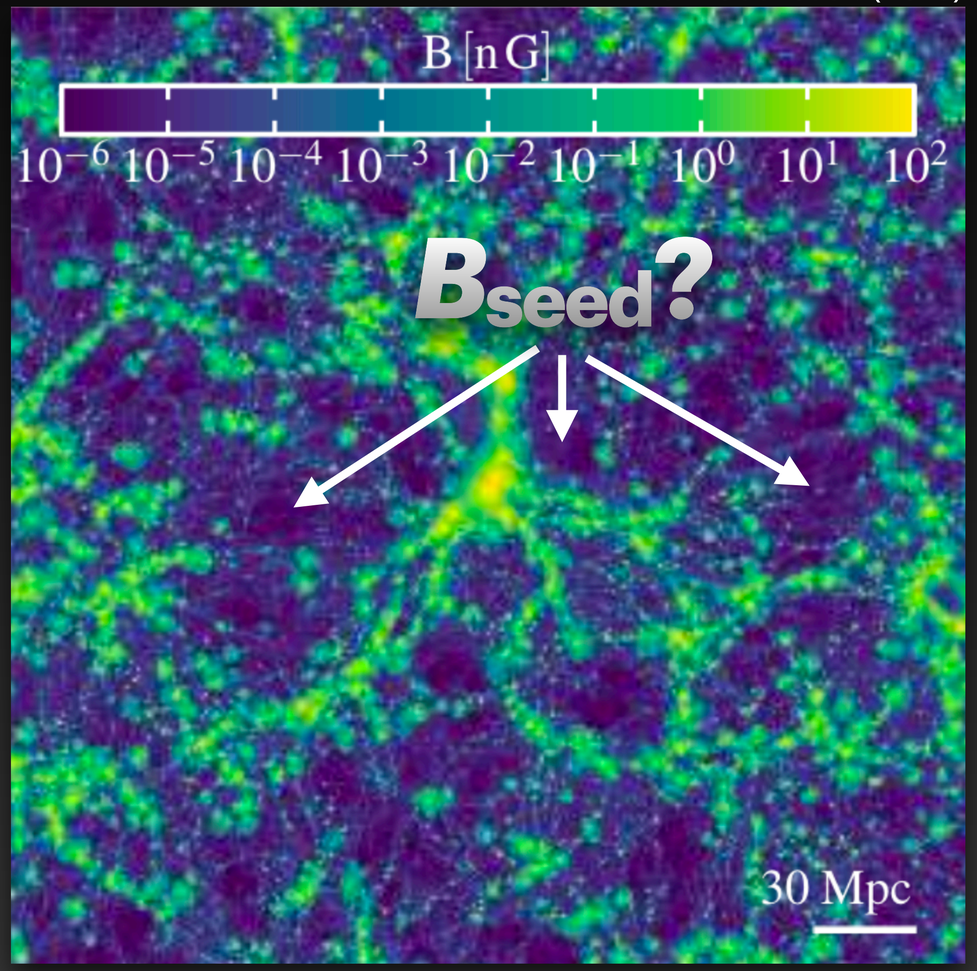

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Indirect detection of the IGMF

Using gamma-ray observations of blazars

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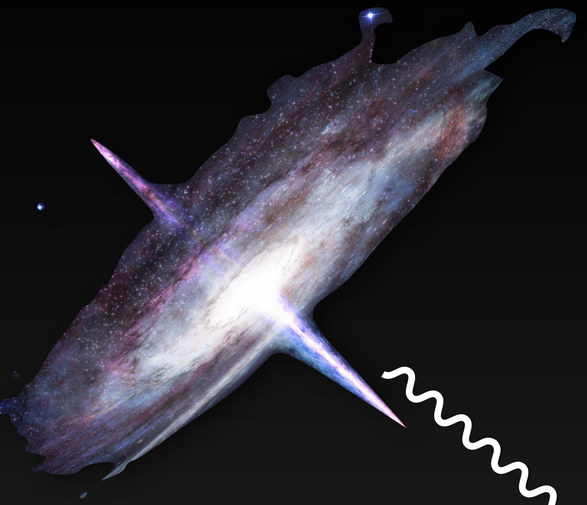

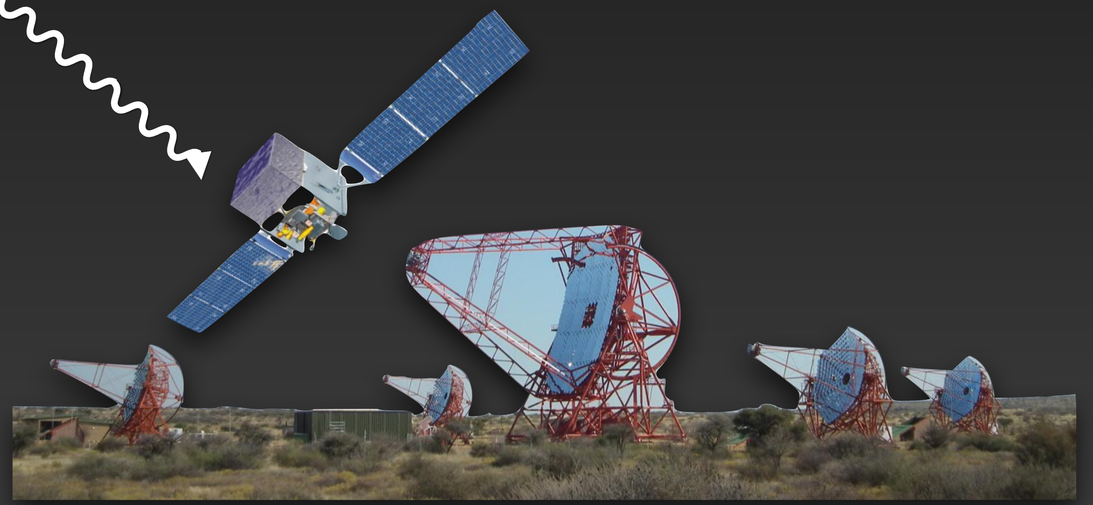

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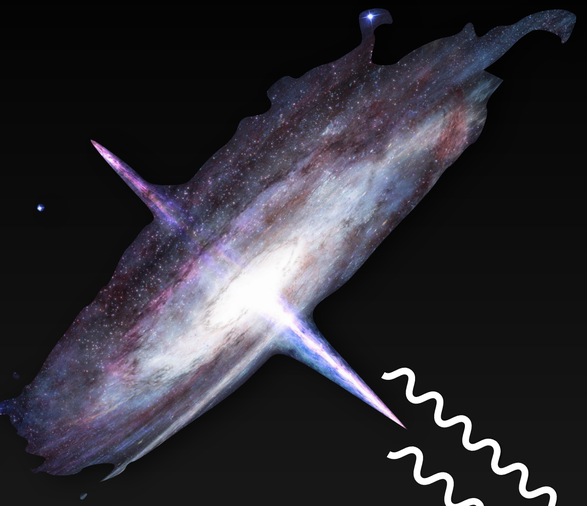

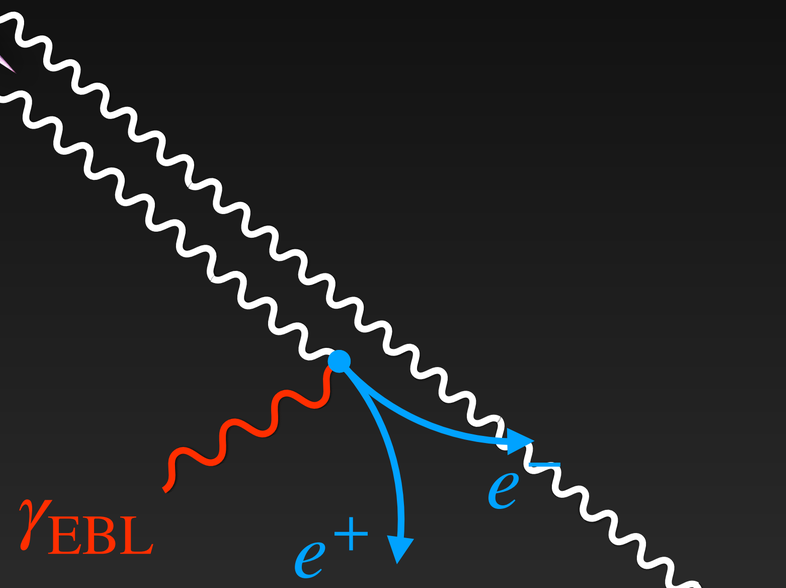

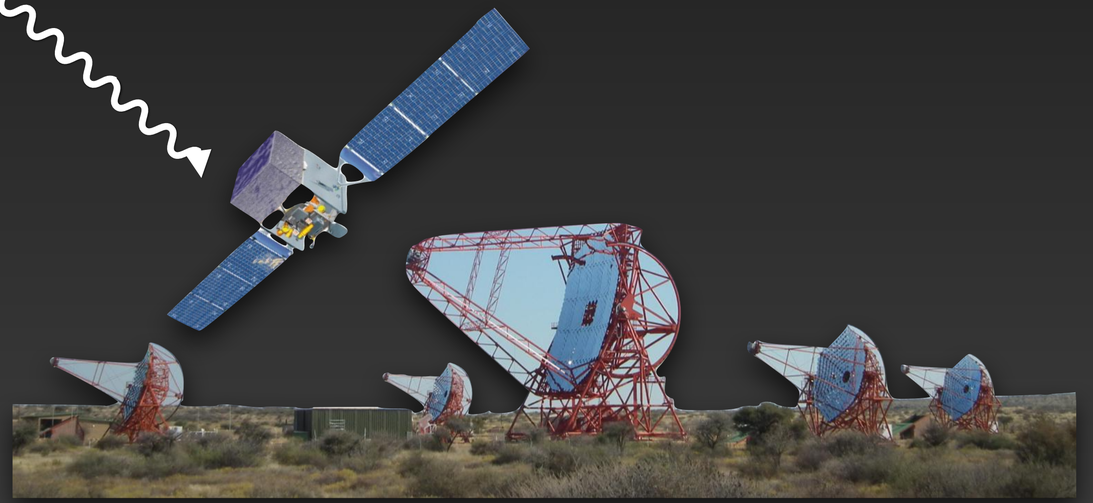

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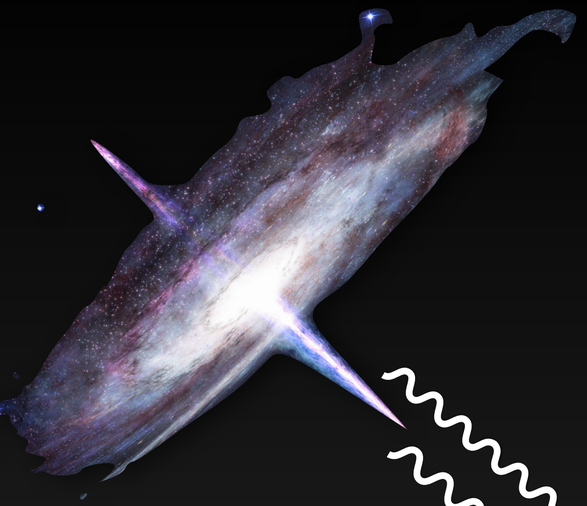

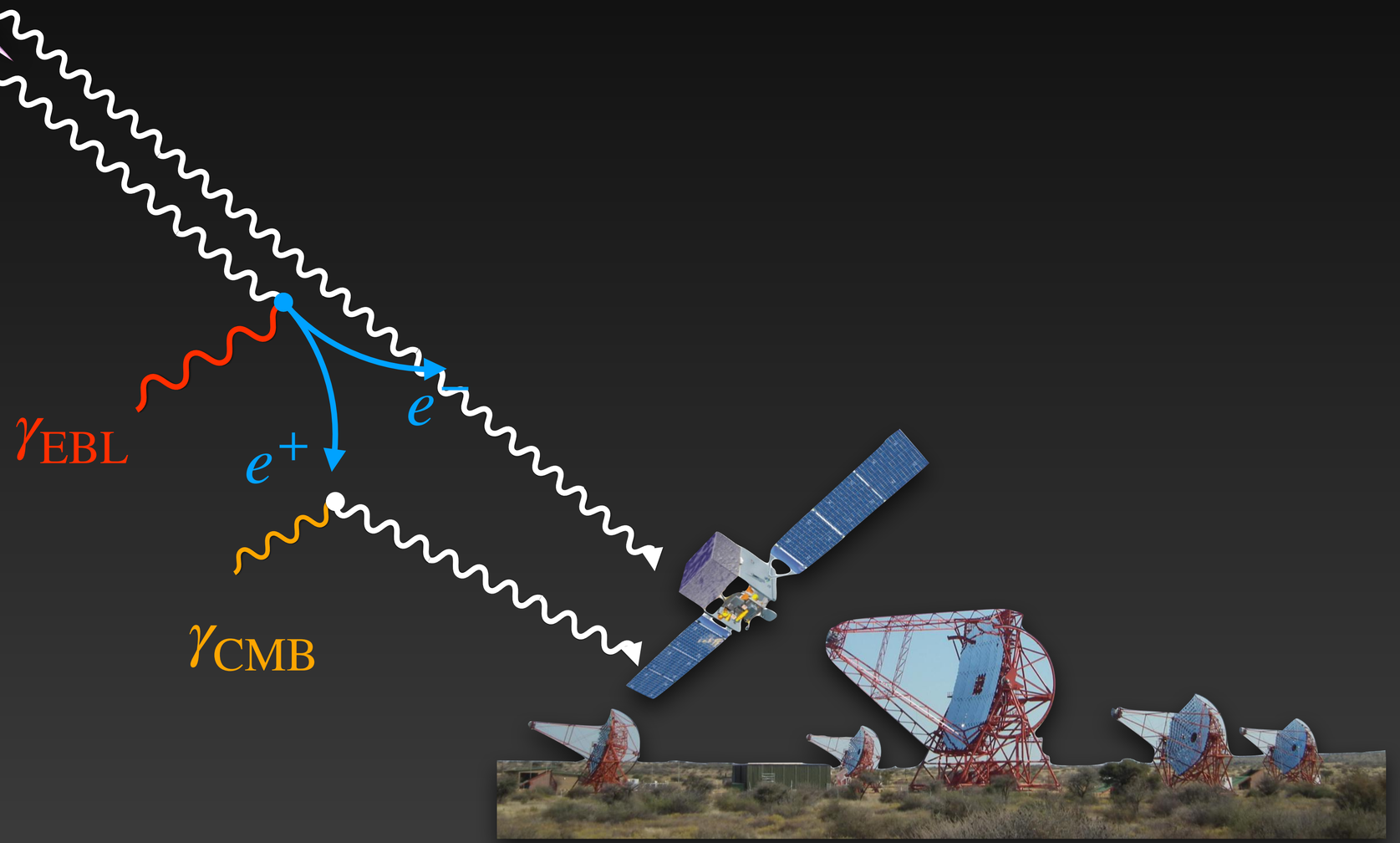

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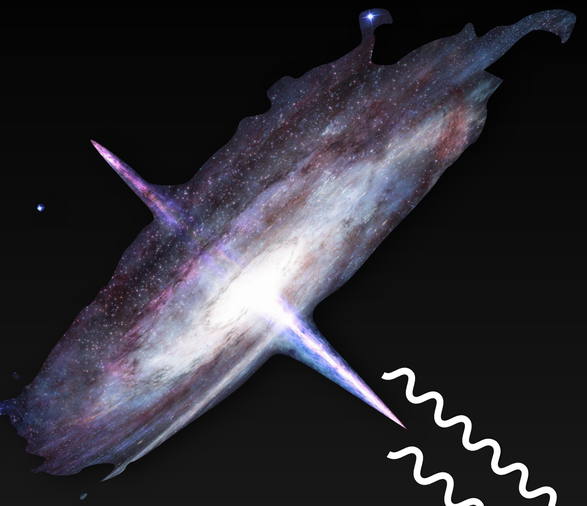

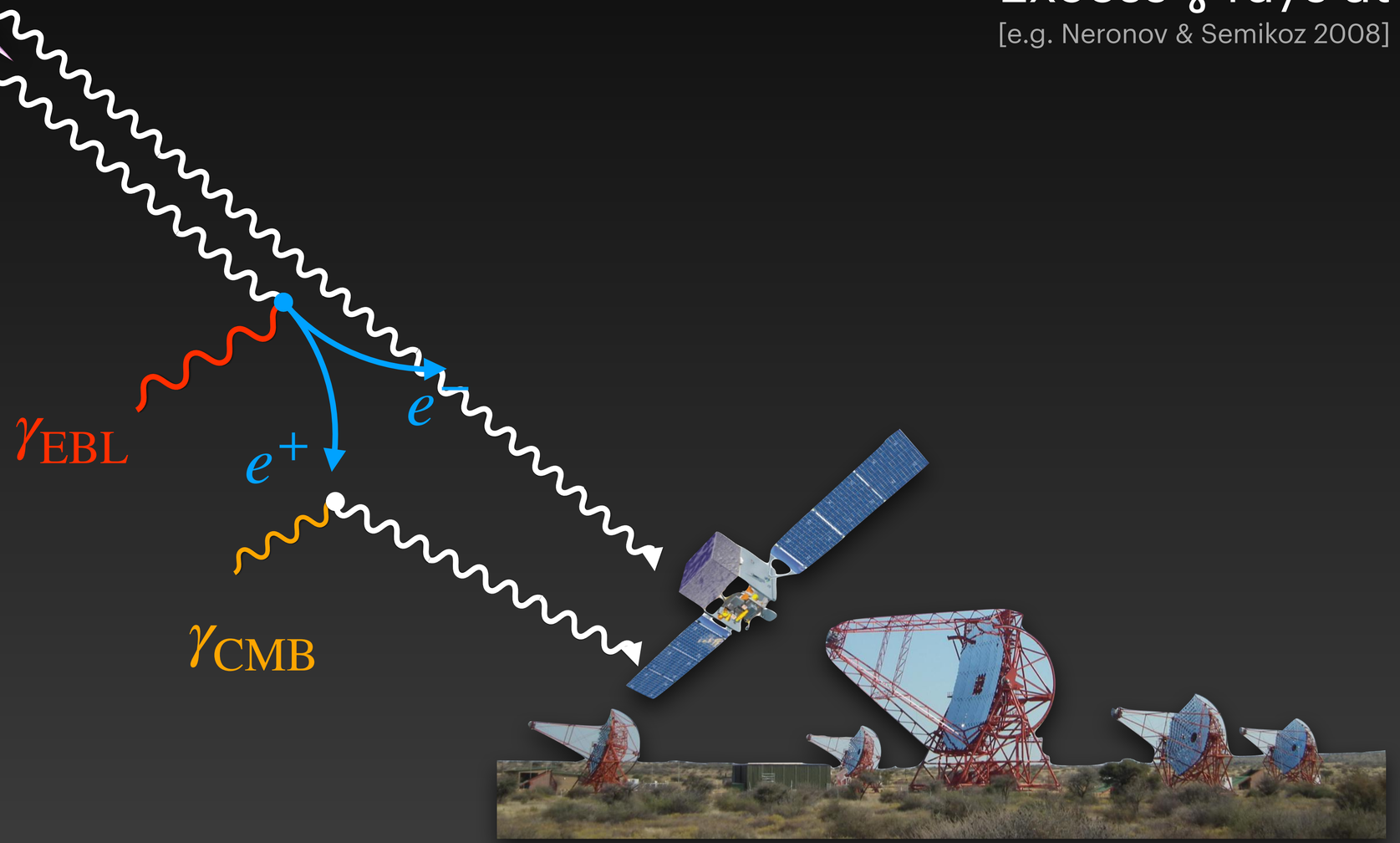

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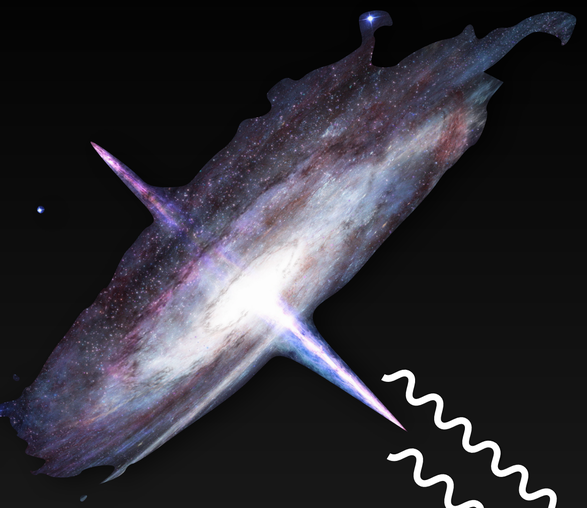

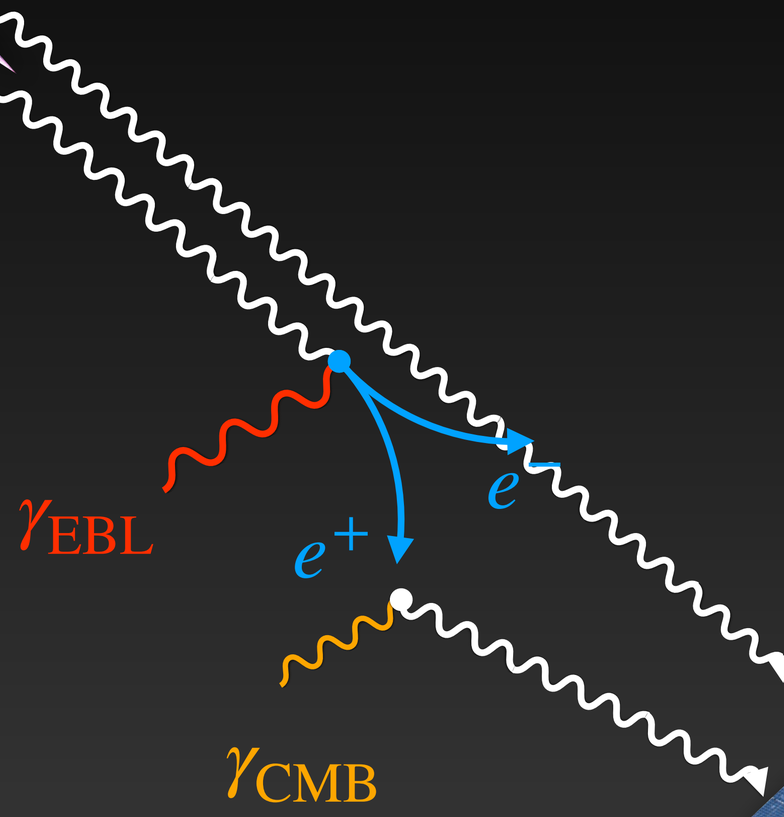

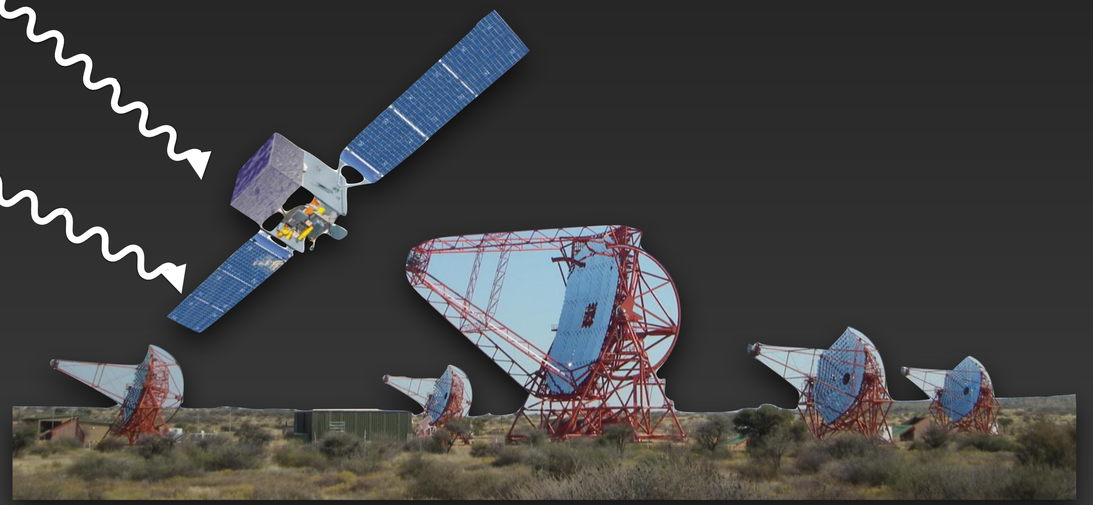

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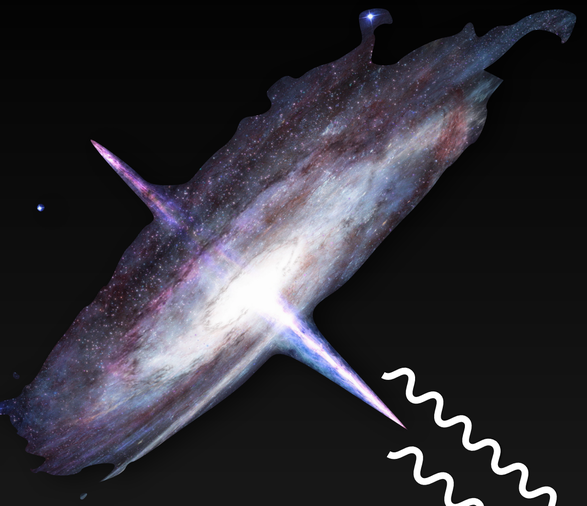

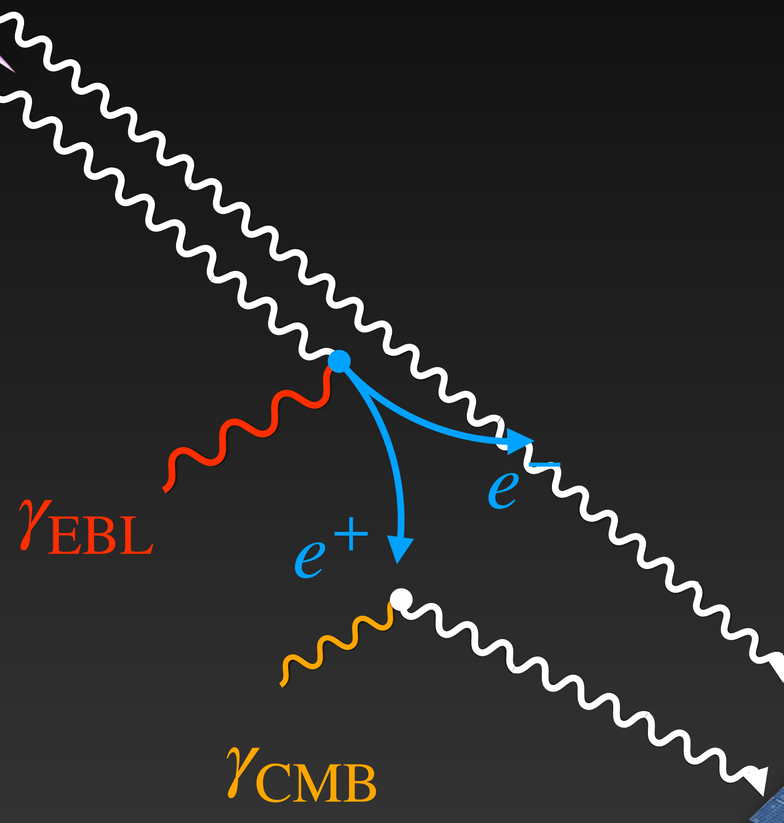

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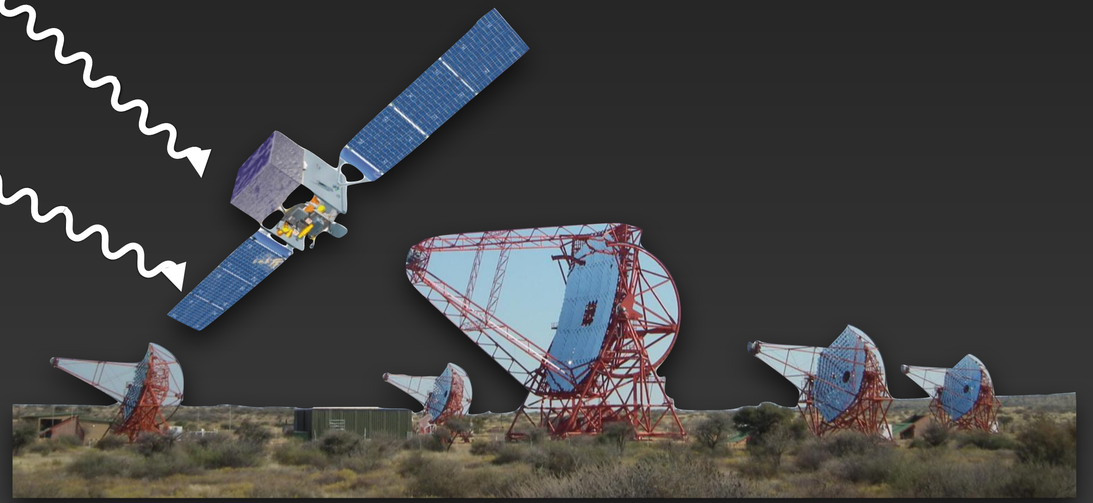

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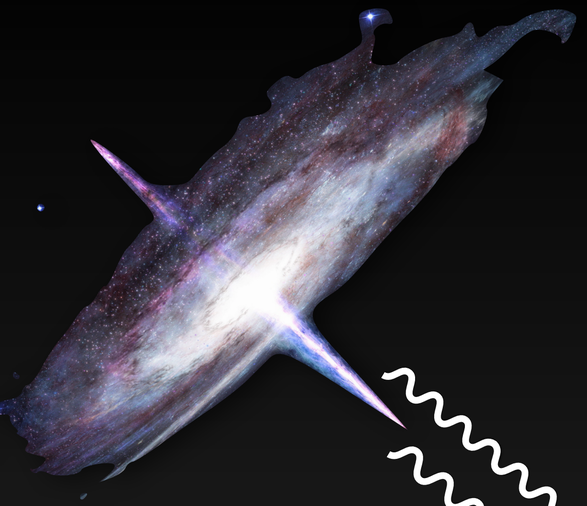

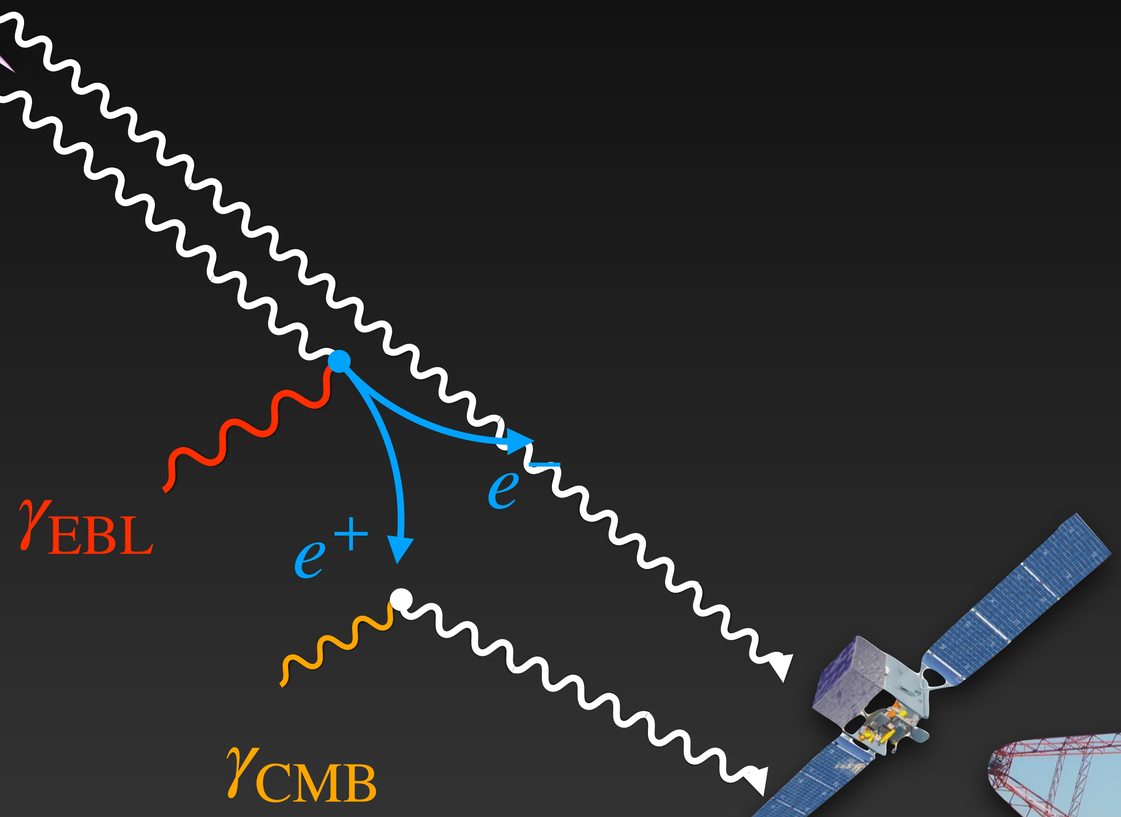

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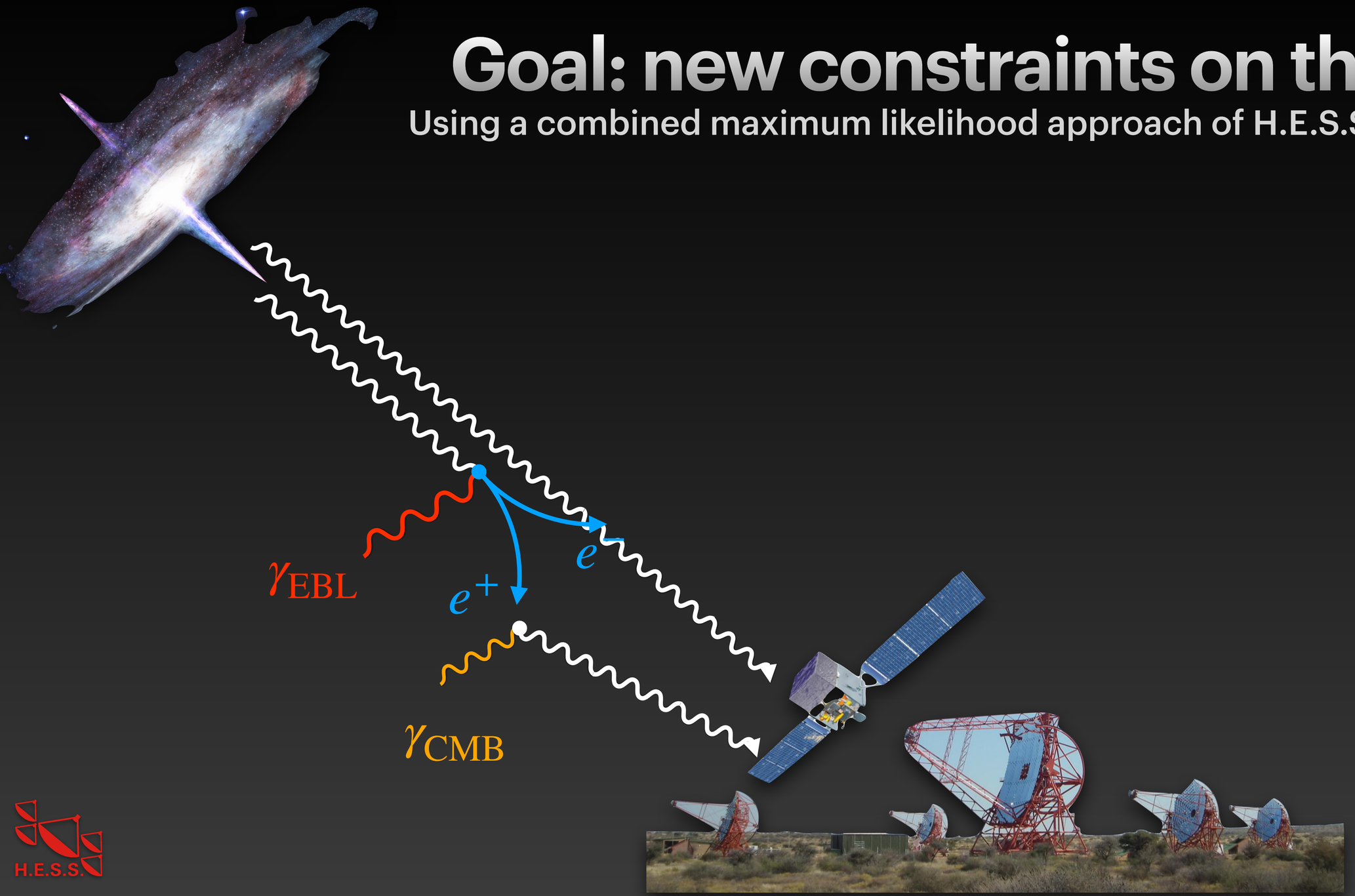
Using a combined maximum likelihood approach of H.E.S.S. and LAT data



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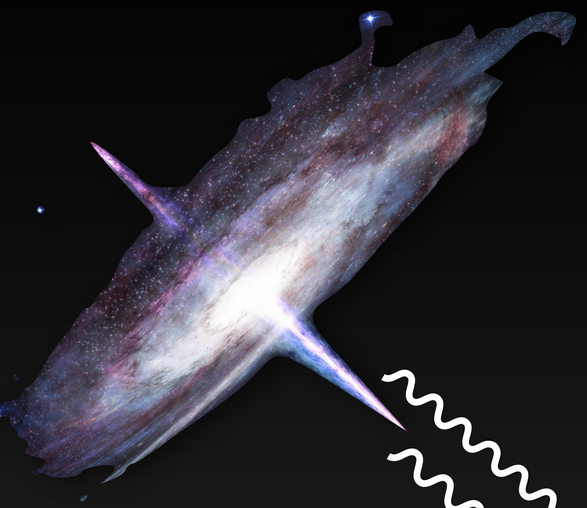

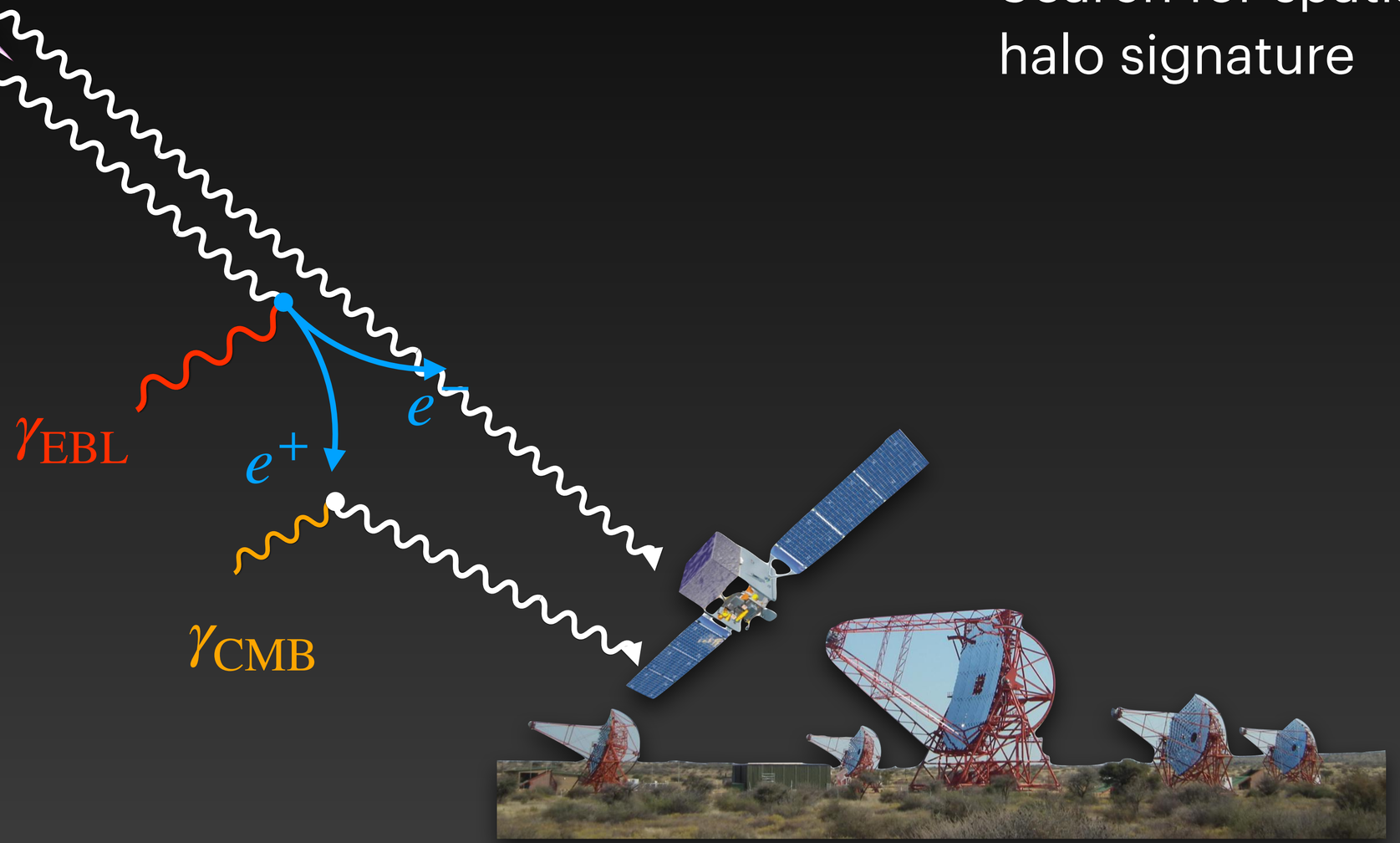

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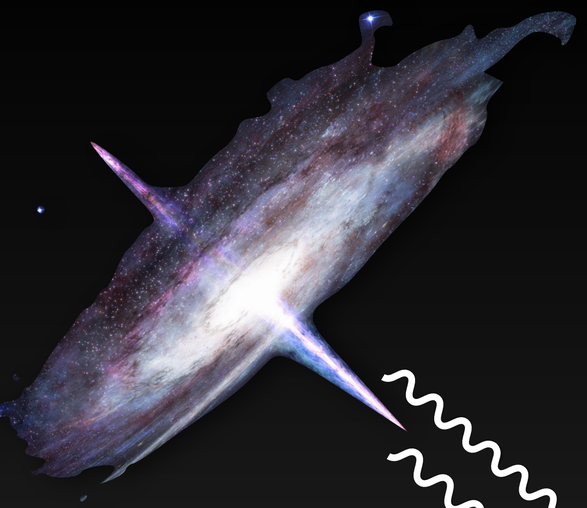

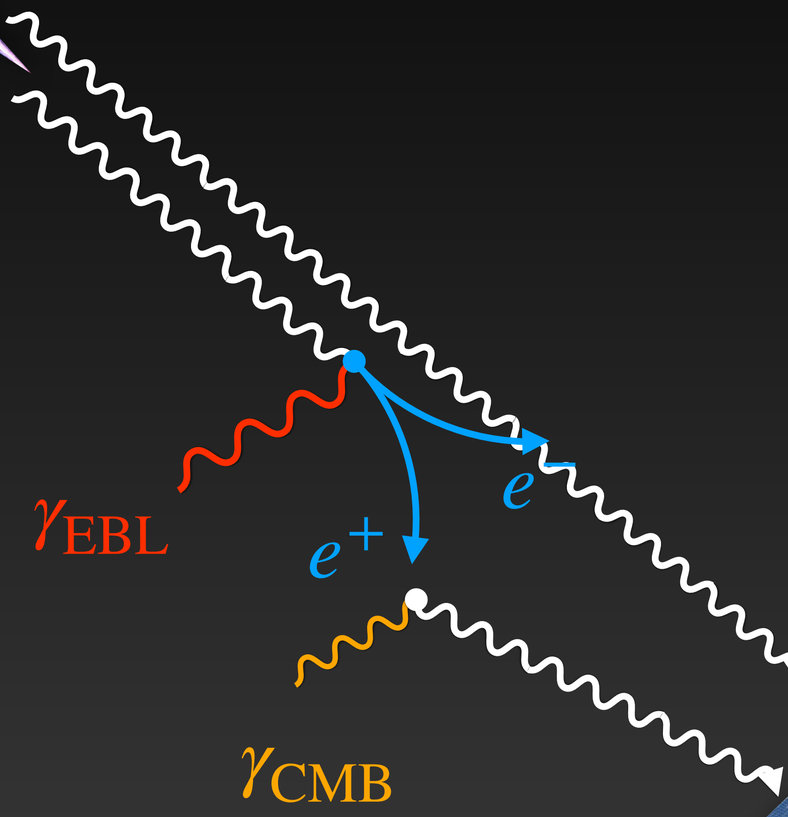

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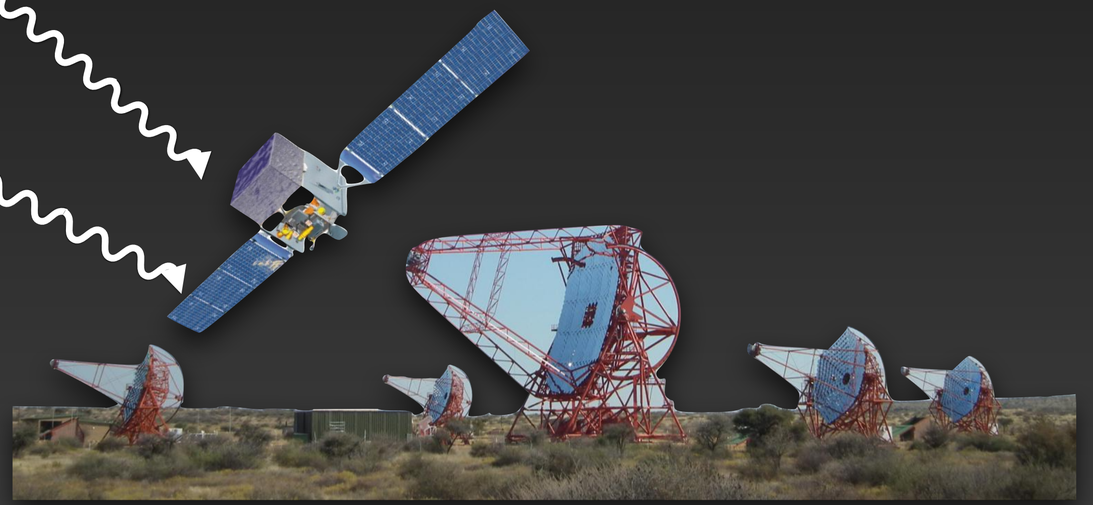

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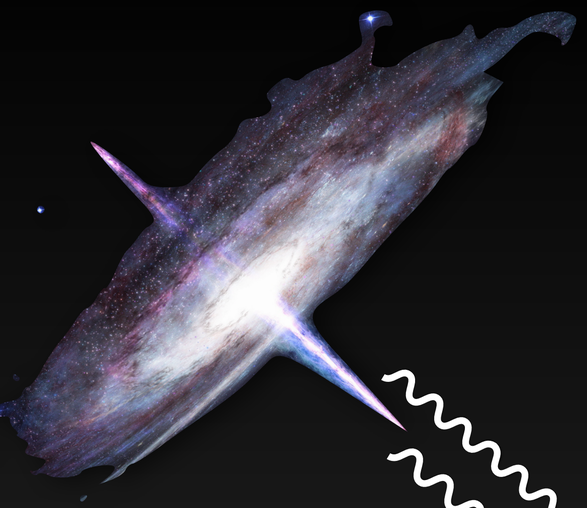

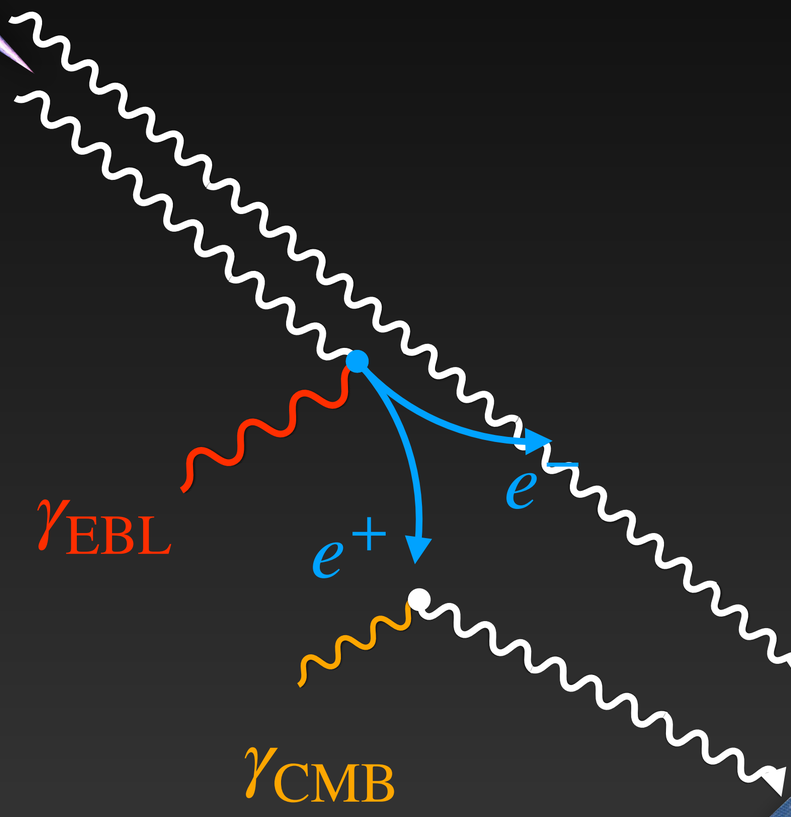

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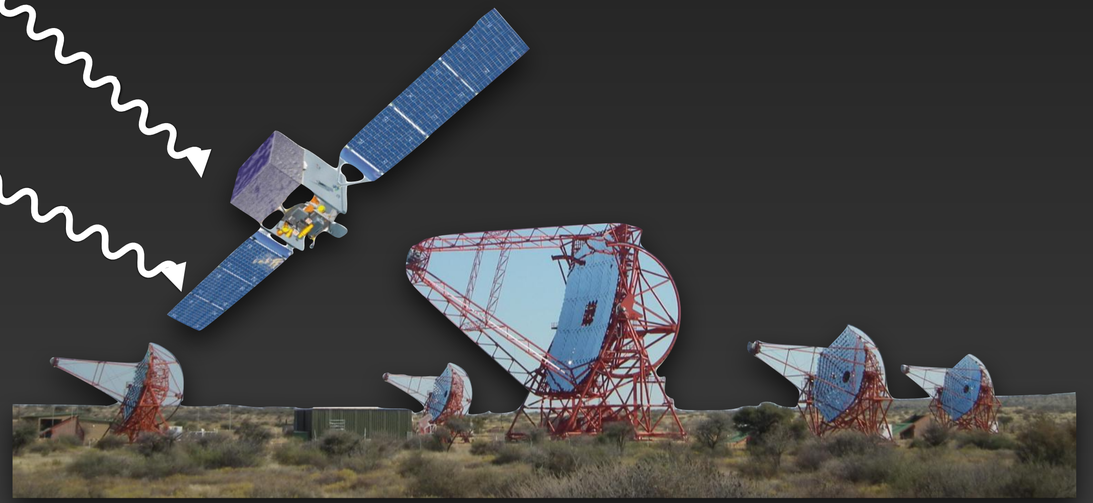

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Resulting sources:

Source Name	Redshift
1ES 0229+200	0,139
1ES 0347-121	0,188
PKS 0548-322	0,069
1ES 1101-232	0,186
H 2356-309	0,165

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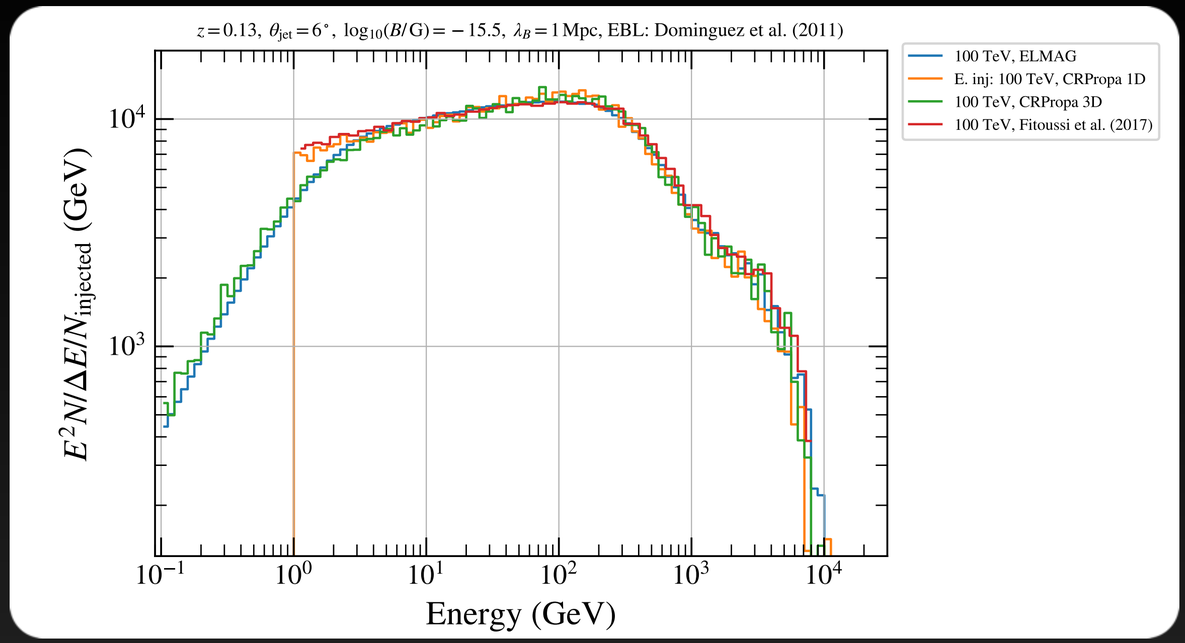

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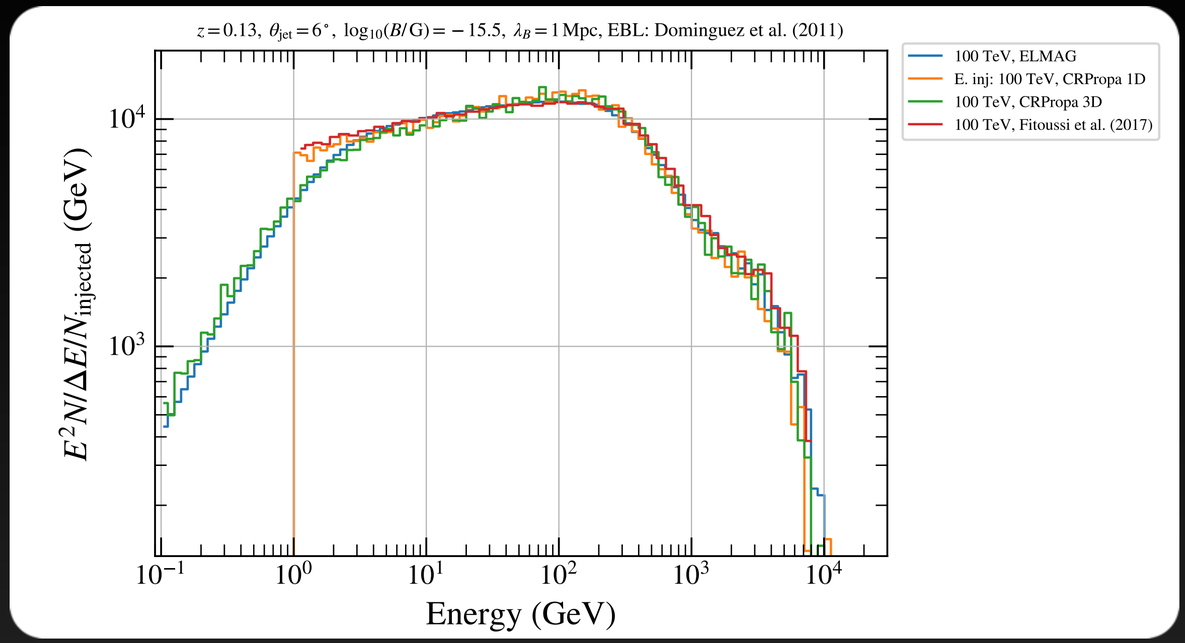

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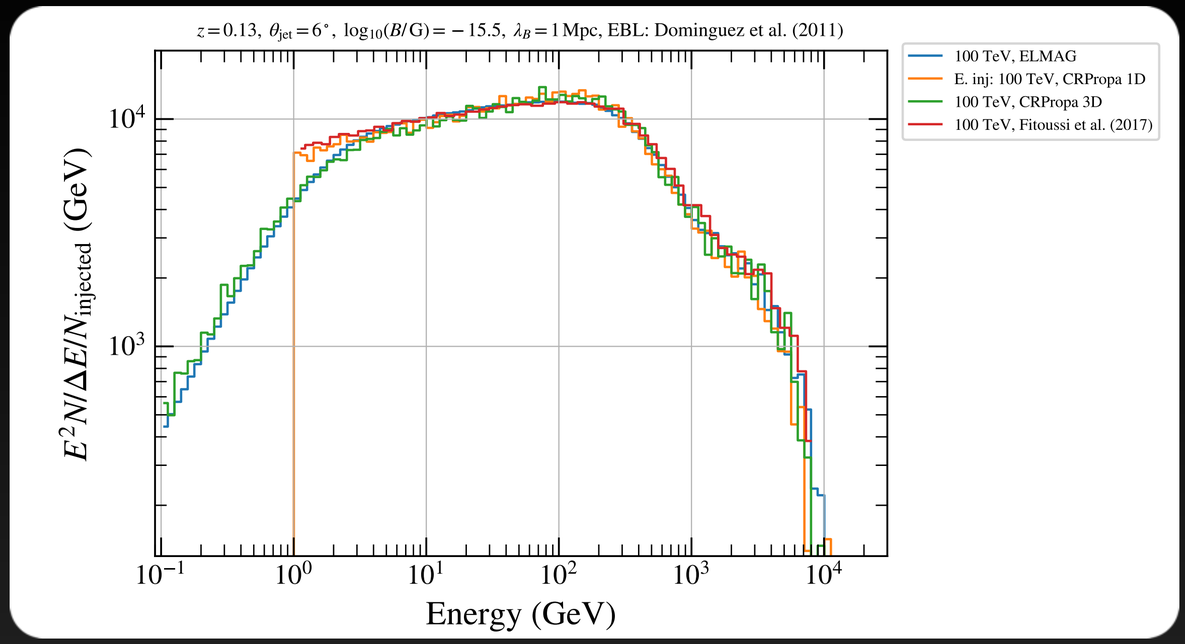

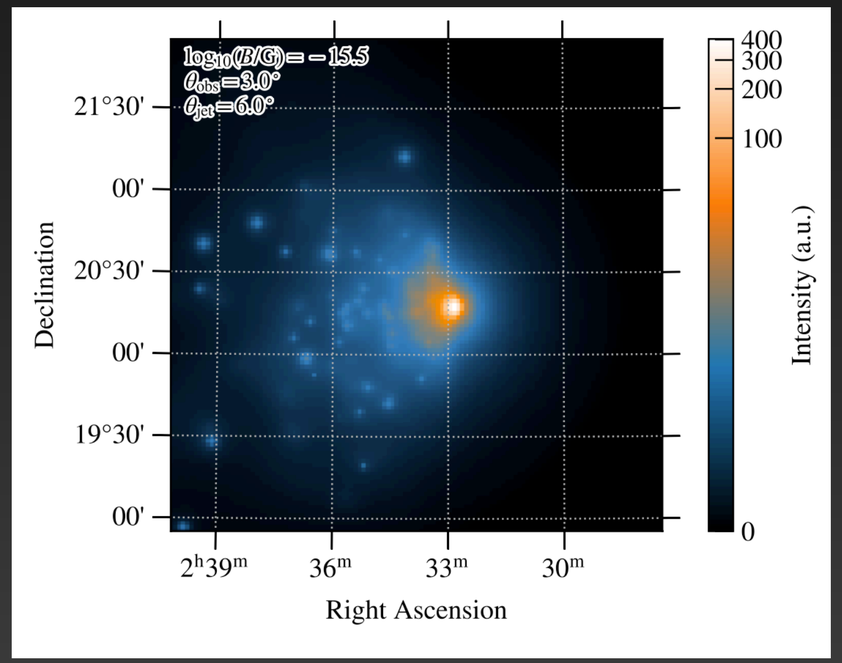

Fermi-LAT data selection

Parameter	Selection
Time range	11.5 years
Energy Range	> 1 GeV
ROI size	6º x 6º
Max. Zenith angle	100º
Filter	DATA_QUAL>0 && LAT_CONFIG==1
Spatial binning	0.025º / pixel
Energy binning	8 bins per decade
Event Class / IRFs	P8R3_SOURCE_V3, inflight PSF
Event types	PSF0-2, PSF3

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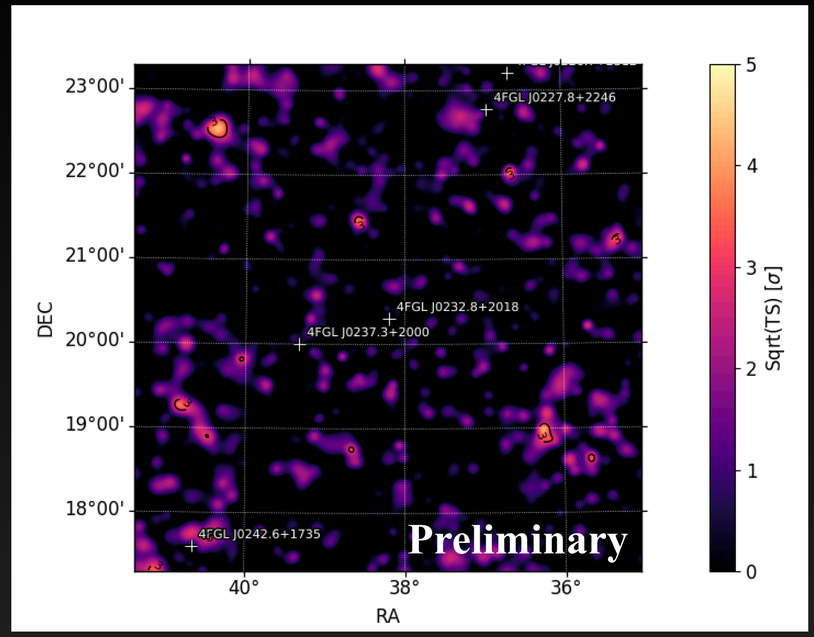

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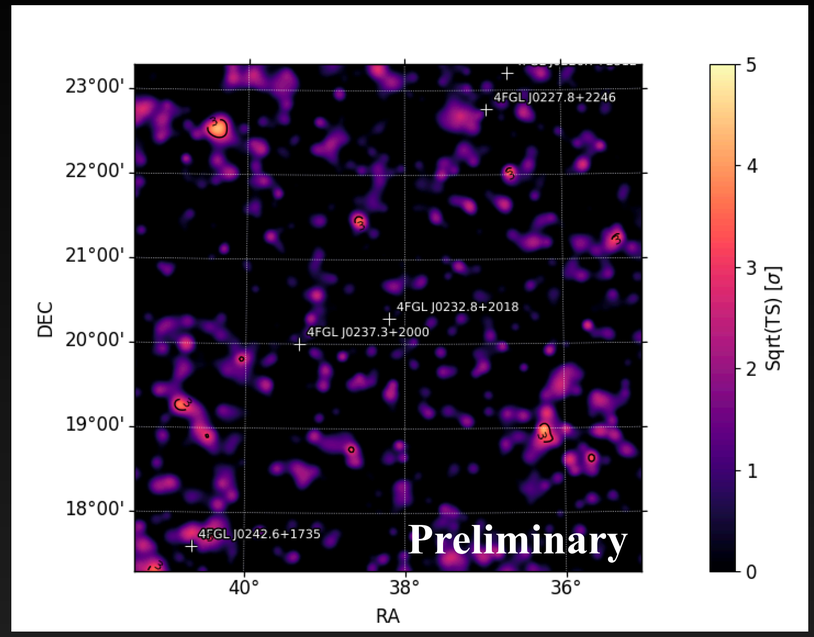

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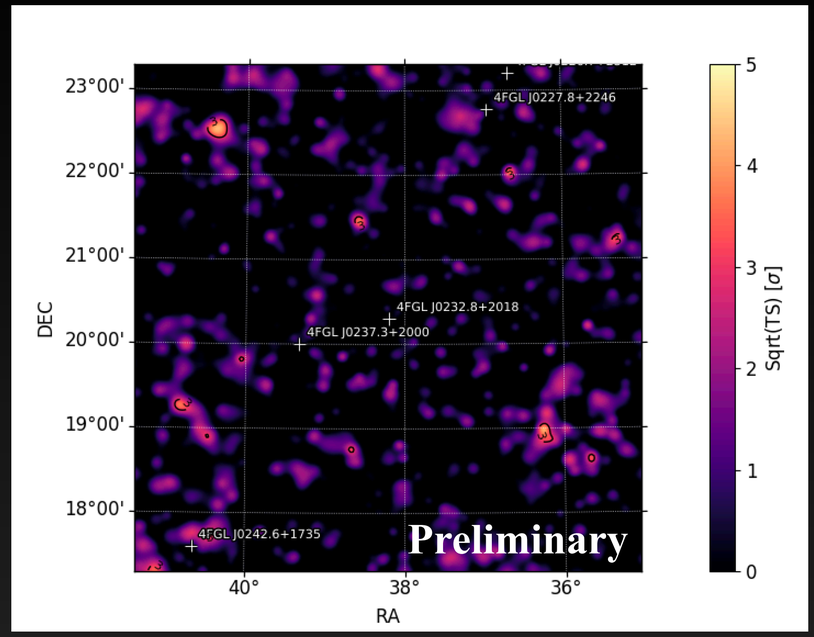

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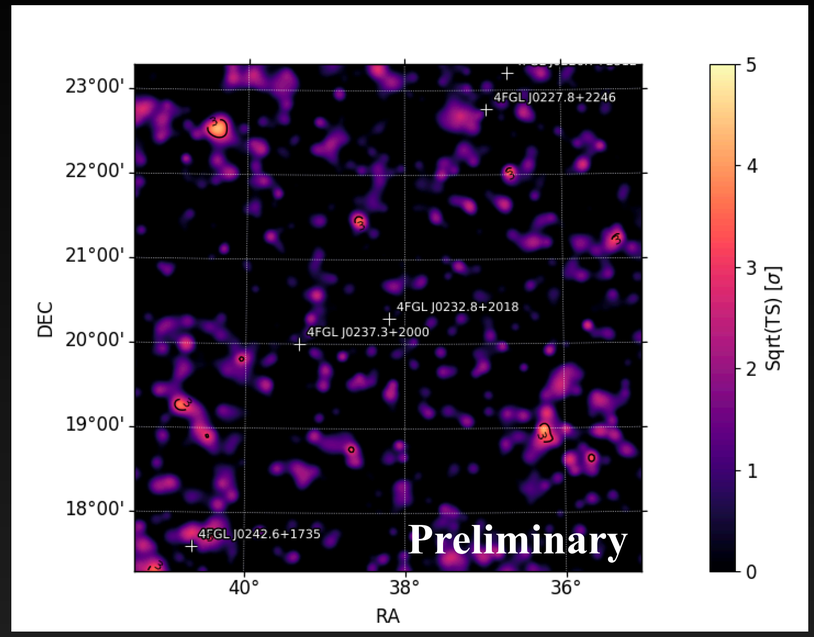

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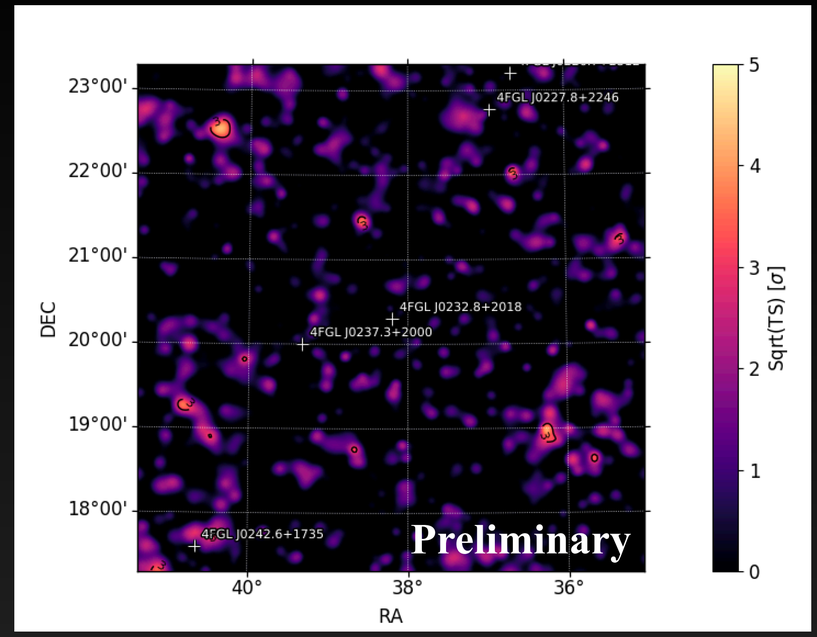

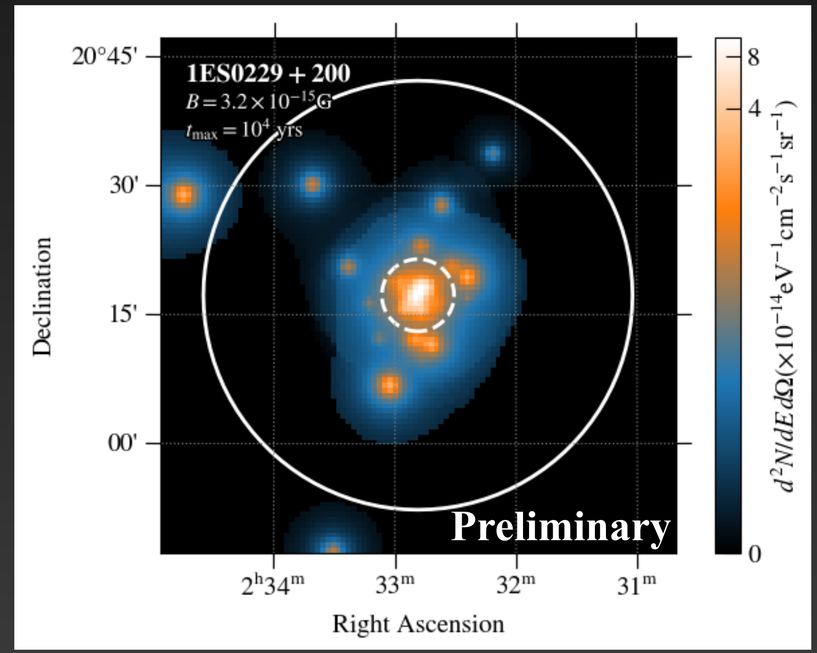

H.E.S.S. Data sets

- Data taken with small telescopes up to 2018 considered here
- Analysis performed using gammapy [Deil et al. 2017]
- Source spectra ϕ_{obs} well described by power law including EBL absorption,
  $\phi_{\mathrm{obs}} = N(E/E_0)^{-\Gamma}\exp(-\tau)$

Preliminary

Source	Life time (hours)	Detection significance	Power law index Γ
1ES 0229+200	144,1	16.5σ	1.76 ± 0.12
1ES 0347-121	59,2	16.1σ	2.12 ± 0.15
PKS 0548-322	53,9	10.2σ	1.92 ± 0.12
1ES 1101-232	71,9	18.7σ	1.66 ± 0.09
H 2356-309	150,5	23.4σ	2.10 ± 0.09

H.E.S.S.

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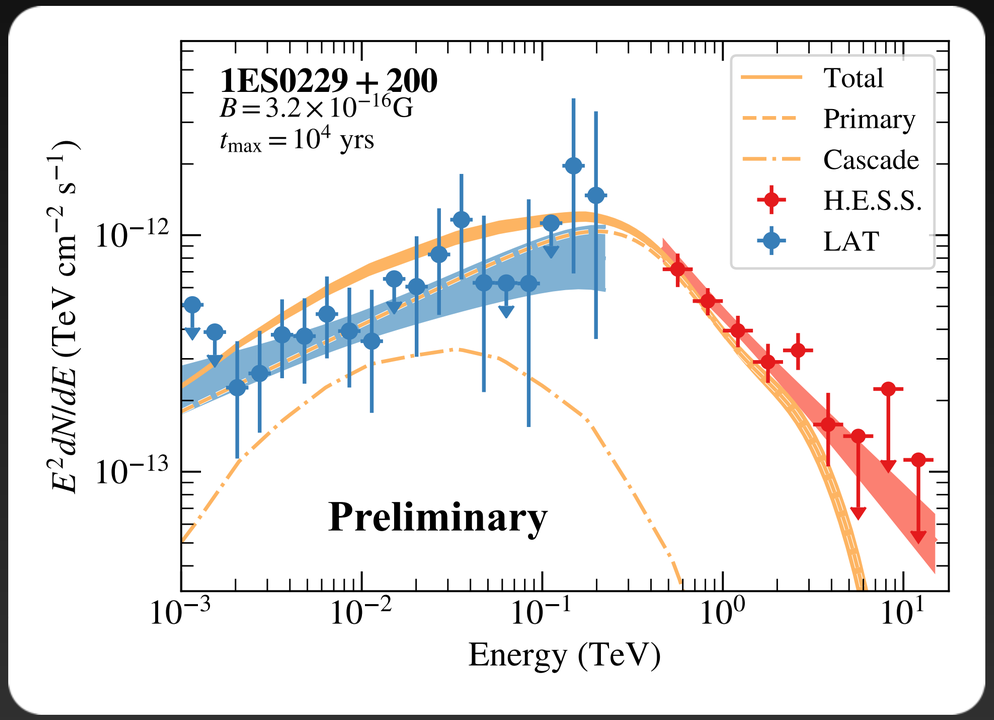

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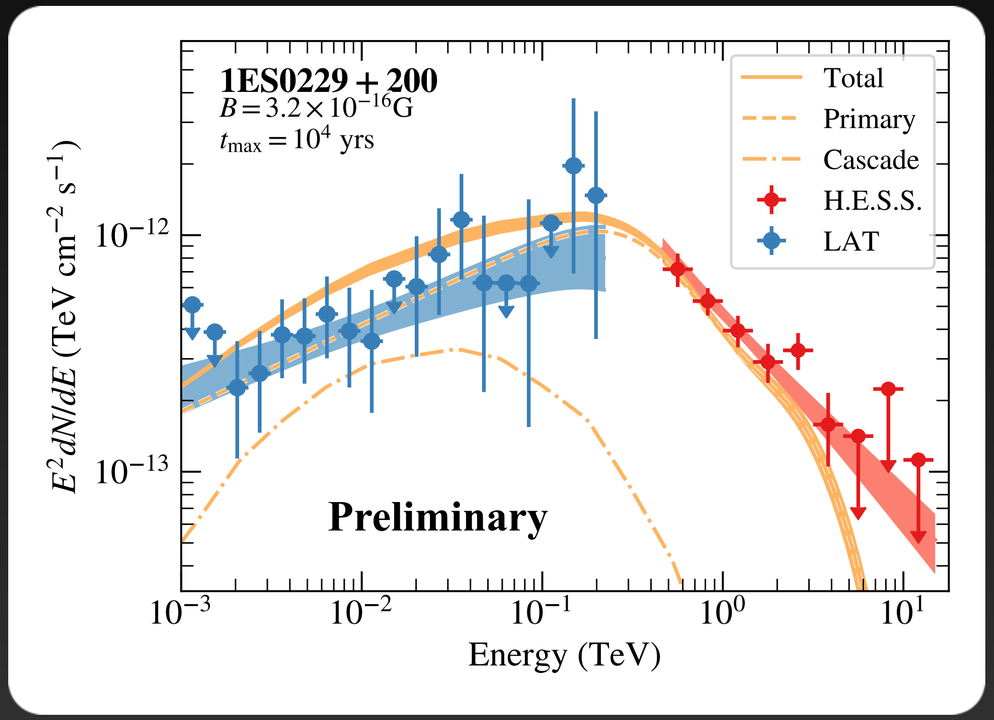

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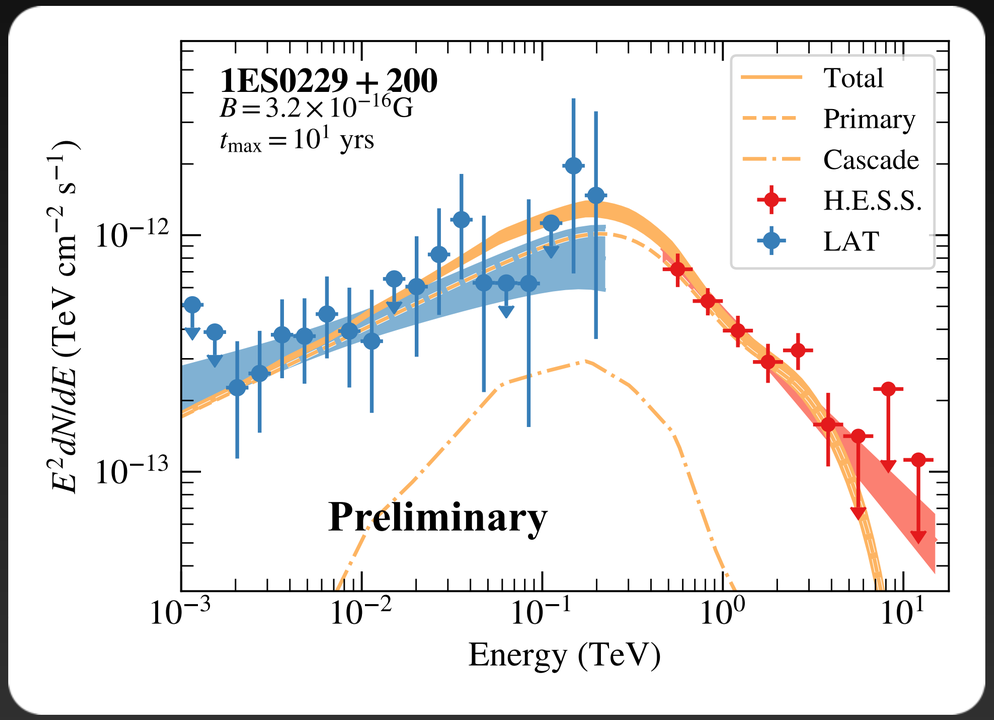

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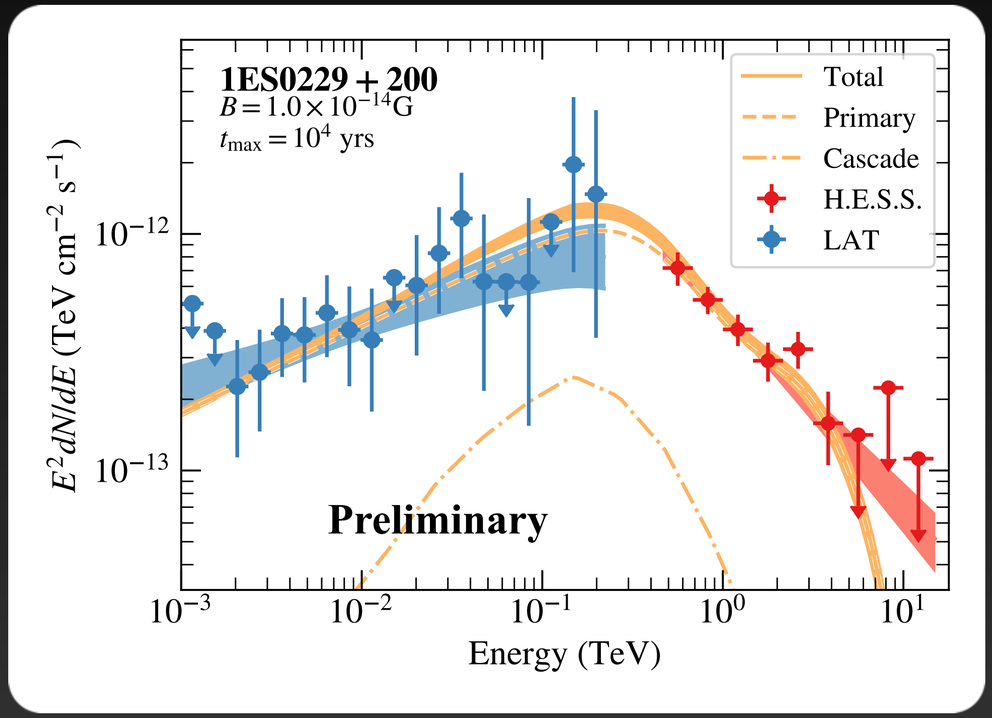
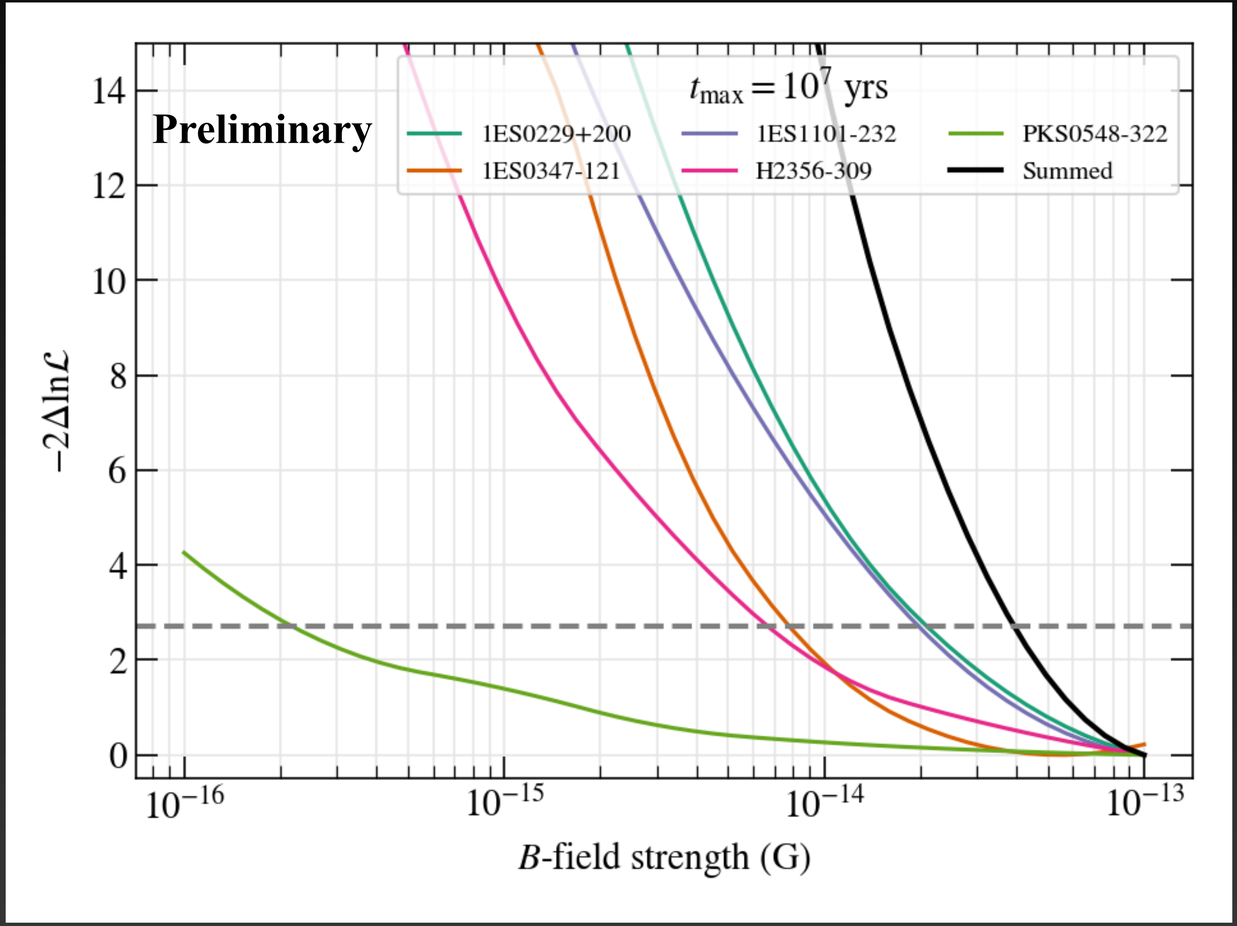


Results: lower limits on IGMF

Data does not prefer presence of halo



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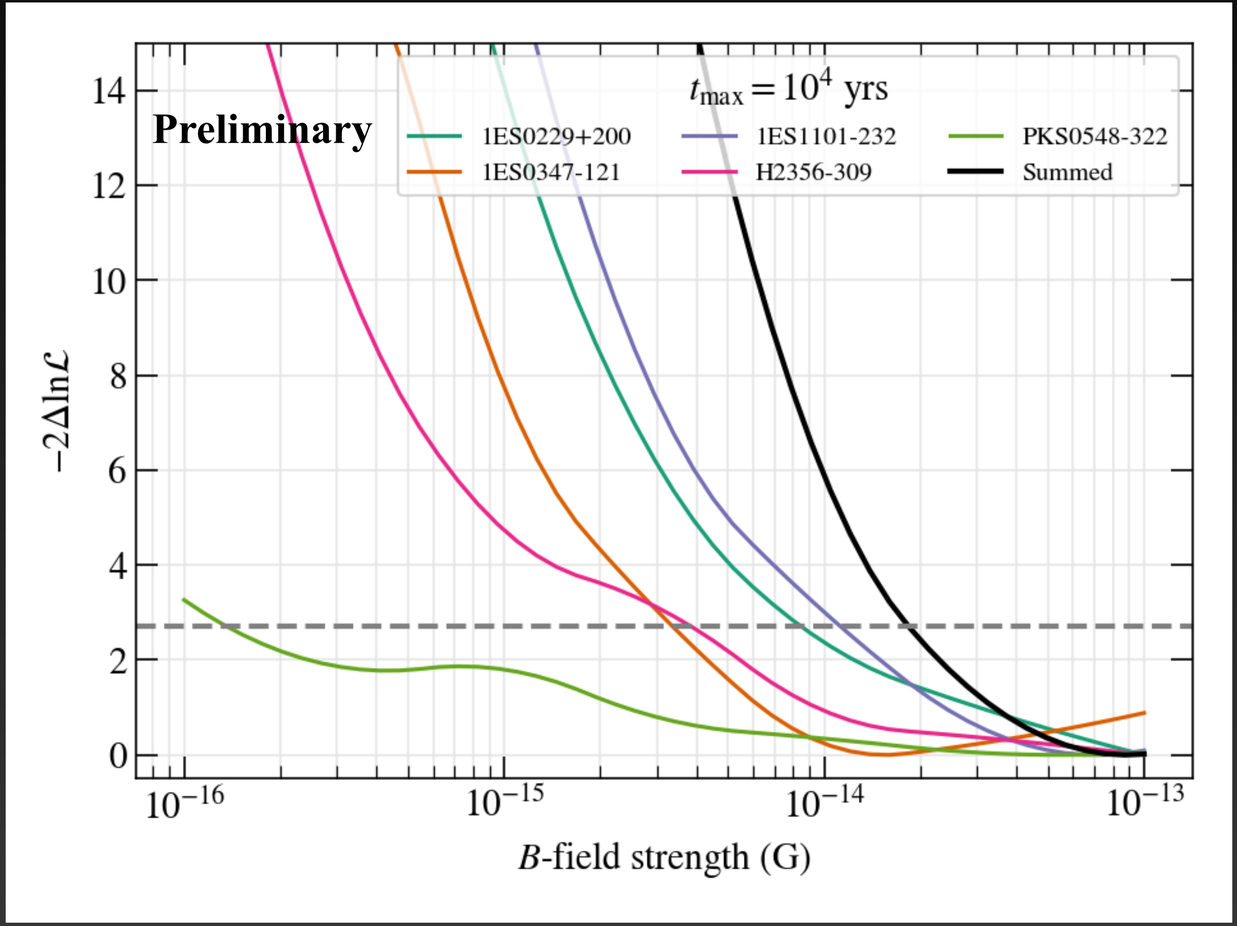

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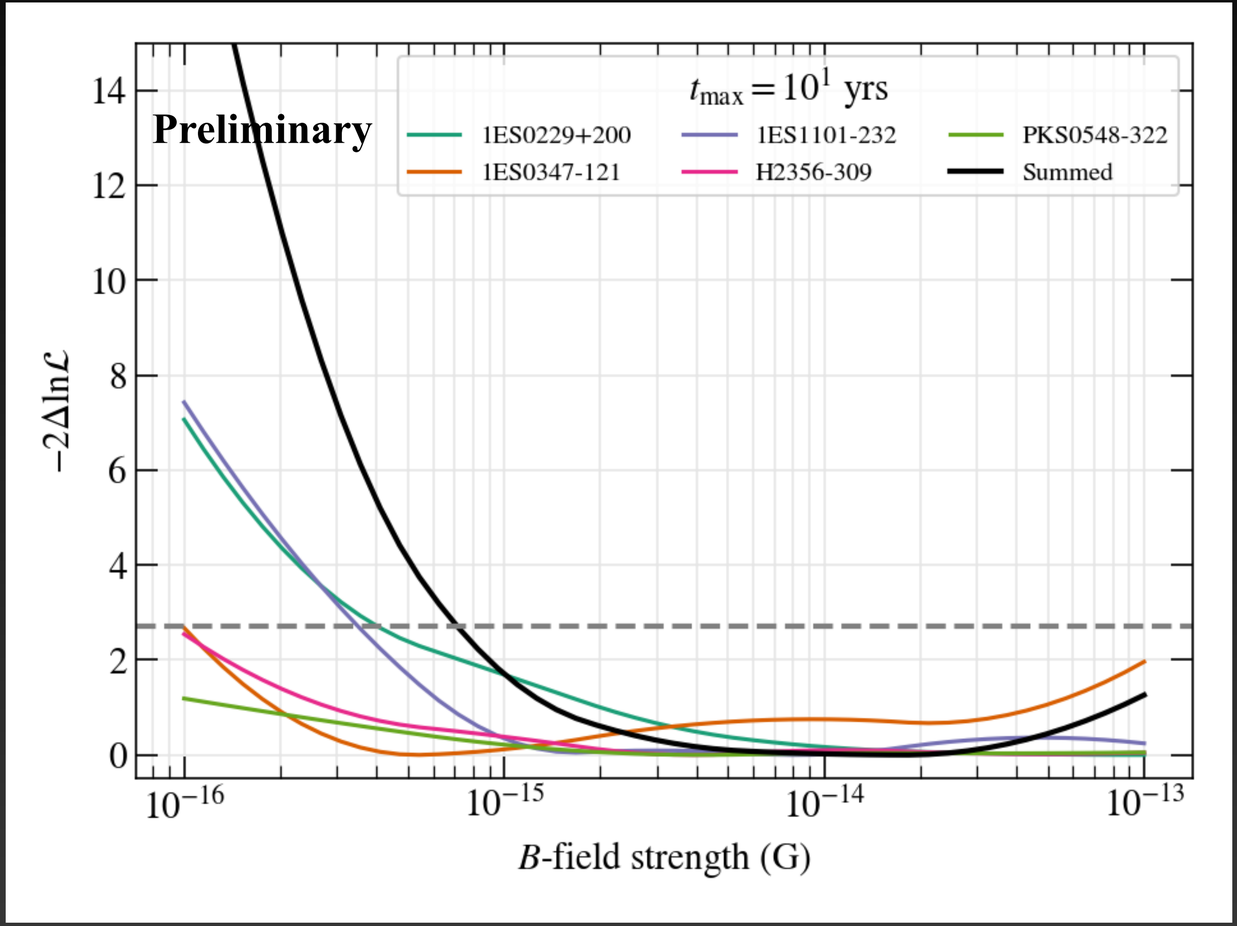

Conclusions

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- No halo detected in combined LAT and H.E.S.S. data
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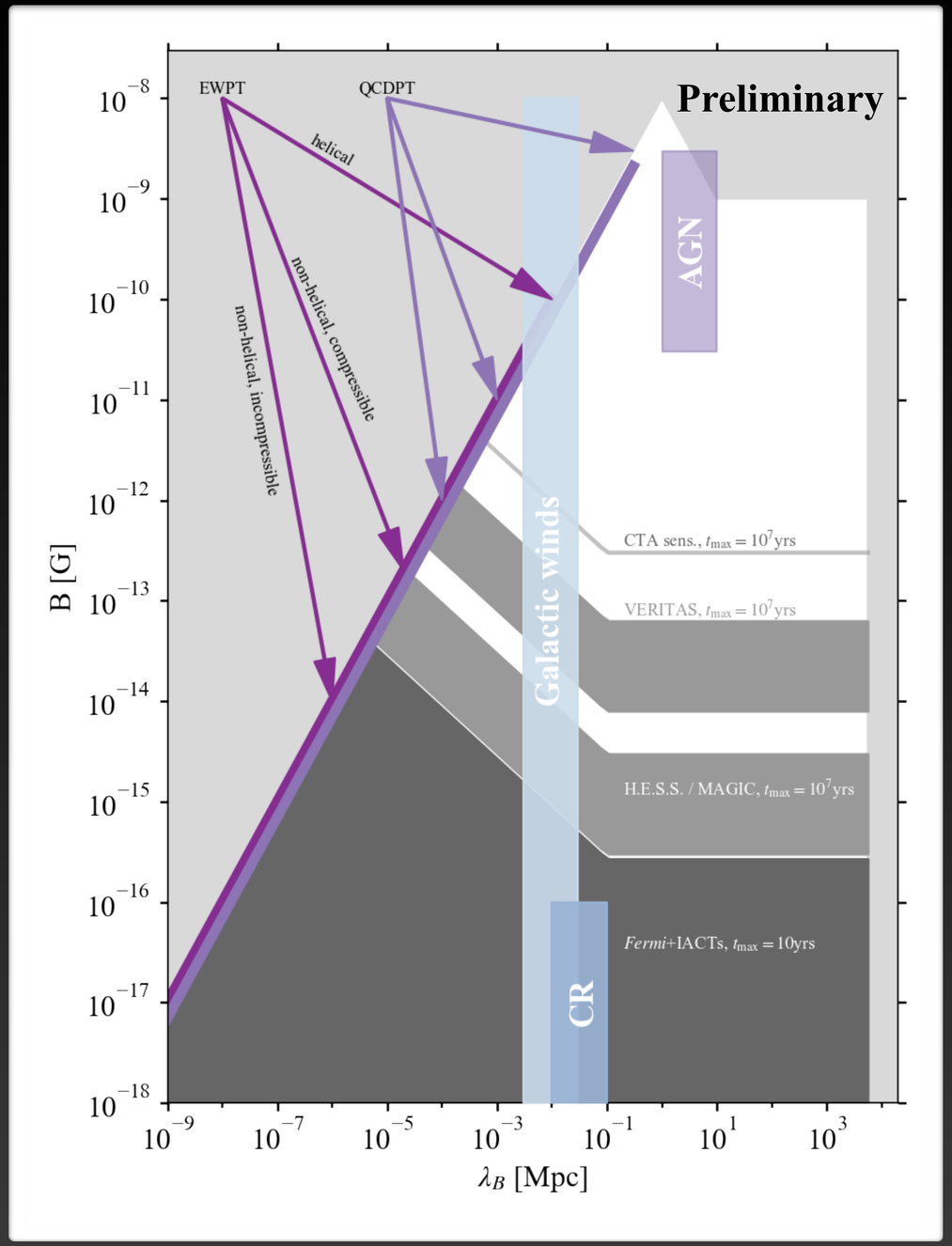

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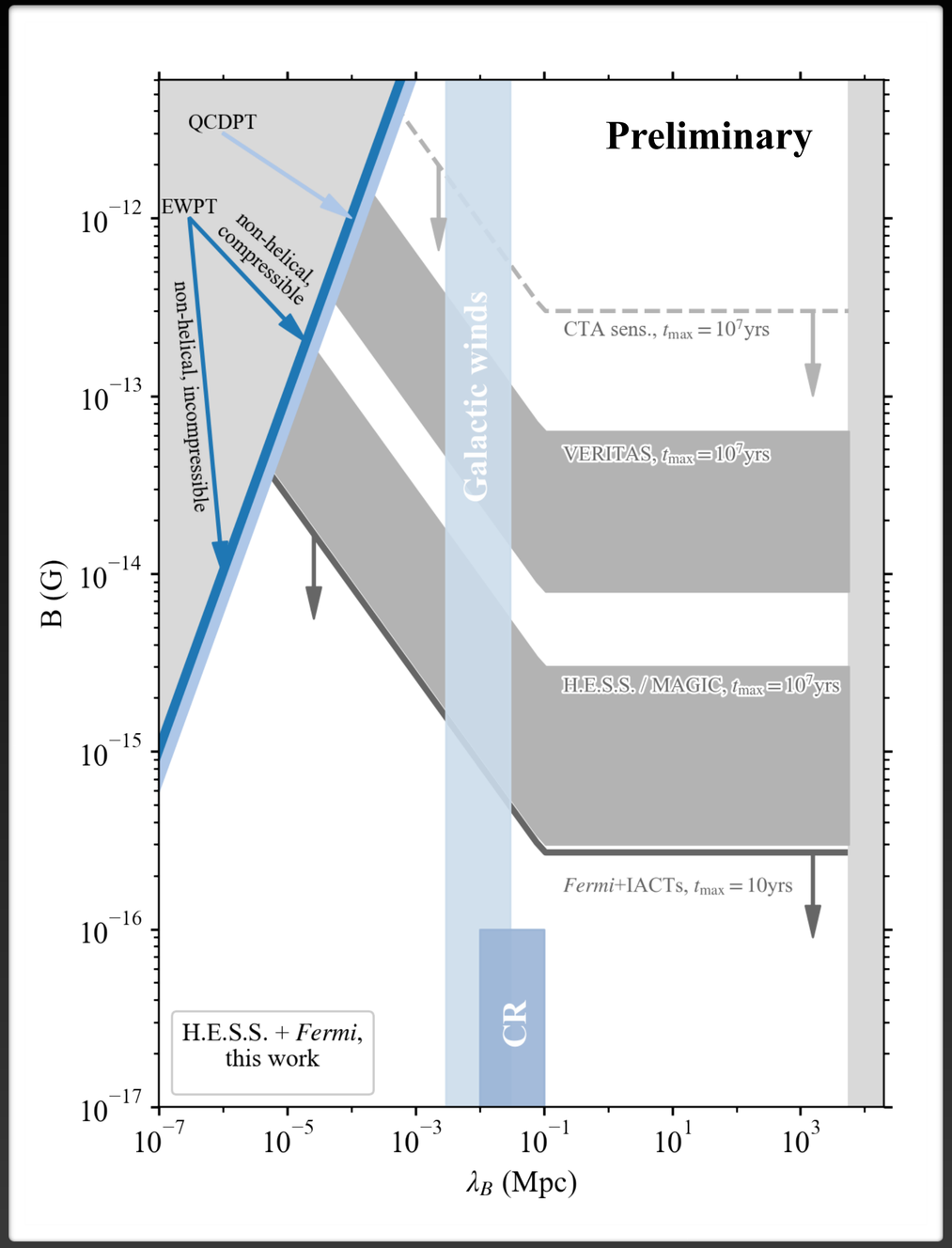

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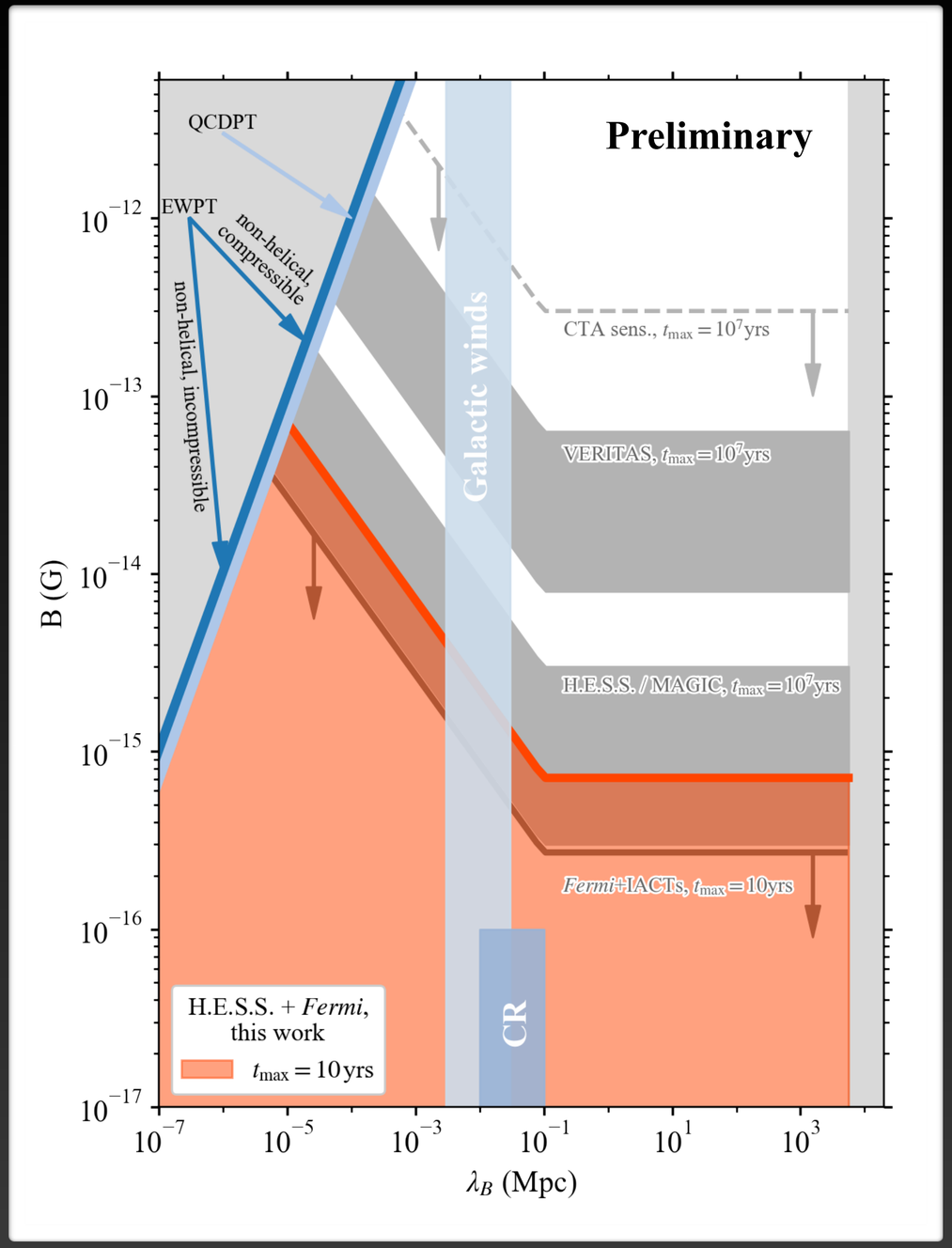

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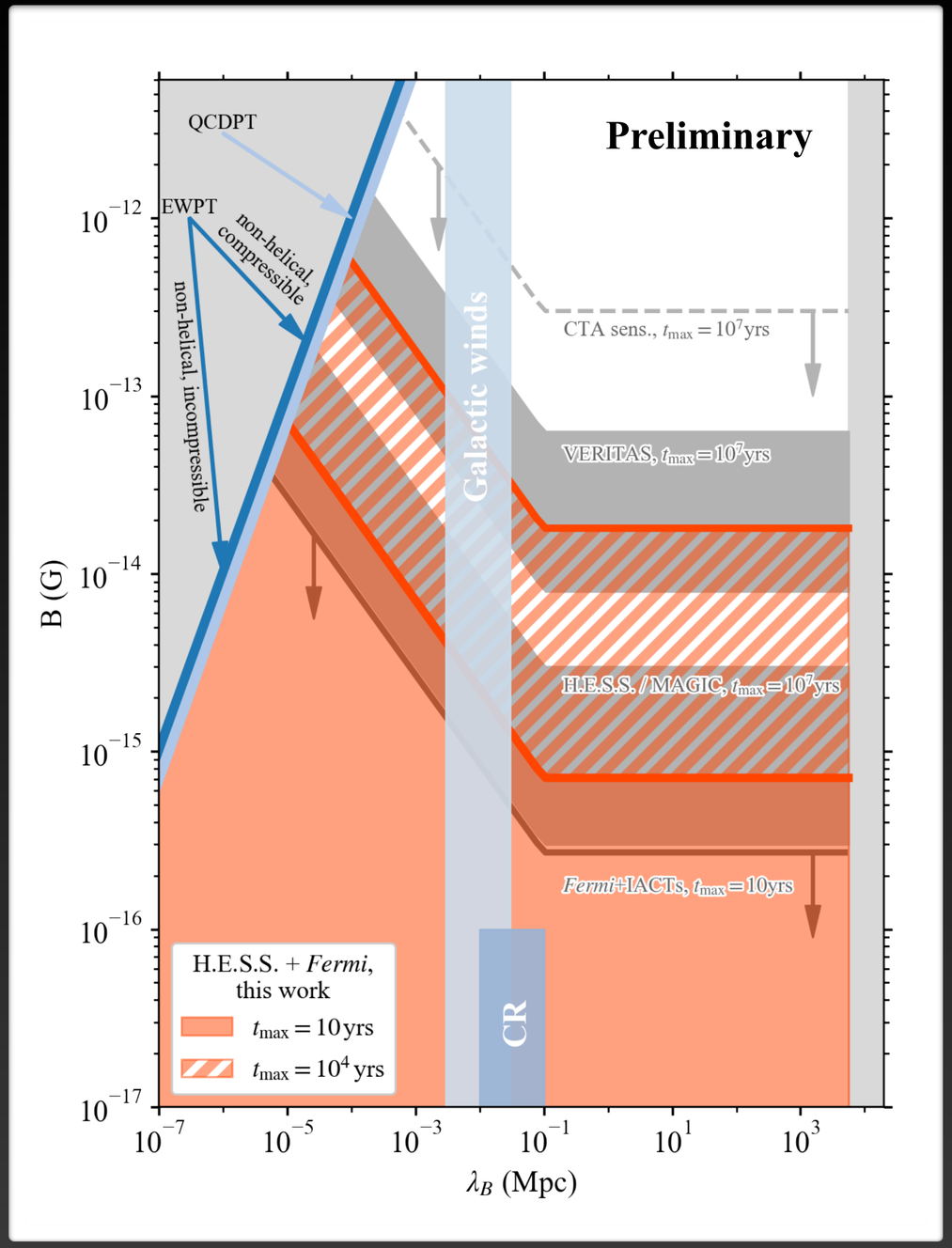

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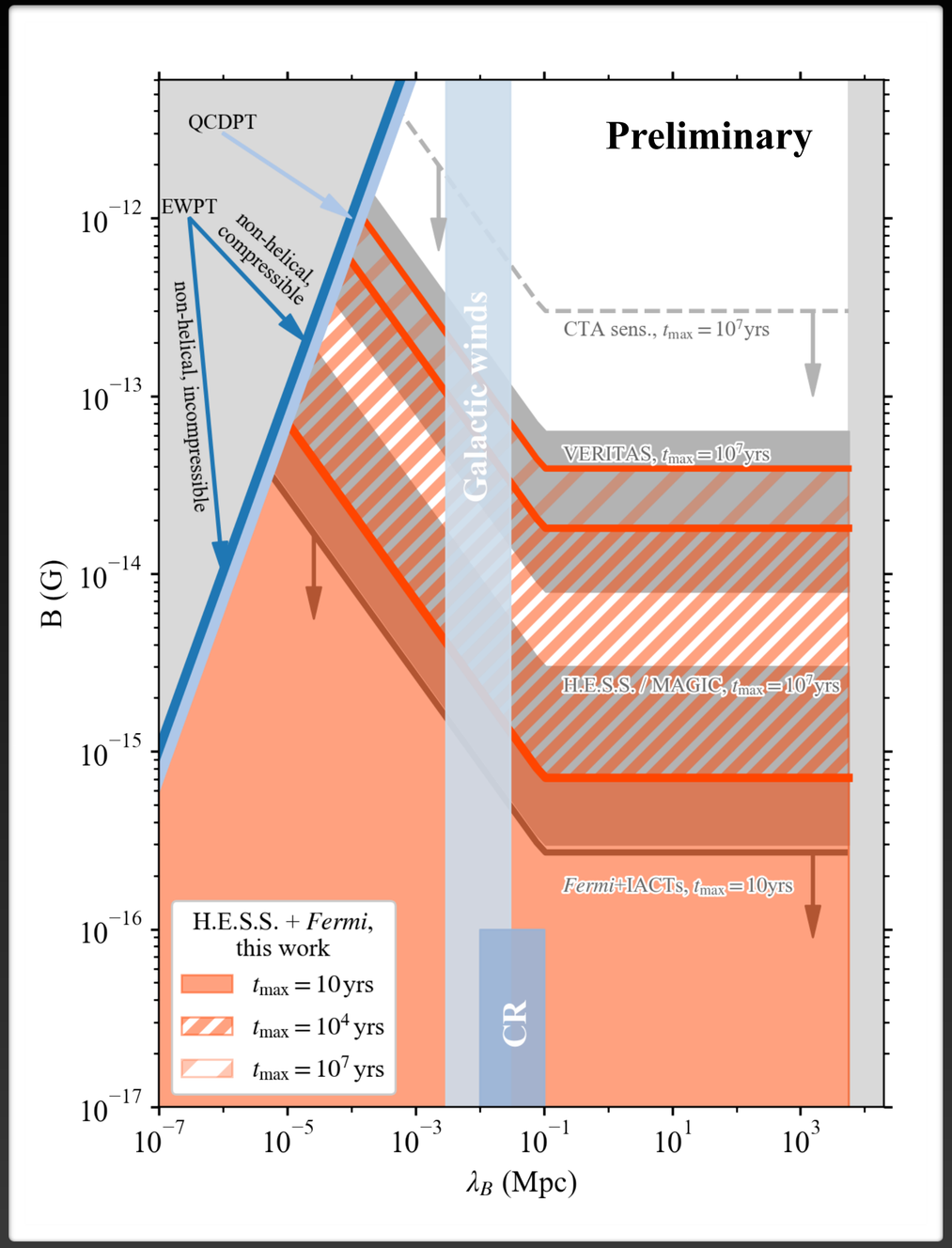

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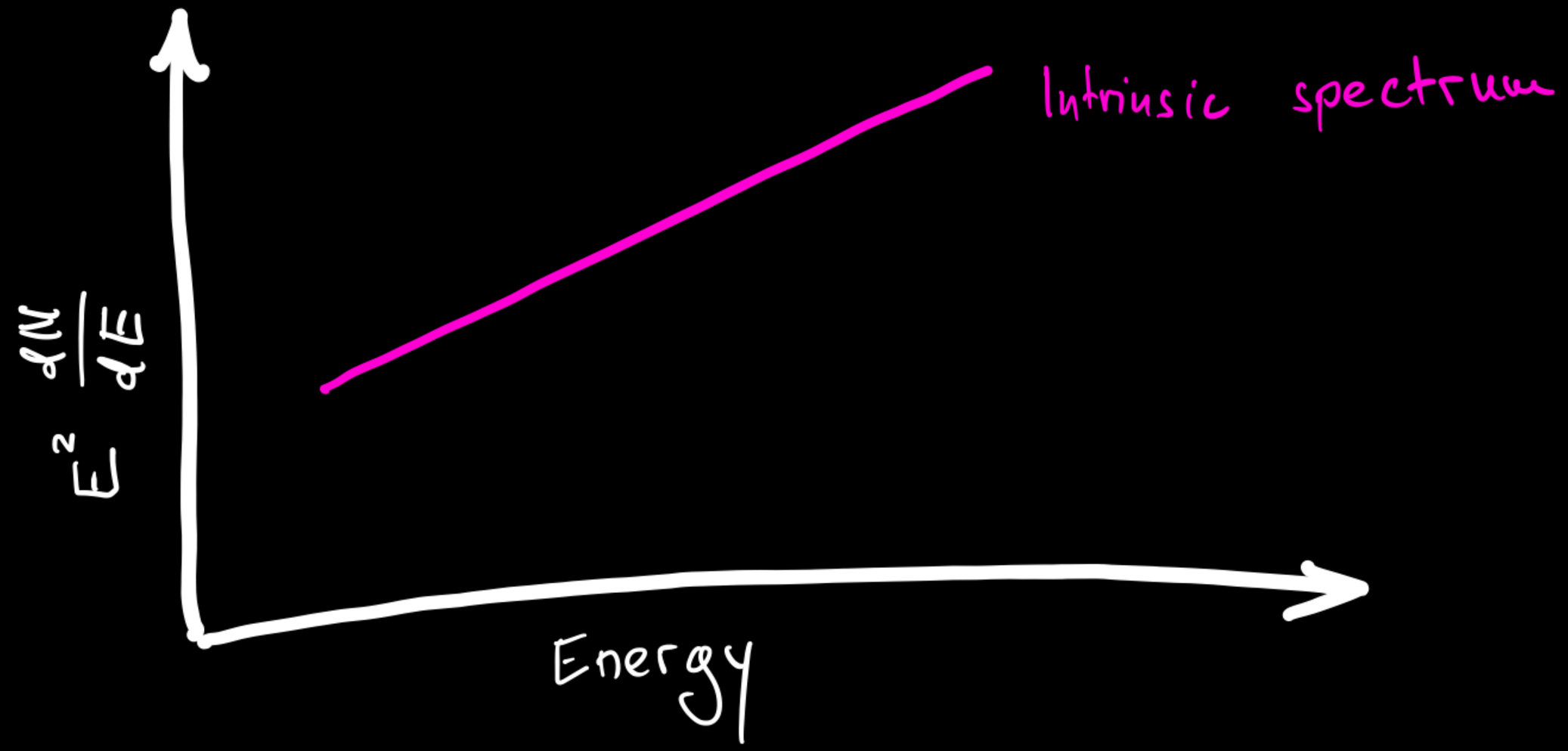
Back up

Basic idea



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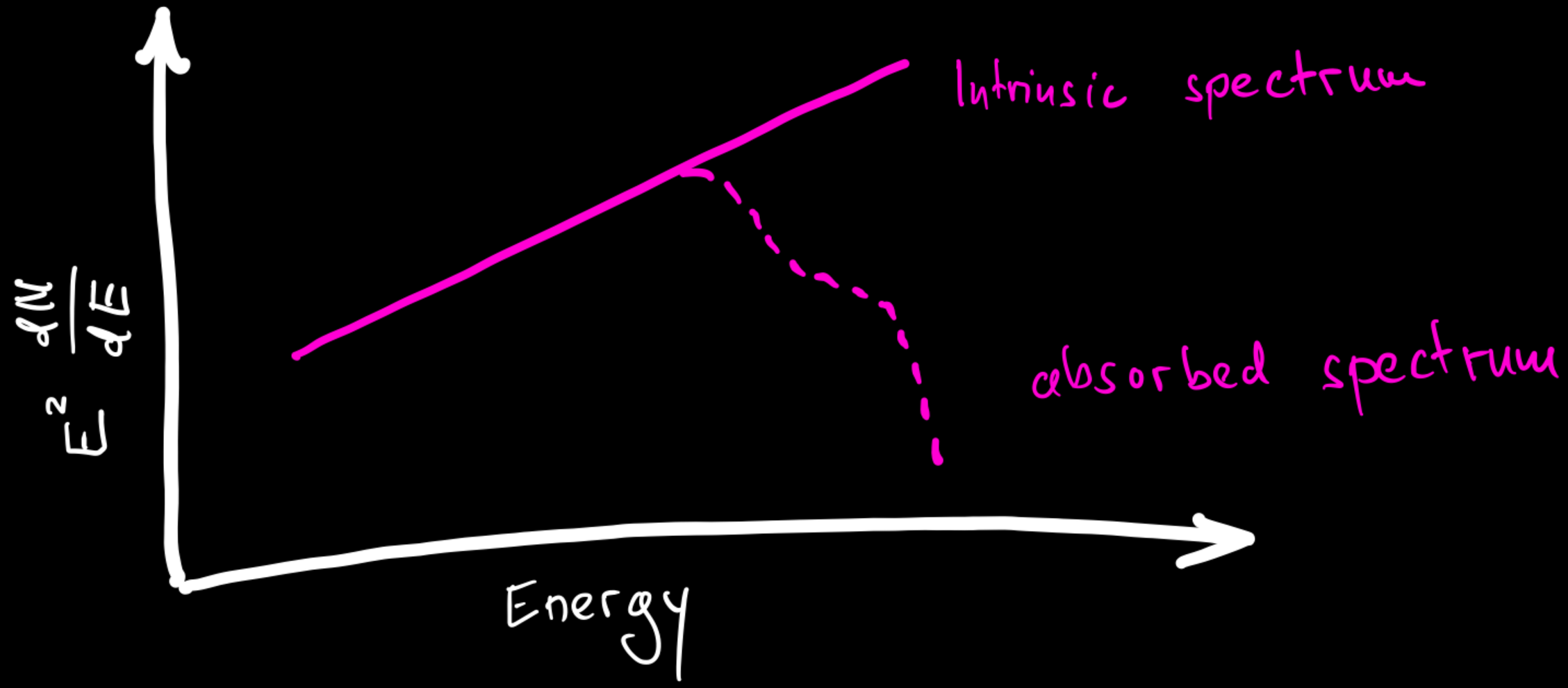

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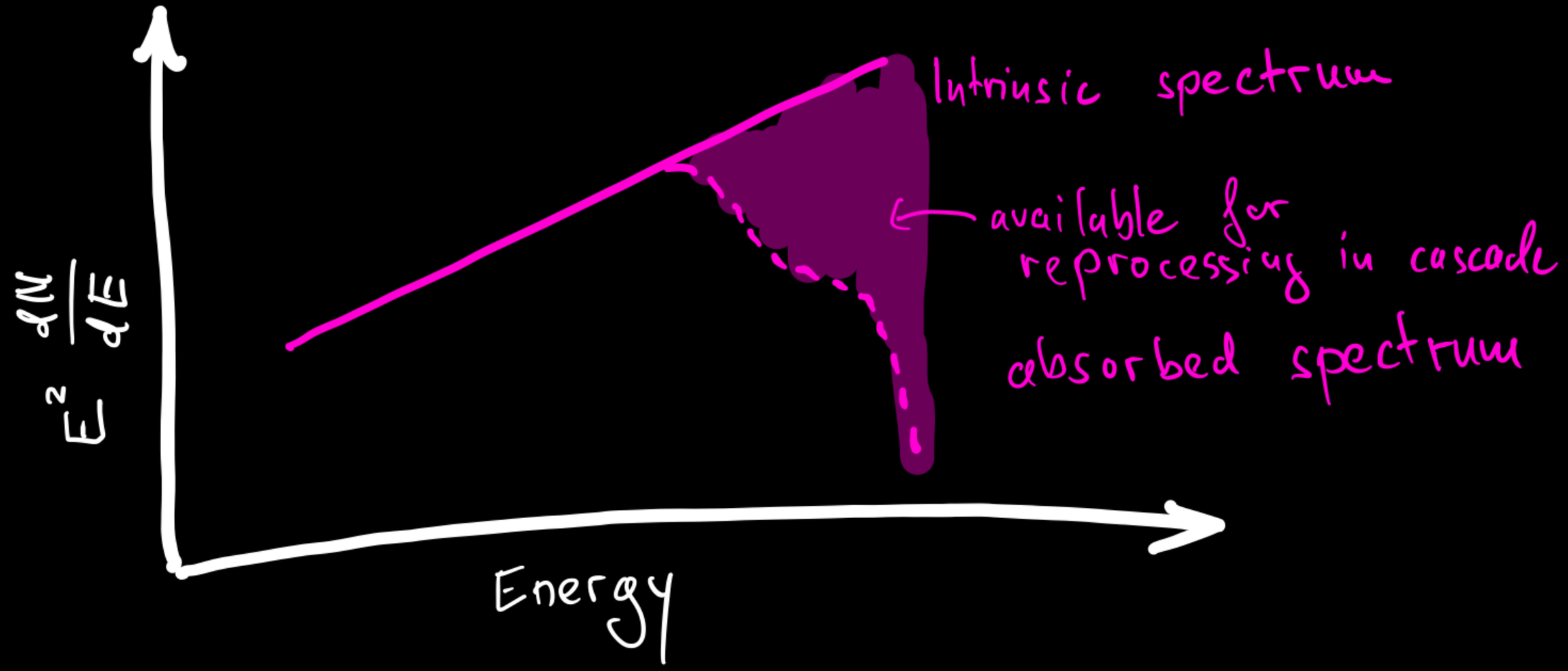
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Energy
Intrinsic spectrum
available for reprocessing in cascade
absorbed spectrum

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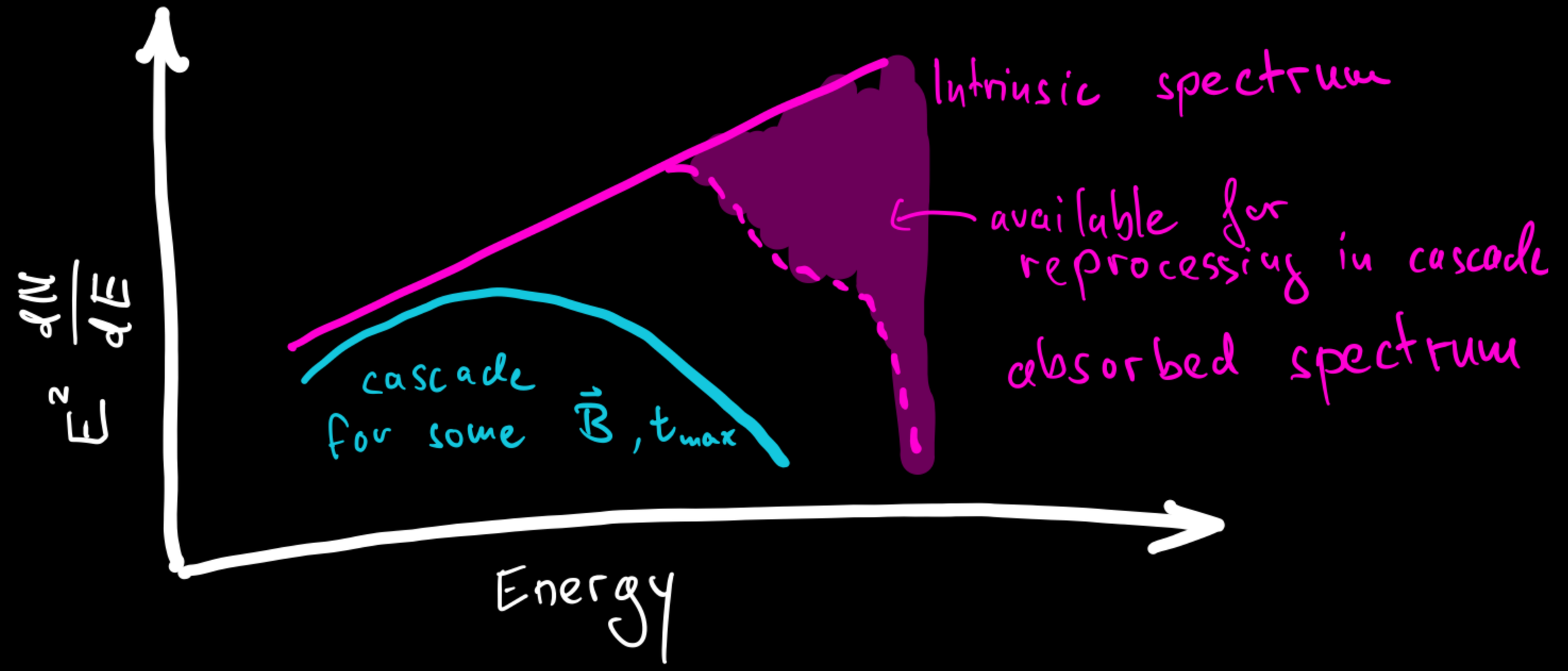
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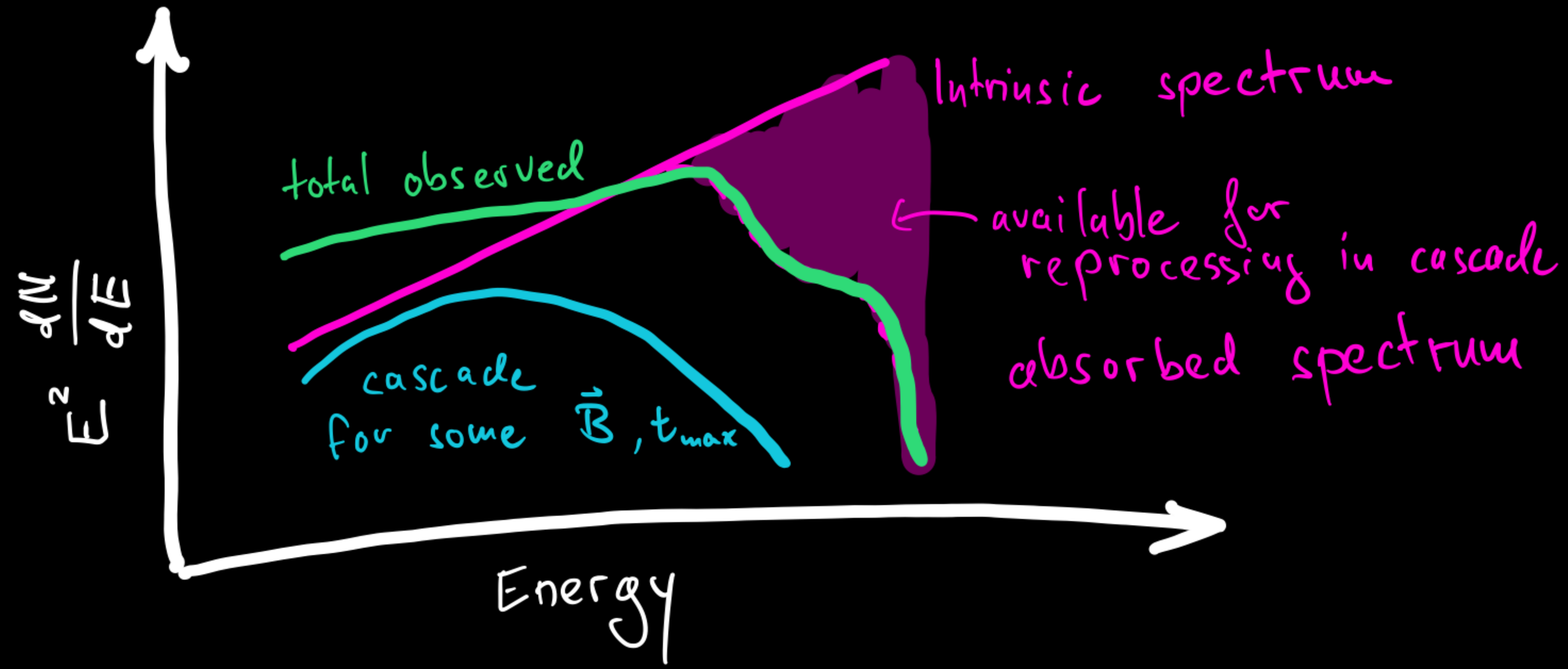
$E^2 \frac{dN}{dE}$
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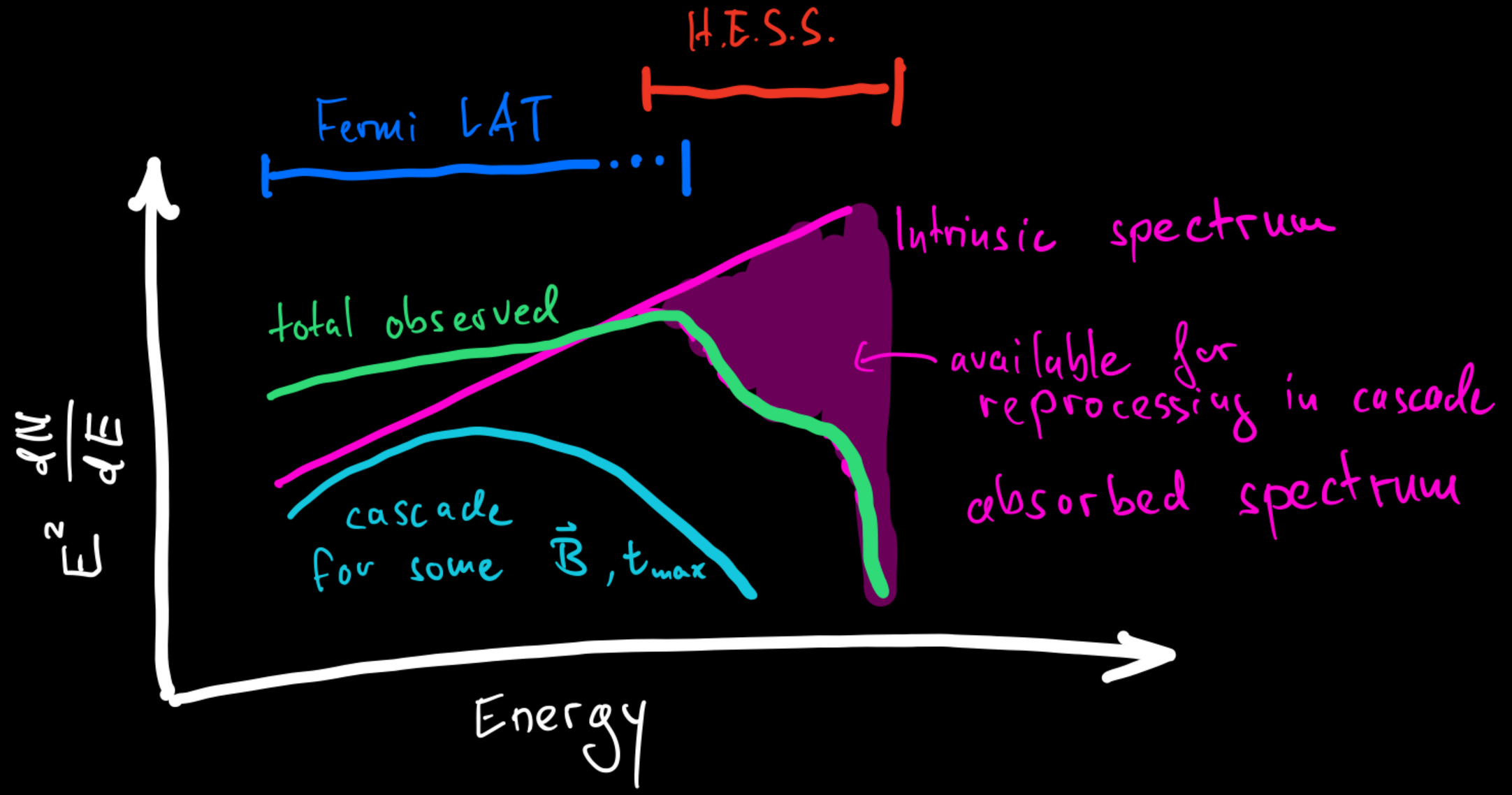
H.E.S.S.
Fermi LAT
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total observed
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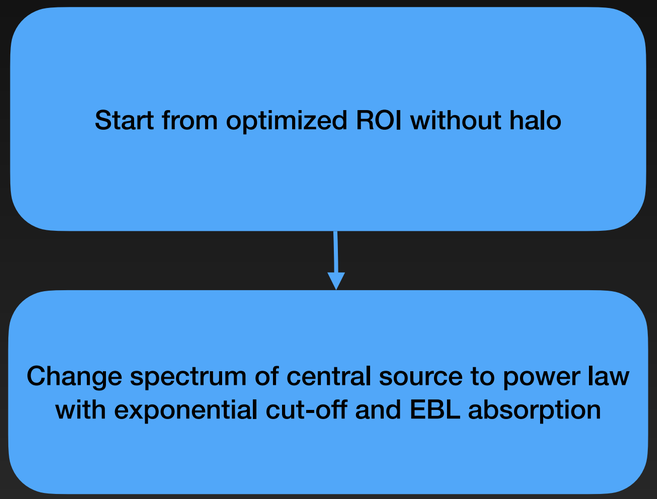
Energy

Fermi-LAT analysis with halo component

Start from optimized ROI without halo

Fermi-LAT analysis with halo component



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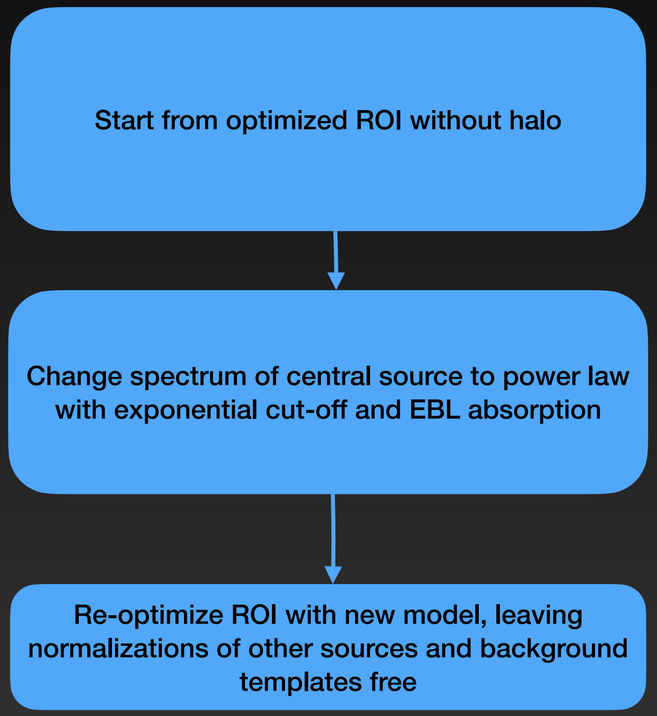

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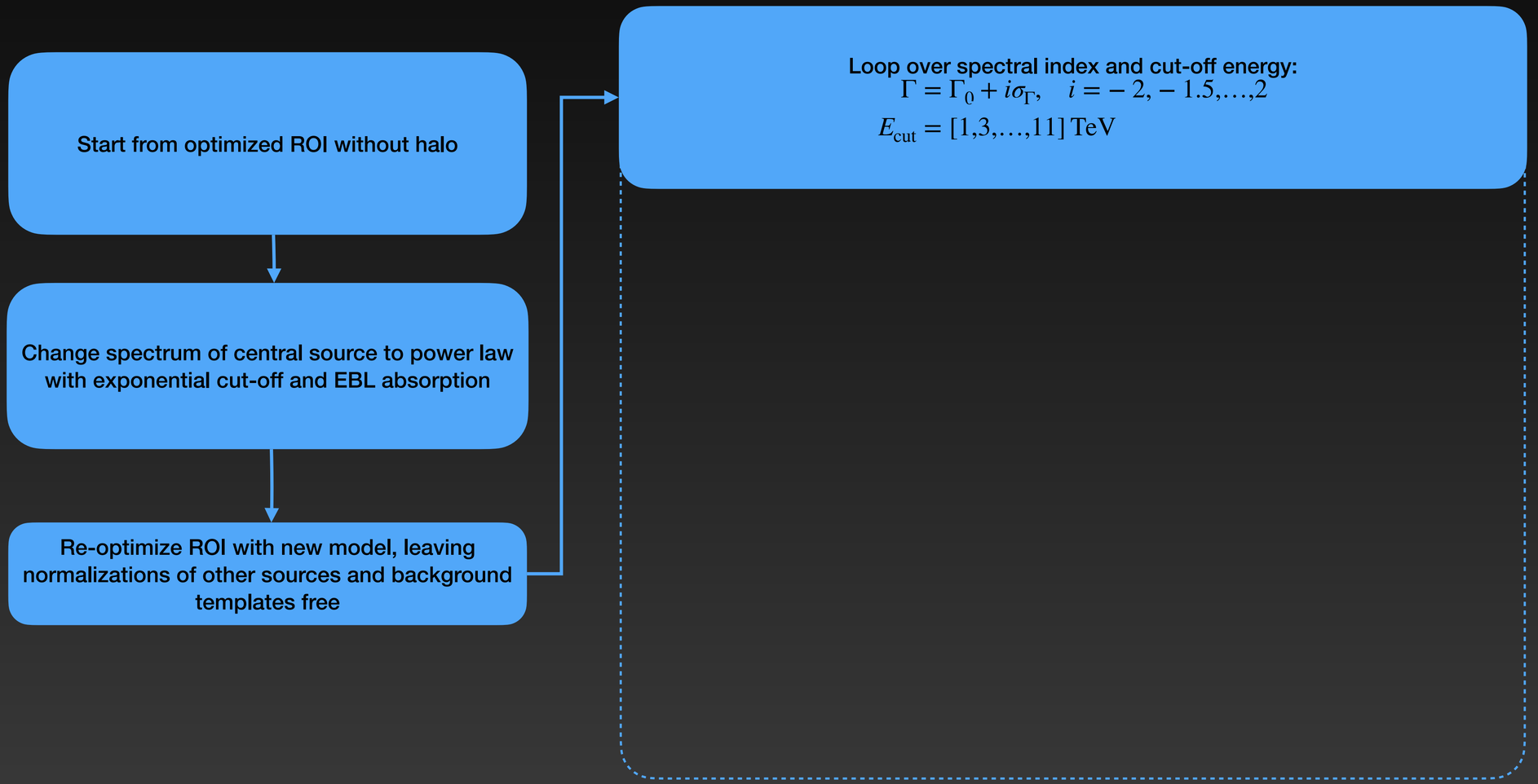

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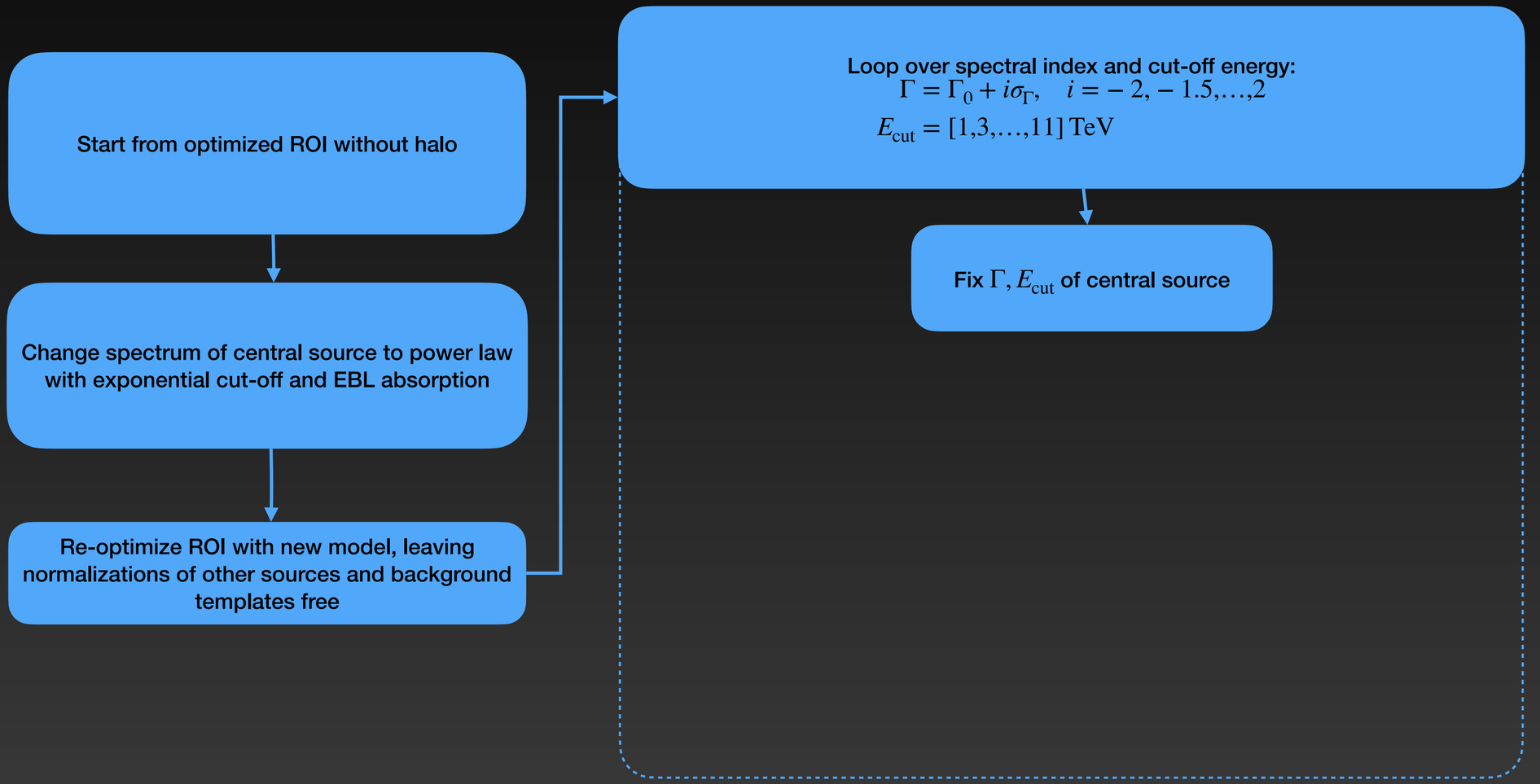

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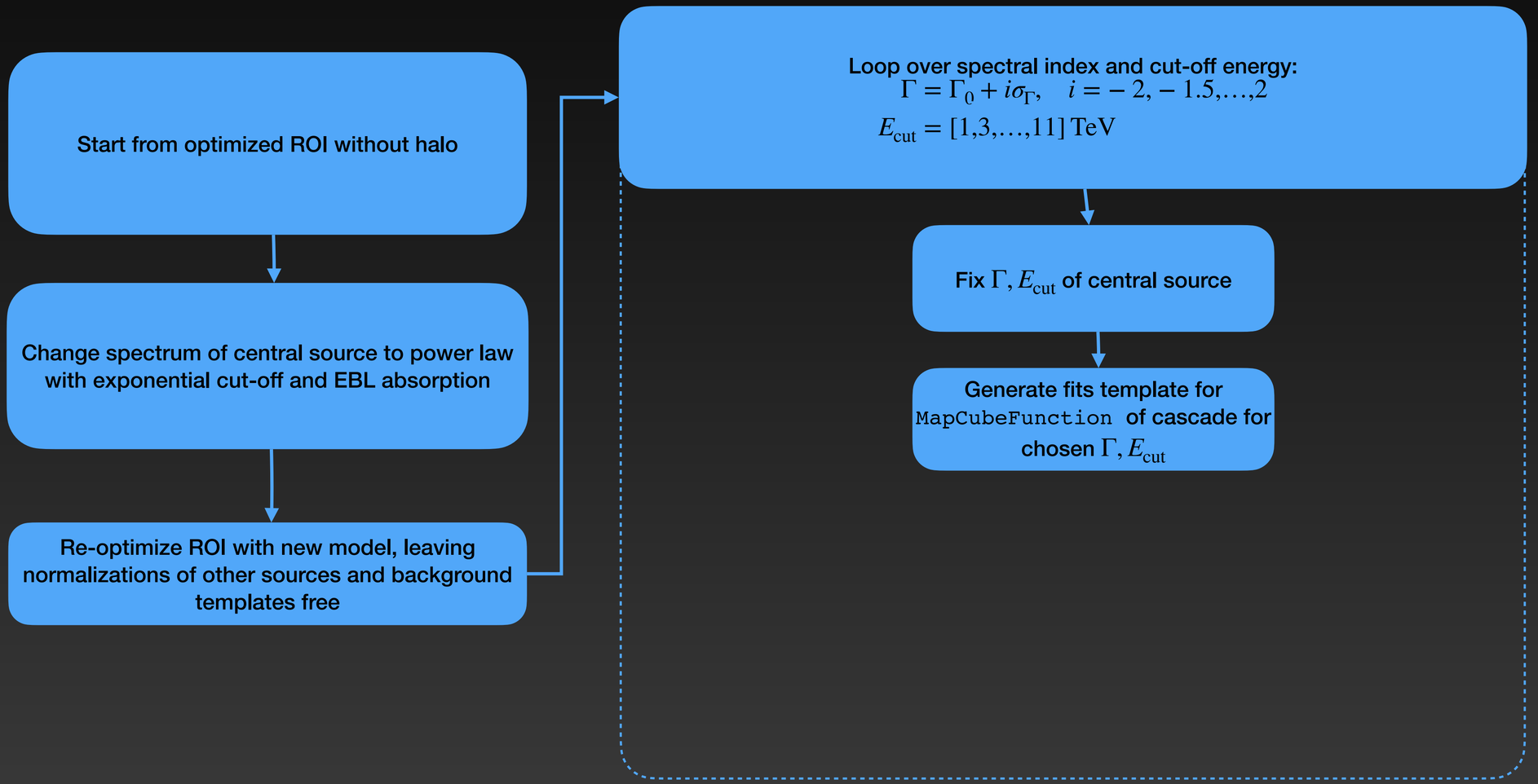

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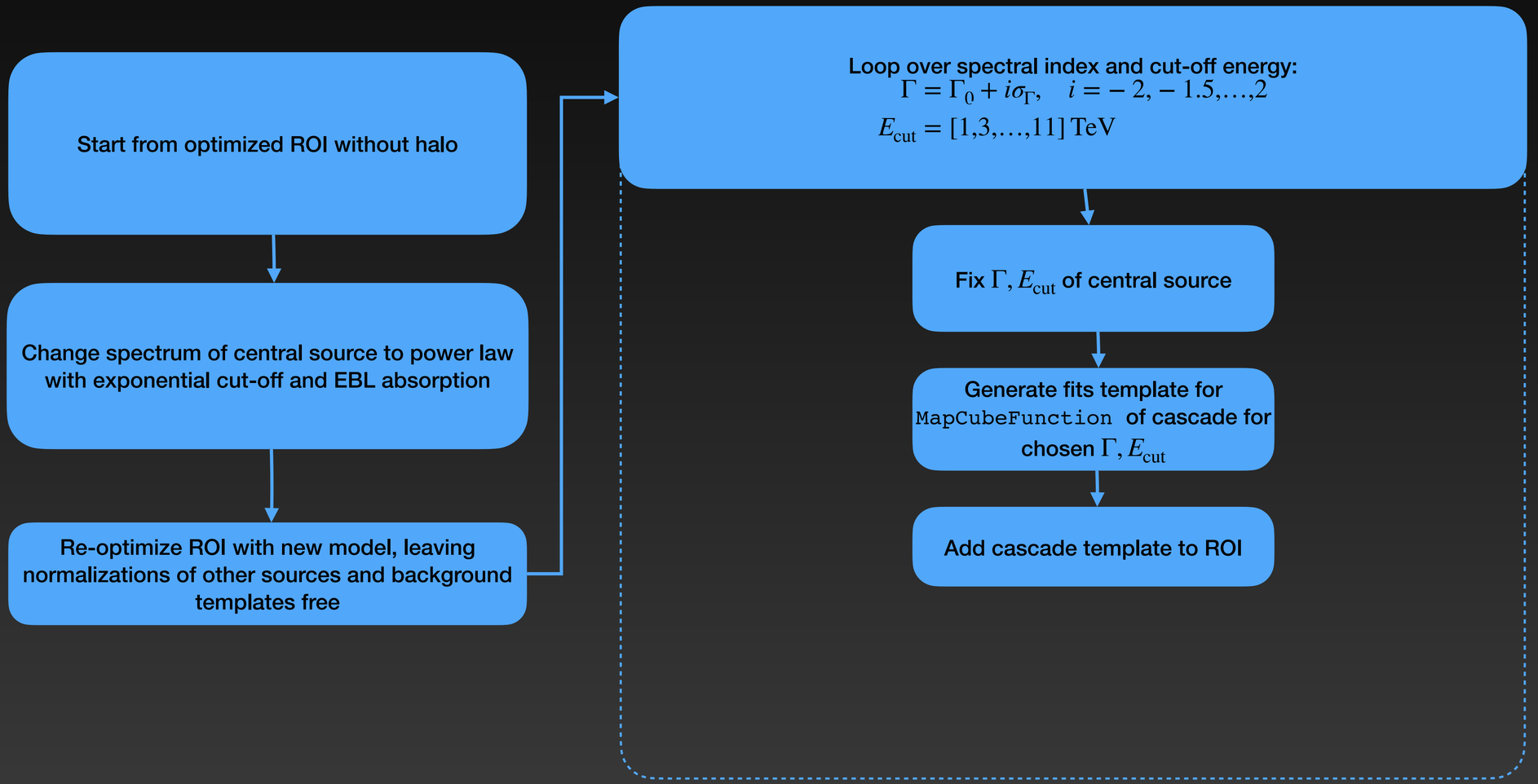

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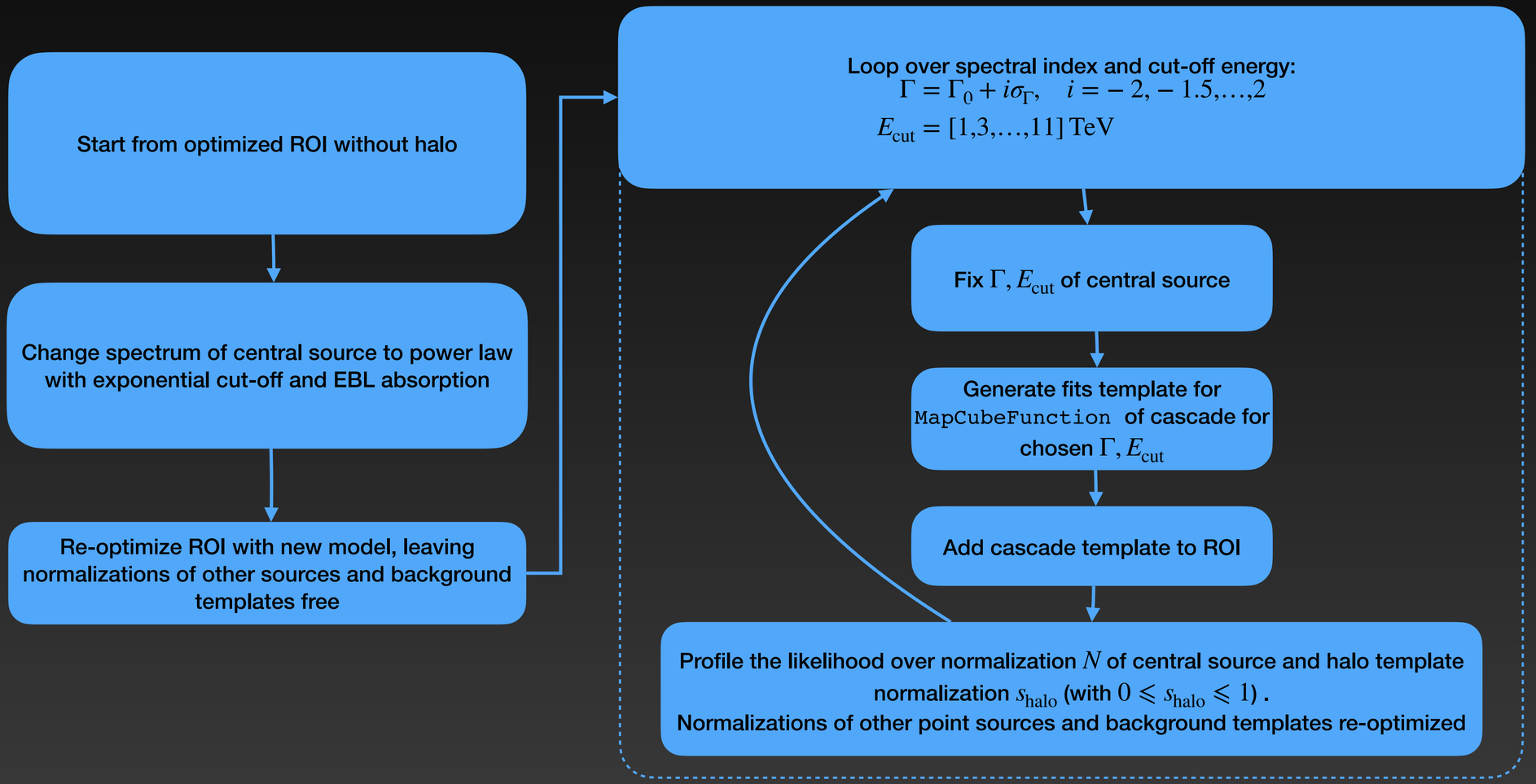

Building cascade templates

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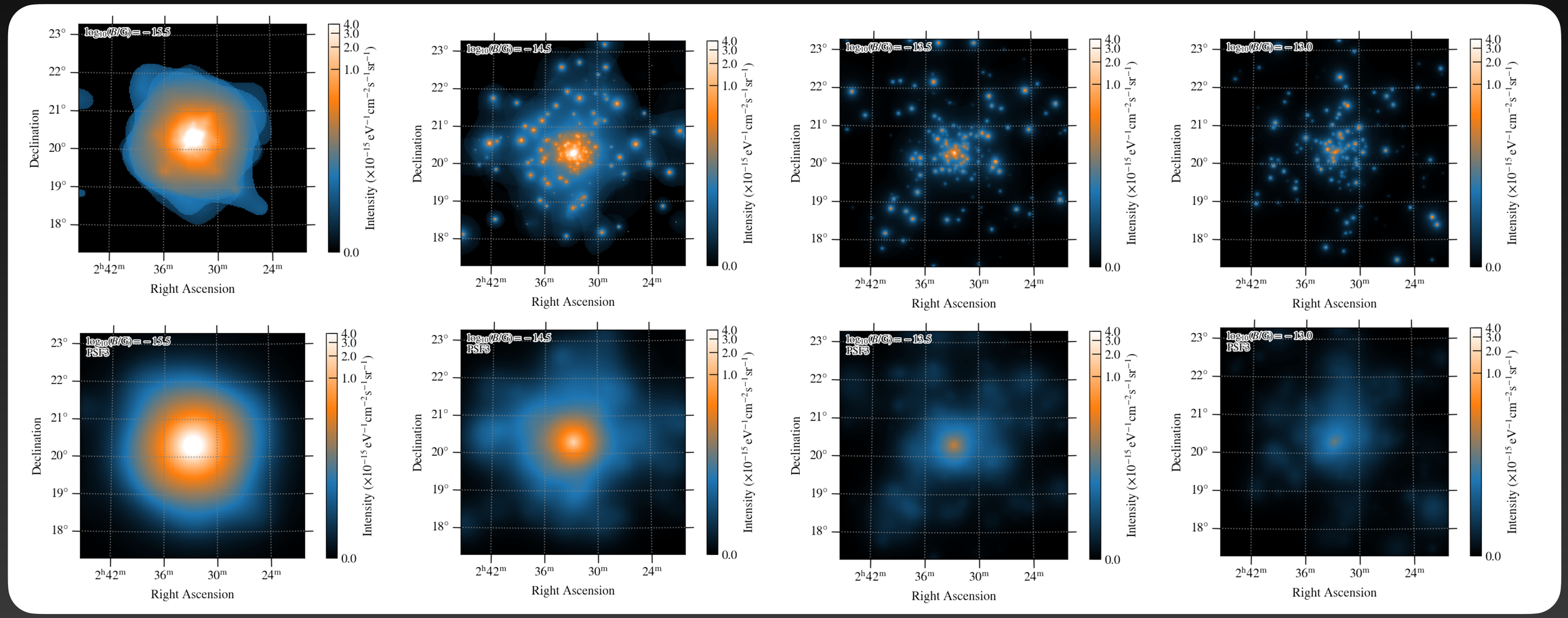
- Cascade flux will depend on IGMF strength B and coherence length λ, injection spectrum, maximum activity time of the source t_{max}, as well as $\theta_{\mathrm{jet}}, \theta_{\mathrm{obs}}$ and source redshift z

Cascade templates as function of IGMF strength: sky maps



Cascade templates as function of IGMF strength: lon/lat profiles

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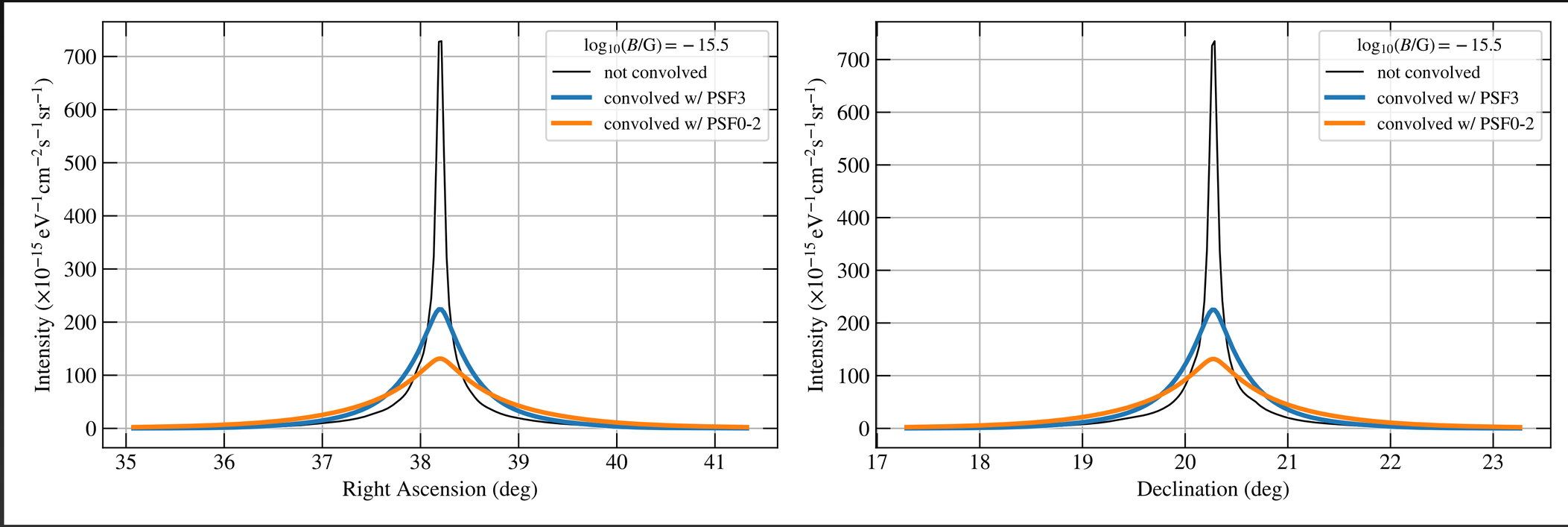
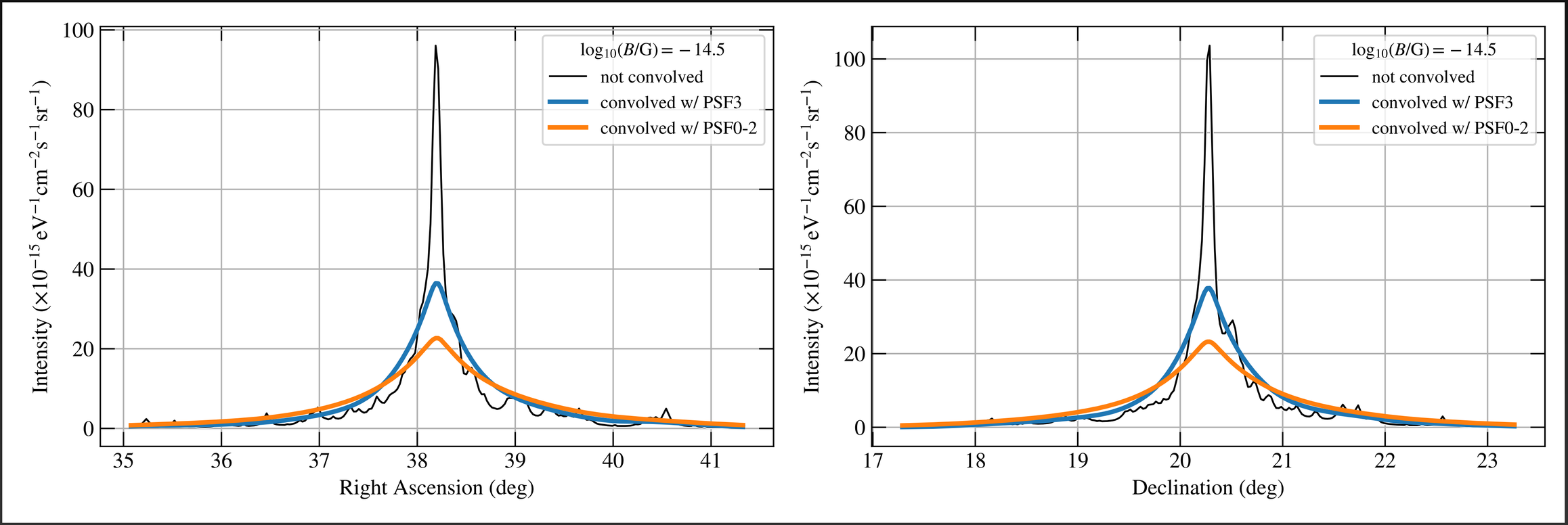


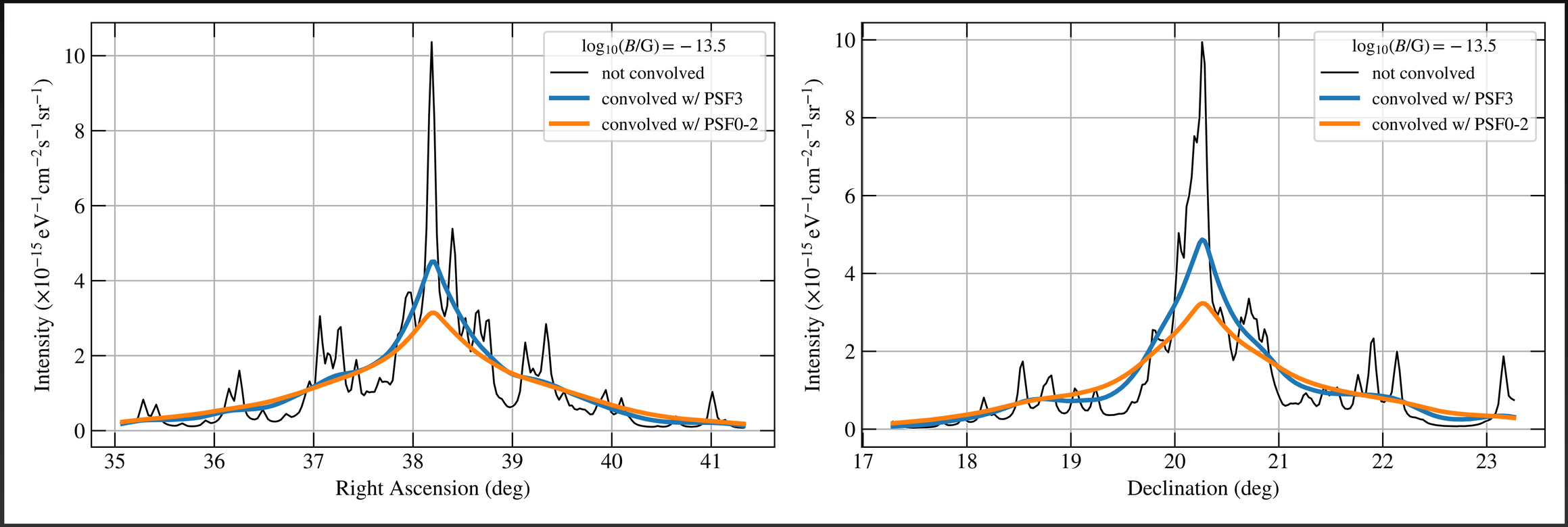
Cascade templates as function of IGMF strength: lon/lat profiles

$B = 3.16 \times 10^{-15}\,\mathrm{G}$, sky map summed over lon/lat and energy



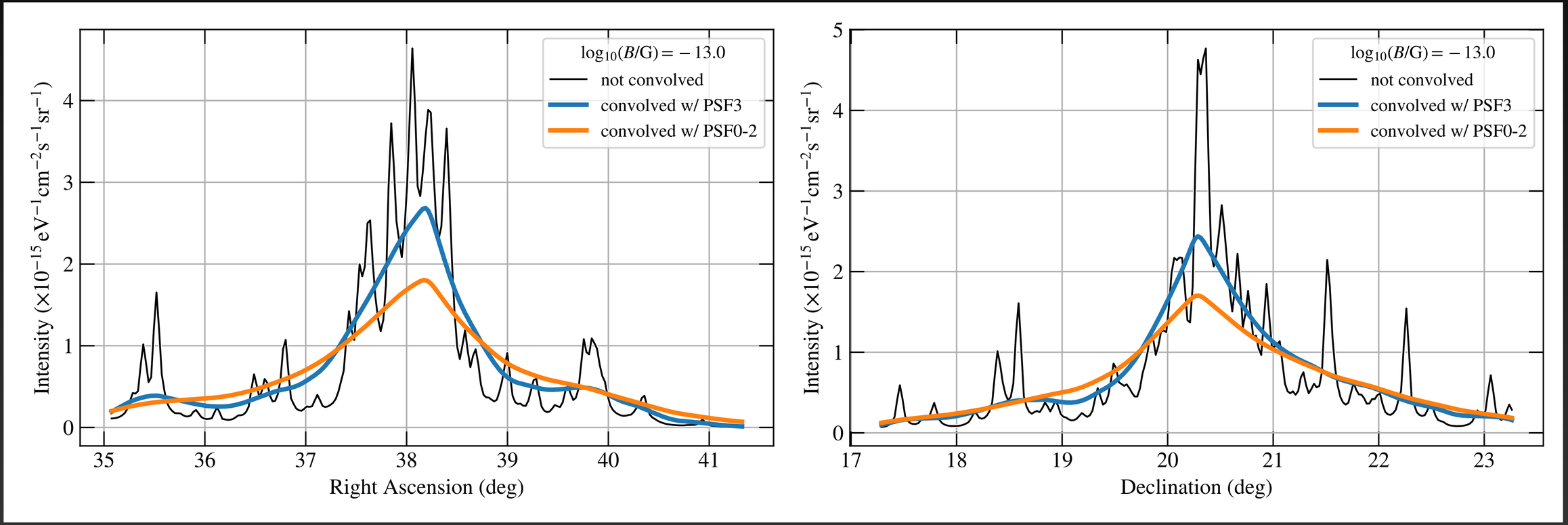
Cascade templates as function of IGMF strength: lon/lat profiles

$B = 3.16 \times 10^{-14}\,\mathrm{G}$, sky map summed over lon/lat and energy

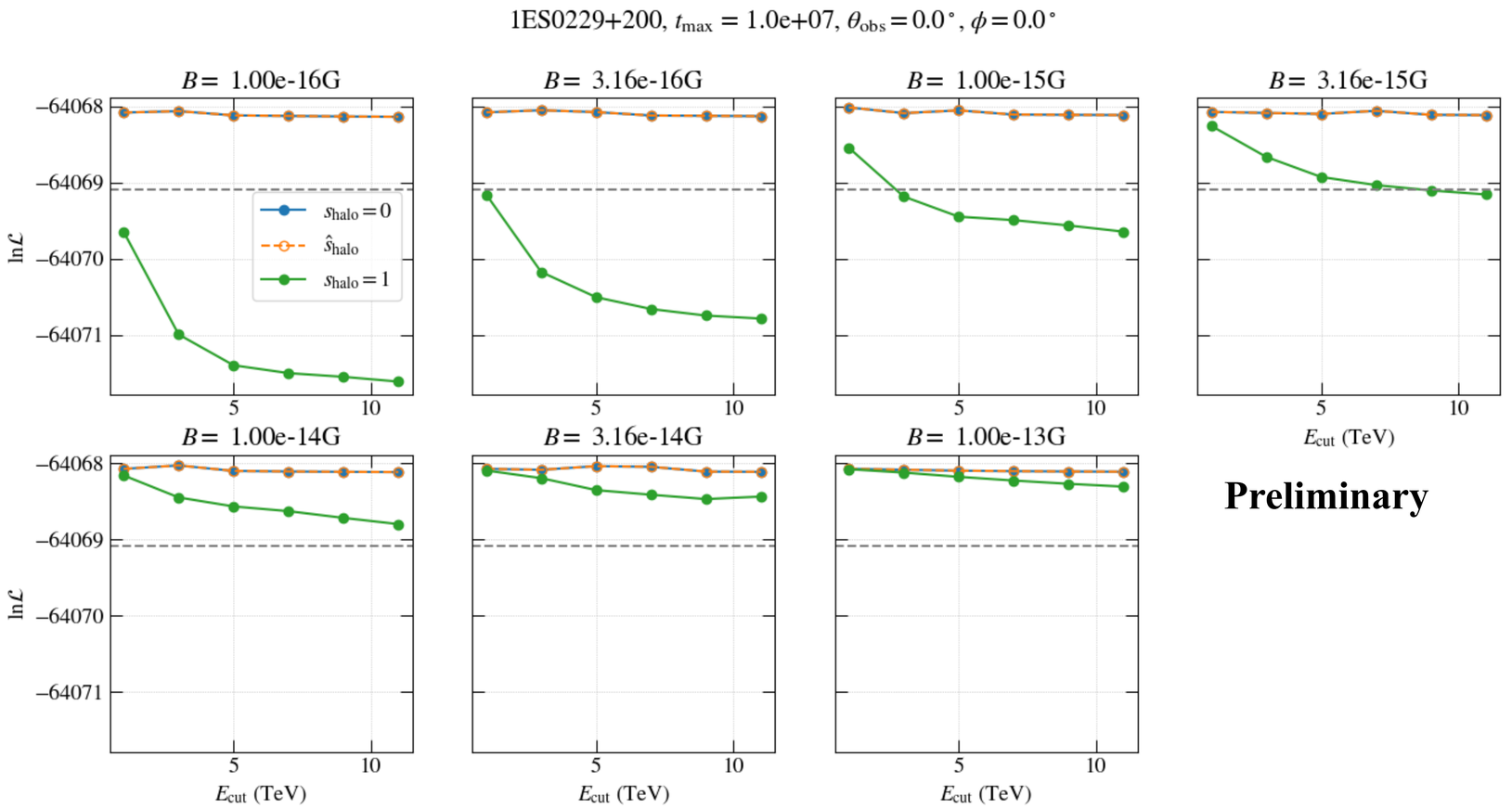


Cascade templates as function of IGMF strength: lon/lat profiles

$B = 10^{-13}$ G, sky map summed over lon/lat and energy



Fermi-LAT Analysis with halo component — Examples of likelihood profile with E_{cut}



Fermi-LAT Analysis with halo component — Examples of likelihood profile with Γ