Search For Anisotropic Pair Halos Associated with Blazar Jets

Ao Zhang, Washington University in St. Louis

Wenlei Chen, Oklahoma State University

Manel Errando, Washington University in St. Louis

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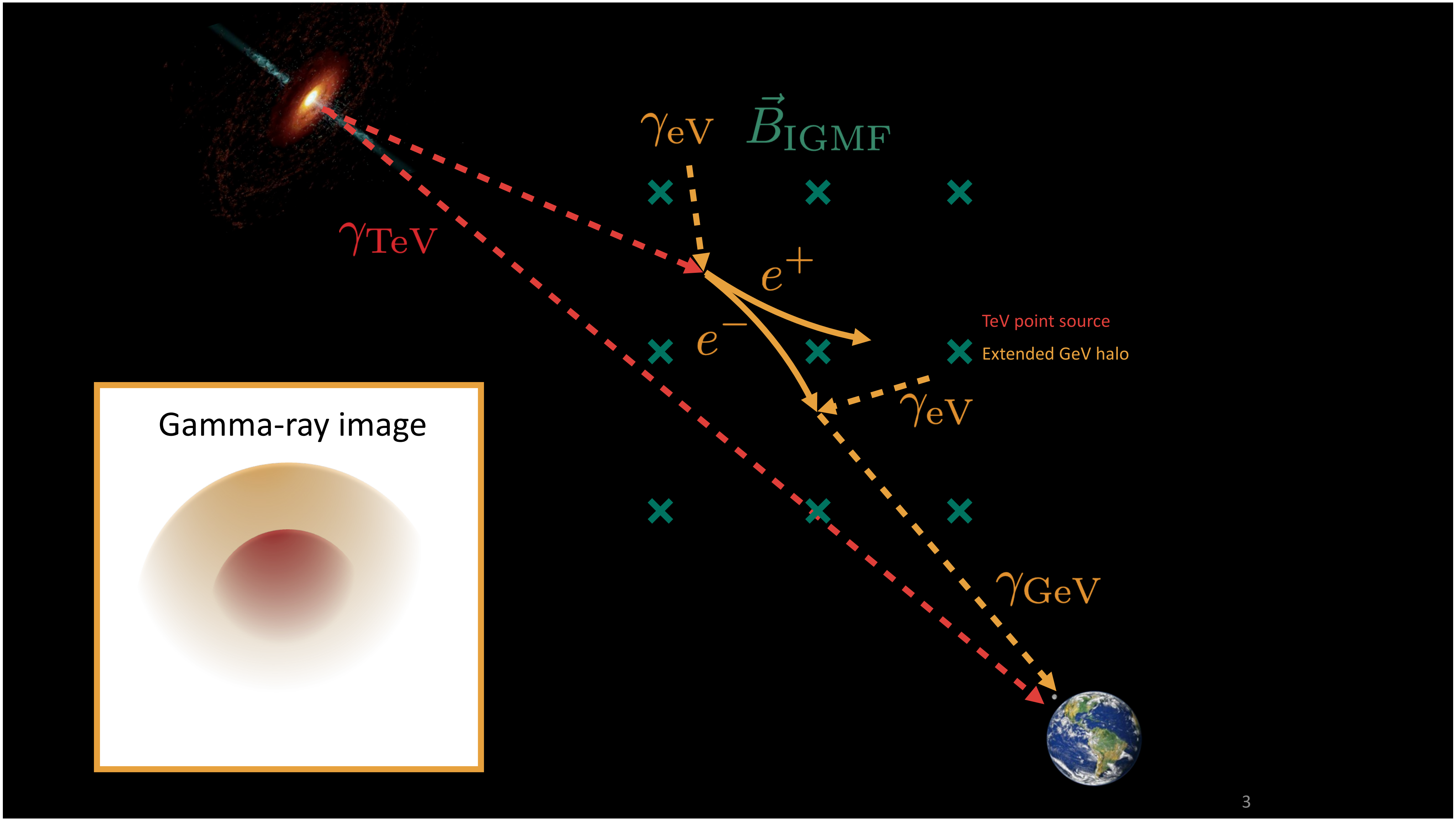
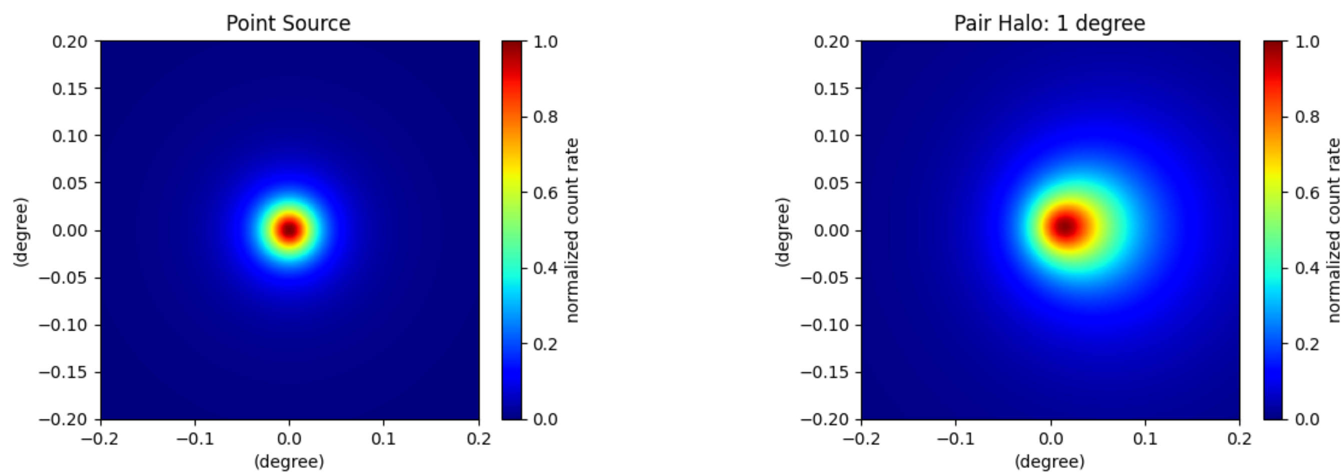
Motivation

- Magnetic fields have been found in galaxies and clusters.
- They might grow from the weaker "seed" fields, whose origins are not known.
- The weaker "seed" fields can be preserved in the intergalactic medium.
- To study them, we want to measure the strength of the intergalactic magnetic field (IGMF).

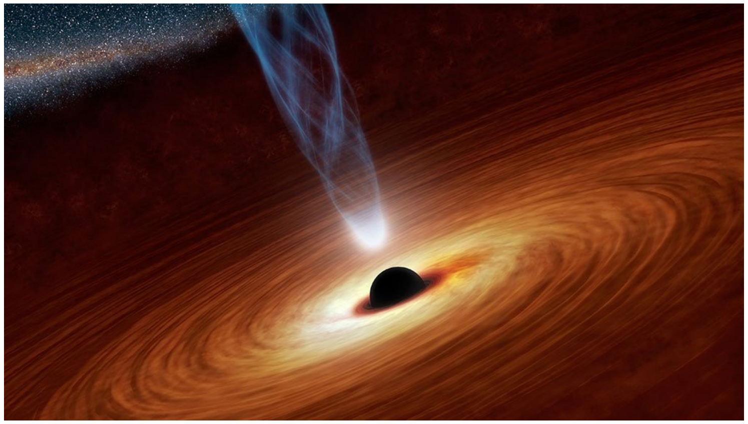

γ_{eV}
$\vec{B}_{\mathrm{IGMF}}$
γ_{TeV}
e^+
e^-
TeV point source
Extended GeV halo
γ_{eV}
γ_{GeV}
Gamma-ray image

Example of a pair halo



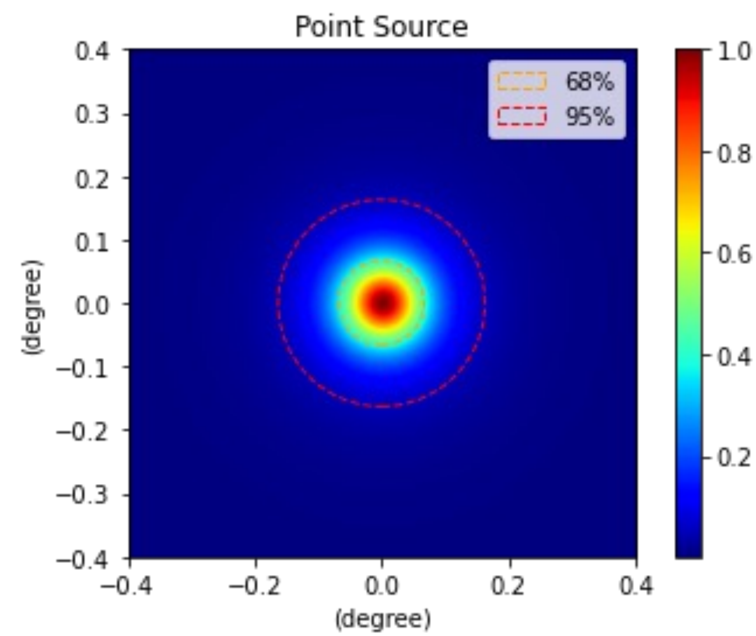
Blazars Selection

- Select high-synchrotron-peaked BL lacs (HBLs) with measured jet position angle from the radio observations
- Select blazars that are in the optimal redshift range to maximize the pair halo signal
- Exclude targets that have known gamma-ray sources within 1 degree.



Find the Optimal Redshift Range

Run simulations at different redshift values to calculate the percentage of photons that fall outside the 95 containment angle.



Pair Halo Model (Chen et al, 2018)

Monte-Carlo simulations which calculate the positions of secondary gamma rays by mixed-raytracing.

- IGMF: homogenous, isotropic, and short coherence length
- The gamma-ray distribution is determined by $B_0, z, \theta_j, f_{halo}$
- The jet profile is modeled as a 2D Gaussian function.

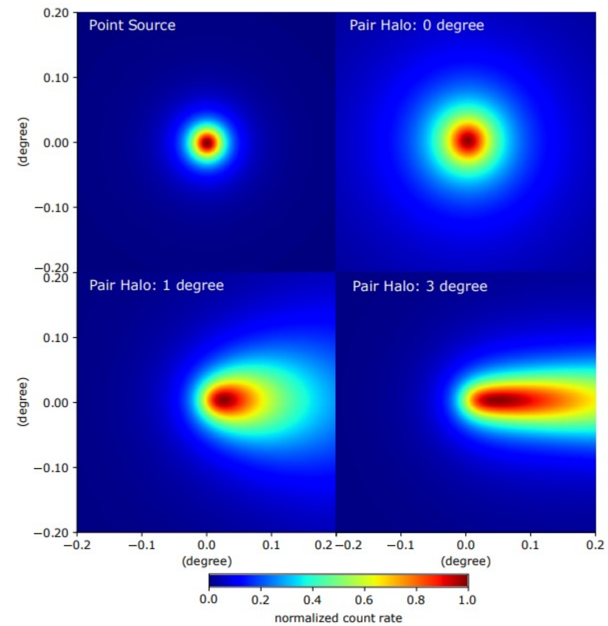
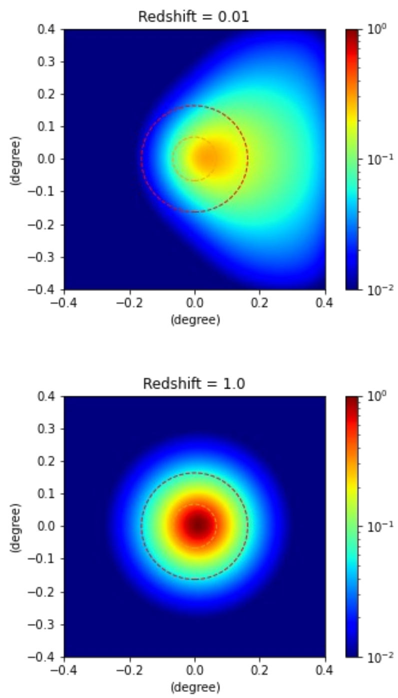
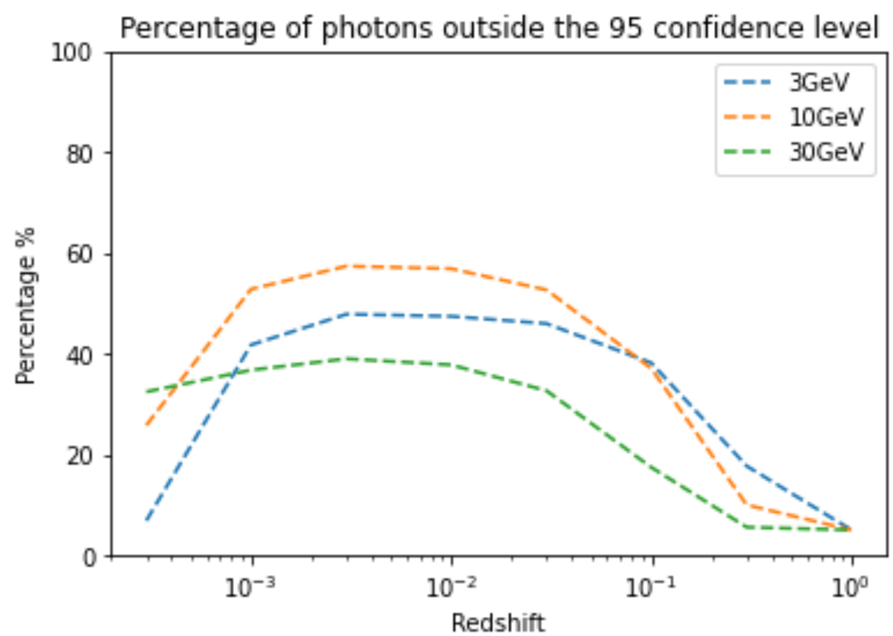


FIG. 10. Expectation of point-source and pair-halo count rate in the presence of the Fermi-LAT PSF at 10 GeV. Pair halos are simulated using 10^6 primary TeV γ-rays from a source at $z = 0.1$ with IGMF strength of 10^{-15} G and jet inclination angle of 0°, 1°, and 3°, respectively. Offset jet-axes are orientated to the right.

Simulation Results





Simulated 10^5 photons with $B_0 = 10^{-15} G$ and $\theta_j = \theta_o = 0.5$

We decided to select HBL with redshift 0.03-0.15

A List of Selected Blazars

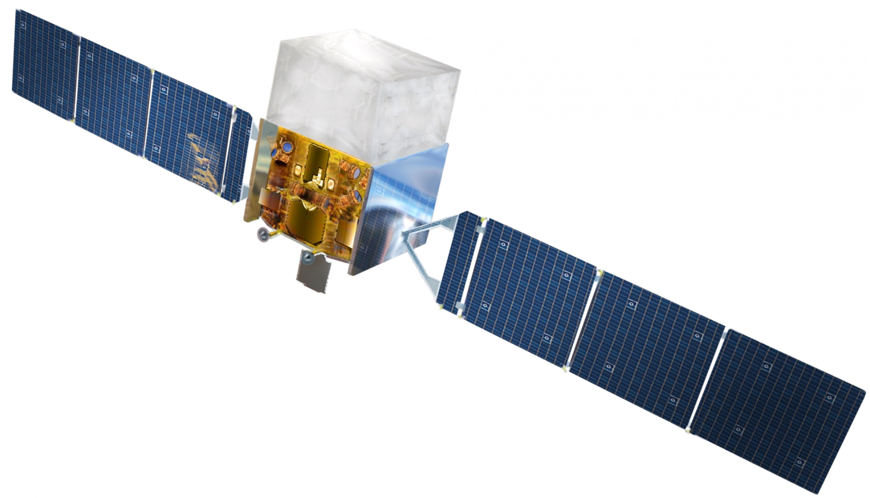
Name	Redshift
I Zw 187	0.055
Mrk 421	0.031
Mrk 180	0.045
1ES 2344+514	0.044
1ES 1741+196	0.084
TXS 0210+515	0.049
TXS 0518+211	0.108
TXS 1515-273	0.1284
1ES 0806+524	0.138
1H 1914-194	0.137

Name	Redshift
PKS 0548-322	0.069
RBS 0030	0.0948
PMN 0152+0146	0.08
1ES1959+650	0.048
1ES 0229+200	0.1396
1H 0658+595	0.125
1RXS 101015.9-311909	0.1426
H 1426+428	0.129
PKS 2155-304	0.116
B3 2247+381	0.1187
PKS 2005-489	0.071

Data Analysis

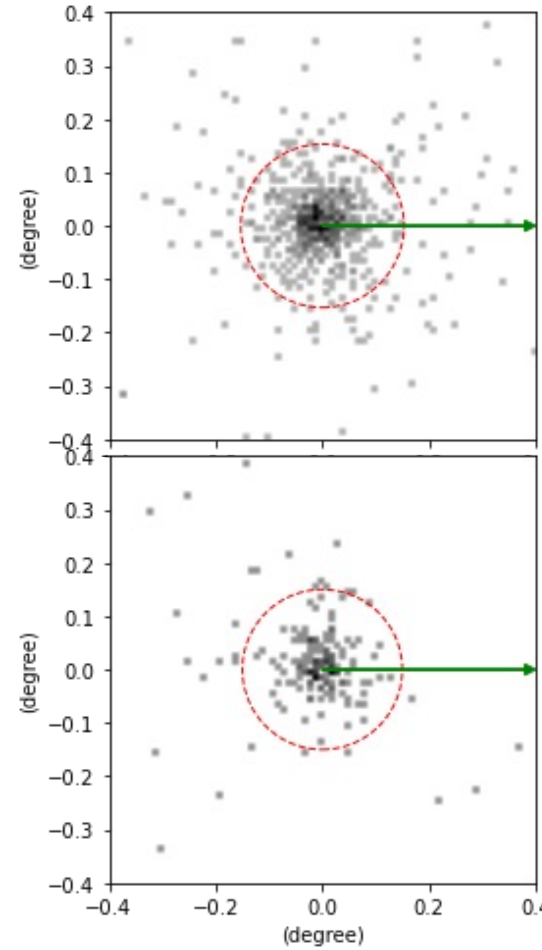
Used 14-Years Fermi-LAT observation

- Apply the ULTRACLEANVETO filter to exclude unwanted emissions.
- Select photons above 30 GeV
- Divide the events into two energy bins: 30GeV-100GeV and 100GeV-300GeV
- Create counts map for individual blazars.

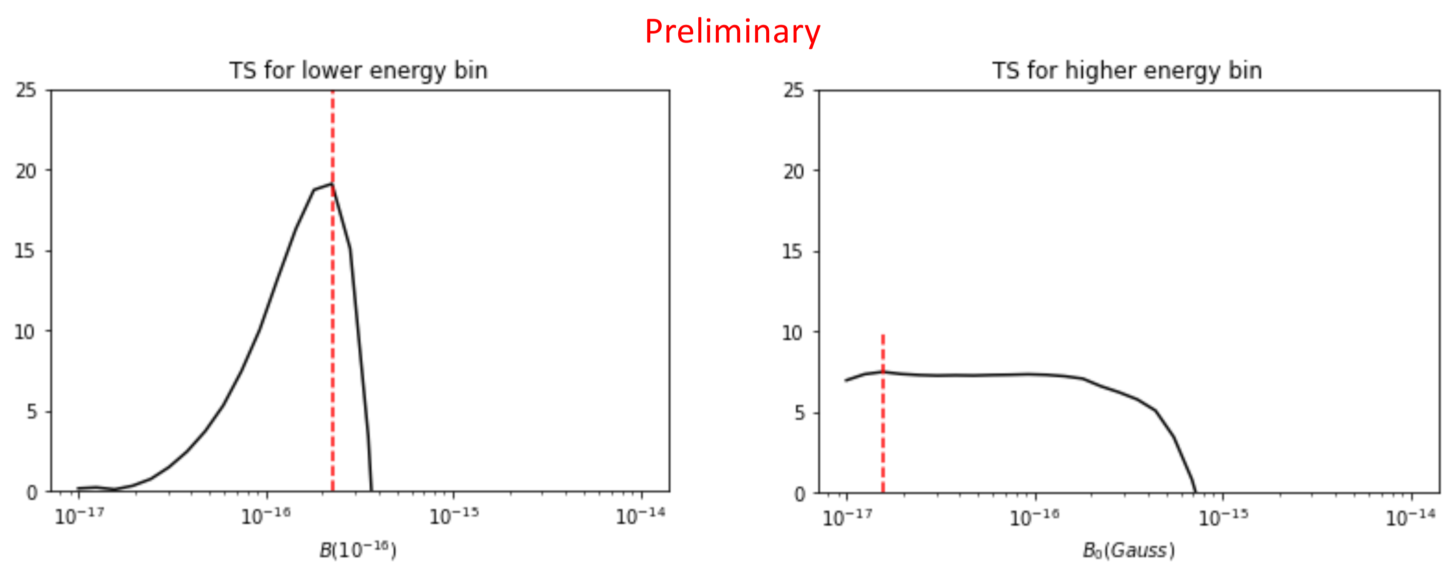


Rotated Photon Counts Map

- Counts map of Mrk 421 with energies 30-100GeV (up) and 100GeV-300GeV (down) from 14-year Fermi-LAT observation.
- The red-dashed circle shows the 95% containment angle of Fermi psf.
- The map is rotated according to the jet position angle in which the green arrow shows the jet orientation.



Joint Likelihood Analysis



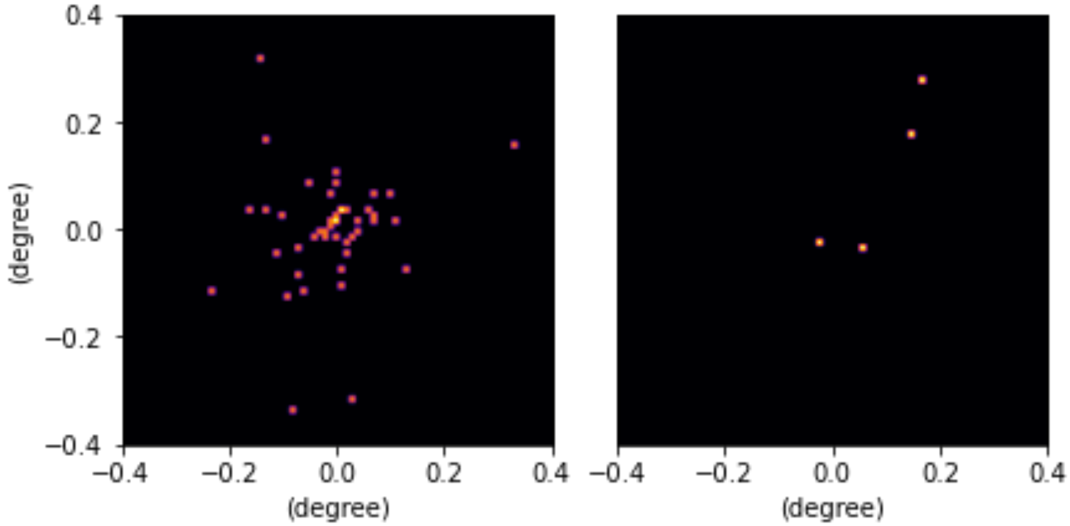
TS value as a function of magnetic field, where the x-axis is shown in logarithmic scale. The left graph and the right graph are the TS for low energy (30GeV-100GeV) and high energy (100GeV-300GeV) bins, respectively. The TS peaks at $2.2\times10^{-16}G$ for low energy bin.

Conclusion

1. We selected 21 HBLs, whose jet orientation angles are known, in the redshift range: 0.03 – 0.15.
2. Used 14 years of Fermi data to create counts maps.
3. The counts maps are rotated with jet angle pointing to the positive x-axis.
4. We used Monte-Carlo pair halo model developed by Chen et al. (2018) to conduct a likelihood ratio test to see whether there is any secondary gamma ray excess along the projected jet direction.
5. Our preliminary result shows the IGMF is around $10^{-16} G$

Example of Low Counts

Counts map of I Zw 187



30-100 GeV energy bin 100-300 GeV energy bin

References

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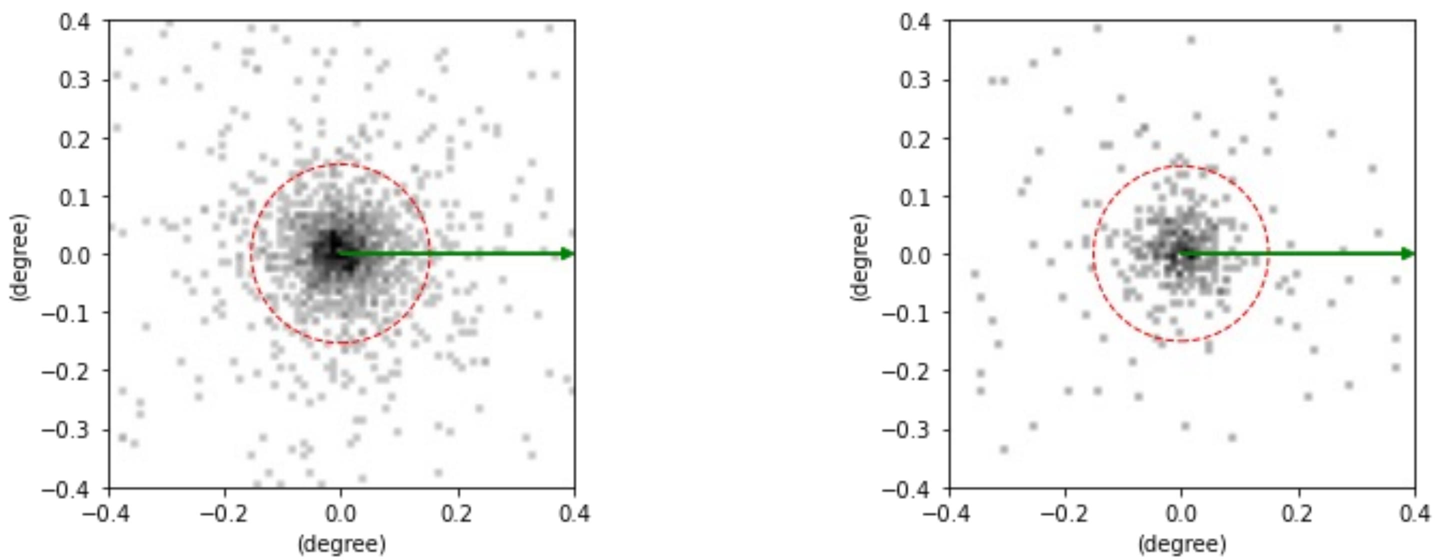
Previous Works

- No detection of IGMF using Faraday rotation and Zeeman effect
  - $B_{IGMF} \leq 5$ nG (Planck Collaboration et al., 2016)
- Such weak field can be measured by looking at the pair halos around blazars which are generated by gamma-ray cascades.
  - $3\times10^{-16}G \leq B_{IGMF}$ (Neronov and Vovk, 2010; H.E.S.S Collaboration, 2014)
  - $10^{-17}G \leq B_{IGMF} \leq 10^{-15}G$ (Chen et al, 2015)
- Pair halo method can only work for a certain range of coherence length of the magnetic field.
  - $30\ kpc \leq \lambda \leq 30Mpc$ (Grasso and Rubinstein, 2001)

Stacked Counts Map



Stacked Counts map of 21 blazars with energies 30-100GeV (left) and 100GeV-300GeV (right) from 14-year Fermi-LAT observation. The red-dashed circle shows the 95% containment angle of Fermi psf. The map is rotated according to the jet position angle in which the green arrow shows the jet orientation.

Morphology of Pair Halo

- Case 1: Uniform B field with large coherence length.
  - The small fraction of the halo can be detected.
- Case 2: Uniform B field with small coherence length.
  - Most fractions of the halo are visible because the electrons can always pick up an ideal tangential part of the B field.