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Searching for Internal Absorption of High-Energy Gamma-rays in Extremely Luminous Blazars

Level: Honour
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Domain: High-energy astrophysics
Direction: Data analysis, modeling
Key concepts: Active Galactic Nuclei; Blazars; Gamma-ray emission mechanisms

Context: Active galactic nuclei (AGN) are cores of certain galaxies that exhibit energy outputs far exceeding those of normal galaxies, with the activity thought to be powered by a central supermassive black hole. Some AGN produce highly collimated relativistic outflows of plasma, called **jets**, which emit radiation from radio frequencies up to gamma-rays. AGN jets provide unique laboratories for studying high-energy physics beyond the reach of Earth-based experiments. **Blazars** are a special type of AGN, with jets that happen to point very close to the direction towards Earth. This favorable orientation of the jet maximizes relativistic effects, resulting in strongly enhanced gamma-ray signals, which carry valuable information about the most extreme physical processes in these sources. Flat Spectrum Radio Quasars (FSRQs) is a category of highly luminous blazars dominated by gamma-ray emission. This gamma-ray emission is believed to be generated through interactions of high-energy particles in the jet with the ambient photon fields, such as the ones of the accretion disk, the broad line region (BLR) and the dusty torus [1], all components of an AGN (see Fig. 1). However, gamma-ray emission can also be strongly attenuated due to **internal photon-photon absorption**, when gamma-rays interact with the same ambient photon fields, and leads to characteristic features in gamma-ray spectra (see Fig. 2) [2]. Reliably detecting and thoroughly studying such features in blazars has been so far very limited; first of all, because of the scarcity of suitable candidate sources, but also due to limited statistics of available data. The study of the internal absorption is a crucial tool for unraveling the complex structure of these sources and gaining insights into physical mechanisms responsible for generation of gamma-rays, and provides a unique probe of the unknown location of the gamma-ray emitting zone in the jet [3].

Aims: **Establish the presence of absorption features in the gamma-ray spectra of selected objects**, quantify the significance and characteristics of these features, and use these results to probe physical conditions in the sources.

Methods: Select a sample of FSRQs which show hints of internal absorption of gamma-rays (e.g. [2]). Extract *Fermi*-LAT gamma-ray spectra of these sources and perform detailed **physical modeling** of the spectra (see examples of absorption feature modeling in Fig. 2). Use statistical analysis to search for the presence of absorption features in the gamma-ray spectrum and characterize their strength, shape and energy-dependence.

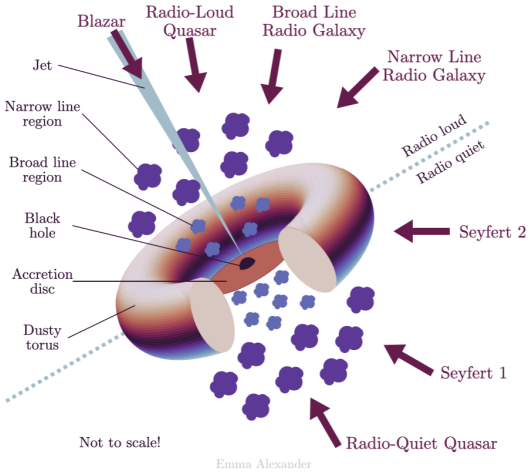

Figure 1: A scheme illustrating the unified view of Active Galactic Nuclei and its different components (credit: Emma Alexander)

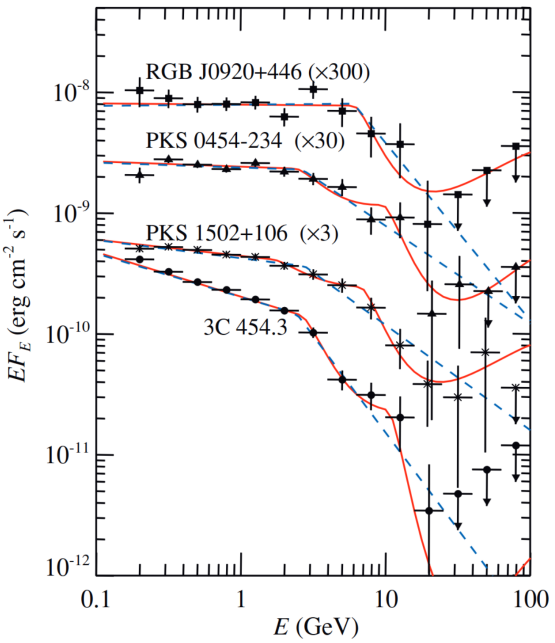

Figure 2: Example of modeling of *Fermi*-LAT blazar gamma-ray spectra with an internal absorption on the BLR photon field (source: [2])

Expected results: The drastically improved quality of the *Fermi*-LAT dataset thanks to a substantial amount of statistics (∼15 years of observational data), is anticipated to enhance the spectral resolution of the absorption features observed in the investigated blazars. Employing an improved model to deduce the properties of these features and their subsequent analysis is expected to provide crucial insights into the gamma-ray emission mechanisms in these sources. Furthermore, it is expected to shed light on the precise location of the gamma-ray emitting region within the jet (see Fig. 3) and to enable characterization of the distribution of the internal photon fields in the source. **These findings hold the potential to significantly advance our understanding of the physical processes governing blazars and the pivotal role played by internal absorption in shaping their gamma-ray emission.**

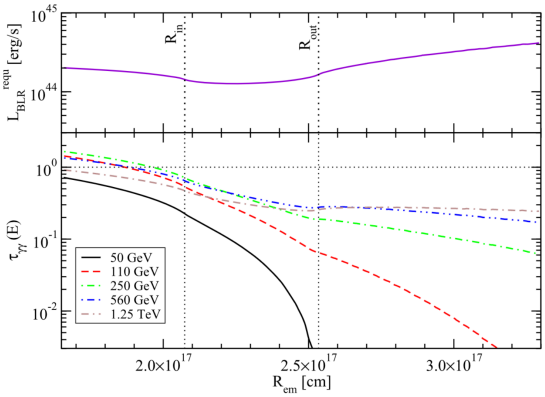

Figure 3: Predicted optical depth of gamma-ray absorption on the BLR photon field as a function of the gamma-ray emitting region location, for several photon energies (FSRQ 3C 279). (source: [3])

References

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[2] [Link to PDF] J. Poutanen, B. Stern, "*GeV Breaks in Blazars as a Result of Gamma-ray Absorption Within the Broad-line Region*", ApJL Vol. 717, Issue 2, pp. L118-L121 (2010).

[3] [Link to PDF] M. Böttcher, P. Els, "*Gamma-Gamma Absorption in the Broad Line Region Radiation Fields of Gamma-Ray Blazars*", ApJ Vol. 821, Issue 2, article id. 102, 5 pp. (2016).