The Study of Gamma-ray Emitting AGN: An Ongoing Revolution

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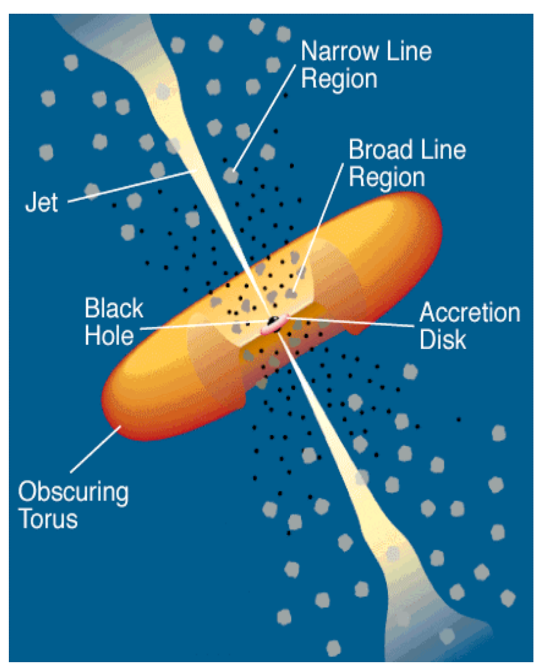
Abstract The field of high energy astrophysics is experiencing a revolution thanks to the advent of a new generation of ground-based telescopes such as HESS, MAGIC and VERITAS. Their improved sensitivity with respect to previous instruments has led to a dramatic increase in the number and type of Active Galactic Nuclei (AGN) detected at the highest energies (100 GeV - 10 TeV), and to a richer picture of their spectra and variability. This ongoing revolution is set to gain even more momentum with the upcoming launch of GLAST, a space-borne instrument which will cover the gamma-ray sky in the energy range 20 MeV to >300 GeV with unprecedented sensitivity and uniform exposure across the whole sky. The combined capabilities of space-borne and ground-based instruments (broad energy coverage, continuous all-sky monitoring, good source localization, and sensitivity to different variability scales) will revamp our knowledge of the extragalactic gamma-ray sky.

Gamma-ray Emitting AGN

Blazars are radio-loud AGN (active galactic nuclei) with core-dominated emission. They display a flat radio spectrum, high and variable optical polarization, and rapid flux variability at all wavelengths from radio to gamma rays [1]. They are also the most extreme subset in the AGN population: they are the brightest, the most variable and the most energetic, reaching photon energies up to the TeV regime.

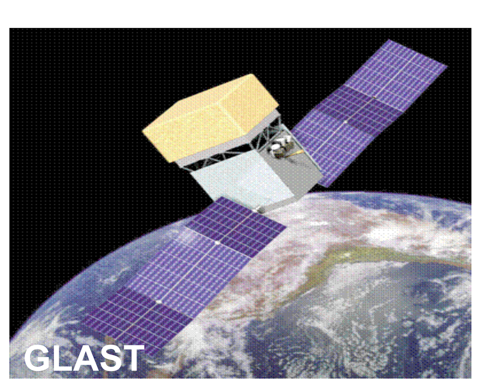


As other radio-loud AGN, blazars are powered by accretion onto super-massive black holes (~10^8 $M_{\odot}$). They also present energetic, highly-collimated, relativistic particle jets.

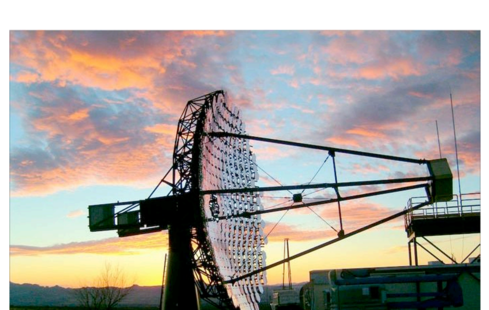
The observational properties of a radio-loud AGN are thought to be largely determined by the orientation of the jet with respect to the observer. In the case of blazars, they are observed "down the jet" (or nearly so).

Blazars are further subdivided into flat-spectrum radio quasars (FSRQs, if they present strong optical emission lines) and BL Lacs (when lines are weak or absent).

Gamma-ray Detectors



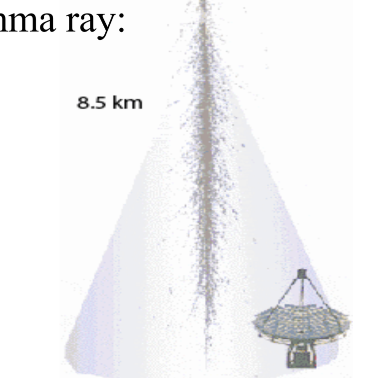
The Large Area Telescope (LAT) on board the Gamma-ray Large Area Telescope (GLAST) is scheduled for launch on May 2008 and will survey the sky in the energy range 20 MeV to >300 GeV [2]. GLAST-LAT will provide much better angular resolution, effective area and field of view than its very successful predecessor EGRET (Energetic Gamma-ray Experiment [3]). In particular, GLAST-LAT will cover ~20% of the sky at any instant and its sky-survey observing mode allows it to observe the entire sky every 3 hours.



VERITAS Telescope (1 out of 4)

VERITAS is a ground-based instrument dedicated to the observations of very-high-energy (100 GeV < E < 10 TeV) gamma rays from astrophysical sources. Located in southern Arizona, the array consists of four 12m-diameter Telescopes [3]. As other ground-based instruments (such as HESS and MAGIC) VERITAS makes use of the Imaging Atmospheric Cherenkov Technique (IACT). This technique works by imaging the very brief flash of Cherenkov radiation produced when a very-high-energy gamma ray strikes the atmosphere.

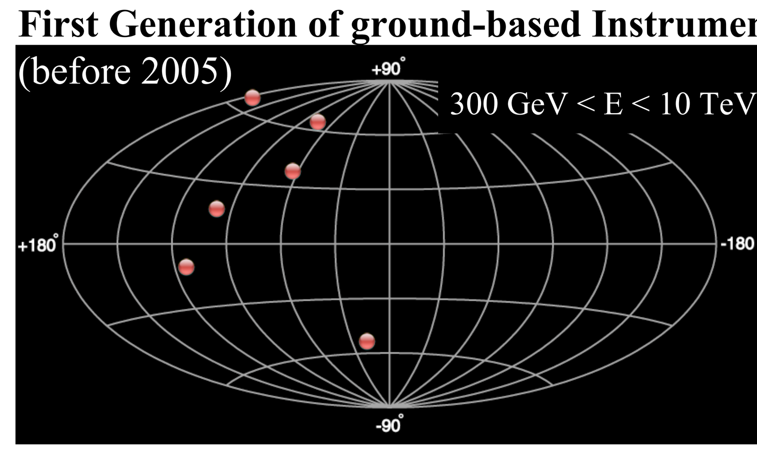
EM shower produced by a gamma ray:



Parameter	GLAST LAT	IACTs
Energy Range	20 MeV - >300 GeV	~100 GeV - >10 TeV
Energy Resolution	<10%	15%
Duty Cycle	100%	12%
Field of View	2.2 sr	2.4 x10^{-2} sr (5 deg)
Angular Resolution	0.1 deg @ 10 GeV	0.1 deg
Effective area	~1 m^2	~10^5 m^2
Point Source sensitivity	1.5x10^{-10} cm^2s^{-1} E>10 GeV	10^{-11} cm^2s^{-1} E>100 GeV

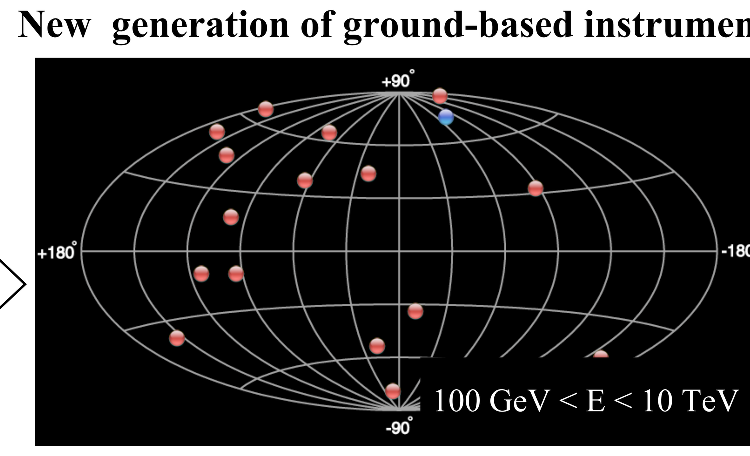
Maps of Extragalactic γ-ray Sources: An ongoing Revolution

First Generation of ground-based Instruments: (before 2005)



- 6 blazars with confirmed detection [7]
- Most distant blazar at z = 0.13
- Only high-frequency peaked BL Lacs (HBLs)

New generation of ground-based instruments:

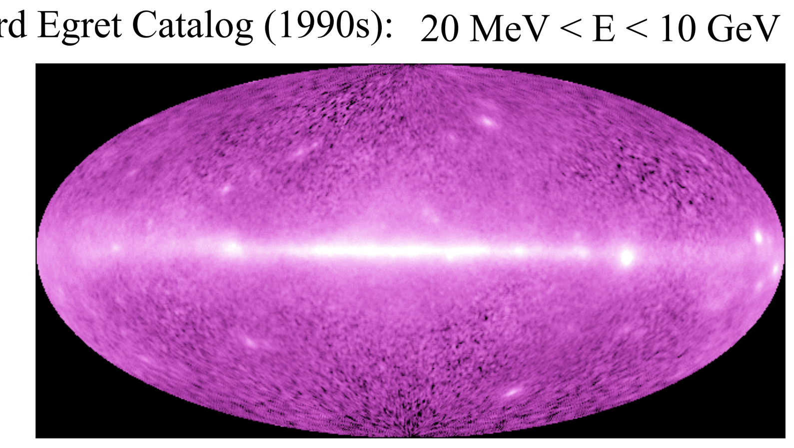


Plots obtained with TeVCAT [6]

- 17 blazars with confirmed detection [6]
- Most distant blazar at z = 0.35 *
- 15 HBLs, 1 low peaked BL Lac (LBL) and 1 radio galaxy (M87, blue point) have been detected.

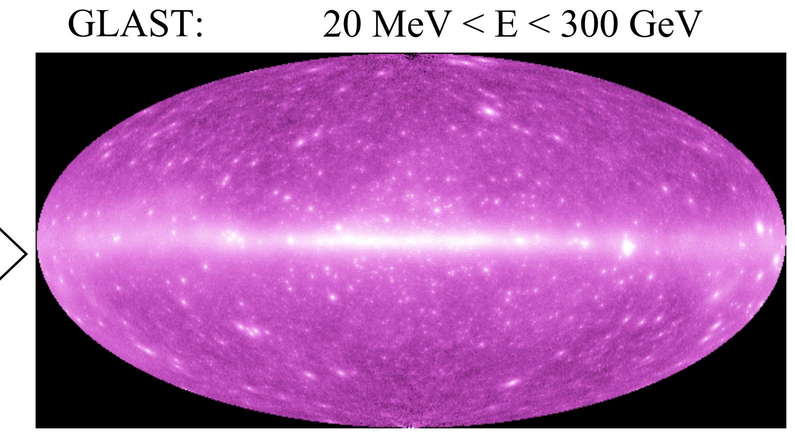
* Pending confirmation of 3C279 detection (z=0.54) by MAGIC [11]

Third Egret Catalog (1990s): 20 MeV < E < 10 GeV



- ~100 blazars with identified counterparts [8]
- Most distant blazar at z ~ 4
- Mostly FSRQs and a few BL Lacs

GLAST: 20 MeV < E < 300 GeV



- 1000 to 10000 expected blazars [9]
- Most distant blazars expected around z~5
- Rich mixture of FSRQs, BL Lacs, few radio galaxies

Plots: glast.gsfc.nasa.gov/science/resources/sims/

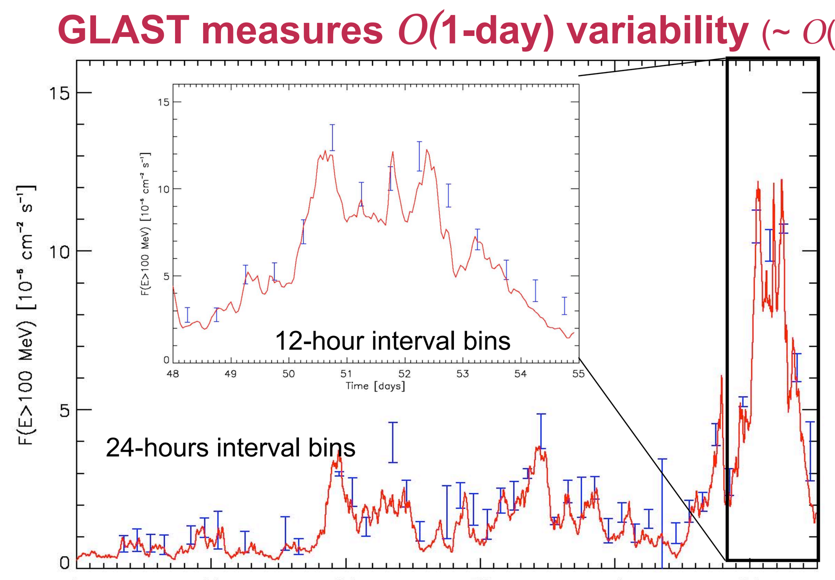
Most of our knowledge of blazars at γ-ray energies comes from observations performed in two disjoint energy regimes: i) the high energy range (20 MeV < E < 10 GeV) which was studied in the 90s by EGRET [4], and ii) the very-high-energy regime (E > 100 GeV) observed by ground-based instruments [5]. Remarkably, most EGRET blazars have not been detected by TeV telescopes; even those that are nearby and bright. Furthermore, blazars detected by EGRET at GeV energies are predominantly FSRQs, while blazars detected by ground-based instruments are all BL Lacs. It is important to understand these observational differences since they are likely related to the physics of the AGN [10], or to the evolution of blazars over cosmic time [12], or both.

The new generation of gamma-ray instruments (space-borne and ground-based) are closing the gap between both energy regimes thanks to their improved sensitivities, leading us towards a deeper and more complete characterization of blazars as a high energy source and as a population.

Blazar Variability

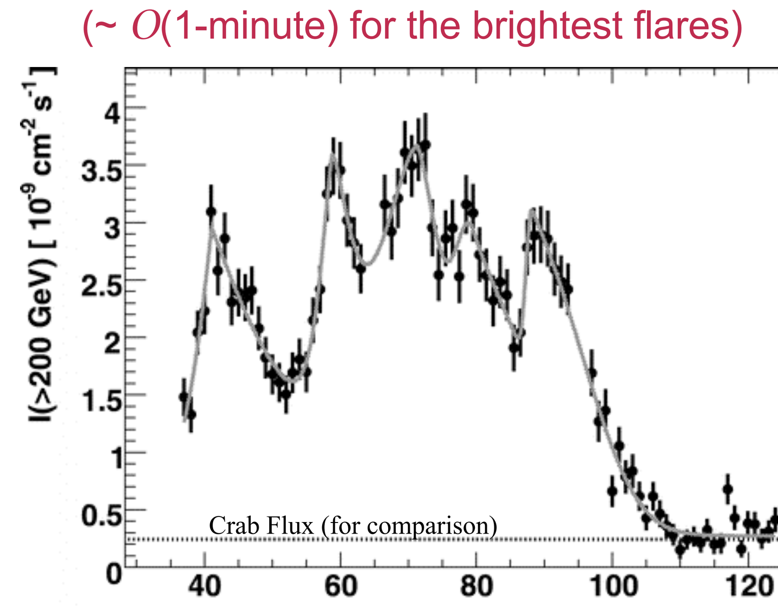
Blazars are illustrious because of their extreme variability down to sub-hour timescales [13,14]. Ground-based instruments are providing flux measurements on very short timescales, providing thus crucial constraints on the possible blazar emission mechanisms.
Blazar variability studies will be enhanced once GLAST is launched. GLAST will survey the entire sky every three hours, thus providing uniform, long-term monitoring of the gamma-ray sky. This will also permit the prompt detection of blazar flares that can be followed with the more sensitive ground-based detectors.

GLAST measures O(1-day) variability (~ O(1-hour) for the brightest flares):



GLAST's sensitivity to different variability timescales [15]. In the main plot, a MC light curve (*red line*) is shown with the measured flux resulting from 24-hour exposures (*blue points*). During moderate flares like the one shown at the end of the lightcurve, 12-hour exposures can be used to measure the flux to better than 10% accuracy and spectral indices to better than 5%.

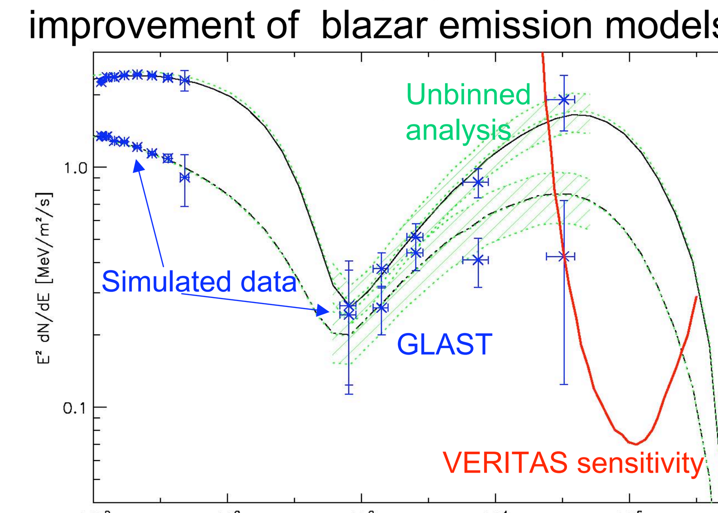
Ground-based instruments measure O(1-hour) variability: (~ O(1-minute) for the brightest flares)



Integral flux as a function of time observed by H.E.S.S. during a major outburst of PKS2155-304 in July 2006 [14]. The variability observed in this flare is the fastest ever observed in a blazar, thus showcasing the remarkable sensitivity of the new generation of ground-based instruments for short-term variability (lightcurve is binned in 1 minute intervals).

Broadband Spectral Energy Distributions

Joint observations with ground-based observatories and GLAST will provide broadband coverage of the high-energy part of the spectral energy distribution for some blazars. Measuring the full shape of the high-energy peak constrains the overall energy budget of the blazar and study of its evolution with time (in the context of multi-wavelength observations) will play a major role towards the validation and improvement of blazar emission models (see [16] for a review).



High and medium states for a TeV-emitting blazar (black lines) are used to predict GLAST counts from a week of observations in survey mode [15]. The blue points show predicted LAT and X-ray counts and the green bands indicate the 3s error on the measured flux. The red line indicates the VERITAS sensitivity expected from 15 hours of observations

Using gamma-ray blazars to probe the IR-Optical-UV cosmic background

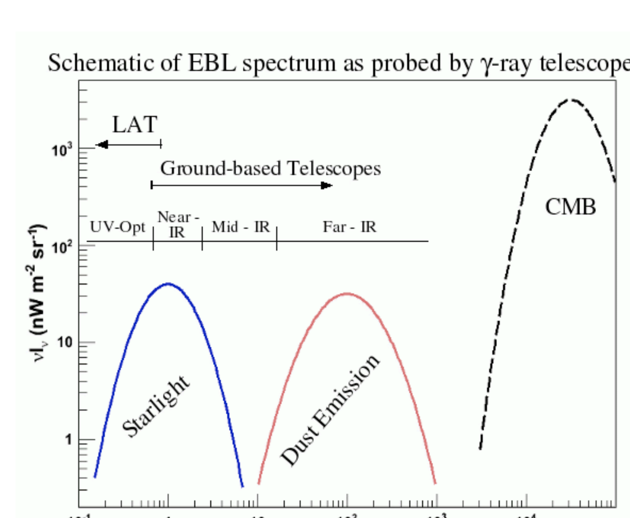
Gamma-rays with energy E > 10 GeV interact via pair-production with photons from the Extragalactic Background Light (EBL) [17]. So far, Very High Energy (VHE) observations of low-redshift BL Lacs have revealed a lower than expected EBL density at Near-infrared wavelengths [18]. The future partnership of the LAT and ground-based telescopes will bring important advances in the understanding of the EBL.

Different regions of the EBL spectrum will be probed: The pair-production cross section for γ-rays with energy E_γ is maximized when the EBL photon wavelength λ_{EBL} is given by λ_{EBL}= 1.33 μm (E_γ / 1 TeV).

In the case of γ-rays detected by GLAST in the 10 GeV < E < 300 GeV energy range, the EBL attenuation occurs with ***UV-optical*** photons from the EBL [19].

Meanwhile, γ-rays detected by ground-based instruments with energies above E > ~ 100 GeV are absorbed by ***optical-infrared*** EBL photons.

Schematic of EBL spectrum as probed by γ-ray telescopes



Therefore, LAT and ground-based observations complement each other by measuring different parts of the EBL.

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