GLAST and Very High Energy astrophysics

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The pioneering age of high energy gamma-ray astrophysics has come to an end for ground-based observatories as the 3rd generation of Atmospheric Čerenkov Telescopes (ACTs) come online. Meanwhile the next generation space-based observatory GLAST is being assembled and is scheduled for launch in 2007. At that point, gamma-ray astrophysics will enter again in a period comparable to the CGRO/EGRET epoch where the combination of ground based and space based observatories reshaped our knowledge in many ways. The instruments have evolved into more performant and efficient machines, making the two techniques very different in their conception, but getting ever closer in their energy ranges. Some aspects and constraints in the two techniques are described, focussing on a few scientific topics that would benefit from a coordinated approach.

1 Introduction

During this conference the status of the major Čerenkov telescopes has been presented. By the time the Gamma ray Large Area Telescope (GLAST) will be fully operational, four of those arrays will be up and running. In the northern hemisphere, MAGIC [1] is operational and is currently building MAGIC II (expected complete in 2006 [2]), and the VERITAS collaboration has built their first of 4 telescopes [3]. In the southern hemisphere, H.E.S.S. is fully operational since December 2004 [4] and is now extending to H.E.S.S. II (expected in 2008 [5]), and the four CANGAROO III telescopes are operational since March 2004 [6].

The geographical location of those experiments is shown in Figure 1 where the spread in longitude is apparent such that there is a potential for quasi-continuous monitoring for a subset of variable sources (although at different energy thresholds) with declination δ seen at the latitude lat for which $|\mathrm{lat} - \delta| < 65°$. It is assumed that sources with zenith angles below $65°$ are too affected by the atmosphere. It seems obvious that one of the main needs for all these IACTs will be to know the time intervals at which a source is visible for GLAST. This allows to optimize observation schedules for monitoring, surveys, and multi-wavelength (MWL) campaigns with ACT and small field-of-view (fov) X-ray telescopes where observation time is competitive.

In this paper I will focus on the potential of GLAST in the current context of detected VHE sources (except for gamma-ray bursts, or GRBs), leaving aside topics such as dark matter and exotic physics, pulsars or diffuse VHE emission.

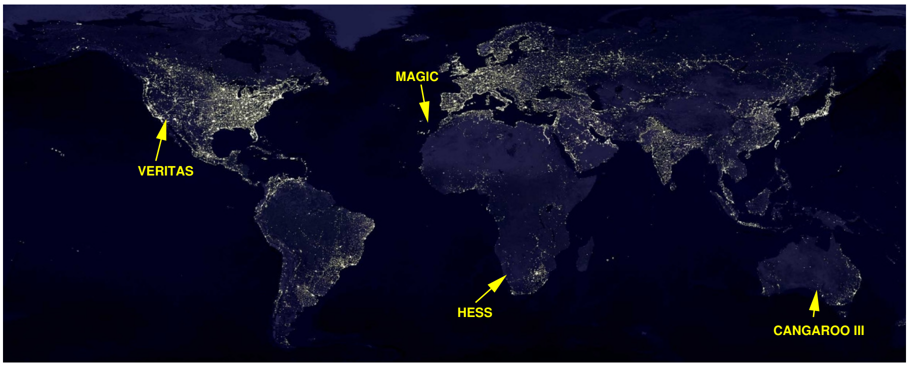

Figure 1: Geographical location of the major Čerenkov telescopes in operation in the GLAST era.

The catalog of VHE sources includes galactic, extragalactic and now also unidentified objects. As reported at the recent ICRC in Pune, India, the VHE sky is now populated by 7 galactic, 11 extragalactic, 5 unidentified and 8-15 additional sources in the Galactic plane [7].

In Figure 2 is illustrated the spectral energy distribution (SED) of a few types of sources likely to be seen by GLAST, but without a systematic counterpart in the VHE range such as pulsed emission from pulsars, or high-redshift objects. The relevant energy windows show that the Large Area Telescope (LAT) and the ACTs are now extremely close if not overlapping around $\sim 100\,\mathrm{GeV}$. The high-energy (HE) gamma-rays have usually been defined as those between 30 MeV and 10 GeV, and the very high energy (VHE) the 10 GeV - 100 TeV range [8]. At 10 GeV the LAT will still have an effective area of $\approx 1\,\mathrm{m}^2$, an order of magnitude more than EGRET, and is expected to make significant source detections in that range. Therefore GLAST will be intrinsically part of not only the HE range where it will see most of its photons, but also the VHE landscape that is still the playground of ACTs and other ground-based instruments.

As indicated in Figure 2 in most cases of common sources the LAT will see the lower tail of the radiating particles while the ACTs see the upper end. A practical consequence of this is that the LAT can provide useful information for ACT calibration purposes using steady sources, and for variable sources, that the LAT can provide triggers for ACTs about radiation coming from the same particles (unlike X-ray monitors). These aspects will be discussed further next.

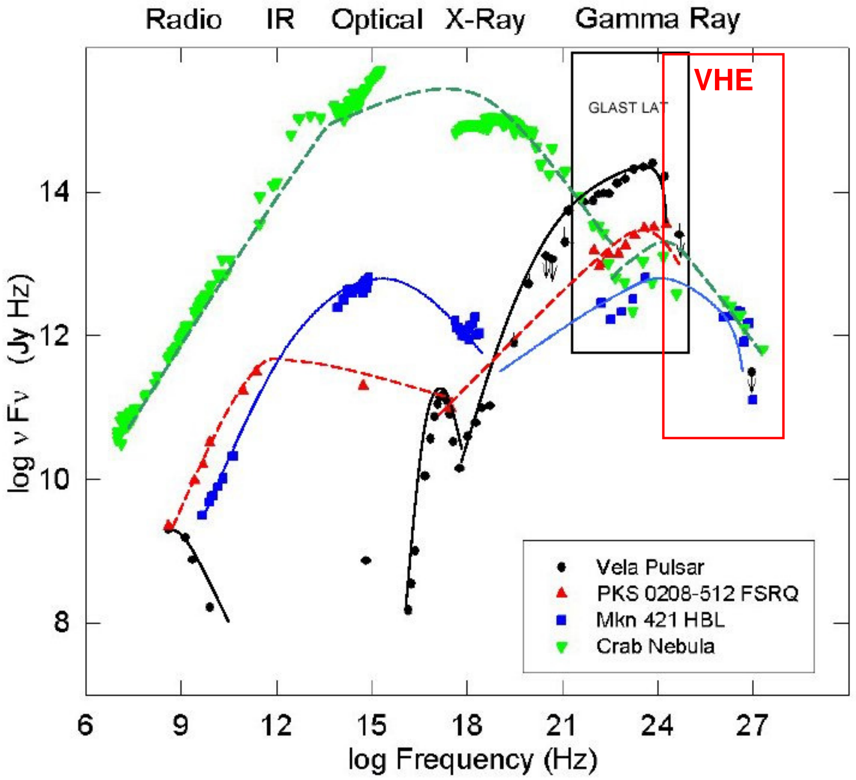

Figure 2: SEDs from Sources of different types and the energy windows of ACTs and GLAST, illustrating the fact that for most sources both techniques will see the same radiative population (from [9])

2 Performance improvements in ACTs and GLAST

GLAST improves over its predecessor EGRET in many ways (see e.g. [10, 11]). Of particular interest to the discussion here is the effective area of the LAT. At high

	GLAST-LAT	ACT
Area	$\simeq 1\,\mathrm{m}^2$	$\simeq 10^5\,\mathrm{m}^2$
Angular resolution	$3.5°(0.1°)$ @$0.1(10)$ GeV	$0.1°$
fov	$100°$	$5°$
Energy resolution	5(10)% @10(100) GeV	20(10)% @50(1000) GeV + syst!
Duty cycle	$\simeq 80\%$	$\simeq$10%

Table 1: Performance comparison between the LAT and ACTs.

energies, interactions of gamma-rays in the detector create upcoming charged secondary particles that, in the past, affected tremendously the efficiency of EGRET since they tended to trigger the anti-coincidence (ACD) system designed to veto cosmic rays [12]. This reduced EGRET's effective area by as much as 50% at 10 GeV compared to the effective area at 1 GeV. A tiled ACD approach in GLAST aims to have no more than a 10% reduction due to backsplash up to 300 GeV. With an effective area of $\approx 10^4\,\mathrm{cm}^2$ we will gain an order of magnitude.

3 Transient sources

The timescales of transient VHE sources range from milliseconds for GRB to days for AGN and now also binary pulsars such as PSR B1259-63 [13]. One tremendous feature of GLAST is its capacity of seeing anti-solar direction oriented sources, which makes it possible to observe sources simultaneously with ground-based instruments. This is of paramount importance for finding correlated variability, as well as finding time lags (if any) between the HE and VHE ranges.

The great advances in modeling variable sources have come from multi wavelength approaches, since the broad band spectral energy distributions (SEDs) often carry information from related radiative particle populations (a proof of which is often correlated variability). These campaigns have proven difficult to organize (see [14] for an overview of those campaigns with EGRET) and the HE/VHE field would benefit tremendously from dedicated and structured efforts before GLAST launches, so that the now known hurdles are crossed ahead of time.

3.1 GRBs

No GRB has to date had a significant VHE counterpart despite searches by the Whipple collaboration [15] and Milagro [16]. Current instruments such as MAGIC have included fast re-pointing as one of their goals in building since it can slew in 30 seconds to any position in the sky [17]. For ACTs there is a range of 0.5 - 2 GRBs occuring in observable conditions per year. Due to their cosmological distances the VHE radiation suffers such large $\gamma - \gamma$ attenuation by the extragalactic background light (EBL) that a TeV detection would raise a considerable number of questions.

GLAST is likely to make ground-breaking progress in the study of GRBs. The GLAST Burst Monitor (GBM) will detect and localize bursts for the GLAST mission, and provide the spectral and temporal context in the traditional 10 keV to 25 MeV band for the high energy observations by the Large Area Telescope (LAT) [18]. The large field of view and the reduced dead time compared to EGRET make for the biggest part of the expected detection improvement in that energy range. Both the GBM and the LAT have burst triggers that will disseminate information through the GCN network.

3.2 Binary pulsars

Until very recently, AGN were the only VHE sources known to vary. With the discovery of VHE emission and variability from PSR B1259-63, and also the discovery of VHE emission in a LMXB EGRET source LS 5039 from which variability is expected, the Galactic sources have become part of the targets that require coordinated multi-wavelength observations.

- **PSR B1259-63**: This binary system with a 3.5 year period was discovered as a VHE emitter [19] during the 2004 periastron passage, providing the first model-independent evidence of particle acceleration in this object. The steep time-averaged photon index of $\Gamma = 2.7 \pm 0.2$ and the orbital variability is in agreement with what is expected from IC scattering of electrons, accelerated in the pulsar wind termination shock, and the target photons of the Be star [20]. There is however also an agreement with a model where the γ-rays are dominantly produced by hadronic processes [21]. The upper limits provided by EGRET on the 1994 periastron are not enough to distinguish both models. An improvement in sensitivity of a factor of 2 at 20 GeV and a factor of $\approx$ 10 at 100 MeV over EGRET would provide sufficient spectral information to disentangle them, which the LAT should be able to do. Interestingly, these models fail however to explain the observed shorter timescale VHE variability, and optimizing the sensitivity of LAT observations on this object at crucial points of the pulsar orbit (periastron, disk crossing) could be investigated. One can gain for instance a factor of ≈ 2 in sensitivity in pointing mode (compared to the nominal scanning mode [11]), since this optimizes the angle-dependent effective area.

- **LS 5039**: In this binary system there is no clear evidence for the nature of the compact object, which is in a much closer orbit (4-day period) than PSR B1259-

63. Before it was detected in VHE γ-rays [22], which provided an unambiguous proof that particles can be accelerated up to TeV energies in X-ray binaries, it was a candidate HE "micro-quasar" since there was a possible association with the EGRET source 3EG J1824-1514. The compact object can possibly be a black hole (BH), forming the scaled-down version of an AGN where γ-rays are emitted in a jet pointing close to the line of sight [23]. The exact nature of the compact object is however still unclear, and we have yet to find evidence for HE gamma-rays coming from Galactic BH systems.

Determining the nature of the secondary, and the physics of the HE/VHE emission process, are issues that will have to be tackled in the future. The LAT will provide a more accurate characterization of the EGRET associated source 3EG J1824-1514 which should allow to check whether this is the same source as the VHE and X-ray emitter. The compact object is constantly within the dense photon field of the companion star, and entangles the orbital-dependent absorption with possible intrinsic variability that should give information about the emission mechanism. GLAST will have the sensitivity to improve spectral measurements and the lightcurve to detect orbital effects and possibly make phase-dependent spectral measurements that will prove crucial to establish the nature of the compact object [24]. A similar system in the northern hemisphere is LSI +61 303 which will be a target for MAGIC and VERITAS in conjunction with GLAST [25].

3.3 AGN

The northern hemisphere VHE AGN such as Mkn421, Mkn501 and 1ES1959+650 exhibit orders of magnitude more amplitude variability than their southern hemisphere counterpart BL Lacs such as PKS 2155-305 and PKS 2005-49. If this situation does not change within the next 10 years (and historical RXTE/ASM measurements from the last 10 years make this scenario plausible) then the northern hemisphere will remain a privileged site for studying VHE AGN variability. For a review of EGRET GeV blazars see [26].

- The shortest measured timescales in the VHE AGN are of the order of 15' both in the X-rays and VHE bands. These AGN however are extremely faint in the HE band which is located in between the maximum synchrotron peak ($\simeq$ keV) and the high-energy peak ($\simeq 100 - 1000$ GeV) as illustrated in Figure 3. They are among the weakest EGRET sources and could therefore not be seen in the HE range even for peak luminosity VHE events. Even though the estimations remain model-dependent, it is not only predicted that the brightest VHE transient from these objects will have a LAT counterpart, but also that the

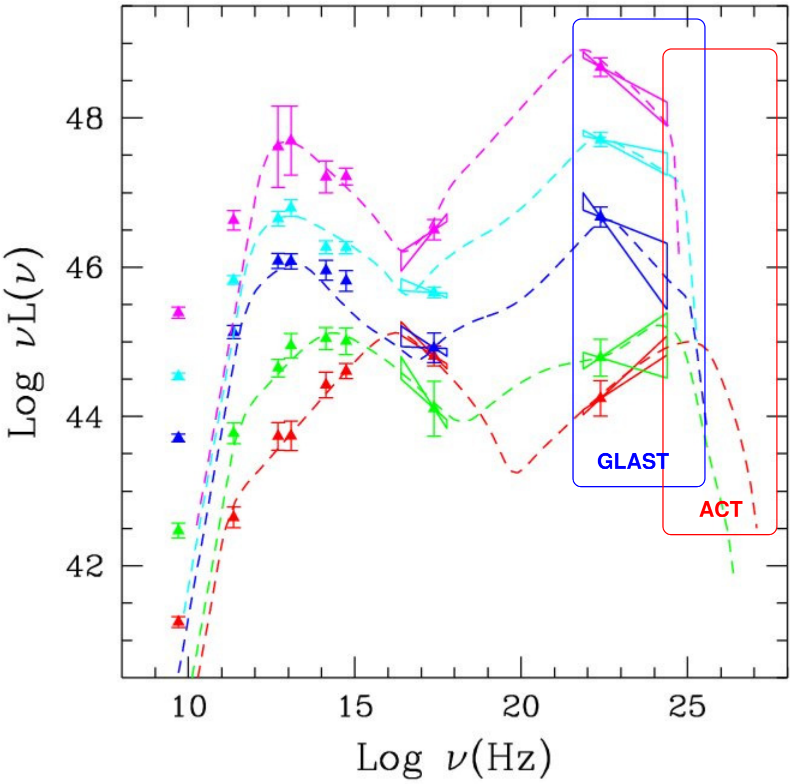

Figure 3: SED sequence and the relevant energy ranges for GLAST and ACTs (from [27]). In this proposed sequence, the most energetic AGN are also the faintest. Also note that while VHE detectors are mostly limited to the closeby energetic sources, GLAST has access to the whole "sequence" of blazars.

LAT can provide high-state triggers for the VHE community on these objects.

- GLAST will have a unique view on the rate of so-called "orphan flares" where VHE transients appear without any detectable low-energy counterpart. So far this phenomenon is far from being ubiquitous since it has only been detected once in the BL Lac object 1ES 1959+650 [28]. The rate and spectral characteristics of such flares are very important to understand how they are related to the more classic flares that are visible at lower energies. Since it is widely accepted that GLAST sees from these objects the same radiative particles as the VHE instruments, we can establish whether these events are unique to this source or also happen it the other VHE AGN. Monitoring such events will of course require an all-sky monitor that will establish the existence or not in the lower energy component of a counterpart (typically X-rays). The best associated telescope for that seems to be the Swift mission, since the BAT instrument with its 1.4 sr fov is a good match for GLAST's $> 2.5\,\mathrm{sr}$ fov.

With an extrapolated number of possible AGN detections numbering in the thousands, more than this is of course expected to come from the AGN field with GLAST.

3.4 Extragalactic background light and magnetic fields

GLAST and the ground-based VHE instruments will be complementary on the study of the EBL density, and possibly also on a way to determinte the intergalactic magnetic field (IGMF) strength.

- **EBL:** Understanding the spectral density of the EBL in the $0.1 - 1000\,\mu\mathrm{m}$ via pair production can probe important issues in galaxy formation (e.g. [29]). The specific issues that GLAST will contribute to can be read in e.g. [30]. Due to their different energy ranges, GLAST and ACTs are sensitive to spectral roll-overs that sign the EBL attenuation at different redshifts and hence EBL wavelengths. This is illustrated in Figure 4. GLAST has however an advantage in that it can probe those effects at greater redshifts ($z \geq 4$) and is thus capable of seeing EBL evolutionary effects other than just density effects due to the expanding universe.

- **IGMF:** A very promising possibility coming from the EBL study is to see the effects of comptonized CMBR photons by the pair-creations of TeV photons on the EBL. Fan and collaborators have investigated the signature of this on the TeV blazar 1ES1426+428 located at a redshift of $z = 0.129$ as a function of intergalactic magnetic field (IGMF) strengths between 10^{-18} and 10^{-20} G and 3 different EBL shape assumptions. The denser the target photons the more such pairs are produced, and the stronger the IGMF the more they are deflected from the line of sight and the less the comptonized CMBR photons contribute to the measured GeV spectrum. To investigate this it is therefore very important to know the VHE spectral counterpart of the HE spectrum which implies as simultaneous measurements as possible if the source is variable.

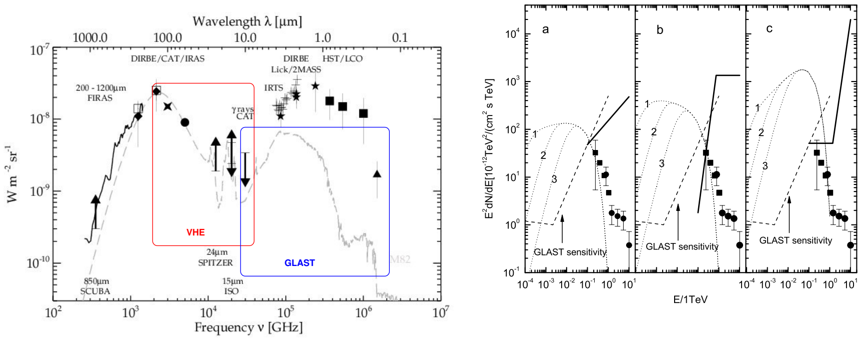

Figure 4: Left: Energy distribution of the extragalactic background radiation in the IR to UV range, with the relevant windows where the LAT and ACTs are affected by attenuation (from [31]). Right: Contribution to GeV emission from cascading pair-creations on the CMBR as a function of the EBL model (a,b,c) and the IGMF strength (1,2,3), (from [32]).

4 Steady sources

By definition, steady sources require little coordination between experiments, be it GLAST or among VHE observatories. As things are now, the most urgent need lies in a better estimation of EGRET sources for which associations with counterparts in other wavelengths are not clear yet. Probably the most controversial now is the exact location of the Galactic center γ-ray source 3EG J1746-285 which has been associated with Sgr A* which is still controversial [33, 34]. For a review on potential γ-ray sources in the Galactic Center region see, e.g., [35].

4.1 Cosmic Ray origin

The Holy Grail of VHE astrophysics still remains the origin of cosmic rays. The search for a signature of hadronic origin of HE/VHE γ-rays is still ongoing especially in supernova remnants (SNRs). Without clear signature of π^0 creations at 70 MeV, the quest becomes more model-dependent since many sources have obvious IC radiation from relativistic electrons. A few sources are outstanding candidates for checking π^0-decay predicted spectra with GLAST and an ACT, such as TeV J2032+4130 in the Northern hemisphere, and RXJ 1713-3946 in the Southern hemisphere. Understanding calibrations at the lower energy end of ACTs (10-100 GeV) and accumulating enough photons to reduce statistical errors at the higher end for GLAST will make for a successful joint spectra with high enough confidence to find evidence of cosmic ray accelerations in SNRs. That is the topic of the next section.

4.2 Prospectives on cross-calibrations

A few authors have pointed out [36] the absolute calibration weaknesses of ACTs, in energy and sensitivity, which are dominated by uncertainties on Monte Carlo simulations and atmospheric models. The resolution of ACTs can be $\simeq 5\%$ but the systematic uncertainties range between 10%-30%. With the current ACTs and GLAST energy ranges getting closer it becomes interesting to investigate the possibilities of cross-calibrating both techniques. How close the first spectral bins of ACTs are of the last LAT spectral bins makes a difference: extrapolating a power law from one to the other over wide ranges becomes increasingly unphysical since intrinsic spectral deviations from power laws for instance are observed in all sources when the energy range increases. Cross calibrations between space-based instruments are common, and in X-ray astronomy the Crab nebula has been used as a standard candle to perform this [37].

Table 2 summarizes the fit parameters available in the literature for power-law fits to the Crab nebula from different observatories. The normalization at 1 TeV and the photon index are found to vary over time (Fig. 5) as well within the same experiment as the analysis becomes more performant and different upgrades are performed. Systematic errors on the flux now dominate the overall error by an order of magnitude, and they have become comparable in the photon index derivation.

Observatory	1 TeV Normalization (10^{-11} cm^{-2} s^{-1})	Photon Index
Whipple (1993)	1.48±0.09±0.41	2.69±0.09±0.3
Whipple (1998)	3.20±0.17±0.60	2.49±0.06±0.04
Whipple (2001)	3.11±0.30±0.62	2.74±0.08±0.05
HEGRA (2000)	2.79±0.02±0.5	2.59±0.03±0.05
HEGRA (2004)	2.83±0.04±0.6	2.62±0.02±0.05
CAT (2000)	2.21±0.05±0.6	2.80±0.03±0.06
CAT (2004)	1.85±0.05±0.62	2.82±0.04±0.06

Table 2: Historical parameters derived from a power law fit to the Crab spectrum, from different ACTs.

An additional difficulty comes from the comparison of power-laws which are essentialy scale-free. A pronounced spectral feature in a spectrum is often of considerable help in calibrations. X-ray instruments often carry radioactive calibration sources, or use well-known spectral features in sources such as Fe and Cu lines. In VHE γ-rays one could investigate the use of spectral breaks which are so far seen in

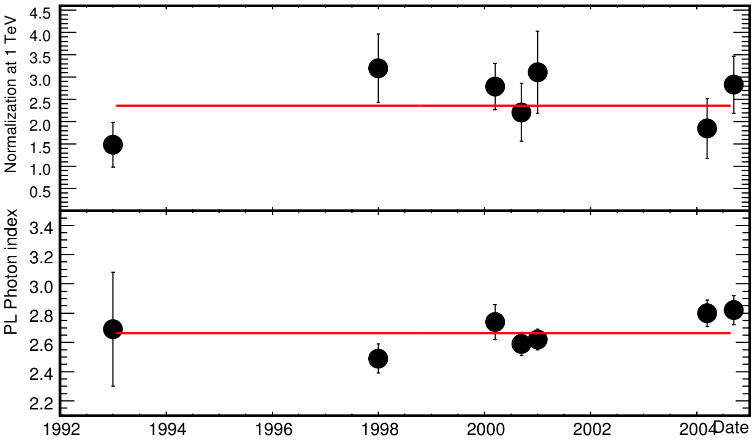

Figure 5: Crab fit parameters from Table 2.

AGN but are unfortunately related to variability (see e.g. [38] for such a study between H.E.S.S. and MAGIC on Mkn421). As Bastieri et al. point out [39] the Crab nebula spectrum is expected to strongly deviate from a power law in the 10-200 GeV range. A pronounced deviation can be approximated by a broken power law which provides then a break energy E_{br} at the transition between the two spectral indexes.

Such a feature would help even more in cross calibrating GLAST and ACTs of the Northern hemisphere (provided their energy threshold is well below 200 GeV) where the Crab nebula can be seen under ideal azimuthal angles by most ACTs. For Southern hemisphere based experiments, such sources have yet to be found, though bright Galactic sources that have a well defined power law and are bright (RXJ 1713-3946 and Vela Jr have fluxes of $\approx$ Crab). It is also possible that narrow VHE spectral bumps in extragalactic objects could serve for the same purpose. From SED modellings such a feature is expected in e.g. M87 and PKS2155-304 which are both VHE sources seen most of the time in their low state.

It is however premature to give accurate estimations of the factor by how much energy scales uncertainties can be reduced with such sources withing the GLAST mission time since this will essentially be limited by LAT statistical uncertainties at the upper energy range. Upcoming *data challenges* working with a simulated sky over time intervals $\approx$ year will provide a better insight on the possibility to reduce the systematic errors to the $\simeq 5-20\%$ range.

It is also worth investigating the need for common GLAST/ACT spectral fitting tools, which have allowed X-ray instruments to increase the accuracy of cross-calibrations [37].

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