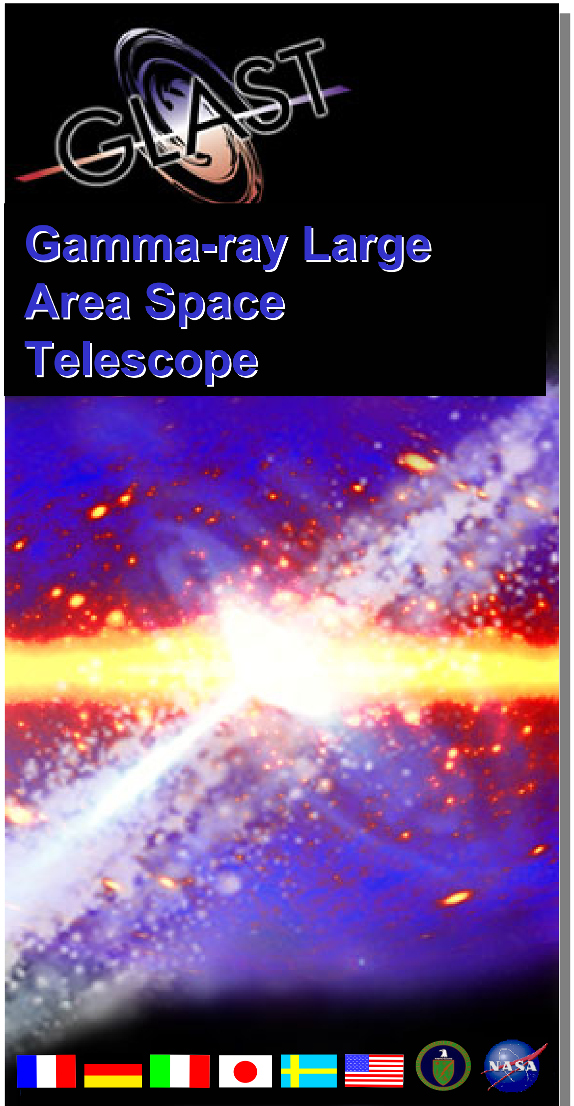


Calibrating Atmospheric Cherenkov Telescopes with the LAT

S. W. Digel
SLAC

Outline

- IACTs vs. LAT
- Cross calibration
  - Issues
  - Advantages & disadvantages of the Crab nebula
  - Alternatives?

This talk is motivated by the recent paper by Bastieri et al. on calibration of MAGIC with LAT observations of the Crab (astro-ph/0504301). Dirk Petry has also studied cross calibration with the Crab.

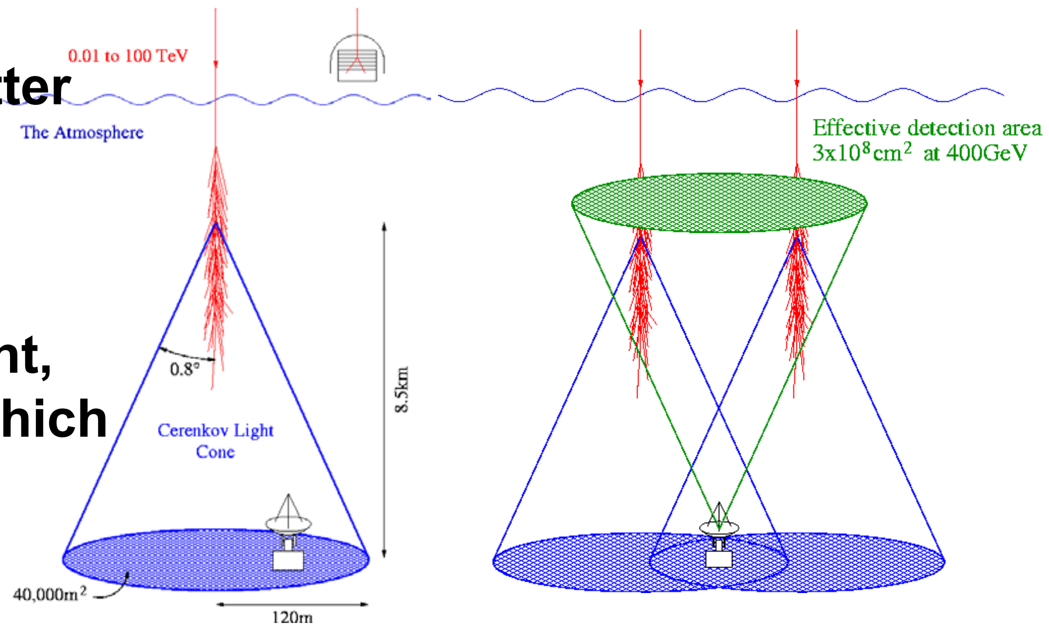
New Generation of IACTs

- **Several are coming online; here we have heard the most about HESS and Veritas**

From Web sites of the respective experiments

IACTs in a Slide

- Effective area is enormous
- Steroscopic (or more) viewing often used to better reject background
- Energy measurement is basically related to the integrated Cherenkov light, only a small fraction of which is detected
  - Reliance on particle interaction codes and models, e.g., for atmos-pheric attenuation is fairly high
- *Response changes a lot with zenith angle*
  - Area goes up, but so does energy threshold



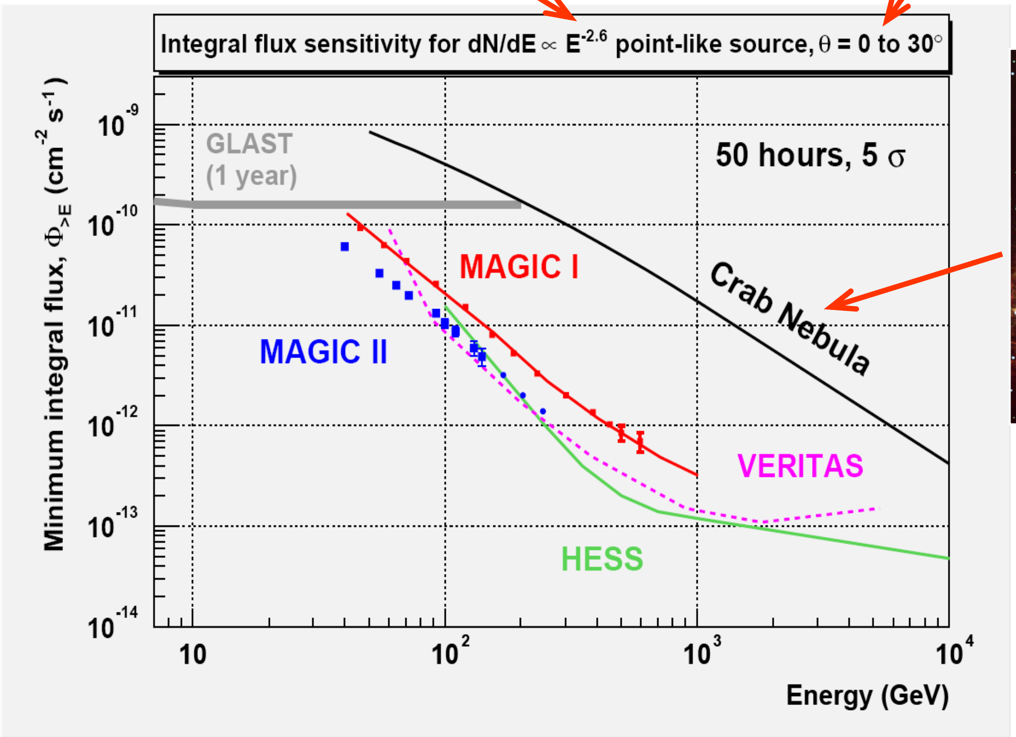
From D. Horan's SLAC Experimental Seminar

Promotional Diagram

- **LAT and VERI-MAGIC-CANGA-HESS should overlap in energy and coverage for sources that *are not too far from zenith for the IACTs***

N.B. fairly steep spectrum

i.e., within 30° of zenith*



FORS Team, VLT, ESO

Bastieri et al.

*Not only is this way, way up in the sky, you are not going to get very many hours per night even for a source at favorable declination

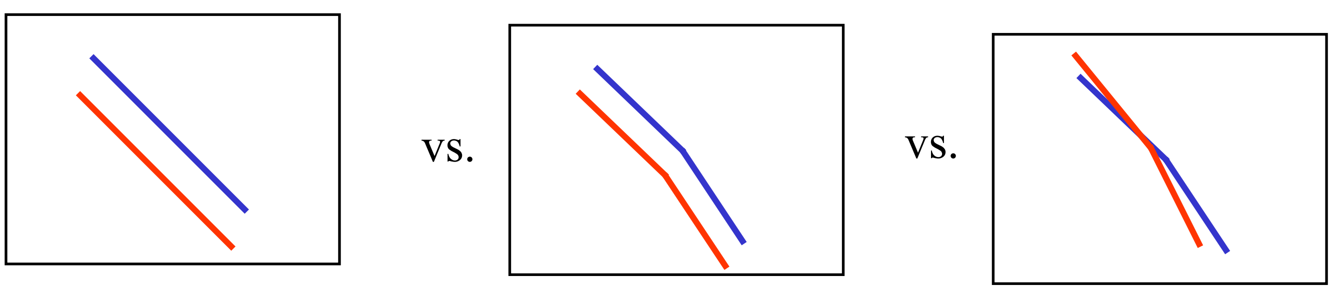
Approximate Performance Comparisons

- **Note that (Effective area)×(Field of view)×(Duty cycle) is about a factor of 5.5 greater for IACTs**

	LAT	New gen. IACTs
Energy range	0.02–300 GeV	~100–10,000 GeV
Angular resolution	~0.1° in energy range of overlap with IACTs	<0.1°
Effective area	~10^4 cm^2	~3 x 10^8 cm^2
Field of view	2.2 sr	~4 x 10^{-3} sr
Duty cycle	~80%	~10%

So What is the Issue?

- Systematic uncertainties in energy measurements and effective area determinations are large for IACTs
  - You may also have noticed that HESS and CANGAROO results for the same sources have not been the same
- Even a bright source like the Crab will take a long time to be well measured >100 GeV with the LAT
  - So cross-calibration sources need to be steady
- Also, as Bastieri et al. and Petry pointed out, the source needs to have some kind of spectral feature, even a kink, in the range of overlap, so that errors in Aeff and energy measurement can be distinguished



Crab Nebula as Calibration Source

- **Advantages: Bright (for a TeV source), steady, and has a spectral break (although it is not well measured yet)**

Spectrum of Crab Nebula

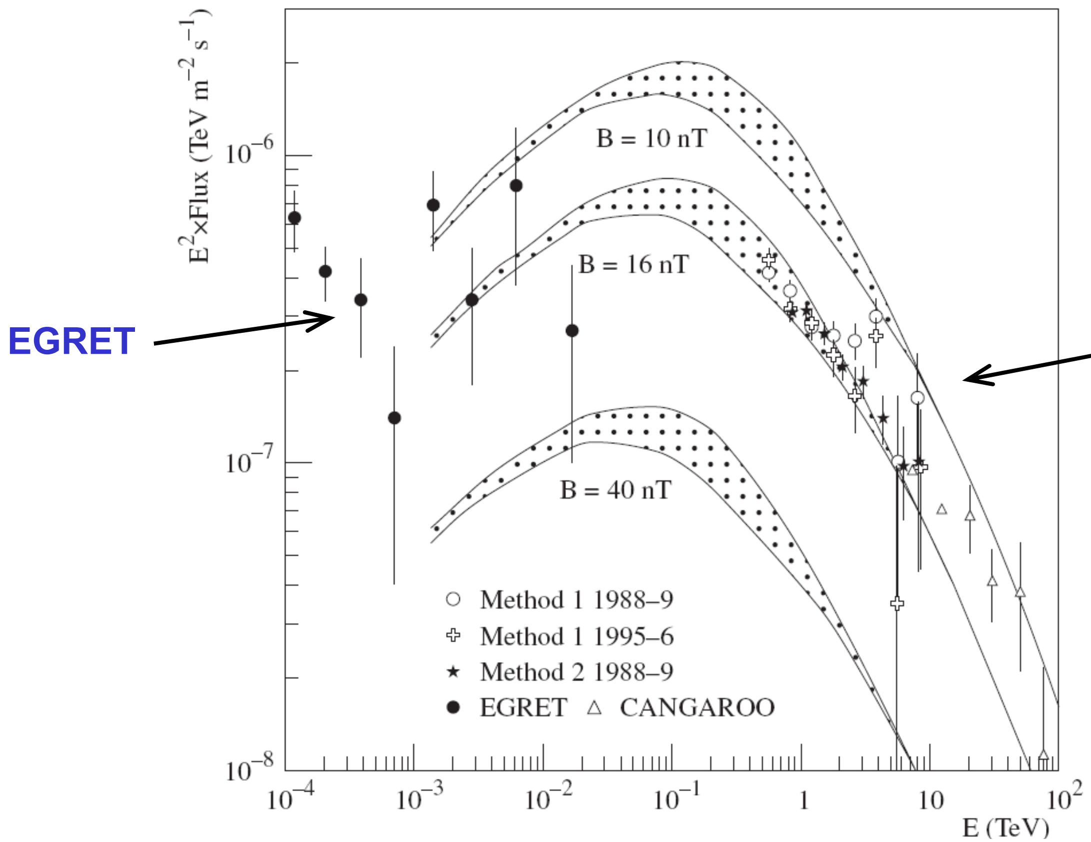


Illustration of spectra in the region of overlap that apparently are consistent with existing data

Hillas et al. (1998)

Estimates of Precision of Measurement of Break

- **Statistical uncertainties in determination of break energy (treating Hillas et al. figure as 2 power laws)**

Number of photons from Crab Nebula detected by GLAST in one year and relative error on the determination of E_{brk}. MAGIC is assumed to collect 50,000 gammas in 50 hours and the error on E_{brk} takes into account only the statistics as explained in the text.

E_{brk} (GeV)	Gammas seen by GLAST	$\delta E_{\mathrm{brk}}/E_{\mathrm{brk}}$	
		GLAST	MAGIC
50	3763	6.2%	4.0%
100	3249	8.2%	3.5%
150	2988	12.7%	2.9%
200	2818	17.2%	5.2%

correspondingly reduced by a factor of 0.8 as seen in Figure 2c.

Bastieri et al.

- **By this analysis, limitations on statistical uncertainties in the LAT measurement are what will limit the level to which systematic uncertainties can be corrected**
- **No comment in the paper about whether this level is useful**

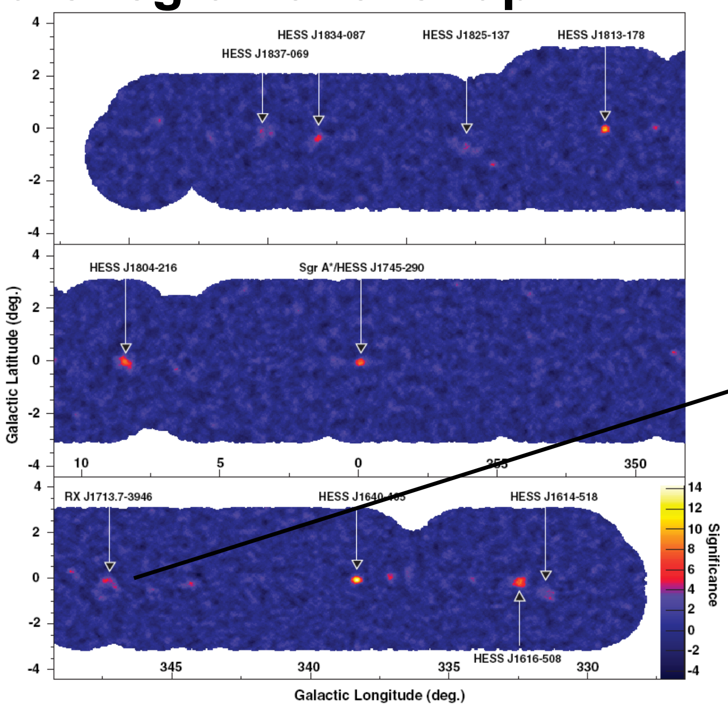
Problem: There's Only One Crab

- HEGRA upper limit on TeV flux of Geminga is 13% of Crab (Aharonian et al. 1999)
- HESS upper limit for Vela is 7% of the Crab (Masterson et al)
- Also, HESS threshold for Crab is >~350 GeV, would be similar for CANGAROO-III
- So, are there any alternatives for cross calibration?

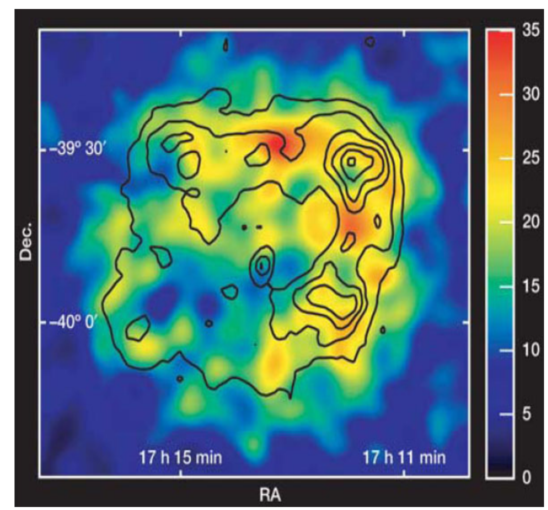
Check Out the HESS Source Catalog

- http://www.mpi-hd.mpg.de/hfm/HESS/public/HESS_catalog.htm
- The new plerions are at ~<10% Crab, so is G.C. source, but SNR RX J1713-3946 is 66% Crab (spectral index 2.2 above ~400 GeV, Aharonian et al. 2004) – a steady source
- Down side is spectrum is unknown, and probably not dramatic, in the region of overlap

HESS Galactic Plane Survey
Aharonian et al. (2005)



RX J1713-3946



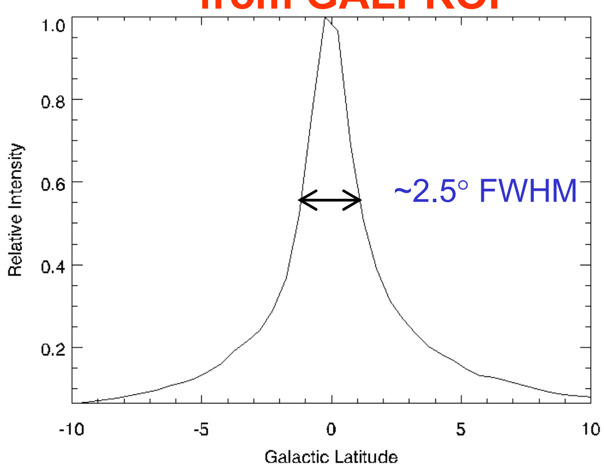
Another Possibility for Cross Calibration

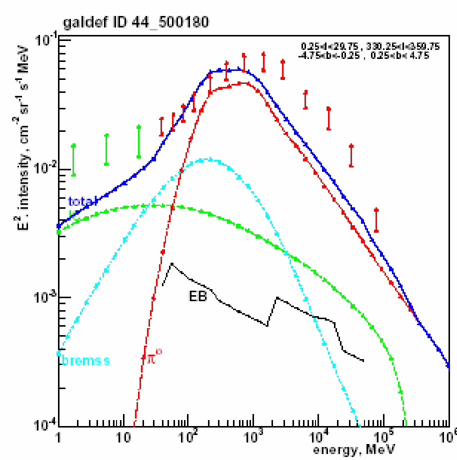
- Diffuse emission from the plane of the Milky Way may be a useful calibration source
- Historical note – it was used for exposure corrections for EGRET (show EGRET VP centers and sizes)
- *Advantages* – steady and bright, and can be studied at all elevations, in case you want to unfold the dependence of threshold and Aeff on zenith angle for your IACT.
- *Disadvantage* – diffuse (harder for background rejection)
  - HESS papers so far are fairly hard cuts on background and strongly filtered for small angular-size sources – so don't let the Galactic plane scan image fool you
  - Sources ~2.5° in extent should be within capabilities of the new generation of IACTs

Diffuse Emission (cont.)

- MILAGRO result (Fleysher 2003) says that the flux >1 TeV of Milky Way is ~10^{-9} cm^{-2} s^{-1} sr^{-1}, with spectral index 2.6
- Extrapolating to >200 GeV and on assumption of solid angle 4 × 10^{-3} sr, this is approximately equivalent to a source flux of 5 × 10^{-11} cm^{-2} s^{-1} (i.e., approx 50% Crab)
- The latitude distribution of diffuse intensity is quite narrow and will be resolved by IACTs
- Spectrally, we may even find a break in the region of overlap

Diffuse Intensity (|*l*| < 15°) from GALPROP





Spectrum of inner Milky Way may have a slight turnover at ~100 GeV from roll off of IC contribution

Strong, Moskalenko, & Reimer (2004)

Conclusions

- Systematic uncertainties in energy scale and effective area for IACTs are significant
- Cross calibration with the LAT is possible in principle, but will require long LAT exposures (steady sources)
- Also requires a spectral feature
- Unfortunately there's only one Crab, and the threshold and Aeff of IACTs depend on zenith angle
- A couple of other possibilities for calibration sources might be worth exploring: RX J1713-3946 (for the southern telescopes) and *diffuse emission of the Milky Way*

Bonus: What If Ground-Based Observatories Had Lower Energy Thresholds?

- Better overlap with GLAST, also better prospects for cross calibration in terms of sources and LAT observing times required
- Solar Tower Experiments – Wavefront sampling – large area collectors. Celeste is shut down, and STACEE is expected to end before GLAST launches.
  - Background problems (including sky brightness) are a fundamental issue for lowering the energy threshold with these experiments
- 5@5 concept (IACT with 5 GeV threshold at 5 km altitude) achieves lower threshold by going higher, where the Cherenkov light is less attenuated (and more light per unit area)
  - Unfortunately, being closer to where the showers form and also the need to use very short time gating apparently fundamentally limits how well the charged particle background can be discriminated against
  - Konopelko: "Altitude Effect in Cherenkov Light Flashes of Low Energy Gamma-ray-induced Atmospheric Showers" (astro-ph/0409514)

Backup slides follow