Calibrating Atmospheric Cherenkov Telescopes with the LAT

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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
- Stereoscopic (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 atmospheric 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
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*

*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

<table>
<thead>
<tr>
<th></th>
<th>LAT</th>
<th>New gen. IACTs</th>
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<tbody>
<tr>
<td>Energy range</td>
<td>0.02–300 GeV</td>
<td>~100–10,000 GeV</td>
</tr>
<tr>
<td>Angular resolution</td>
<td>~0.1° in energy range of overlap with IACTs</td>
<td>&lt;0.1°</td>
</tr>
<tr>
<td>Effective area</td>
<td>~10⁴ cm²</td>
<td>~3 x 10⁸ cm²</td>
</tr>
<tr>
<td>Field of view</td>
<td>2.2 sr</td>
<td>~4 x 10⁻³ sr</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>~80%</td>
<td>~10%</td>
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</table>
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

**EGRET**

**Whipple-era ACTs**

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 $E_{\text{brk}}$. MAGIC is assumed to collect 50,000 gammas in 50 hours and the error on $E_{\text{brk}}$ takes into account only the statistics as explained in the text.

<table>
<thead>
<tr>
<th>$E_{\text{brk}}$ (GeV)</th>
<th>Gammas seen by GLAST</th>
<th>$\delta E_{\text{brk}}/E_{\text{brk}}$</th>
<th>$\delta E_{\text{brk}}/E_{\text{brk}}$</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>GLAST</td>
<td>MAGIC</td>
</tr>
<tr>
<td>50</td>
<td>3763</td>
<td>6.2%</td>
<td>4.0%</td>
</tr>
<tr>
<td>100</td>
<td>3249</td>
<td>8.2%</td>
<td>3.5%</td>
</tr>
<tr>
<td>150</td>
<td>2988</td>
<td>12.7%</td>
<td>2.9%</td>
</tr>
<tr>
<td>200</td>
<td>2818</td>
<td>17.2%</td>
<td>5.2%</td>
</tr>
</tbody>
</table>

Bastieri et al.

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

- **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 $\sim 350 \text{ GeV}$, would be similar for CANGAROO-III
• So, are there any alternatives for cross calibration?
Check Out the HESS Source Catalog

- 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

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 $\sim 10^{-9} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$, with spectral index 2.6
- Extrapolating to >200 GeV and on assumption of solid angle $4 \times 10^{-3} \text{ sr}$, this is approximately equivalent to a source flux of $5 \times 10^{-11} \text{ cm}^{-2} \text{ s}^{-1}$ (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 ($|\ell| < 15^\circ$)

from GALPROP

~2.5° FWHM

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
Backup slides follow