First results from HAWC on GRBs

Dirk Lennarz
Ignacio Taboada
for the HAWC collaboration

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Gamma-Ray Bursts (GRBs)

- Central engine (e.g., the core-collapse of a rapidly rotating star, merger of two compact stellar remnants)
- Collimated relativistic outflow (fireball)
- Internal and external shocks
- Prompt keV– MeV emission ($10^{-2} - 10^3$ s)
- Multiwavelength afterglow emission

Artist impression of a GRB. Credit: NASA/Dana Berry, SkyWorks Digital
GRBs at Higher Energies

**Fermi-LAT**
- High energy (HE, $>100$ MeV) emission delayed
- HE emission temporally extended
- GRBs produce photons at very high energies (VHE, $>100$ GeV)

Acceleration mechanisms?

**VHE Observation of GRBs**
- Acceleration mechanisms (e.g. VHE photons challenge synchrotron emission scenarios)
- Probe the extragalactic background light (EBL)
- Search for Lorentz invariance violation

Artist impression of a GRB. Credit: NASA/Dana Berry, SkyWorks Digital
> 10 GeV Gamma-Ray Observatories

Wide Field of View
Continuous Operation

TeV Sensitivity

Fermi
AGILE
EGRET

HAWC
Milagro
ARGO
Tibet AS-γ

H.E.S.S.
VERITAS
MAGIC

Artist impression of Fermi. Credit: Fermi collaboration
- Sierra Negra volcano near Puebla, Mexico
- High altitude: 4,100m
- 20,000 m² covered with 300 water Cherenkov detectors (WCD)
- 200,000 litres of purified water per WCD
- 1,200 PMTs
- Completed in March 2015
HAWC Limits on GRB 130427A

- Most powerful burst ever detected $z < 0.5$
- Longest lasting HE emission ever detected

- Low in the sky for HAWC
- 10% of final detector

Upper limits

Easily detectable for the final detector at low zenith!

HAWC GRB Observations

- Science operations started August 2, 2013
- HAWC-111: data until July 8, 2014
- Uptime fraction 83% (includes time for construction)

GRB selection

- Using LAT, GBM, Swift online tables
- Considering GRBs down to a zenith angle of 51°
- LAT: 1 (GRB 130907A), but during downtime
- GBM: ~40 (6 without data, only 1 since October 2013)
- Swift: 22 (4 without data)

✔ Analyse the 18 well localized Swift bursts
Analysis Method

- Define angular bin (search bin) around GRB position
- Estimate number of background events in search bin
- Significance of excess from Poisson distribution

Optimal search bin size

- GRB with $E^{-2}$ spectrum
- Optimise signal (S) over square root of background (B)
- Depends on burst redshift $z$

Conservatively chose 3°
Detector Rate

- Search duration: $T_{90}$
- Rate is constant with 12 h sinusoidal oscillation on top (~0.5%)
Search Bin Rate

- ON/OFF method (at T=0 follow GRB for $T_{90}$, otherwise offset search bin by multiples of $T_{90}$ in right ascension)
- Red line: scaled detector rate to match summed counts in search bin

[Graph showing time vs. rate with GRB 140423A]
### Results

<table>
<thead>
<tr>
<th>GRB</th>
<th>Trigger Number</th>
<th>Time UTC</th>
<th>RA J2000</th>
<th>DEC J2000</th>
<th>Zenith Angle</th>
<th>BAT T90 s</th>
<th>Significance σ</th>
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<td>140628A</td>
<td>602803</td>
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<td>02h42m39.88s</td>
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<td>09:36:04</td>
<td>21h08m41.56s</td>
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<td>33.4</td>
<td>0.13</td>
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<td>601051</td>
<td>17:13:31</td>
<td>05h45m29.52s</td>
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<td>27.9</td>
<td>109.9</td>
<td>3.42</td>
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<td>599287</td>
<td>09:17:46</td>
<td>15h09m00.60s</td>
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<td>60.5</td>
<td>-0.61</td>
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<td>12.4</td>
<td>4.9</td>
<td>0.96</td>
</tr>
</tbody>
</table>
Results

- 25,188 fake GRB positions in HAWC-111 data, at zenith angles between 0 and 60°
- Well fitted by a Gaussian, background understood to the 4σ level

\[
\chi^2 / \text{ndf} = 32.5 / 36 \\
\text{Mean} = -0.049 \pm 0.006 \\
\text{Sigma} = 1.014 \pm 0.005
\]
• Only burst above $3\sigma$
• Accounting for trials: $2.5\sigma$
• Detected by the BAT only, *Swift* couldn’t slew (Sun observing constraint)
• No other observations were reported for this GRB
Online Analysis

Triggered GRB analysis
- Connected to GCN
- Apply analysis to online reconstructed data
- Results for 1s, 20s, 300s within < 2 hours

Untriggered GRB analysis
- Near real time
- Low latency search of overhead sky (within 60° of zenith)
- Searching 0.1, 1, 10s
- Sensitivity cost compared to triggered search due to trials

Poster #68, J. Wood
*The All-Sky Sensitivity of HAWC to Gamma-Ray Bursts*
Outlook

- Search other time windows than $T_{90}$
- Optimised angular bin size for next stage of HAWC
- Exploring application of gamma-hadron separation cuts

HAWC is sensitive enough to detect several historical (like GRB 090510, 090902B, 130427A) [HAWC collaboration, Astropart. Phys. 35 (2012) 641]

In addition to exceptional bursts, HAWC might detect other GRBs with a rate as high as 1–2 GRBs per year [Taboada & Gilmore, NIM A 742 (2014) 276]

Even the absence of detections will be useful in constraining the highest energy of GRB spectra