Initial Results from HAWC on Gamma-Ray Bursts

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for the HAWC Collaboration

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Outline

• What is the HAWC Observatory?
• What can it contribute to GRB Science?
• Initial Results on Gamma-Ray Bursts
• Current real-time searches
High Altitude Water Cherenkov Observatory

- Inaugurated in March, 2015
- In central Mexico at an altitude of 4100 m
- Comprised of 300 water tanks instrumented with 4 upward facing photomultiplier tubes
- Detects secondary air shower particles at ground level from both gamma- and cosmic-ray primaries
HAWC Overview

- continuous readout of air shower events @ 24 kHz trigger rate
- for each event we reconstruct its angle & energy and determine type (γ or CR)
- ~100 GeV threshold near zenith
- angular resolution < 1.0°
- near 100% duty cycle
- 2 sr FoV (no need for pointing)
- 100 times size of FERMI @ 100 GeV
Simulated response to GRB090510

- Simulate response to GRB090510
  - extrapolate FERMI SED with abrupt 125 GeV cutoff
  - $z = 1$
  - $\cos(\Theta) = 0.9$
  - 200 signal photons

- HAWC can see full high energy time structure before, during & after a GRB
HAWC and GRBs

Simulated response to GRB090510

- Simulate response to GRB090510

FERMI

Simulated HAWC

HAWC and GRBs

Expect < 1.5 GRB per year from follow-ups of satellite reported GRBs with the full HAWC-300 detector

(I. Taboada, R.C. Gilmore, NIM A 742 (2014), 276-277)

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Initial Results

• Follow-up observations of reported GRBs

Time Period

August 2, 2013 - July 8, 2014 (HAWC-111)
Partial detector, 83% uptime due to construction

GRB Selection

GRBs within 51° of zenith reported from:

LAT: 1 (GRB 130907A), but during downtime
GBM: ~40 (6 without data, only 1 since October 2013)
Swift: 22 (4 without data)
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  Analyzed 18 well localized bursts from **Swift**
Follow-up Method

- Define a 3° radius spatial bin (optimized for GRB gamma-rays seen by HAWC-111) around the reported Swift location.

- Count the number of air showers arriving in this bin during T90

- Compare to expected counts from rate at that location in local coordinates

- Obtain p-value from Poisson statistics and convert to $\sigma$
Follow-up Results

- No $>5\sigma$ detections
- Most significant result is GRB140607A
  $3.4\sigma$ pre-trials,
  $2.5\sigma$ post-trials
- Performing the follow-up method on 25,000 random locations across the sky throughout HAWC-III period yields $\mu = 0, \sigma = 1$

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Full list of analyzed GRBs:

D. Lennarz, I. Taboada. Proceedings of the 34th ICRC
http://arxiv.org/abs/1508.07325
GRB130427A

• Most powerful ever detected z < 0.5. Longest high energy emission.

• Main data acquisition system (DAQ) was OFF at the time

• Less sensitive scaler DAQ was ON. No direction, just overall PMT rates. Provides limits on high energy emission.

• Easily detectable now with HAWC-300!

Real-Time GRB Searches

• HAWC triggers and reconstructs showers in real-time (~ 4 sec), all day, every day

• Currently running two search methods on real-time data:

  **Method 1:** Follow-ups of *Swift* triggers with ~2 min latency
  (same as presented here, but with full HAWC300)

  **Method 2:** Untriggered search of the full overhead sky on
  4 timescales (0.1, 1, 10, 100 sec) with ~4 sec latency

  Idea is roughly the same as method 1 (tile sky with optimal
  bins, analyze poisson distributed counts within fixed window)
  but you search the full sky continuously in time.

  Lots of trials!

  **Full details:** J. Wood. Proceedings of the 34th ICRC
Untriggered, All-Sky Search

- 1 second duration, shifted by 10% over the course of a full day with spatial bins shifted by 10% over the full sky yields $\sim 10^{12}$ trials

- Only requires 2x flux increase over triggered search, opens up sky where satellites are not overhead

- Let’s you see really cool background fluctuations!
  
  $P_{\text{pre}} = 6 \times 10^{-13}$, $P_{\text{post}} = 4 \times 10^{-2}$

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**Light Curve (Candidate #729)**

**Polarization Map**

- Candidate location
- Signal

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<table>
<thead>
<tr>
<th>Pre</th>
<th>Post</th>
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<tbody>
<tr>
<td>$P_{\text{pre}} = 6 \times 10^{-13}$</td>
<td>$P_{\text{post}} = 4 \times 10^{-2}$</td>
</tr>
</tbody>
</table>

No significant detections yet.

AMON is working on adding our sub-threshold events to their database for correlation with other experiments.

Still working on getting a framework for reporting results to GCN.
Summary

• HAWC should be able to detect ~1 GRB per year, providing temporal and spectral information at ~100 GeV

• Sensitive enough to detect several historical bursts (GRB090510, GRB130427A)

• Running both triggered and untriggered GRB searches in real-time

• No significant detections yet, but the future is bright!
Backup
18 *Swift*-detected GRBs

<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 (deg)</th>
<th>BAT T90 (s)</th>
<th>Significance (σ)</th>
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<tr>
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<td>602803</td>
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<td>21h08m41.56s</td>
<td>-14d25m09.3s</td>
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<td>0.13</td>
<td>-0.93</td>
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<td>109.9</td>
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<td>599287</td>
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<td>15h09m00.60s</td>
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<td>597722</td>
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<td>13h09m08.54s</td>
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<td>08h27m57.56s</td>
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