All-Sky Sensitivity of the HAWC Observatory to Gamma-Ray Bursts

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GRB Science

Gamma-ray bursts (GRBs) are intense gamma-ray flashes believed to originate from the collapse of massive stars and the merger of compact object binaries [1]. The basic theory of GRB emission is the same for both progenitors: a black hole powering a highly relativistic jet [2][3]. Measurements of the highest energy GRB photons are key to developing emission models because they provide estimates of the bulk Lorentz factor in the region where gamma-rays are produced [4]. They can also constrain the density of extra-galactic background light [5] and possible violations of Lorentz invariance [6].

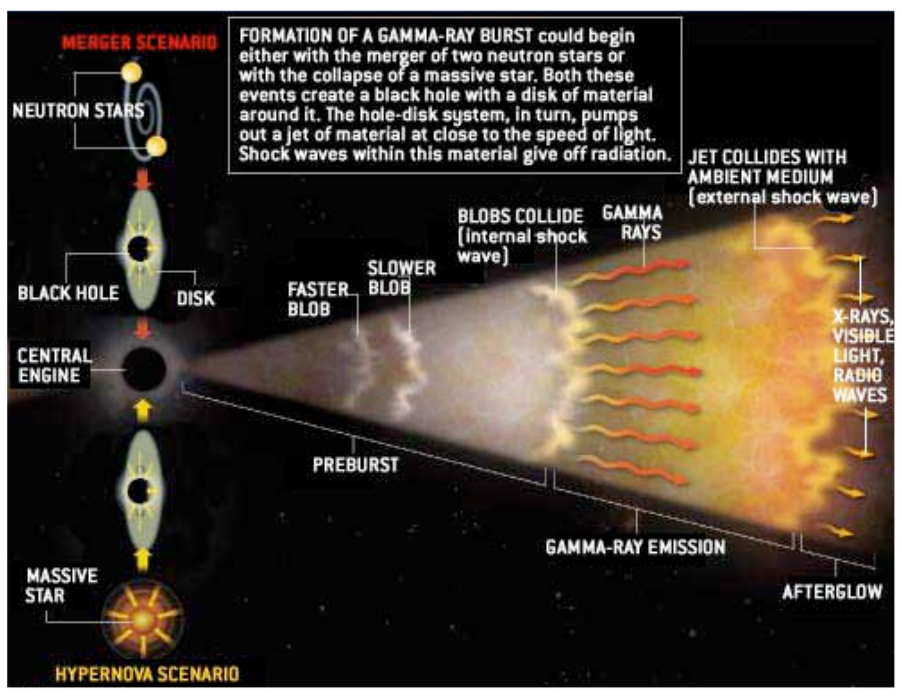
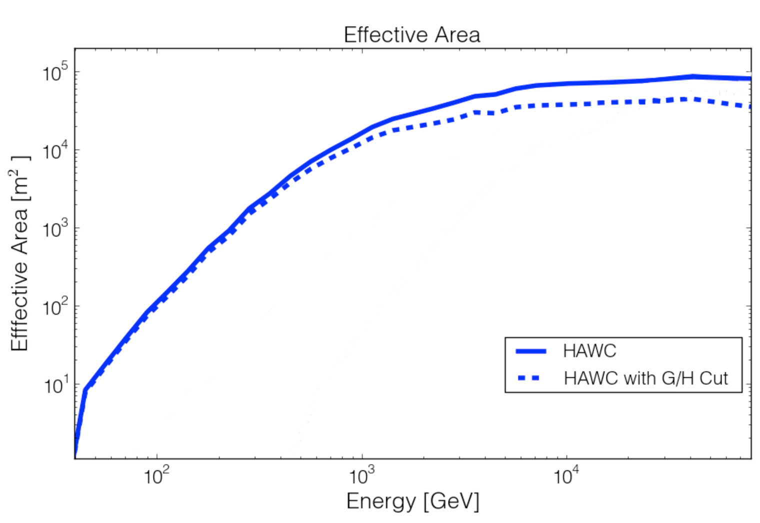


Figure 1 - Theoretical fireball model for GRB emission [7]

The HAWC Observatory

The HAWC Observatory is an array of 300 water tanks located at 19˚ N at an altitude of 4100m. Each tank is instrumented with 4 upward facing PMTs that record Cherenkov light from gamma- and cosmic-ray air shower particles as they arrive at ground level. Showers are reconstructed with an angular resolution better than 1˚ [8].

The main advantages of HAWC for detecting high energy GRB photons are its large effective area (>100x the size of Fermi at energies >100 GeV) and its wide (2 sr) field of view, which eliminates the need for pointing.



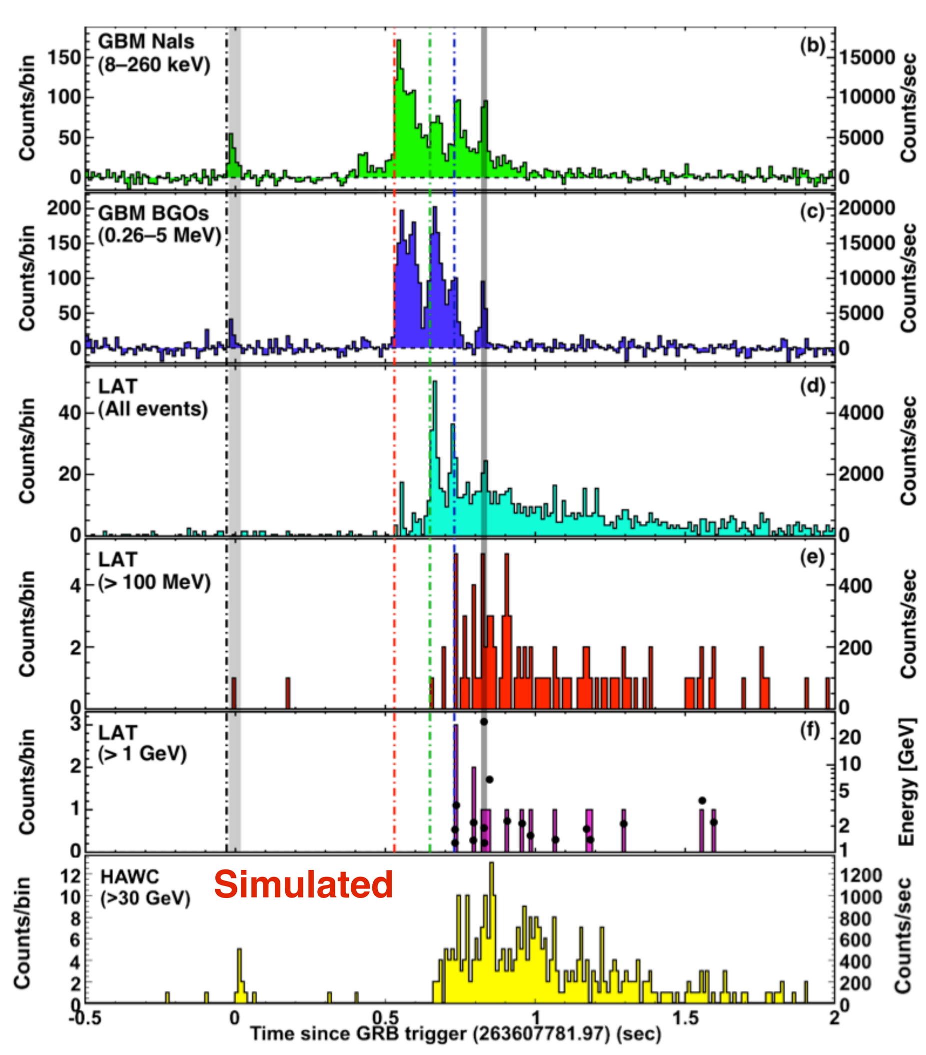


Figure 2 - (Top) Effective area vs energy for the 300 tank array. (Right) Simulated response of HAWC to GRB090510. There have been even brighter bursts since this figure was made.

Background Estimation

We estimate the background in each bin by integrating all triggered showers in a map of declination versus hour angle over a 1.5 hour period. We normalize this map to one and smooth it into our 2.3˚ x 2.3˚ spatial search bins to obtain the fraction of showers entering each bin. This gives:

N_{BG}(bin) = (integrated map bin) x (trigger rate) x (search duration)

The observed counts for this expectation follow a Poisson distribution.

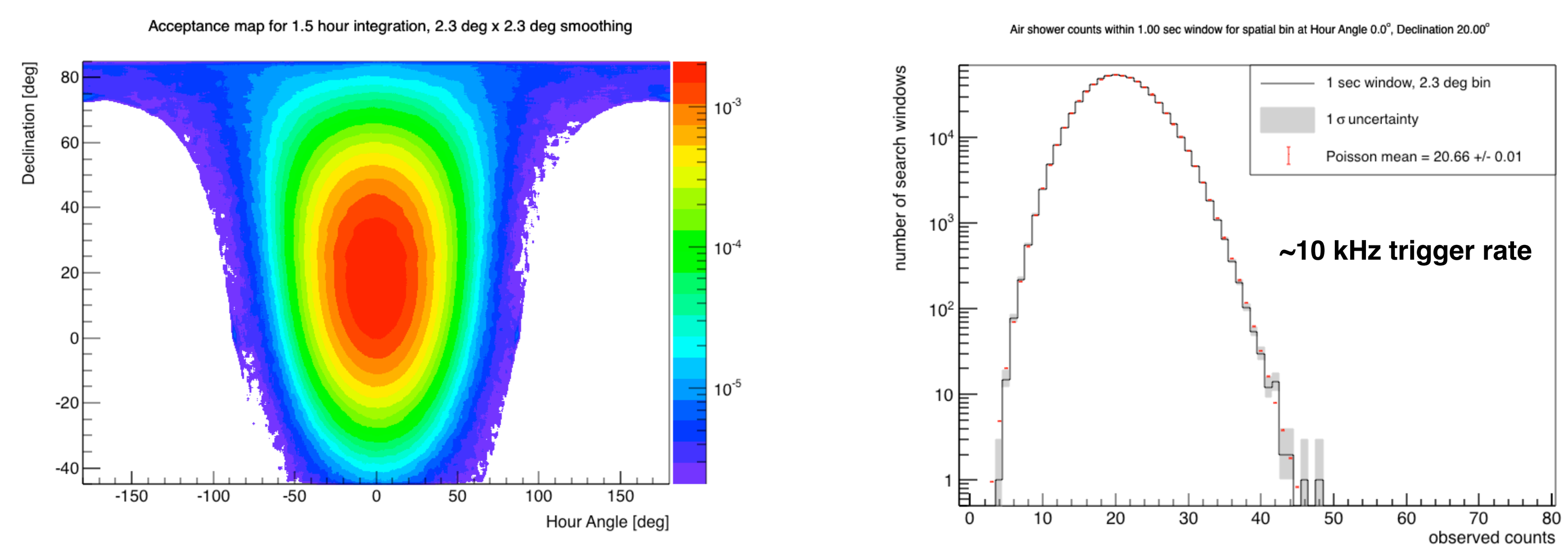


Figure 4 - (Left) Background integrated for 1.5 hours and normalized to one. (Right) Observed counts near zenith for 1 day of 250 tank data.

Speedup Techniques

We employ two methods to skip the computation of search bins consistent with background

(1) skip bins with < 2 counts for durations < 0.1 seconds

(2) skip bins adjacent to P ≥ 10^{-2} for durations ≥ 0.1 seconds

We efficiently obtain probabilities in each method using a pre-calculated table of Poisson probabilities.

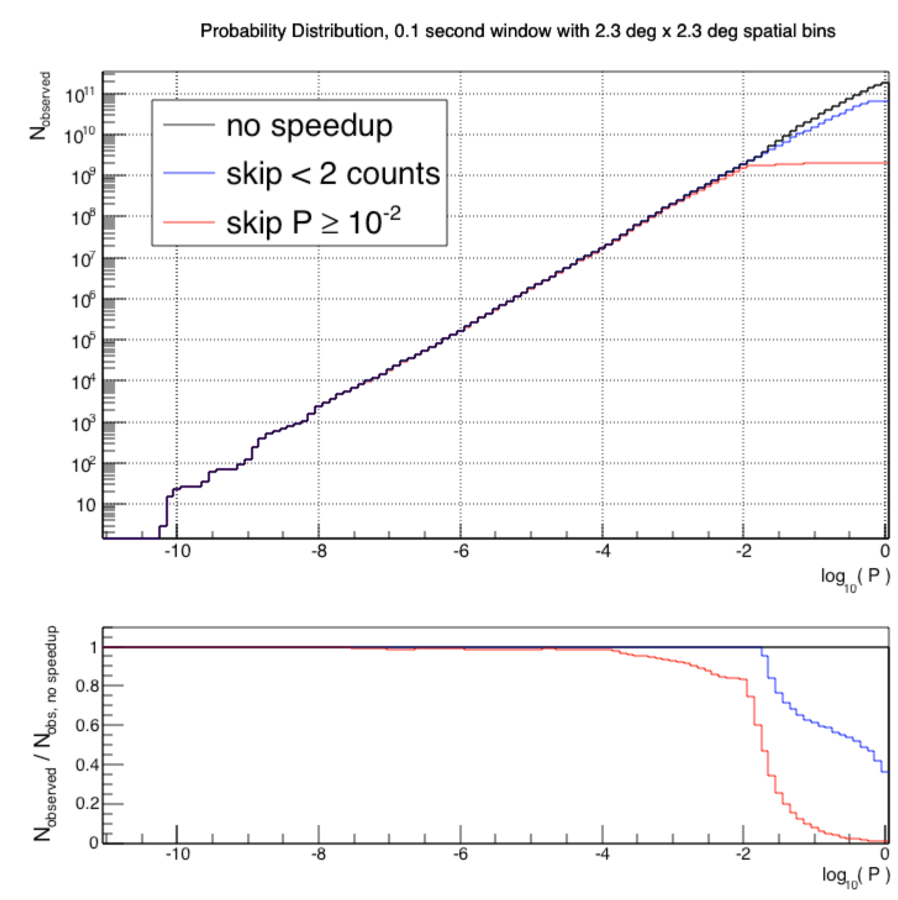


Figure 5 - Probability distributions for searching every bin (black), skipping bins with < 2 counts (blue), and skipping bins adjacent to P ≥ 10^{-2} (red). Searching every bin correctly produces a line of slope 1. Both methods for skipping bin evaluation preserve rare probabilities where we expect signal.

All-Sky GRB Search Sensitivity

For the 1 second search duration we take:

(8.64×10^5 temporal trials) X (1.33×10^6 spatial trials)

over the course of 1 day. This requires only a 2x higher flux compared to the flux for a 5σ discovery in single trial if we treat each trial independently. This gives a sensitivity of ~ 4×10^{-6} erg cm^{-2} s^{-1} at 10 GeV assuming a spectrum $dN/dE \propto E^{-2}$, a high energy cutoff of 100 GeV, and the detector response in [9]. A burst like GRB090510 is detectable under these assumptions. This search should also be sensitive to other transients with similar timescales and spectra, such as evaporating primordial black holes [10].

All-Sky GRB Search Method

We continuously search the HAWC observatory's field of view in near-real time for GRB signals over three durations: 0.1, 1, and 10 seconds. We shift each duration forward by 10% its width and test all points within 60˚ of detector zenith against the hypothesis that the air shower count comes from the average air shower rate. We smooth showers with 2.3˚ x 2.3˚ square bins roughly equal in area to the optimal round bin in reference [8]. This is computationally efficient, allowing us to search using 0.11˚ steps in right ascension and declination with an average latency < 5 seconds.

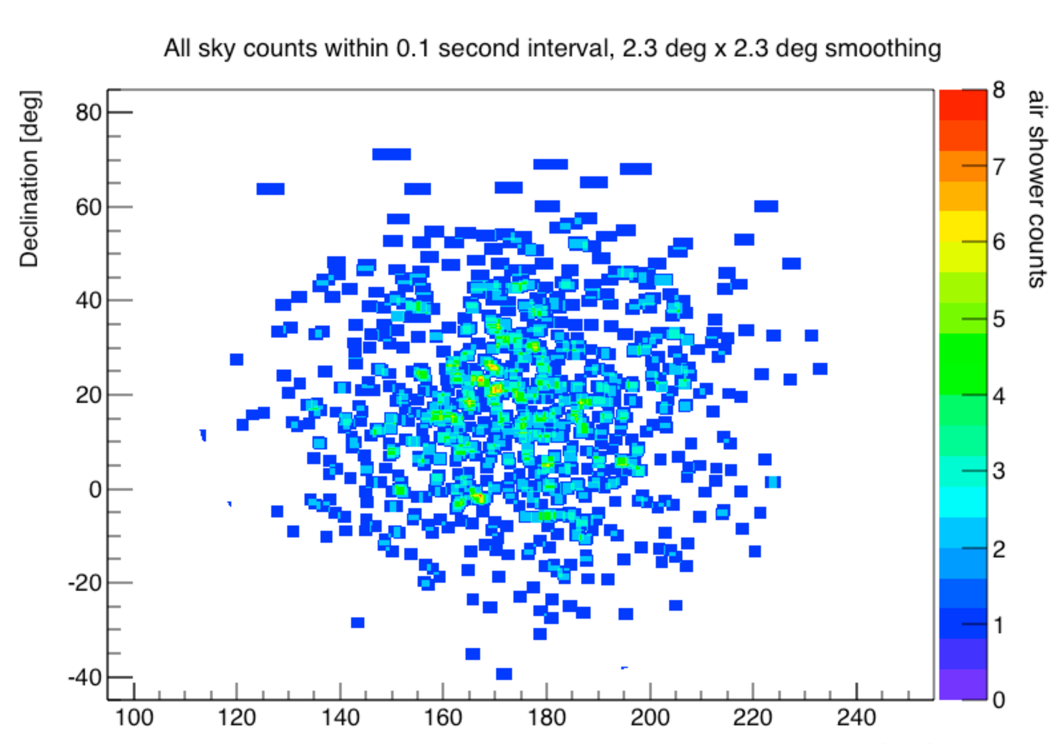


Figure 3 - Sky map in equatorial coordinates of air shower counts within 0.1 second duration

Acknowledgements

We acknowledge the support from: the US National Science Foundation (NSF); the US Department of Energy Office of High-Energy Physics; the Laboratory Directed Research and Development (LDRD) program of Los Alamos National Laboratory; Consejo Nacional de Ciencia y Tecnología (CONACyT), Mexico (grants 260378, 232656, 55155, 105666, 122331, 132197, 167281, 167733); Red de Física de Altas Energías, Mexico; DGAPA-UNAM (grants IG100414-3, IN108713, IN121309, IN115409, IN111315); VIEP-BUAP (grant 161-EXC-2011); the University of Wisconsin Alumni Research Foundation; the Institute of Geophysics, Planetary Physics, and Signatures at Los Alamos National Laboratory; the Luc Binette Foundation UNAM Postdoctoral Fellowship program.

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