Search of very high energy emission from GRBs with HAWC

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Abstract:
Gamma-ray bursts (GRBs) are the most captivating extragalactic astrophysical phenomena. These transient events have been widely proposed as the sources of the most energetic cosmic rays and gravitational waves. With its wide field of view (~2 str) and its >95% duty cycle, the High Altitude Water Cherenkov (HAWC) Observatory, installed at 4,100 m a.s.l. in the state of Puebla (Mexico), is the optimal instrument to search for VHE photons (> 100 GeV) from GRBs. We report results obtained from the analysis of a sample of GRBs detected by satellite instruments in the field of view of HAWC. We particularly discuss the case of GRB 170817A/GW 170817 which has been associated to the first detection of gravitational waves and multi-messenger observations from a merger of two neutron stars. We also describe different search approaches currently used by HAWC, an all-sky search method as well as a real-time analysis of GRBs triggered by satellites. Results and physical implications are discussed in the framework of current GRBs models.

Very high energy (VHE) emission from GRBs

In the framework of the external shock model, electrons are accelerated by a relativistic expanding blast wave, emitting radiation by **synchrotron** and **inverse Compton** (**synchrotron self-Compton - SSC**) processes. SSC emission is expected up to VHE [1,2,3]

$$E^{ssc}_{\gamma,m} \propto \epsilon_e^4 \epsilon_B^{1/2} n^{-1/4} E^{3/4} t^{-9/4}$$

$$E^{ssc}_{\gamma,c} \propto \epsilon_B^{-7/2} n^{-9/4} E^{-5/4} t^{-1/4}$$

assuming $E^{ssc}_{\gamma,c} \le E_\gamma \le E^{ssc}_{\gamma,m}$

Light curve & Spectrum of the expected signal ➡

$$\boxed{F_\nu^{ssc} \propto \epsilon_{B,f}^{-5/4} n^{1/8} D^{-2} E^{5/8} t^{1/8} E_\gamma^{-1/2}}$$

The High Altitude Water Cherenkov Observatory

HAWC, installed at 4100 m a. s. l in volcano Sierra Negra in the state of Puebla, México, is the **ideal instrument** to study the transient sky at very high energies (VHE):

- 24/7 continuous observations,
- duty cycle > 95% and,
- instantaneous field of view of 2 sr (16% of the sky each day)

HAWC can follow up all the GRB triggers inside its field of view during their prompt phase (around the trigger time)

Two search strategies

1. All-sky search

A self-triggered all-sky analysis system is continuously running. It scans the field of view of HAWC searching for possible transient candidates over three different sliding **time windows**: **0.2, 1, and 10 seconds.**

Each window shifts forward in time by 10% its width and is binned in space using a **grid of 2.1 x 2.1 square degrees**. [4].

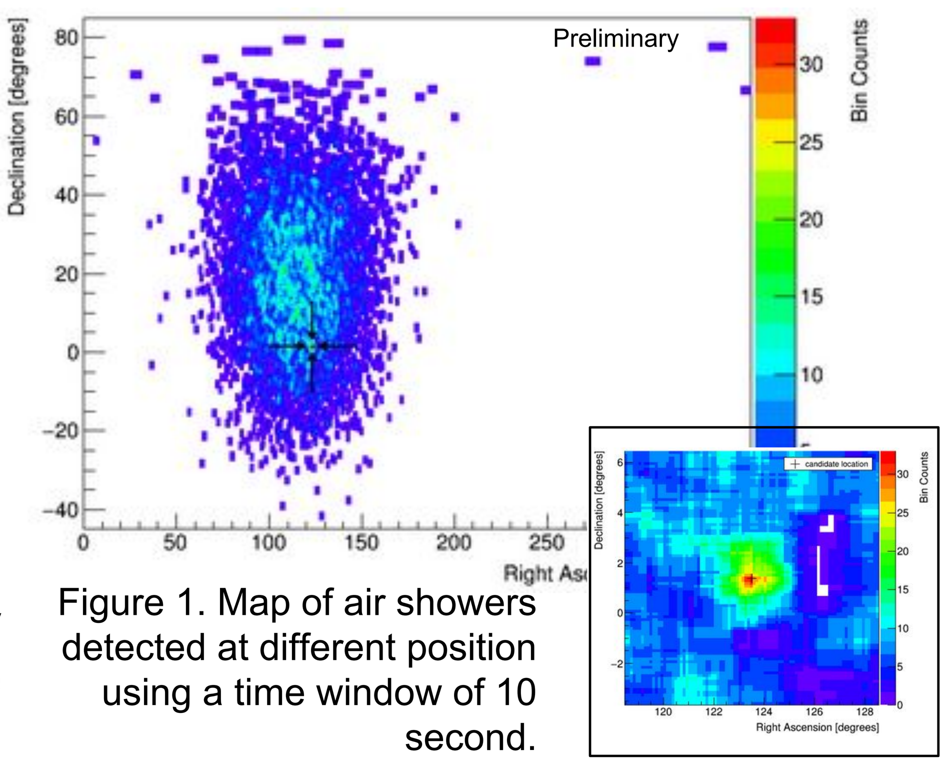
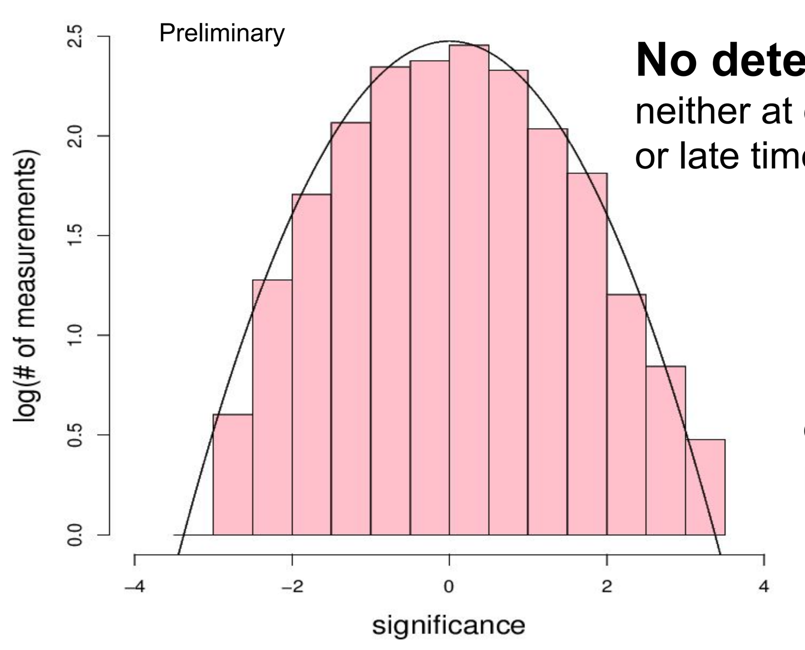


Figure 1. Map of air showers detected at different position using a time window of 10 second.
The bottom-right plot is a zoom on the position of the best candidate.

2. Triggered GRB follow-up

- An automatic procedure runs for each GRB detected by satellites inside the HAWC´s field of view (zenith angle < 45°).
- First Search is performed at the position provided by the satellite.
- A second analysis is performed after a refined calibration and reconstruction.
- A full description of the method used to analyze the signal is presented in [5]
- **146 GRBs analyzed:** 29 shorts 117 long from December 2014 to February 2018.
- A search for delayed and/or extended signal (as expected from Fermi/LAT [6] observations) is performed.



No detection neither at early or late times

Significance derived over **ten consecutive time windows** of the same duration for each GRB

Short GRBs - 2 s time window
Long GRBs - T_{90} time window

Figure 2. Distribution of all the significances derived for each time window and for all the GRB positions inspected in our sample. The histogram is consistent with a standard normal distribution.

We use the HAWC upper limits to constrain the **density of the external medium** and the **microphysical parameters**

GRB 170206A

GRB 170206 is the **third brightest GRB** ever detected by Fermi/GBM [7]. It provides the **Most constraining upper limits!**

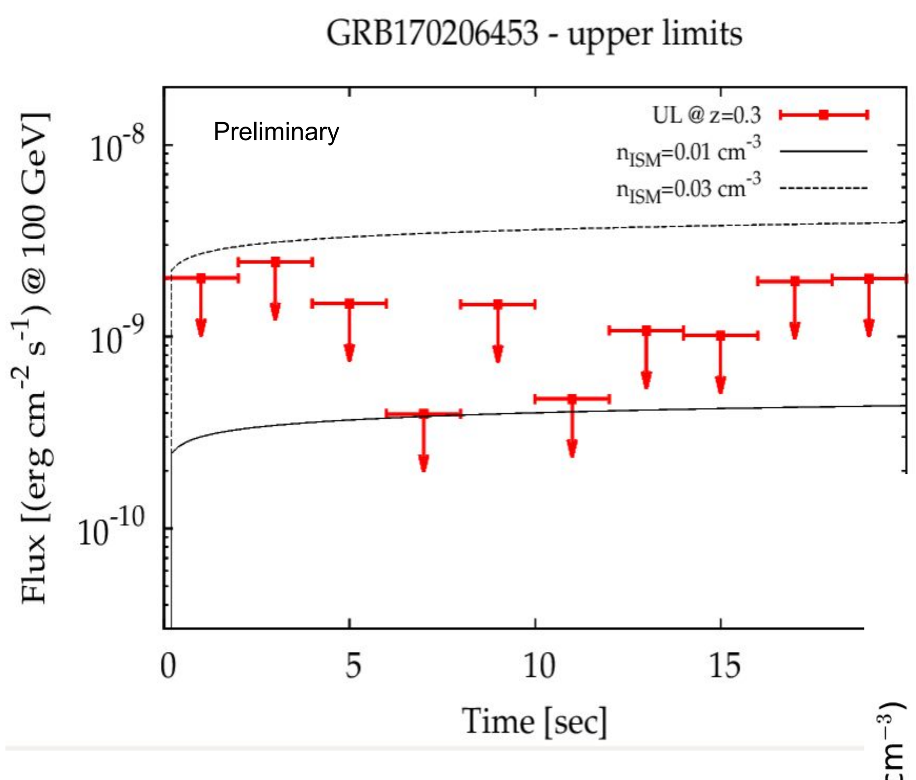


Figure 3. Upper limits compared to the theoretical expectations. Flux limits are calculated considering EBL absorption [8]. For an external medium density of 0.01 particles per cm^3 the flux limits are consistent with the model expectations. It is not the case assuming n=0.03 particles per cm^3.

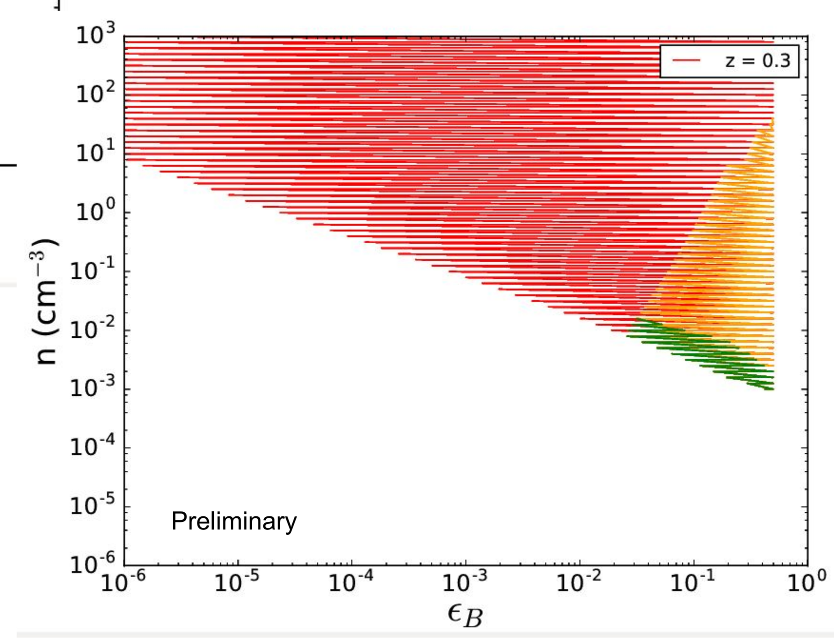


Figure 4. Density of the external medium vs fraction of energy transferred to the magnetic field. The red region is the set of parameters excluded considering the HAWC limits. Orange and green are the allowed regions for the relativistic (Klein-Nishina) and non relativistic regime, respectively

GRB 170817A / GW 170817

HAWC started the observation of GRB 170817A ~9 hrs from the GRB/GW trigger and **no detection** was reported for this first transit [9] . Radio and X-ray detections came 9 and 16 days later.

If a SSC counterpart exists, it most likely will be observed at the same time of the X-rays and/or radio emissions.

Flux limits were derived above 40 TeV over 9 consecutive logarithmic time windows between the trigger and the maximum of the X-rays/radio light curve. The limits are above the VHE flux expected for SSC from the external shock.

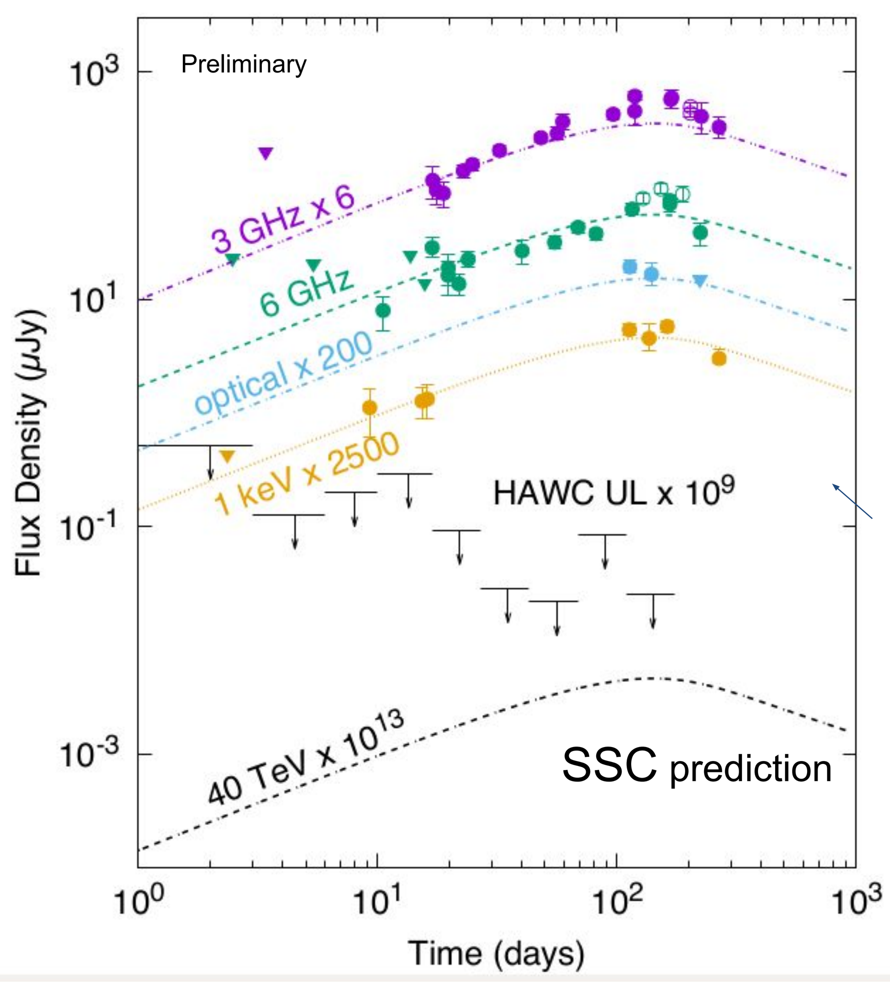


Figure 5. GRB 170817A afterglow multiwavelength observations (radio, optical and X-ray) together with the HAWC upper limits. Black dashed line shows the signal expected from the external shock by SSC.
We take into account the EBL absorption [8]

SUMMARY

- Different techniques are currently used to search for VHE emission from GRBs:
  - An **all-sky search** constantly looking for possible candidates
  - A **follow-up system** analyzing the position of the GRB triggered by the satellite
- We analyzed **146 GRB** inside the field of view of HAWC from December 2014 to February 2018
- **No detection** of signal, neither during the prompt phase nor at late time.
- **GRB170817A** was not visible from HAWC during the prompt. **We do not find any VHE signal related to the afterglow phase**
- Most conservative upper limits were obtained for GRB 170206A

  Flux limits used to **constrain the density of the external medium, bulk Lorentz factor** and **microphysical parameters**

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