Searching for Gamma-Ray Bursts with the High-Altitude Water Cherenkov (HAWC) Observatory

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HAWC Collaboration

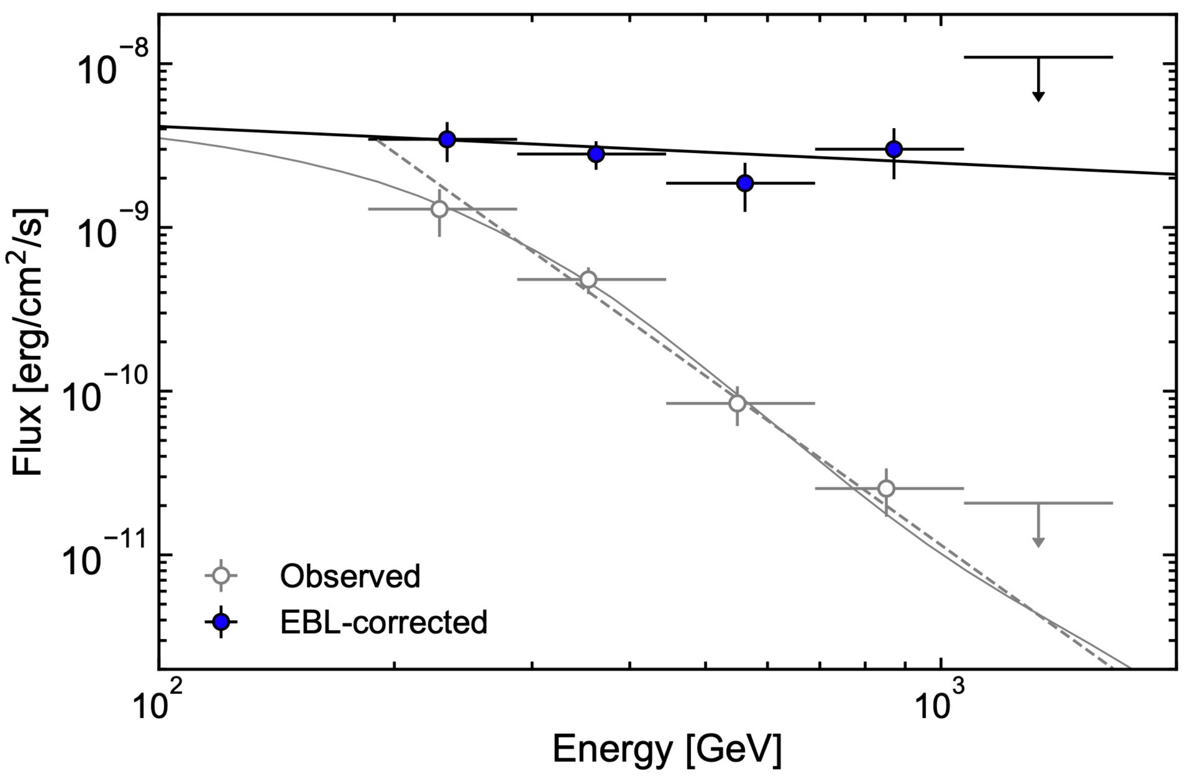
The Highest-Energy Emission from GRBs

→Satellites and IACTs have shown that GRBs are capable of producing VHE photons

- GRB 190114C Observed up to 1 TeV by the MAGIC Telescopes

→Detection of such high-energy emission would provide key information about the origins of prompt GRB emission as well as other potential physics:

- Insights into acceleration mechanisms—estimate bulk Lorentz factor
- Probe extragalactic background light (EBL)
- Test for Lorentz Invariance Violation



MAGIC Spectrum above 0.2 TeV averaged over T_0+62 s to T_0+2,454 s for GRB 190114C

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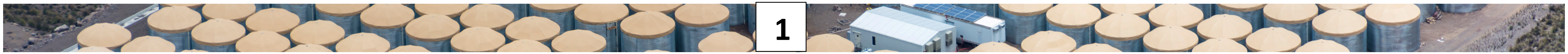
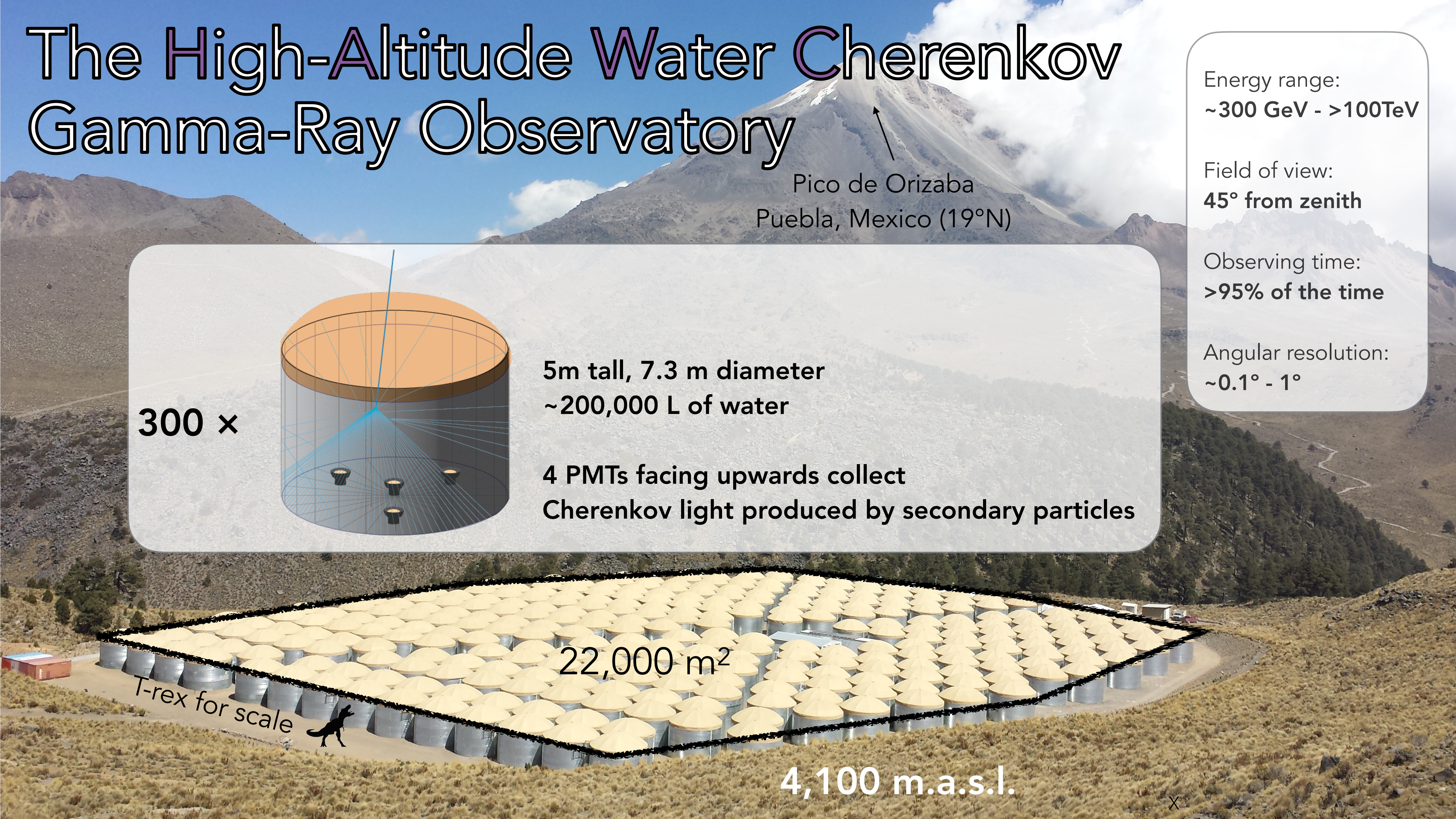
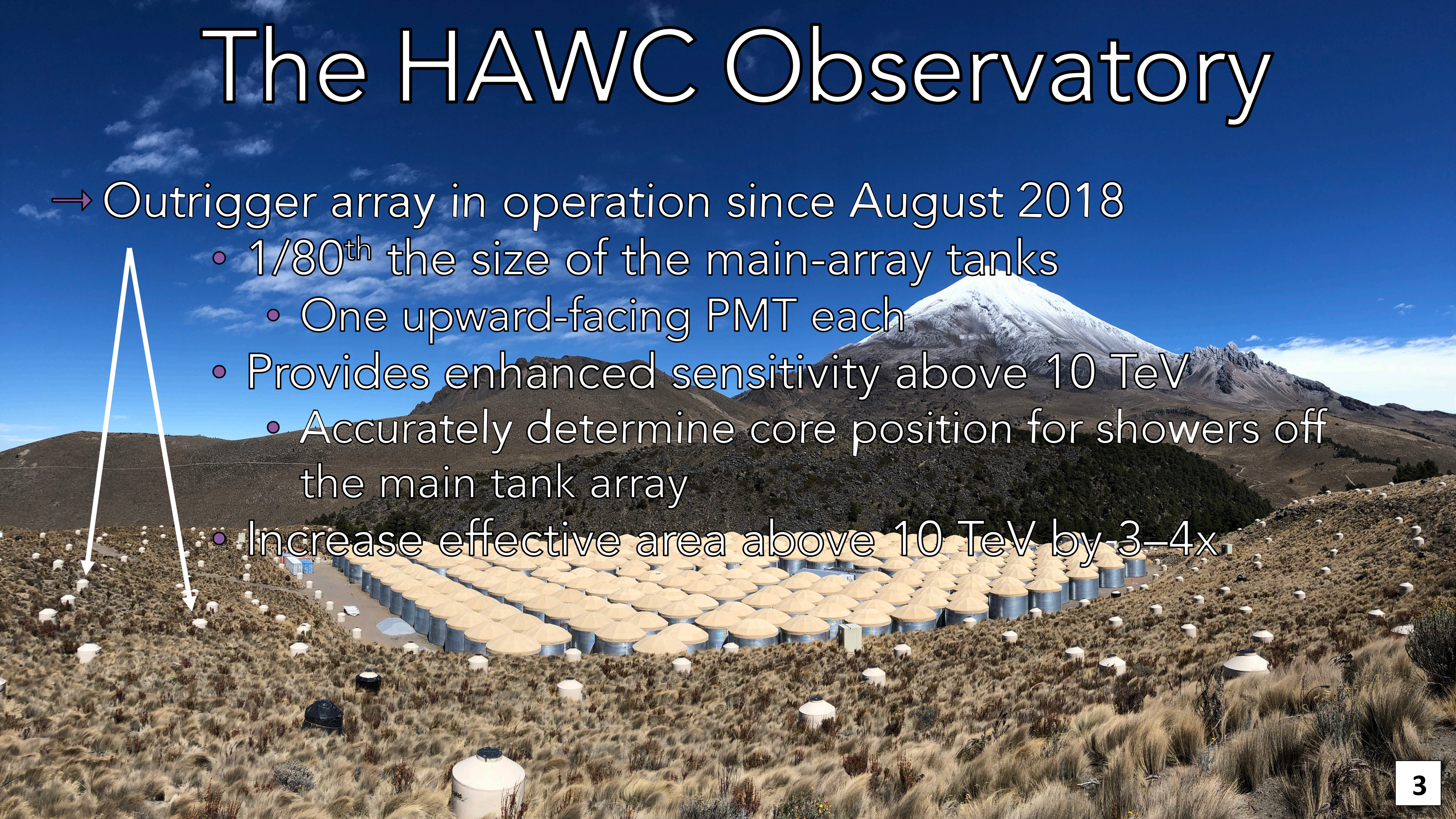



The High-Altitude Water Cherenkov
Gamma-Ray Observatory
Pico de Orizaba
Puebla, Mexico (19°N)
Energy range:
~300 GeV - >100TeV
Field of view:
45° from zenith
Observing time:
>95% of the time
Angular resolution:
~0.1° - 1°
300 ×
5m tall, 7.3 m diameter
~200,000 L of water
4 PMTs facing upwards collect
Cherenkov light produced by secondary particles
22,000 m²
T-rex for scale
4,100 m.a.s.l.

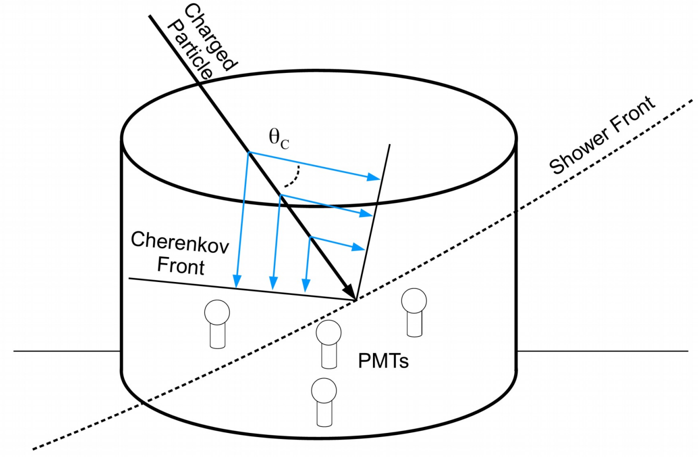
The HAWC Observatory

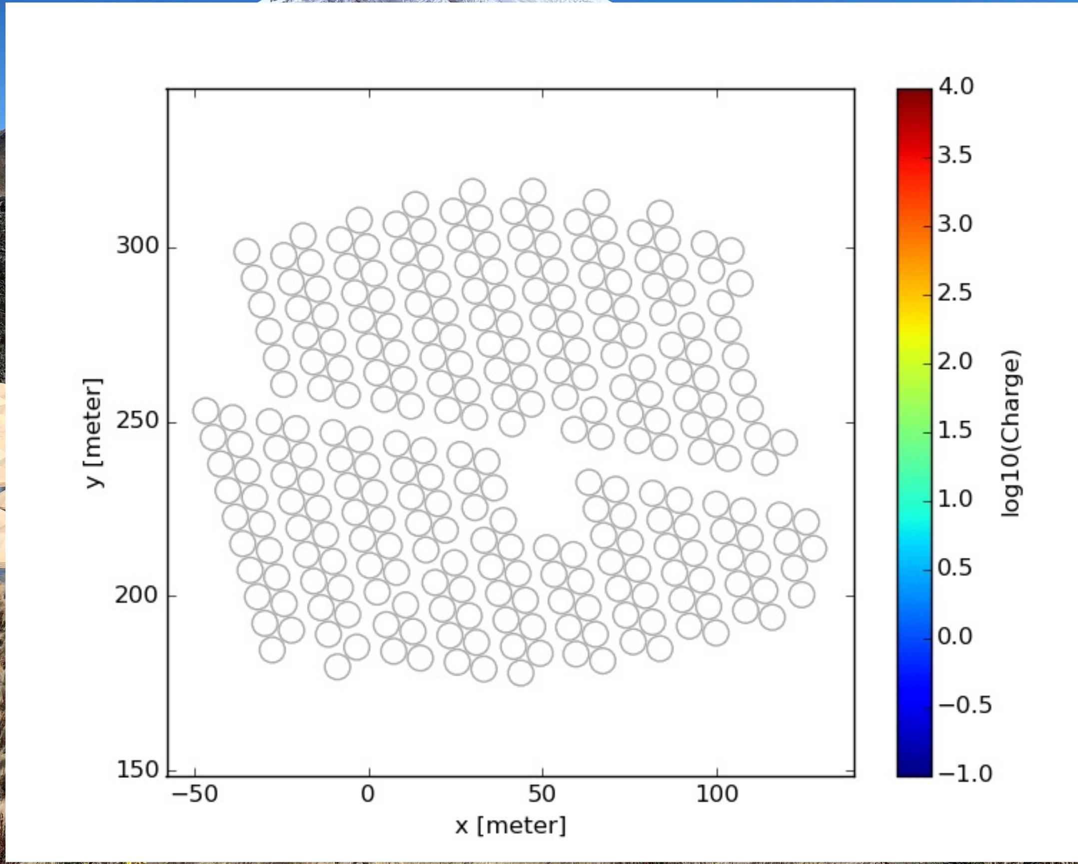
- → Outrigger array in operation since August 2018
  - 1/80th the size of the main-array tanks
    - One upward-facing PMT each
  - Provides enhanced sensitivity above 10 TeV
    - Accurately determine core position for showers off the main tank array
  - Increase effective area above 10 TeV by 3–4x



The HAWC Observatory

- → Uses the water-Cherenkov technique to detect air showers from particles incident on Earth's atmosphere
  - Reads in every PMT; processing in near real time
- → Large field-of-view; can see 2/3 of the sky every day





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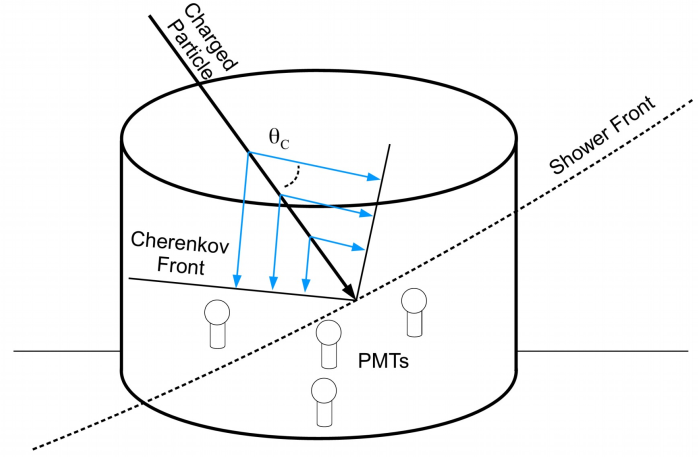
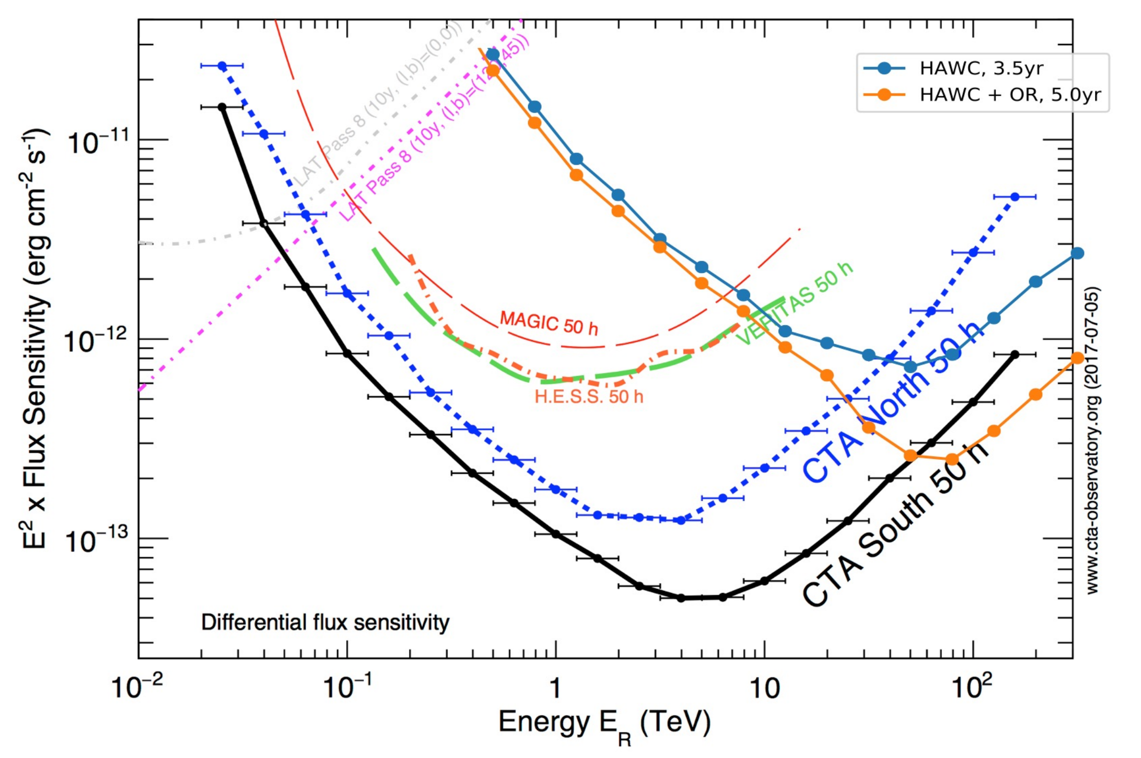
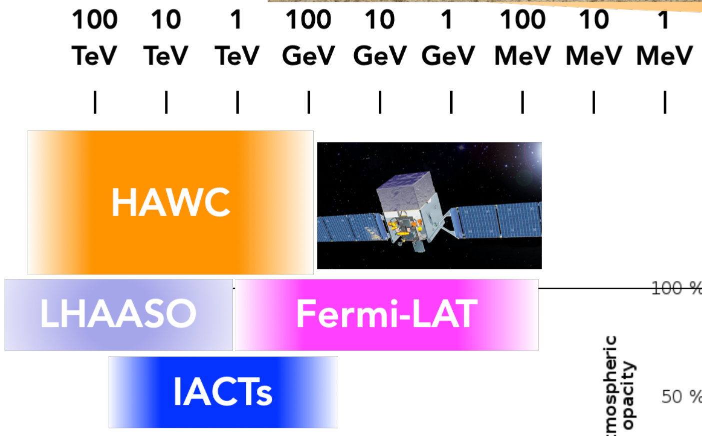


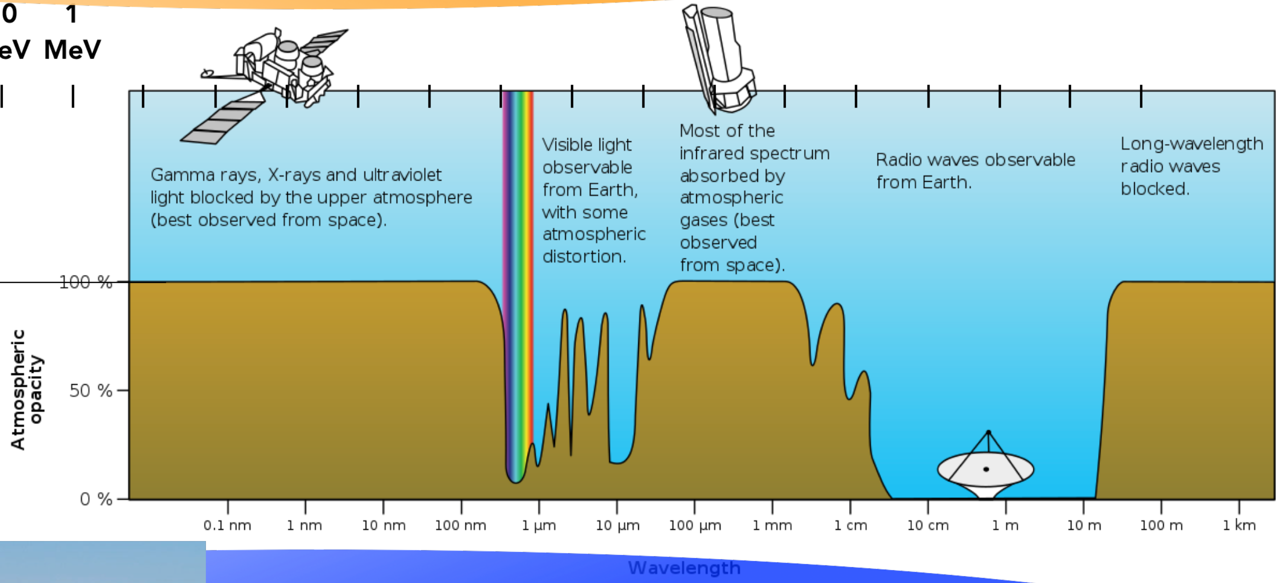


Adapted from arXiv:1907.08171

The Gamma-Ray Detector Landscape

- Wide field of view
- High duty cycle (~95%)
- Good sensitivity





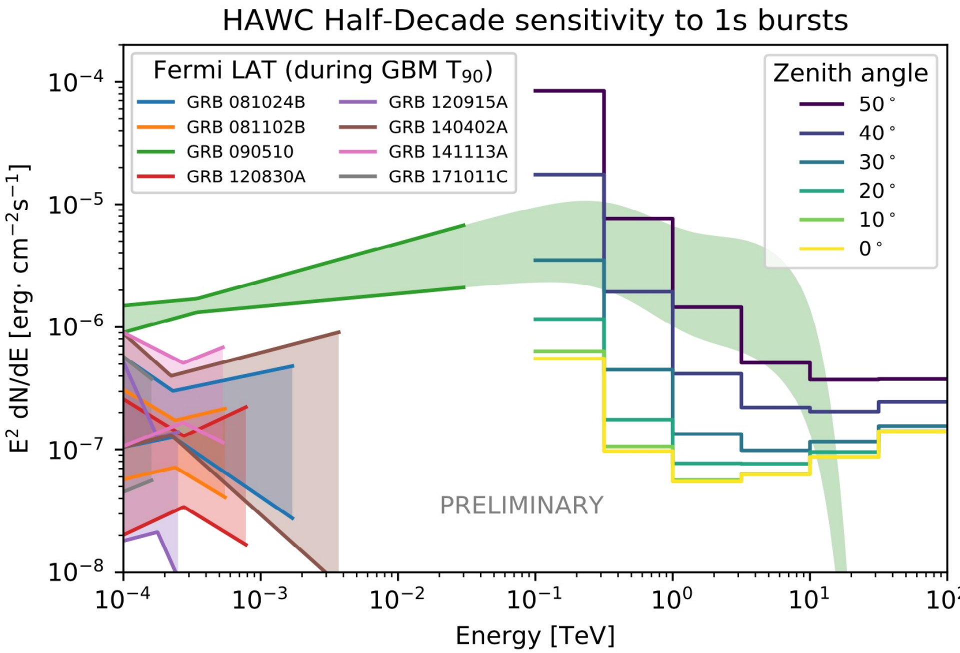
- Narrow field of view
- Limited duty cycle (~15%)
- Excellent sensitivity

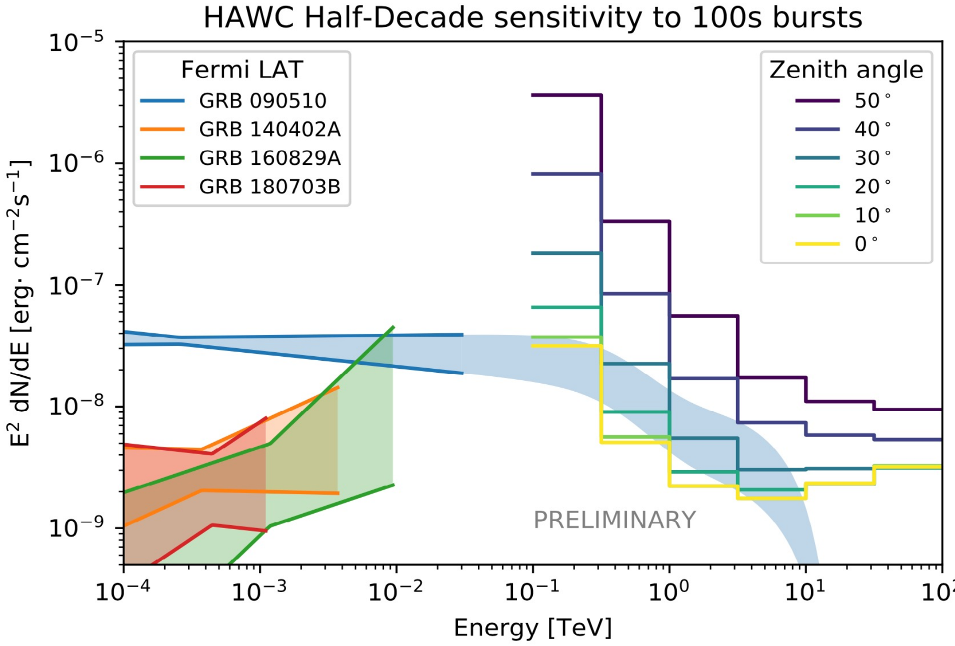
HAWC and GRB Emissions

→HAWC's wide field of view (~2 sr), large effective area, and near-continuous uptime make it ideal to search for GRB emission at the highest energies

→Can observe GRBs before, during, and after the prompt emission phase measured by satellites

- Essential for determining the start time and duration of prompt emission at ~300 GeV— relatively unknown given the paucity of photons detected by satellites at these energies





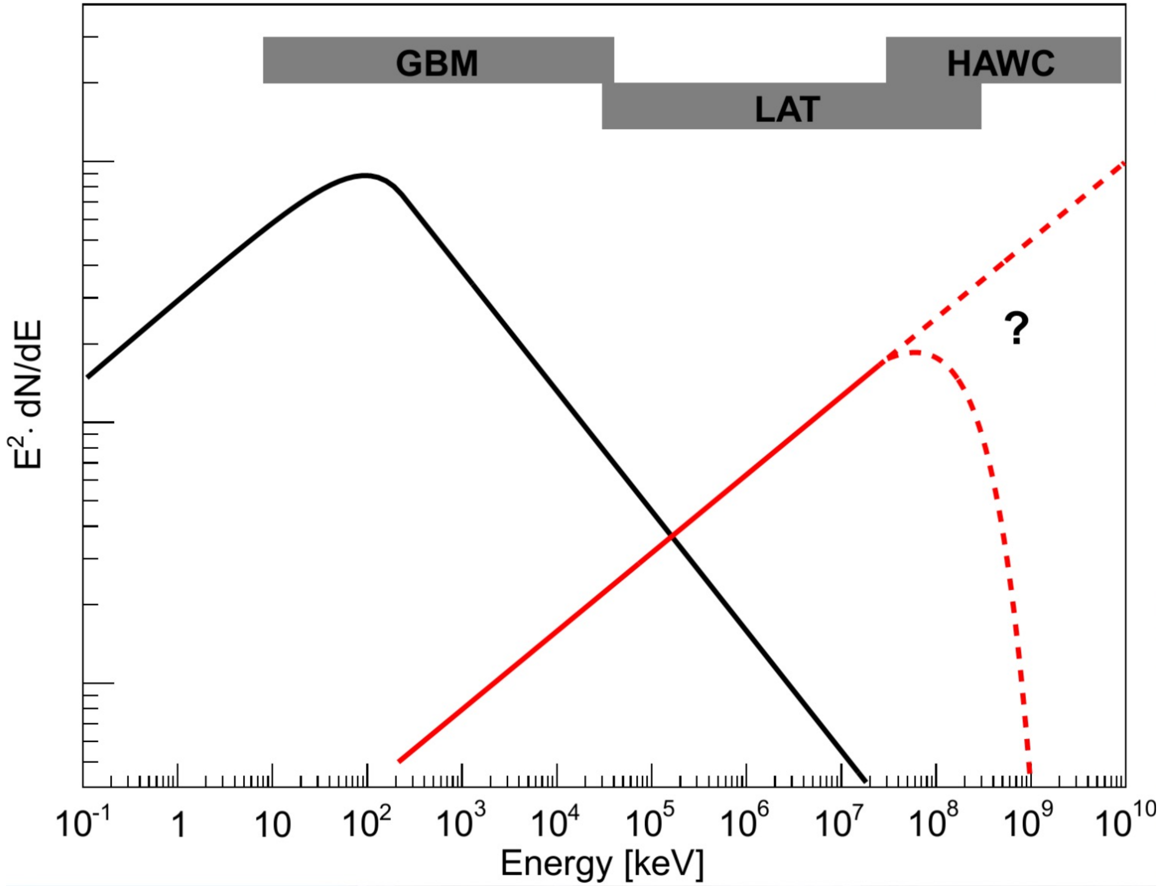
Plots by Israel Martinez-Castellanos

HAWC and GRB Emissions

→VHE emissions from GRBs have only been seen late in time (afterglow)

- IACT untriggered observations limited by slewing time and narrow field of view

→Optimal complement to observations by satellites



Broadband GRB spectrum with a band function (black) and an additional hard power-law component (red).

The HAWC GRB Program

→Comprises two dedicated analyses:

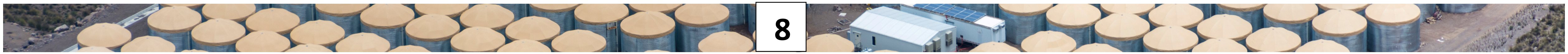
1. A self-triggered, all-sky search
2. Rapid response follow-up of GRBs reported by satellites

→Both methods are performed in real time at the HAWC site as well as on archival data

- Archival data especially important for following up on reported emission from IACTs

→Can also be used to follow-up and search for other transients with timescales and fluxes similar to GRBs

- E.g., Primordial Black Holes, Fast Radio Bursts

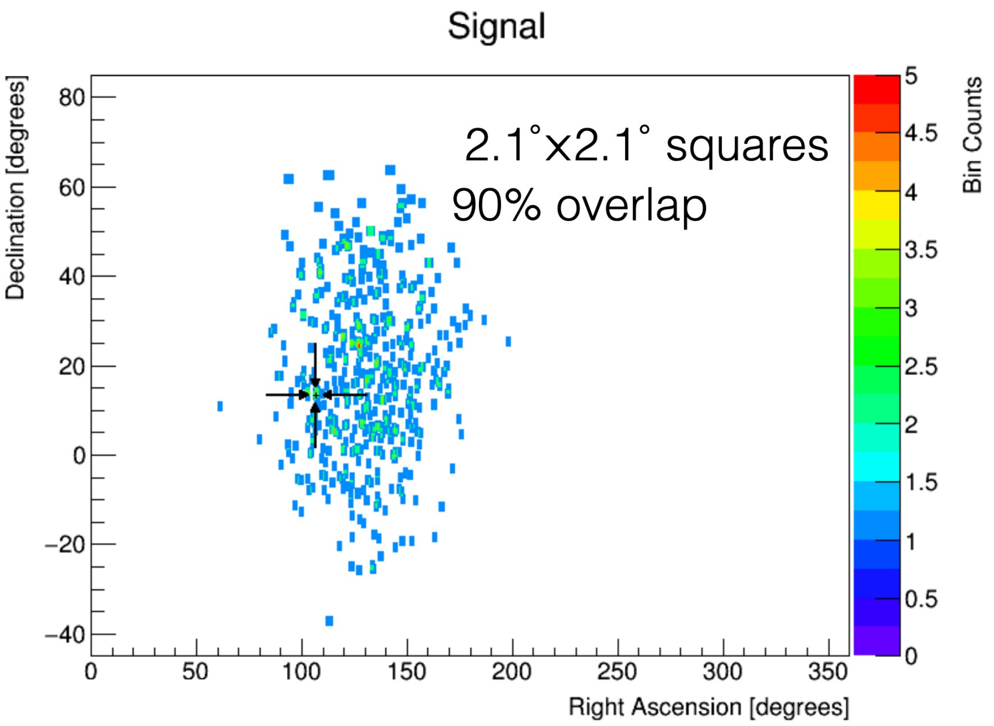


Self-Triggered, All-Sky Search

→Continuously searches for GRB transients with E > 300 GeV using sliding time windows typical of peak structures within GRB light curves

→Have ability to pass external triggers in order to perform a limited sliding time window search near the trigger time and location of known GRBs

- Allows fine-tuning of start time of VHE emission when performing follow-ups
- Can perform look-backs, not just the look-forward that IACTs, etc., can



Plot by Joshua Wood

Rapid Response Follow-Up

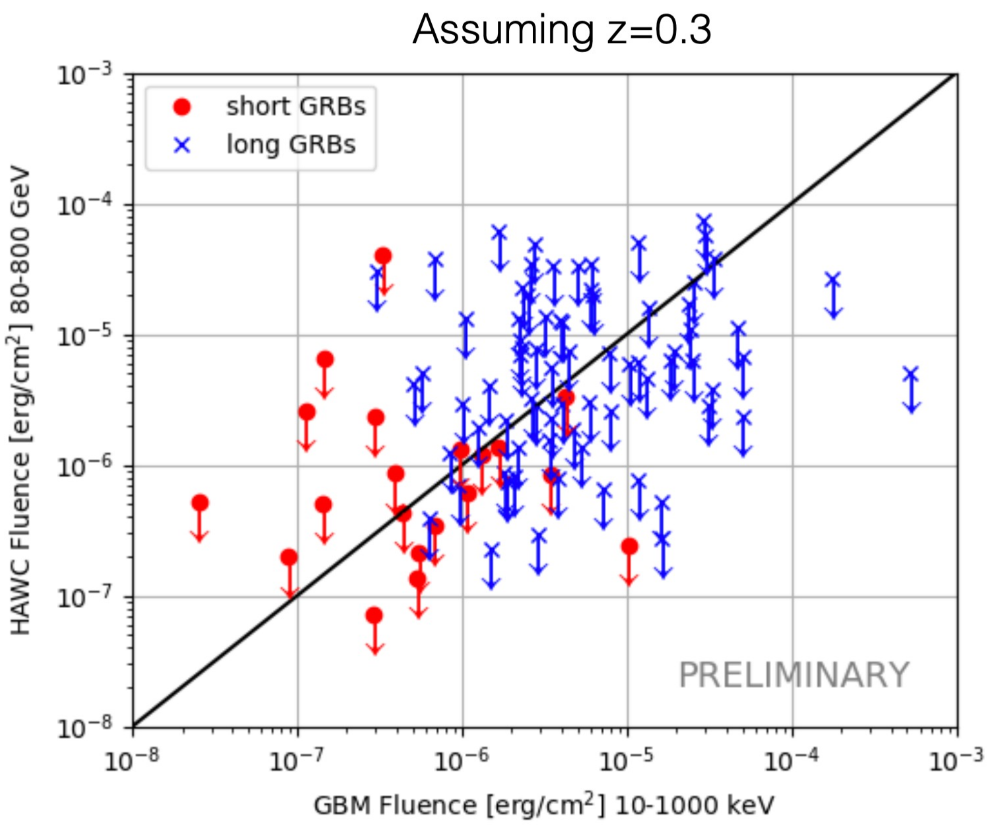
→We use triggers from Swift BAT, the *Fermi*-LAT, and the *Fermi*-GBM that fall within HAWC's field of view to search for indications of VHE GRB emissions in our data

- Events can be separated based on quality and background (among other improvements)

→Fixes the search window start time to match the external trigger provided by a satellite

- Spatial portion of the search also restricted to the reported error on the GRB location

→Ability to test for delayed-onset VHE emission when performing follow-ups of satellite-detected GRBs



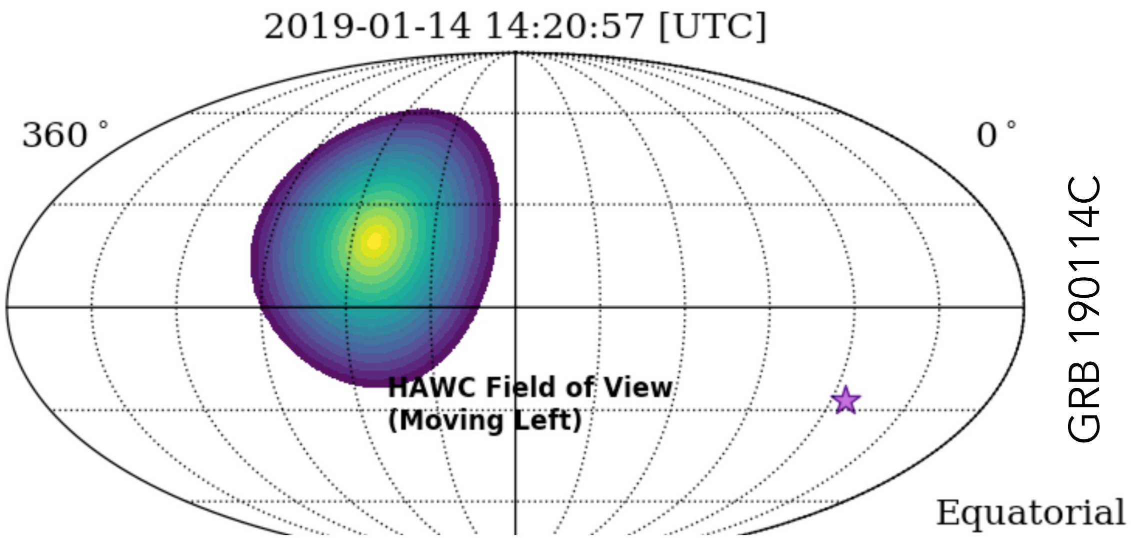
Even for a non-detection, upper limits for nearby GRBs with known redshift can place strong constraints on models

Very-High-Energy GRBs and HAWC

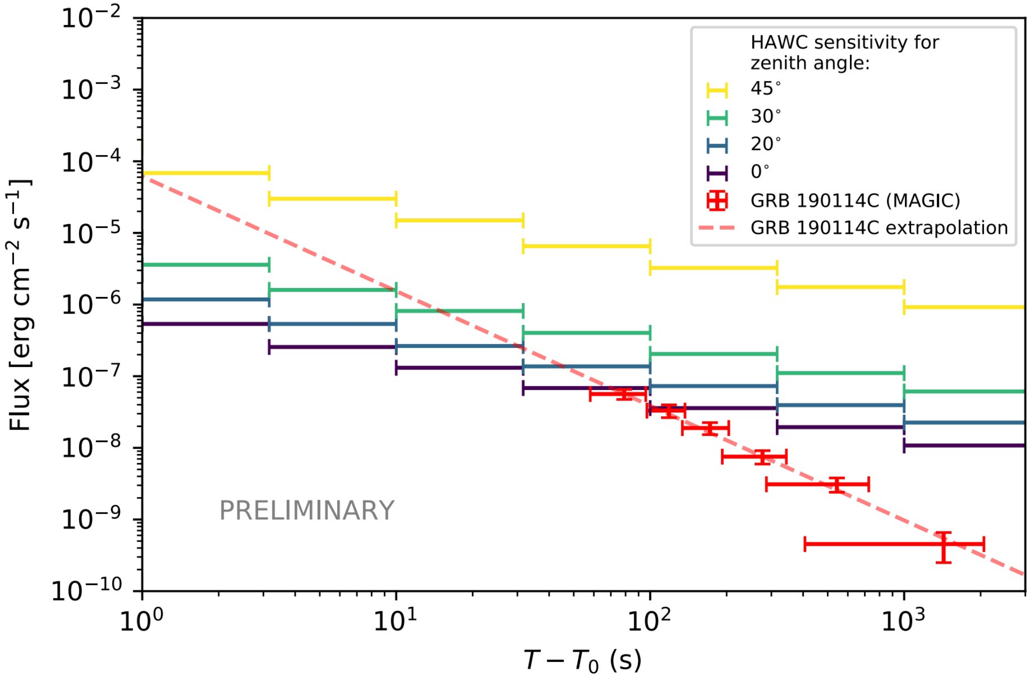
→The GRBs that have been detected to-date with a very-high-energy component were not in the HAWC field of view:

- GRB 190114C, detected by MAGIC
- GRB 180720B and GRB 190829A, detected by H.E.S.S.

→HAWC would likely have detected GRB 190114C if it had happened in its field of view



GRB 190114C



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HAWC and the GRB Community

→If HAWC were to trigger on a GRB, we are set up to alert the community/coordinate alerts between different experiments:

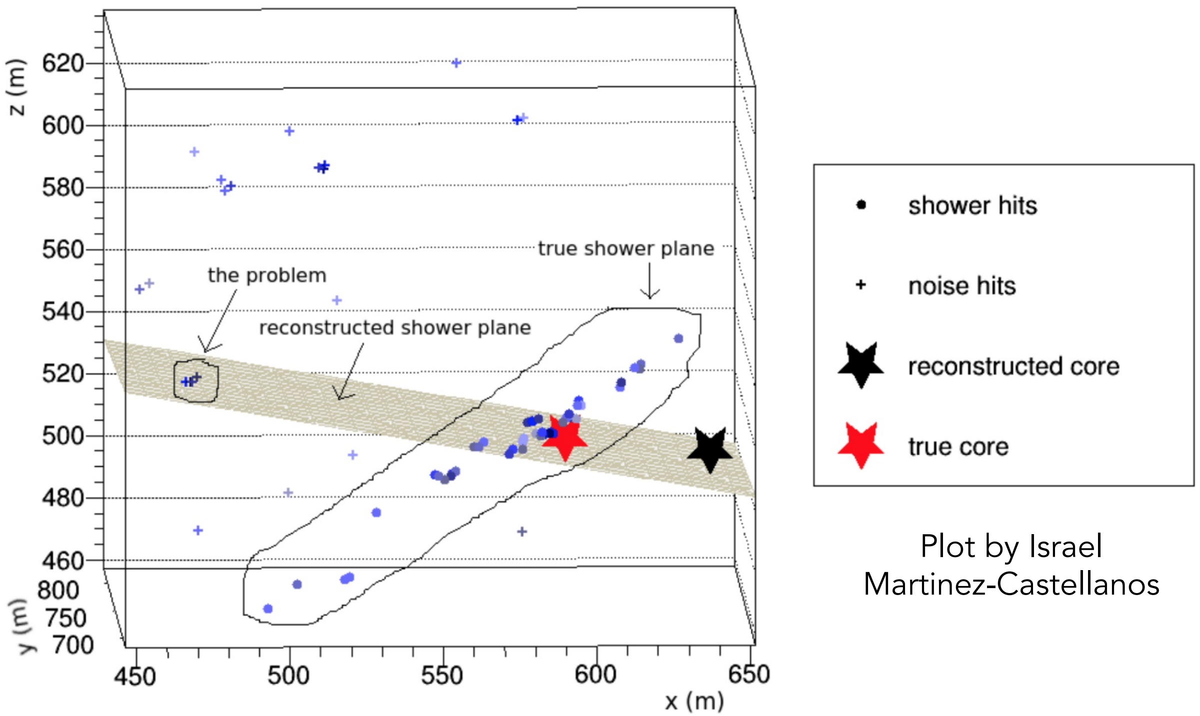
- Would use GCN/ATels for confirmed significant observations
  - HAWC has sent out 47 circulars in the last year
- Already using AMON (the Astrophysical Multimessenger Observatory Network)[7] for sub-threshold triggers
  - Report "hotspot" parameters for events above the estimated cosmic-ray background level >2.75σ
  - AMON sends alerts to GCN if event passes the false-alarm-rate threshold

Future Outlook

→While HAWC has yet to observe a significant signal from a GRB, either self-triggered or as a follow-up, we are very optimistic that recent improvements will greatly improve our sensitivity to GRBs

- Better reconstruction for low-energy events (noise reduction)
- Multi-bin maximum-likelihood analysis for short timescales
- Multi-shower fit increases statistics
- Improved angular resolution for multiple showers on the array
- Data re-reconstructed around known GRBs

Simulated Bin 0 Air Shower



Plot by Israel Martinez-Castellanos

Thank you! Miigwetch!

Acknowledgements

- The entire HAWC Collaboration for their tireless work towards new and exciting physics

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INAOE

CONACYT
Consejo Nacional de Ciencia y Tecnología

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