Searching for Very-High-Energy Gamma Rays from Binary Black Hole Mergers with VERITAS.

TeVPA - September 3, 2026.

Presented by

Madalyn Johnson

on behalf of the VERITAS collaboration.

Motivation

2017: First joint detection of a binary neutron star (BNS) merger, GW170817, and a short gamma-ray burst (GRB) GRB 170817A.

Since then, LIGO/Virgo/KAGRA (LVK) has confirmed:

- 2 binary neutron star mergers
- 3 neutron star–black hole (NSBH) mergers

Could binary black hole (BBH) mergers also produce electromagnetic (EM) emission?

Is there a very-high-energy (VHE; >100 GeV) gamma-ray component?

LVK Collaboration

The Laser Interferometer Gravitational-Wave Observatory (LIGO) facilities in Hanford (top left) and Livingston (bottom left).

The **Virgo** detector (bottom right),

The **Kamioka Gravitational Wave Detector (KAGRA)** (top right).

Image Credit: ICRR, Univ. of Tokyo/LIGO Lab/Caltech/MIT/Virgo Collaboration.

EM Emission from GW Events

Short GRBs are produced by BNS mergers.

If BBH produce EM emission, what would it look like?

- Example: A BBH in accretion discs of active galactic nuclei (AGN).

Model any BBH emission as a generic afterglow.

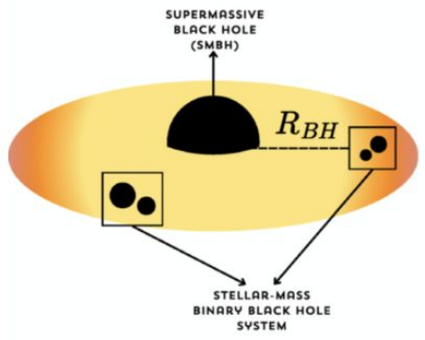


Image adapted from: Darc, P, et al. (2025).

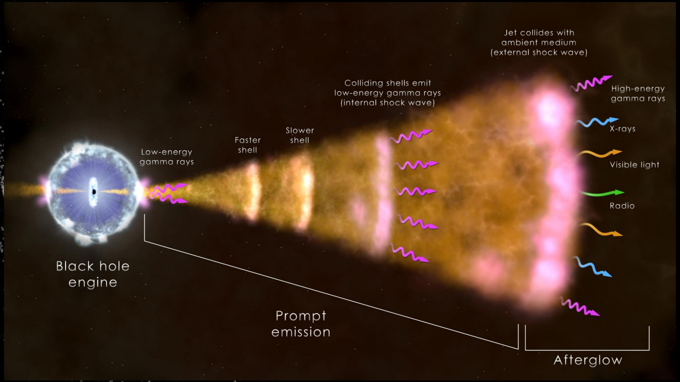


Image Credit: NASA's Goddard Space Flight Center.

VERITAS

VERITAS (Very Energetic Radiation Imaging Telescope Array System) is a ground-based gamma-ray observatory in southern Arizona, using four 12m optical reflectors to detect gamma rays between 100 GeV and 30 TeV.

Photon interacts with atmosphere and produces a cascade of secondary particles traveling at speeds faster than light in the air.

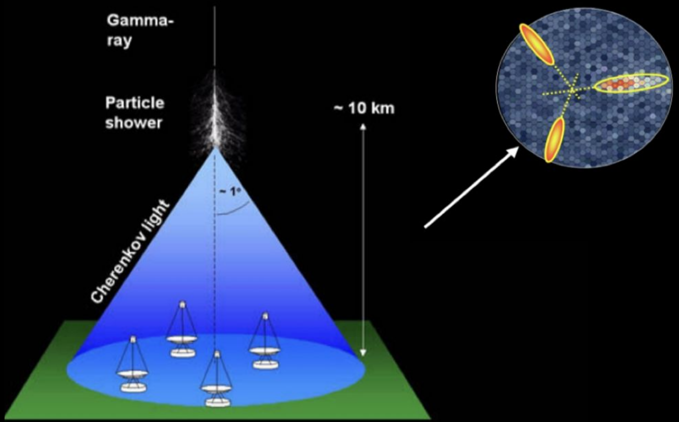


Image Credit: Cherenkov detectors in astroparticle physics.
Image Credit: Center for Astrophysics | Harvard & Smithsonian.

VERITAS GW Follow-Up Methods

Utilize Kafka Notices via GCN to receive real-time LVK alerts.

Retrieve/plot GW event skymaps.

Calculate tilings for an event for VERITAS 3.5° field of view to cover the large LVK localization region.

36 pointings for BBH and NSBH, or **72 pointings** for BNS events.

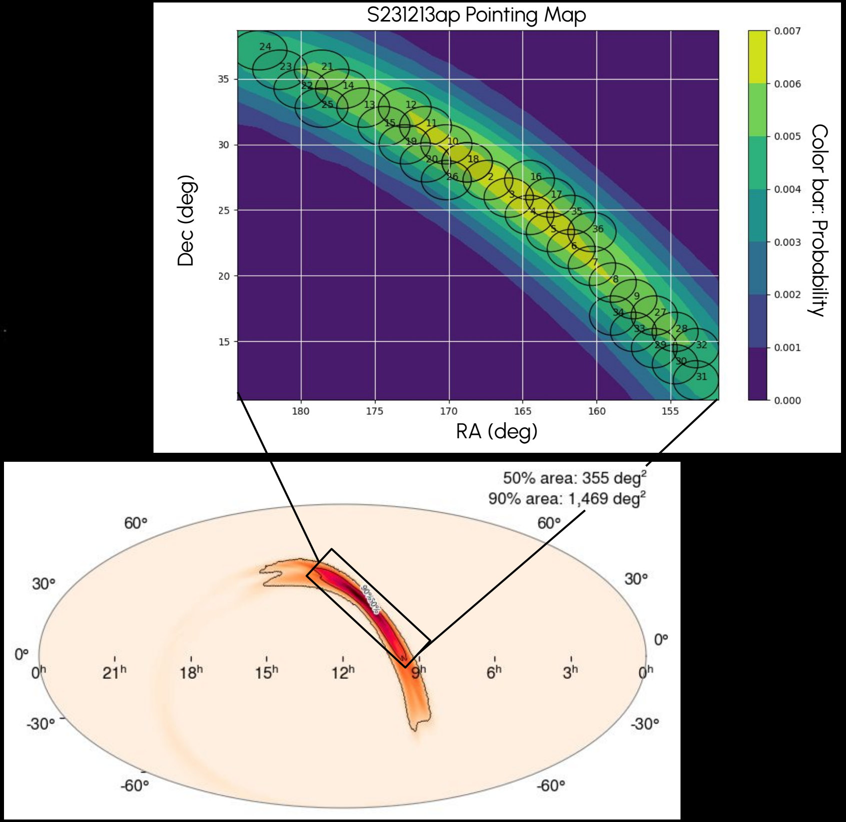


Figure 1 (top): Pointing plot of S231213ap (x-axis Dec in degs, y-axis RA in degs).
Figure 2: (bottom) Skymap with localization region of S231213ap.
https://gracedb.ligo.org/

VERITAS Analysis

To validate the observation method, we conducted a point-source analysis of the Crab Nebula using the standard VERITAS data pipeline.

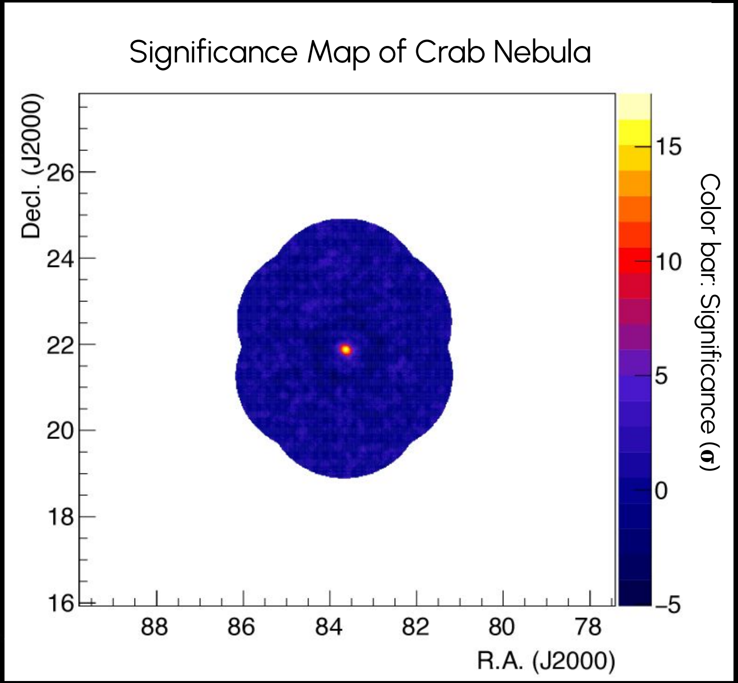


Figure 3: Significance map of the Crab Nebula for 6 pointings.

VERITAS Analysis

To validate the observation method, we conducted a point-source analysis of the Crab Nebula using the standard VERITAS data pipeline.

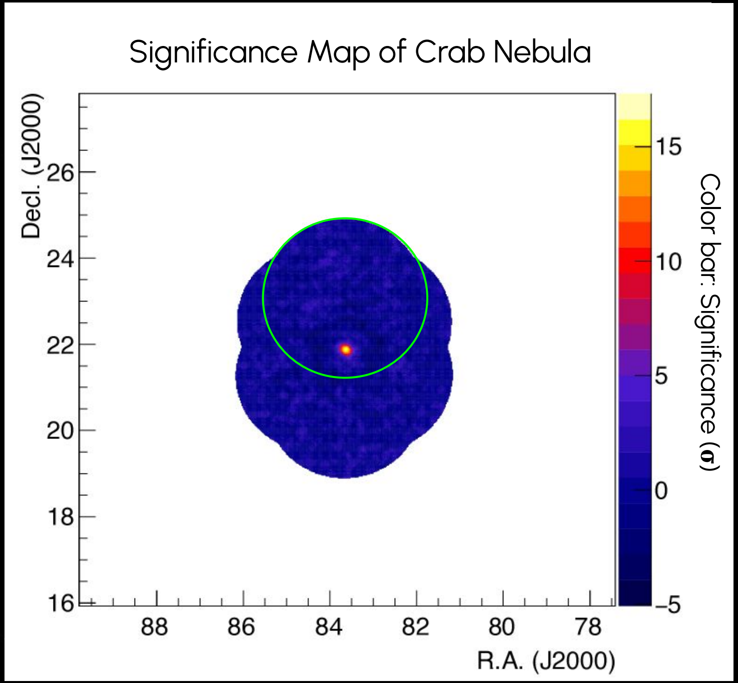


Figure 3: Significance map of the Crab Nebula for 6 pointings.

VERITAS Analysis

To validate the observation method, we conducted a point-source analysis of the Crab Nebula using the standard VERITAS data pipeline.

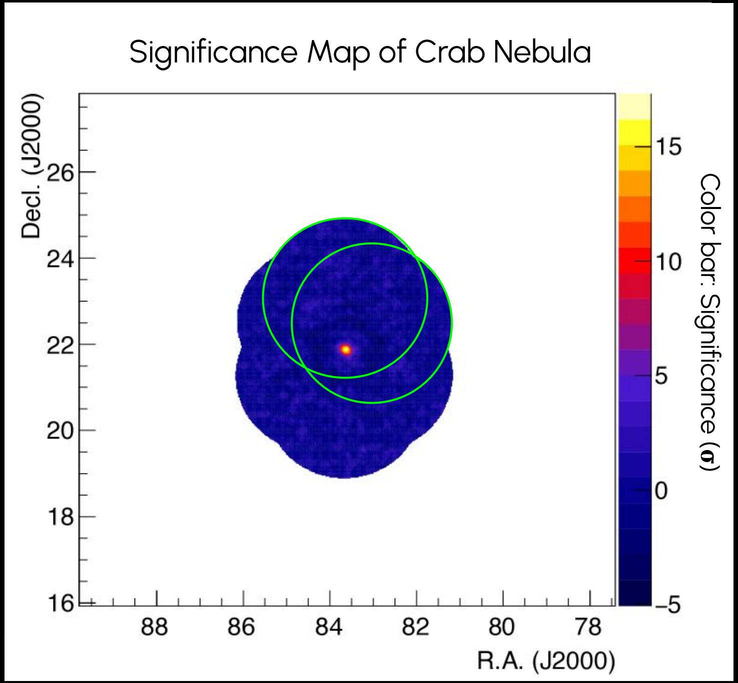


Figure 3: Significance map of the Crab Nebula for 6 pointings.

VERITAS Analysis

To validate the observation method, we conducted a point-source analysis of the Crab Nebula using the standard VERITAS data pipeline.

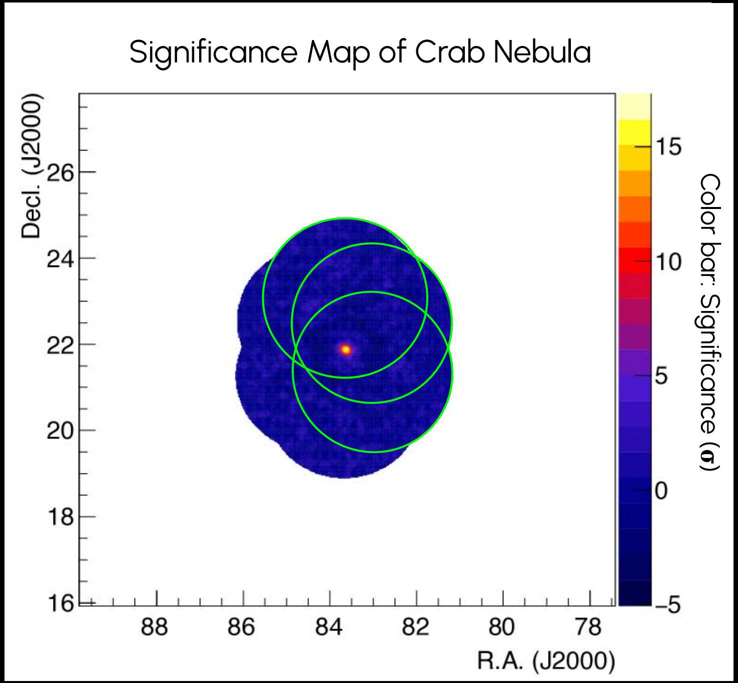


Figure 3: Significance map of the Crab Nebula for 6 pointings.

VERITAS Analysis

To validate the observation method, we conducted a point-source analysis of the Crab Nebula using the standard VERITAS data pipeline.

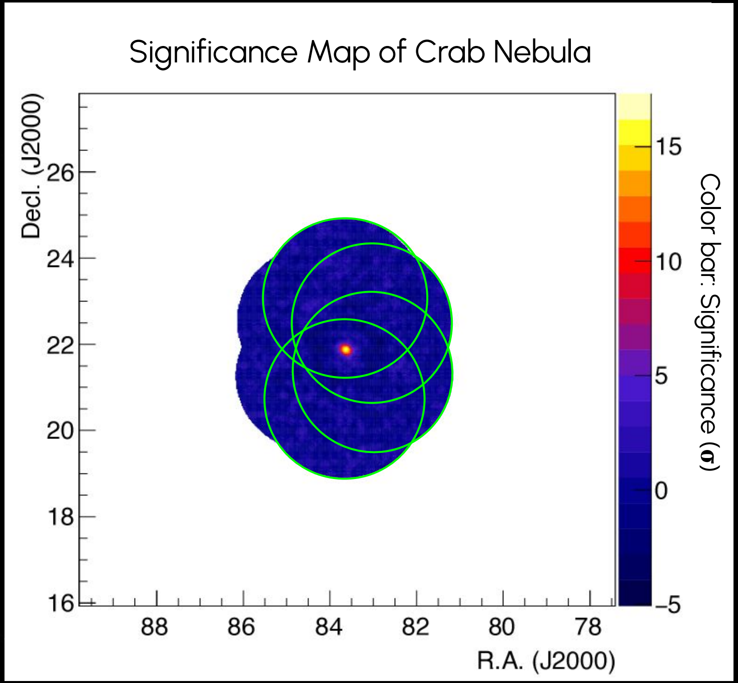


Figure 3: Significance map of the Crab Nebula for 6 pointings.

VERITAS Analysis

To validate the observation method, we conducted a point-source analysis of the Crab Nebula using the standard VERITAS data pipeline.

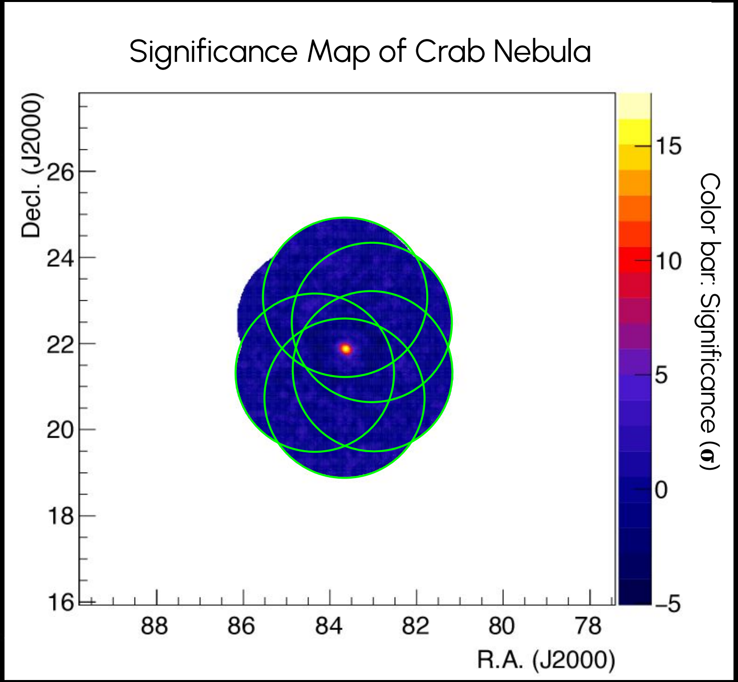


Figure 3: Significance map of the Crab Nebula for 6 pointings.

VERITAS Analysis

To validate the observation method, we conducted a point-source analysis of the Crab Nebula using the standard VERITAS data pipeline.

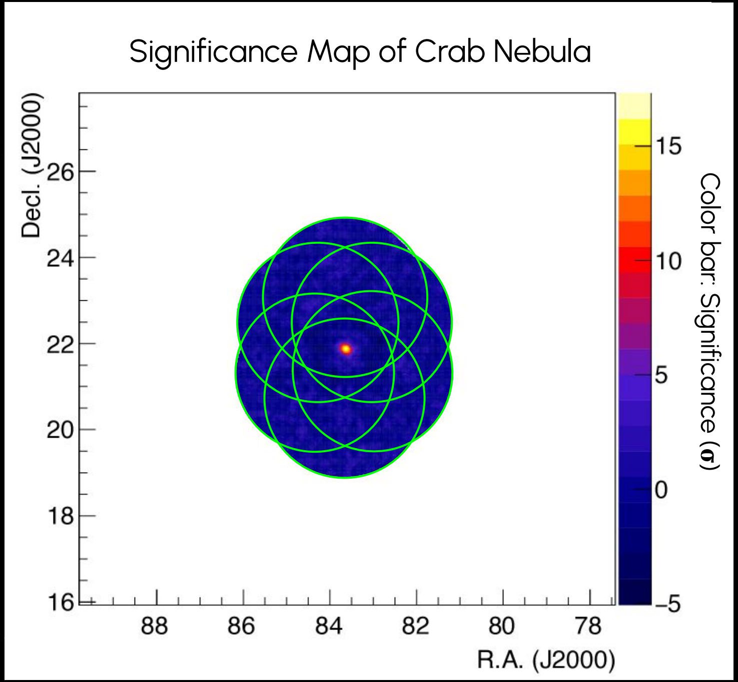


Figure 3: Significance map of the Crab Nebula for 6 pointings.

VERITAS Data

43 significant GW events:

- O2 Run - 1 event (BBH)
- O3 Run - 10 events (1 BNS · 2 Mass Gap · 7 BBH)
- O4 Run - 32 events (All BBH)

Took a subset of BBH mergers that have mass information published in GWTC 2.0 - 5.0.

- **28 BBH remain in sample**

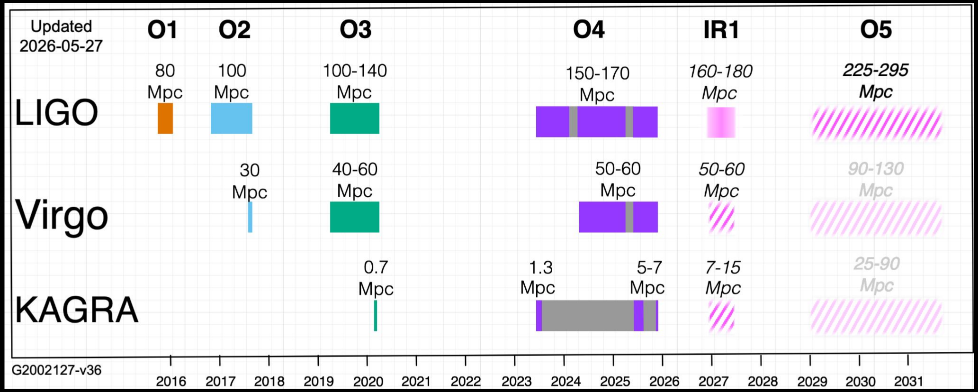


Figure 4: LVK observing timeline and expected binary neutron star (BNS) detection range for LIGO, Virgo, and KAGRA detectors.

BNS - S190425z

Figure 5: Skymap with localization region.

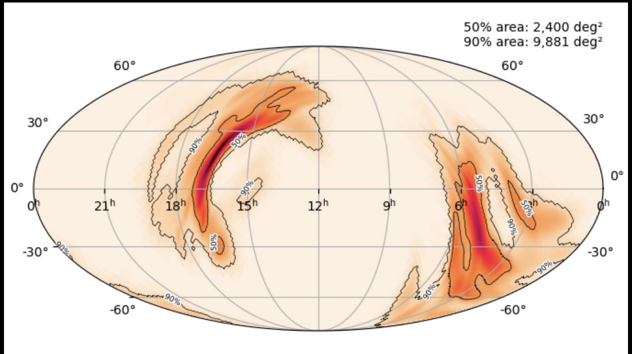
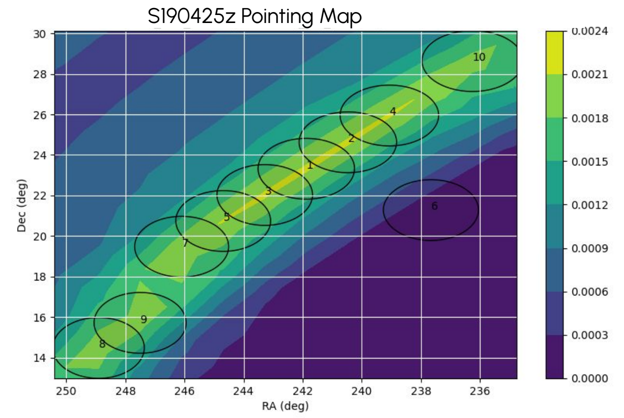


Figure 6: Pointing plot of S190425z.



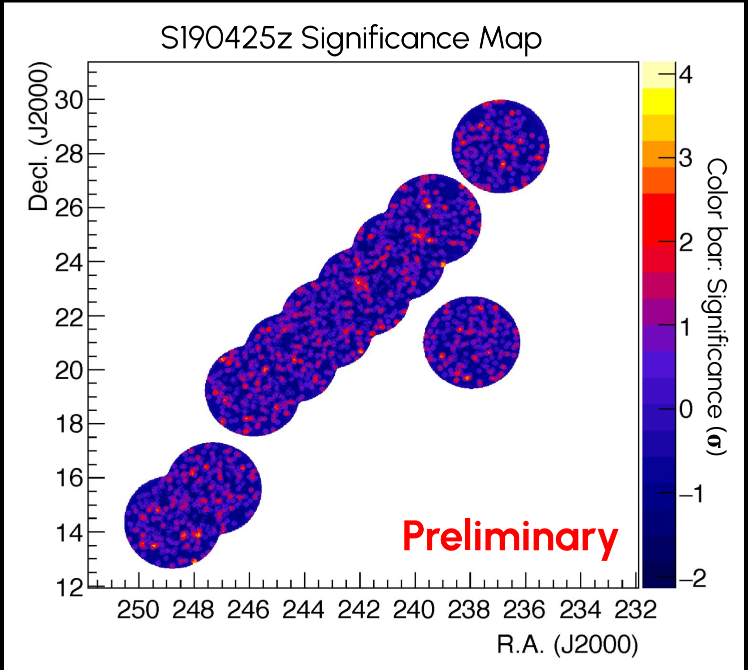


Figure 7: Preliminary significance map of BNS S190425z.

BBH Population Study - Results

No significant VHE emission detected from 28 BBH mergers.
Derived upper limits on the integral photon flux.
Fluence estimated using a generic afterglow decay model.

$$g(t) = \frac{1}{[1 + \frac{t}{c}]^{\alpha}} \cdot$$

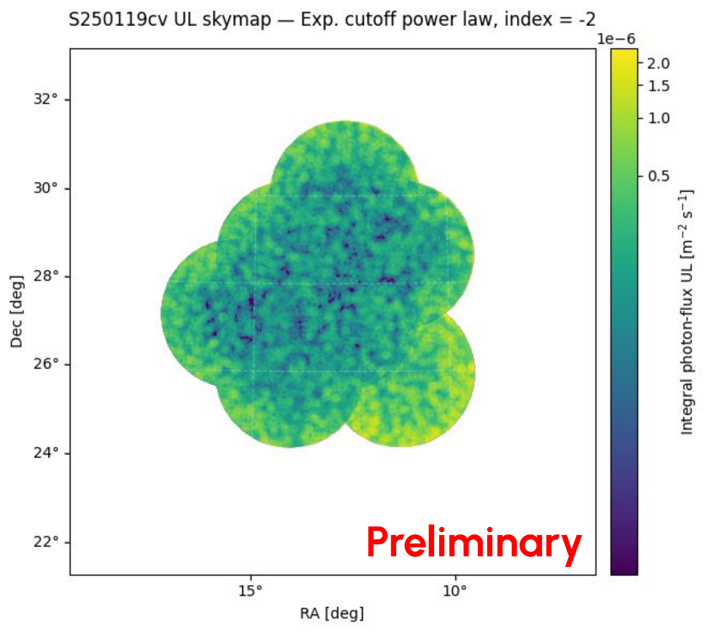


Figure 8: Upper limit on the integral photon flux for S250119cv.

Estimating the Gamma-ray Energy Fraction

Calculate the isotropic-equivalent gamma-ray energy, $E_{\gamma,iso}$.

- From the fluence and sampled luminosity distances.

$$E_{\gamma,iso} = \frac{4\pi D_L^2 \mathcal{F}_E}{1+z} \quad [\mathrm{erg}] \quad .$$

Calculate the gravitational-wave energy, E_{GW}.

- From GWTC component masses and remnant mass.

$$E_{GW} = (m_{initial} - m_{final})\ c^2 \quad [\mathrm{erg}] \ .$$

Compute the gamma-ray energy fraction, f_γ.

$$f_\gamma = \frac{E_{\gamma,iso}}{E_{GW}} \ .$$

If the true fraction of gravitational-wave energy emitted as gamma rays were some value f_{true}, what is the probability that VERITAS would have detected at least one event?

BBH Population Study - Results

$$P_i(f_{true}) = \frac{N(f_{true} > f^{UL}_{\gamma,\,i})}{N_{samples}}$$

Calculate the detection probability for each BBH event.

Combine all 28 events to obtain the ensemble detection probability.

Estimate the gamma-ray energy fraction, f_γ, corresponding to a **95% probability of at least one VERITAS detection.**

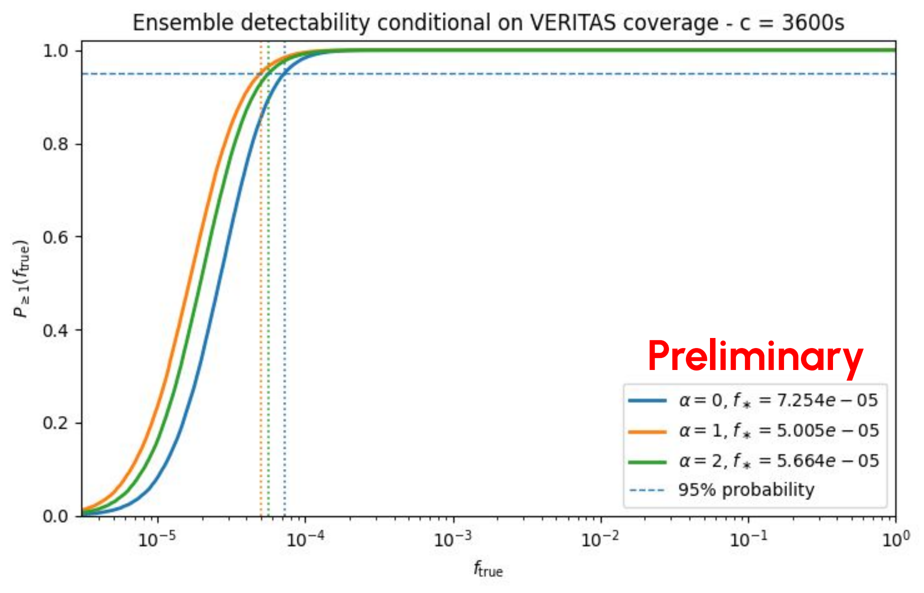
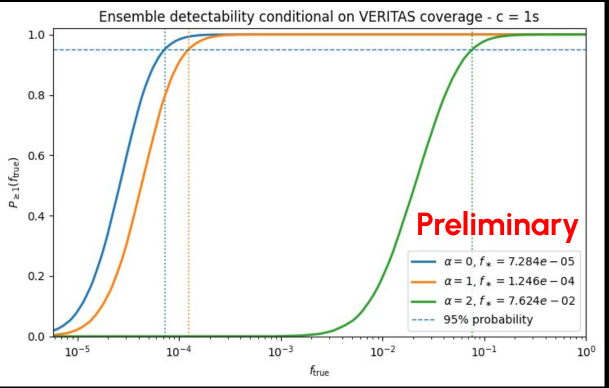


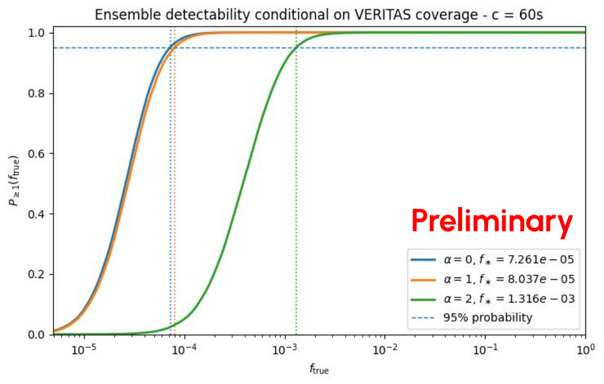
Figure 9: Ensemble detection probability as a function of the assumed gamma-ray energy fraction, f_{true}.

BBH Population Study - Results

Test how the results change for emission evolving on different characteristic timescales, c.

$$g(t) = \frac{1}{[1 + \frac{t}{c}]^{\alpha}}.$$





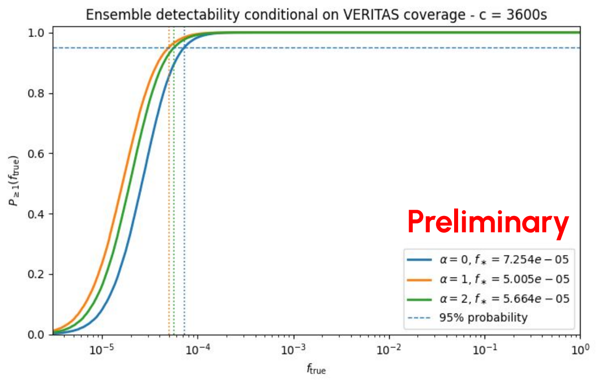


Figure 10a, 10b, and 10c demonstrate the ensemble detection probability as a function of the assumed f_{true} for three distinct values of c: 1 s, 60 s, and 3600 s, respectively.

Conclusion

- VERITAS analysis of 28 LVK O3/O4 binary black hole (BBH) mergers yielded no significant >100 GeV gamma-ray detections.
- Derived upper limits on the VHE gamma-ray energy output assuming a generic afterglow temporal evolution.
- Constraints on rapidly evolving VHE emission are strongest for early VERITAS observations.
- These results place population-level constraints on models predicting VHE gamma-ray emission from BBH mergers.

Questions?

Madalyn Johnson, email: mjohns56@ucsc.edu