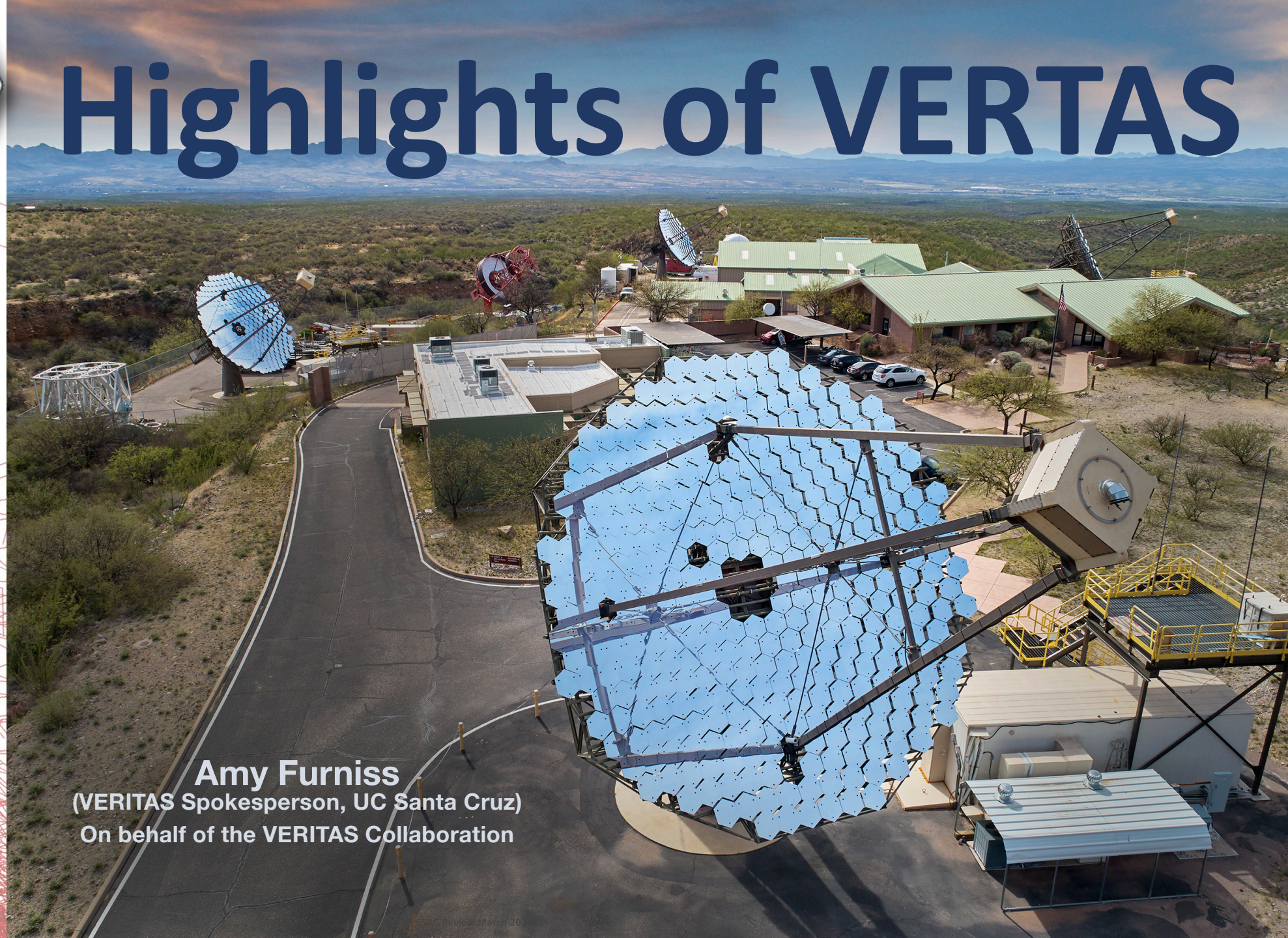
Highlights of VERITAS



Amy Furniss
(VERITAS Spokesperson, UC Santa Cruz)
On behalf of the VERITAS Collaboration

VERITAS Status

Facility and Collaboration:

- Located at the Fred Lawrence Whipple Observatory in southern Arizona @ 1,268 m a.s.l.
  - CTAO prototype SCT telescope co-located
- Starting 18th year of full-array operations this month.
- International Collaboration:
  - ~80 members incl. 20 graduate students and 8 Postdocs
  - +10 active Associate Members

Funding Sources:

- **USA**: National Science Foundation, Smithsonian Astrophysical Observatory
- **Canada**: Natural Sciences and Engineering Research Council
- **Germany**: Helmholtz Association

News:

- Plans to apply for operations support from NSF for 2025-2028 window.

Recognition: Outstanding Contribution Awards

Awards given annually to recognize the outstanding contributions made by early-career members for critical service work that enables the publications of VERITAS and the pSCT, but do not result in any scientific publications directly.

- **Trevor C. Weekes Award - Postdocs:**
  - **Serena Loporchio** (2023): Development of the pSCT camera components.
  - **Stephen O'Brien** (2022): Support of calibration , observation program coordination.
  - **Qi Feng** (2021): Innovations in the commissioning of the SCT optics system.
  - **Mireia Nievas Rosillo** (2020): VERITAS flux correction method.
  - **Greg Richards** (2019): Calibrations czar and TAC chair.
  - **Ralph Bird** (2018): Data archive and VEGAS leadership and development.
- **Simon Swordy Award - Graduate Students:**
  - **Matthew Lundy** (2023): VEGAS development, instrument response production.
  - **Colin Adams** (2022): VERTAS and pSCT calibration work.
  - **Deivid Ribiero** (2021): Wide range of service to both pSCT and VERITAS.
  - **Alisha Chromey** (2020): ACG simulations processing and validation, observing shifts.
  - **Alasdair Gent** (2019): Simulations production.
  - **Tony Lin** (2018): FLWO long-term visitor - startup shift and three czar shifts.

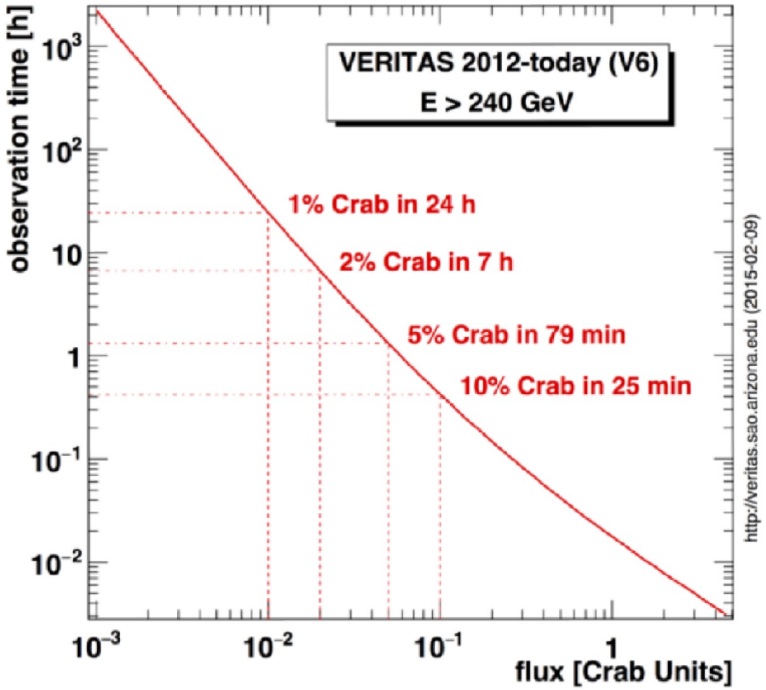
https://veritas.sao.arizona.edu/about-veritas/veritas-outstanding-contribution-awards

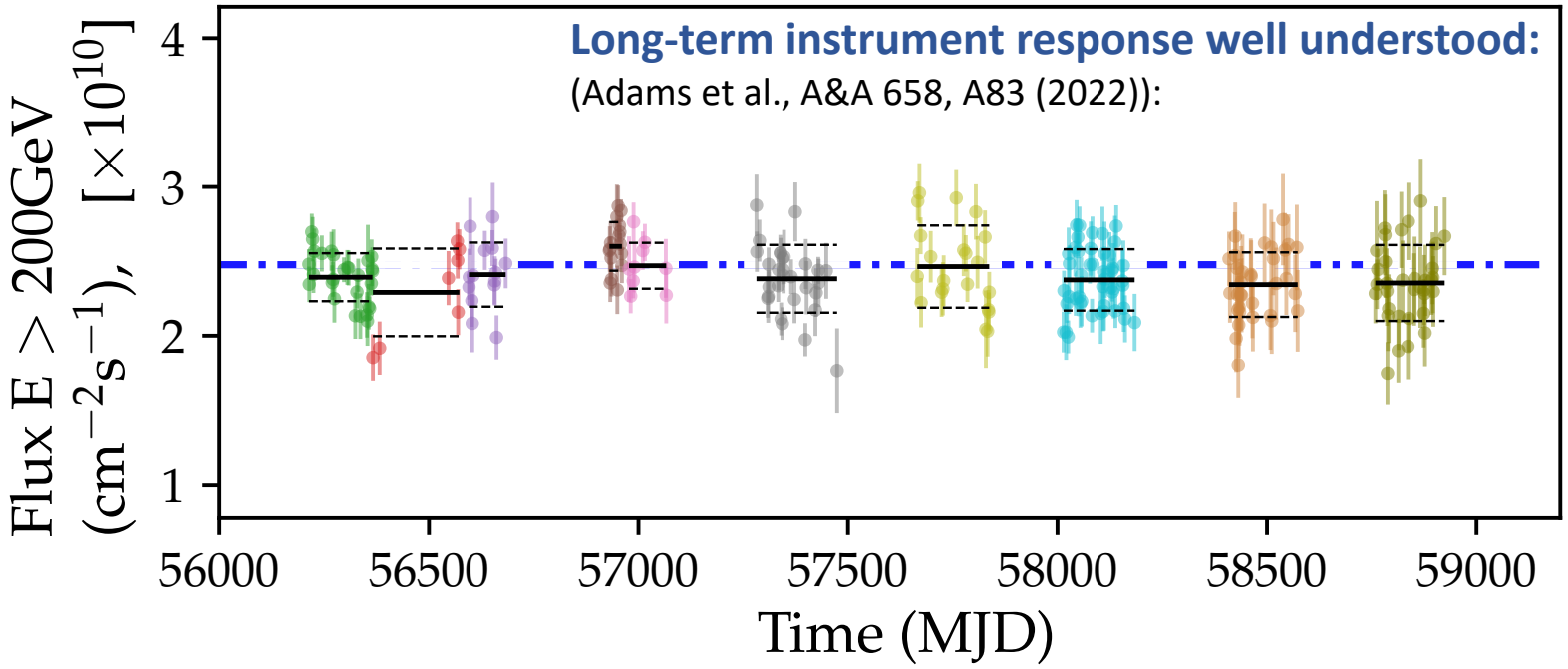
VERITAS Performance

Aurora Interruptions, 5th May 2024

Field of View	3.5° diameter
Energy Range	~85 GeV to ~30 TeV
Effective Area	~10^5 m^2 at 1 TeV
Sensitivity	1% Crab in <25 h

Angular Resolution (r_{68})	~0.08° @ 1 TeV
Energy Resolution	~17%
Sys. Errors: Flux	~20%
Sys. Errors: Spectral Index	~ 0.1





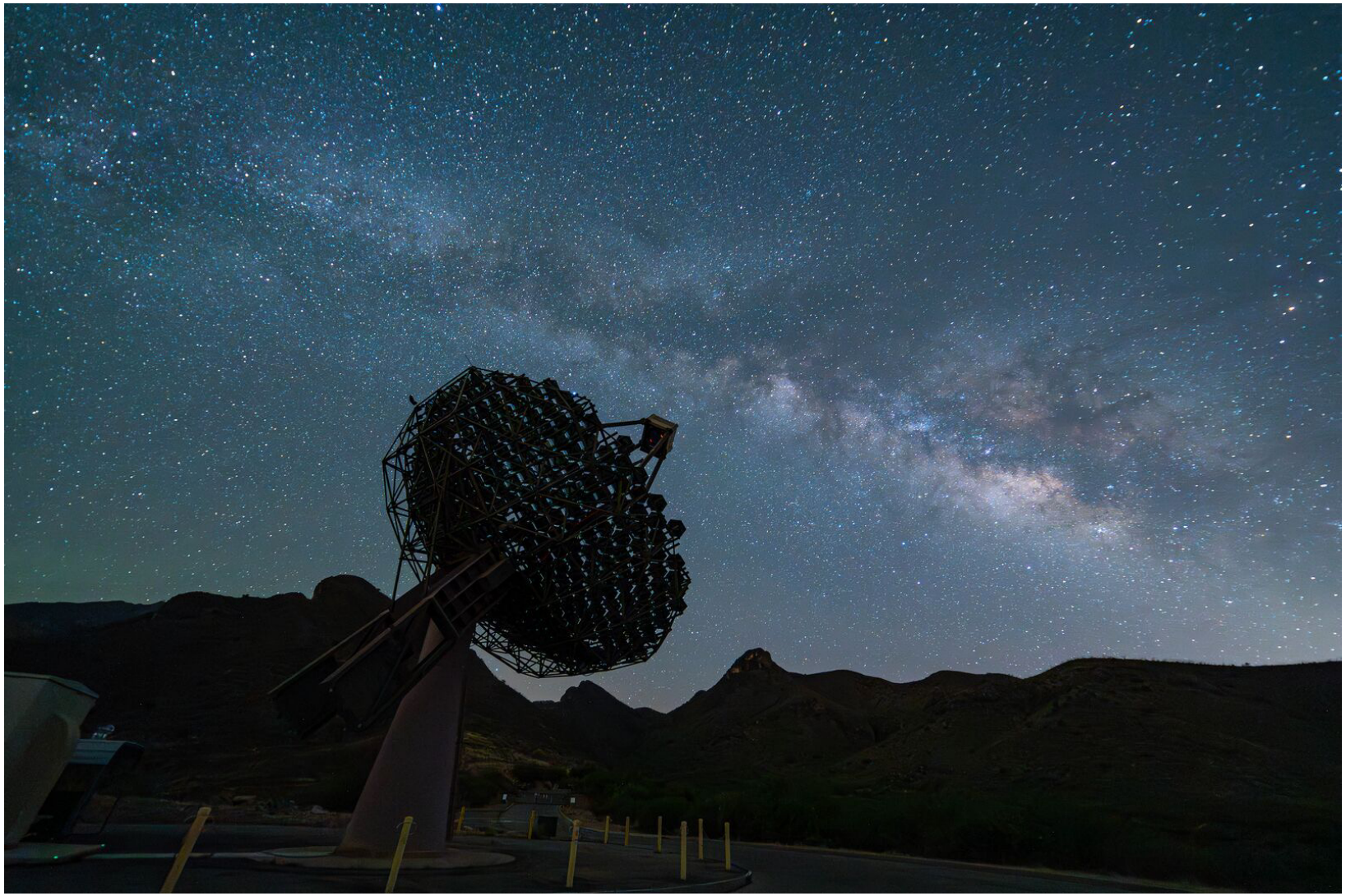
VERITAS Observations

Season:

- September to July each year.
- Seasonal good-weather data:
  - ~950 h of dark sky exposure
  - ~250 h of “bright” sky exposure
    - Moon illumination 30-65%
- 4-telescope efficiency: ~ 98%

Stellar Intensity Interferometry (SII) Observations:

- Utilize very bright and full-moon time.
- More than 250 hours per season.



VTSCat: The VERITAS Catalog of Gamma-ray Observations

https://heasarc.gsfc.nasa.gov/W3Browse/all/verimaster.html

- High-level data products from all VERITAS publications (yaml or ecsv)
  - Spectral flux points
  - light curves
  - spectral fits
  - Table data
  - Skymaps (fits files)
- Regular updates with new publications
- Archived at HEASARC

Over 100 journal articles since 2008

Browse this table...

VERIMASTER - VERITAS Source Catalog

HEASARC Archive

Overview

The Very Energetic Radiation Imaging Telescope Array System (VERITAS) is a major ground-based gamma-ray observatory operating at the Fred Lawrence Whipple Observatory (FLWO) in southern Arizona, USA. It is an array of four 12m optical telescopes for gamma-ray astronomy in the GeV - TeV energy range. VERITAS is an imaging air Cerenkov system. Gamma-rays from astrophysical sources create particle showers in the Earth's upper atmosphere that produce Cerenkov photons detected on the ground using the large optical telescopes. These telescopes are deployed such that they have the highest sensitivity in the VHE energy band (50 GeV - 50 TeV), with maximum sensitivity from 100 GeV to 10 TeV. The four telescope array is needed for stereoscopic observations that allow the reconstruction of the particle shower geometry, thus giving precise angular and energy resolution. This very high energy observatory, completed in 2007, effectively complements the Fermi Gamma-ray Space Telescope due to its large collection area as well as its higher energy bound and improved angular resolution.

VERITAS started four-telescope operations in 2007 and collects about 1100 hours of good-weather data per year. The VERITAS collaboration has published over 100 journal articles since 2008 reporting on gamma-ray observations of a large variety of objects: Galactic sources like supernova remnants, pulsar wind nebulae, and binary systems; extragalactic sources like star forming galaxies, dwarf-spheroidal galaxies, and highly-variable active galactic nuclei. Additional details are available at the VERITAS website.

The catalog lists the sources observed by VERITAS as of April 2022, including cross-matches with other gamma-ray observations and spectral fits. This catalog has associated high-level data products containing data from VERITAS publications.

Catalog Bibcode

2023RNAAS...7....6A

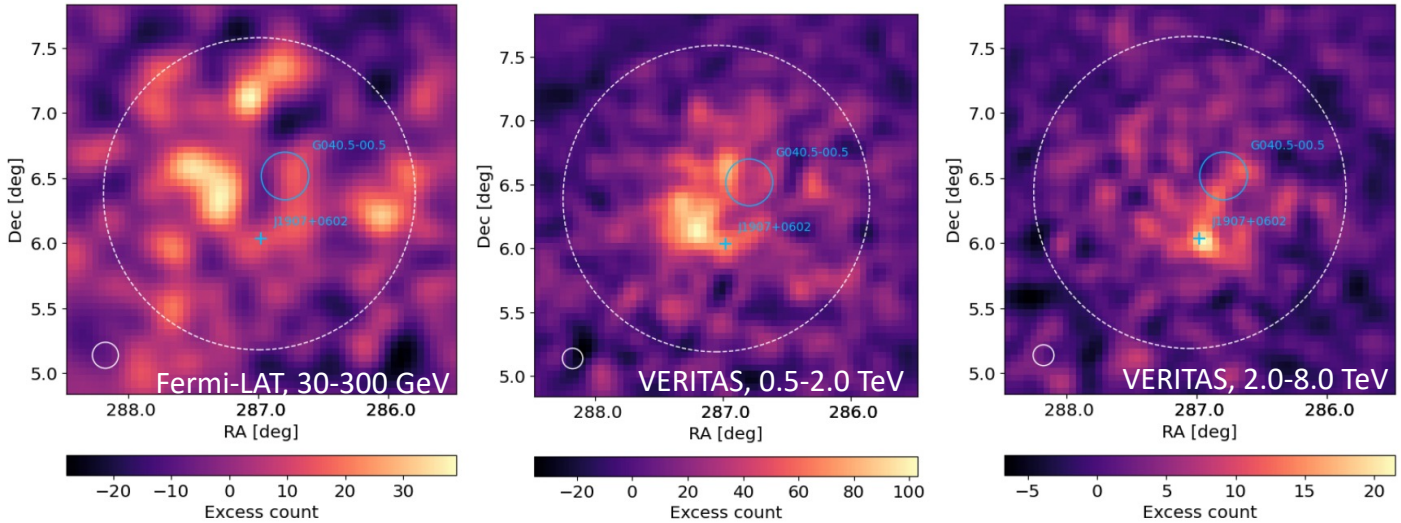
References

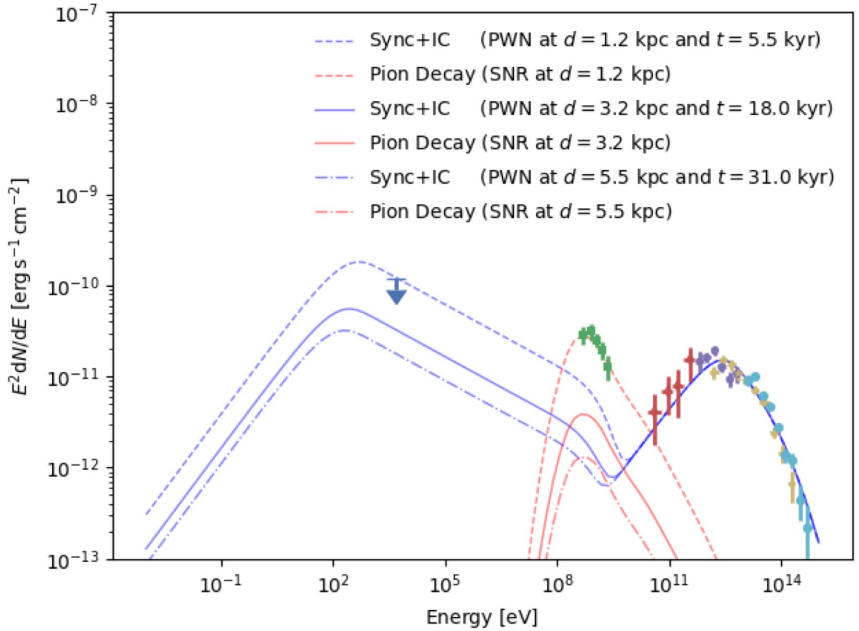
VTSCat: The VERITAS Catalog of Gamma-Ray Observations
Acharyya, A., Adams, C. B., Archer, A., Bangale, P., Bartkoske, J. T., Batista, P., Benbow, W., Brill, A., Brose, R., Buckley, J. H., Capasso, M., Christiansen, J. L., Chromey, A. J., Daniel, M. K., Errando, M., Falcone, A., Farrell, K. A., Feng, Q., Finley, J. P., Foote, G. M., Fortson, L., Furniss, A., Gallagher, G., Gent, A., Giuri, C., Gueta, O., Hanlon, W. F., Hanna, D., Hassan, T., Hervet, O., Hoang, J., Holder, J., Hughes, G., Humensky, T. B., Jin, W., Kaaret, P., Kertzman, M., Kieda, D., Kleiner, T. K., Korzoun, N., Krennrich, F., Kumar, S., Lang, M. J., Lundy, M., Maier, G., McGrath, C. E., Millard, M. J., Mooney, C. L., Moriarty, P., Mukherjee, R., Nieto, D., Nievas-Rosillo, M., O'Brien, S., Ong, R. A., Otte, A. N., Pandel, D., Park, N., Patel, S. R., Patel, S., Pfrang, K., Pichel, A., Pohl, M., Prado, R. R., Pueschel, E., Quinn, J., Ragan, K., Reynolds, P. T., Ribeiro, D., Richards, G. T., Roache, E., Rovero, A. C., Rulten, C., Ryan, J. L., Sadeh, I., Santander, M., Schlenstedt, S., Sembroski, G. H., Shang, R., Splettstoesser, M., Stevenson, B., Tak, D., Vassiliev, V. V., Wakely, S. P., Weinstein, A., Williams, D. A., Williamson, T. J., Angelini, L., Basu-Zych, A., Sabol, E., and Smale, A.
<Research Notes of the American Astronomical Society, 7, 6 (2023)>
=2023RNAAS...7....6A

A. Acharyya et al. 2023 Res. Notes AAS 7 6

Multiwavelength Investigation of γ-ray Source MGRO J1908+06 Emission Using *Fermi*-LAT, VERITAS and HAWC

- Observations support scenario where bright emission is from evolved PWN with extended morphology (radius ~ 1.8 deg).
- First application of a newly-developed VERITAS data analysis method for extended sources.
- Energy-dependent morphology.
- Modeling PWN interacting with SNR reverse shock (d=3.2 kpc):
  - true age of 22+/- 9 kyr
  - magnetic field of 5.4+/-0.8 μG

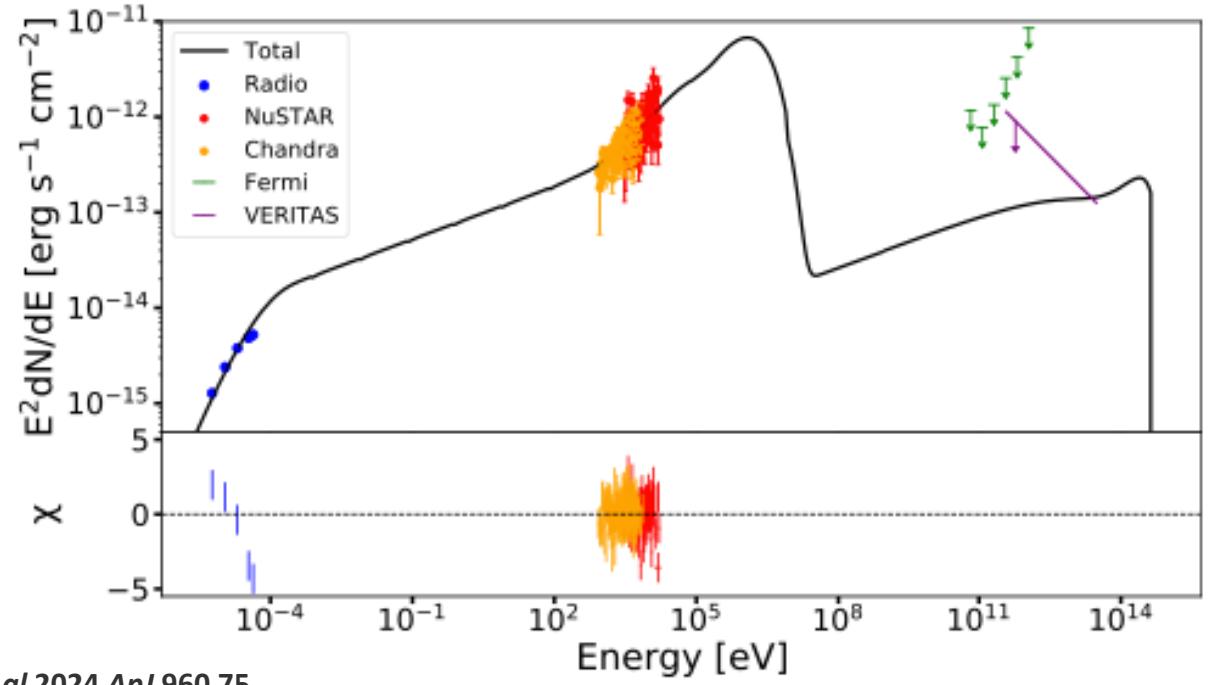


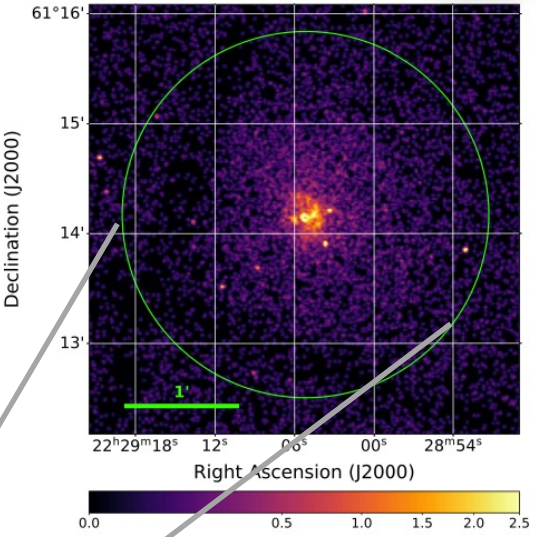


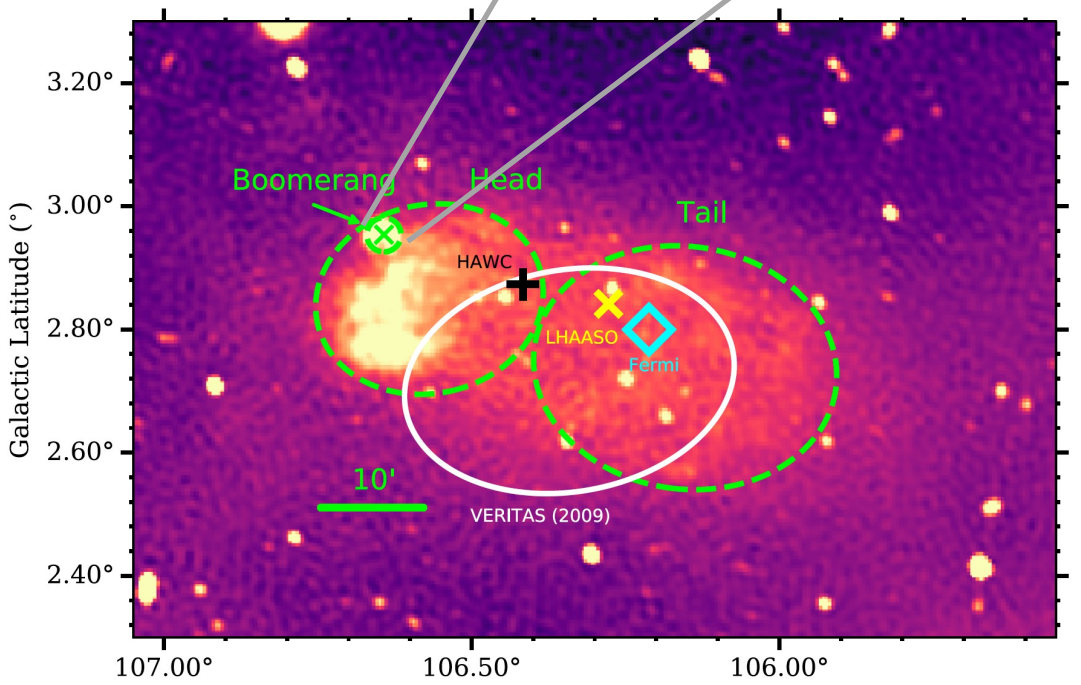
Corresponding author **Ruo-yu Shang**, accepted by ApJ, https://arxiv.org/pdf/2408.01625

A Multiwavelength Investigation of PSR J2229+6114 and its Pulsar Wind Nebula in the Radio, X-Ray and Gamma-ray Bands

- NuSTAR detection of extended emission on Boomerang PWN.
- A 51.67 ms spin period from PSR J2229+6114 in 3-20 keV band.
- To keep synchrotron emission consistent with measurements, SED modeling suggests
  - Magnetic field ~3μG
  - Distance of ~8 kpc.
- Supported by lack of X-ray variability and energy-dependent X-ray size of PWN.
- PWN may be re-expanding after reverse shock compression ~ 1000 years ago.



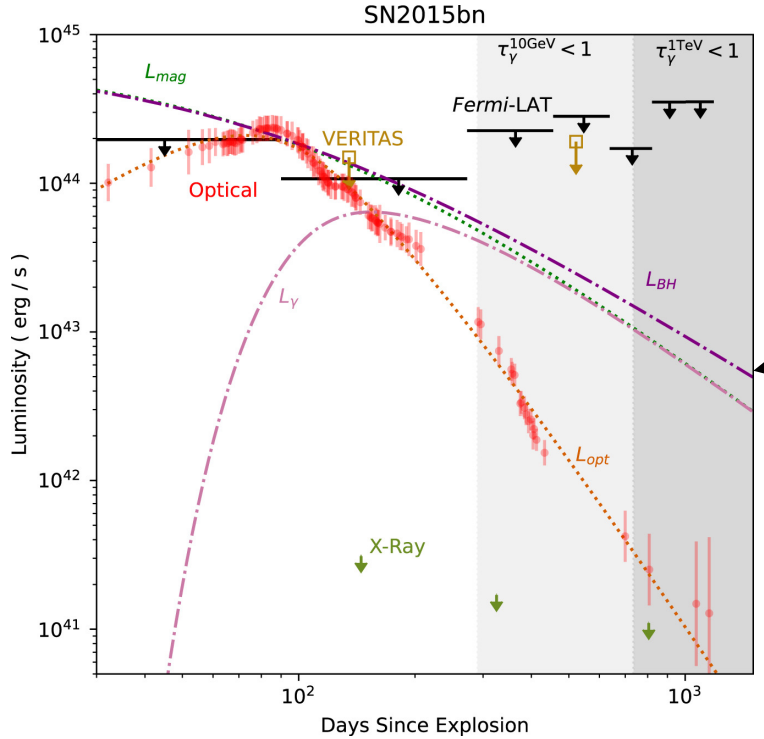




I. Pope *et al* 2024 *ApJ* 960 75

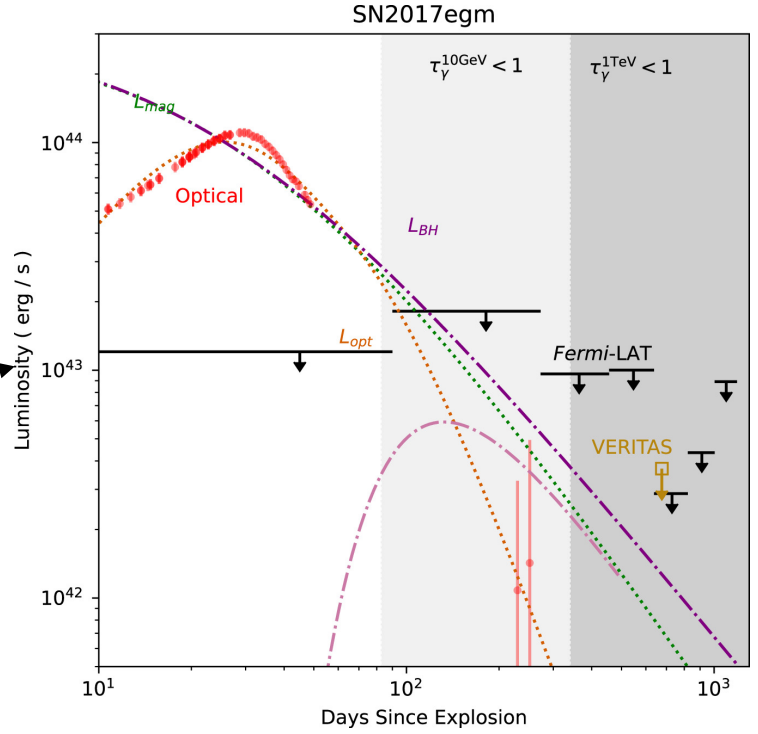
Constraints on the Gamma-ray Emission from Superluminous Supernovae SN2015bn and SN2017egm

- Rare stellar explosions with very high luminosities.
- The optical luminosity over 1000 days informs the magnetar model.
- The total magnetar energy budget is larger than measured – look in gamma-ray bands for missing energy.
  - Search for 100 MeV - 30 TeV emission resulted in non-detections.
- Gamma-ray upper limits approach magnetar's spin-down luminosity for SN 2015bn (green dotted line).



~ 3 hours VERITAS exposure ~135 days after the explosion.

8.7 hours exposure VERITAS observations ~670 days after the explosion.

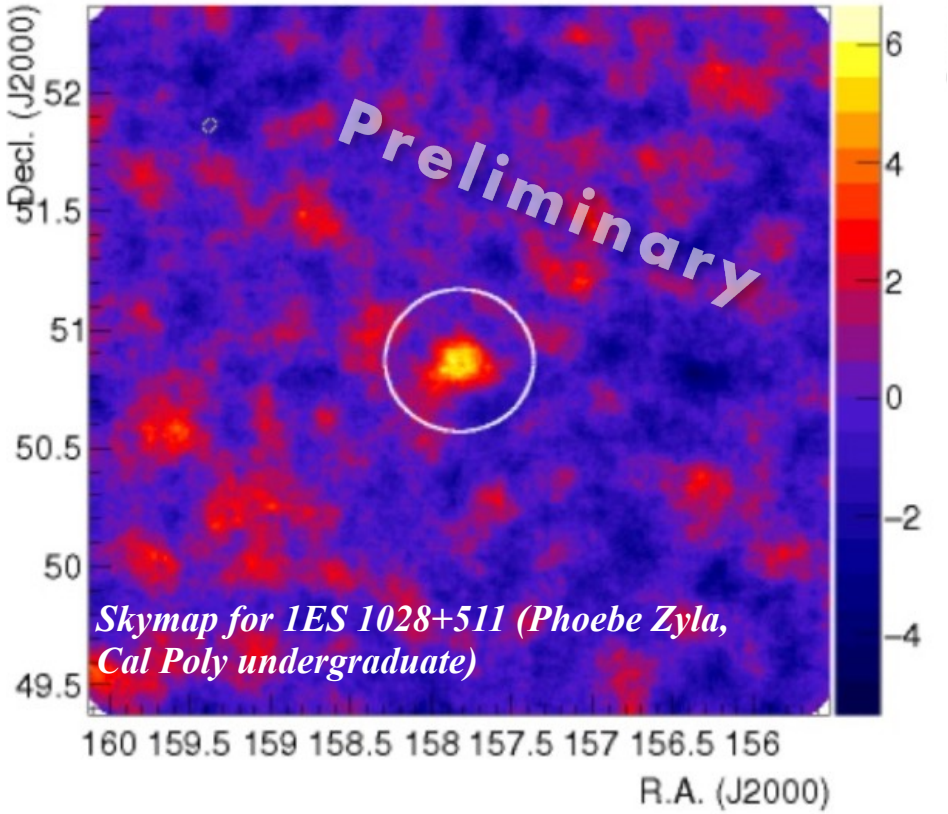


A. Acharyya *et al* 2023 *ApJ* **945** 30

Recent Announcements on Galaxy Detections

VERITAS Discovery of VHE Emission from the EHBL 1ES 1028+511: ATel #16458 (Feb 2024)

- Redshift of 0.361.
- VERITAS observations (2007 – 2024).
- 40+ hours of exposure.



Skymap for 1ES 1028+511 (Phoebe Zyla, Cal Poly undergraduate)

VERITAS Detection of VHE Emission from IC 310: ATEL #16535 (Mar 2024)

- VERITAS observations in response to LHAASO ATel #16513 reporting rapid variability.
- ~ 2 hours of VERITAS data March 10-13 result in 6.6σ.
- Flux estimate above 1 TeV ~15% Crab.

The Astronomer's Telegram

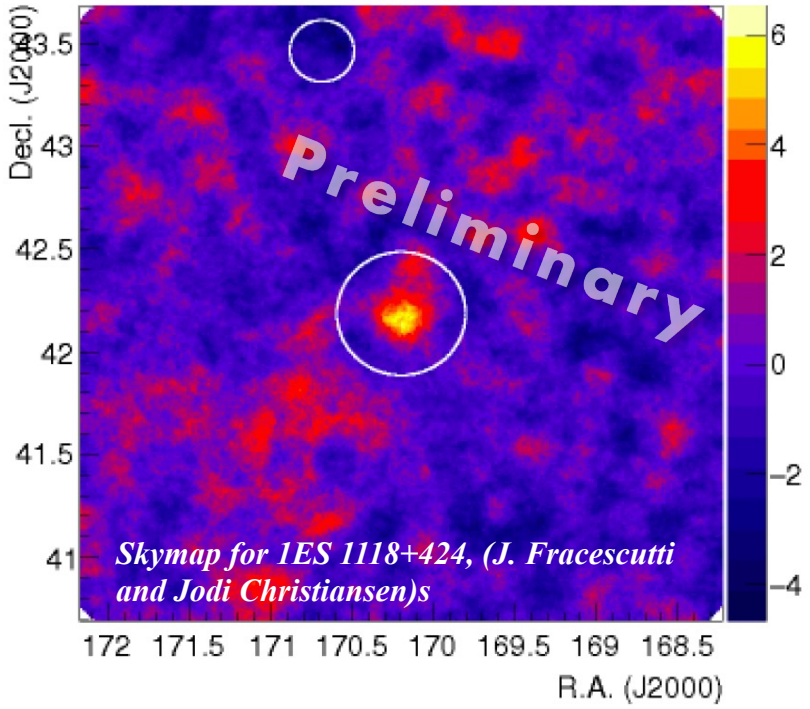
New VHE Blazars!

VERITAS Discovery of VHE Emission from B2 0912+29

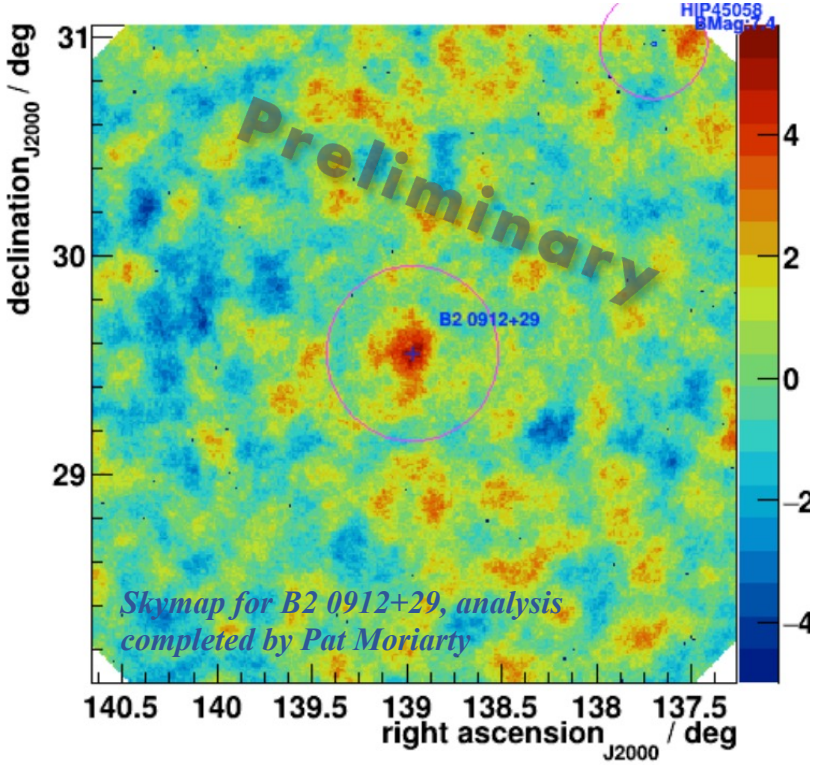
- Distant HBL at a redshift z > 0.19 detected at ~0.4% Crab above 200 GeV.

VERITAS Discovery of VHE Emission from 1ES 1118+424

- Distant HBL at redshift z > 0.28 detected at ~0.8% Crab above 200 GeV.

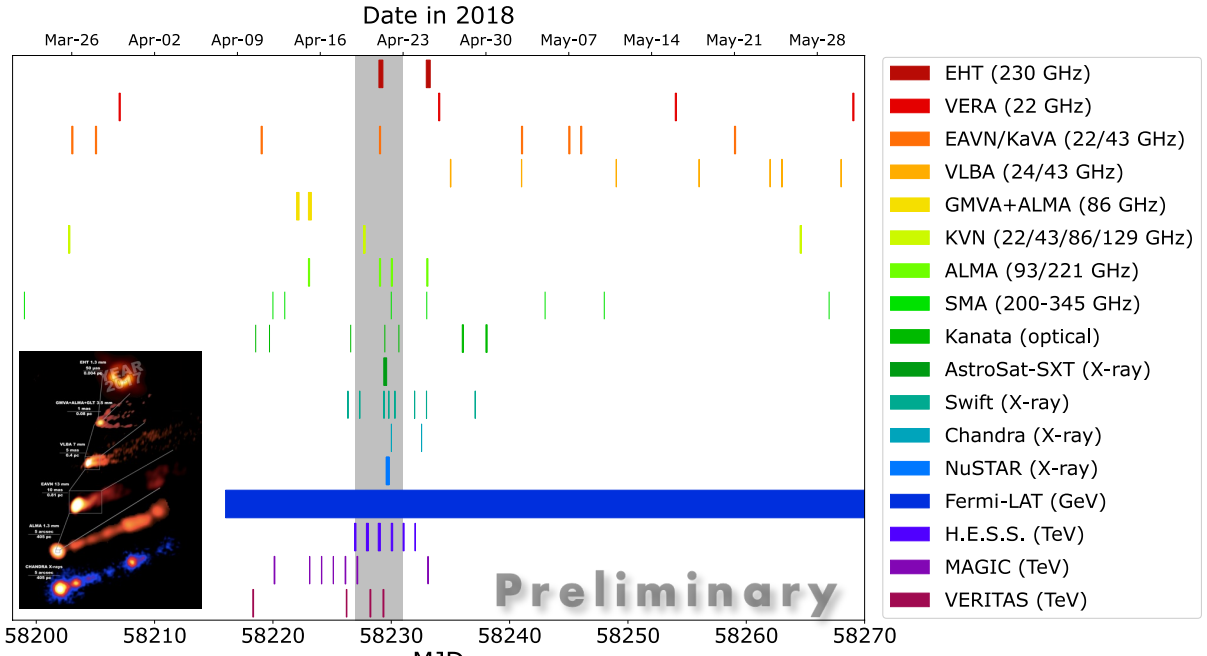


- VERITAS continues with a strong discovery program, surveying well known sources displaying hard LAT spectra and bright in X-ray.
- More in talk by Benbow at 2:45pm today!

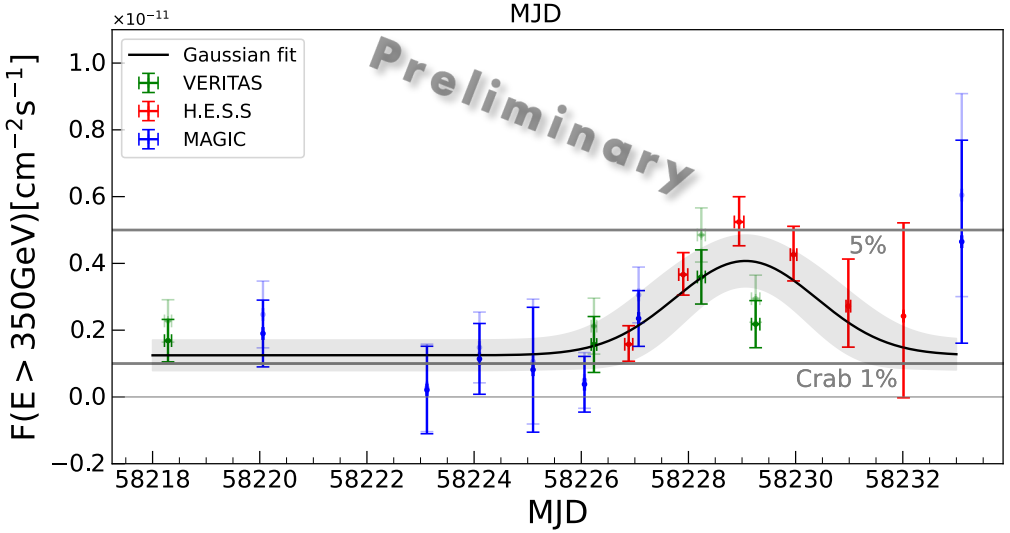


Broadband Multiwavelength Properties of M87 during the 2018 EHT Campaign including a Very High Energy Flaring Episode

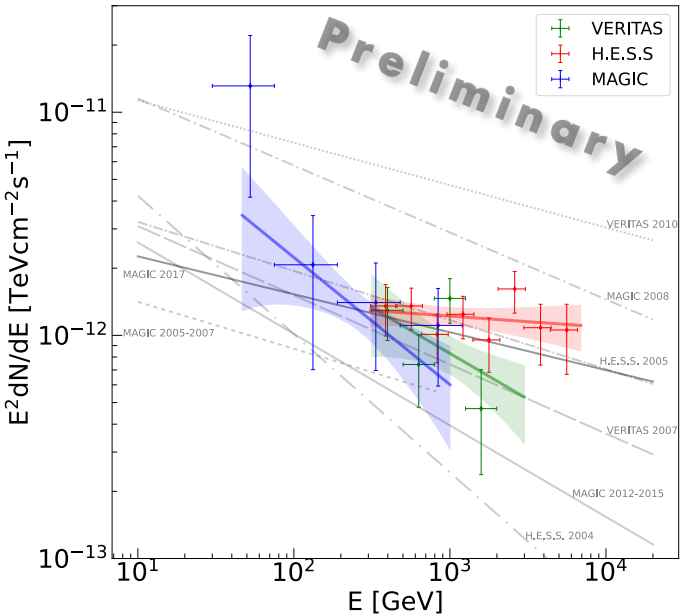
W. Jin and M. Santandar for the VERITAS Collaboration, and The EHT, Fermi LAT, HESS, MAGIC, EAVN Collaborations.



- Second EHT campaign supports study of accreting black hole, inflow and inner jet, and particle acceleration.
- 3-day VHE flaring period
- Contemporaneous MWL data provide one of the most complete SEDs
- Flux above 350 GeV seen to double within 36 hours.



- X-ray only band to show enhancement during period.
- Evidence for monotonically increasing jet position angle corresponding with variations in EHT image bright spot.
- Challenge for simple one-zone leptonic emission models.

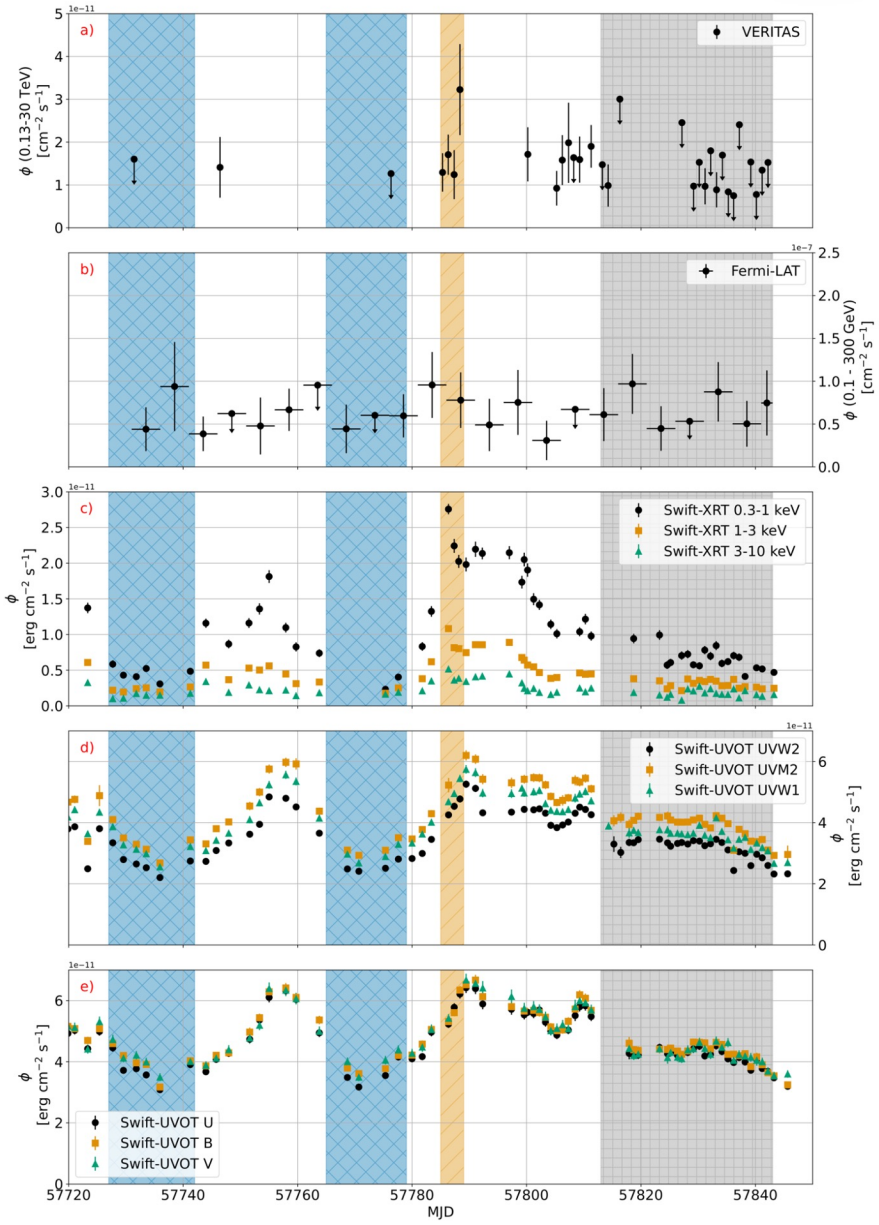


ArXiv:2404.17623. Manuscript submitted to A&A and under review processes.

A multi-wavelength Study to Decipher the 2017 Flare of the Blazar OJ 287

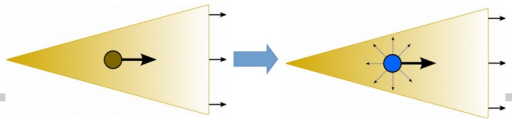
- An IBL at z = 0.306
- Showed strong signs of activity in UV/X-ray starting in middle of 2016
- VERITAS observed for months starting 2016
- First VHE detection February 2017, coincident with Swift detected X-ray flare
  - ***Mukherjee et al., Atel 10051,2017***

- Three states investigated
  - **Low state:** MJD 57731-57740 & MJD57765-57777
  - **Flare:** MJD 57785-57789
  - **Post-flare:** MJD 57813-57843



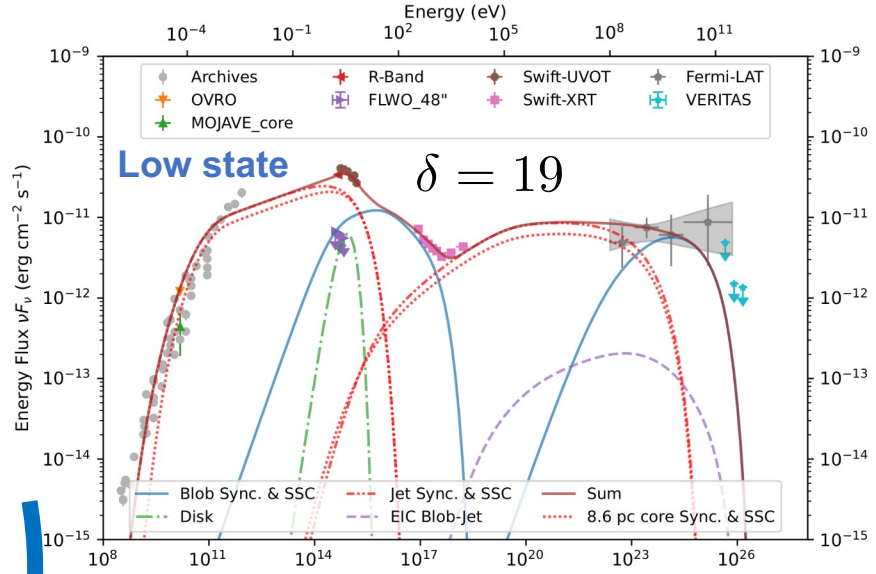
O'Brien and Hervet for the VERITAS Collaboration, ApJ Accepted, posted on arXiv:2407.11848

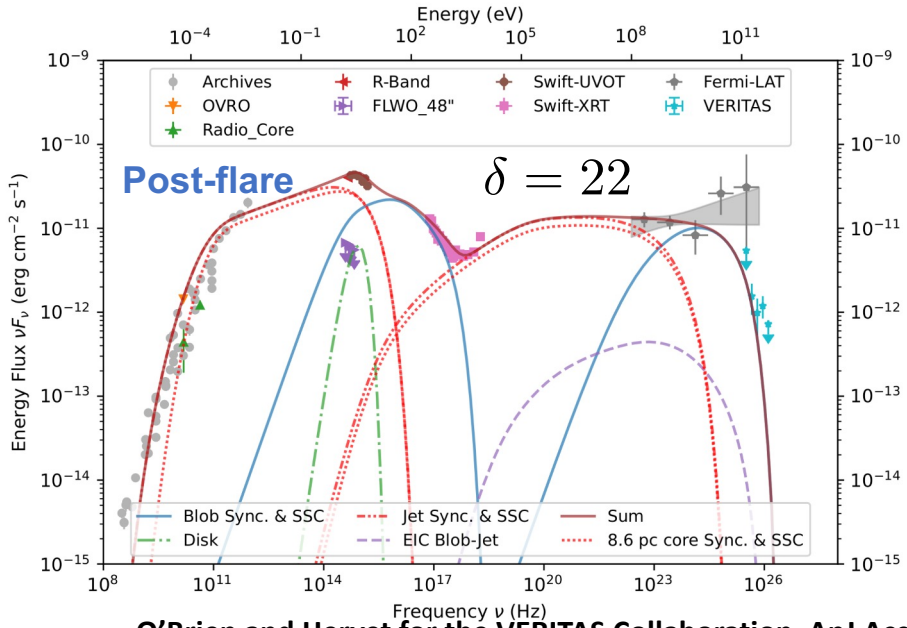
A multi-wavelength Study to Decipher the 2017 Flare of the Blazar OJ 287

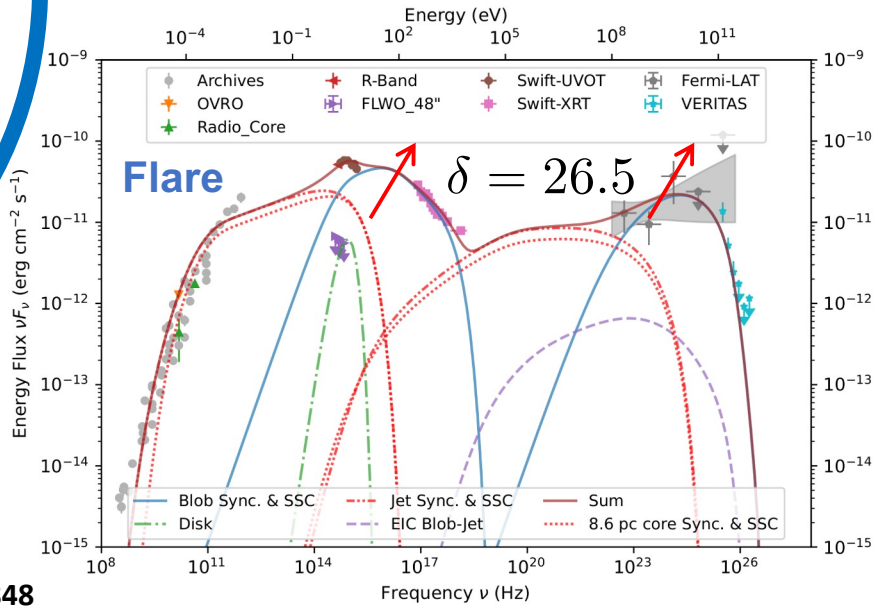


A flaring blob in a steady jet

- Variability can be explained by a variation of the blob's Doppler factor δ
- The abrupt change of δ is consistent with a strong recollimation shock *(e.g. Hervet 2017)*
- Contemporaneous radio observations suggest the flare originates within a radio knot ~10pc from the core *(Lico 2022)*

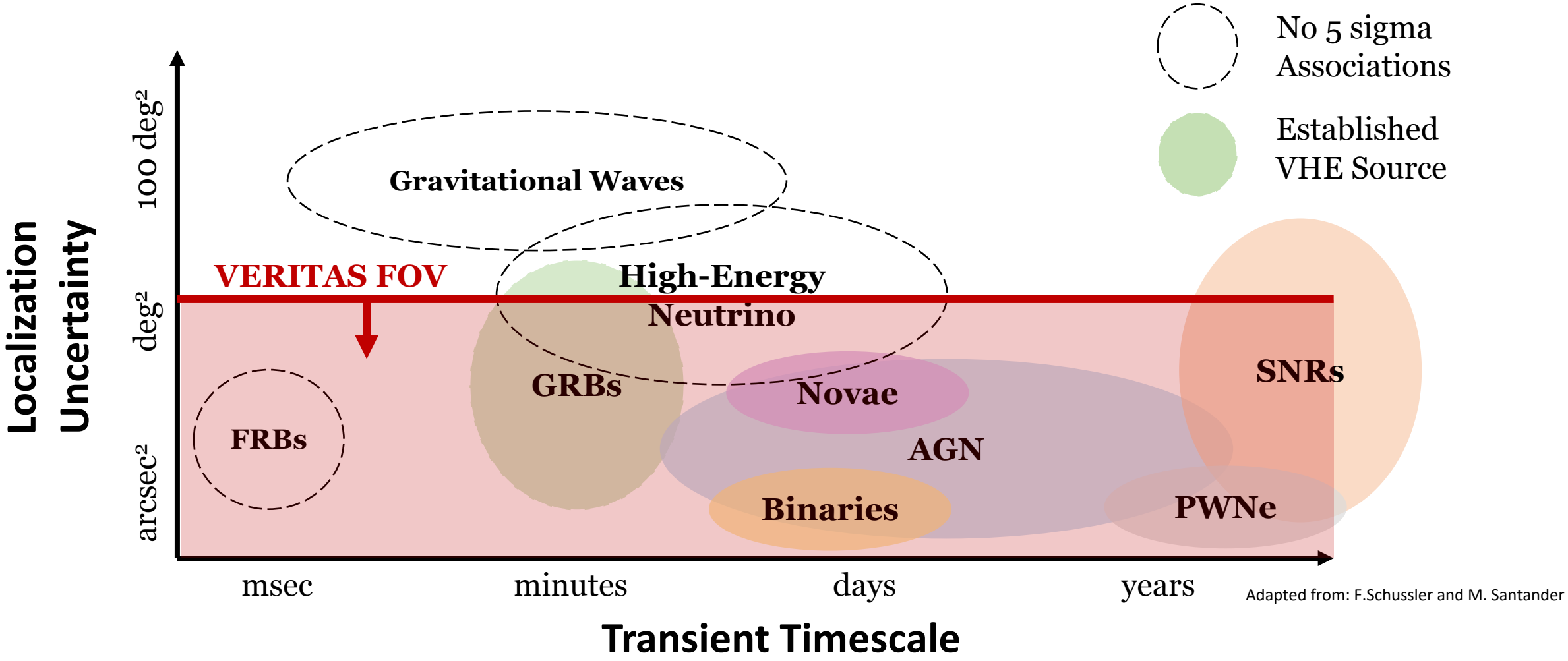






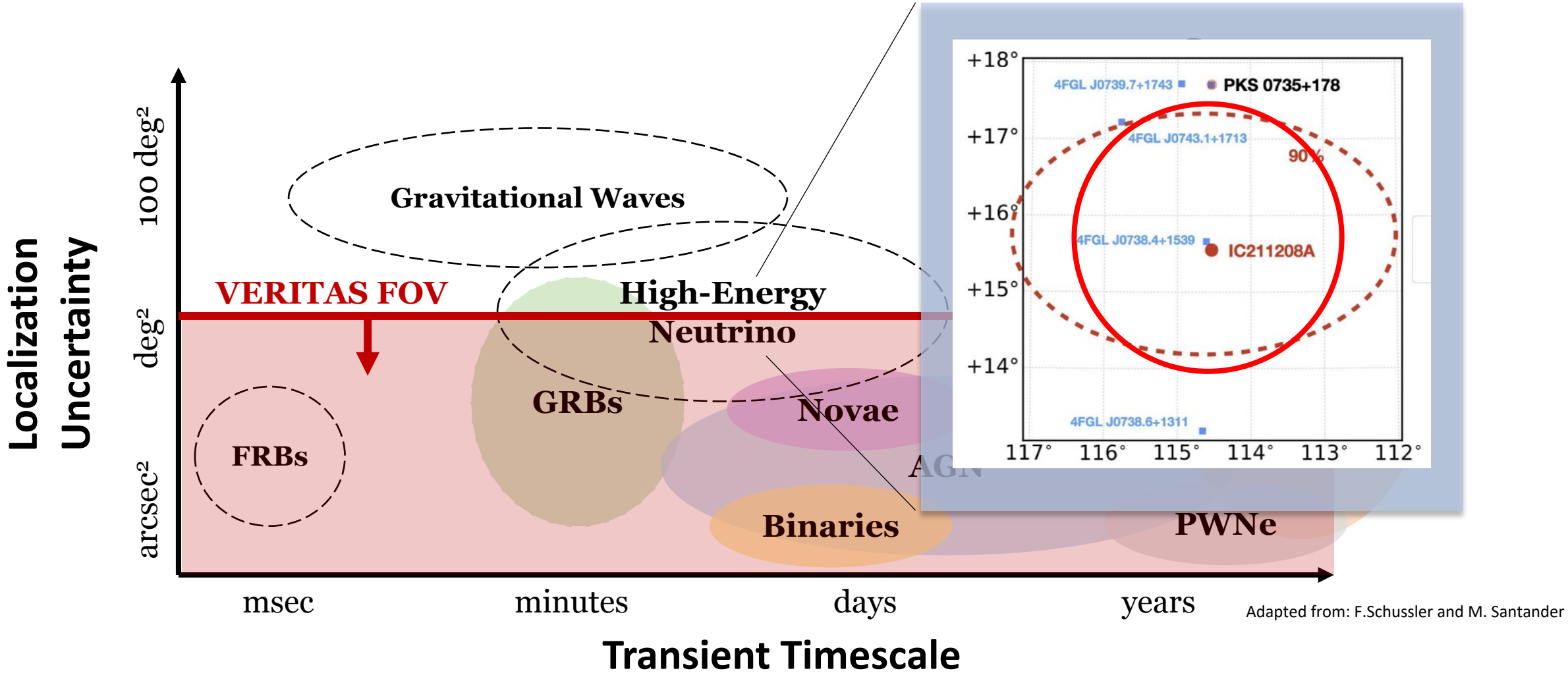
O'Brien and Hervet for the VERITAS Collaboration, ApJ Accepted, posted on arXiv:2407.11848

Multimessenger Transients Follow-Up



~10 deg² FoV, + high sensitivity allow VERITAS to observe a wide variety of VHE sources and candidate emitters.

Multimessenger Transients Follow-Up



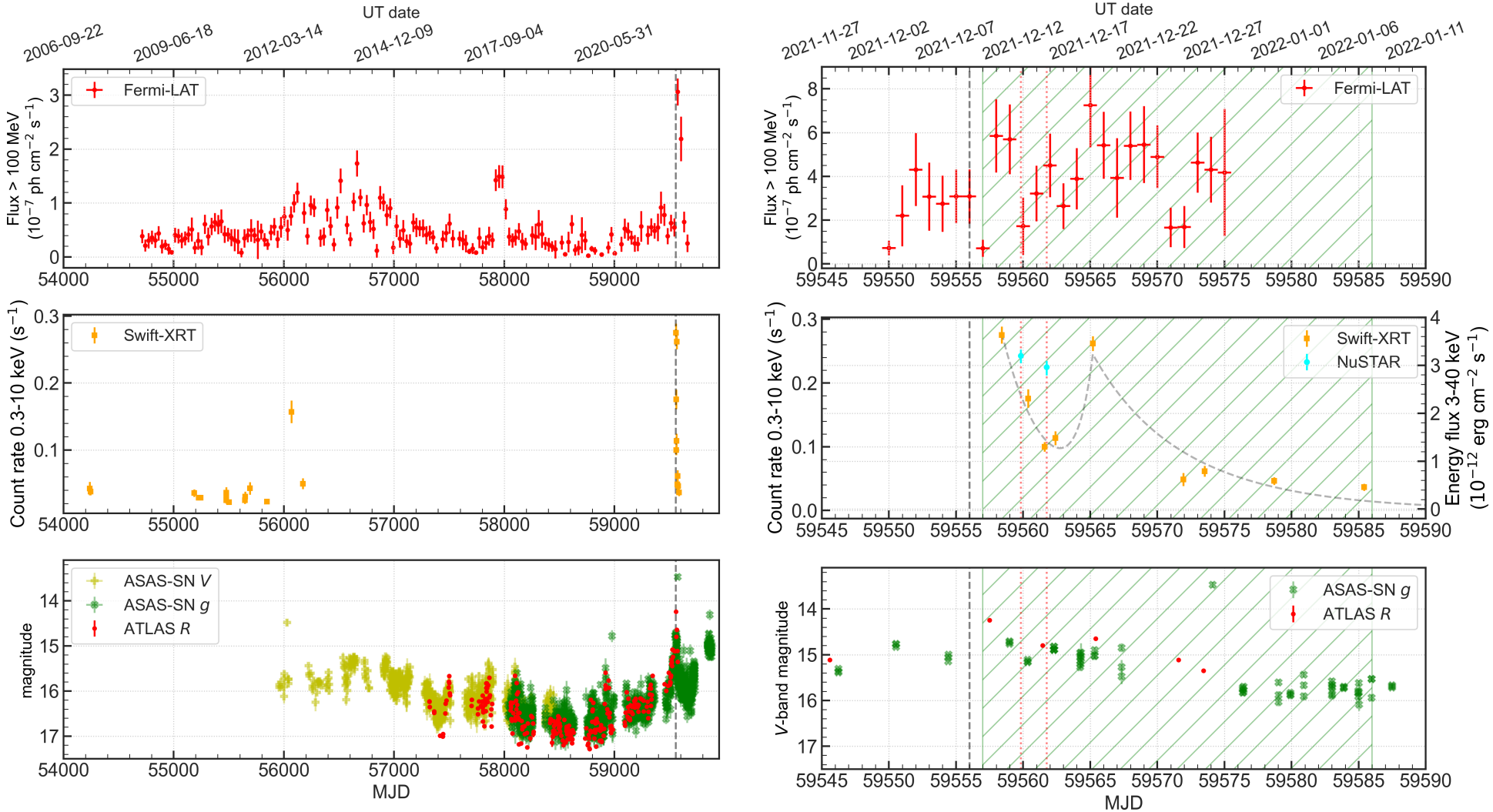
Adapted from: F.Schussler and M. Santander

~10 deg² FoV, + high sensitivity allow VERITAS to observe a wide variety of VHE sources and candidate emitters.

Multiwavelength Observations of the Blazar PKS 0735+178 in Spatial and Temporal Coincidence with an Astrophysical Neutrino Candidate IceCube-211208A

- Possible association with IceCube-211208A (E_ν=171 TeV; Dec 2021).
- NuSTAR, LAT and optical show historically high flux and daily variability.

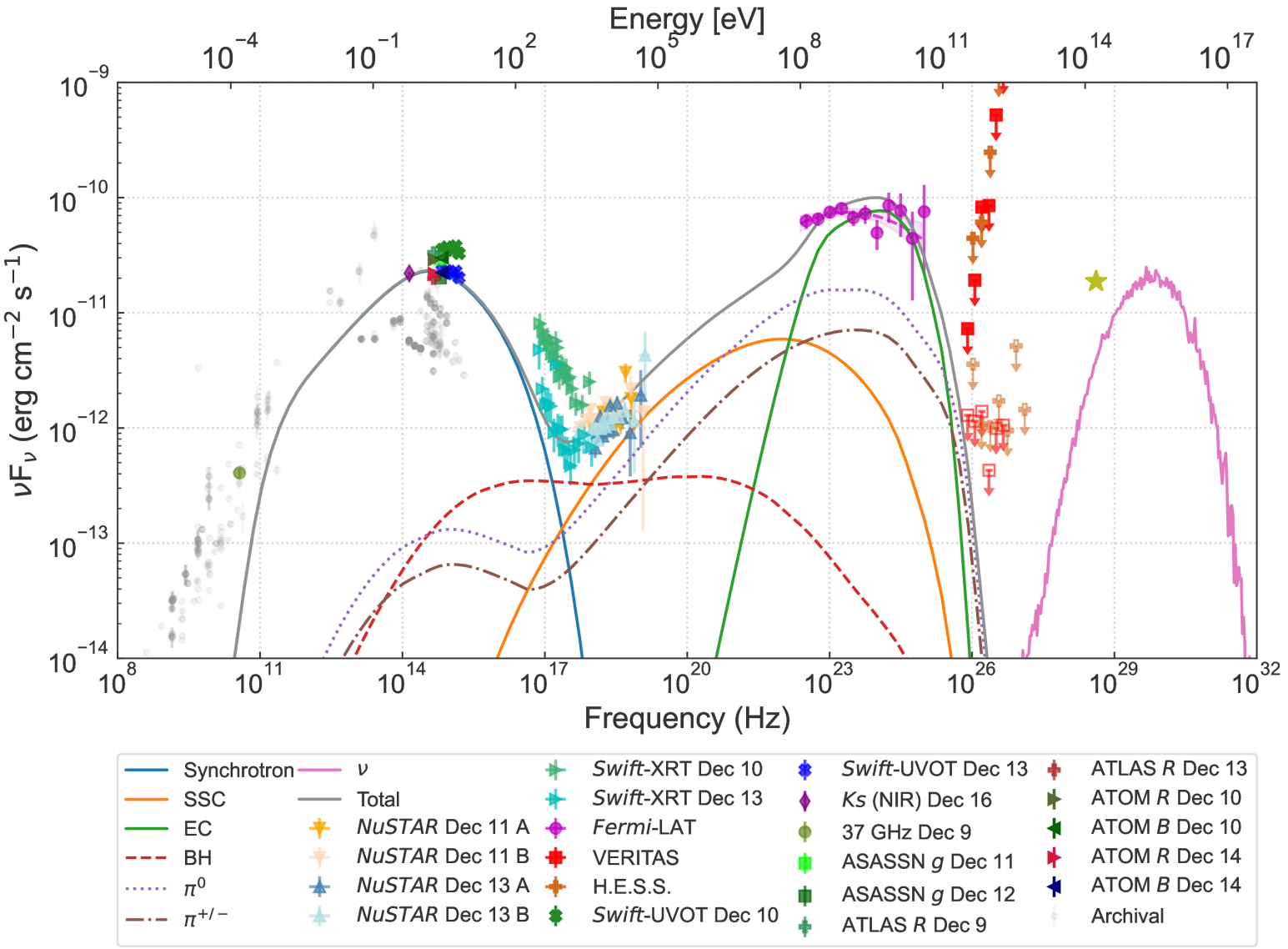
- Year timescale
  - Historic high fluxes coincident with the neutrino.
- Day timescale
  - Soft X-ray variability constrains R < ~5e16 cm



Feng, VERITAS + HESS 2023ApJ...954...70A

Multiwavelength Observations of the Blazar PKS 0735+178 in Spatial and Temporal Coincidence with an Astrophysical Neutrino Candidate IceCube-211208A

- Upper limits from H.E.S.S. and VERITAS indicate cutoff at 100 GeV.
- External soft photon field is necessary to explain SED
- With BLR photon field:
  - purely leptonic external inverse-Compton model can explain the photon emission.
  - dominate at multi-GeV and cutoff above 100 GeV.
- Lepto-hadronic with external target photons also explain neutrino rate



Feng, VERITAS + HESS 2023ApJ...954...70A

Summary of the Talks at Gamma 2024

- **VERITAS is operating well and planning for operations in coming three years.**
- **VERITAS has a strong and varied science program in the gamma-ray and optical regimes.**
- **We are a relatively small consortium compared to others (with lots of data) and welcome collaboration…**

VERITAS Contributions at Gamma 2024:

Megan Splettstoesser	Multiwavelength Modeling Results of Two Flaring States of the Distant HB 1ES 0647+250	Poster	Monday Poster Session
Connor Mooney	Long-term VERITAS Monitoring and Multi-wavelength Data of TXS 0506+056: Probing Intergalactic Cascades with VERITAS, Swift, and Fermi Observations	Poster	Monday Poster Session
Claire Hinrichs	A multi-wavelength Study of a Long-Duration VHE flare from BL Lacertae with VERITAS	Oral	Monday 2:30pm (Parallel Session 2)
Martin Pohl	Deep observations of the starburst Galaxy M82 by the VERITAS gamma-ray Observatory	Oral	Monday 4:30 PM (Parallel Session 2)
Manel Errando	Mapping the blazar radiation zone with X-ray Polarization and TeV Gamma-ray Observations	Oral	Tuesday 2:00 PM (Parallel Session 2)
Wystan Benbow	Recent Highlights from the VERITAS AGN Discovery Program	Oral	Tuesday 2:45 PM (Parallel Session 2)
Weidong Jin	Exploring the Multi-Messenger Universe with VERITAS	Poster	Wednesday Poster Session
Maria Kherlakian	Search for VHE emission from Fast Blue Optical Transients with the VERITAS telescopes	Poster	Wednesday Poster Session
	A novel image cleaning technique for the VERITAS telescopes	Poster	
Matthew Lundy	LHAASO Archival Analysis	Oral	Thursday 2:05pm (Parallel Session 1)
Maria Kherlakian	Search for VHE emission from Tidal Disruption Events with the VERITAS telescopes	Oral	Thursday 6:00pm (Parallel Session 2)

Thank you!

VERITAS Collaboration Meeting, Oxford UK, July 2024