Highlights from VERITAS

Manel Errando
Washington University in Saint Louis

on behalf of the VERITAS Collaboration

VERITAS Status

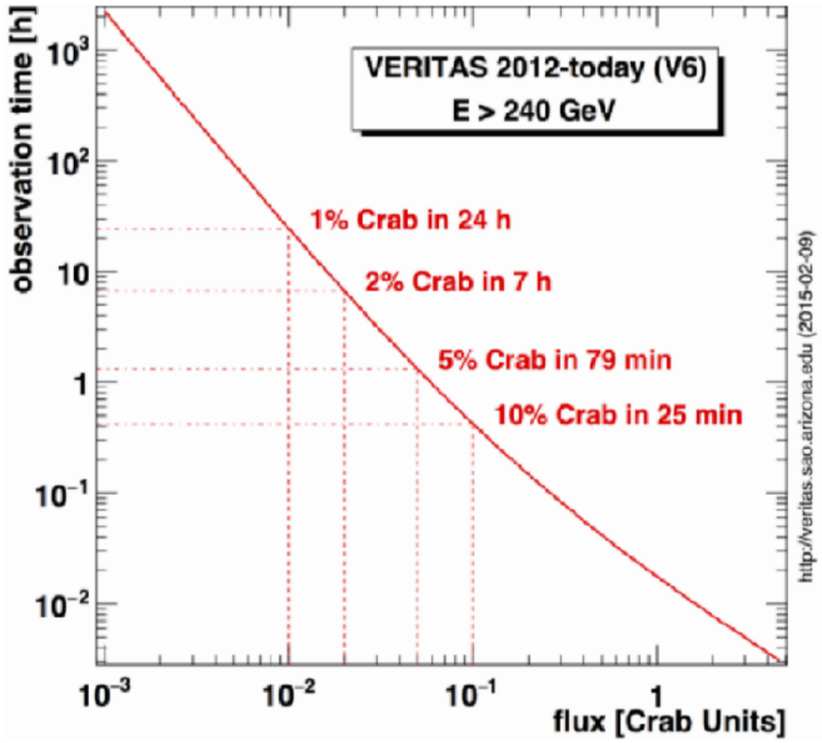
VERITAS array
Fred Lawrence Whipple Observatory
in southern Arizona @ 1,268 m a.s.l.
Co-located CTA SCT prototype

- VERITAS just started its 17th year of full-array operations.
- International Collaboration:
  - ~100 members
  - >20 active Associate Members
- VERITAS operations funded through 2025.
- Funded FADC upgrade to extend optical transient monitoring to all pixels.
- Funded mirror re-coating to improve reflectivity.

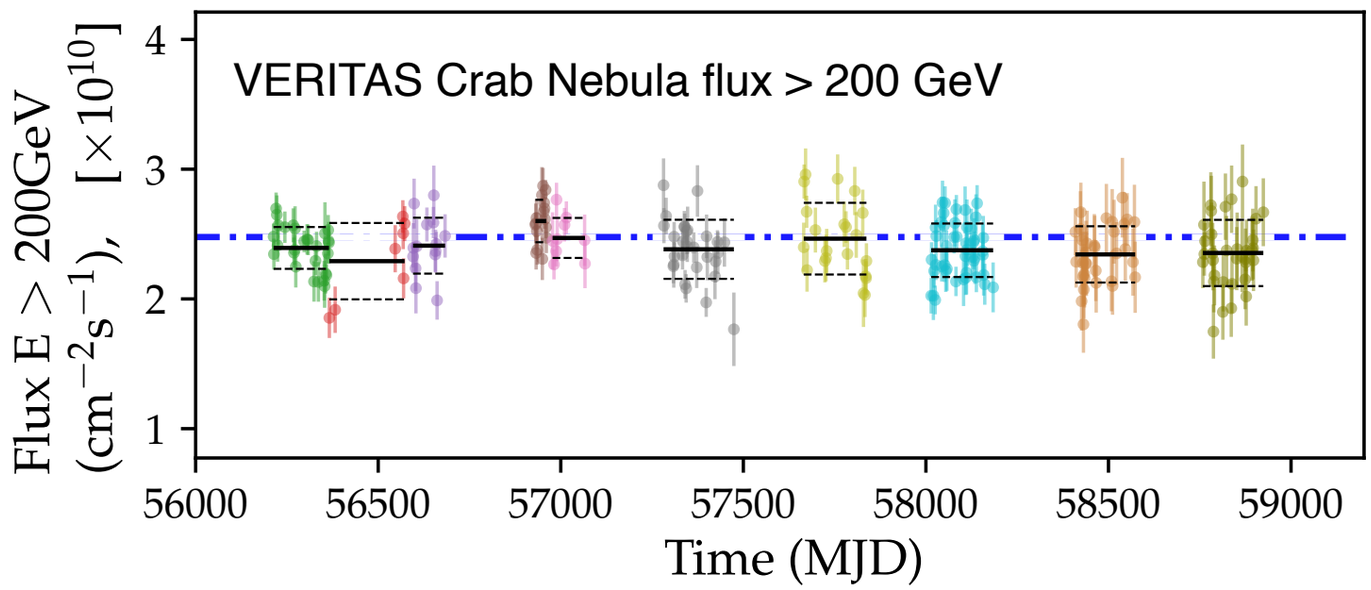
VERITAS Performance

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	~ 0.1



Long-term instrument response well understood:
Adams et al., A&A 658, A83 (2022)



VERITAS Observations

VERITAS Observations

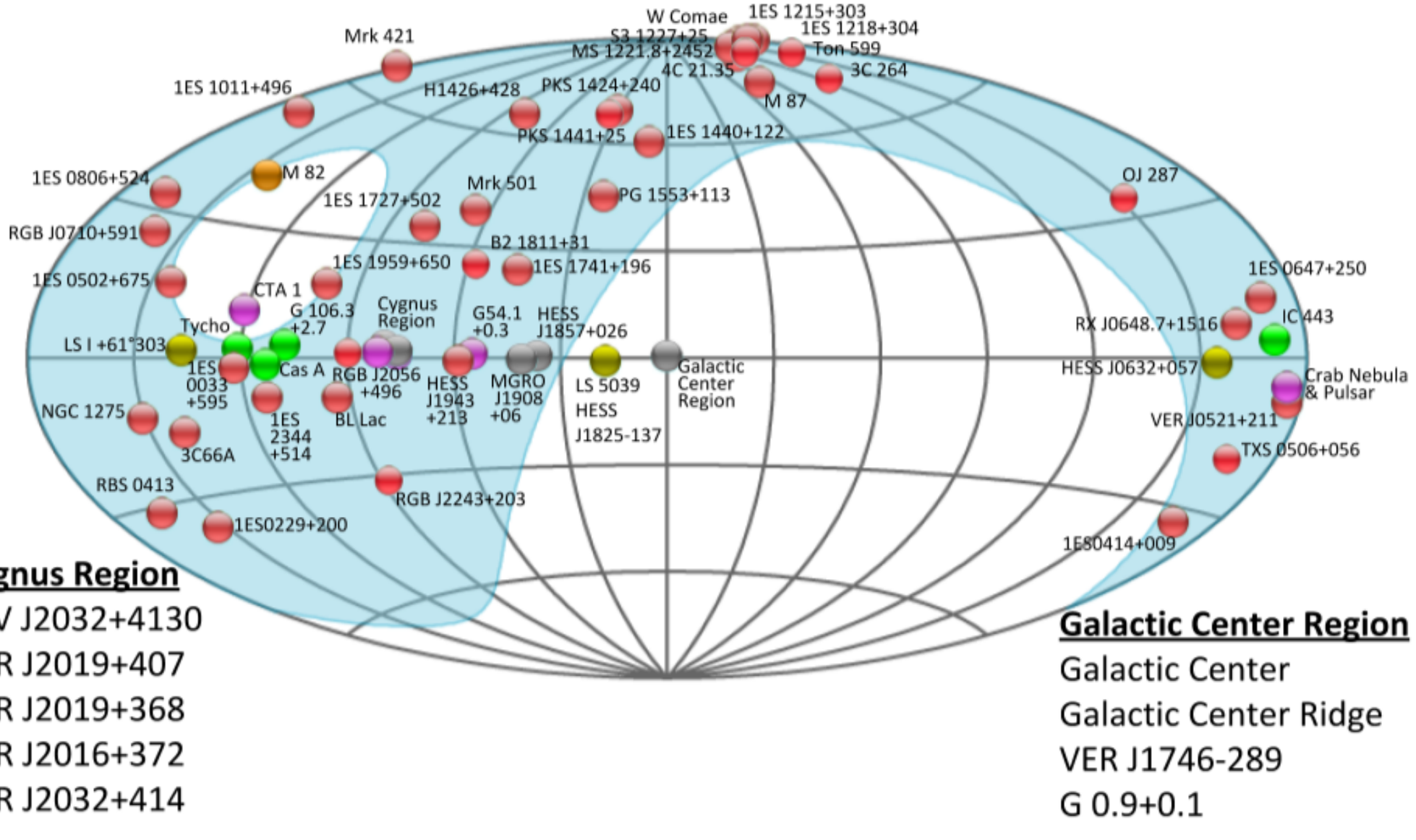
- Season: September to July each year.
- Good-weather gamma-ray data / yr:
  - ~950 h in “dark time”.
  - ~250 h in “bright moon” (illum. 30-65%).
- 4-Telescope efficiency: > 97%.

- Stellar Intensity Interferometry Observations:
  - Utilize very bright and full-moon period.
  - 250 hrs+ / year

COVID impact :

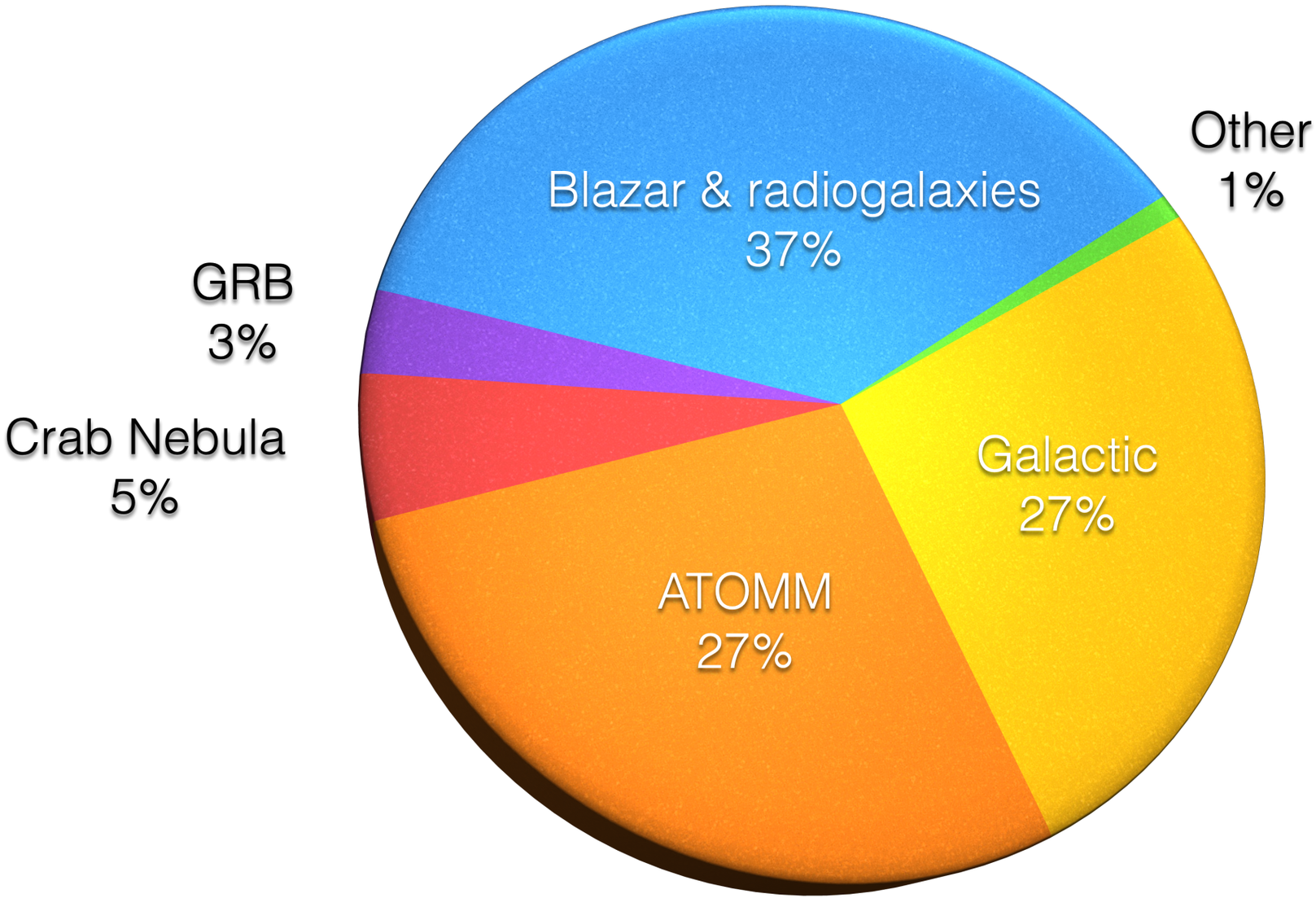
- Shut down on 17 March 2020
- Resumed in early September 2020 with remote observing capability.
- Back to mostly on-site operations in Fall 2022.

The VERITAS source catalog



- 65 sources detected, 8 astrophysical source classes.
- 23 Galactic sources: SNR, PWN, Pulsar
- 41 Extragalactic sources: 41 AGN + 1 starburst galaxy

VERITAS Science Program

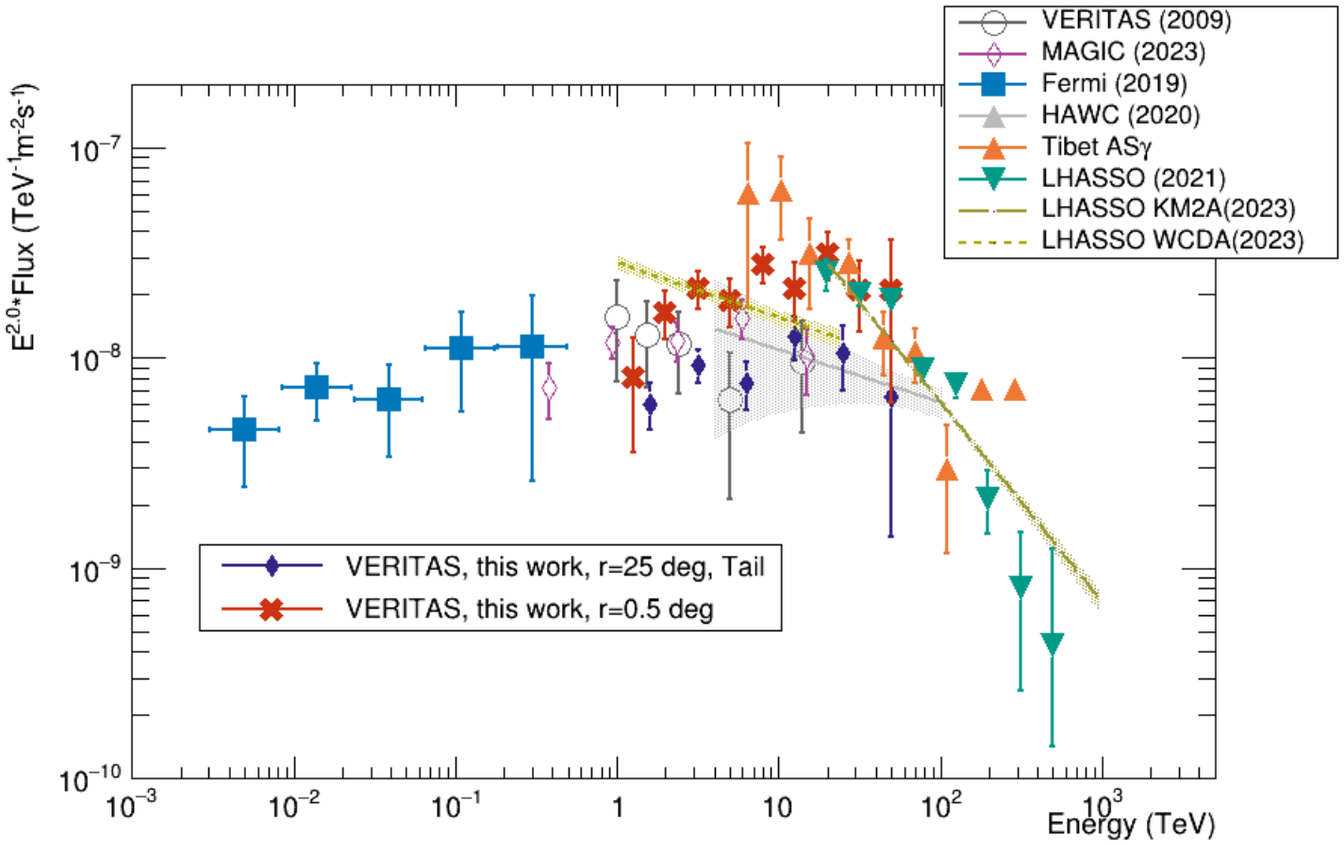


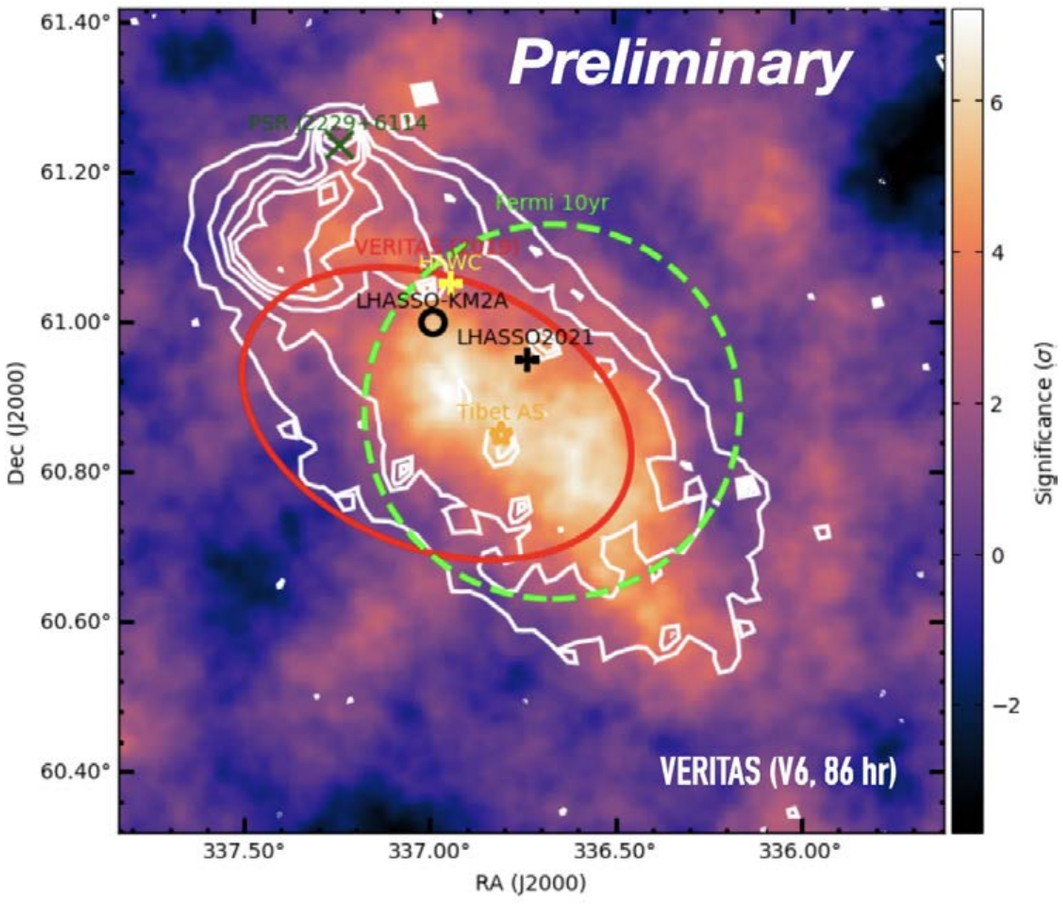
ATOMM:
Astroparticle, Transient,
Optical, Multi-Messenger

Split of data taken in 2022-23 season by Science Working Group

Galactic: SNR G106.3+2.7

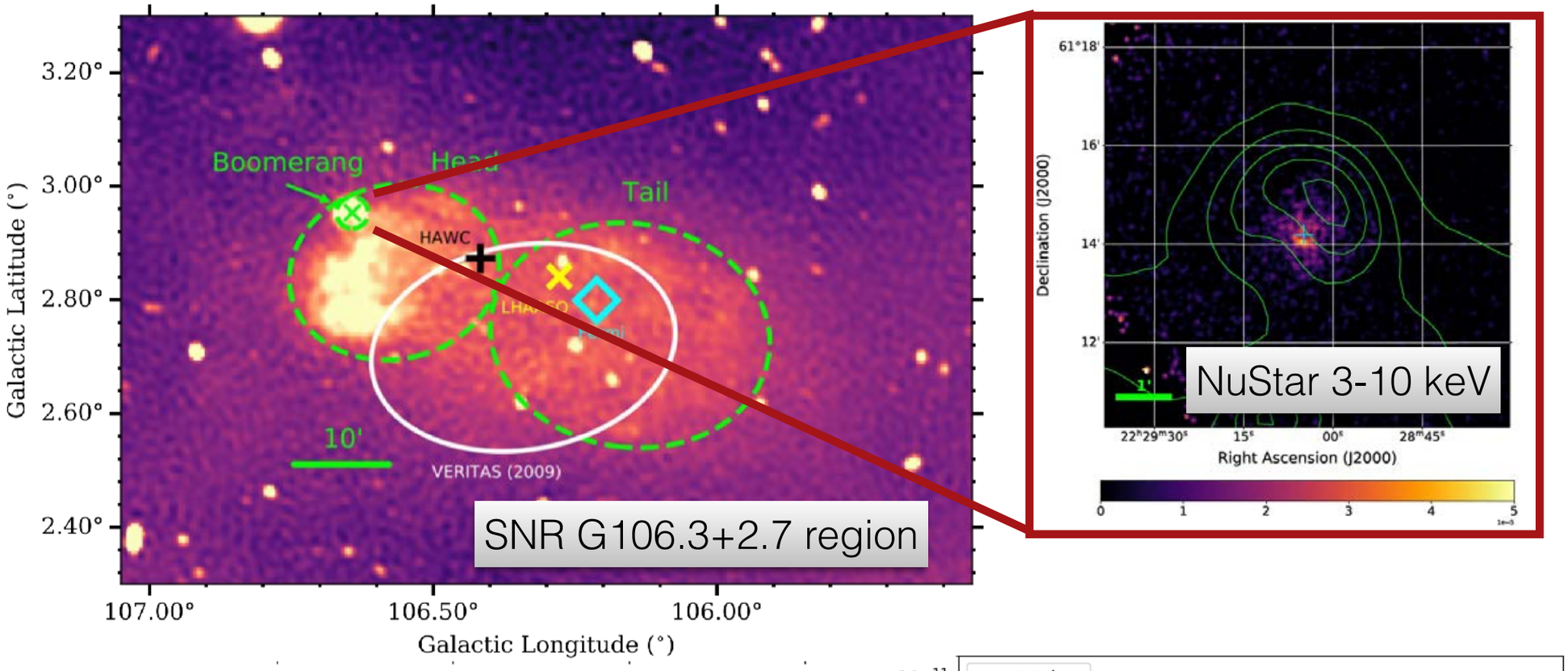
- Updated results with 86h of observations
  - Boomerang PWN: No strong TeV emission is detected.
  - Head region: Diffuse emission detected by VERITAS (MAGIC reports significant emission).
  - Tail region: Strong gamma-ray emission detected.
- Systematic checks on the full data set (>150h) ongoing.





Park (VERITAS Collaboration), PoS (ICRC'23) 869

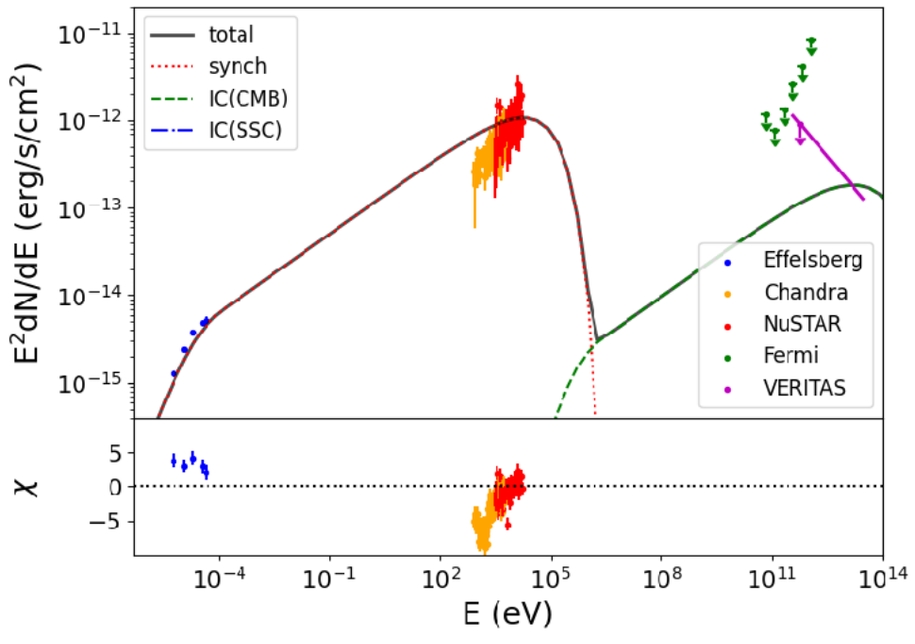
Galactic: PSR J2229+6114 and Boomerang PWN



Massimo Capasso
Columbia U

Jooyun Woo
Columbia U

- Detailed study of the Boomerang PWN with NuSTAR.
- No significant TeV emission associated with the PWN.
- Time-evolved SED model prefers low B field and d=7.5kpc.

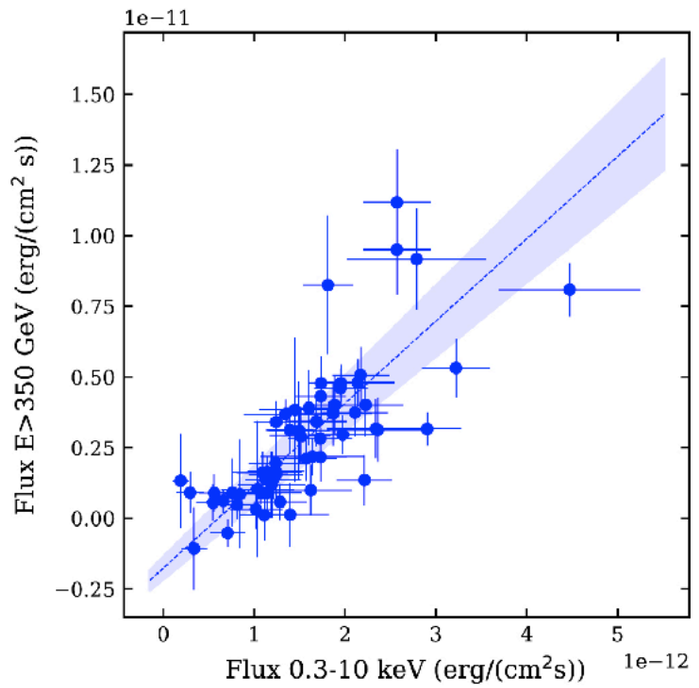


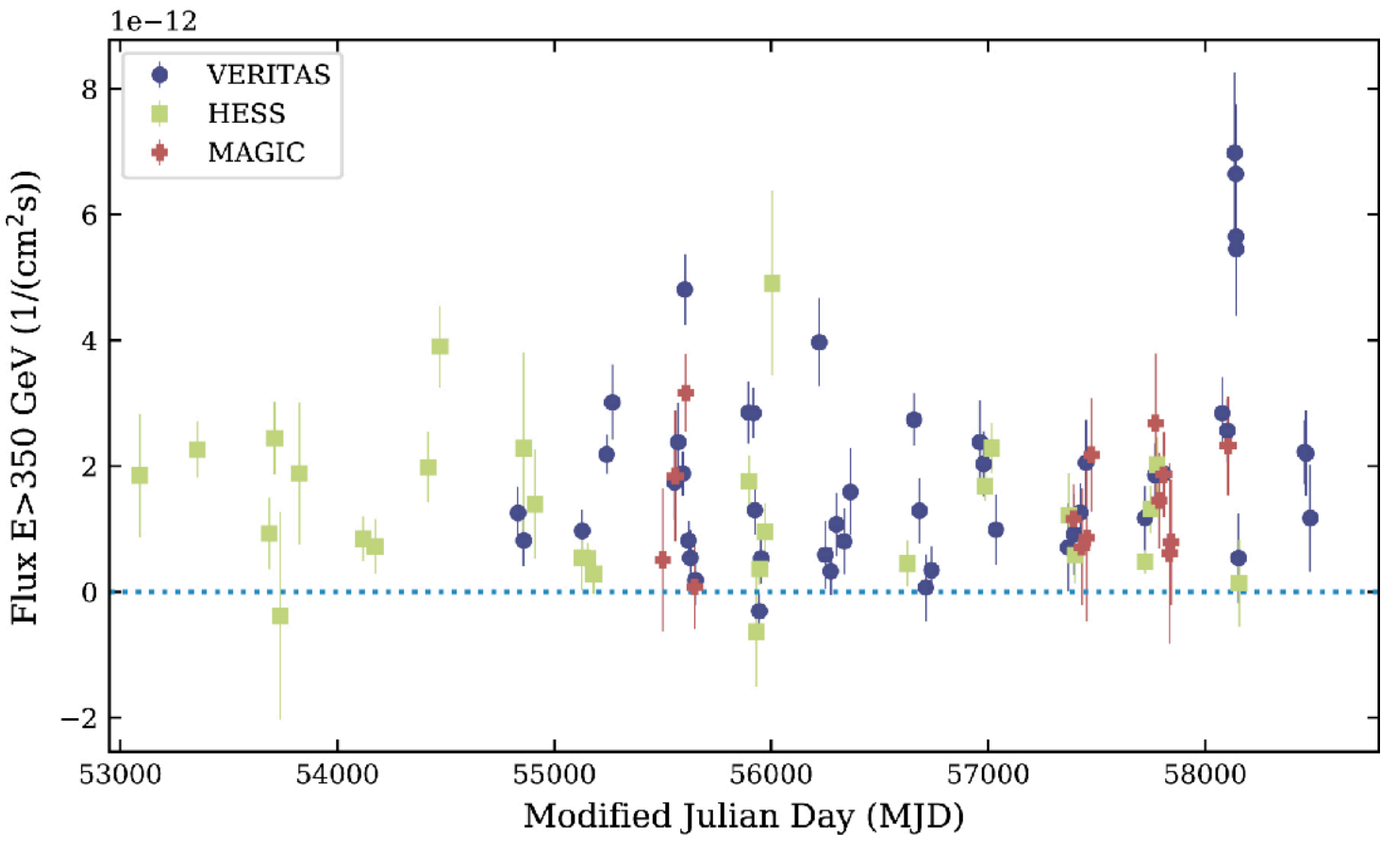
Pope et al. (NuSTAR+VERITAS), ApJ submitted

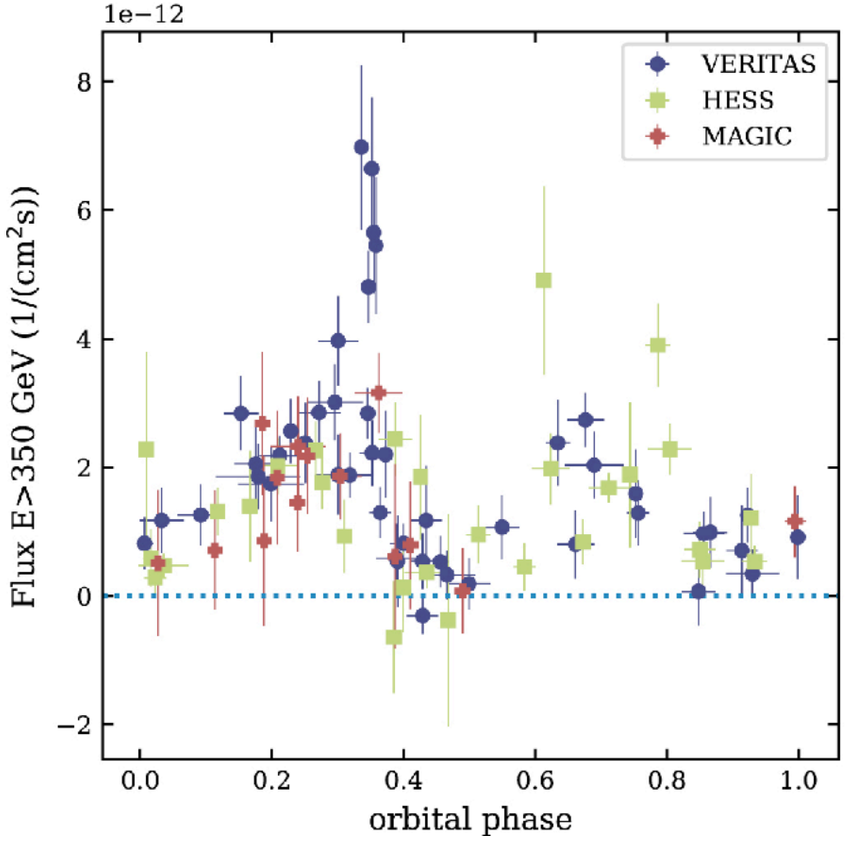
Galactic: Binary HESS J0632+054

- More than 450h of data (H.E.S.S.+MAGIC+VERITAS) taken over 15 years.
- Characterized gamma-ray period to be 316±4 days, compatible X-ray period.
- Year-to-year flux variation indicates orbit-to-orbit variability.
- Very high significance correlation between X-ray and TeV flux.

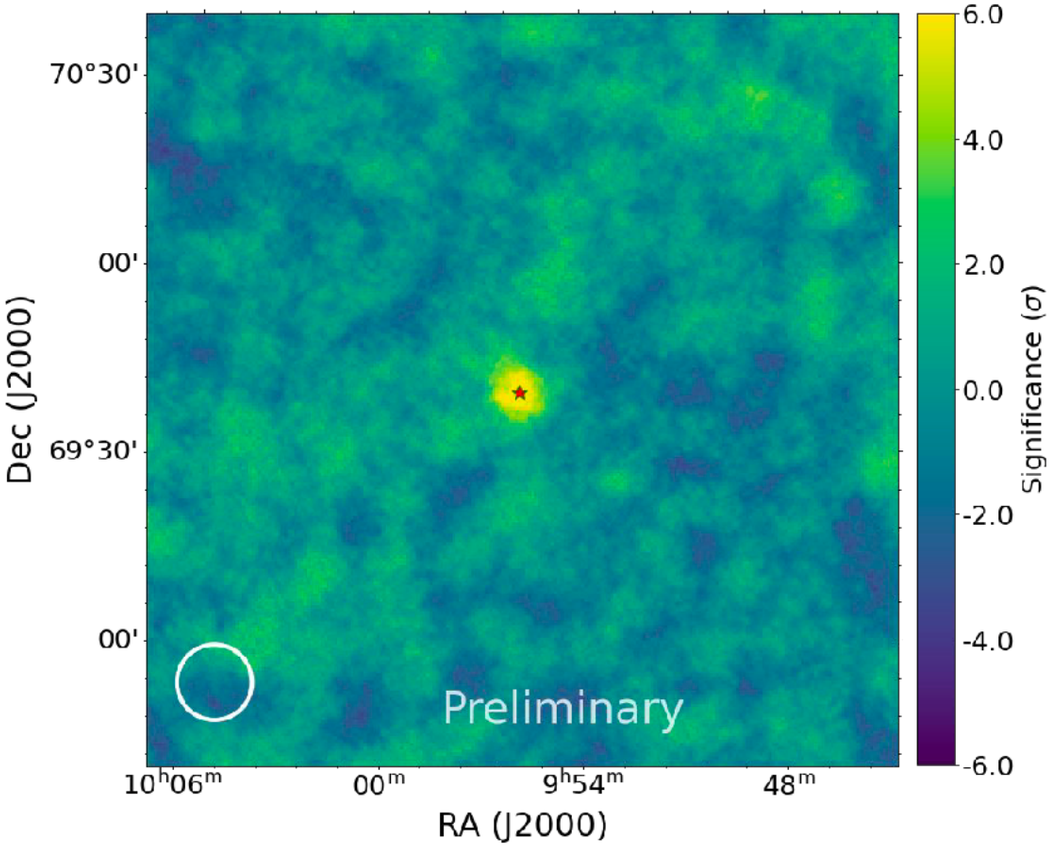
Adams et al. (VERITAS+MAGIC+H.E.S.S.), 2021, ApJ, 923, 421

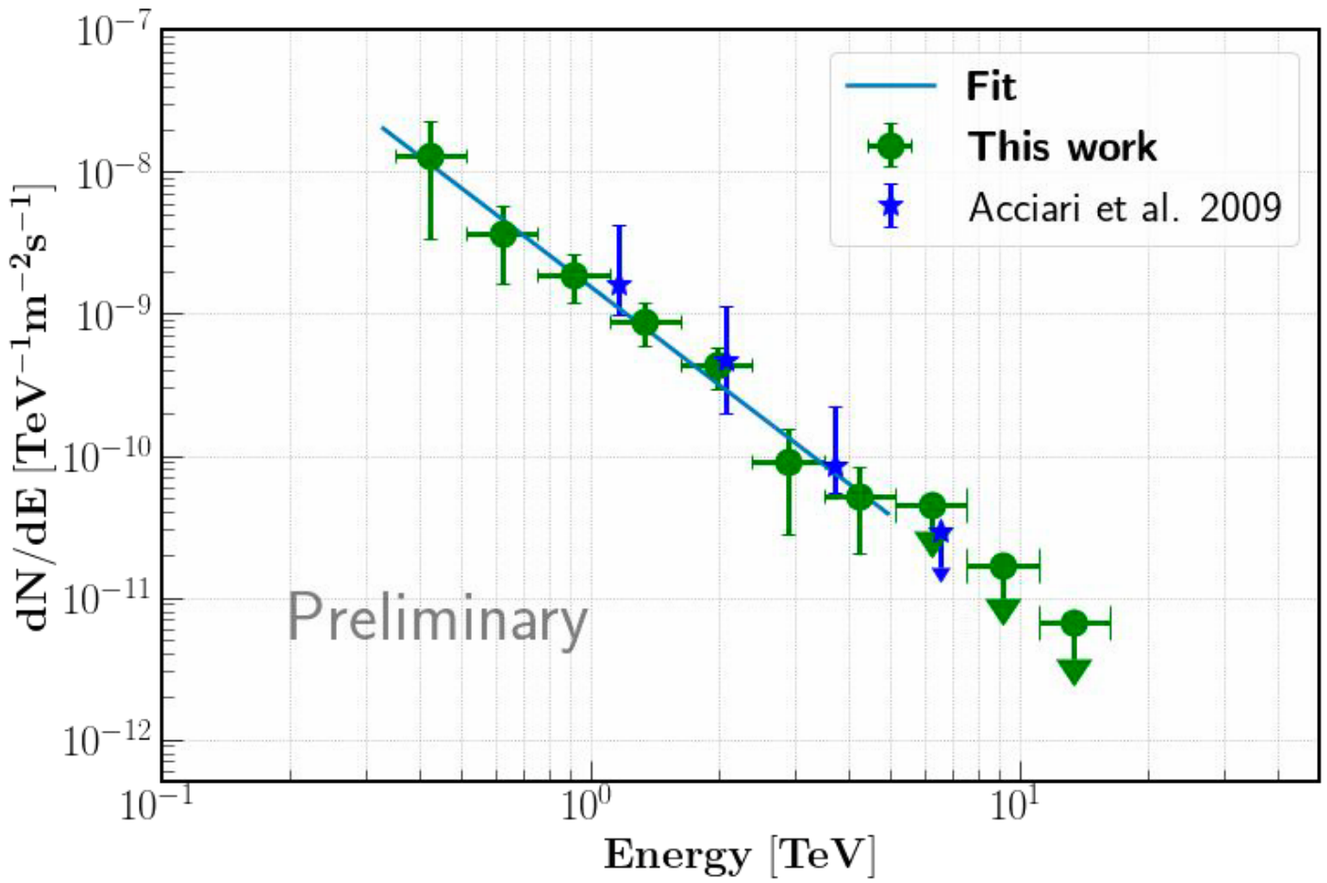






Starburst galaxies: M 82



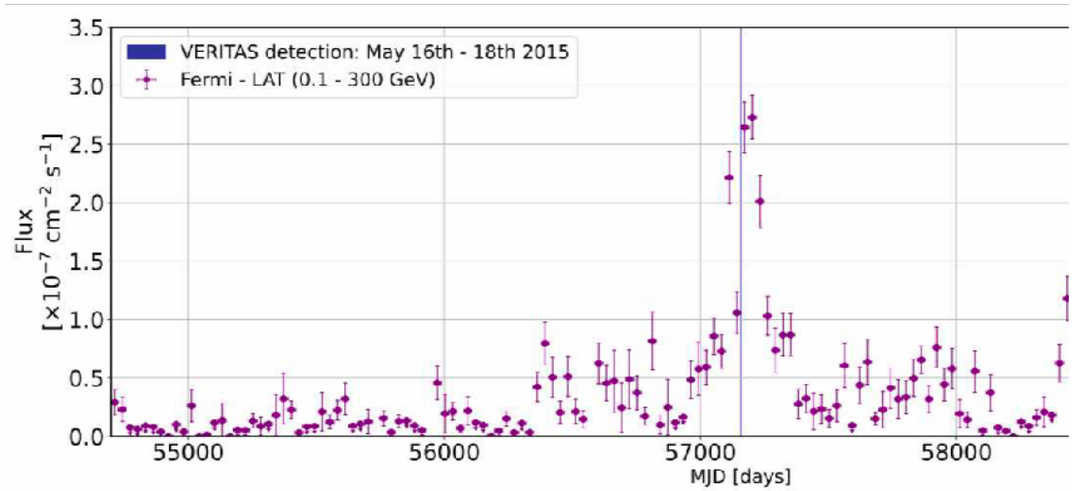


- Discovery of TeV emission in 2008-09, ~5σ in 137h of data, Γ= 2.5 ± 0.6; F ~ 0.9% Crab
- Models: The cosmic-ray density in M82 is 500x Milky Way & If SN are the primary source of cosmic rays in the Milky Way, this requires 10-30x higher supernova rate in M82 (this is observed by others)
- Update: ~335 h in 2008-22: 6.5σ in 254 h (good data): Γ= 2.3 ± 0.3stat ± 0.2sys; F(>450 GeV) ~ 0.4% Crab

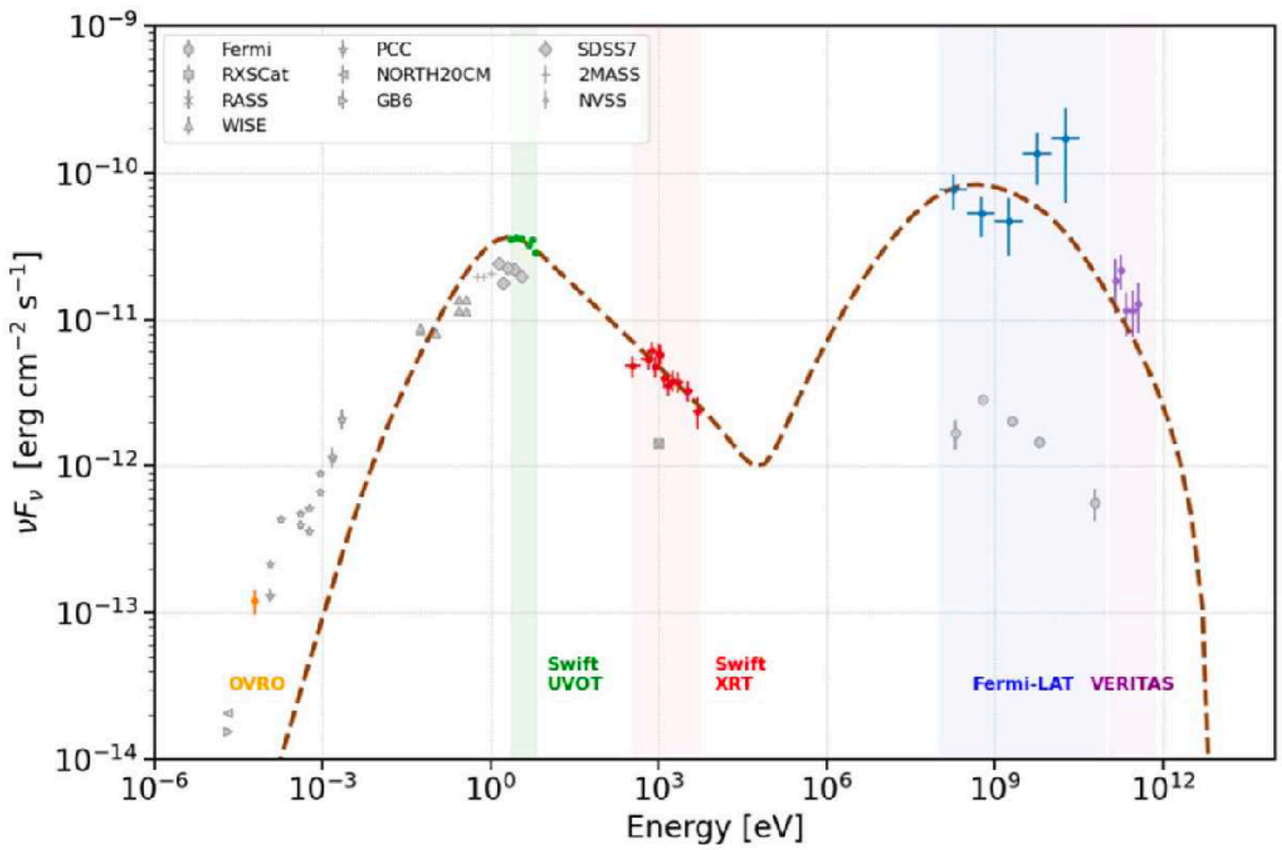
Lab Saha, SAO

Saha (VERITAS Collaboration), PoS (ICRC'23)

Blazars: VHE Discovery of S3 1227+25



Atreya Acharyya
U Alabama

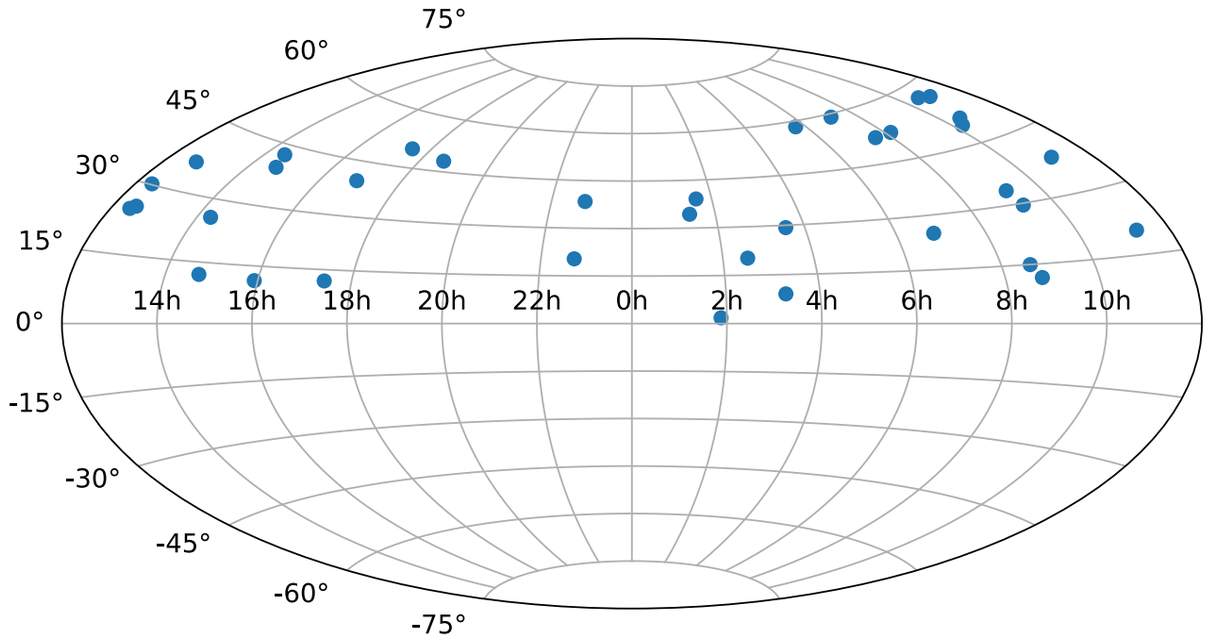


- Fermi-detected IBL @ z = 0.325: Unlikely VHE source (Γ4FGL ~ 2.10; Γ3FHL ~ 3.3; F(>10 GeV) ~ 1% Crab)
- Discovery during LAT-based ToO in May 2015: ~7 h on 5 nights => Detected on only 2 nights (~13σ)
- Soft spectrum (Γ = 3.8 ± 0.4); F(>120 GeV) ~ 9% Crab Nebula flux; Strong correlation between optical / gamma-ray fluxes.
- Data are well described by a single-zone leptonic (SSC) model.

Acharyya et al, 2023, ApJ, 950, 152

Blazars: The VERITAS HBL sample

- Based on the 3HSP catalog (Chan et al. 2019): synchrotron peak in the UV to X-ray range.
- Good observing conditions with VERITAS: 1.7° < decl. < 61.7°.
- Off the galactic plane: |b| >10°.
- Estimated synchrotron peak luminosity > 6.3×10^{-12} erg cm^{-2} s^{-1}.
- Total of 36 sources (21 already TeV-detected).



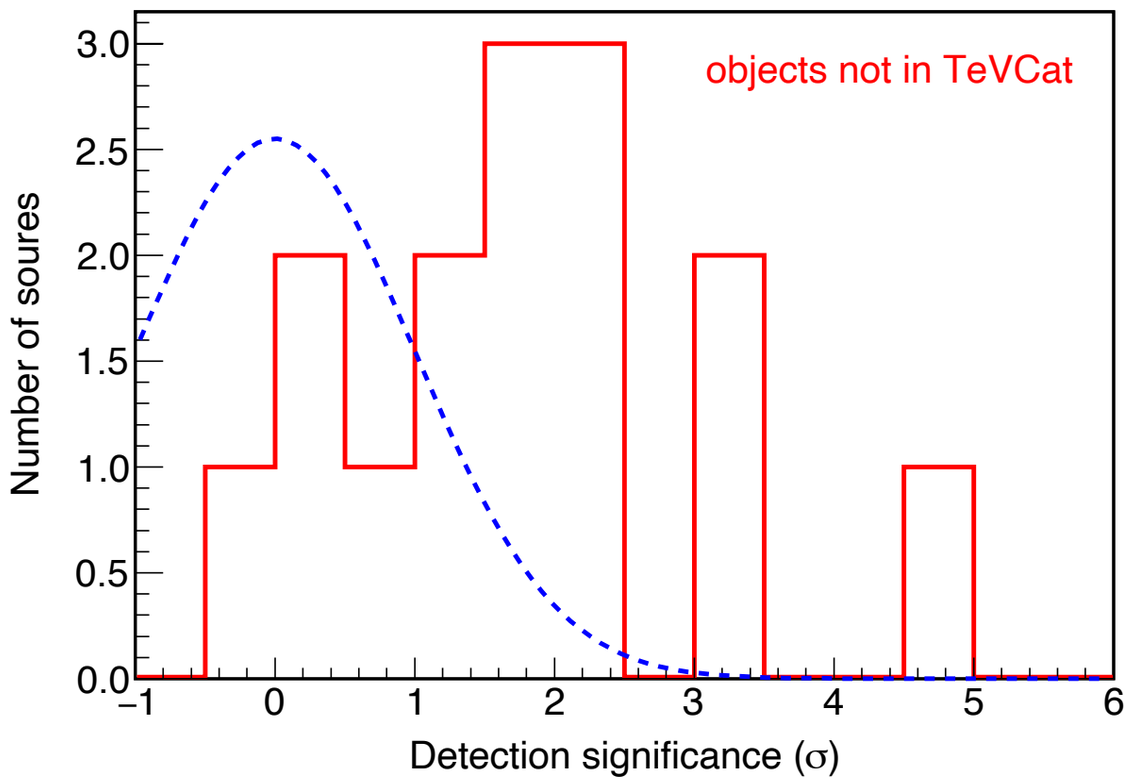
The VERITAS HBL sample, in celestial coordinates.

Pazit Rabinowitz
Washington U in St Louis

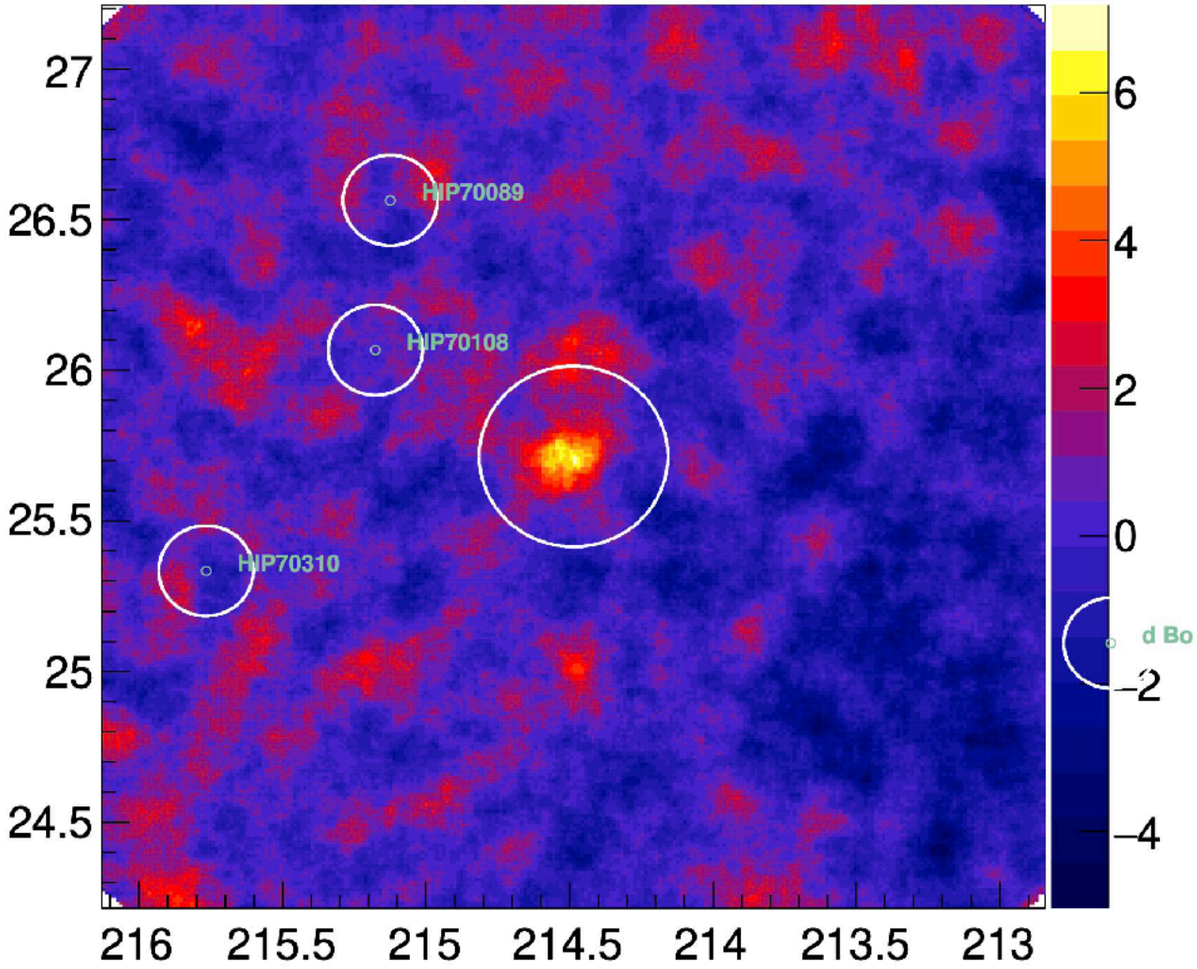
Blazars: The VERITAS HBL sample

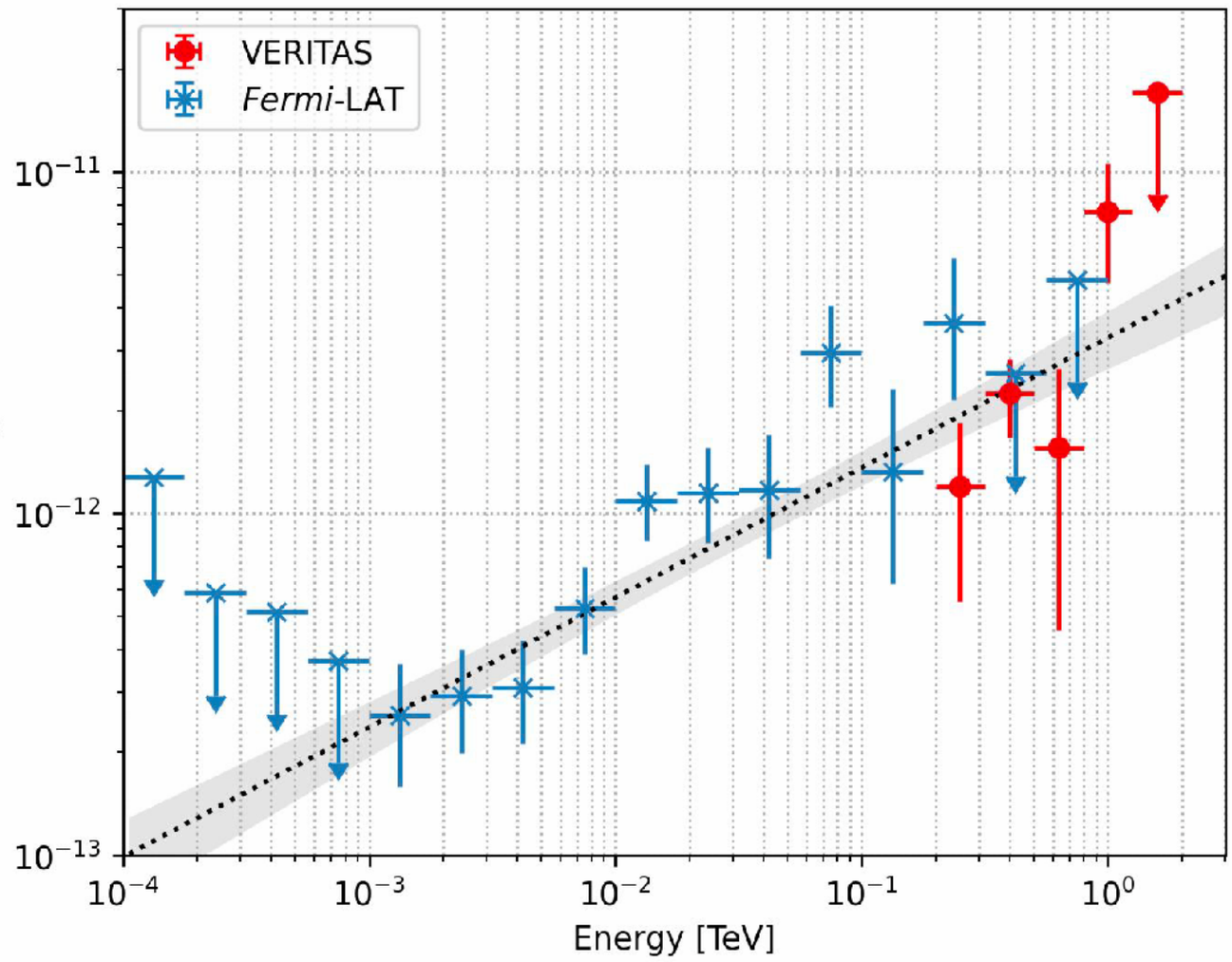
- We use all 4-telescope data available for sources in the VERITAS HBL sample.
- To minimize bias in flux measurements, we remove all data runs that were triggered by other observations (optical, X-ray, Whipple 10-m, MAGIC, HAWC, VERITAS self-triggers).
- Minimum source exposure is 8h, median exposure is 35h.
- Goal of the observing campaign is to achieve 3σ-sensitivity for 1% Crab blazars.

Using more than 1,800h of archival observations obtained since 2007 + 215h of dedicated observations completed in 2019-22.



Blazars: Discovery of RBS 1366





- RBS 1366: Extreme high-frequency-peaked (3HSP => νsynch ~ $10^{17.6}$Hz) BL Lac @ z = 0.237
- Extensive VHE observations (~57 h; 2008-22) with VERITAS => VHE discovery (6.5σ, ~360 γ)

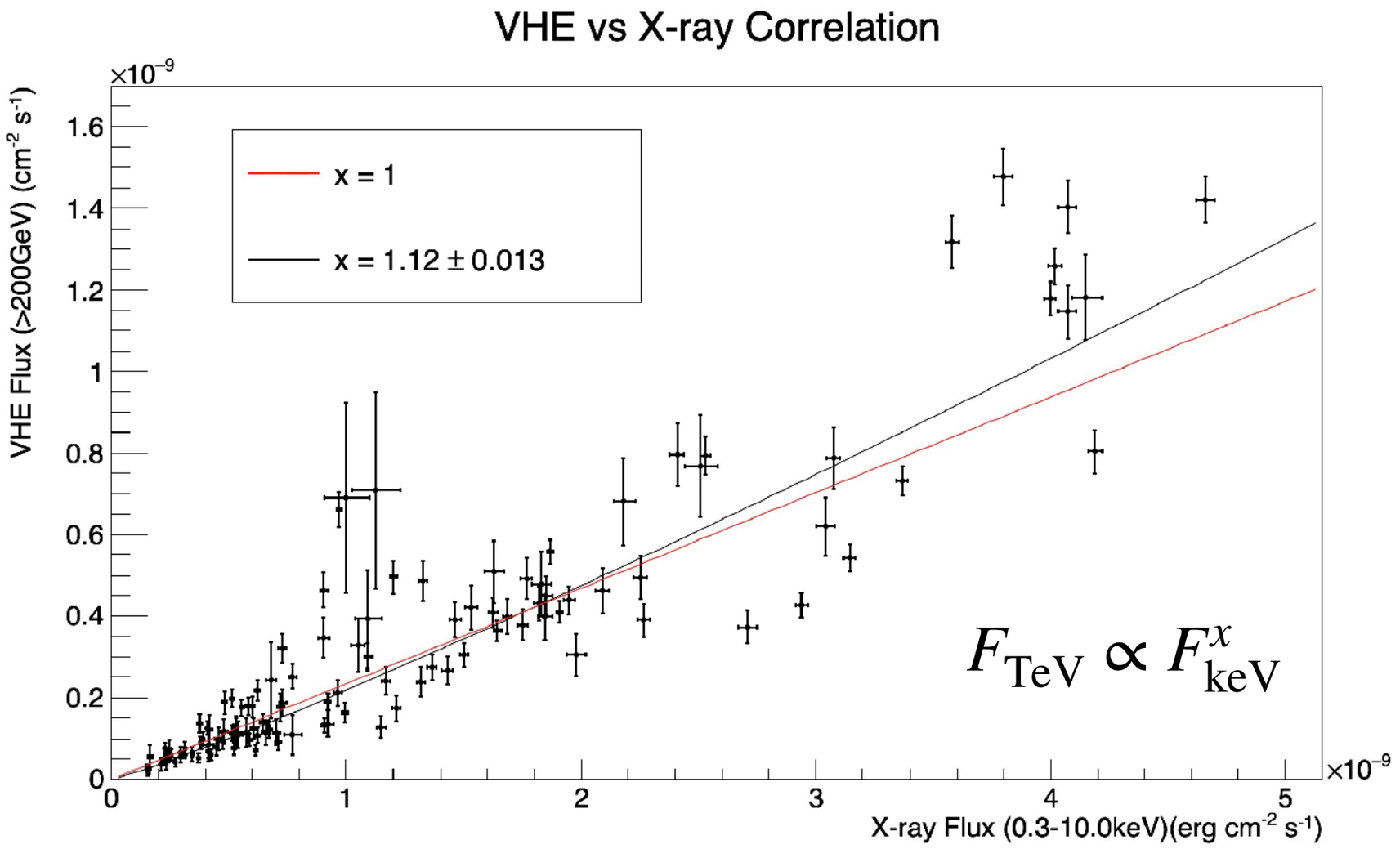
Ribeiro (VERITAS Collaboration), PoS (ICRC'23)

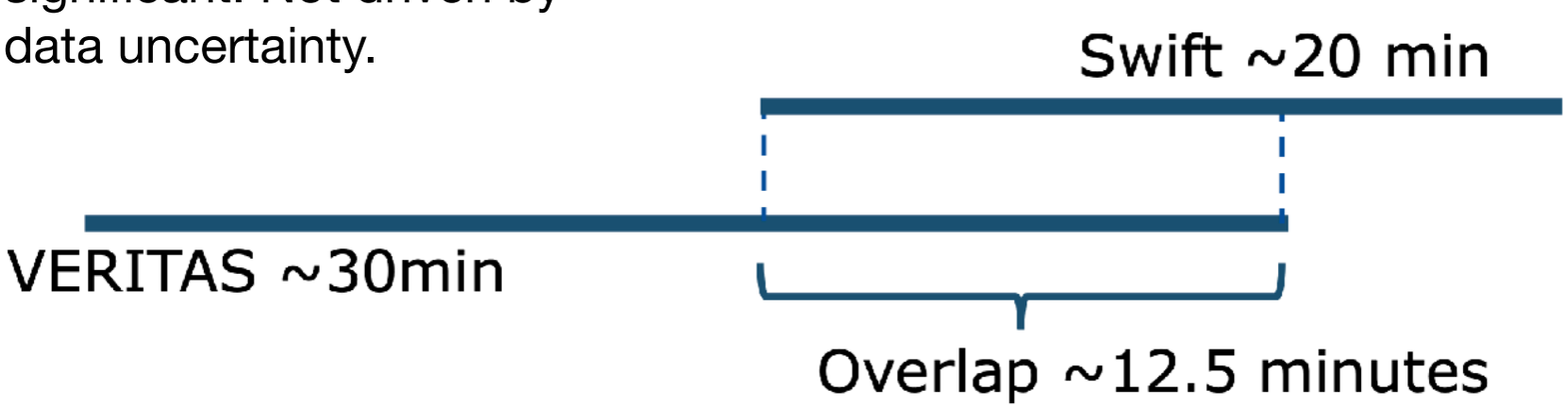
Pazit Rabinowitz
Washington U in St Louis

Deivid Ribeiro
U Minnesota

Blazars: X-ray—TeV correlation Mrk 421

- Strictly simultaneous observations with Swift.
- 127 coincident data runs, 26h of strictly simultaneous exposure, spanning 15 years.
- Median VERITAS exposure is 12 min.
- Remarkable correlation spanning almost two orders in magnitude in X-ray/TeV flux.
- χ^2/ndf= 956/125 = 7.65
- Scatter must be scientifically significant. Not driven by data uncertainty.

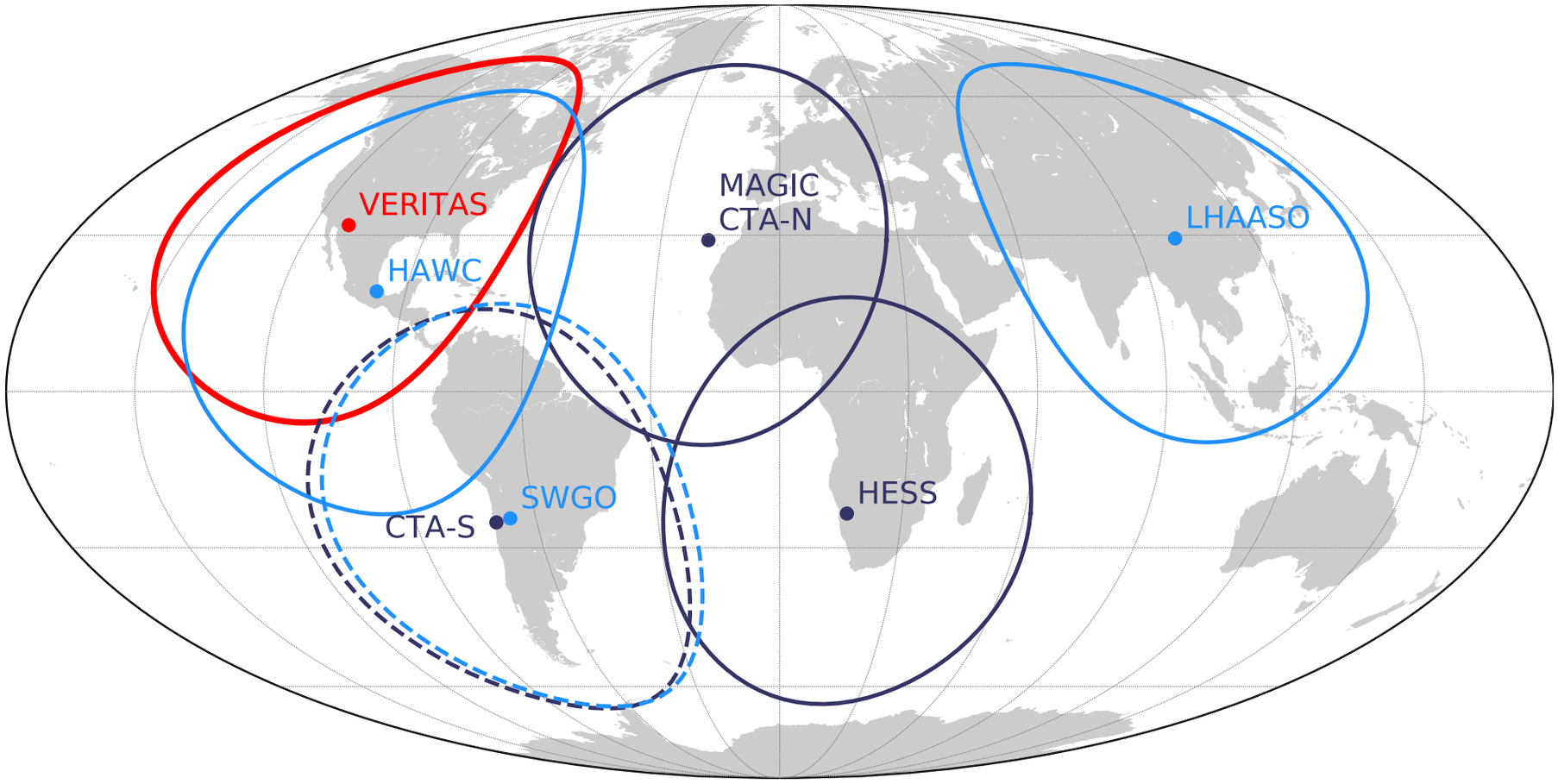




Mooney (VERITAS Collaboration), PoS (ICRC'23)

Connor Mooney
U Delaware

Multi-messenger and transients

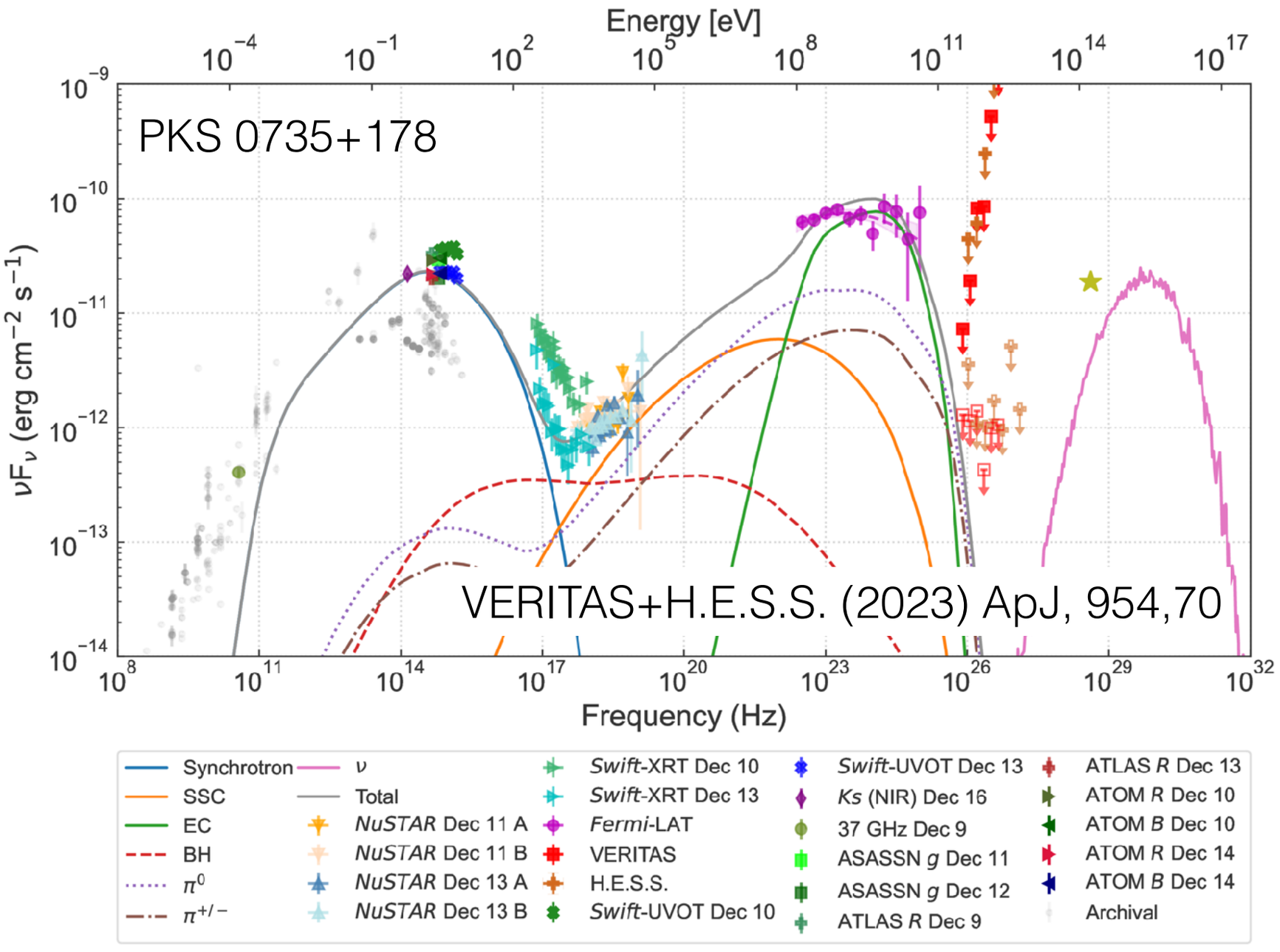


Extensive follow-up programs:

- Neutrinos
- Gravitational Waves
- Fast Radio Bursts
- Gamma-ray Bursts
- Tidal Disruption Events
- Superluminous Supernovae

Transients: Neutrino follow-up PKS 0735+178

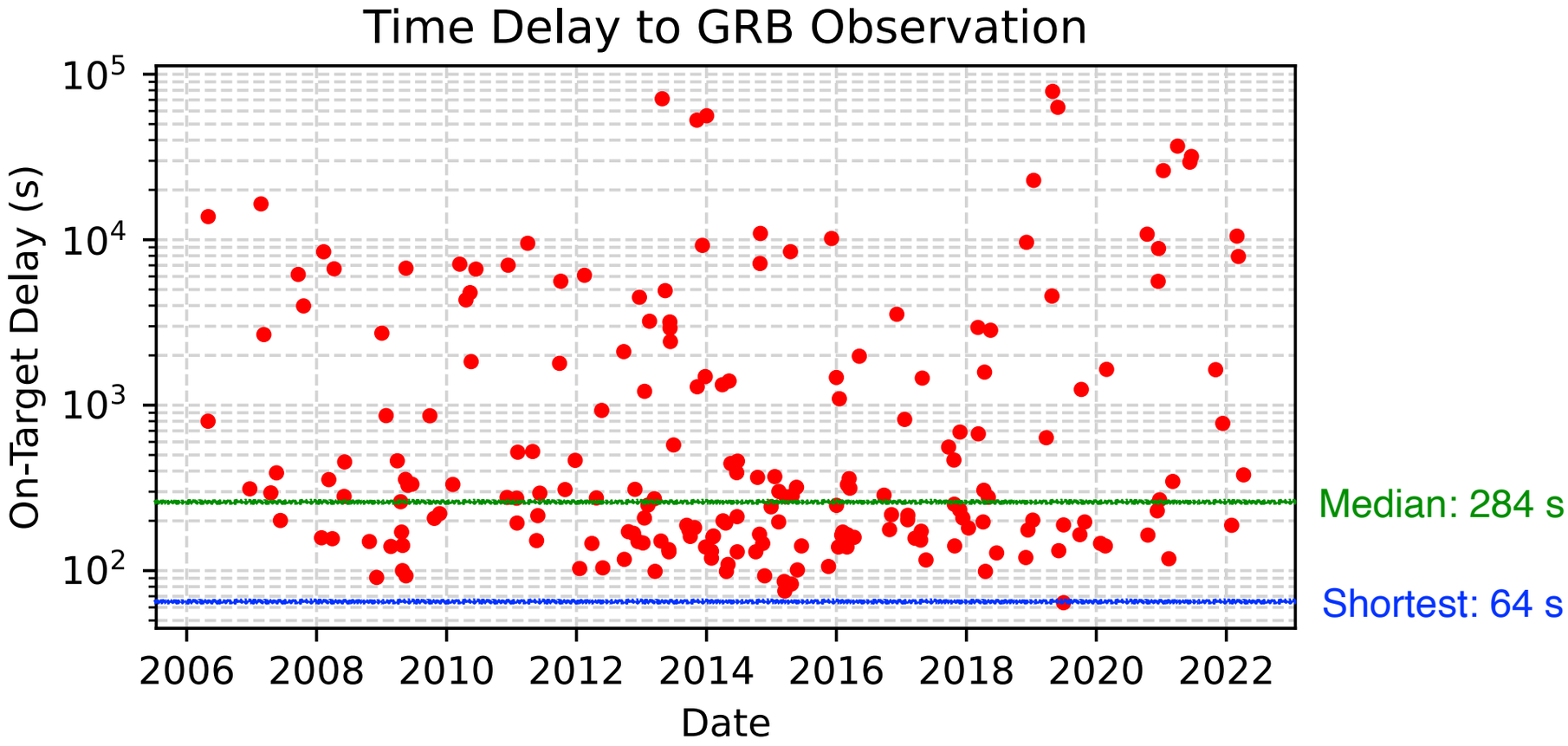
- PKS 0735+178 associated with IceCube-211208A in December 2021.
- IceCube track event with E_ν=171 TeV with 50% astrophysical origin.
- NuSTAR detects hard X-ray emission from PKS 0735+178.
- Strong GeV detection.
- Upper limits from H.E.S.S. and VERITAS indicate cutoff at 100 GeV.
- External soft photon field is necessary to explain SED.



VERITAS+HESS, 2023, ApJ, 950, 70

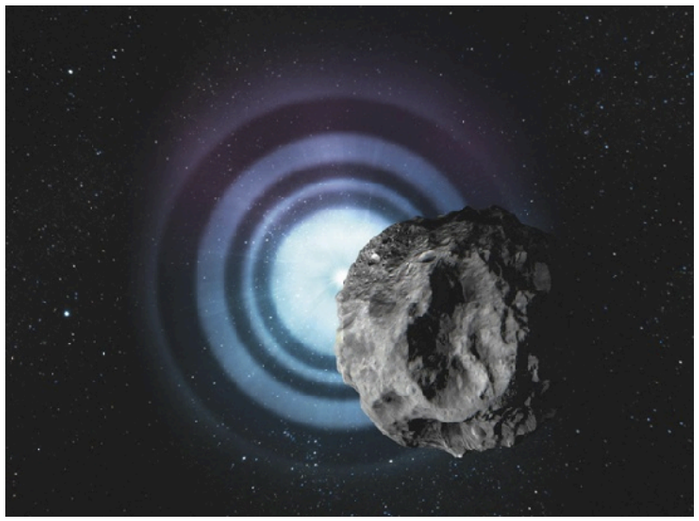
Gamma-Ray Burst program

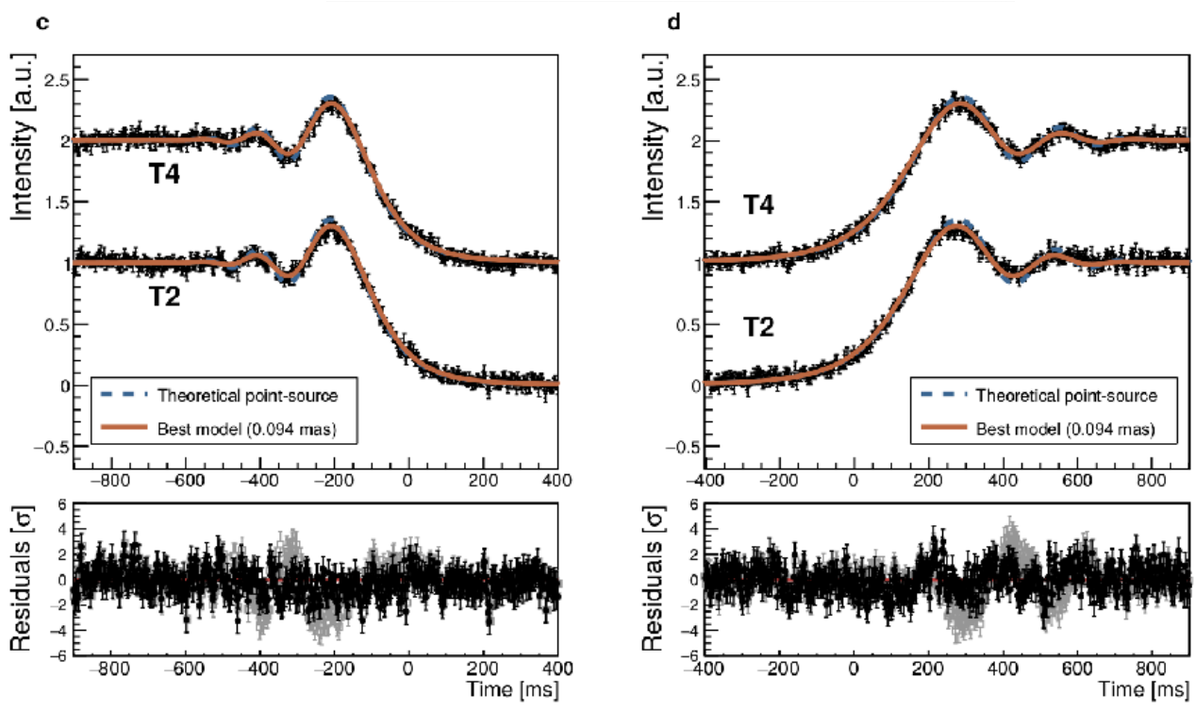
- Gamma-ray burst observations have high-priority - interrupt all other observations.
- 211 GRBs observed to date
- 127 bursts with a position < VERITAS PSF (Swift [122], INTEGRAL[4], MAXI[1])
  - No detections, stacked analysis underway
- Observed GRB 221009A with UV filters starting at T_0+36h.



VERITAS Optical Science: Transients

- VERITAS Enhanced Current Monitor: measures 2-4 pixels in the camera at a rate of 1,200 - 2,400 Hz down **to a magnitude limit of ~12 mag**
  - Applications:
    - FRBs
    - Direct measurement of stellar angular diameters by the VERITAS Cherenkov Telescopes
- VERITAS NSF-funded FADC upgrade
  - Continuous NSB monitoring of all pixels.
  - Capability:
    - Full FoV optical transients on timescales from μs to 10s of seconds (mag. ~10 to ~19)

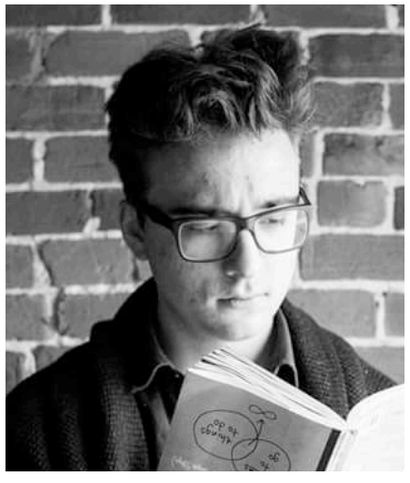




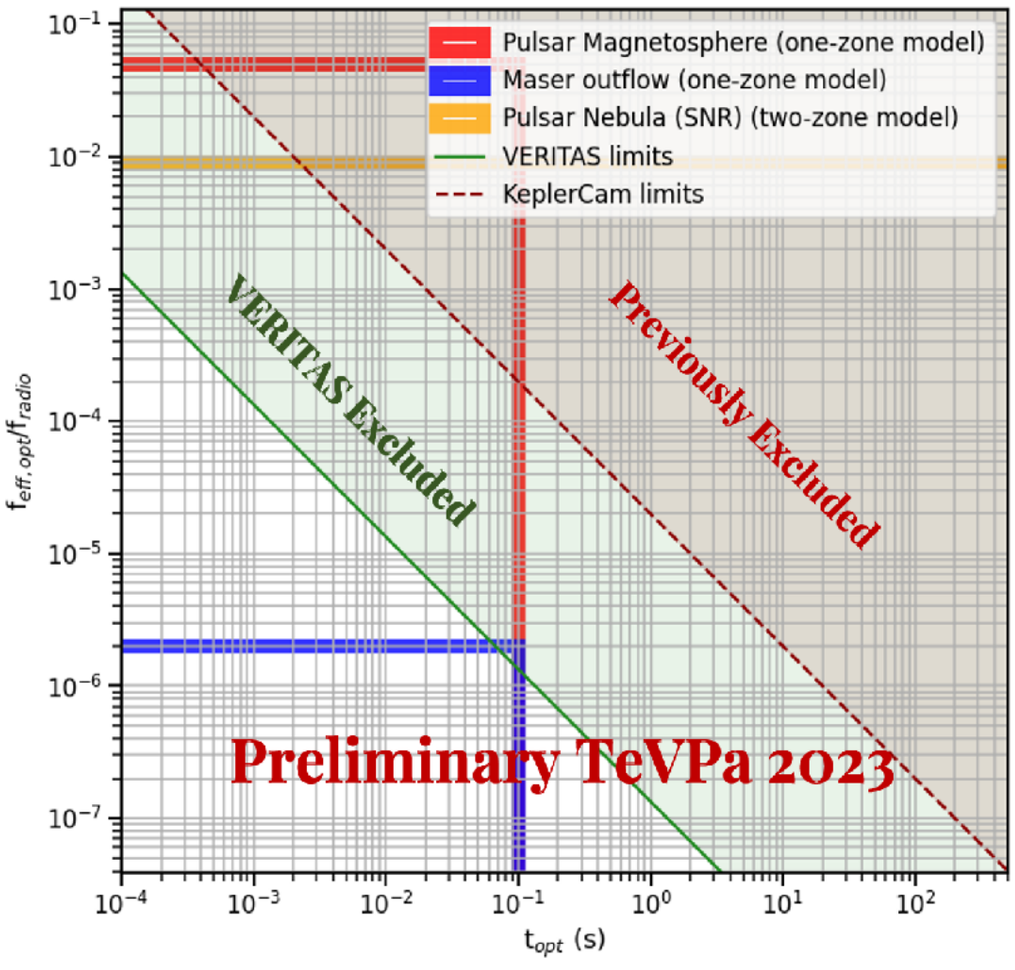
VERITAS Collaboration, 2019, Nature Astronomy, 3, 511

Fast Radio Burst program

- VERITAS can observe FRB candidates simultaneously with CHIME.
- Several FRBs observed with VERITAS + optical monitor in the central pixel.

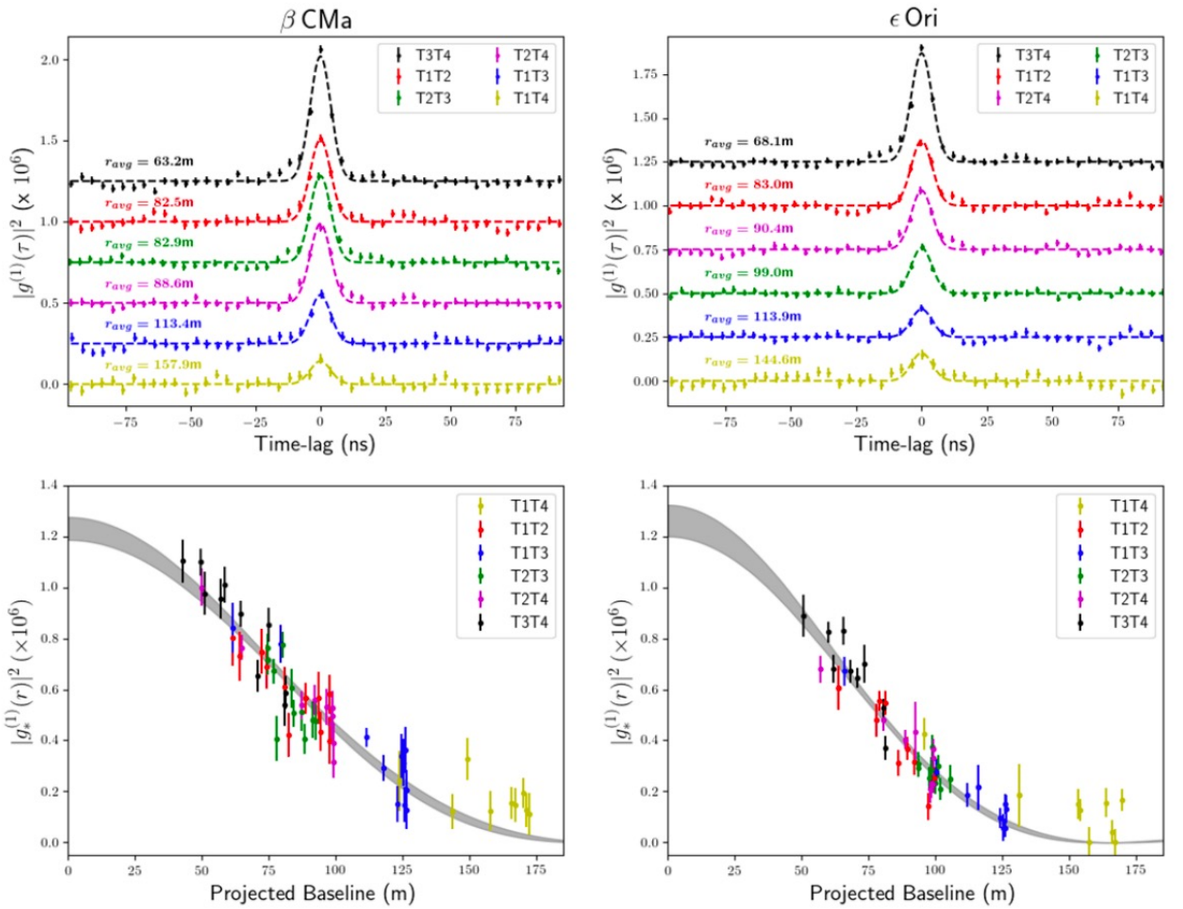


Matthew Lundy
Mc Gill



Stellar Intensity Interferometry

- Digital (offline) version of Michelson Stellar Interferometer
- *Demonstration of stellar intensity interferometry with the four VERITAS telescopes*:
  - Sub-milliarcsecond optical resolution @ 400 nm
- Extensive work done since on expanding SII working group, improving hardware and analysis techniques, science targeting + lots of observations.
- **Science**: survey of stellar diameters, Cepheids & fast rotators, Limb darkening (post upgrade)



Source	θ_{UD} (mas)	T (h)	θ_{UD} (mas)	T (h)
β CMa	0.50 ±0.03	63.4	0.523 ±0.017	5.5
ϵ Ori	0.67 ±0.04	56.0	0.631 ±0.017	4.25

(T= Observation Time)

Narrabri SII
Observations 1970

VERITAS-SII
Nature Astronomy 2020

VERITAS Collaboration, 2020, Nature Astronomy, 4, 1164

Summary

- VERITAS is running and operating well.
- Operations funded through 2025. Plan to request NSF for continued funding in 2025-2028.

Congratulations MAGIC on 20 years of scientific success!

VERITAS Collaboration meeting
Santa Cruz, CA - July 2023