



VERITAS Highlights 2022



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VERITAS Collaboration



VERITAS



- VERITAS: Very Energetic Radiation Imaging Telescope Array System
- Prototype SCT telescope for CTA on site
- Located in Southern Arizona, USA
- Full array operations begin: 2007 - 15 years of operation
- Currently ~100 members in total
- **News: Funded to operate through 2025**
- Funded by National Science Foundation (USA), Smithsonian Astrophysical Observatory (USA), Natural Sciences and Engineering Research Council (Can), Helmholtz Association (Ger)

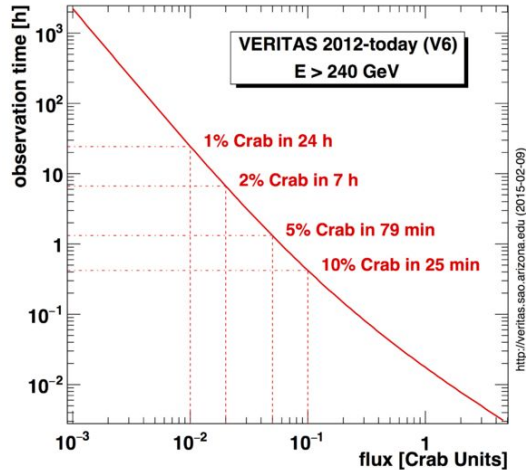




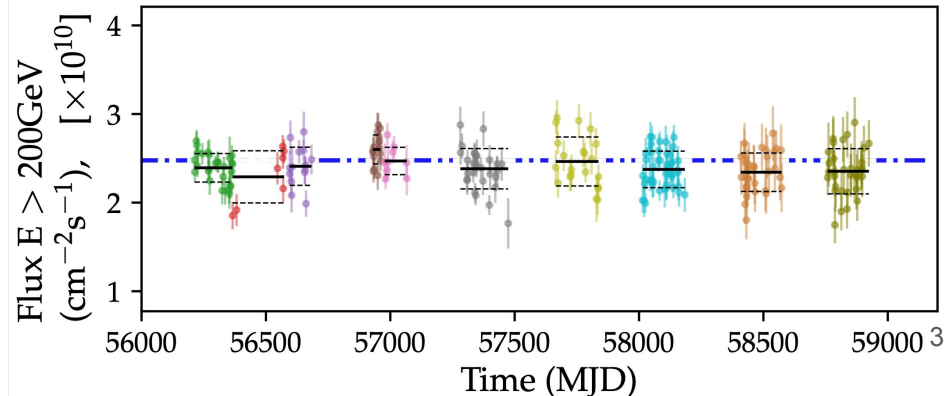
VERITAS Performance + Observations

- FOV 3.5 deg (diameter)
- Energy range: ~85 GeV to ~30 TeV
- Effective Area: 10^5 m^2 @ 1TeV
- Ang. resolution: 0.08° resolution @ 1 TeV
- Sensitivity: 1% Crab in 25 hours
- Energy resolution: ~17%

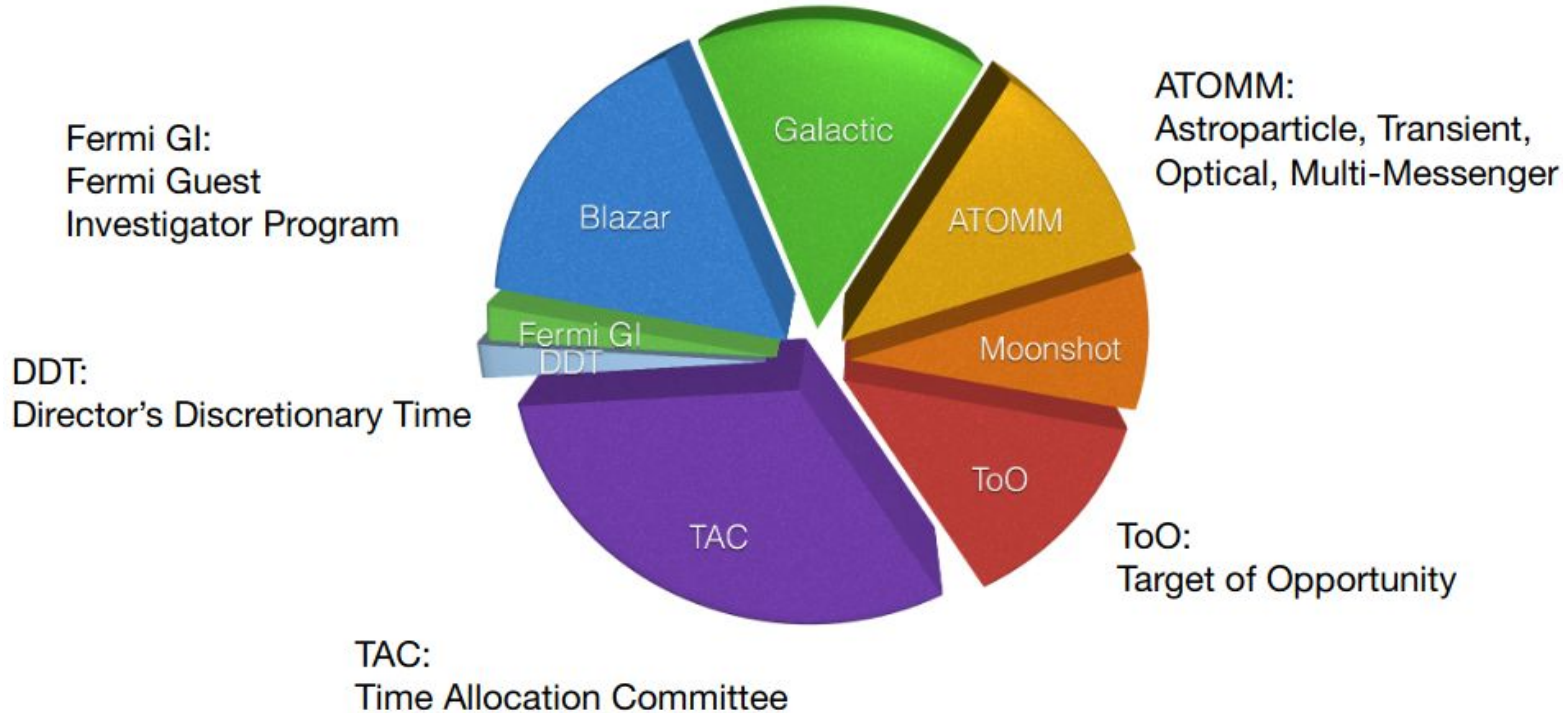
- Runs September - July
- ~950 hrs dark time, ~250 hrs bright moon (30-65% illum.).
- Optical stellar intensity interferometry during full moon (> 65%)
- Remote observing capabilities introduced during lockdowns - now a long term option



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



Gamma Ray Science Programme

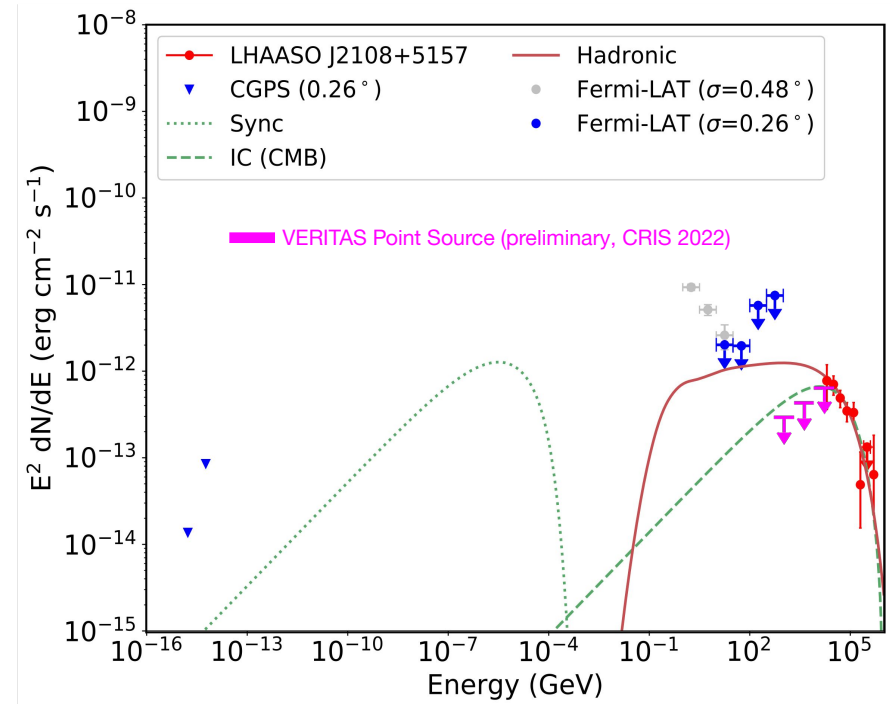


Galactic: PeVatrons with VERITAS

- Tycho's SNR : 147 hrs: $E_{\text{cut}} \text{ (TeV)} = 1.70 \pm 1.23 (2\sigma)$ (*Archambault et al. 2017*)
- Cassiopeia A : 65 hrs: $E_{\text{cut}} \text{ (TeV)} = 2.31 \pm 0.51 (4\sigma)$ (*Abeysekara et al. 2020*)

LHAASO J2108+5157 + LHAASO J0341+5258

- New LHAASO sources with no VHE counter-parts
- Location, morphology, and broadband spectra unknown
- **LHAASO J2108+5157**: 35hrs - no detection in point like (0.09) or extended (0.25 deg)
- **LHAASO J0341+5258**: 23hrs - no detection in point like (0.09) or extended (0.25 deg)



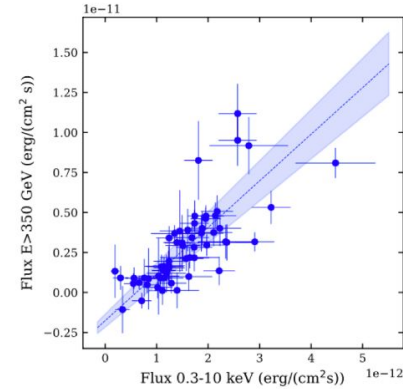
Gamma Ray Binaries



VERITAS has detected 3 systems: HESS J0632+057, LS I +61 303 and PSR J2032+4127

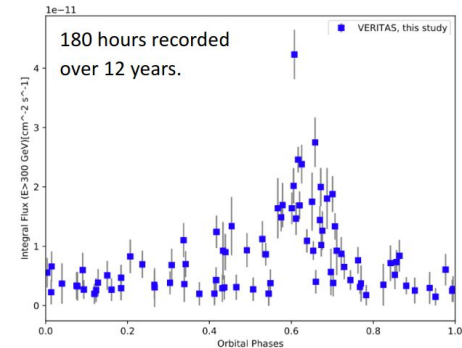
HESS J0632+057

- 450 hrs over 15 years (VERITAS, MAGIC, HESS)
- Orbital period measured in gamma-ray consistent with X-Ray
 - Gamma : 316.7 ± 4.4 days, X-Ray : 317.3 ± 0.7 days
- Gamma and X-Ray Fluxes highly correlated



LS I +61 303

- 180 hrs over 12 years
- Rapid variability on <1 day timescales
- TeV and X-Ray emission well correlated on short timescales
- Detected at all orbital phases
 - No evidence for spectral variability



Extra-galactic: Blazars and Radio Galaxies



Science Drivers

- Jet physics, EBL, Intergalactic Magnetic Field, Particle processes and acceleration mechanisms, neutrino/cosmic ray origin.

Observations

- ~ 200 hrs/year
 - Monitoring & ToO (self-triggering)
- Multiwavelength coverage
- Simultaneous observations with IXPE (2022-2025)

Multi-year projects

- HBL luminosity function
- Nightly Mrk 421 snapshots
 - Looking for a repeating flaring pattern

Flaring

- OJ 287 - 2017 flare
- Mrk 421 giant 2010 flare (*Abeysekara et al., ApJ, 890, 97 (2020)*)
- FSRQs (3C 279, PKS 1222+216, and Ton 599) (*Adams et al., ApJ, 924, 95 (2022)*)
- Radio Galaxies

Blazars with uncertain redshift: 7

Blazar	Type	z
1ES 0647+250	HBL	>0.29
3C 66A	IBL	0.33 < z < 0.41
RGB J2243+203	HBL	>0.39
PG 1553+113	HBL	0.43 < z < 0.58
1ES 0033+595	HBL	0.467?
HESS J1943+213	HBL	?
RGB J2056+496	Blazar	?

Radio Galaxies : 4

AGN	Type	z
M 87	FR I	0.004
NGC 1275	FR I	0.018
IC 310	FR I/HBL	0.019
3C 264	FR I	0.026

Blazars with well measured redshift: 30

Blazar	Type	z
Mkn 421	HBL	0.030
Mkn 501	HBL	0.034
1ES 2344+514	HBL	0.044
1ES 1959+650	HBL	0.047
1ES 1727+502	HBL	0.055
BL Lac	IBL	0.069
1ES 1741+196	HBL	0.084
W Comae	IBL	0.102
VER J0521+211	IBL	0.108
RGB J0710+591	HBL	0.125
H 1426+428	HBL	0.129
B2 1215+30	HBL	0.131
S3 1227+25	IBL	0.135
1ES 0806+524	HBL	0.138
1ES 0229+200	HBL	0.139
1ES 1440+122	HBL	0.163
RX J0648.7+1516	HBL	0.179
1ES 1218+304	HBL	0.182
RBS 0413	HBL	0.190
1ES 1011+496	HBL	0.212
MS 1221.8+2452	HBL	0.218
RBS 1366	HBL	0.237
1ES 0414+009	HBL	0.287
OJ 287	LBL	0.306
TXS 0506+056	HBL	0.337
1ES 0502+675	HBL	0.341
PKS 1222+216	FSRQ	0.432
PKS 1424+240	IBL	0.601
Ton 599	FSRQ	0.720
PKS 1441+25	FSRQ	0.939

Radio Galaxies



Larger viewing angle than Blazars

- Aids understanding of jet physics

Long-term monitoring of all detected radio galaxies:

- M87: Including and excluding EHT campaign
- NGC 1275: 8 years of VERITAS and MWL (X-ray - radio) data

Ongoing discovery program

- **4C +39.12:**
 - 11 hrs: 0.17σ
- **3C 303:**
 - 9.5 hrs: 1.23σ
- **B2 1113+29:**
 - 9.5 hrs: 0.89σ

3C 264 discovery
Archer et al. (2020)

VHE detected Radio Galaxies

VERITAS detected so far

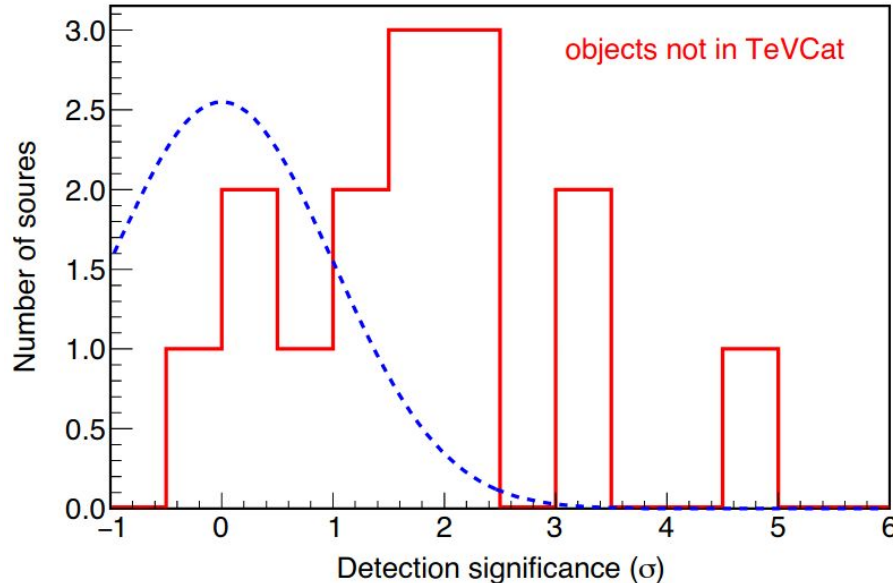
Name	Cross-ID	Type	Distance	BH mass [10^8 Msun]
Cen A	NGC 5128	FR 1	3.7 Mpc	(0.5-1)
M87	NGC 4486, Virgo A	FR 1	16 Mpc	(20-60)
NGC 1275	3C84, Perseus A	FR 1	70 Mpc	3-4
IC 310	B0313+411	FR I/BL Lac	80 Mpc	3 [0.3?]
3C 264	NGC 3862	FR I	95 Mpc	4-5
PKS 0625-35	OH 342	FR I/BL Lac	220 Mpc	~10

Rieger & Levinson 2018

HBLs



- Ongoing study to derive the luminosity function of HBLs
- The 3HSP catalog (Chang et al. 2019, A&A, 632,77) uses radio and X-ray data to select high-frequency-peaked BL Lacs.
- 36 objects (21 VHE detected)
- VERITAS search using > 2000 hrs of data - extracted unbiased data plus additional if required
- All source exposures > 8hrs

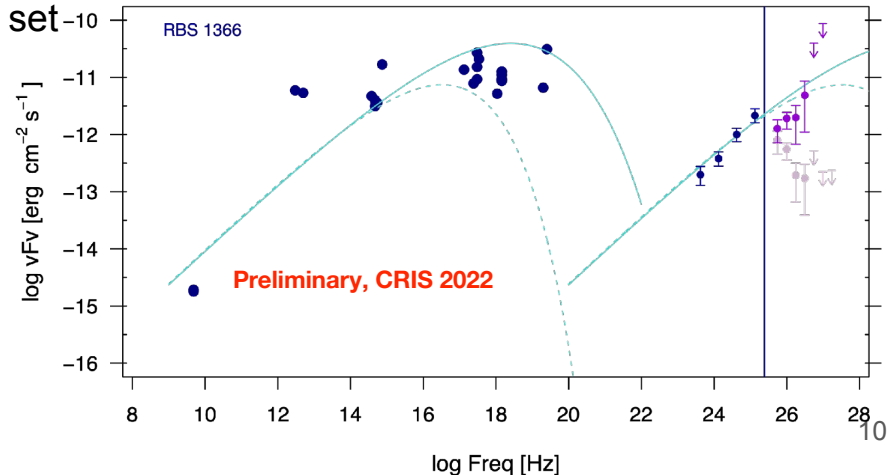




RBS 1366 (RGB J1417+257) - A new detection

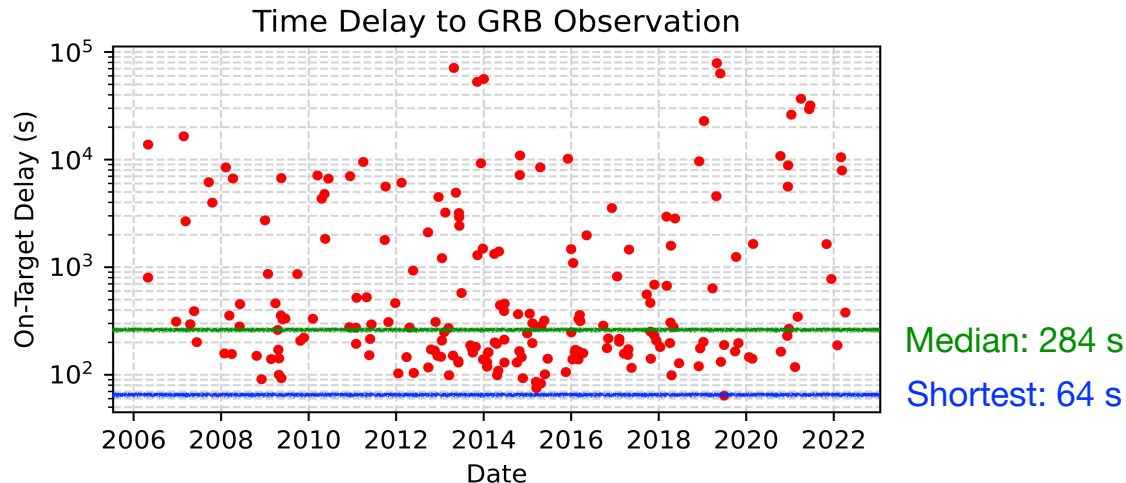
- $z=0.237$
- Synchrotron peak $> 10^{17}$ Hz (Keenan et al., 2021)
- Proposed as TeV-peaked BL Lac ([Constamante \(2020\)](#))
- Possible UHECR accelerator ([Twoomey et al., \(2020\)](#))
- 60 hours total including unbiased Luminosity Function study
- **Detected at $>5\sigma$** after analysis of complete data set
 - A new VHE Extreme HBL
- Flux : $\sim 0.5\%$ Crab

*MWL data and SSC scaling
courtesy of Eileen Meyer*



GRBs

- High priority observations - Interrupt other observations
- 211 observed to date - 127 with a position $<$ VERITAS PSF
 - 16 published in ApJ 743, 62 (2011)
 - 1 in ApJL 795, L3 (2014); 1 in ApJ 857, 33 (2018)
- No detections to date - stacked analysis underway





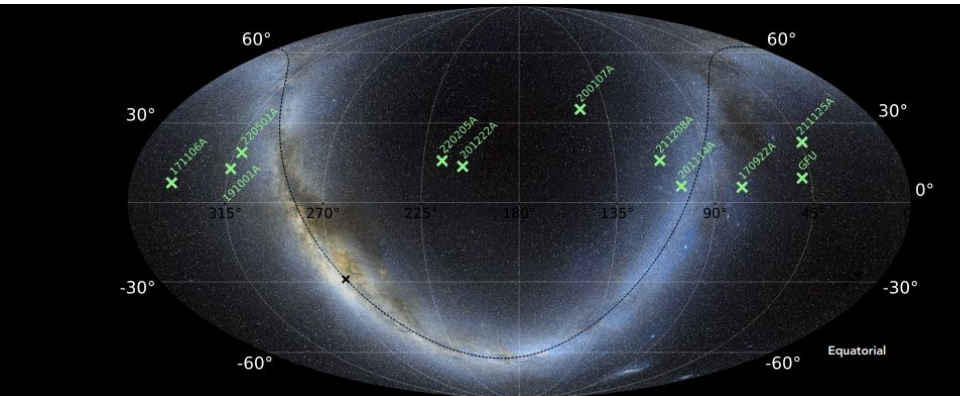
Neutrino Follow-up Program

- Automatic repointing for IceCube alerts - 45 hrs/yr on potential neutrino counterparts
- 9 follow ups on real-time neutrino alerts since TXS 0506+056 detection - No detections

TXS 0506+056

- VERITAS detection following IceCube
- Monitoring since detection in 2018
- >100 hrs collected
- MWL with Swift and NuSTAR
- Paper in preparation

MAGIC, IceCube, FACT, H.E.S.S. and
VERITAS collaborations PoS ICRC2021 960

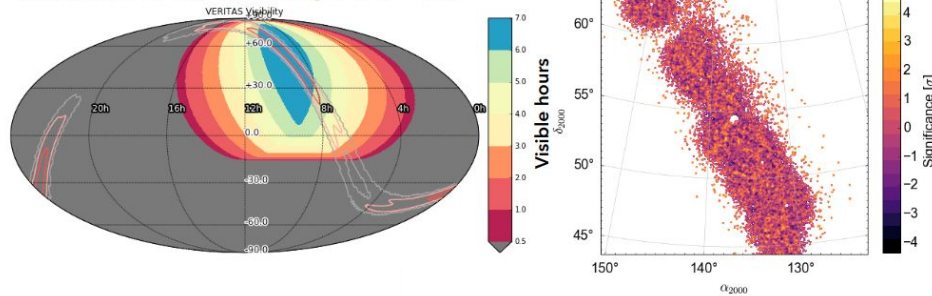


Name	Energy [TeV]	Signalness	FACT	H.E.S.S.	MAGIC	VERITAS
IceCube-171106A	230	0.75	19 h	—	4.5 h	2.5 h
IceCube-181023A	120	0.28	1 h	—	—	—
IceCube-190503A	100	0.36	—	—	0.5 h	—
IceCube-190730A	299	0.67	—	—	3.1 h	—
IceCube-190922B	187	0.50	5.4 h	—	2.2 h	—
IceCube-191001A	217	0.59	2.0	—	2.3 h	1.0 h
IceCube-200107A	—	—	—	—	2.7 h	9.5 h
IceCube-200926A	670	0.44	—	1.3 h	1.0 h	—
IceCube-201007A	683	0.88	—	3.25 h	0.5 h	—
IceCube-201114A	214	0.56	—	14.5 h	6 h	7 h
IceCube-201222A	186	0.53	—	—	—	1.0 h

Gravitational Wave Follow Ups

On Jan 5, 2017 VERITAS follow-up of a GW event GW170104 (GCN #21153). First systematic follow-up of a GW event by an IACT.

GW170104: 50- M_{\odot} BBH merger @ $z = 0.2$.



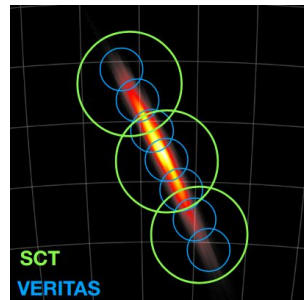
- *An Archival Search for Neutron-Star Mergers in Gravitational Waves and Very-High-Energy Gamma Rays*, [Adams et al., ApJ 918, 66 \(2021\)](#)

O3 LIGO/Virgo run (2019-2020)

- Development of automated tiling algorithm for GW error regions
- 12 GWs followed up

O4 Plans (March 2023)

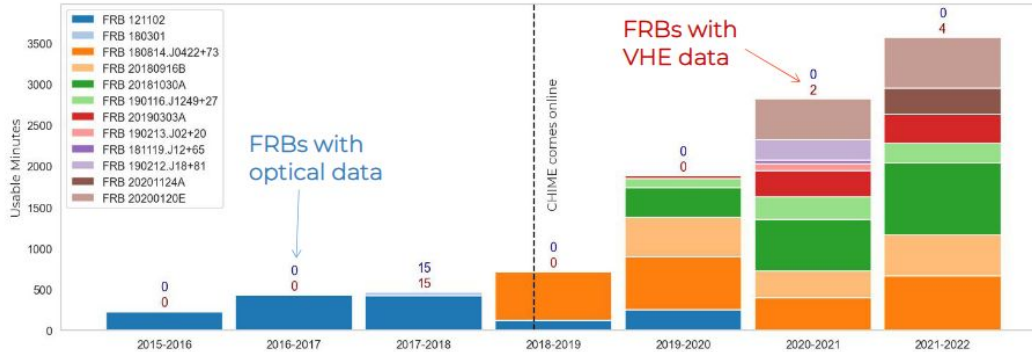
- Synergise with SCT



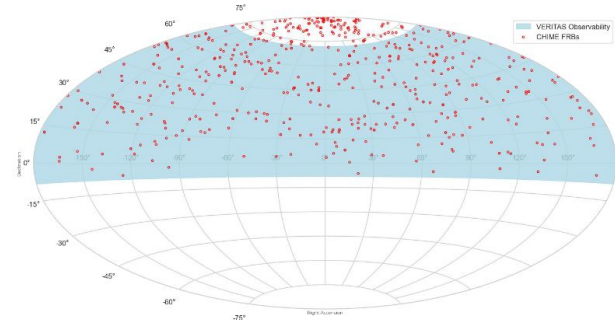
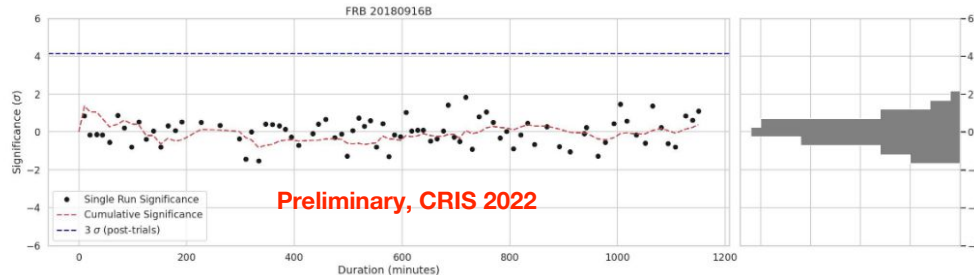
Candidate Label	LIGO BNS Candidate Event ID	LIGO				VERITAS		
		FAR (yr^{-1})	S/N	p-astro (10^{-3})	Area (deg^2)	t_{first}	t_{coinc}	Coverage Probability
C1	2015Oct12T02:40:22.39	142.27	8.42	3.82	2321	-0:11:17	0:18:53	0.22%
C2 ^L	2015Oct24T09:03:52.00	7.52	9.69	79.6	24218	1:33:08	1:11:08	0.06%
C3 ^H	2015Nov17T06:34:02.07	7.52	8.84	181	24221	-0:08:02	2:37:43	0.18%
C4	2015Dec04T01:53:39.14	225.02	9.09	2.5	2909	0:16:20	1:00:00	0.19%
C5 ^L	2015Dec06T06:50:38.17	77.45	7.72	6.64	24264	-0:09:02	2:10:18	0.15%
C6	2015Dec09T07:25:24.68	141.65	7.85	3.84	2606	1:36:25	0:15:00	0.03%
C7	2016Jan02T02:47:29.35	356.13	7.51	1.63	3487	1:44:55	0:30:00	0.18%

Fast Radio Bursts

- VERITAS performs simultaneous gamma-ray and rapid (ms) optical observations (2-4 pixels)
- VERITAS data on ~11 FRBs (objects) - with VHE data overlapping 21 bursts from FRBs detected in radio



Observations are taken simultaneously with CHIME - a radio instrument that has detected > 500 FRBs



Dark Matter



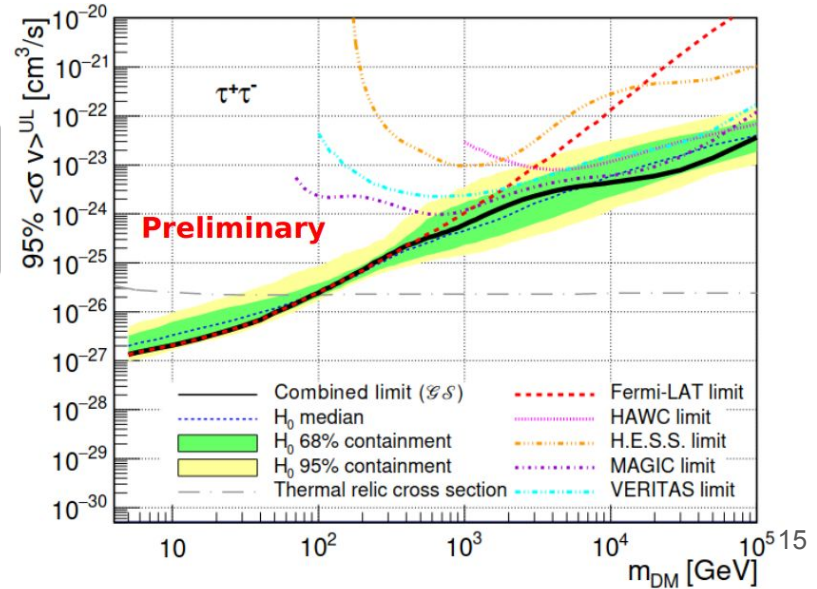
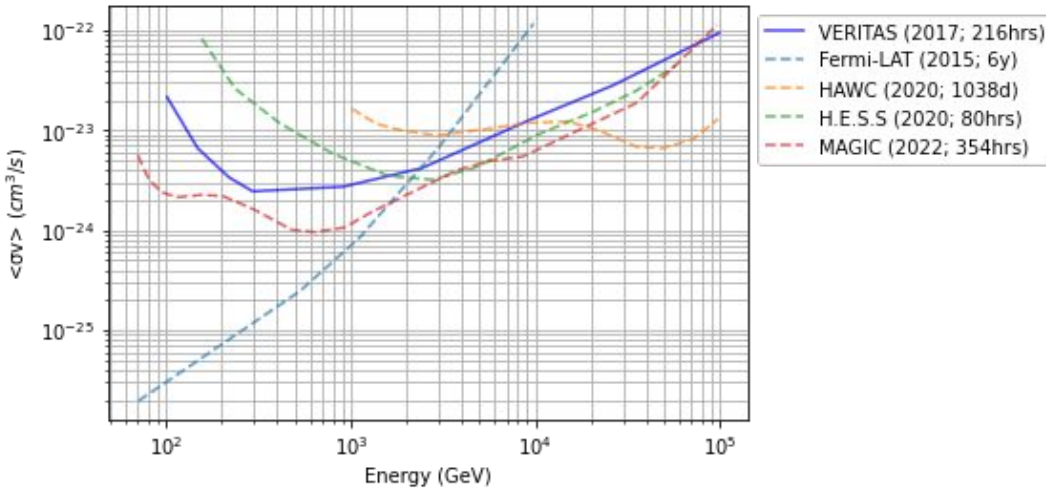
Three dark matter programs:

- Dwarf Spheroidal Galaxies
 - ~230 hrs published (*S. Archambault et al. 2017*)
- Galactic Centre: ~250 hrs
- Sub-halos

Dwarf Spheroidals

- Combined analysis with Fermi-LAT, HAWC, H.E.S.S. and MAGIC
- VERITAS analysis of 960 hrs underway

95% confidence level $\langle \sigma v \rangle$ upper Limits ($\chi\chi \rightarrow \tau^+ \tau^-$)



Summary

- VERITAS has been awarded NSF operations funding through 2025
- VERITAS has a varied science program in galactic, extra-galactic and cosmic-ray astrophysics
- VERITAS has a large data set and welcomes collaboration



VERITAS hybrid Summer Collaboration Meeting 2022 at DESY (Zeuthen)

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