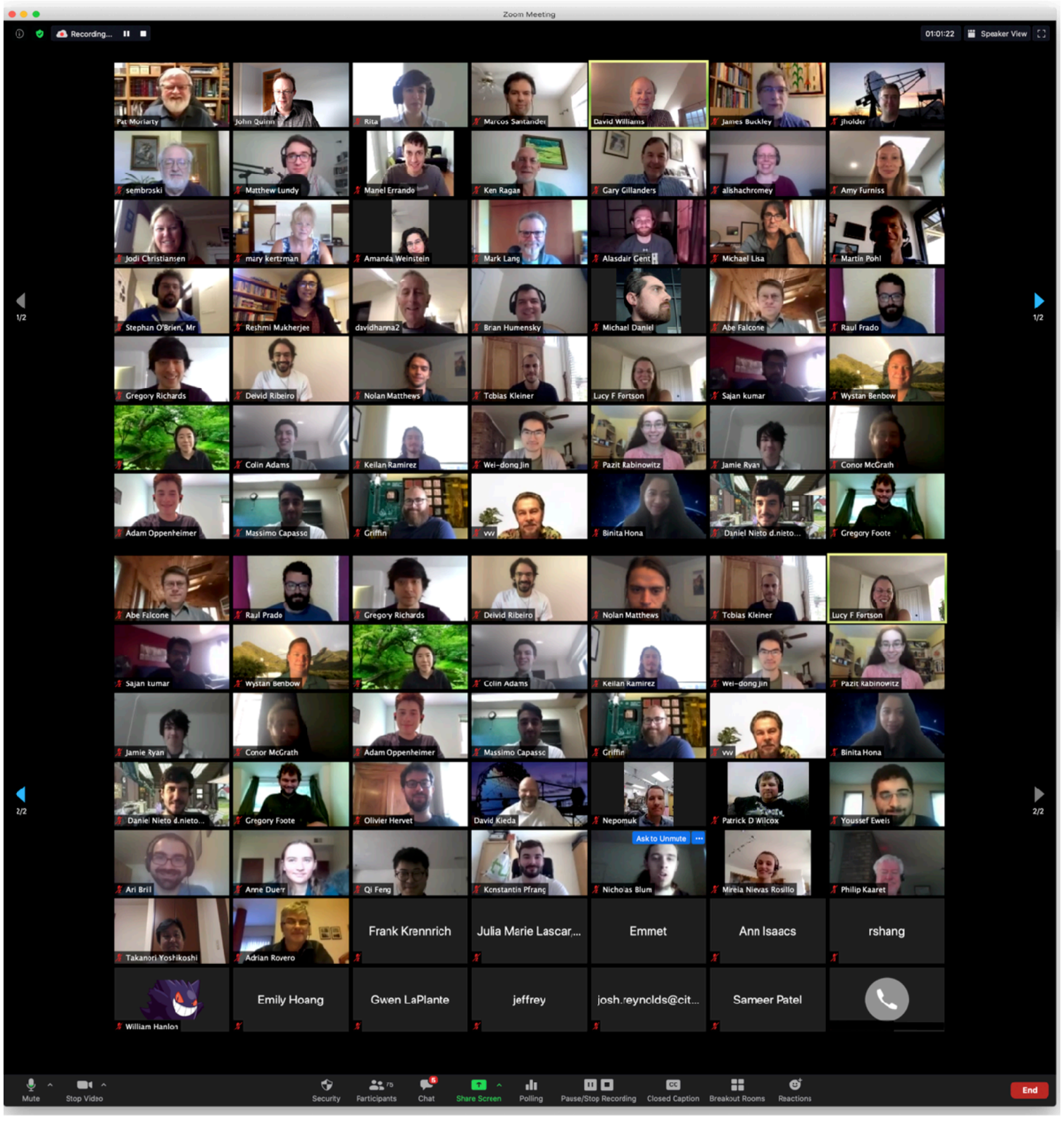
VERITAS Highlights

John Quinn
(University College Dublin)
for the VERITAS Collaboration

The VERITAS Collaboration



- ~80 Members
  - 47% PhDs and Postdocs
- 20 active Associate Members

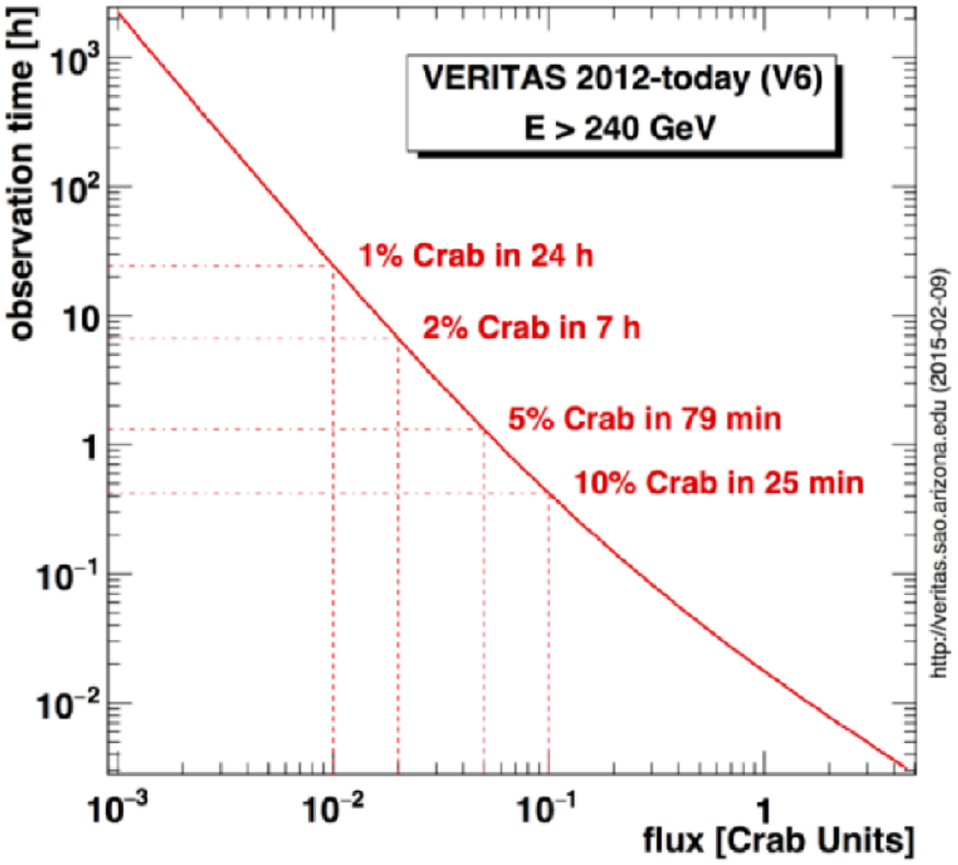
- Summer 2020 Collaboration Meeting:
  - DESY (Zeuthen): 13-16 July - postponed!
- Zoom instead!

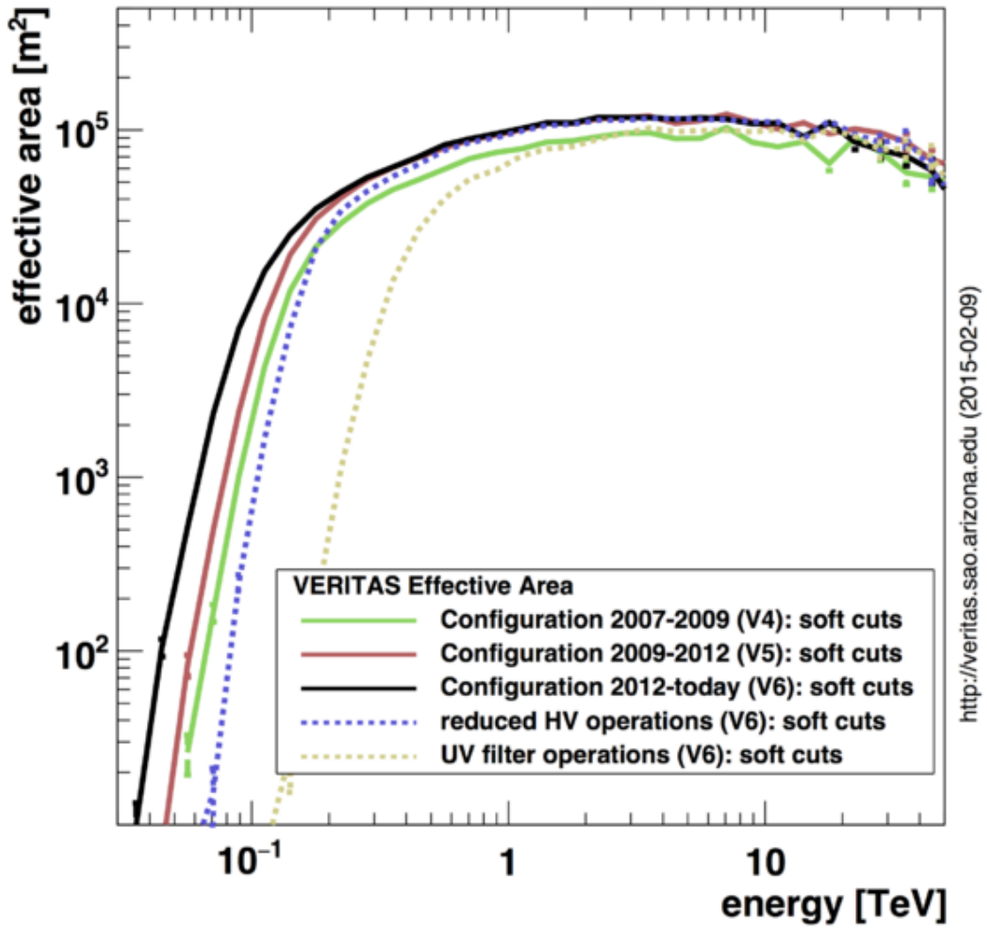
VERITAS is supported by grants from the U.S. National Science Foundation and the Smithsonian Institution, by NSERC in Canada, and by the Helmholtz Association in Germany.

VERITAS

- VERITAS entered full 4-telescope scientific operation in 2007.
- Operations are fully funded through mid-2022 - proposal for operations through 2025 under discussion.
- CTA prototype SCT telescope is co-located.
- COVID-19 Impact:
  - operations temporarily suspended on March 17
  - currently operations are halted due to the annual monsoon season
  - operations will resume in September.

VERITAS Performance





VERITAS Specification

Energy Range	~85 GeV to ~30 TeV
Sensitivity	1% Crab in <25 h
Effective Area	~10^5 m^2 at 1 TeV
Angular Resolution	r_{68} ~0.08º @ 1 TeV
Energy Resolution	~17%
Systematic Errors	Flux ~20%; Γ ~ 0.1
Field of view	3.5 deg. diameter

- Good-weather data / yr:
  - ~950 h in “dark time”
  - ~250 h in “bright moon” (illum. >30%)
- 4-Telescope efficiency: ~ 97%

VERITAS Synergies with LHAASO

- VERITAS/IACTs and LHAASO are highly complementary instruments!
  - VERITAS angular resolution, energy resolution, effective area and sensitivity to short-timescale variability makes it ideal to follow up on LHASSO transient events, but small field-of-view and sensitivity decreases at 10s of TeV.
  - LHAASO: field-of-view, duty cycle, sensitivity to large-scale sources, sensitivity at 10s of TeV

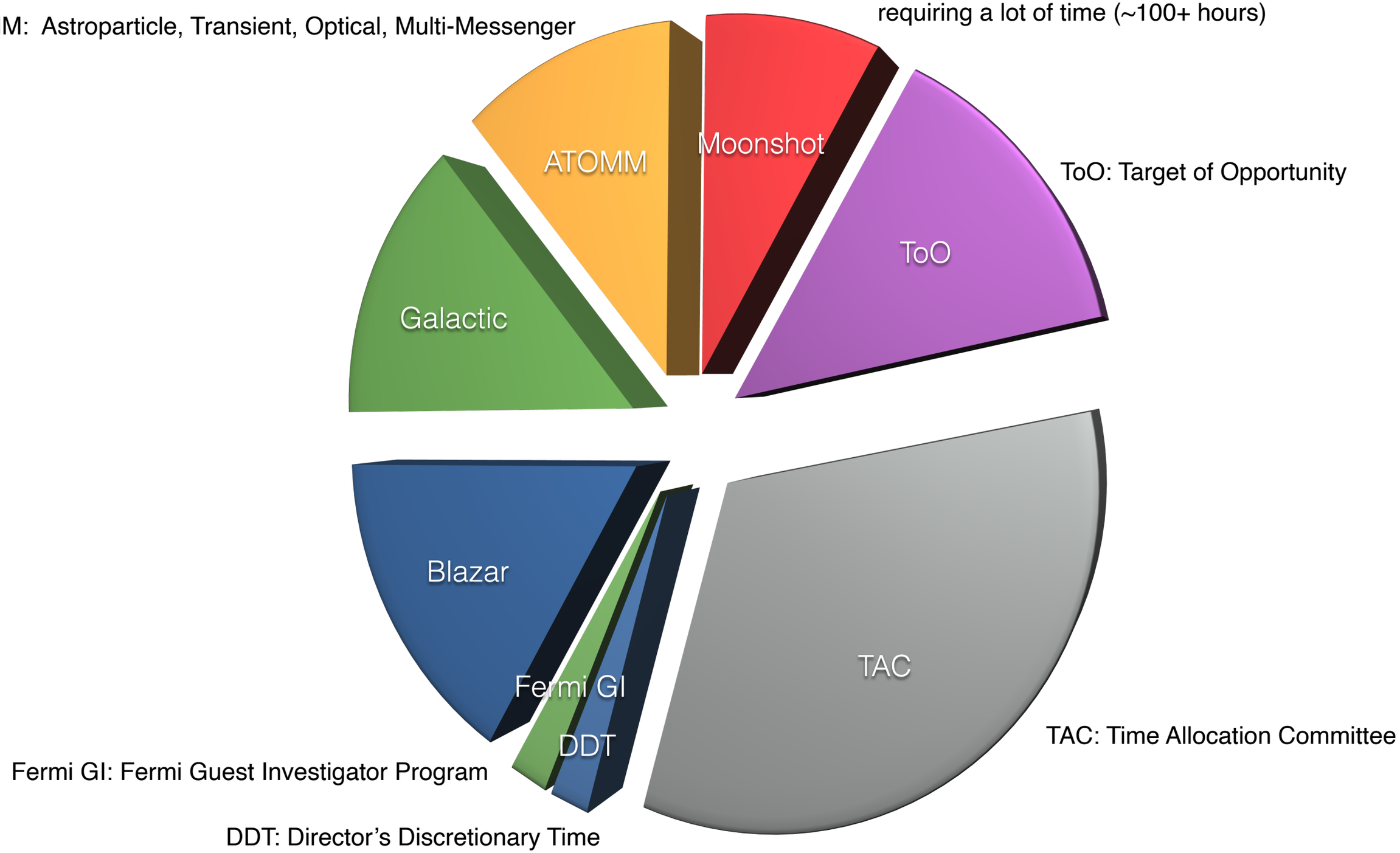
- LHAASO all-sky monitor and triggering facility for transient events, variable sources (such as binaries) and flaring VHE blazars

- Joint studies of hard-spectrum sources by combined spectral and morphological analyses
  - Studying Extreme HBLs: probing the intrinsic absorbed regime:
    - Example targets: 1ES 0033+595, 1ES 0502+675, 1ES 1011+496,1ES 1218+304, 1ES 0229+200, RGB J0710+591 and PG 1553+113 (see e.g. https://arxiv.org/abs/1908.03085)
  - Search for PeVatrons and energy-dependent morphologies in Galactic sources.
    - disentangling crowded emission regions

VERITAS Science Program

ATOMM: Astroparticle, Transient, Optical, Multi-Messenger

Moonshot: risky, potential high-payoff potentially requiring a lot of time (~100+ hours)



ToO: Target of Opportunity

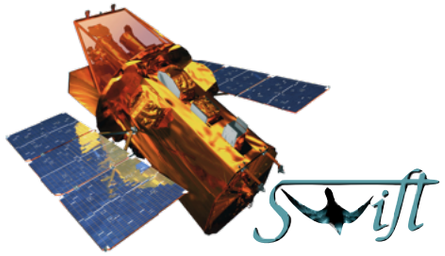
TAC: Time Allocation Committee

Fermi GI: Fermi Guest Investigator Program

DDT: Director's Discretionary Time

Multi-Messenger & Transient Science

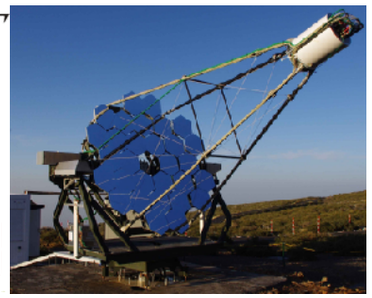
- Responding to and providing multi-messenger alerts in a timely fashion is a top priority for VERITAS.

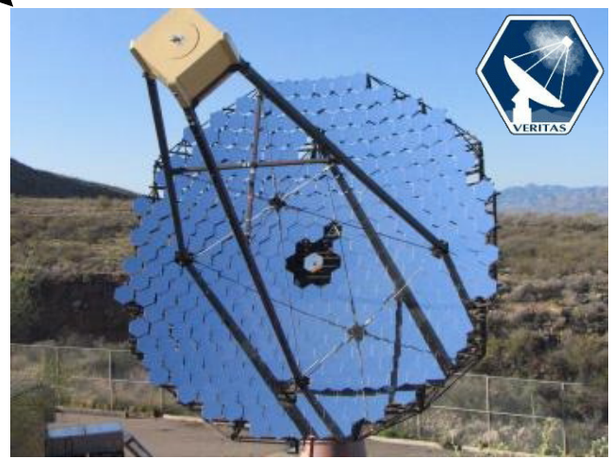


FACT

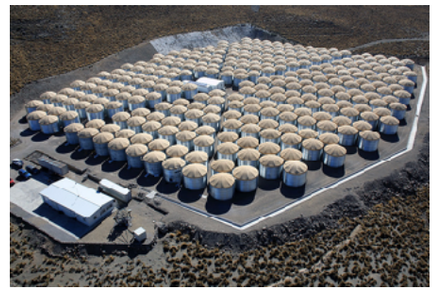
MAGIC

HESS

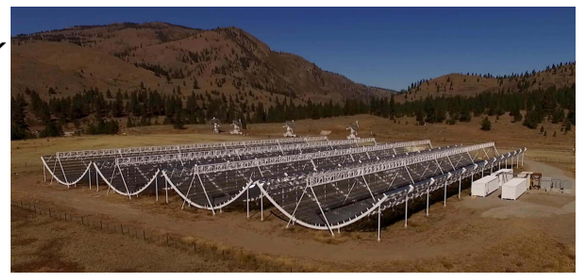




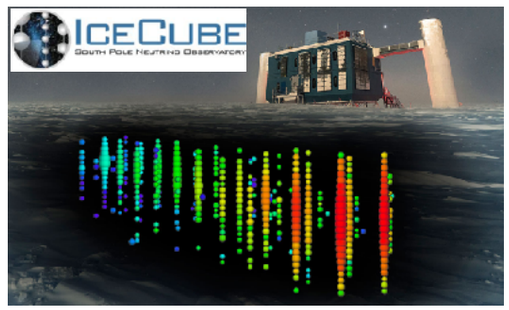
HAWC
High Altitude Water Cherenkov



chime



ICECUBE
South Pole Neutrino Observatory

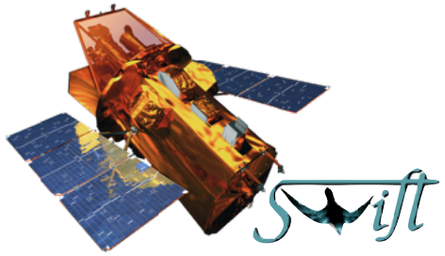


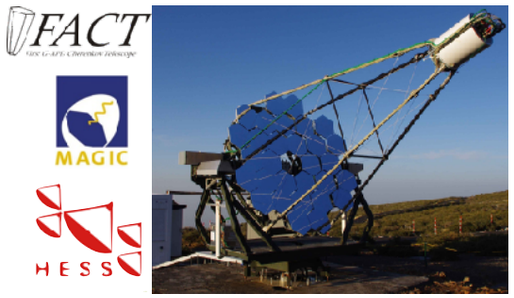
+general MWL/
ATELs etc.

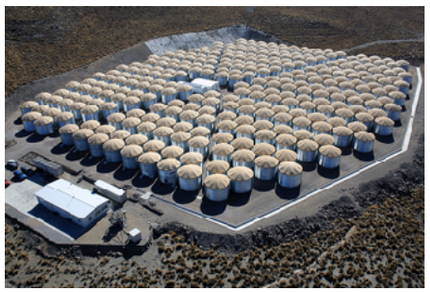
LIGO

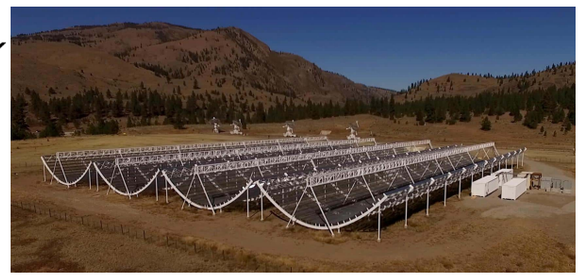
Multi-Messenger & Transient Science

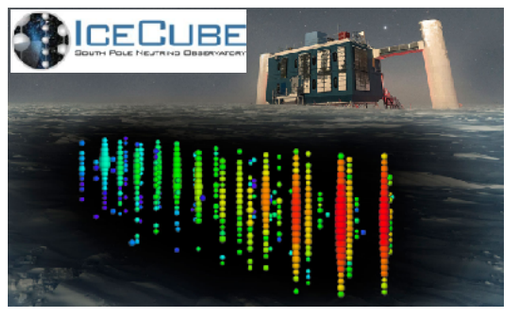
- Responding to and providing multi-messenger alerts in a timely fashion is a top priority for VERITAS.

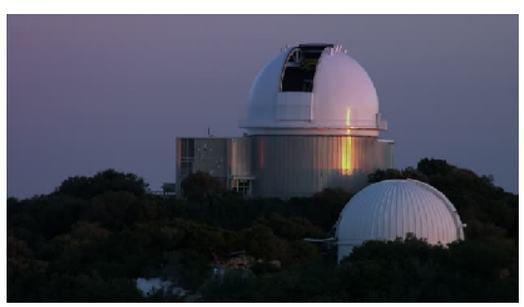












+general MWL/
ATELs etc.

VERITAS AGN Catalogue

Blazar	Type	z
Mkn 421	HBL	0.03
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	0.19
1ES 1011+496	HBL*	0.212
MS 1221.8+2452	HBL	0.218
1ES 0414+009	HBL	0.287
OJ 287	Blazar	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

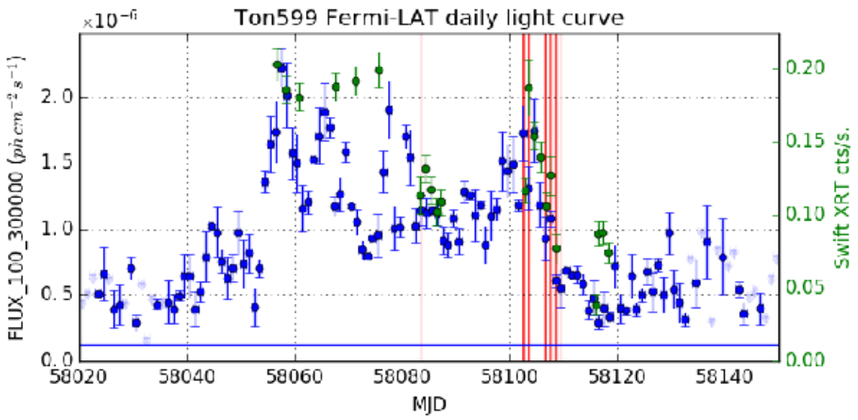
- 39 VHE AGN: 24 HBL, 7 IBL, 3 FSRQ, 2 uncertain & 3 FR I
  - ~25% have uncertain redshift
- All VERITAS AGN are Fermi-LAT detected
- All VERITAS detections have simultaneous MWL data to enable modelling
- All detected AGN are variable, some detected only during flares.
- Long-term monitoring of many visible VHE-detected AGN:
  - Blazar Physics, especially low/quiescent states
  - Cosmological Implications: EBL and IGMF
  - Several HBL (*) have hard spectra when corrected for EBL abs.

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

AGN	Type	z
M 87	FR I	0.004
NGC 1275	FR I	0.018
3C 264	FR I	0.026

VERITAS MWL / MMGR Triggering

External Triggering:

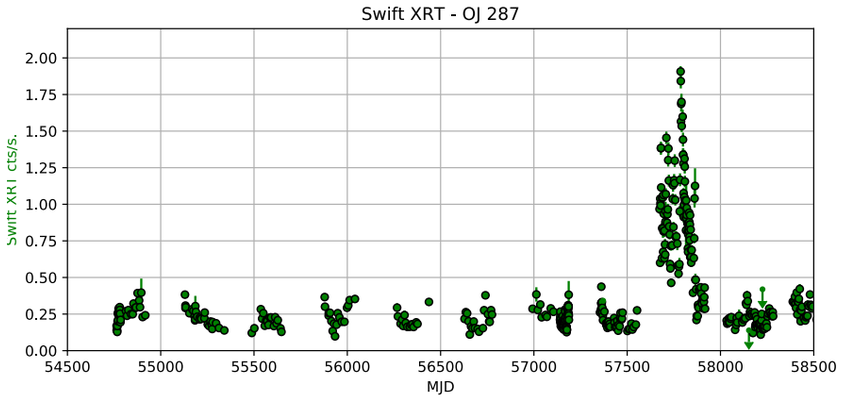


Ton 599: FSRQ @ z=0.72

3rd most distant VHE source

Fermi-LAT trigger, November 2017

VERITAS & MAGIC detected

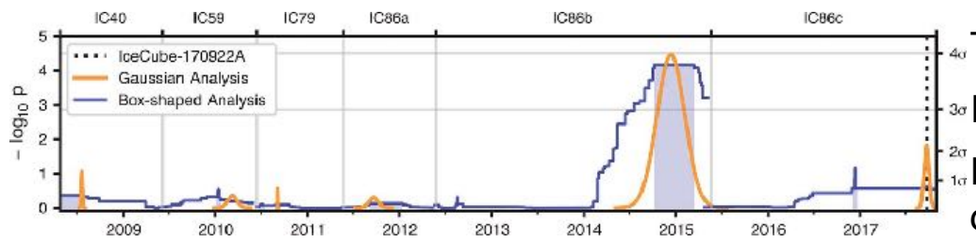


OJ 287: Blazar @ z=0.31

Binary black-hole system

Swift XRT trigger January 2017

VERITAS detected and triggered further Swift XRT



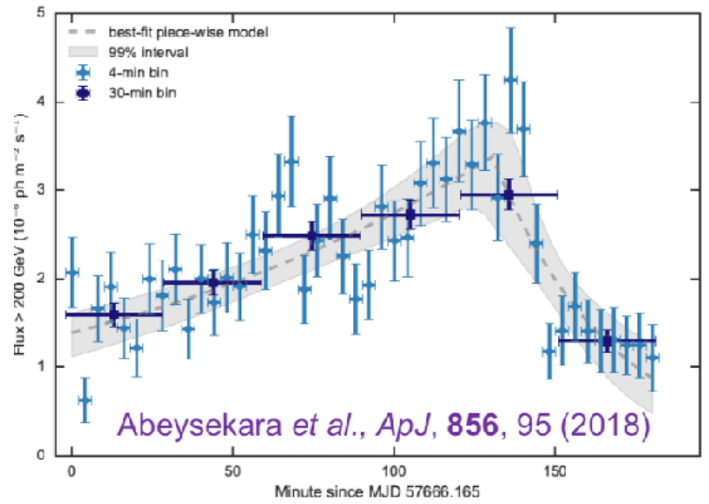
TXS 0506+056: Blazar @ z=0.34

IceCube-170922A **neutrino trigger**

Fermi-LAT, MAGIC, VERITAS detected

+ HAWC & other IACT Blazar alerts

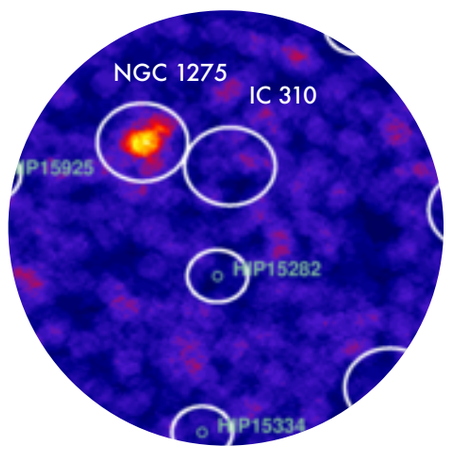
Self-Triggering:



BL Lac: IBL @ z=0.069

Not usually detected at VHE

A few very rapid (hour-scale) self-triggered flares



MJD57690

NGC 1275, Radio Galaxy @ z=0.017

Halloween flare 2016 while monitoring IC 310.

Recent AGN Highlights: 3C 264

- FR-I radio galaxy, z = 0.0216
- VERITAS 44 hrs taken in 2018 → 8σ detection:
  - motivated by evolving radio-knot structures.
  - hard spectrum with index Γ~2.3
  - low ~0.5% Crab, weakly variable flux (timescale ~ months)
  - 4th VHE Radio Galaxy and most distant
- Unusual SED for a radio galaxy with a high-frequency synchrotron peak.
- More distant (6x) analogue to M87?
  - if intrinsically similar then implication is that the jet is oriented at smaller angle to the line of sight.

THE ASTROPHYSICAL JOURNAL

VERITAS Discovery of VHE Emission from the Radio Galaxy 3C 264: A Multiwavelength Study

A. Archer[1], W. Benbow[2], R. Bird[3], A. Brill[4], M. Buchovecky[3], J. H. Buckley[5], M. T. Carini[6], J. L. Christiansen[7], A. J. Chromey[8], M. K. Daniel[2] + Show full author list

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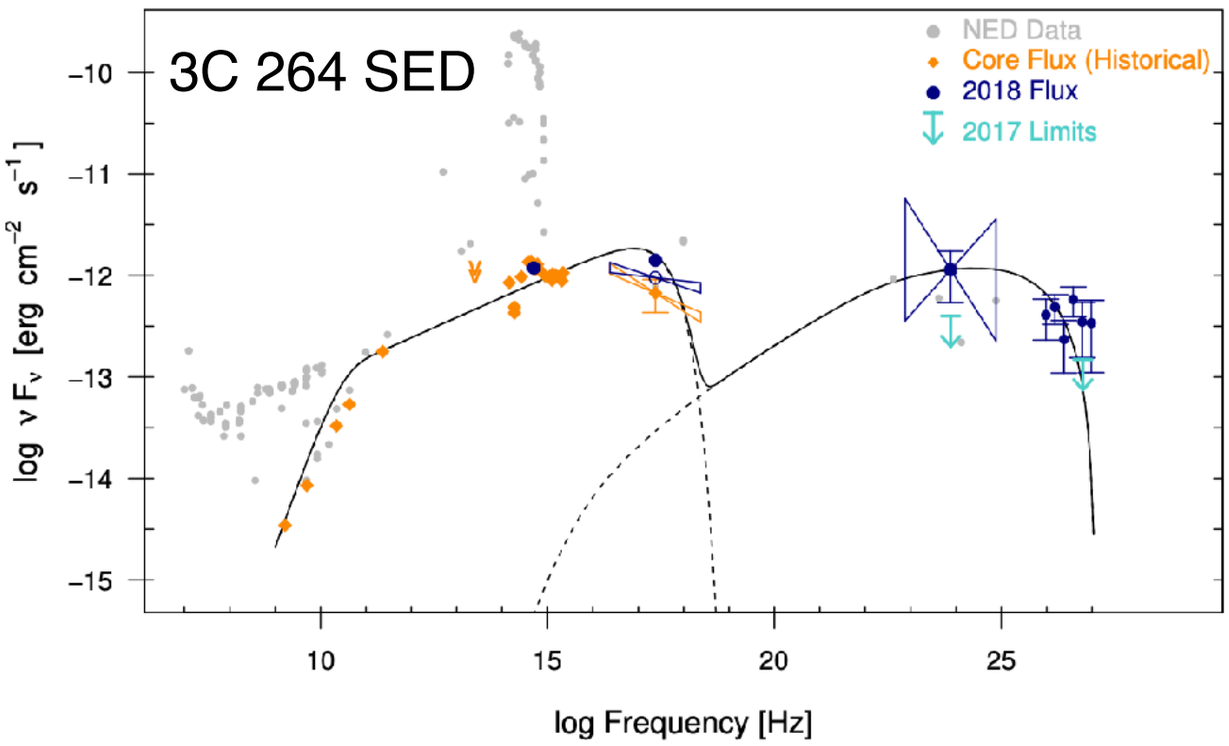
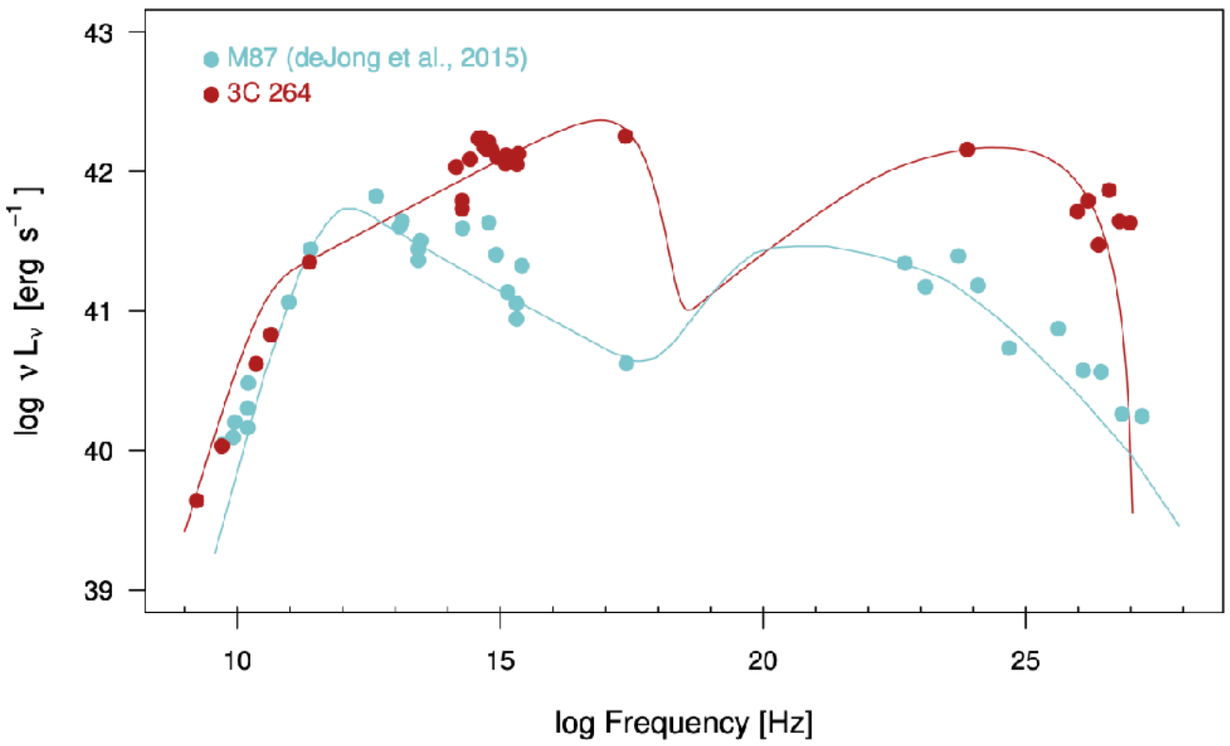
The Astrophysical Journal, Volume 896, Number 1



3C 264 & M87 SEDs



Recent AGN Highlights

THE ASTROPHYSICAL JOURNAL

A Decade of Multiwavelength Observations of the TeV Blazar 1ES 1215+303: Extreme Shift of the Synchrotron Peak Frequency and Long-term Optical–Gamma-Ray Flux Increase

Janeth Valverde[1], Deirdre Horan[1], Denis Bernard[1], Stephen Fegan[1] (Fermi-LAT Collaboration), A. U. Abeysekara[2], A. Archer[3], W. Benbow[4], R. Bird[5], A. Brill[6], + Show full author list

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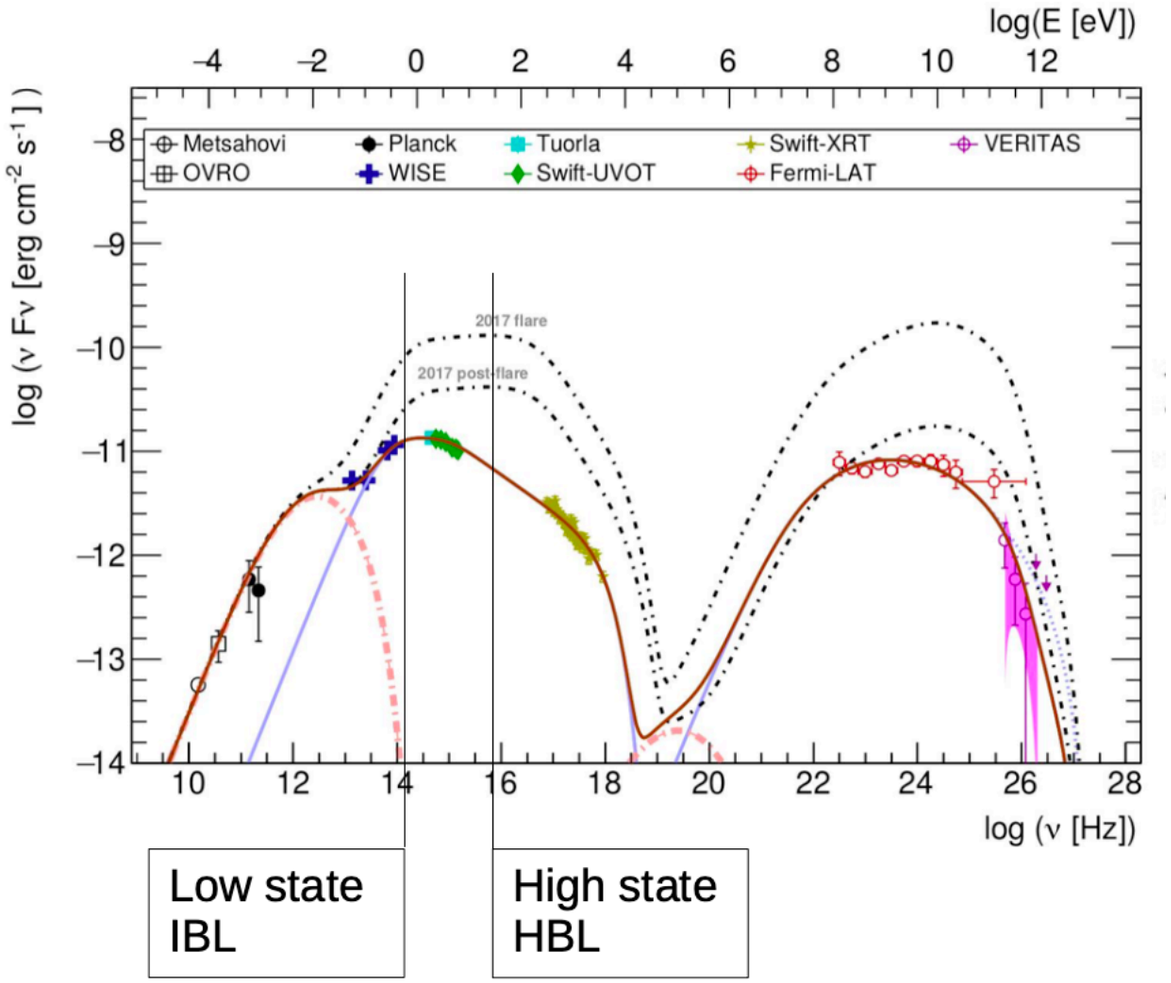
The Astrophysical Journal, Volume 891, Number 2



THE ASTROPHYSICAL JOURNAL

The Great Markarian 421 Flare of 2010 February: Multiwavelength Variability and Correlation Studies

A. U. Abeysekara[1], W. Benbow[2], R. Bird[3], A. Brill[4], R. Brose[5,6], M. Buchovecky[3], J. H. Buckley[7], J. L. Christiansen[8], A. J. Chromey[9], M. K. Daniel[2] + Show full author list

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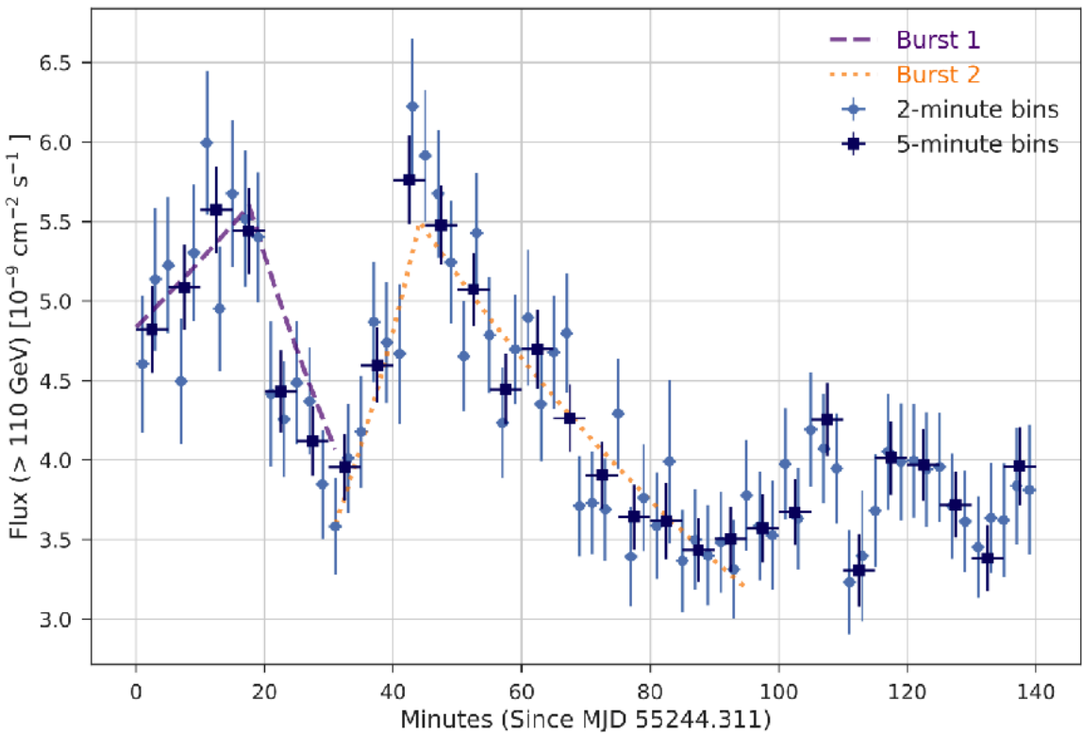
The Astrophysical Journal, Volume 890, Number 2

Markarian 421 VERITAS light curve > 110 GeV



- Flux > 1 TeV reached 27 Crab units.

Recent AGN Highlights: VER J0521+211

VER J0521+211: Unprecedented Flaring in February 2020

The Astronomer's Telegram

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VERITAS detection of unprecedented gamma-ray flare from the blazar VER J0521+211

ATel #13522; *John Quinn (University College Dublin) for the VERITAS Collaboration*
on 25 Feb 2020; 20:25 UT
Credential Certification: Deirdre Horan (deirdre@llr.in2p3.fr)

Subjects: Gamma Ray, >GeV, TeV, VHE, AGN, Blazar

Referred to by ATel #: 13523, 13528, 13532, 13548, 13727

Tweet

The VERITAS Collaboration reports the detection of a flare in very-high-energy (VHE; >100 GeV) gamma rays from the blazar VER J0521+211 (05h21m45s +21d12m51.4s, J2000) for observations made on 2020 February 25 (MJD 58904.12 - 58904.24). A preliminary analysis of the data indicates a steadily rising flux, reaching >130% the VHE flux from the Crab Nebula as the source set. VER J0521+211 typically has a VHE flux ~7% Crab but has been seen to flare to ~50% Crab. A coordinated Swift/VERITAS campaign also resulted in simultaneous Swift observations that show an elevated X-ray state with a 0.3-10 keV flux that is ~10× that of observations taken in prior weeks and months. For more details see the Swift VERJ0521+212 monitoring site. VER J0521+21, associated with RGB J0521.8+2112, is classified as an intermediate BL Lac (IBL) object and its redshift is uncertain. Multiwavelength observations are encouraged.

Questions regarding the VERITAS observations should be directed to John Quinn (john.quinn@ucd.ie). VERITAS (the Very Energetic Radiation Imaging Telescope Array System) is located at the Fred Lawrence Whipple Observatory in southern Arizona, USA, and is most sensitive to gamma rays between ~85 GeV and ~30 TeV. For further information see the VERITAS web site.

Related

- 13779 Fading of MAXI J0637-430 towards quiescence
- 13727 Optical variability in gamma-ray blazar VER J0521+211
- 13719 Fading of low-mass X-ray binary Swift J1858.6-0814 to quiescence level
- 13710 XB-NEWS detects a new outburst from MAXI J1348-630
- 13548 Possible Orphan Flare in the flaring gamma-ray blazar VER J0521+211
- 13532 VER J0521+211 flare: IceCube neutrino search
- 13528 Fermi-LAT detection of a hard GeV flare from the TeV source VER J0521+211
- 13523 No optical outburst of VER 0521+211 detected (yet)
- 13522 VERITAS detection of unprecedented gamma-ray flare from the blazar VER J0521+211
- 13520 Another Strong X-Ray Flare of TeV-Detected Blazar 1ES 0647+250
- 13467 MeerKAT and Swift/XRT detection of MAXI J1348-630
- 13465 Re-brightening and decaying of MAXI J1348-630 as observed with NICER
- 13459 MAXI J1348-630: MAXI/GSC detection
- 13454 XB-NEWS detects a new optical rise during the current outburst of MAXI J0637-430
- 13451 XB-NEWS detection of a new outburst of MAXI J1348-630

- VERITAS self-triggered observations Feb 25 UT
  - rising flux, peaking at > 130% Crab.
- Flaring activities in MAGIC, Fermi-LAT, and Swift-XRT data; IceCube neutrino search
- MAGIC reported >1 Crab again on Feb 29
- Swift ToO triggered
- VLBA ToO triggered:
  - study knot structure and evolution - look for correlations with VHE emission.
- Redshift undetermined - new measurement requested.

Galactic Highlights: Cas A

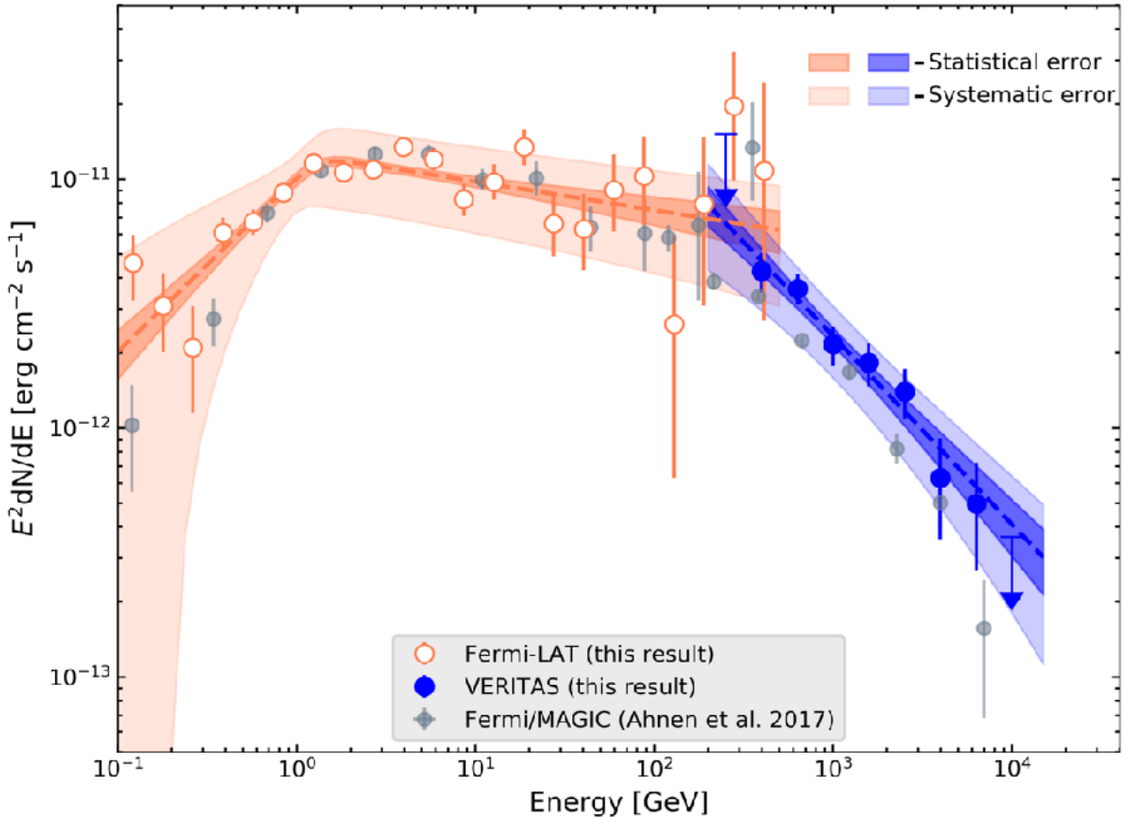
THE ASTROPHYSICAL JOURNAL

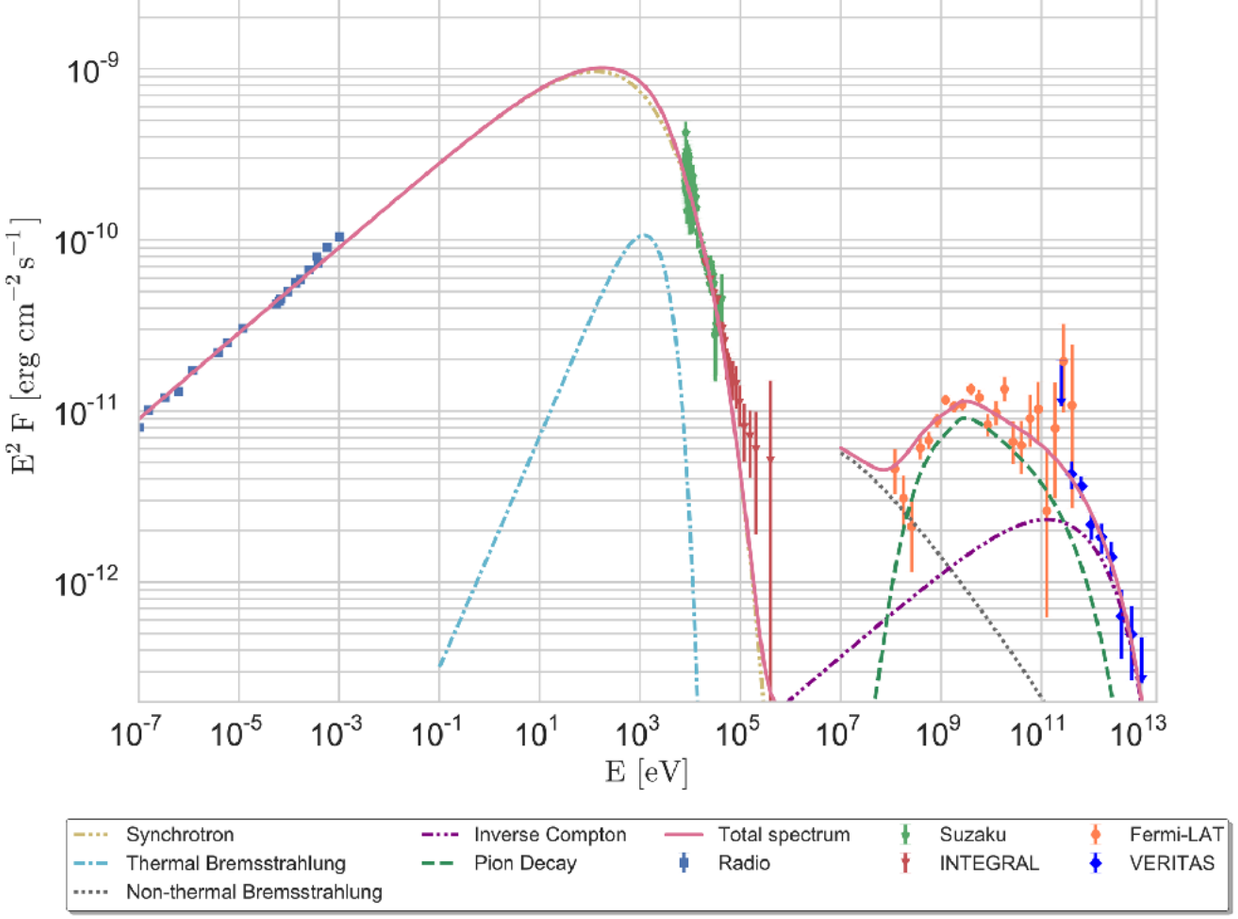
Evidence for Proton Acceleration up to TeV Energies Based on VERITAS and Fermi-LAT Observations of the Cas A SNR

A. U. Abeysekara[1], A. Archer[2], W. Benbow[3], R. Bird[4], R. Brose[5,6], M. Buchovecky[4], J. H. Buckley[7], A. J. Chromey[8], W. Cui[9,10], M. K. Daniel[3] + Show full author list

The Astrophysical Journal, Volume 894, Number 1

- 65 hrs VERITAS + 10.8 yrs *Fermi*-LAT
- Significant spectral curvature at $1.3 \pm 0.4_{stat}$ GeV, consistent with that expected from pion decay
- Broadband SED modelling - purely leptonic scenario ruled out and proton acceleration up to at least 6 TeV required.

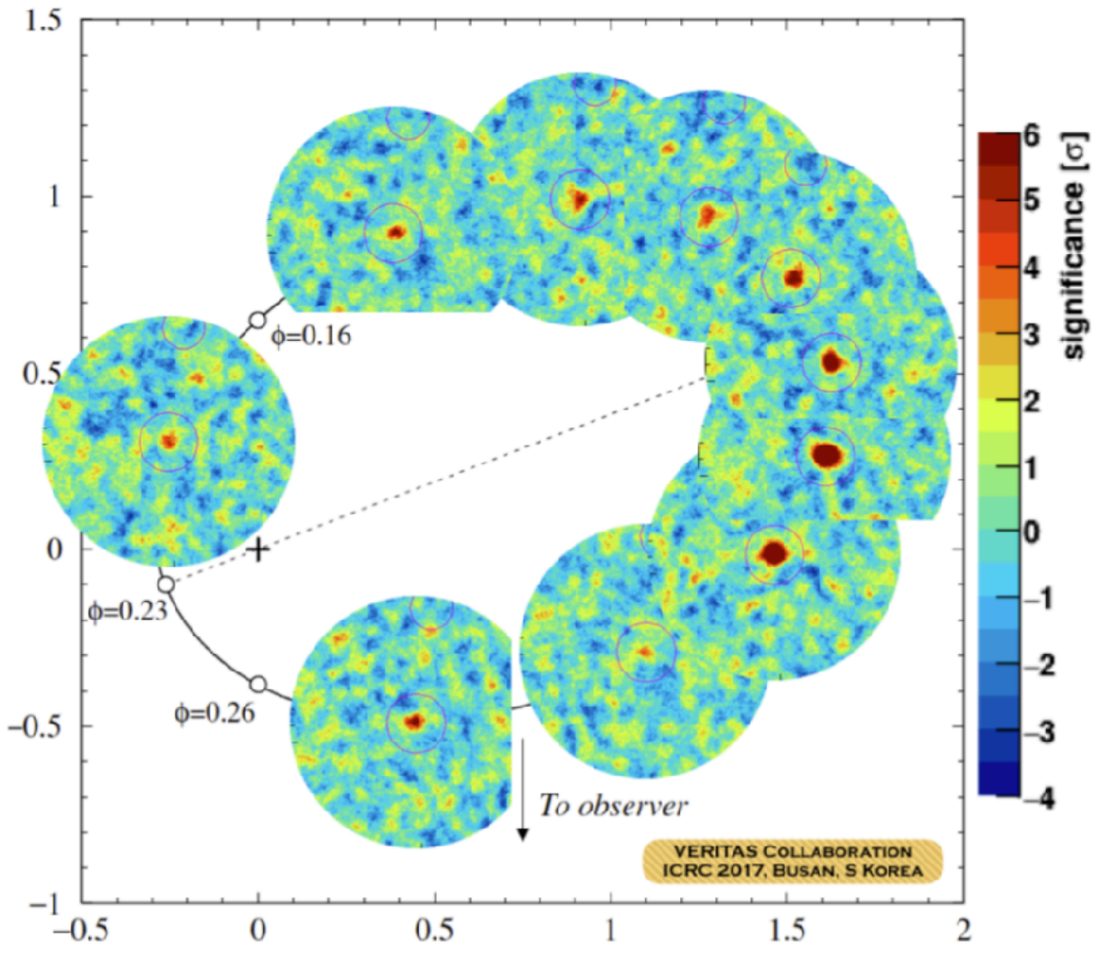




Galactic Highlights: Binary Systems

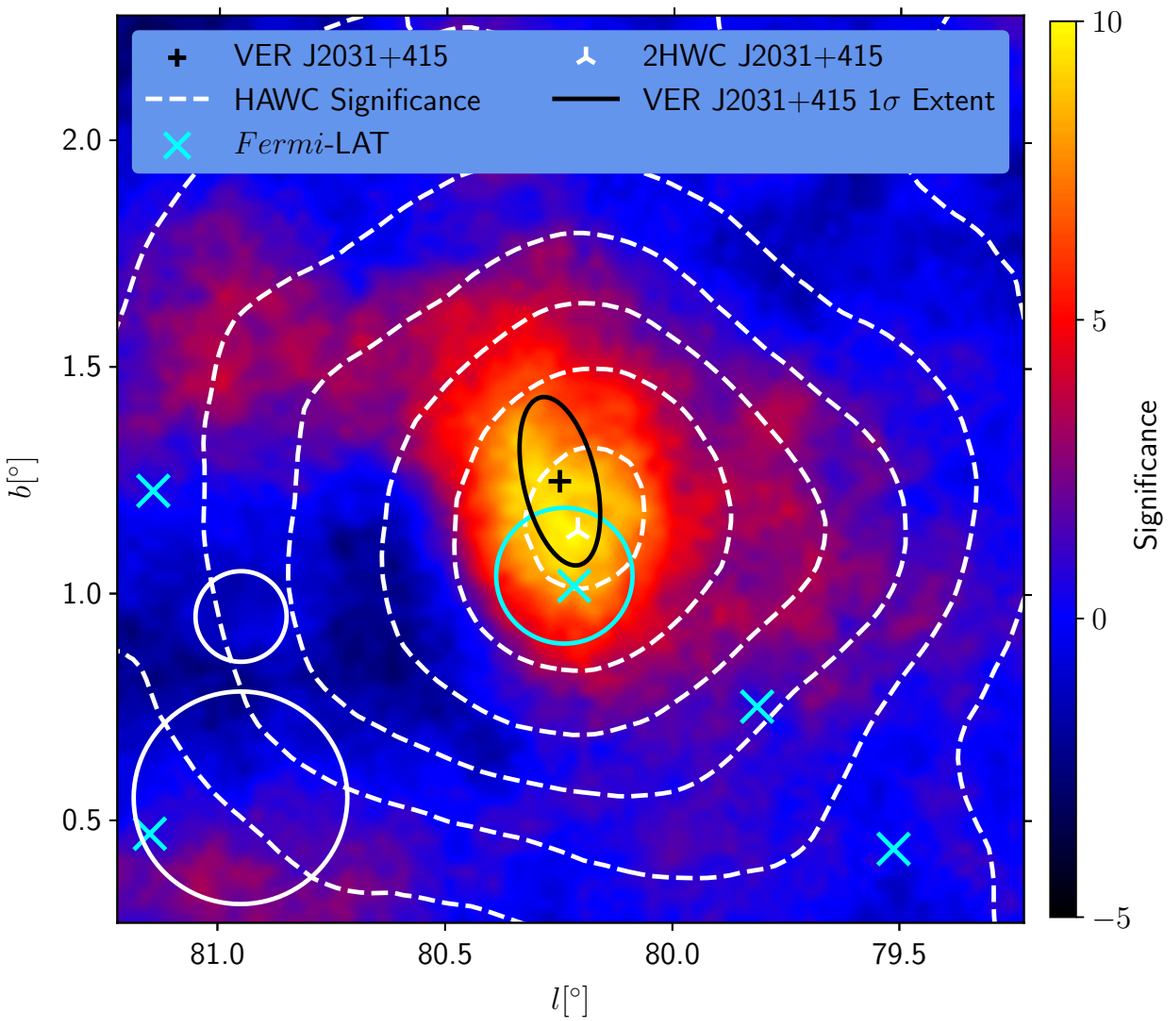
- VERITAS makes extensive observations of several binary systems including:
  - LS I +61 303 (>220 hrs),
  - HESS J0632 (>260 hrs),
  - PSR J2032+4127/ MT91 213 (~180 hrs)
  - Ongoing MWL monitoring to allow detailed modelling of these systems

LS I +61 303 VERITAS 2007-2016



Detection of the TeV γ-ray binary PSR J2032+4127/ MT91 213

- TeV J2032+4130:
  - First unidentified TeV source (Aharonian et al. 2002)
  - Later found to be extended (Aliu et al., 2014)
  - PSR J2032+4127, a Fermi-LAT pulsar in southeast corner - is TeV J2032 a PWN?



THE ASTROPHYSICAL JOURNAL LETTERS

Periastron Observations of TeV Gamma-Ray Emission from a Binary System with a 50-year Period

A. U. Abeysekara[1], W. Benbow[2], R. Bird[3], A. Brill[4], R. Brose[5,6], J. H. Buckley[7], A. J. Chromey[8], M. K. Daniel[2], A. Falcone[9], J. P. Finley[10] + Show full author list

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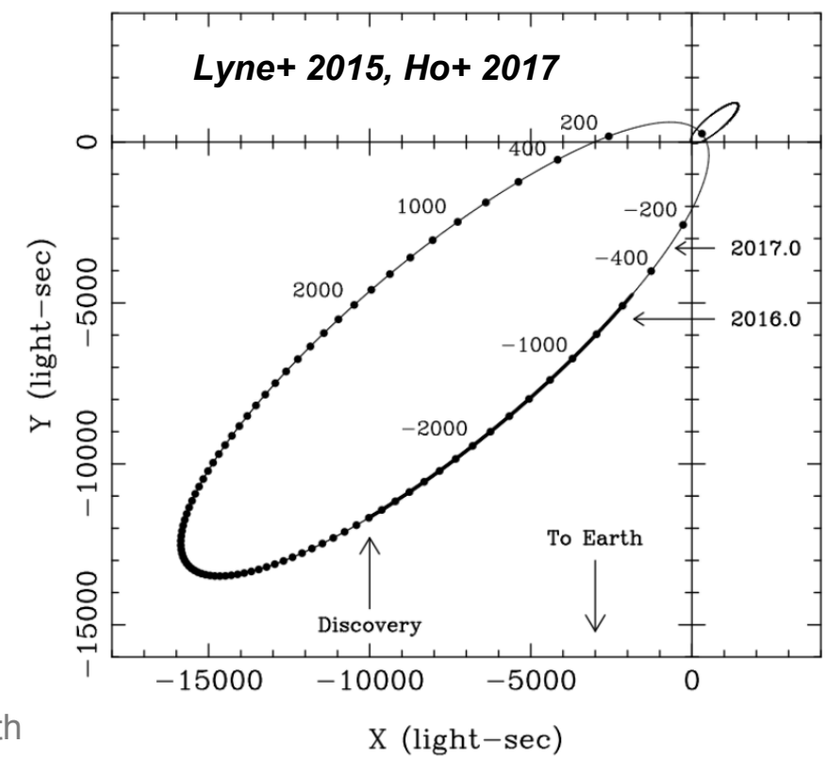
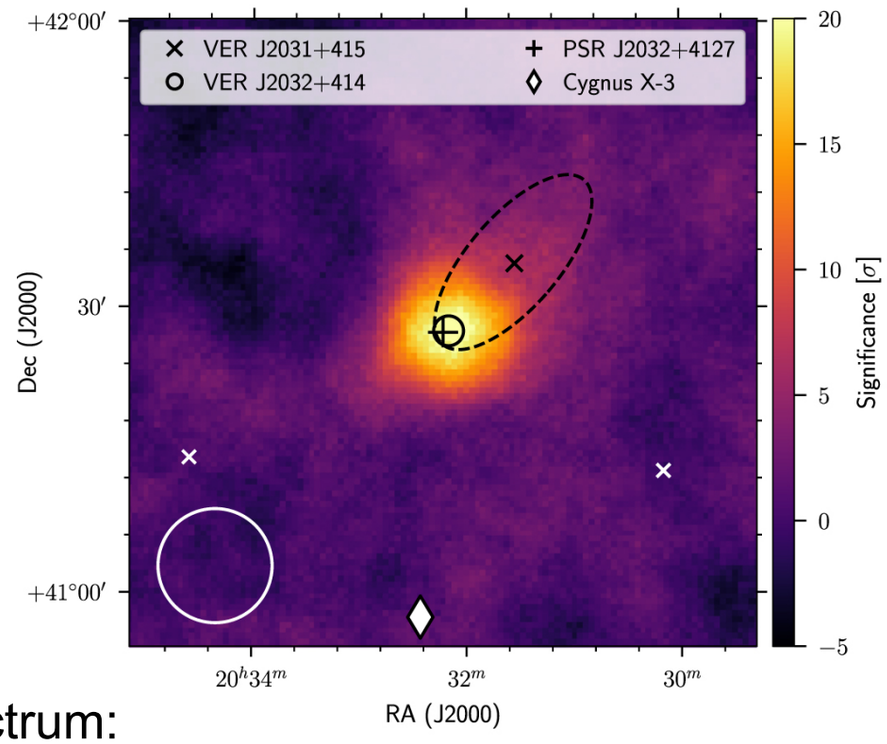
The Astrophysical Journal Letters, Volume 867, Number 1

- PSR J2032+4127:
  - In 2015 identified as being in a binary with 15 $M_\odot$ Be star MT91 213
    - ~50 year period orbit
    - Eccentricity ~ 0.95
    - Periastron 13 November 2017



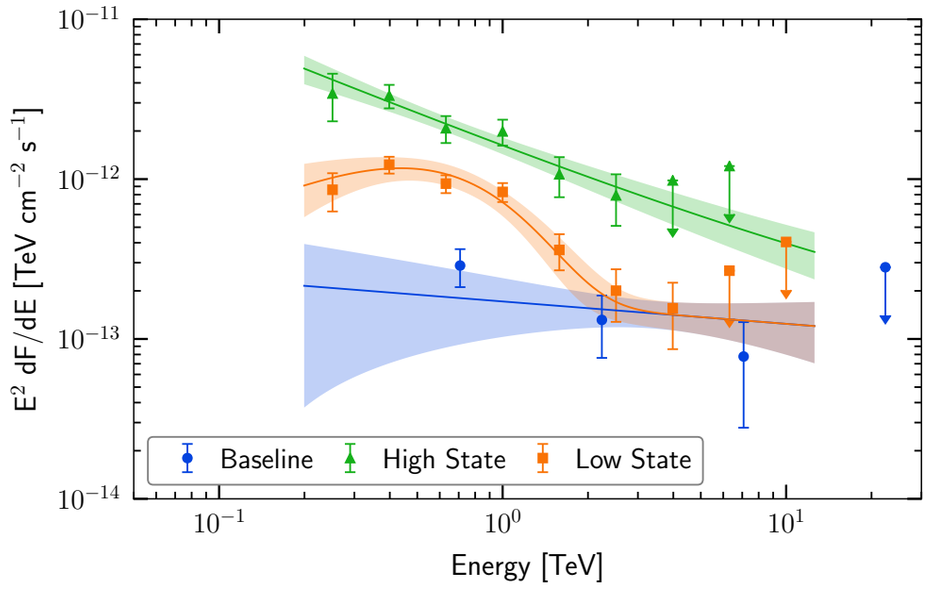
Detection of the TeV γ-ray binary PSR J2032+4127/ MT91 213

- Detection of significant and variable (10x) flux:
  - VERITAS and MAGIC both ~20 sigma

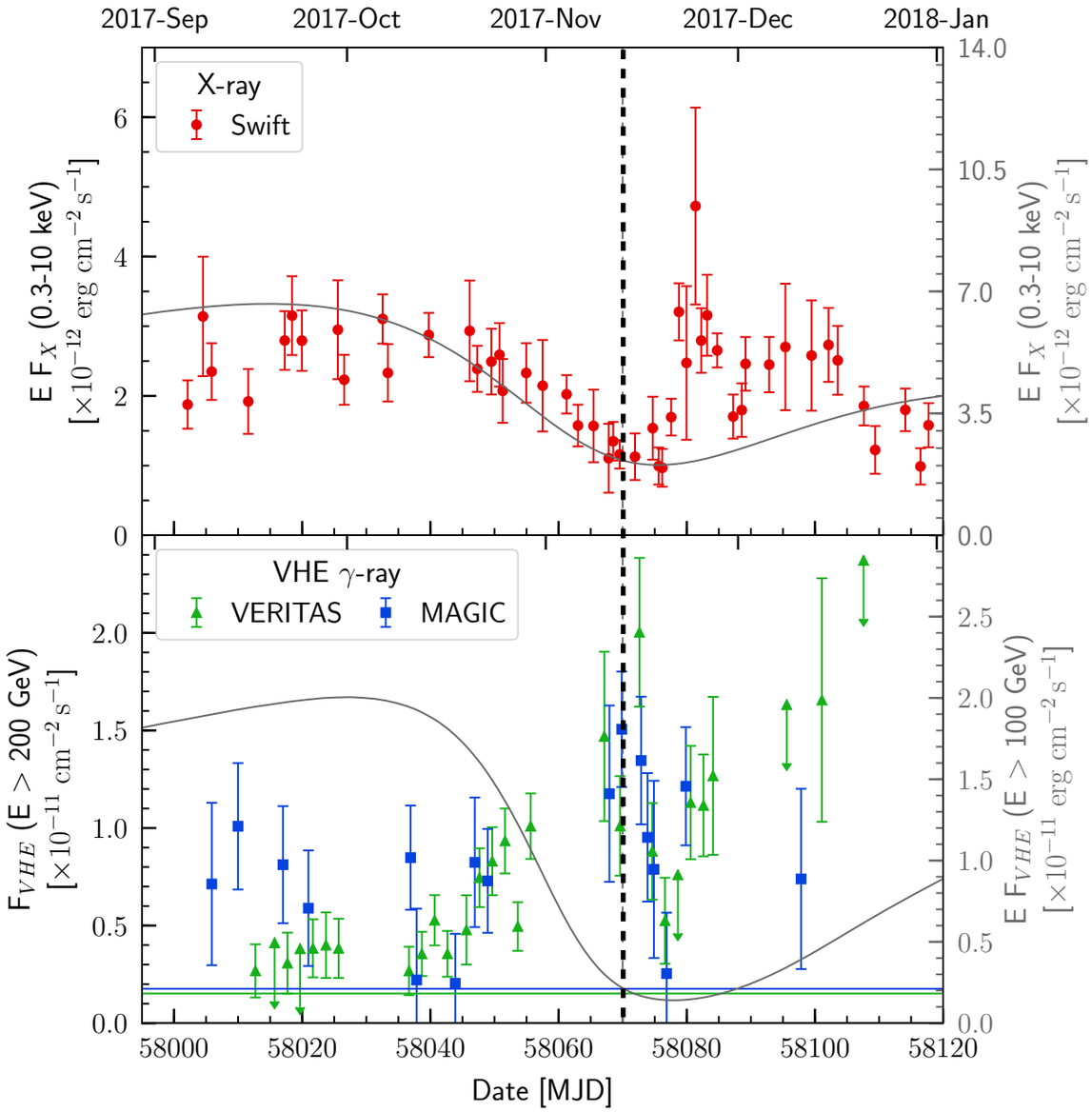


(a)

- Spectrum:



- Light curve around periastron:



Grey lines:
- X-ray: model of predictions of Liu et al. (2018)
- VHE: model of Takata et al (2017) using parameters from Liu et al (2018) (Takate, private comm.)

Galactic Highlights: HAWC followups

- 2HWC: 507 days of observation, found 39 γ-ray sources
- 19 sources > 0.5° from any known TeV γ-ray sources
- VERITAS analysed 218 hrs exposure on 14 objects:
  - archival <1.5° away (134 hrs) + new targeted obs. (84 hrs)
  - Limits for several sources below extrapolated HAWC flux:
    - spectral change or extended source
  - New detection: **2HWC J1953+294 = VER J1952+294 = DA 495 PWN**

THE ASTROPHYSICAL JOURNAL

VERITAS and *Fermi*-LAT Observations of TeV Gamma-Ray Sources Discovered by HAWC in the 2HWC Catalog

A. U. Abeysekara[1], A. Archer[2], W. Benbow[3], R. Bird[4], R. Brose[5,6], M. Buchovecky[2], J. H. Buckley[2], V. Bugaev[2], A. J. Chromey[7], M. P. Connolly[8] + Show full author list

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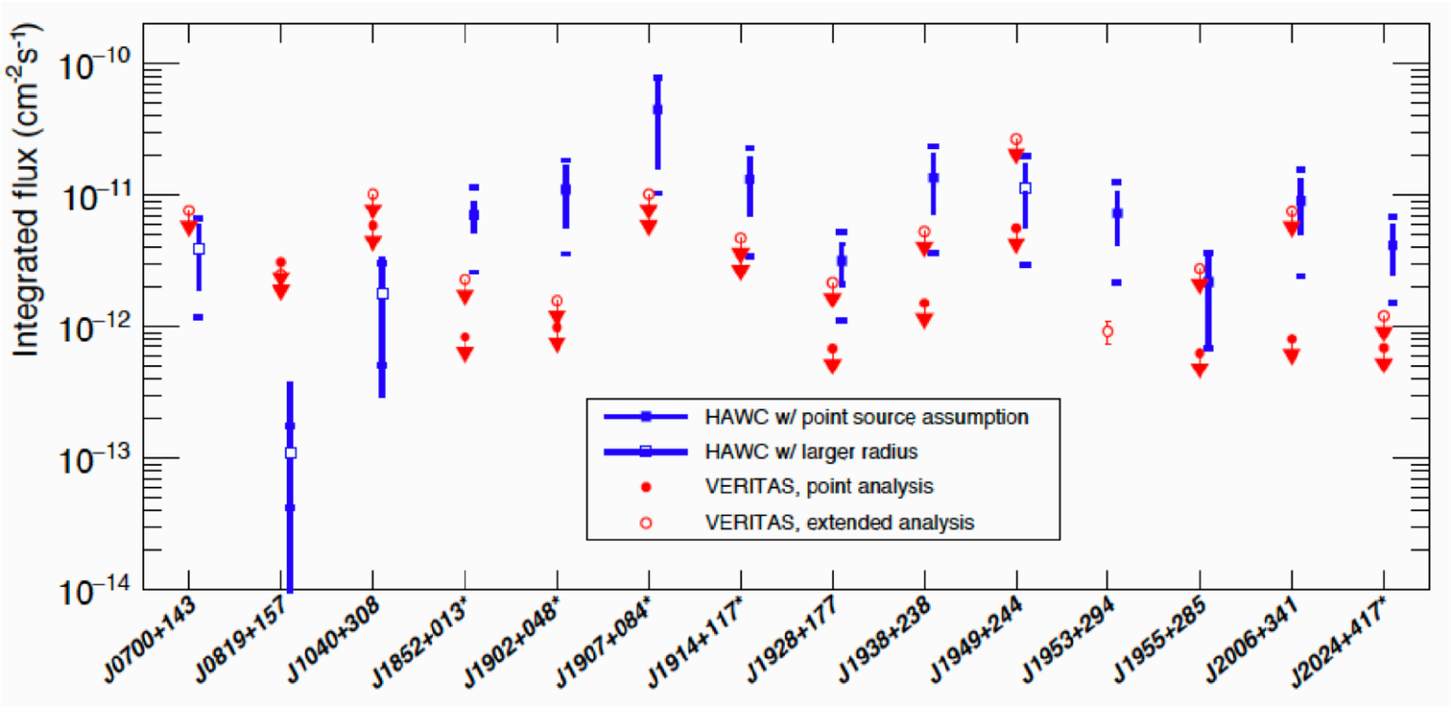
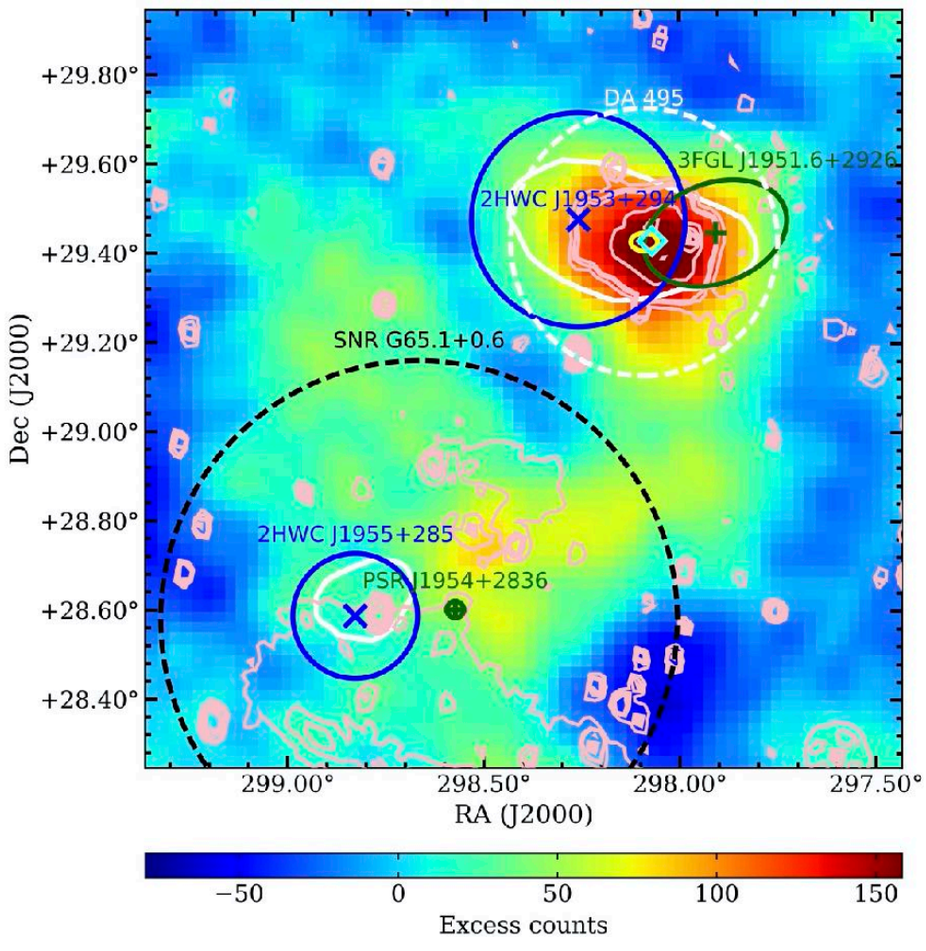
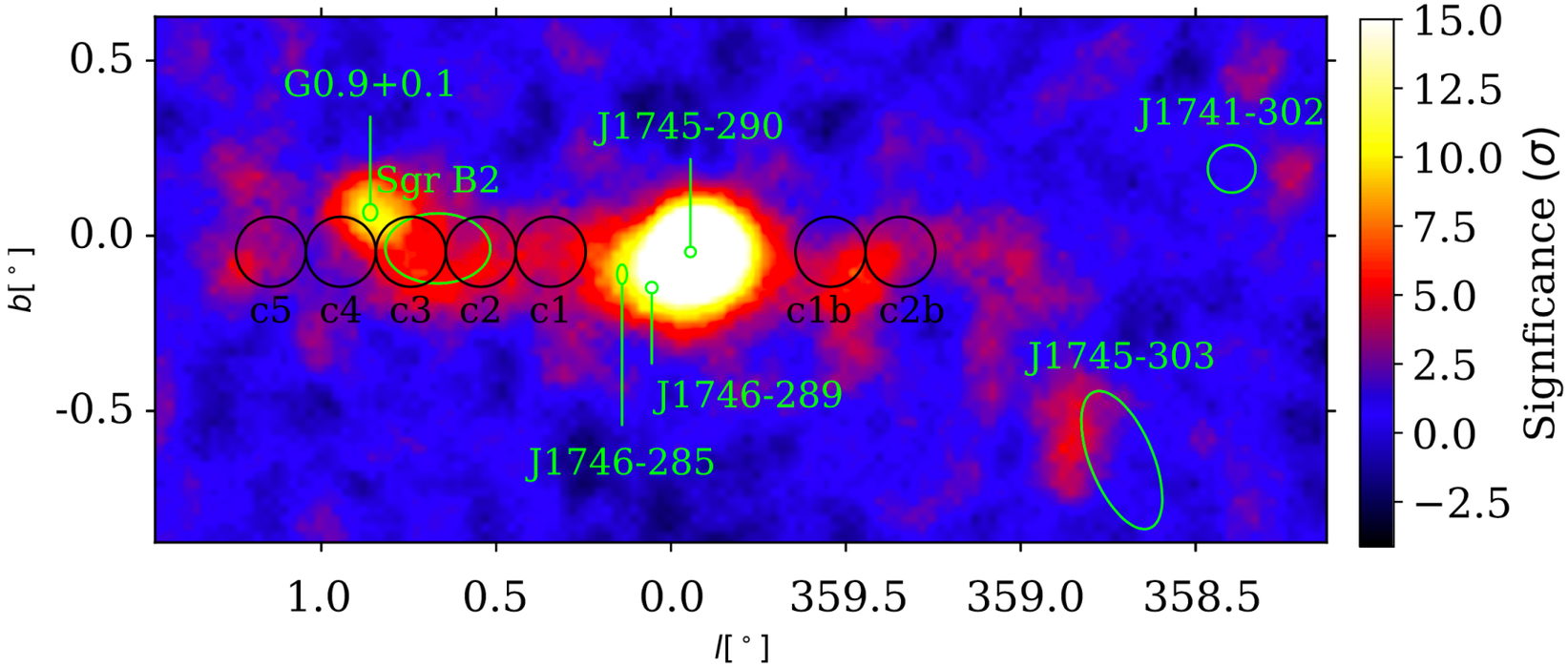
The Astrophysical Journal, Volume 866, Number 1

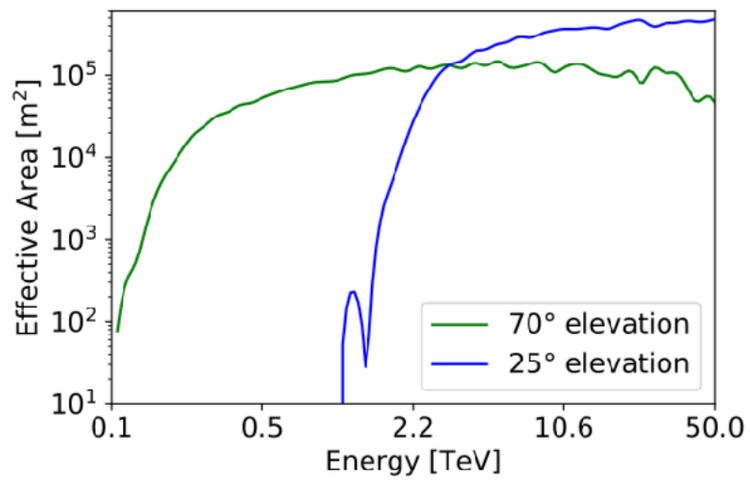


DA 495 PWN



Galactic Centre > 2 TeV

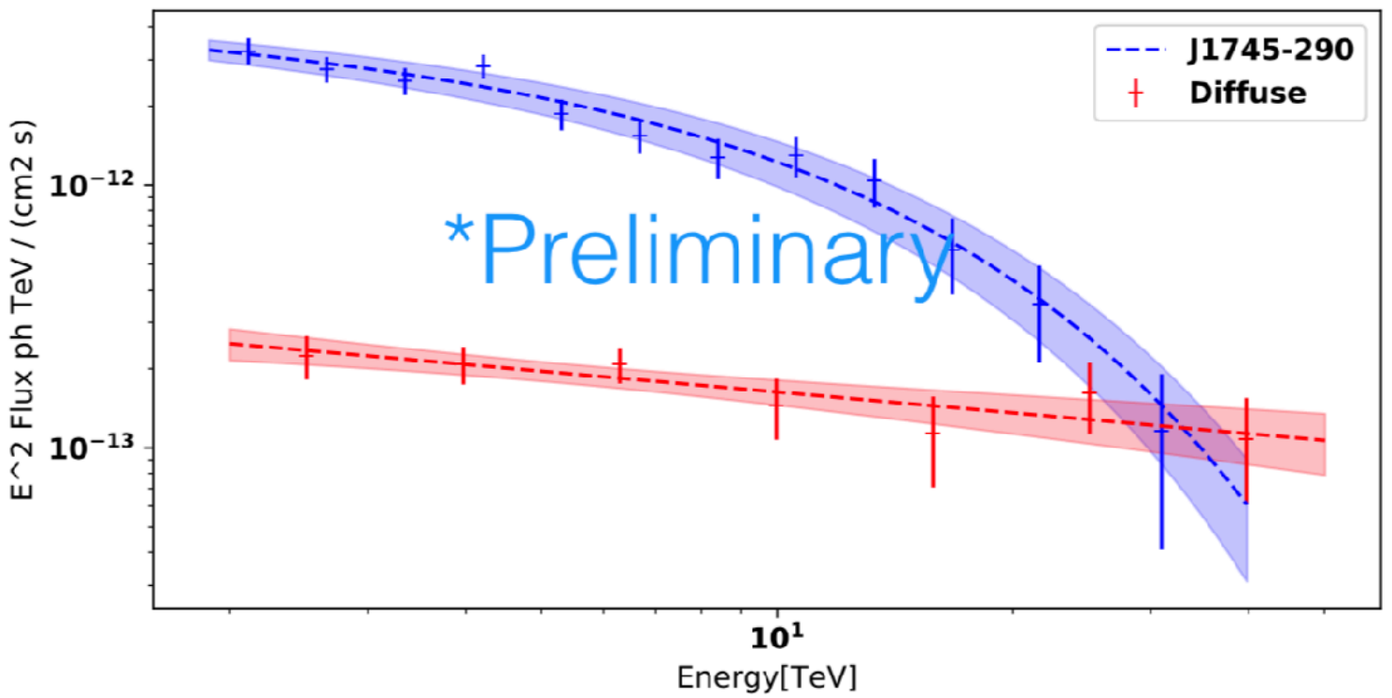




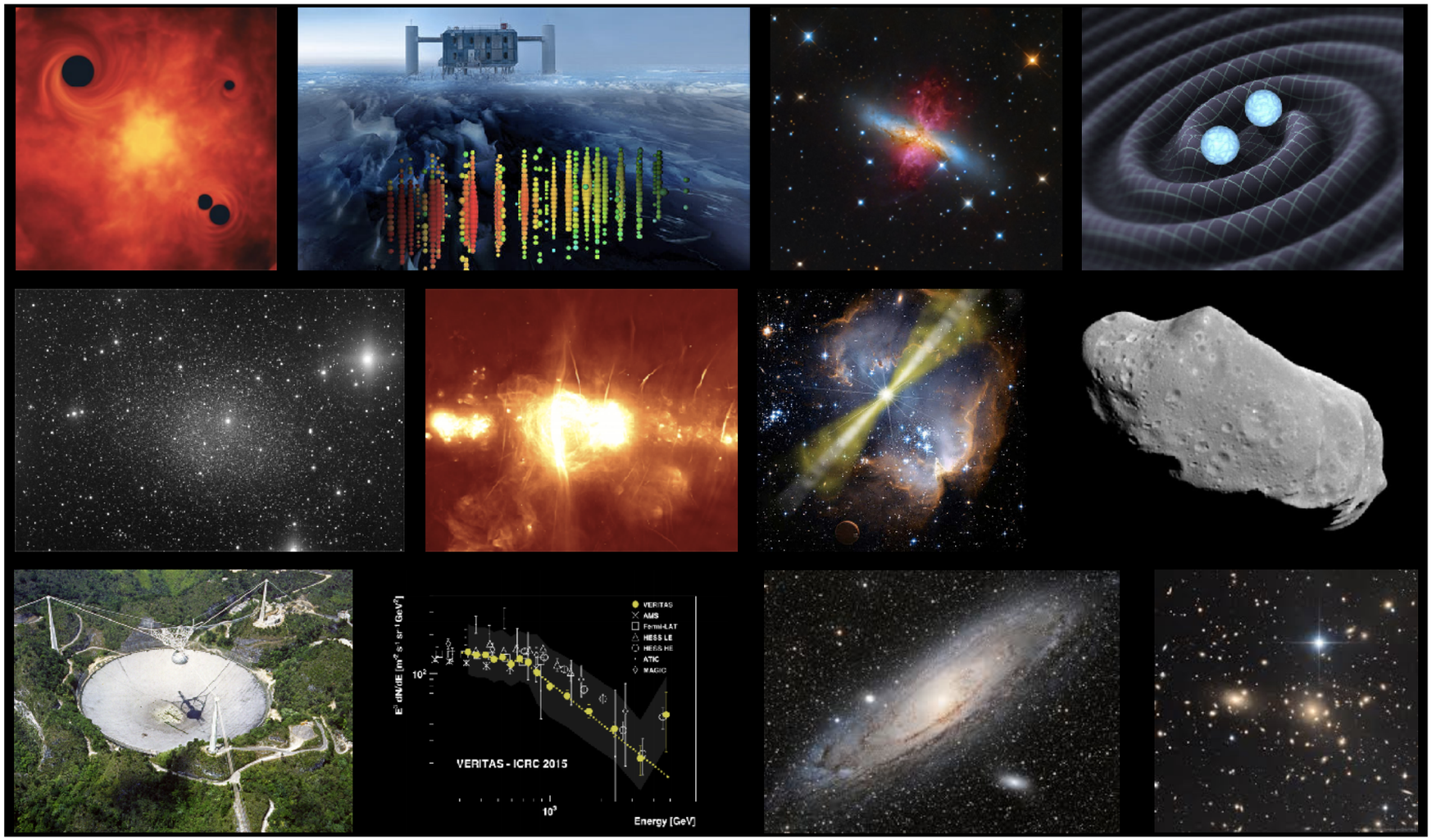
Effective Area 4x at 10 TeV

Buchovecky+ VERITAS, COSPAR (2018)

- 155 hrs of observations at large zenith angles.
- J1745-290 (Sgr A*):
  - >35σ, consistent w/point source
  - constant flux
  - spectrum:PL w/exp. cutoff:
    - Γ=-2.16 ± 0.18$_{stat}$
    - cutoff at 10.8±3.0 TeV
- Diffuse emission:
  - ‘c’ regions in figure above (from H.E.S.S)
  - PL with index -2.26±0.13
  - no cutoff observed up to 40 TeV



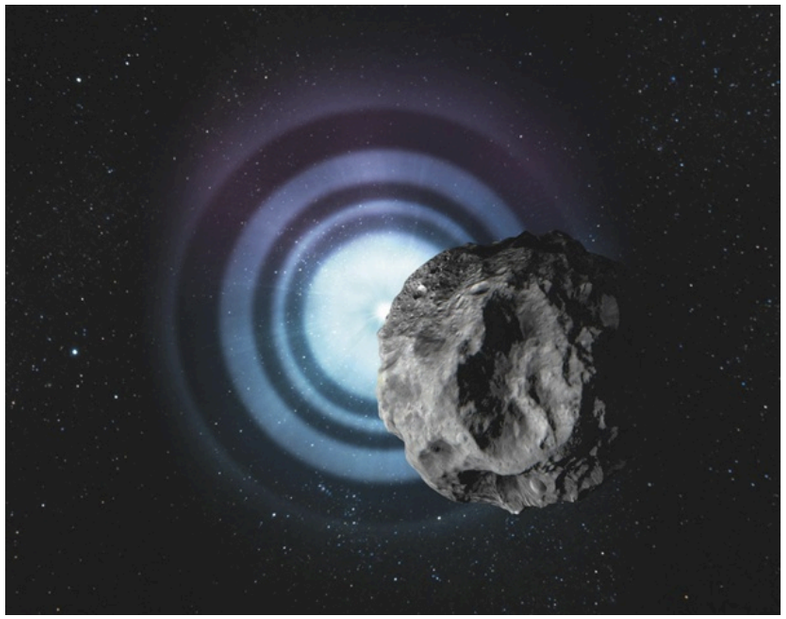
ATOMM: Astroparticle, Transient, Optical & Multi-Messenger

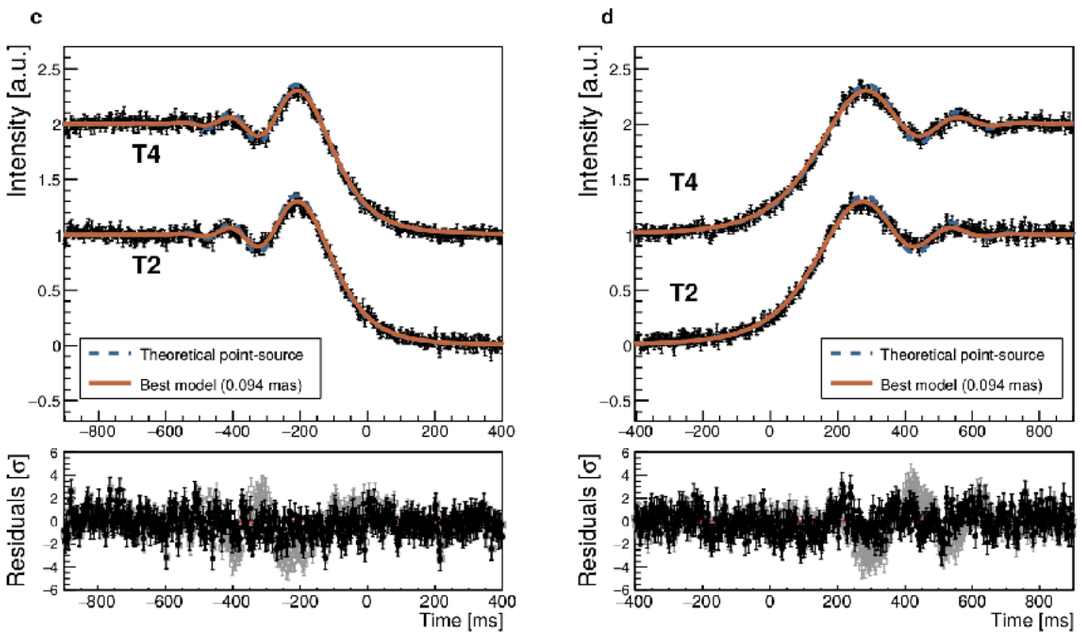


- BSM physics: dark matter, primordial black holes, Lorentz invariance violation.
- Transients: gamma-ray bursts, fast radio bursts
- Astroparticle: measurement of primary CR spectra (e-, Fe)
- Optical: Stellar occultations, fast optical transients, Stellar Intensity Interferometry.
- Multi-messenger

Optical Highlights

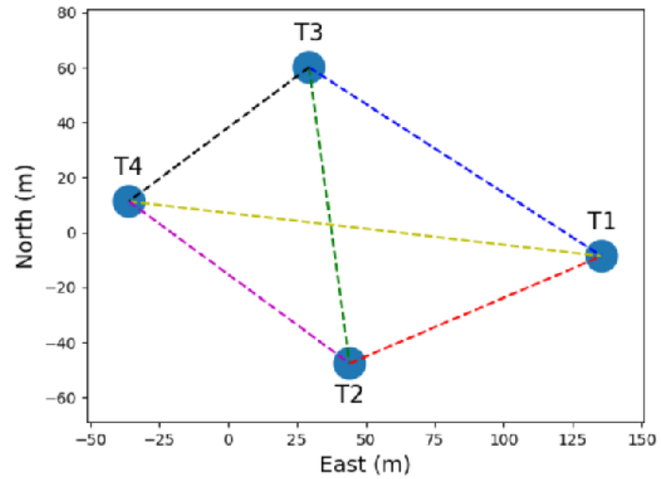
Stellar Diameter Measurements Through Diffraction caused by Asteroid Occultation

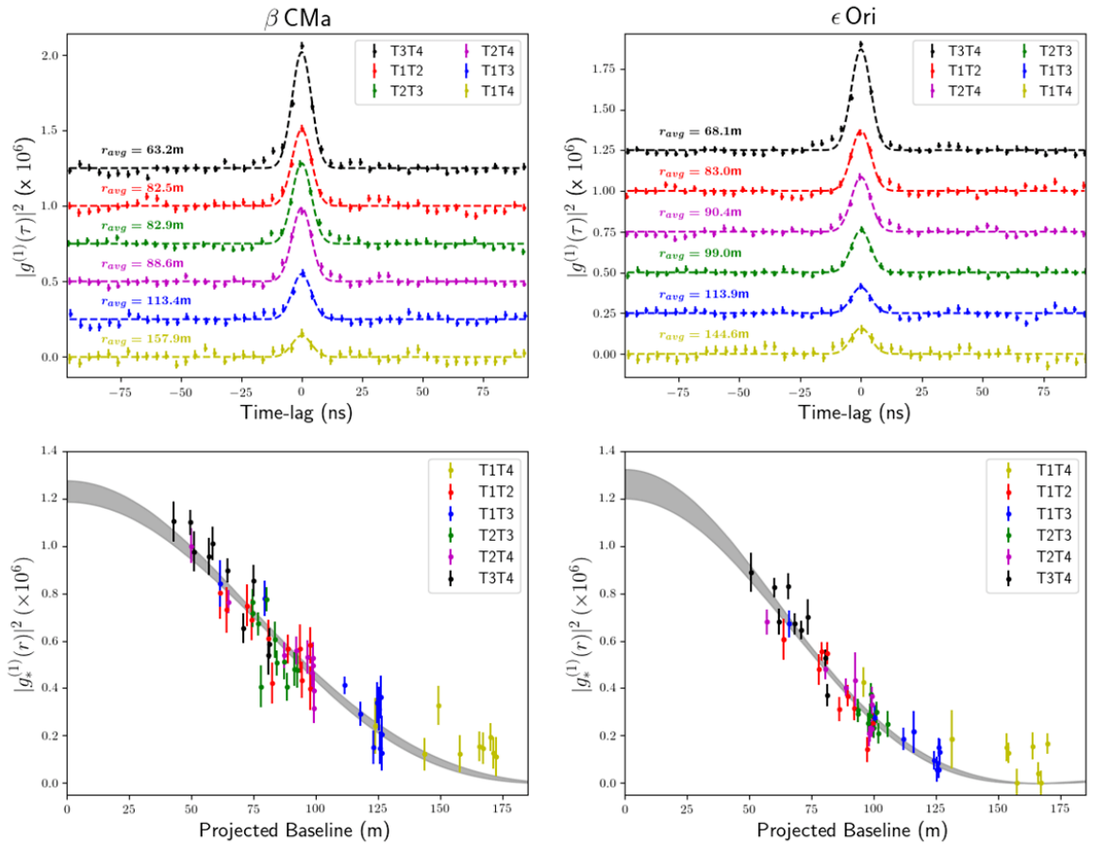




Two stars observed: 94 μas and 125 μas diameters.
Nature Astronomy 3: 511 (2019)

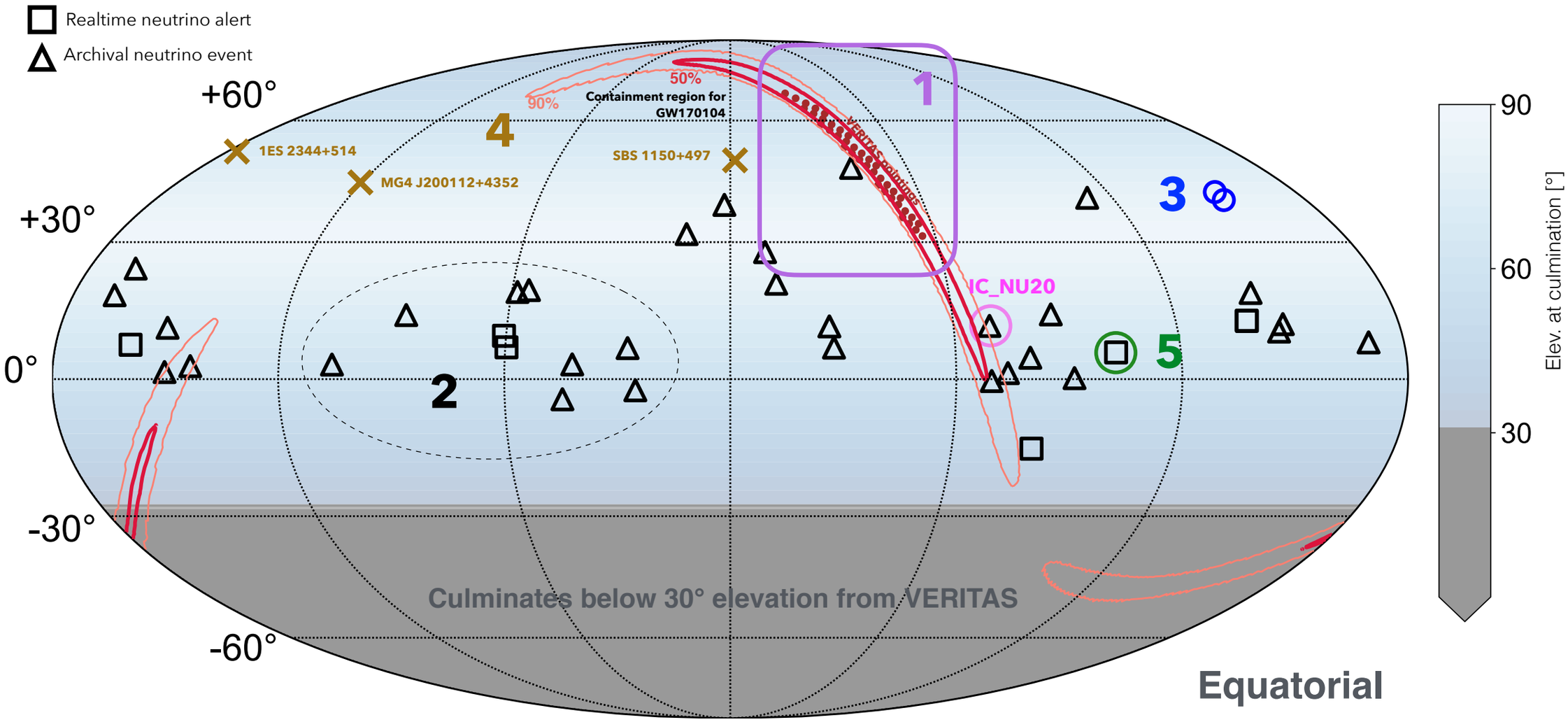
Stellar Intensity Interferometry





Two stars observed: 0.52 mas and 0.63 mas diameters.
Nature Astronomy (20/07/2020)

Current MMGR efforts

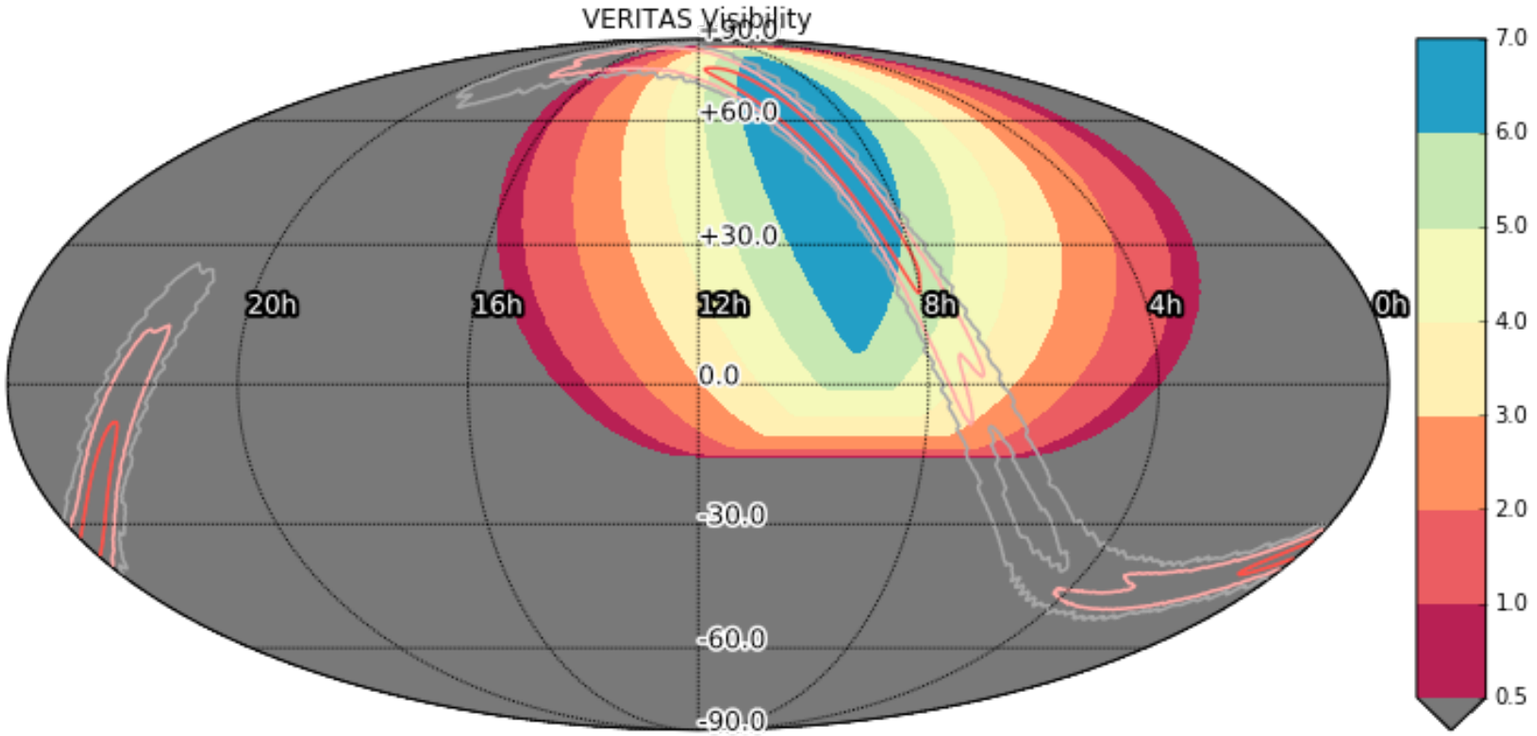


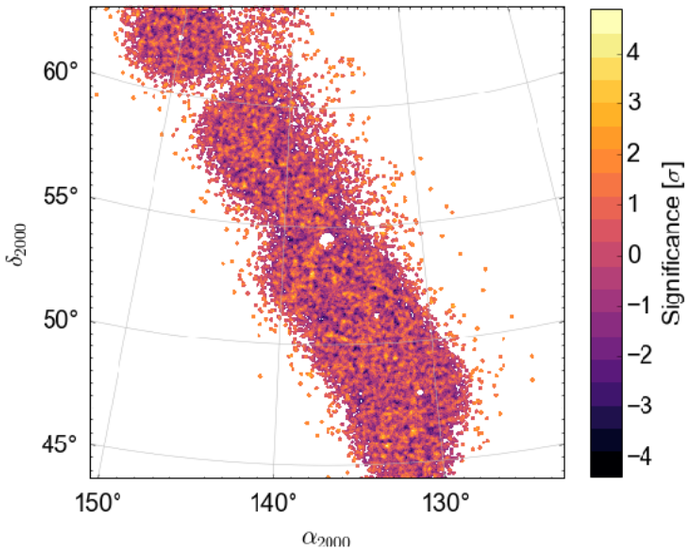
1. Gravitational-wave VHE counterpart searches
2. Realtime and archival neutrino event follow-ups
3. Follow-up of IceCube neutrino event multiplets
4. Follow-up of neutrino clusters near known VHE sources
5. Long-term monitoring of the candidate neutrino blazar TXS 0506+056

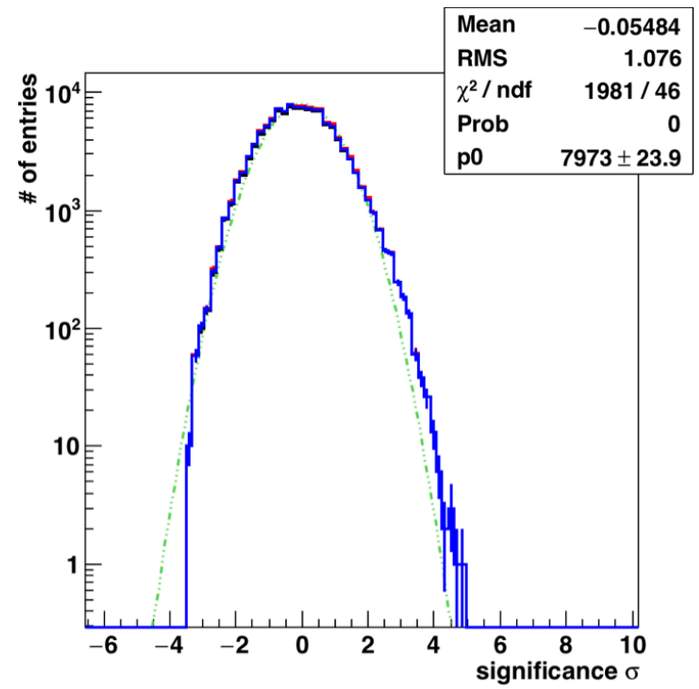
Current MMGR efforts

First systematic IACT follow-up of a GW alert

- GW170104: 50-$M_\odot$ BBH merger at z = 0.2 detected by LIGO.
- No EM emission expected. Event was 6.5 hours old when alert issued, observations started 14.5 hours later. Good visibility of the core region of the event.
- VERITAS: 39 pointings of 5 mins. each
- optimised to maximise probability coverage and minimise slewing time







- Preliminary results circulated as GCN #21153
- Followed up alerts in O3 (until LIGO suspended operations on March 23 due to COVID 19):
  - 13 follow-ups done so far - analysis in progress

Current MMGR efforts

IceCube follow-up programs

Goal: Searching for hadronic VHE emission at the location of single (or clusters of) high-energy muon neutrinos (~1° ang. resolution).

Variety of follow-up approaches:

months
years

- Searches for VHE emission at “archival” muon neutrino positions that are likely astrophysical ($E_\nu \gtrsim 100$ TeV)
- Correlation studies of neutrino and gamma-ray emission from VHE sources.

days
weeks

- Observation of neutrino “flares” from known VHE sources.
- Observation of neutrino multiplets.

seconds
minutes

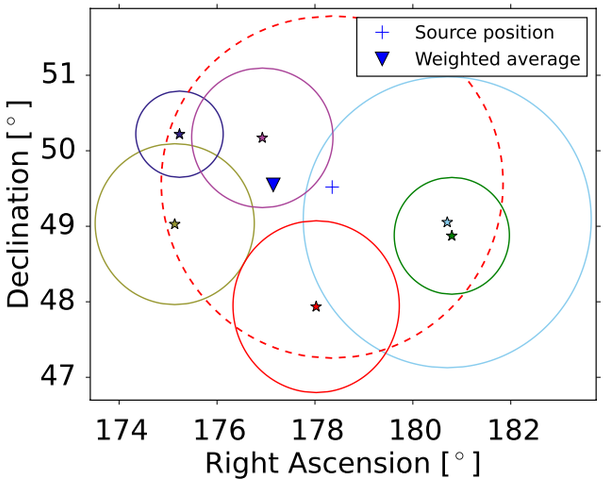
- Observation of prompt online HESE* alerts.
- Observation of prompt EHE* alerts.

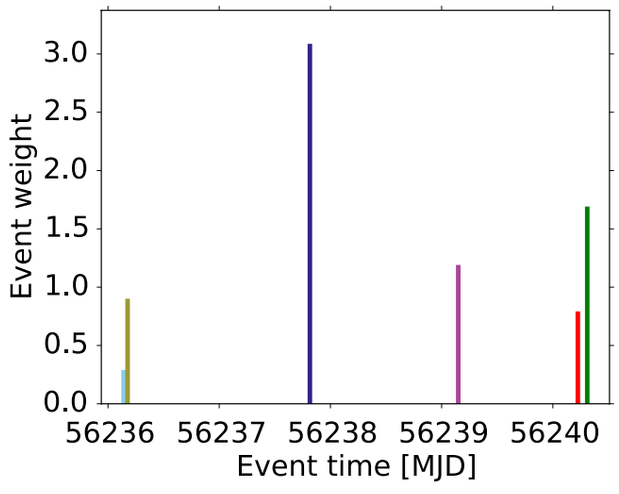
Follow-up time scale

Current MMGR efforts

Search for neutrino “flares”and “multiplets”

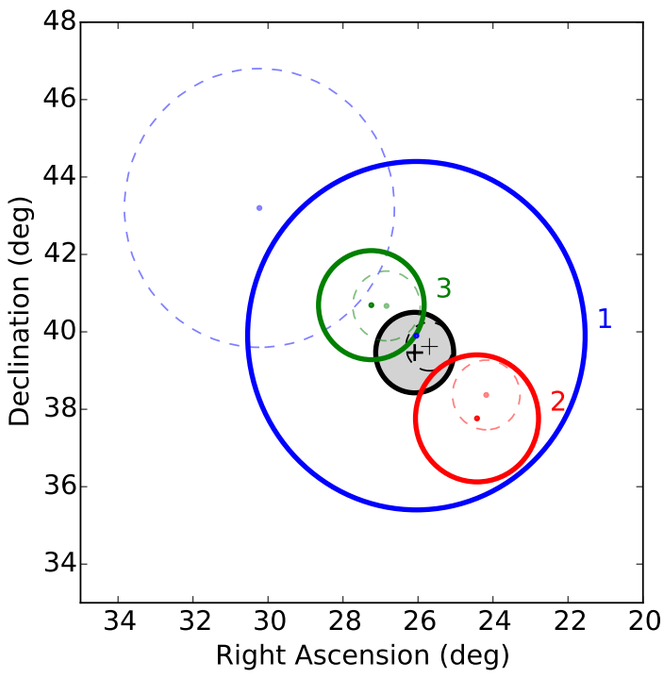
Search for a time-dependent neutrino emission from known VHE sources (days)

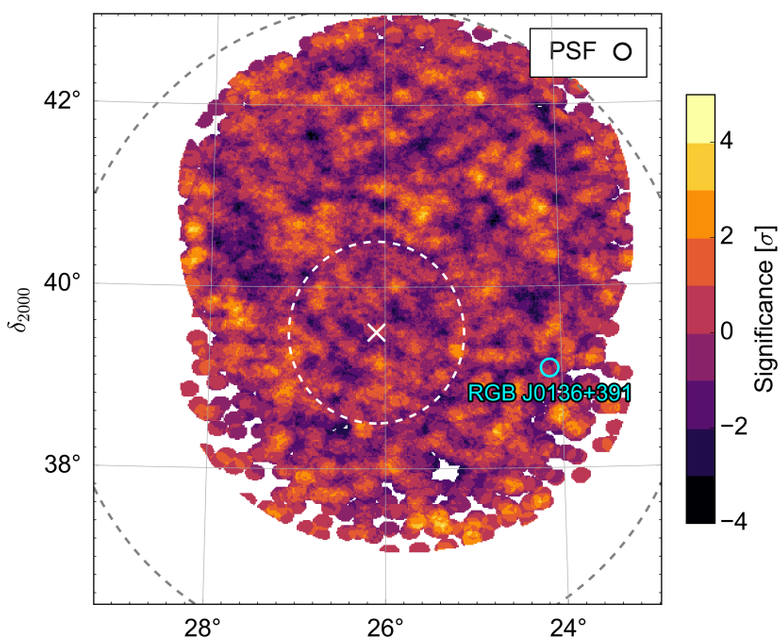




- *Three alert follow-ups with VERITAS*
- *2016 JINST 11 P11009 (IceCube, MAGIC, VERITAS)*
- *Neutrino candidates are identified around a list of VHE sources. Number, energy, and position of the events are considered and an alert is sent by IceCube once a trigger condition is satisfied.*

Search for neutrino “bursts” (multiplicity >= 2) (minutes)





- *Two or more neutrinos in spatial coincidence within 100 s.*
- *Most significant: event triplet detected in Feb 2016. VERITAS observations constrain VHE emission.*
- *IceCube and MWL partners (including VERITAS) A&A 607, A115 (2017)*

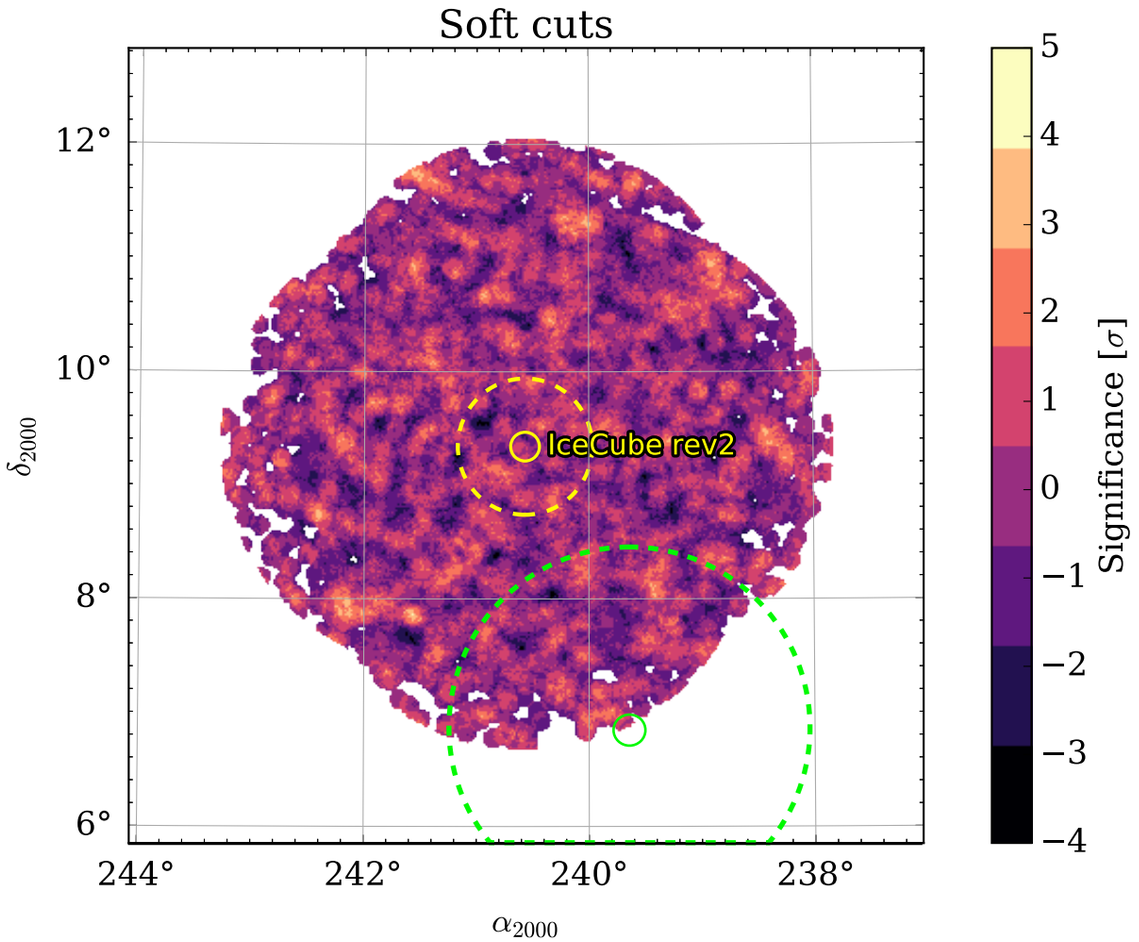
Current MMGR efforts

Rapid neutrino follow-up observations

- *IceCube distributes realtime GCN alerts for muon neutrino events. Two event streams with ~ 30 events/ year total. (EHE/HESE replaced with GOLD/BRONZE)*
- *Alerts are received and processed by the VERITAS software as GRBs.*
- *Alerts started in April 2016, first follow-up by VERITAS on April 27, 2016.*
- *8 alerts followed-up to date.*

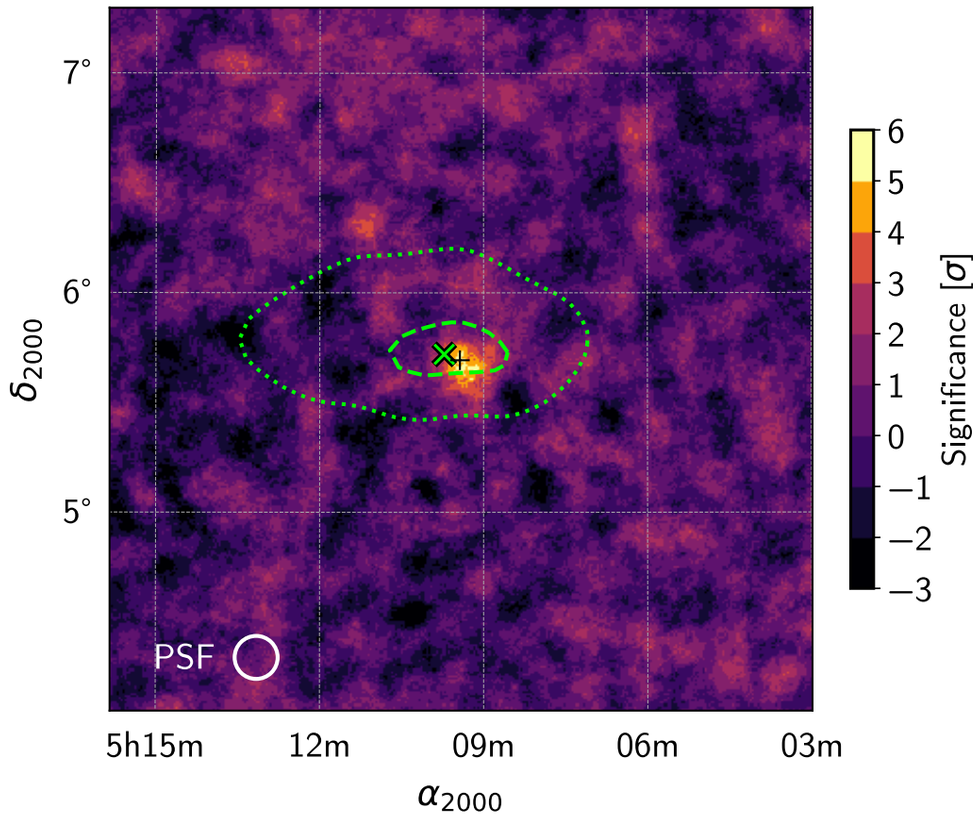
Observation latency: 112 s

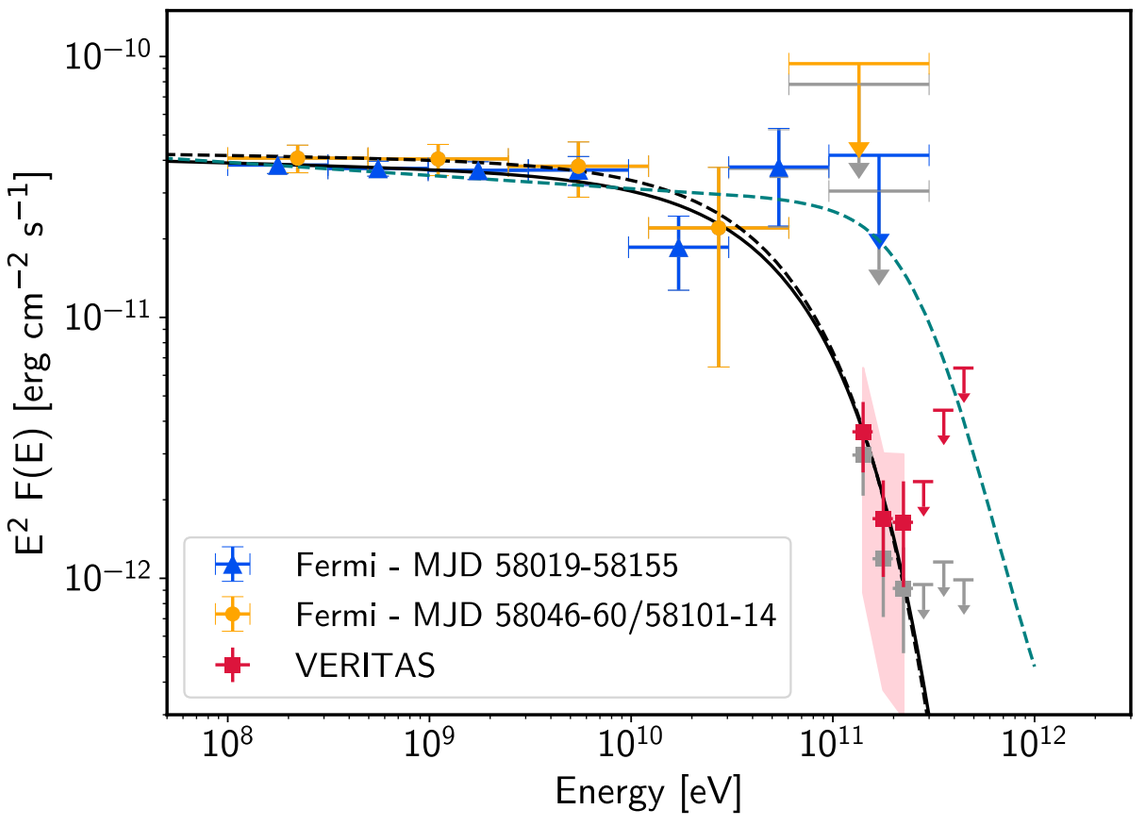
http://gcn.gsfc.nasa.gov/gcn3/19377.gcn3



Current MMGR efforts

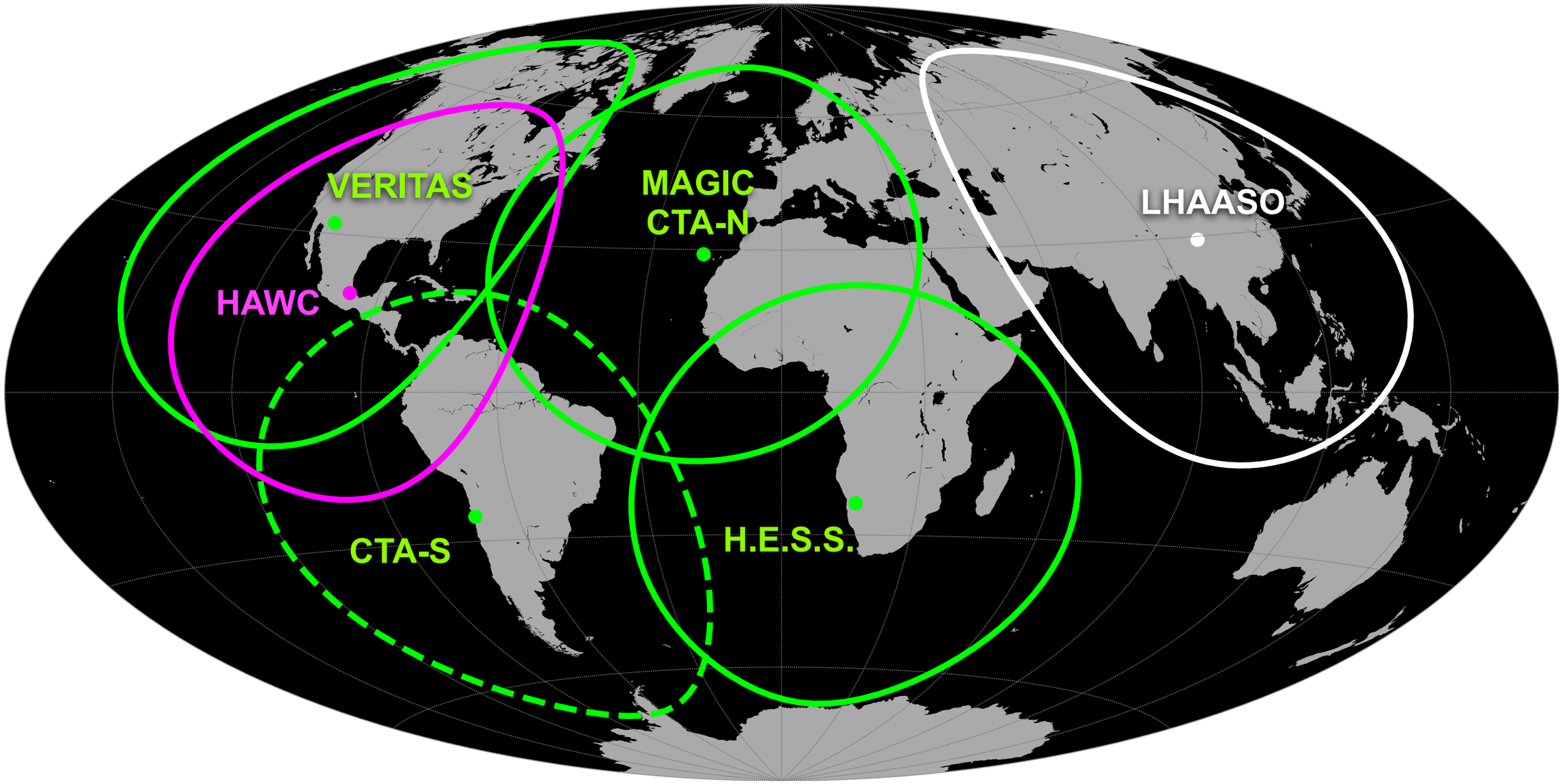
VERITAS observations of IC170922A





- ***IceCube detected a HE neutrino*** *of potential astrophysical in origin on Sept 22, 2017.*
- *The event is colocated with the blazar* ***TXS 0506+056****, observed in a flaring state by Fermi. MAGIC detected VHE emission from the blazar within a few days of the neutrino.*
- ***VERITAS detected the blazar in extended observations through Feb 2018*** *at a lower flux than MAGIC, also with a soft spectrum (~ E^{-5}).*

VHE Gamma-ray Landscape



- The start of LHAASO operations will not only improve our view of the VHE sky but also increase the global VHE coverage to transient and multi-messenger events.
- Our best wishes for a successful operation of LHAASO and many discoveries. We look forward to future collaborations!