Highlights from the VERITAS Blazar Observation Program

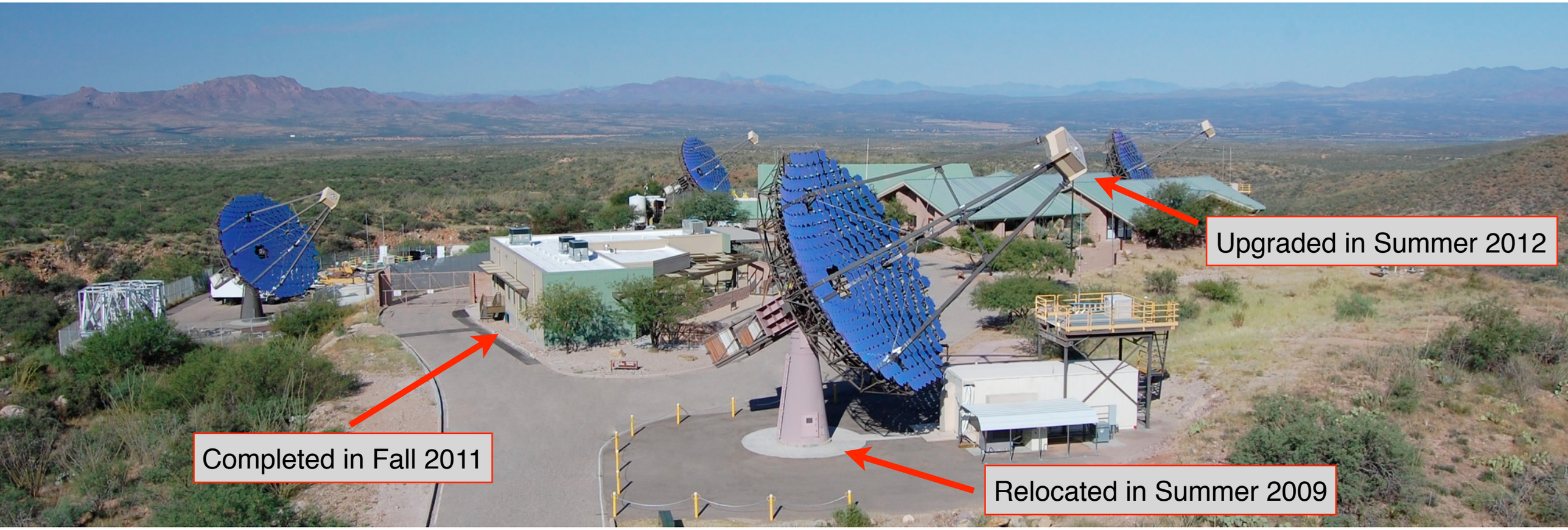
Wystan Benbow[1] for the VERITAS Collaboration[2]

1. Smithsonian Astrophysical Observatory
2. http://veritas.sao.arizona.edu

Half a Century of Blazars & Beyond

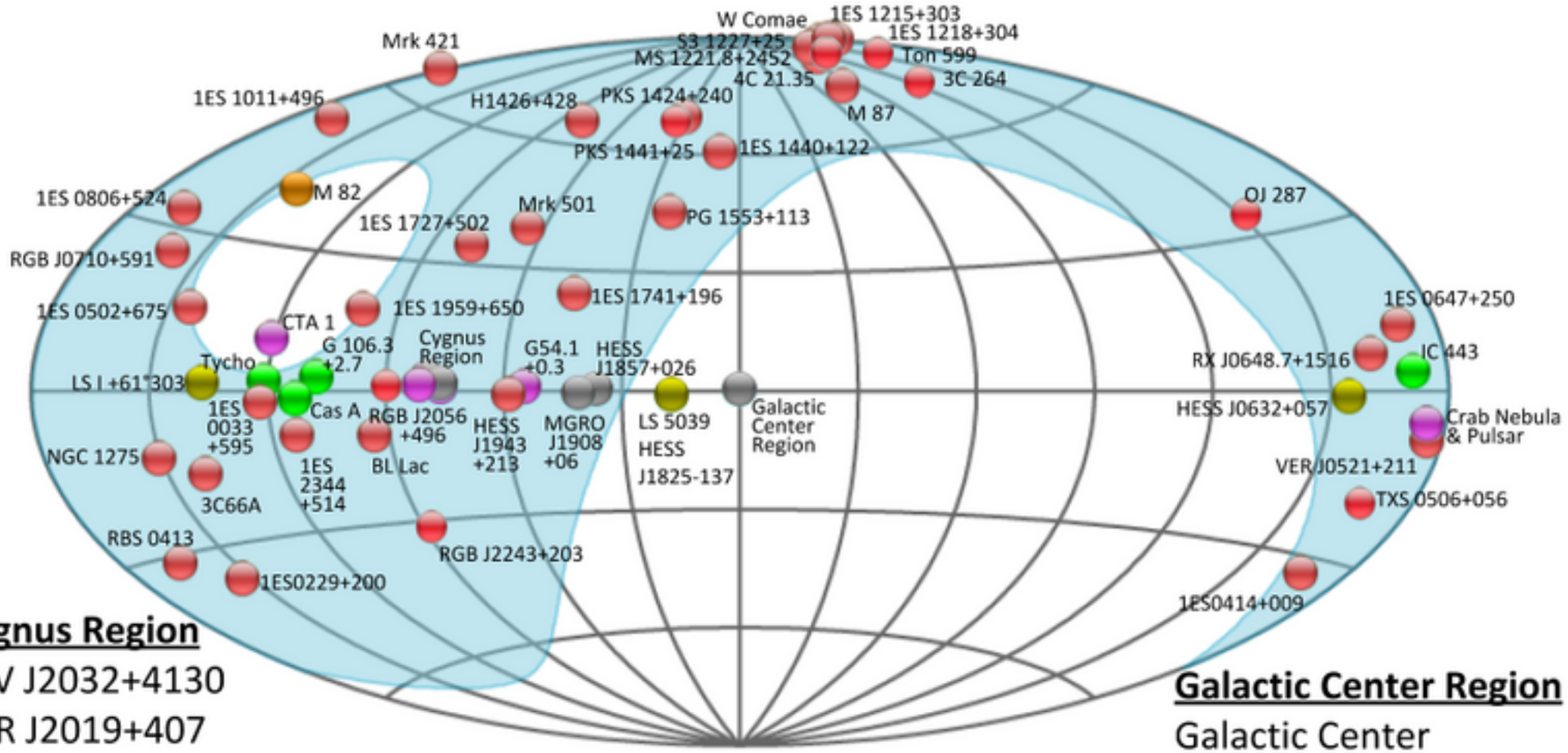
Turin, Italy; June 11, 2018

VERITAS: Observatory Overview



- Study very-high-energy (~85 GeV to ~30 TeV) γ-rays from astrophysical sources
- Full-scale operations since 2007; Major upgrade completed in 2012
- Good-weather data / yr: ~950 h in "dark time" + ~250 h in "bright moon" (illum. >30%)
  - Sensitivity: 1% Crab in <25 h
  - Angular resolution: r_{68} ~ 0.08° @ 1 TeV
  - Energy resolution: ~17%
  - Energy Threshold: ~85 GeV
  - Spectral reconstruction > 100 GeV
  - Systematic errors: Flux ~20%; Γ ~ 0.1

The VERITAS Source Catalog



Cygnus Region

TeV J2032+4130
VER J2019+407
VER J2019+368
VER J2016+372
VER J2032+414

Galactic Center Region

Galactic Center
Galactic Center Ridge
VER J1746-289
G 0.9+0.1

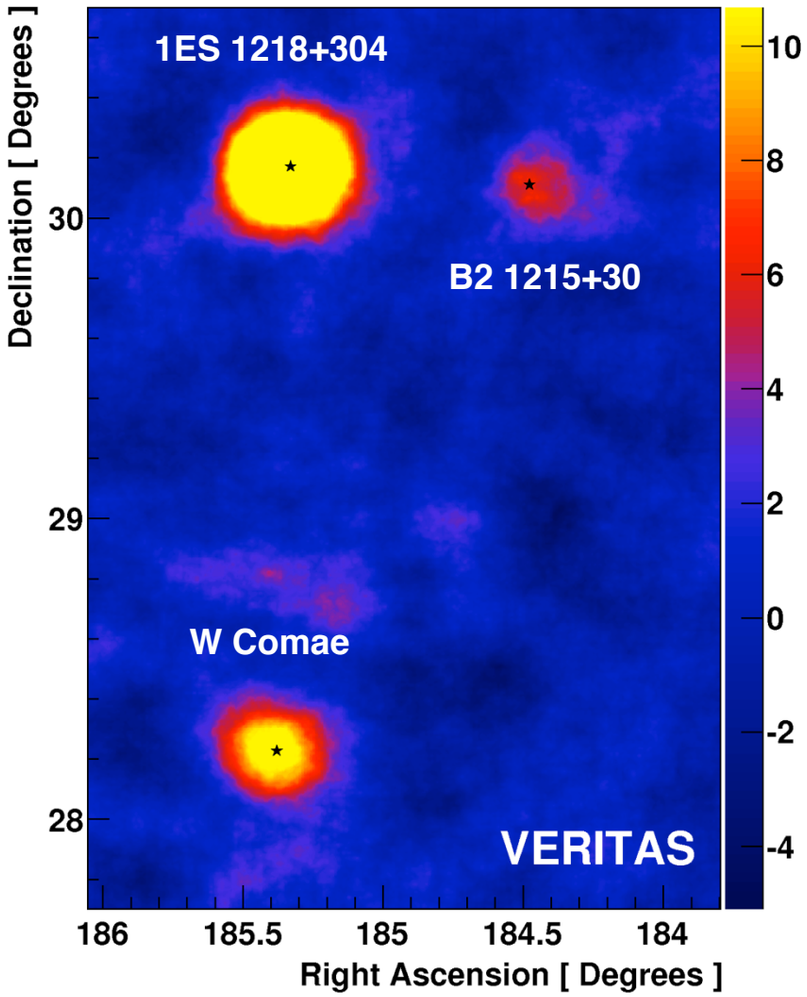
63 sources from 8 astrophysical classes

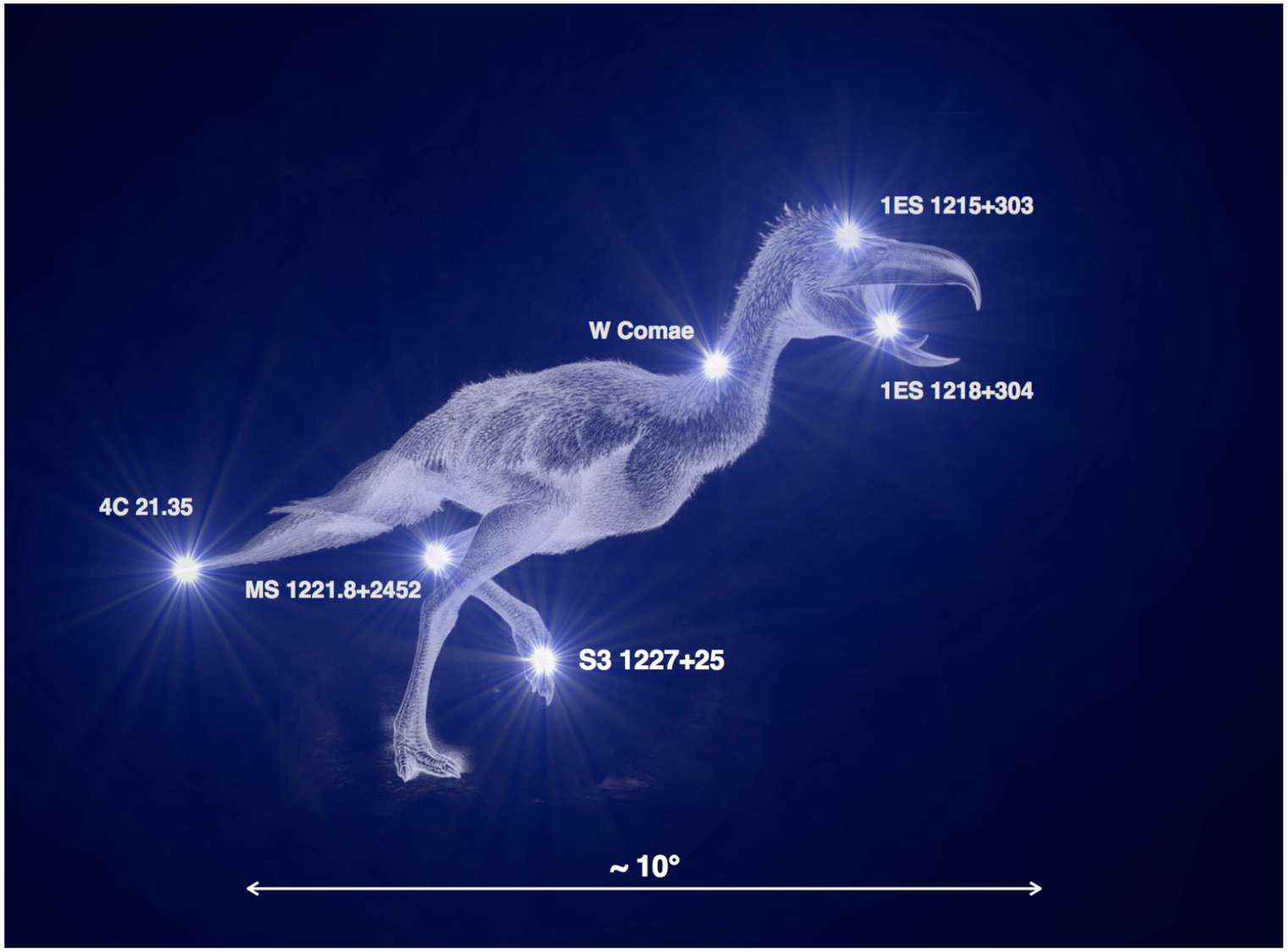
40 Extragalactic (63%) & 23 Galactic (37%) objects

Extragalactic: 39 AGN & a starburst galaxy (M82)

The VERITAS Blazar Catalog is Plentiful!

3 Blazars in 1 FoV

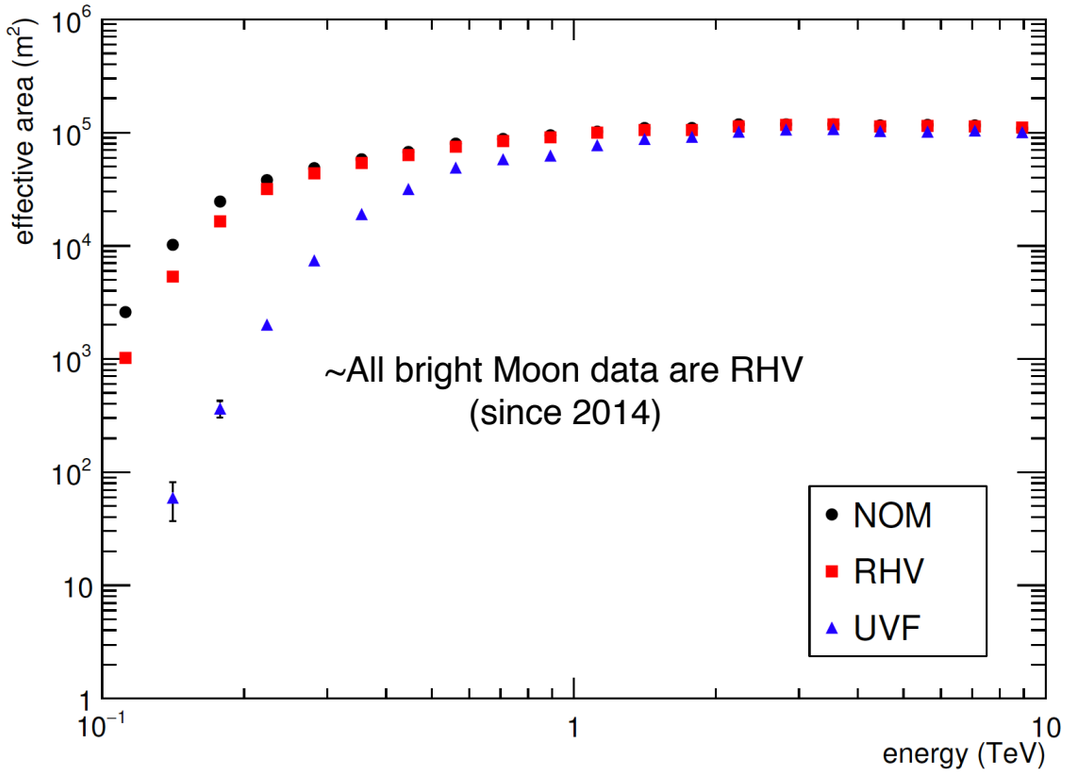




VERITAS AGN Program: ~600 h / yr

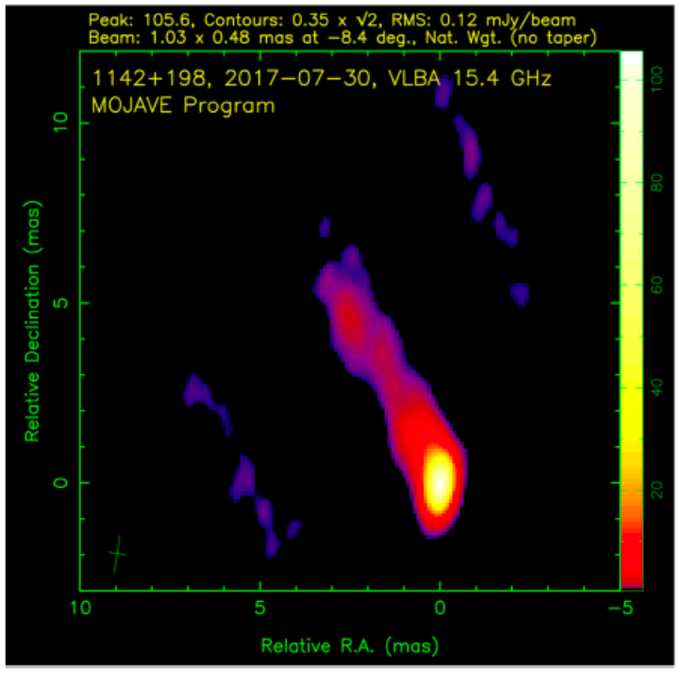
- 2007-2018: ~4700 h of good-weather "normal" AGN data; Average ~425 h / yr
  - 90% blazars / 10% radio galaxies
- 2012-2018: ~950 h of good-weather "bright moon" AGN data; Average ~160 h / yr
  - Similar sensitivity (>250 GeV) & several blazars detected; S. Archambault et al., *Astroparticle Physics*, **91,** 34, 2017
- Blazar program: Primarily BL Lac objects
  - ~33% are VHE discovery observations
  - ~50% is for regular monitoring of all known VHE blazars
    - Depth / cadence depends on "importance"
    - Observations intensified during any VHE (or MWL) flaring
    - Strong MWL coordination => Long-term MWL light curves
  - ~25% Target of Opportunity (ToO) observations
- Radio galaxy (RG) program
  - Primarily M87 monitoring & NGC 1275 flare follow-up
  - Restarted discovery effort in '17

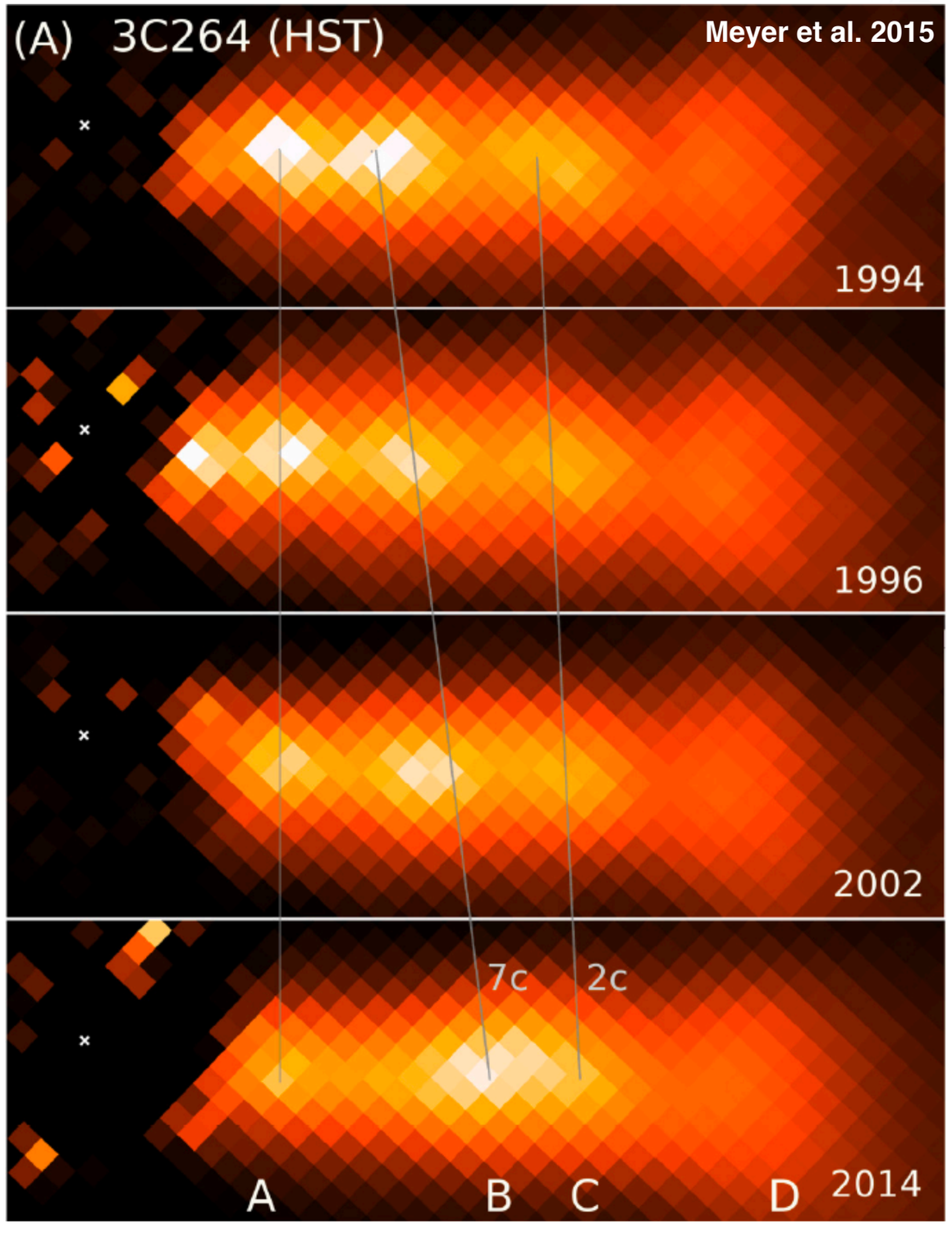
Post-Analysis Effective Area
Normal vs Bright Moon



VERITAS Observations of 3C 264

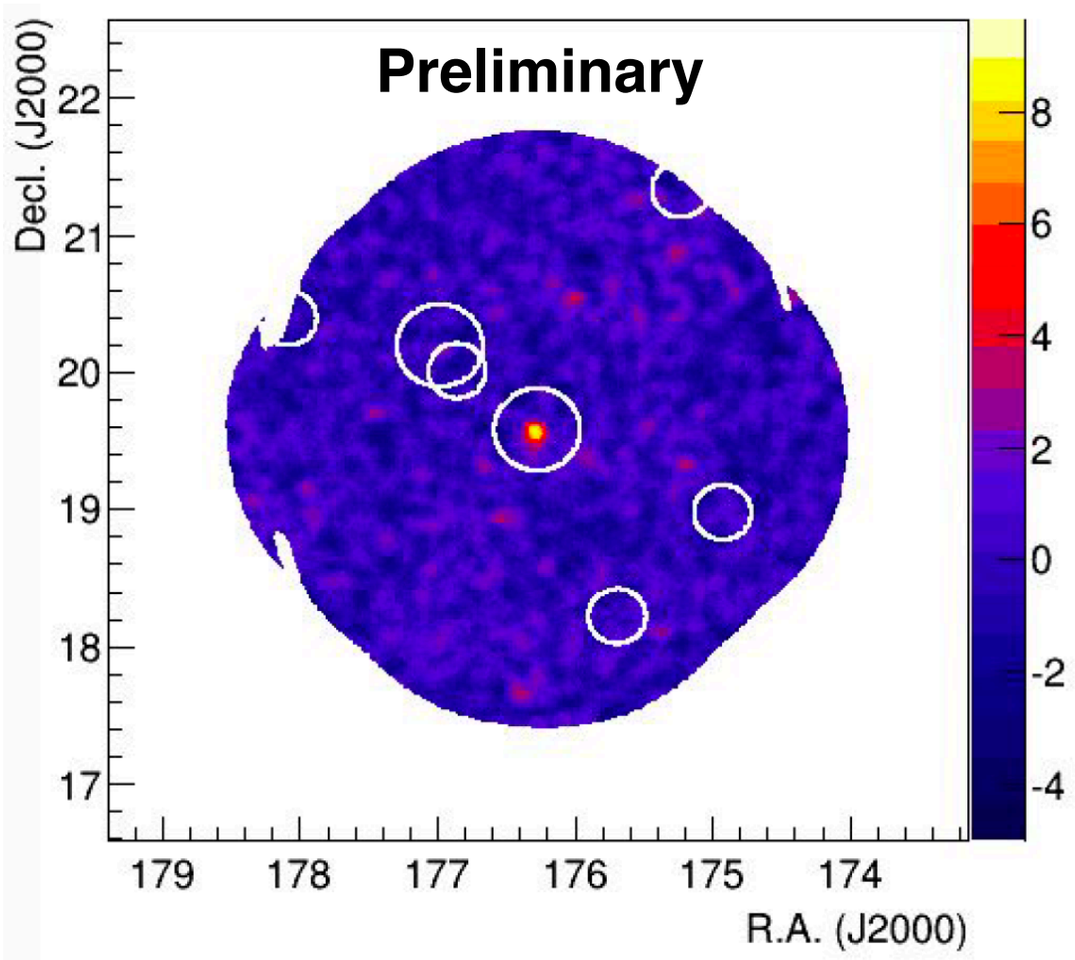
- More distant (~6x) “M87” analog
  - FR-I radio galaxy, z = 0.0216
- Rapidly evolving knot-structure
- MeV-GeV source: 3FGL, 2FHL & 3FHL
  - Γ_{3FHL} ~ 1.65 => F(>200 GeV) ~ 1.6% Crab
- VERITAS ~10 h observation in 2017
- Curious ~2σ excess => 2018 follow-up





VERITAS VHE Discovery of 3C 264

Significance map for 3C 264



VERITAS discovery of VHE emission from the FRI radio galaxy 3C 264

ATel #11436; *Reshmi Mukherjee (Barnard College) for the VERITAS Collaboration*
on 17 Mar 2018; 00:25 UT
Credential Certification: Reshmi Mukherjee (muk@astro.columbia.edu)

Subjects: Gamma Ray, TeV, VHE, Request for Observations, AGN, Blazar

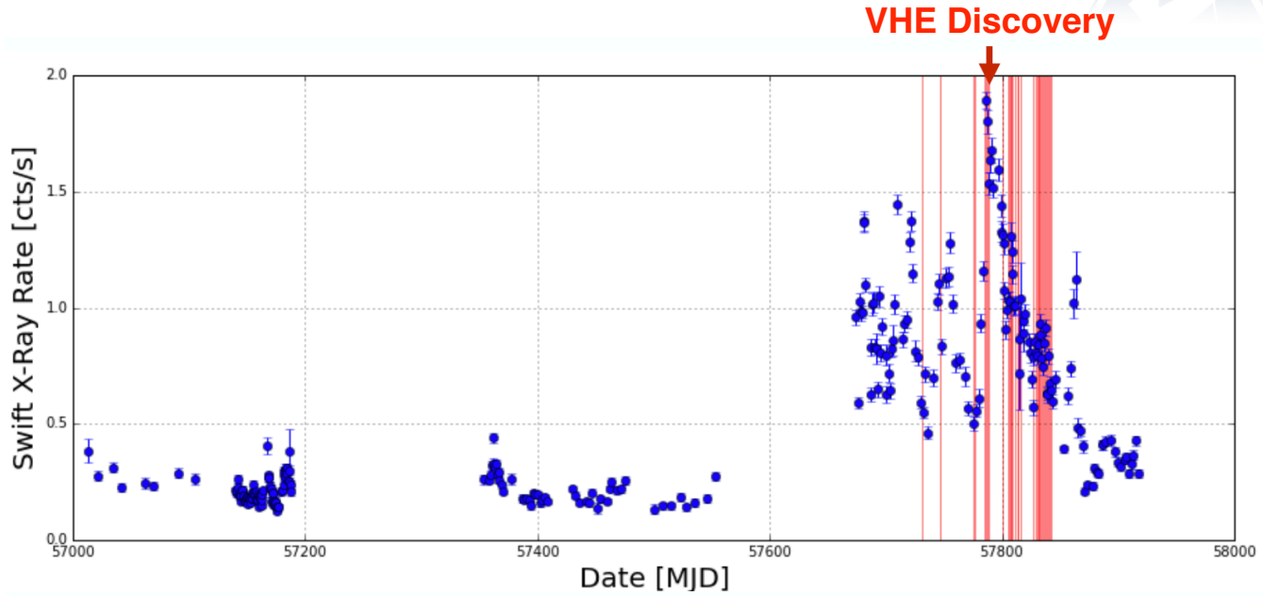
Tweet Recommend 49

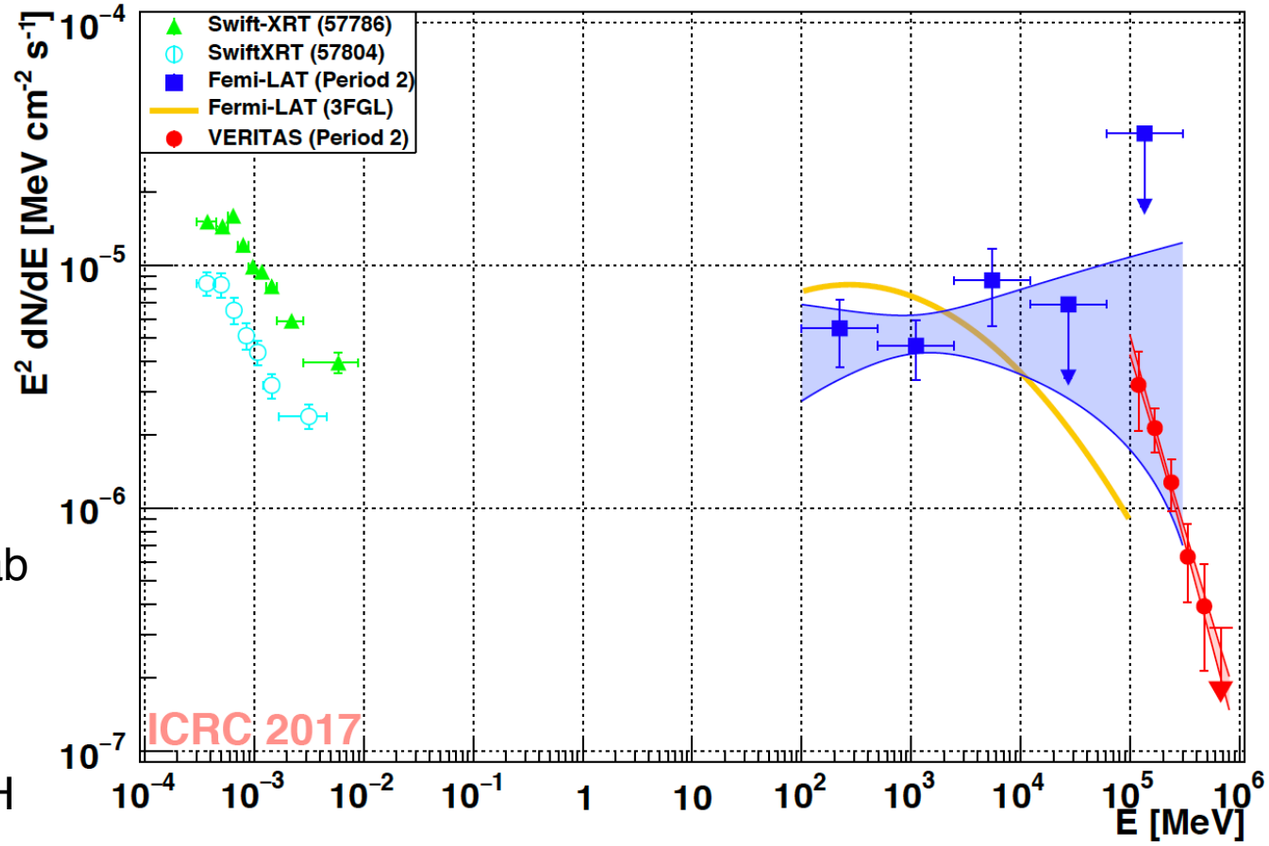
We report the VERITAS discovery of very-high-energy emission (VHE; >100 GeV) from the FRI radio galaxy 3C 264, also known as NGC 3862. Nearly 12 hours of quality selected data, collected by VERITAS between 09 February 2018 and 16 March 2018 (UTC), were analyzed. Preliminary results yield an excess of 60 gamma-ray events above background at the position of the source, corresponding to a statistical significance of 5.4 standard deviations. Our preliminary flux estimate (E>300 GeV) is (1.3 ± 0.2)e-12 cm^-2 s^-1, or approximately 1% of the Crab Nebula flux above the same threshold. The Fermi-LAT 3FHL catalog (Ackermann et al. 2017 ApJS 232, 18) lists a photon index of 1.65 ± 0.33 for 3C 264 which, when extrapolated to the VHE band, is consistent with the VERITAS detection. At a redshift of 0.0217, 3C 264 is a more distant analog to M87, with superluminal motion of ~7c (Meyer et al. 2015, Nature 521, 495) detected in its kpc-scale optical jet. With this discovery, 3C 264 is the most distant radio galaxy detected at VHE so far. VERITAS will continue to observe 3C 264; multi-wavelength observations are encouraged. Questions regarding the VERITAS observations should be directed to Reshmi Mukherjee (rm34@columbia.edu). Contemporaneous target-of-opportunity observations with the Swift satellite have also been scheduled. VERITAS (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 (http://veritas.sao.arizona.edu).

- Strong, hard-spectrum detection: ~8σ in ~44 h; Γ ~ 2.3
- Low, weakly variable VHE flux: ~0.5% Crab; ~Month-scale variations
- Major VERITAS + MWL effort: Radio (e.g. VLBA), Optical (HST, ground-based), X-ray (Chandra + Swift), Fermi-LAT => No major activity in knot sub-structure

OJ 287: A VERITAS ToO Discovery

- Optically bright blazar @ z = 0.306
  - Classification uncertain
  - TeV candidate: Costamante & Ghisellini 2002
- "Periodic" optical behavior: T ~ 12 yr
  - Binary black hole system? Helical jet?
  - Next optical outburst in 2019
- VERITAS limit in '07: 10 h, <2.6% Crab
- Swift XRT flaring => 2016-17 ToO
- VHE discovery in Feb. '17: ATel #10051
- 2016-17: ~50 h, 9.7σ, Γ = 3.49 ± 0.28
  - F(>150 GeV) = (4.61± 0.61) x 10^{-12} cm^{-2} s^{-1}; 1.3% Crab
- Copious MWL data: SED shifts
  - Possible contemporaneous birth of radio knot near BH

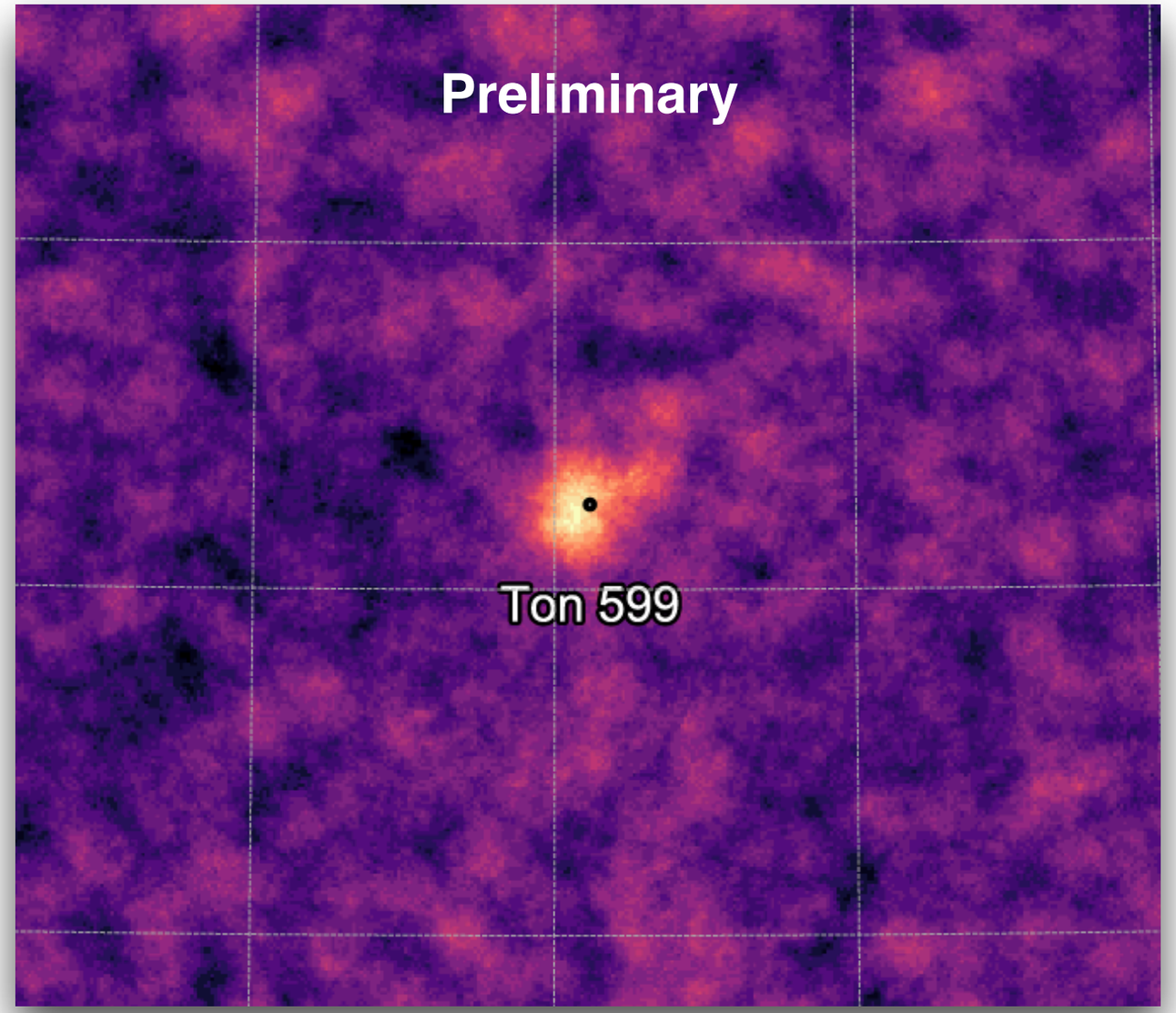




VHE “Co-Discovery” of Ton 599

- FSRQ @ z = 0.72
- Fermi-LAT flare in early Nov. 2017
  - ATel #10931: ~20x 3FGL flux
- Exceptional NIR flares in Nov. 2017
  - ATel #10949: 0.5 mag. after 10x flux
- VERITAS observes on 12/15-16
  - ~8σ in ~2 h; Γ ~ 5
  - F(>100 GeV) ~ 12% Crab
- MAGIC also detects on 12/15: ATel #11061

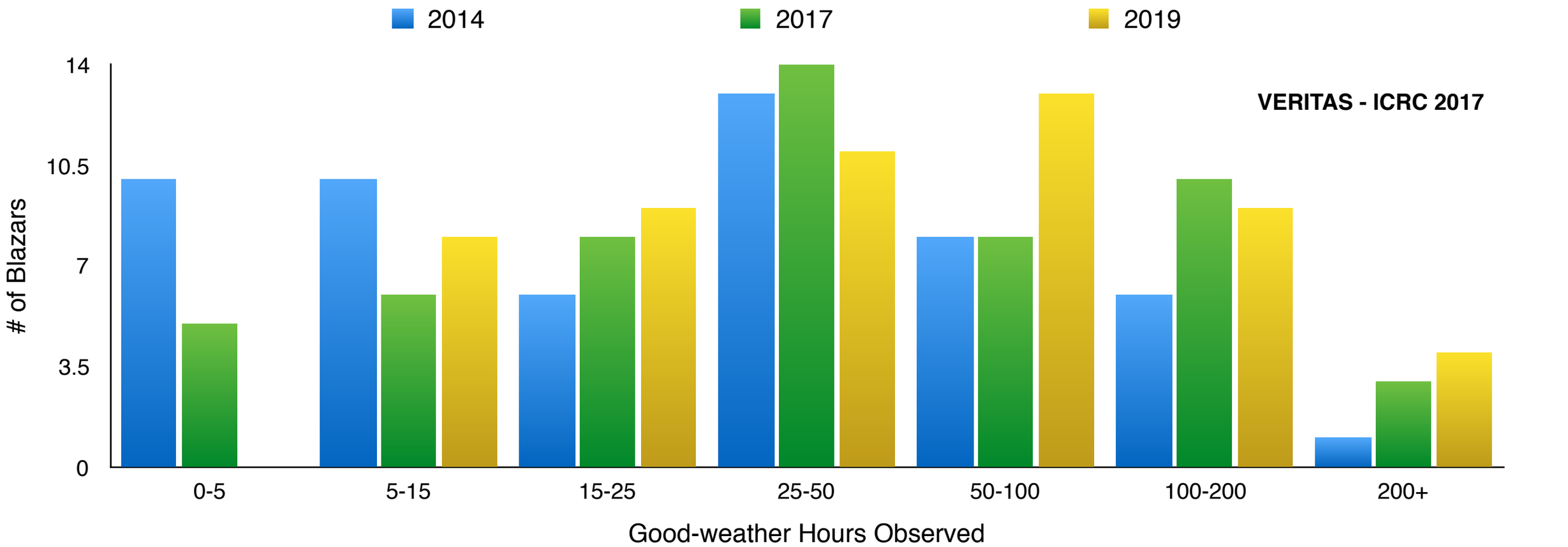
Significance map for Ton 599



VERITAS’ 3rd FSRQ & 7th in VHE

PKS 1441+25 (z ~ 0.94) & 4C +21.35 (z ~0.43)

VERITAS' Long-term Blazar Plan

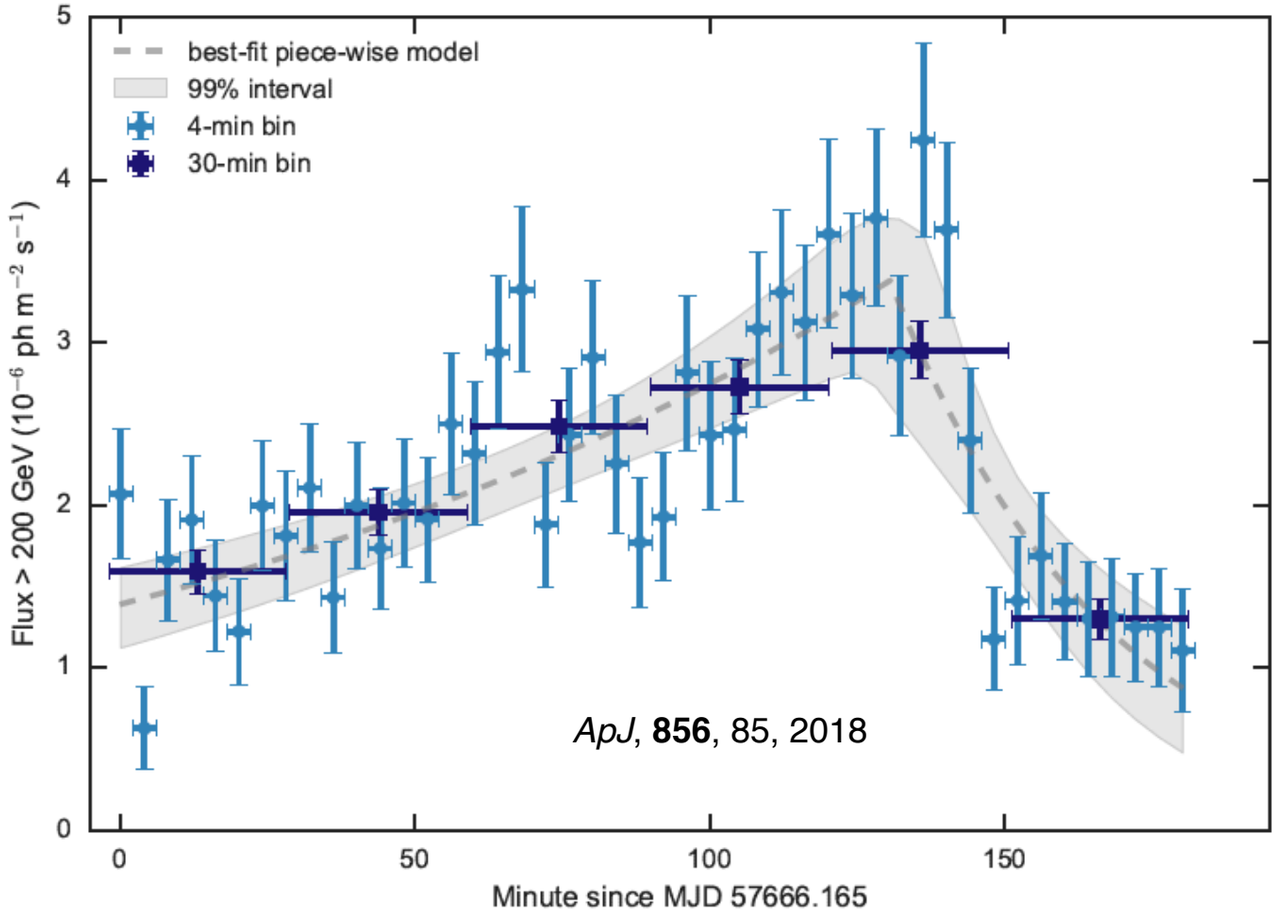


We will sample every VHE blazar at least weekly (>10% Crab sensitivity) when best visible & will intensify observations (at all ƛ) during any bright flares!

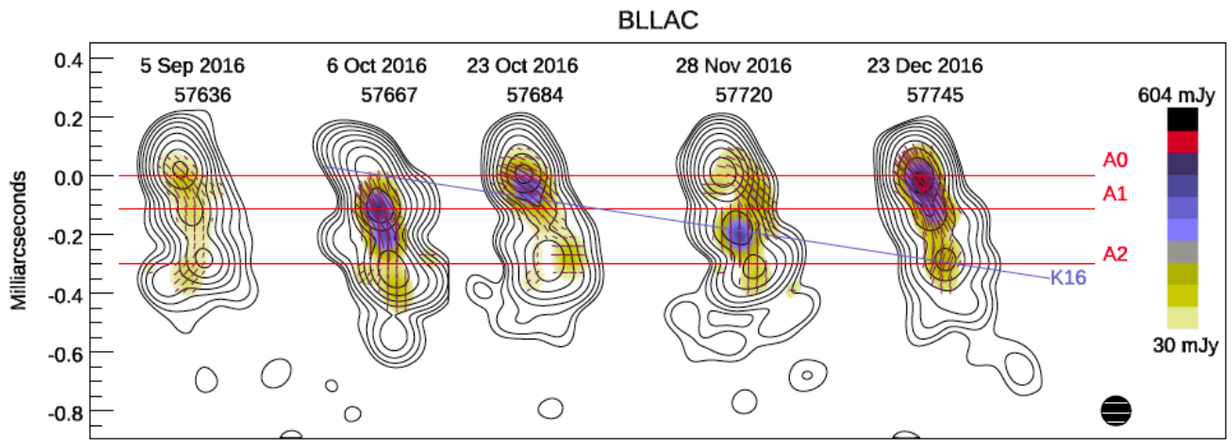
Automatic MWL flare-alert pipelines: Weekly optical exposures for all, Fermi-LAT naturally observes,
Weekly Swift XRT & UVOT exposures for ~1/3

BL Lacertae: Major Flare in October 2016

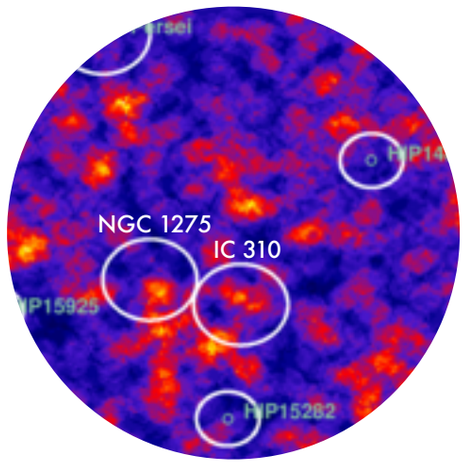
- MAGIC flare in 2005 (3% Crab)
- VERITAS: 70 h of data since 2010
  - 4 flares, but not usually detected at VHE
- Brief, rapid flare in 2011: ApJ, **762**, 92, 2013
  - Peak: ~125% Crab; Exp. decay: $\tau = 13 \pm 4$ min
  - Associated w/ birth of superluminal radio knot
- Two, single-night flares in 2015
  - 16% Crab on June 21 & 9% Crab on Nov. 30
- Major flare on Oct. 5, 2016
  - Monitoring => 2.6 h, 71σ, Peak ~ 180% Crab
  - Slow rise (t_{rise} ~ 140 min) & rapid fall (t_{fall} ~ 36 min)
  - Another candidate superluminal knot appears

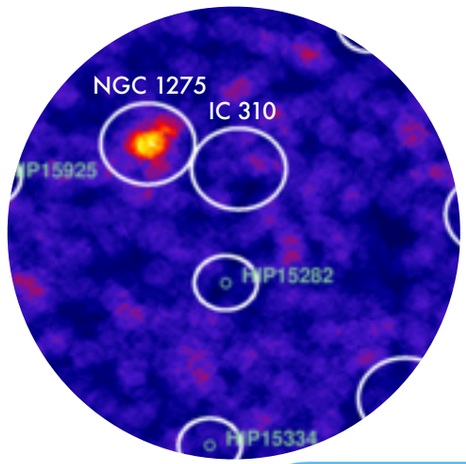


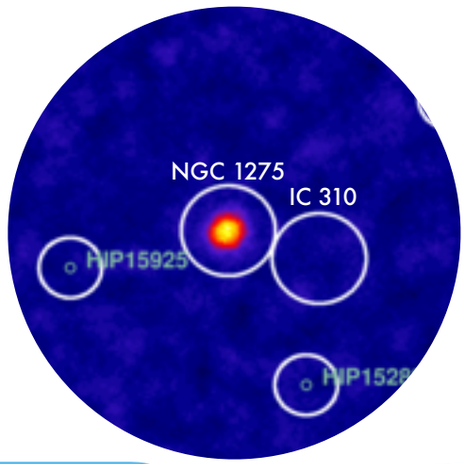
VLBA 43 GHz Maps: Sept - Dec 2016

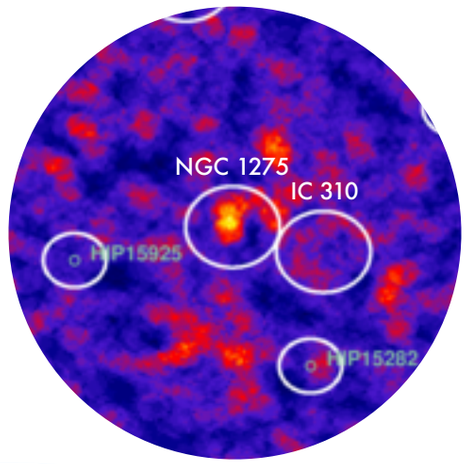


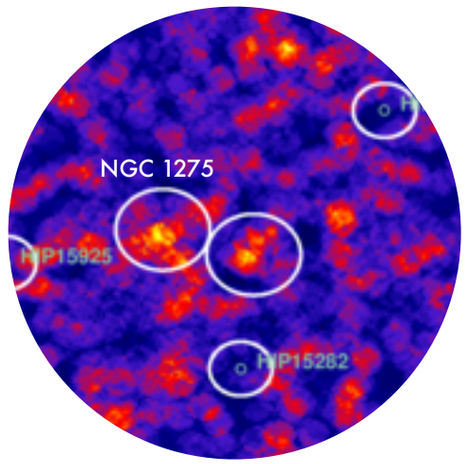
NGC 1275: Halloween 2016 Flare











Flux ~15 % C.U.

MAGIC ATel# 9689
VERITAS ATel# 9690

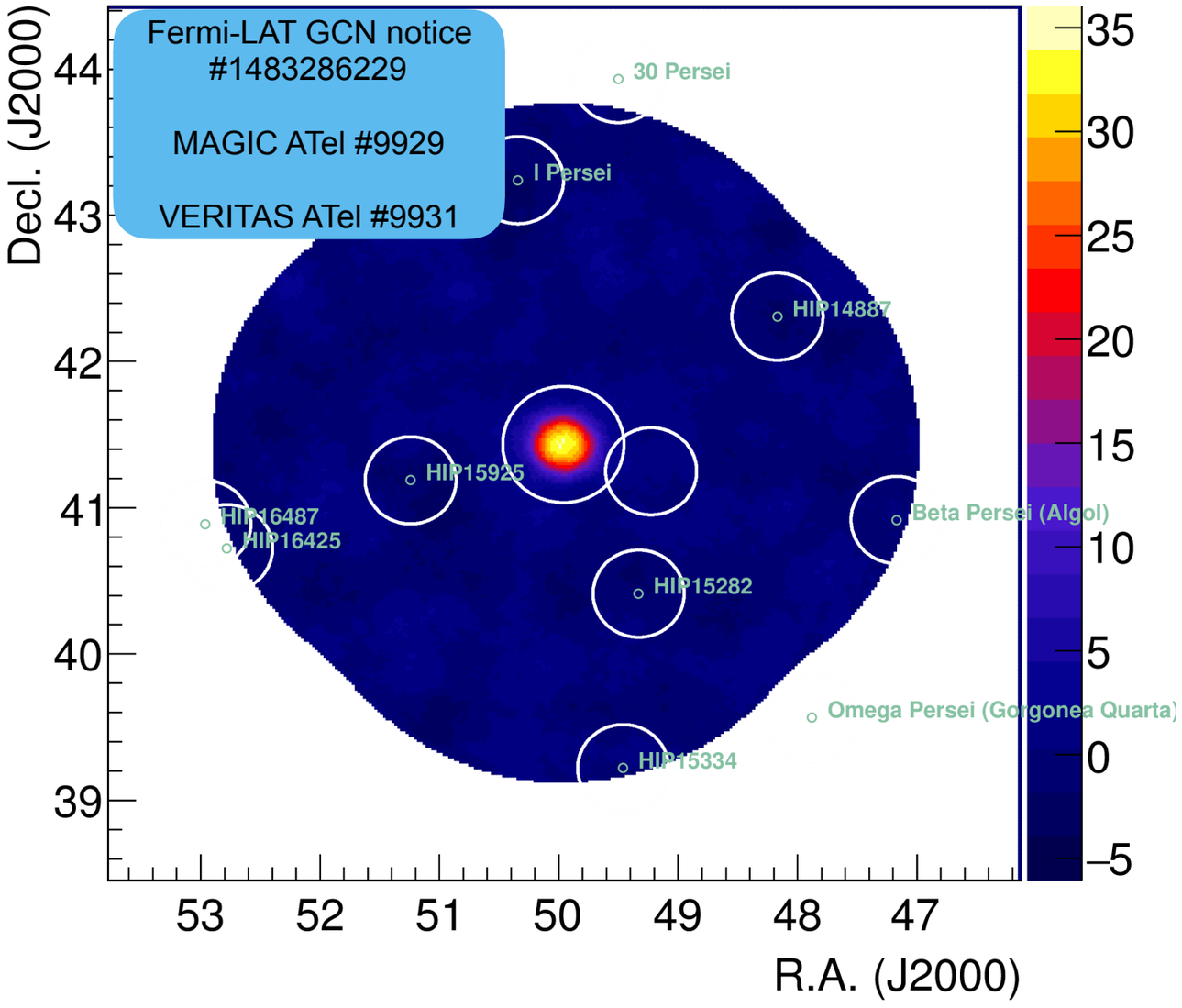
Maps have higher threshold

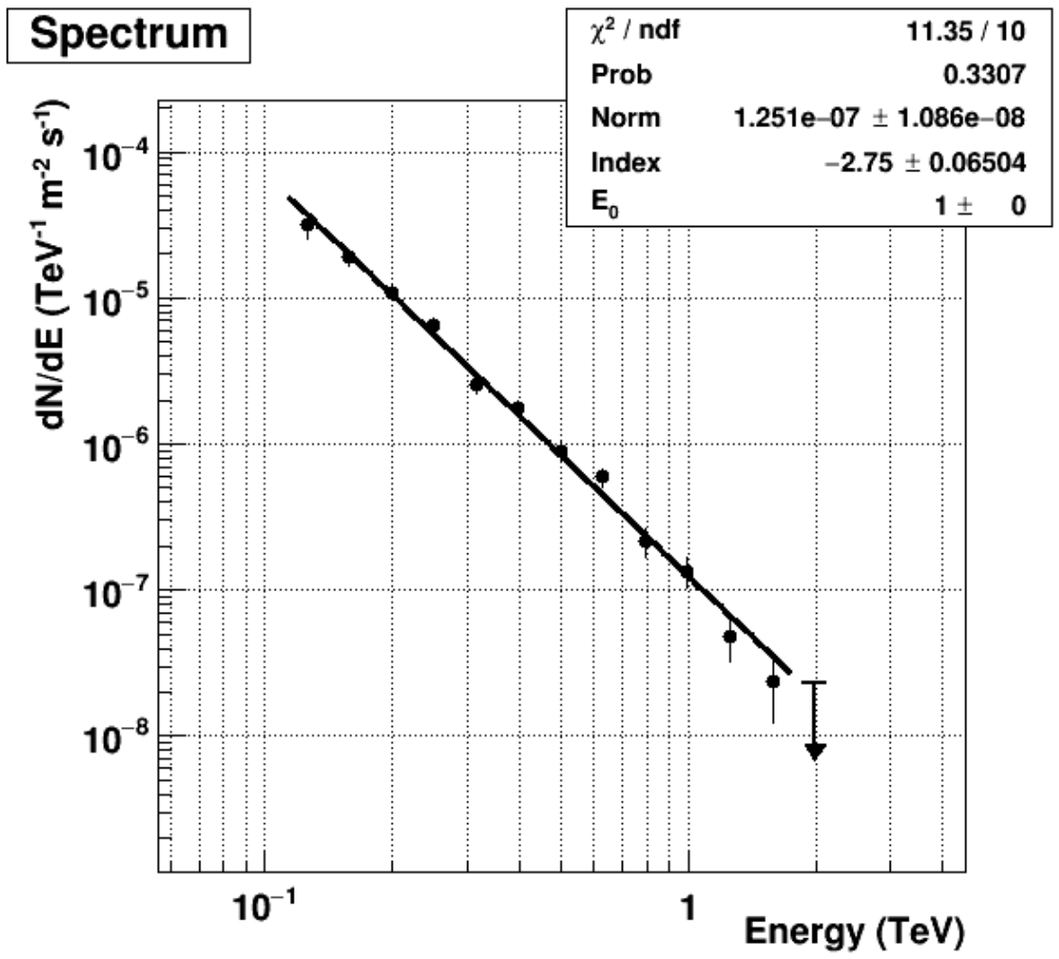
MJD57687 — MJD57690 — MJD57691 — MJD57692 — MJD57694

Significance = 1.7σ Exp. = 25 min. Rate = 0.6 γ / min.	Significance = 4.0σ Exp. = 26 min. Rate = 1.8 γ / min.	Significance = 18.1σ Exp. = 286 min. Rate = 1.8 γ / min.	Significance = 3.0σ Exp. = 51 min. Rate = 0.6 γ / min.	Significance = 4.1σ Exp. = 26 min. Rate = 1.3 γ / min.

- Central radio galaxy (FR I) of the Perseus Cluster: $\Gamma_{3FGL} \sim 2.0$; $\Gamma_{2FHL} \sim 3.0$
- MAGIC VHE discovery (2010-12): ~2% Crab >100 GeV; $\Gamma \sim 4.1$
- Prior VERITAS data: Limits in 2009 & detected in 2013
  - Fermi-LAT flares in 2013: ~30 h => 7σ; Flux ~ 1-2% Crab, Soft $\Gamma \sim 4$
  - All VERITAS data from Sept '08 - July '16: ~65 h, ~11σ, <1% Crab; 0.06 γ / min

NGC 1275: Massive “New Year’s 2017” Flare





- Jan 2, 2017: 2.2 h, ~34σ, ~6 γ / min
  - Brightest-ever VHE radio galaxy detection (flux ~50% Crab), but no intra-night variation
  - Significant spectral hardening: Γ ~ 2.75; c.f. Γ ~ 4.1 prior to 2016-17
- FYI: NGC 1275 flared again in early 2018

TXS 0506+056: A Multi-messenger Blazar?

TITLE: GCN CIRCULAR
NUMBER: 21916
SUBJECT: IceCube-170922A - IceCube observation of a high-energy neutrino candidate event
DATE: 17/09/23 01:09:26 GMT
FROM: Erik Blaufuss at U. Maryland/IceCube <blaufuss@icecube.umd.edu>

Claudio Kopper (University of Alberta) and Erik Blaufuss (University of Maryland) report on behalf of the IceCube Collaboration (http://icecube.wisc.edu/).

On 22 Sep, 2017 IceCube detected a track-like, very-high-energy event with a high probability of being of astrophysical origin. The event was identified by the Extremely High Energy (EHE) track event selection. The IceCube detector was in a normal operating state. EHE events typically have a neutrino interaction vertex that is outside the detector, produce a muon that traverses the detector volume, and have a high light level (a proxy for energy).

After the initial automated alert (https://gcn.gsfc.nasa.gov/notices_amon/50579430_130033.amon), more sophisticated reconstruction algorithms have been applied offline, with the direction refined to:

Date: 22 Sep, 2017
Time: 20:54:30.43 UTC
RA: 77.43 deg (-0.80 deg/+1.30 deg 90% PSF containment) J2000
Dec: 5.72 deg (-0.40 deg/+0.70 deg 90% PSF containment) J2000

We encourage follow-up by ground and space-based instruments to help identify a possible astrophysical source for the candidate neutrino.

The IceCube Neutrino Observatory is a cubic-kilometer neutrino detector operating at the geographic South Pole, Antarctica. The IceCube realtime alert point of contact can be reached at roc@icecube.wisc.edu

- AMON / GCN neutrino alert on Sept. 22
  - E > 100 TeV, $P_{astro} \sim 0.5$
- VERITAS: No detection in 1 h on Sept. 22
- LAT ATel: 6x 3FGL flux in ±1 week period

Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

ATel #10791; *Yasuyuki T. Tanaka (Hiroshima University), Sara Buson (NASA/GSFC), Daniel Kocevski (NASA/MSFC) on behalf of the Fermi-LAT collaboration*
*on **28 Sep 2017; 10:10 UT***
Credential Certification: David J. Thompson (David.J.Thompson@nasa.gov)

Subjects: Gamma Ray, Neutrinos, AGN

Referred to by ATel #: 10792, 10794, 10799, 10801, 10817, 10830, 10831, 10833, 10838, 10840, 10844, 10845, 10861, 10890, 10942, 11419, 11430, 11489

Tweet Recommend 3

We searched for Fermi-LAT sources inside the extremely high-energy (EHE) IceCube-170922A neutrino event error region (https://gcn.gsfc.nasa.gov/gcn3/21916.gcn3, see also ATels 10773, 10787) with all-sky survey data from the Large Area Telescope (LAT), on board the Fermi Gamma-ray Space Telescope. We found that one Fermi-LAT source, TXS 0506+056 (3FGL J0509.4+0541 and also included in the 3FHL catalog, Ajello et al., arXiv:1702.00664, as 3FHL J0509.4+0542), is located inside the IceCube error region. The FAVA (Fermi All-sky Variability Analysis) light curve at energies above 800 MeV shows a flaring state recently (https://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/SourceReport.php?week=477&flare=27). Indeed, the LAT 0.1--300 GeV flux during 2018 September 15 to 27 was (3.6+/-0.5)E-7 photons cm-2 s-1 (errors are statistical only), increased by a factor of ~6 compared to the 3FGL flux, with nearly the same power-law index of 2.0+/-0.1. We strongly encourage multiwavelength observations of this source. We also encourage optical spectroscopy for this source, because the redshift is still unknown. According to NED, the R-band magnitude is reported as 15.1 (Healey et al. 2008, ApJS 175, 97). Radio observations show that this blazar has had increasing flux during the past year: http://www.astro.caltech.edu/ovroblazars/data.php?page=data_query, http://www.physics.purdue.edu/astro/MOJAVE/sourcepages/0506+056.shtml.

Multi-messenger paper in preparation

TXS 0506+056: A Multi-messenger VHE Blazar?

First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

ATel #10817; ***Razmik Mirzoyan for the MAGIC Collaboration***
*on **4 Oct 2017; 17:17 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Optical, Gamma Ray, >GeV, TeV, VHE, UHE, Neutrinos, AGN, Blazar

Referred to by ATel #: 10830, 10833, 10838, 10840, 10844, 10845, 10942

Tweet Recommend 448

After the IceCube neutrino event EHE 170922A detected on 22/09/2017 (GCN circular #21916), Fermi-LAT measured enhanced gamma-ray emission from the blazar TXS 0506+056 (05 09 25.96370, +05 41 35.3279 (J2000), [Lani et al., Astron. J., 139, 1695-1712 (2010)]), located 6 arcmin from the EHE 170922A estimated direction (ATel #10791). MAGIC observed this source under good weather conditions and a 5 sigma detection above 100 GeV was achieved after 12 h of observations from September 28th till October 3rd. This is the first time that VHE gamma rays are measured from a direction consistent with a detected neutrino event. Several follow up observations from other observatories have been reported in ATels: #10773, #10787, #10791, #10792, #10794, #10799, #10801, GCN: #21941, #21930, #21924, #21923, #21917, #21916. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) E. Bernardini (elisa.bernardini@desy.de), K.Satalecka (konstancja.satalecka@desy.de). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatory Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

- MAGIC weakly detects: ~12 h; 9/28 - 10/3
- VERITAS does not: ~5 h; 9/28 - 9/30

VERITAS follow-up observations of IceCube neutrino event 170922A

ATel #10833; ***Reshmi Mukherjee***
*on **9 Oct 2017; 22:32 UT***
Credential Certification: Reshmi Mukherjee (muk@astro.columbia.edu)

Subjects: Gamma Ray, TeV, VHE, Neutrinos, AGN

Referred to by ATel #: 10838, 10844, 10845, 10861

Tweet Recommend 15

The VERITAS gamma-ray telescope array was used to perform follow-up observations of the high-energy neutrino event detected by the IceCube collaboration on September 22nd, 2017 20:54:30 UTC (GCN Circular #21916).

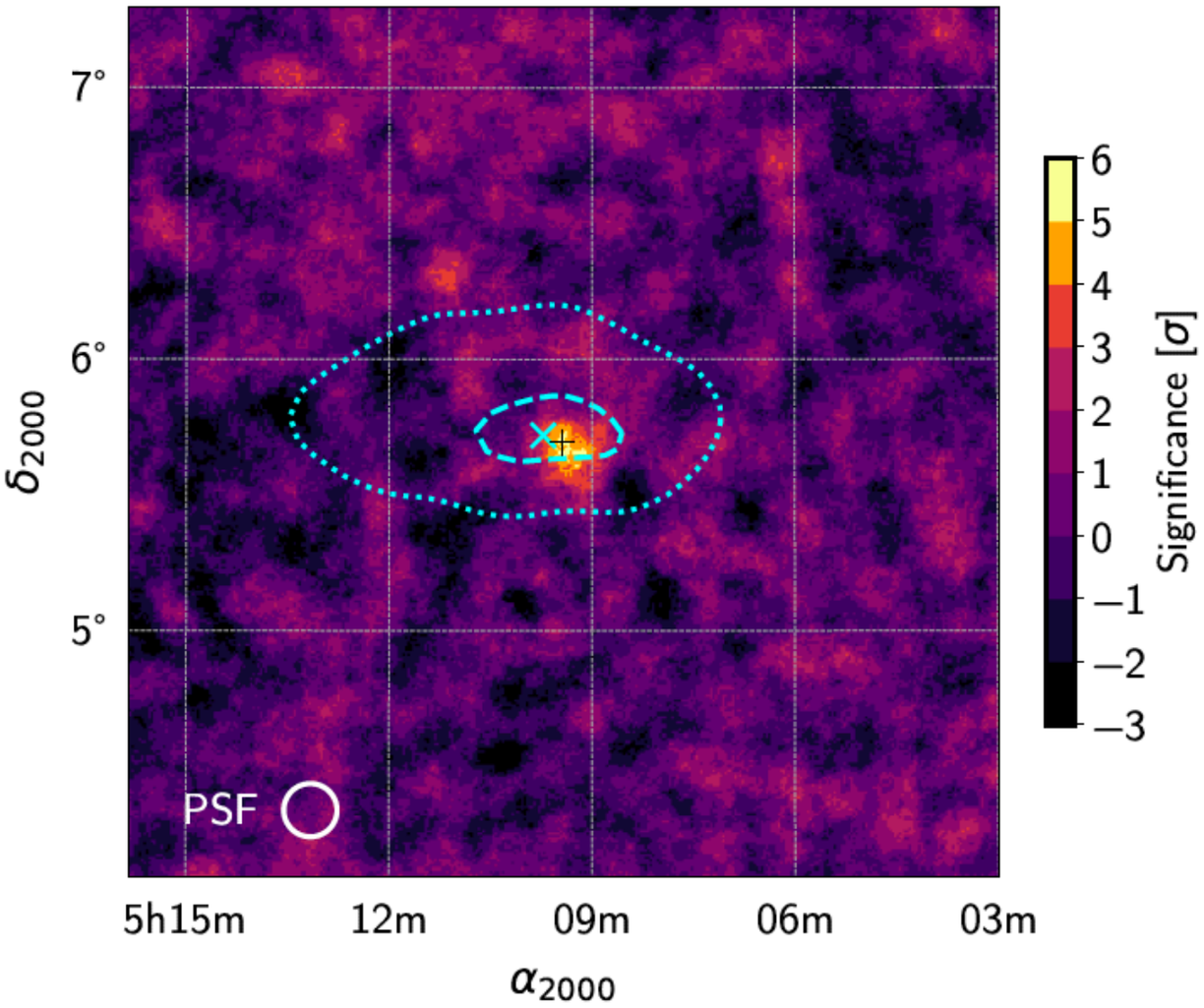
VERITAS observed the location around the initial position reported by IceCube in the GCN/AMON Notice dated Fri 22 Sep 17 20:55:13 UTC (RA = 77.29 deg, Dec = 5.75 deg in J2000 coordinates) under partial cloud coverage for one hour. Observations started on September 23rd, 2017 09:06 UTC, 12.2 hours after the IceCube detection. No gamma-ray source was detected at the neutrino position or anywhere else in the 3.5-degree VERITAS field of view.

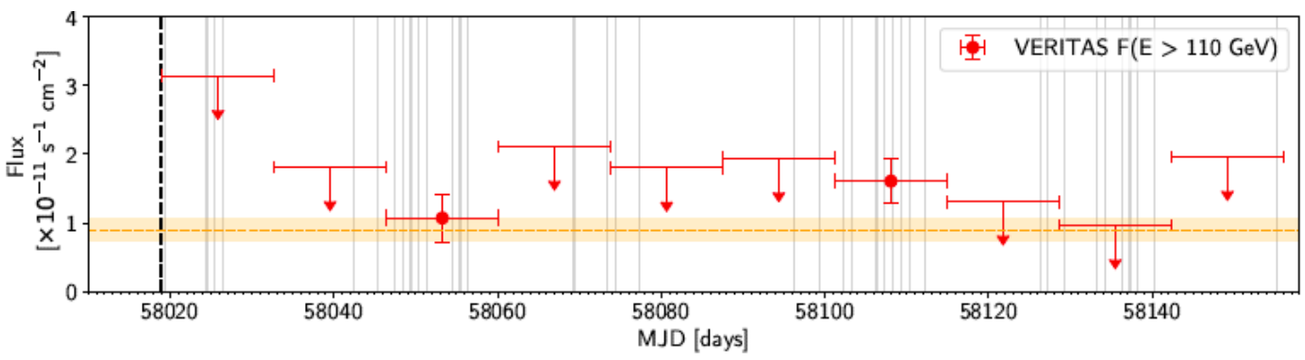
Additional VERITAS observations were collected following the report by the Fermi LAT collaboration (ATel #10791) of the detection of a strong, hard GeV flare from the blazar TXS 0506+056 (RA = 77.358 deg, Dec = 5.693 deg in J2000 coordinates) located within the neutrino error region.

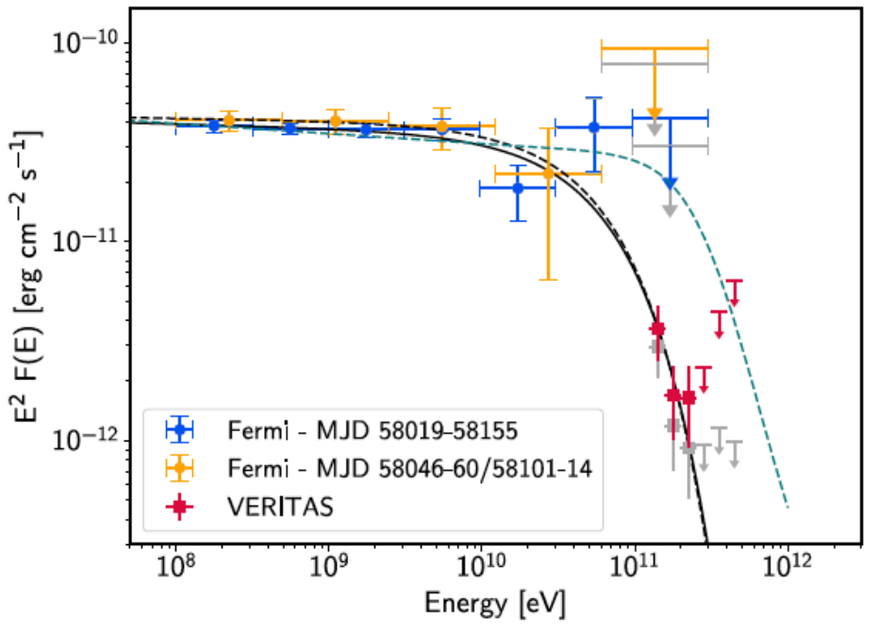
A total of five hours of additional observations centered on the blazar location were collected between September 28th 08:57 UTC and September 30th 11:04 UTC. A preliminary analysis of the data optimized for soft-spectrum sources shows no evidence of gamma-ray emission at the blazar location. The integral gamma-ray flux upper limit derived from these observations at the TXS 0506+056 position is 6.80 x 10^-12 cm^-2 s^-1 at 99% CL above an energy threshold of 160 GeV for an assumed spectral index of -2.7. Null VHE gamma-ray observations were also reported by the H.E.S.S. (ATel #10787) and HAWC collaborations (ATel #10802), while the MAGIC collaboration reports the detection of a gamma-ray source coincident with the blazar position above a 100 GeV energy threshold in 12 hours of observations taken between September 28 and October 3 (ATel #10817).

Multi-messenger paper in preparation

Nevertheless, VERITAS persisted…







- VERITAS detects blazar (5.8σ) in 35 h of good-quality data from Sept. ’17 - Feb. ’18
- Weak flux: F(>110 GeV) ~ 1.6% Crab; Soft VHE spectrum: Γ = 4.8 ± 1.3
- If LAT flare & VHE detections associated with neutrino => Cosmic-ray implications
  - VERITAS is already performing neutrino follow-up: Expect deeper VERITAS campaigns in the future!

Conclusions

- VERITAS is running very well & is funded to operate until at least 2019
  - Exploring the possibility of further operations (e.g. until ~2022)
- The VERITAS source catalog is now at 63 sources from 8 classes: 39 are AGN
- Discovery program has 2 approaches: ToO & pre-planned observations
  - Pre-planned: Comprehensive survey of hardest 2FHL & 2WHSP objects; Follow-up on old excesses
- Long-term plan: Monitoring all Northern VHE AGN & quickly follow up on any flares
  - Cadence / annual exposures & simultaneous MWL coverage varies by “importance”
  - By Summer 2019, we plan to have a deep, multi-year VERITAS exposure for every known VHE blazar
  - ToO follow-up (VERITAS / MWL triggers) for known VHE blazars is very important & supplements exposures
- Multi-messenger physics taking on major role in VERITAS future
  - VERITAS detection of TXS 0506+056 following IceCube HE neutrino alert: Expect more deep campaigns
- We are always looking to collaborate!
  - VERITAS has new moonshot program: Ideas are welcome!

VERITAS AGN Catalog

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
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
  - 17 new AGN since VERITAS upgrade
- All VERITAS AGN are Fermi-LAT detected
- All VERITAS detections have simultaneous MWL data to enable modeling
  - 1-zone SSC model generally works, even during flares
  - Hints that IBLs may need SSC + external-Compton
  - Hints some “UHBLs” may even favor lepto-hadronic model

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

Blazar	Type	z
3C 66A	IBL	$0.33 < z < 0.41$
PG 1553+113	HBL	$0.43 < z < 0.58$
1ES 0033+595	HBL	?
1ES 0647+250	HBL	?
B2 1215+30	HBL	?
HESS J1943+213	HBL	?
RGB J2056+496	Blazar	?
RGB J2243+203	HBL	?

VERITAS AGN Publications

(1) V. Acciari et al., "VERITAS Discovery of >200 GeV Gamma-ray Emission from the Intermediate-frequency-peaked BL Lac Object W Comae", *Astrophysical Journal Letters*, **684,** L73, 2008

(2) V. Acciari et al., "Discovery of Very High-Energy Gamma-Ray Radiation from the BL Lac 1ES 0806+524", *Astrophysical Journal Letters*, **690**, L126, 2009

(3) I. Donnarumma et al., "The June 2008 Flare of Markarian 421 from Optical to TeV Energies", *Astrophysical Journal Letters*, **691**, L13, 2009

(4) V. Acciari et al., "VERITAS Observations of a Very High Energy Gamma-ray Flare from the Blazar 3C 66A", *Astrophysical Journal Letters*, **693**, L104, 2009

(5) V. Acciari et al., "VERITAS Observations of the BL Lac Object 1ES 1218+304", *Astrophysical Journal*, **695**, 1370, 2009

(6) V. Acciari et al., "Radio imaging of the very-high-energy gamma-ray emission region in the central engine of a radio galaxy", *Science,* **325**, 444, 2009

(7) V. Acciari et al., "Simultaneous Multiwavelength Observations of Markarian 421 During Outburst", *Astrophysical Journal*, **703**, 169, 2009

(8) V. Acciari et al., "VERITAS Upper Limit on the VHE Emission from the Radio Galaxy NGC 1275", *Astrophysical Journal Letters*, **706**, L275, 2009

(9) V. Acciari et al., "Multiwavelength observations of a TeV-Flare from W Com", *Astrophysical Journal*, **707**, 612, 2009

(10) V. Acciari et al., "Discovery of very high energy gamma rays from PKS 1424+240 and multiwavelength constraints on its redshift", *Astrophysical Journal Letters*, **708**, L100, 2010

(11) V. Acciari et al., "Discovery of Variability in the Very High Energy Gamma-Ray Emission of 1ES 1218+304 with VERITAS", *Astrophysical Journal Letters*, **709**, L163, 2010

(12) V. Acciari et al., "The Discovery of γ-ray emission from the Blazar RGB J0710+591", *Astrophysical Journal Letters,* **715**, L49, 2010

(13) V. Acciari et al., "VERITAS 2008 - 2009 monitoring of the variable gamma-ray source M87", *Astrophysical Journal*, **716**, 819, 2010

(14) A. Abdo et al., "Multi-wavelength Observations of Flaring Gamma-ray Blazar 3C 66A in October 2008", *Astrophysical Journal*, **726**, 43, 2011

(15) A. Abdo et al., "Insights Into the High-energy γ-ray Emission of Markarian 501 from Extensive Multifrequency Observations in the Fermi Era", *Astrophysical Journal*, **727**, 129, 2011

(16) V. Acciari et al., "Spectral Energy Distribution of Markarian 501: Quiescent State vs. Extreme Outburst", *Astrophysical Journal*, **729**, 2, 2011

(17) V. Acciari et al., "TeV and Multi-wavelength Observations of Mrk 421 in 2006-2008", *Astrophysical Journal*, **738**, 25, 2011

(18) V. Acciari et al., "Multiwavelength Observations of the VHE Blazar 1ES 2344+514", *Astrophysical Journal*, **738**, 169, 2011

(19) E. Aliu et al., "Multiwavelength Observations of the Previously Unidentified Blazar RXJ0648.7+1516", *Astrophysical Journal*, **742**, 127, 2011

(20) A. Abramowski et al., "The 2010 VHE Flare & 10 Years of Multi-Wavelength Observations of M87" *Astrophysical Journal*, **746**, 151, 2012

(21) E. Aliu et al., "VERITAS observations of day-scale flaring of M87 in April 2010", *Astrophysical Journal*, **746**, 141, 2012

(22) E. Aliu et al., " Discovery of High-energy and Very High Energy γ-Ray Emission from the Blazar RBS 0413" *Astrophysical Journal*, **750**, 94, 2012

(23) E. Aliu et al., " Multiwavelength Observations of the AGN 1ES 0414+009 with VERITAS, Fermi-LAT, Swift-XRT, and MDM", *Astrophysical Journal*, **755**, 118, 2012

(24) E. Aliu et al., "VERITAS Observations of Six Bright Hard-Spectrum Fermi-LAT Blazars", *Astrophysical Journal*, **759**, 102, 2012

(25) T. Arlen et al., "Rapid TeV Gamma-ray Flaring of BL Lacertae", *Astrophysical Journal*, **762**, 92, 2013

VERITAS AGN Publications

(26) E. Aliu et al., “Multiwavelength Observations and Modelling of 1ES 1959+650”, *Astrophysical Journal*, **775**, 3, 2013

(27) S. Archambault et al., “Discovery of a New TeV Gamma-ray Source: VER J0521+211”, *Astrophysical Journal,* **776,** 69, 2013

(28) E. Aliu et al., “Long term observations of B2 1215+30 with VERITAS”, *Astrophysical Journal,* **779,** 92, 2013

(29) V. Acciari et al., “Observation of Markarian 421 in TeV gamma rays over a 14-year time span”, Astroparticle Physics, **54**, 1, 2014

(30) E. Aliu et al., “A Three-Year Multi-Wavelength Study of the Very High Energy gamma-ray Blazar 1ES 0229+200”, *Astrophysical Journal,* **782,** 13, 2014

(31) S. Archambault et al., “Deep Broadband Observations of the Distant Gamma-ray Blazar PKS 1424+240”, *Astrophysical Journal Letters,* **785,** L16, 2014

(32) S. Archambault et al., “Test of Models of the Cosmic Infrared Background with Multi-wavelength Observations of the Blazar 1ES 1218+30.4 in 2009”, *Astrophysical Journal,* **788,** 158, 2014

(33) E. Aliu et al., ”Investigating Broadband Variability of the TeV Blazar 1ES1959+650”, *Astrophysical Journal,* **797**, 89, 2014

(34) E. Aliu et al., ”VERITAS Observations of the BL Lac Object PG 1553+113”, *Astrophysical Journal,* **799**, 7, 2015

(35) F.D. Ammando et al., “The most powerful flaring activity from the NLSy1 PMNJ0948+0022”, *Monthly Notices of the Royal Astronomical Society*, **446**, 2456, 2015

(36) J. Aleksic et al., “Multiwavelength Observations of Mrk 501 in 2008”, *Astronomy & Astrophysics*, **573**, 50, 2015

(37) J. Aleksic et al., “The 2009 multiwavelength campaign on Mrk 421: Variability and correlation studies”, *Astronomy & Astrophysics*, **576**, 123, 2015

(38) J. Aleksic et al., “Unprecedented Study of the Broadband Emission of Mrk 421 during Flaring Activity in March 2010”, *Astronomy & Astrophysics*, **578**, 22, 2015

(39) S. Archambault et al., “VERITAS Detection of γ-ray Flaring Activity from the BL Lac Object 1ES 1727+502 During Bright Moonlight Observations”, *Astrophysical Journal,* **808**, 110, 2015

(40) A. Furniss et al., “First NuSTAR Observations of Mrk 501 within a Radio to TeV Multi-Instrument Campaign”, *Astrophysical Journal,* **812**, 65, 2015

(41) A. Abeysekara et al., “Gamma Rays from the Quasar PKS 1441+25: Story of an Escape”, *Astrophysical Journal Letters,* **815**, L22, 2015

(42) M. Balaokovic et al., “Multiwavelength study of quiescent states of Mrk 421 with unprecedented hard X-ray coverage provided by NuSTAR in 2013”, *Astrophysical Journal,* **819**, 156, 2016

(43) A. U. Abeysekara et al., “Multiwavelength Observations of the BL Lac 1ES 1741+196”, *Monthly Notices of the Royal Astronomical Society*, **459**, 2550, 2016

(44) S. Archambault et al., “Upper Limits from Five Years of Blazar Observations with the VERITAS Cherenkov Telescopes”, *Astronomical Journal*, **151**, 142, 2016

(45) S. Archambault et al., “Discovery of Very High Energy Gamma Rays from 1ES 1440+122”, *Monthly Notices of the Royal Astronomical Society,* **461**, 202, 2016

(46) E. Aliu et al., “Very-High-Energy Outburst of Markarian 501 in May 2009”, Astronomy & Astrophysics, **594**, 76, 2016

(47) A. U. Abeysekara et al., “A search for spectral hysteresis and energy-dependent time lags from X-ray and TeV gamma-ray observations of Mrk 421”, *Astrophysical Journal*, **834**, 2, 2017

VERITAS AGN Publications

(48) A. U. Abeysekara et al., “A search for spectral hysteresis and energy-dependent time lags from X-ray and TeV gamma-ray observations of Mrk 421”, *Astrophysical Journal*, **834**, 2, 2017

(49) S. Archambault et al., “Search for Magnetically Broadened Cascade Emission From Blazars with VERITAS”, *Astrophysical Journal*, **835**, 288, 2017

(50) A. U. Abeysekara et al., “A Luminous and Isolated Gamma-ray Flare from the Blazar B2 1215+30”, *Astrophysical Journal*, **836**, 205, 2017

(51) M.L. Ahnen et al., “Multi-band variability studies and novel broadband SED modeling of Mrk 501 in 2009”, Astronomy & Astrophysics, **603**, 31, 2017

(52) C. Allen et al., “Very-High-Energy Gamma-Ray Observations of the Blazar 1ES 2344+514 with VERITAS”, *Monthly Notices of the Royal Astronomical Society,* **471**, 2117, 2017

(53) A. U. Abeysekara et al., “Discovery of Very High Energy Emission from RGB J2243+203 and Derivation of its Redshift Upper Limit”, *Astrophysical Journal Supplement Series*, **233**, 7, 2017

(54) A. U. Abeysekara et al., “Multiwavelength Observations of the Blazar BL Lacertae: A New Fast TeV Gamma-Ray Flare”, *Astrophysical Journal*, **856**, 85, 2018

(55) A. Archer et al., “HESS 1943+213: An Extreme Blazar Shining Through the Galactic Plane”, *Astrophysical Journal*, **submitted**, 2018

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