



VERITAS

Very Energetic Radiation Imaging Telescope Array System

<https://veritas.sao.arizona.edu/>

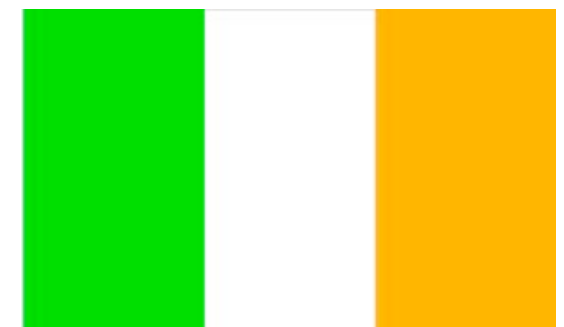
Gareth Hughes for the VERITAS Collaboration
Smithsonian Astrophysical Observatory



Our Collaboration



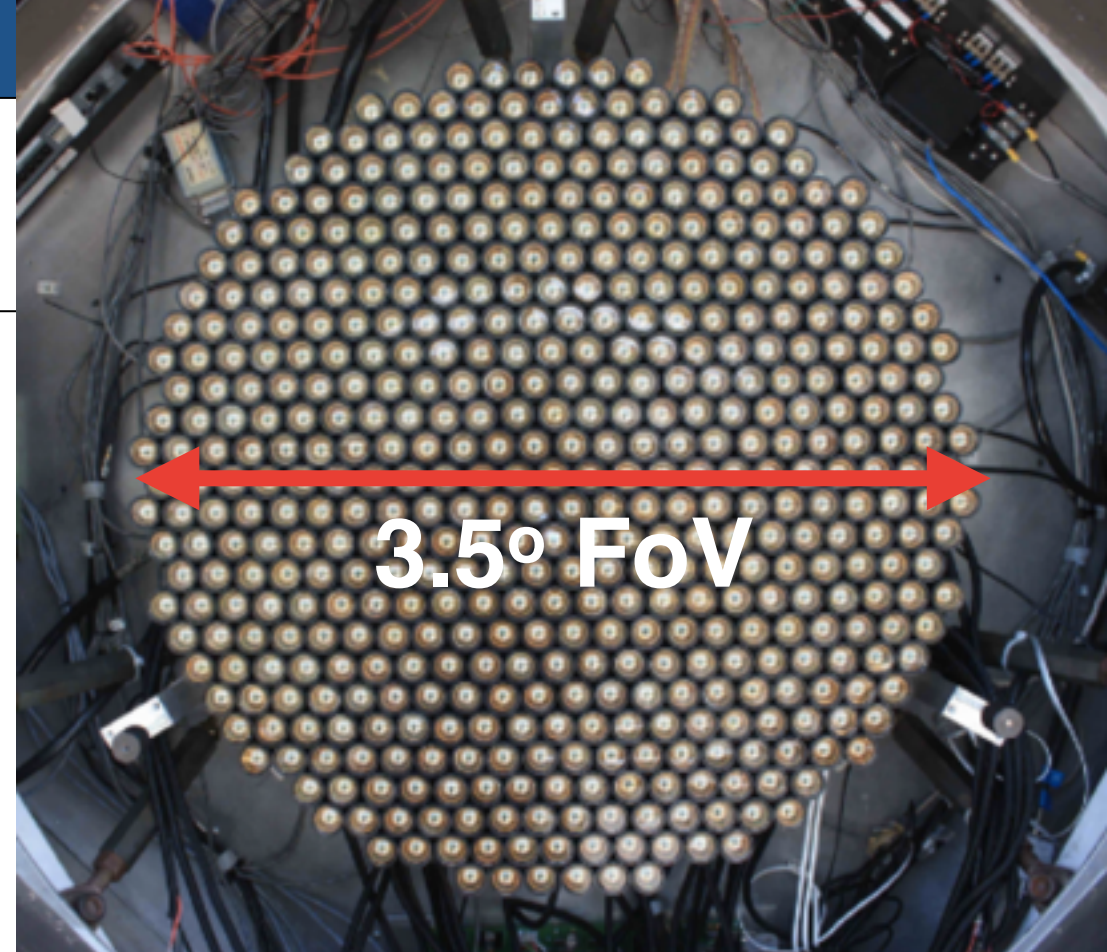
~80 scientists
> 4 countries





VERITAS

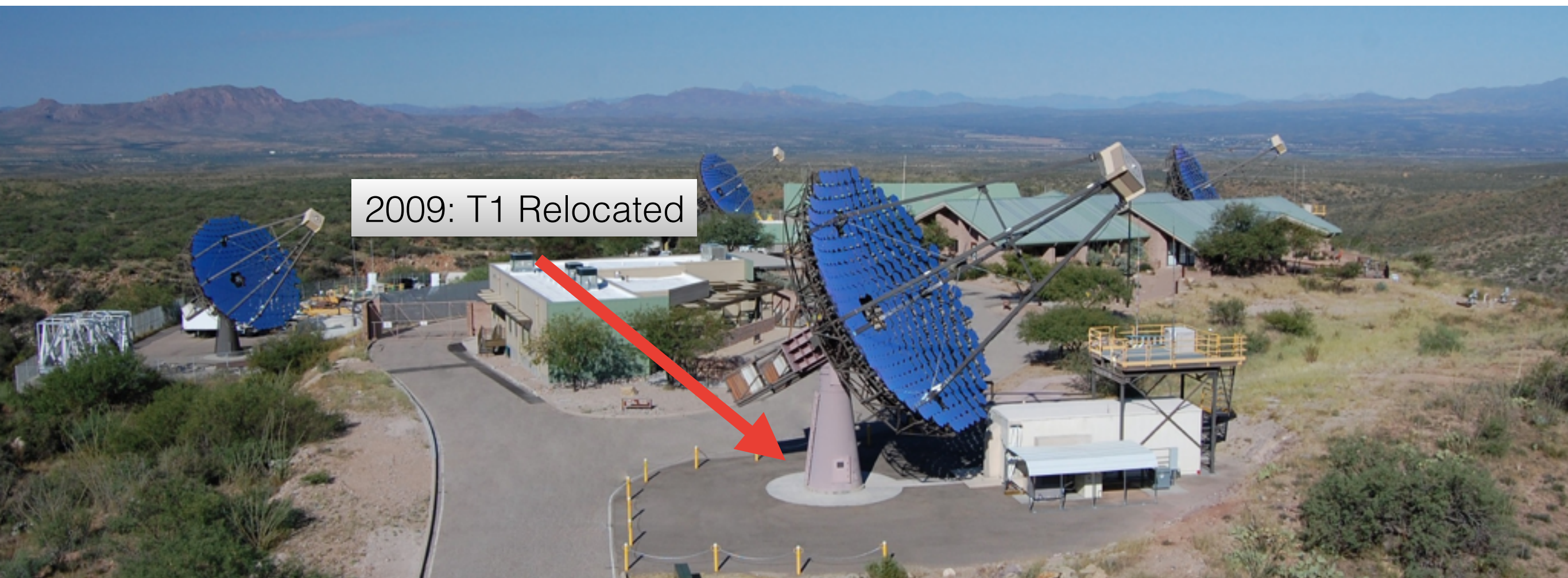
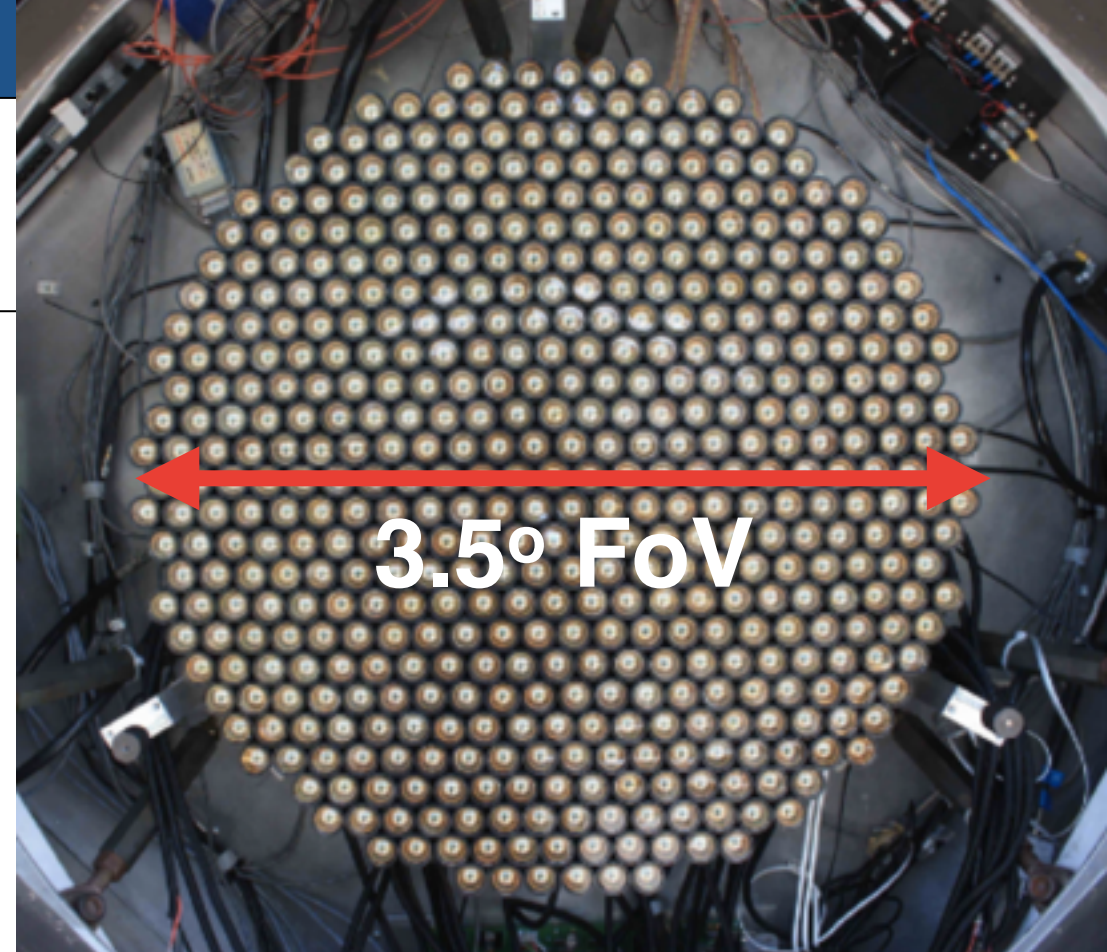
- Four 12m diameter, Cherenkov Telescopes
- 499 pixels/camera
- Energy range: 85 GeV to > 30 TeV
- Energy resolution: 20% @ 1 TeV
- Angular resolution (68% containment): 0.08° @ 1 TeV
- Point source sensitivity: 1% Crab in ~ 25 h





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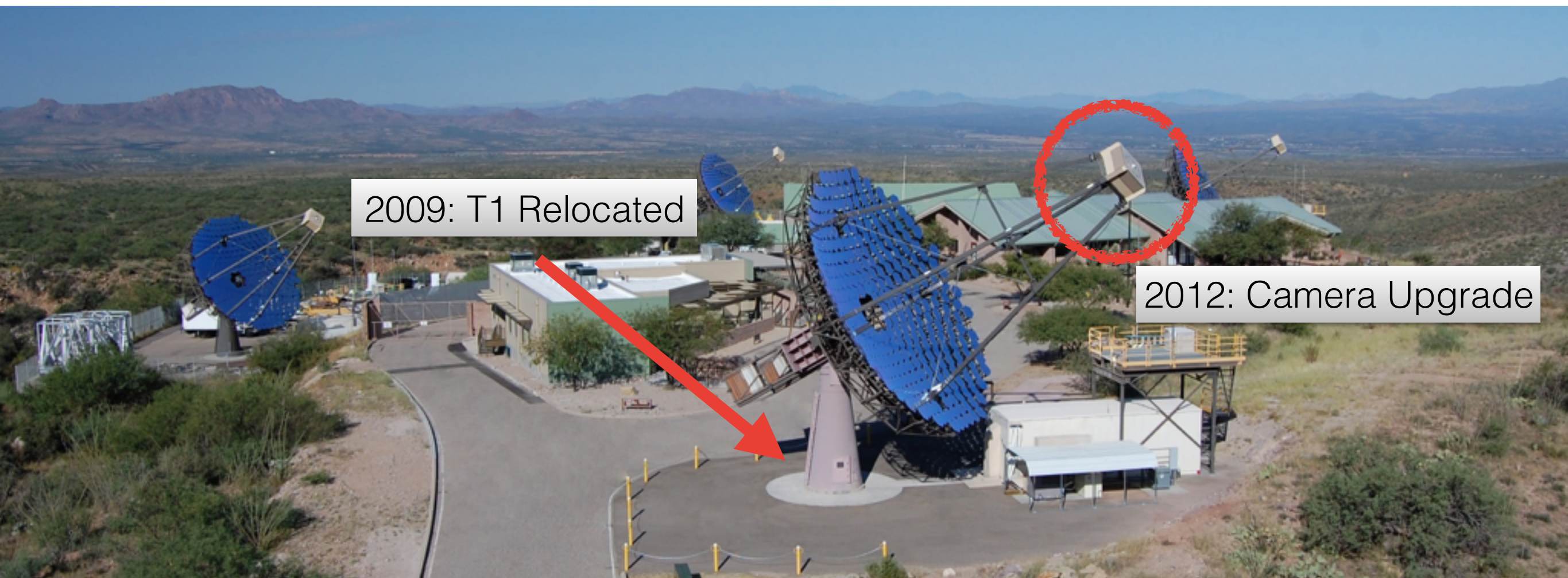
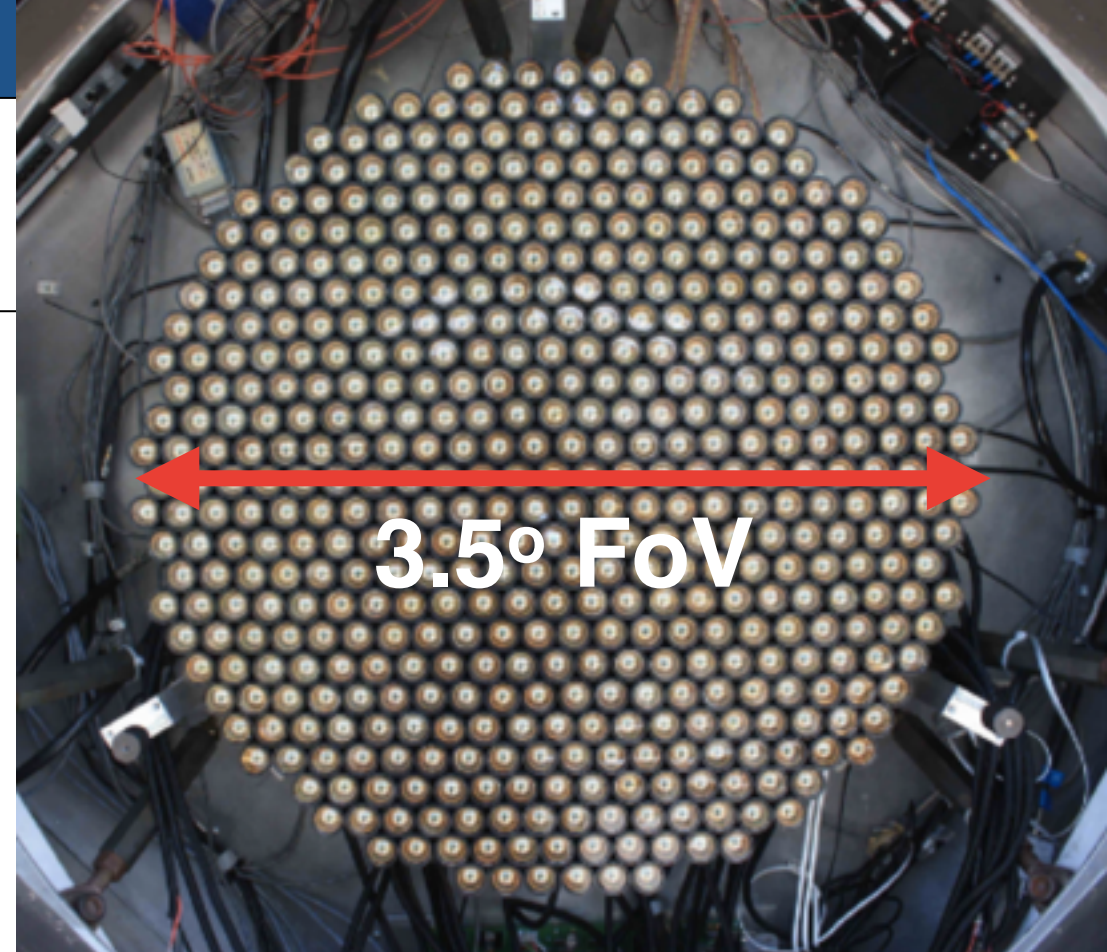


2009: T1 Relocated



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10 Years of VERITAS

- 10 year celebration June 2017 Tucson
- <http://veritasj.sao.arizona.edu/10Years/>
- >12,000 hours of observations



Nahee Park

VERITAS
Ten-Year Celebration

A celebration and conference to mark ten years of VERITAS operations.

JUNE 28-29, 2017
Tucson, AZ

<http://veritasj.sao.arizona.edu/10Years/>

BARNARD
Smithsonian

CALIFORNIA STATE UNIVERSITY SAN FRANCISCO
UCLA

IOWA STATE UNIVERSITY
UNIVERSITY OF DELAWARE

PURDUE UNIVERSITY
THE UNIVERSITY OF UTAH

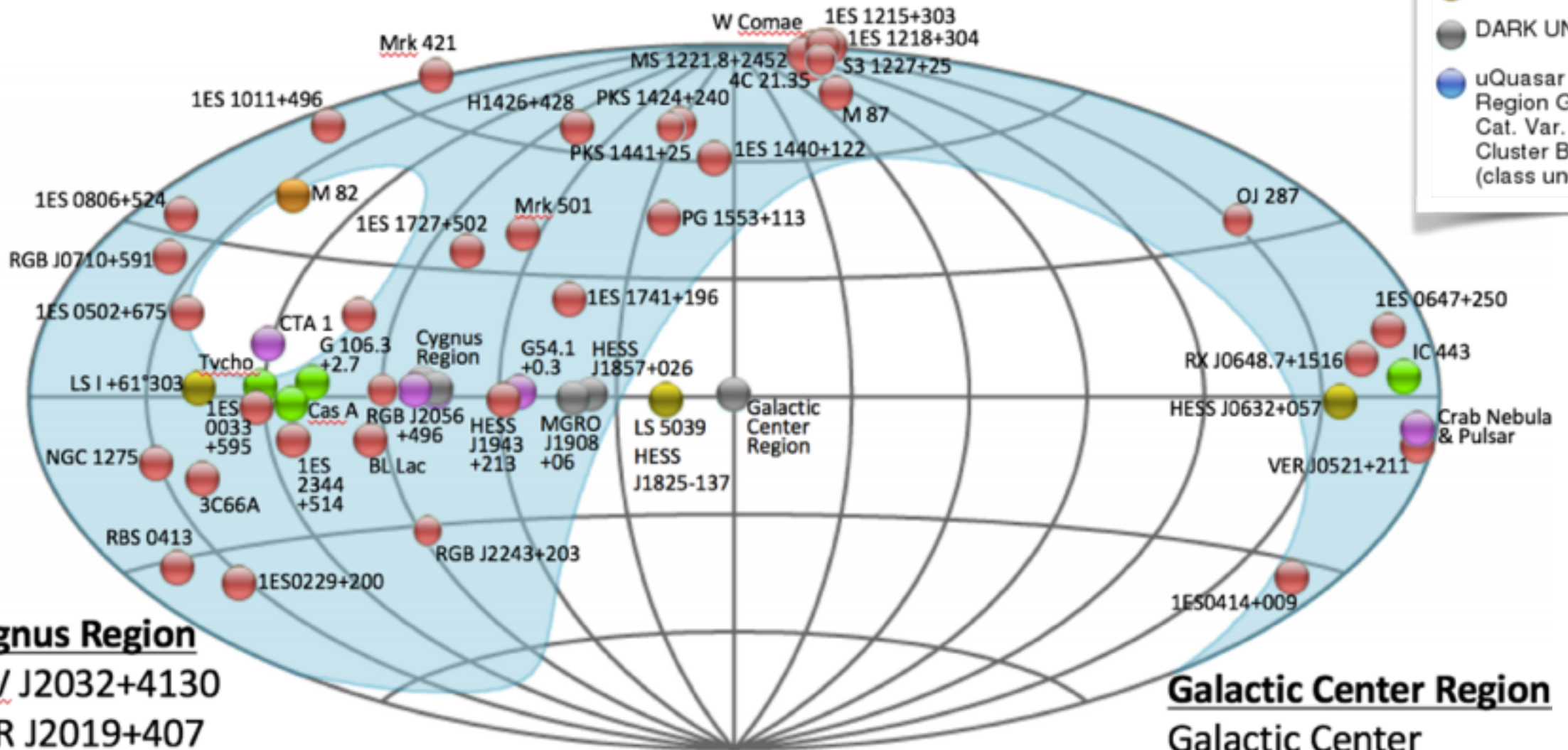
McGill
Washington University in St. Louis



VERITAS Source Catalogue

- 58 sources from 8 astrophysical classes
- 37 Extragalactic (64%) & 21 Galactic (36%) objects

- PWN
- Binary XRB PSR Gamma BIN
- HBL IBL FRI FSRQ Blazar LBL AGN (unknown type)
- Shell SNR/Molec. Cloud Composite SNR Superbubble
- Starburst
- DARK UNID Other
- uQuasar Star Forming Region Globular Cluster Cat. Var. Massive Star Cluster BIN BL Lac (class unclear) WR



Cygnus Region
TeV J2032+4130
 VER J2019+407
 VER J2019+368
 VER J2016+372

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



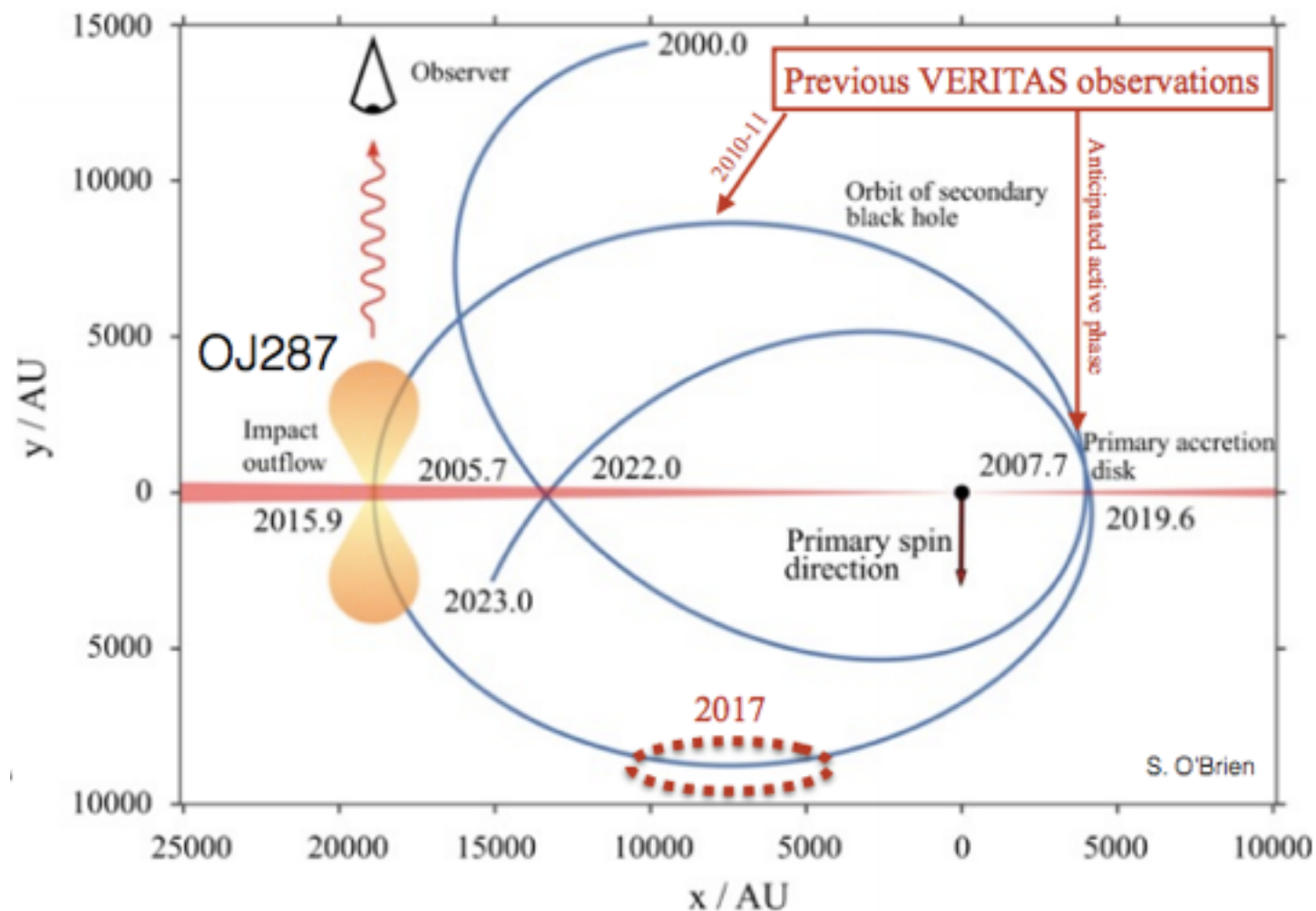
Recent Highlights

- ATel #9599 (Oct. 2016): BL Lac flare
- ATel #9690 (Oct. 2016): NGC 1275 flare
- ATel #9721 (Nov. 2016): VERITAS detection of RGB J2056+496
- ATel #9931 (Jan. 2017): VERITAS observations of NGC 1275
- ATel 10051 (Feb. 2017):
VERITAS detection of VHE Emission from OJ 287
- ATel 10252 (Apr. 2017):
VERITAS [upper limits] of Cygnus X-3 during a major radio flare
- GCN Circular 20364
VERITAS follow-up observations of this LIGO trigger (Jan 5)



OJ 287

- Optically bright blazar @ $z = 0.306$
 - Classification uncertain
 - TeV candidate: Costamante & Ghisellini 2002
- “Periodic” optical behavior: $T \sim 12$ yr
 - Binary black hole system? Helical jet?
 - Next optical outburst in 2019
- VERITAS limit in '07: 10 h $< 2.6\%$ Crab

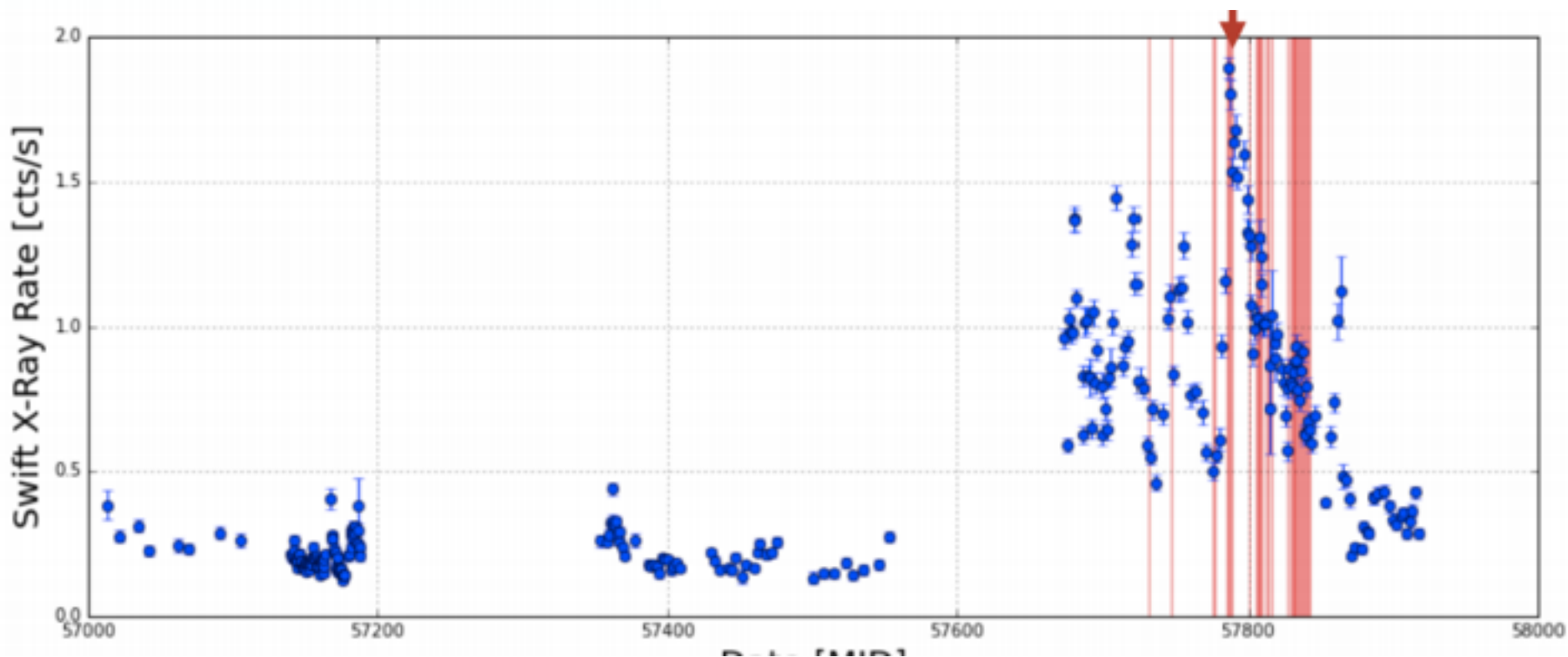
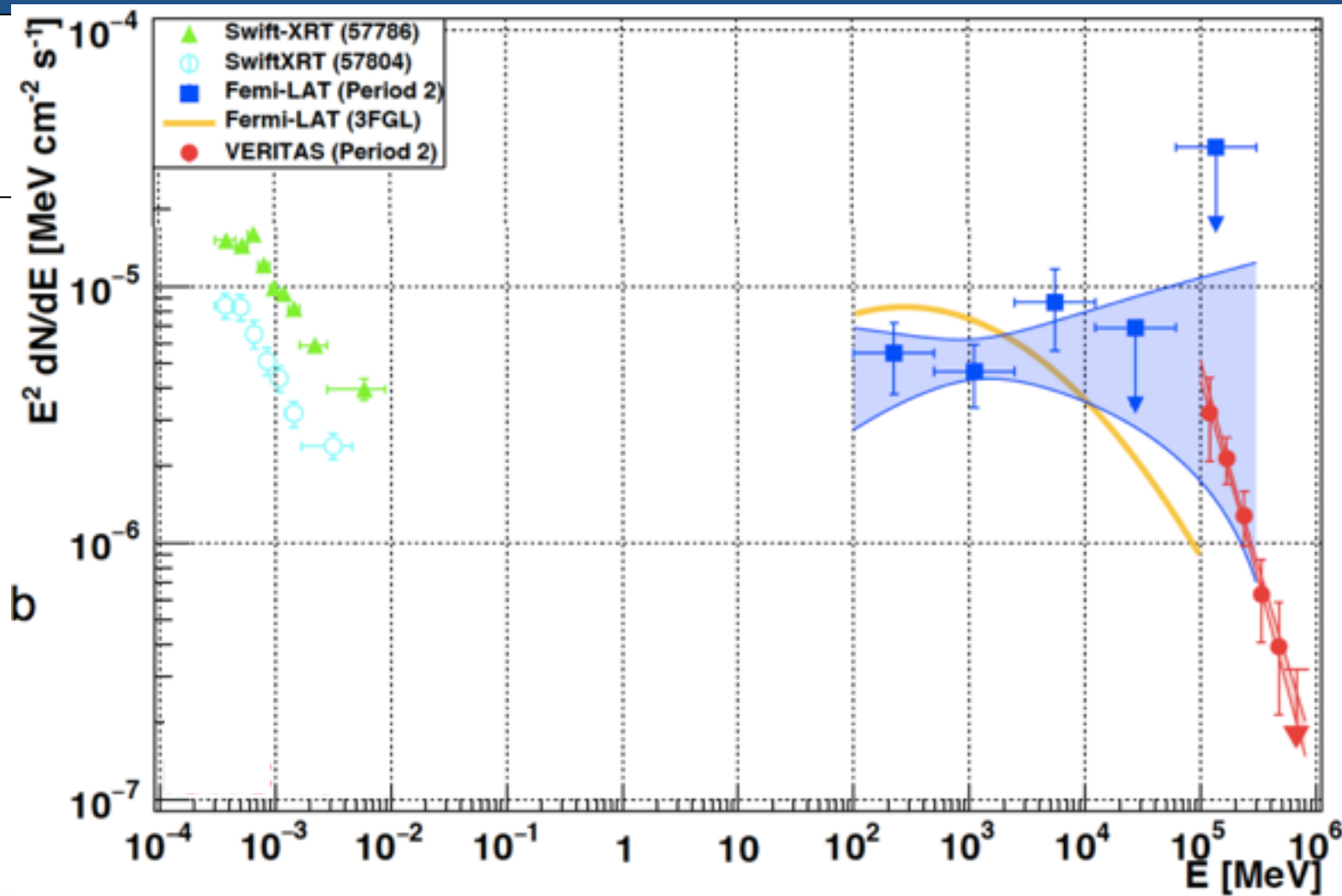


M. J. Valtonen et al 2016 *ApJ* 819 L37



OJ 287

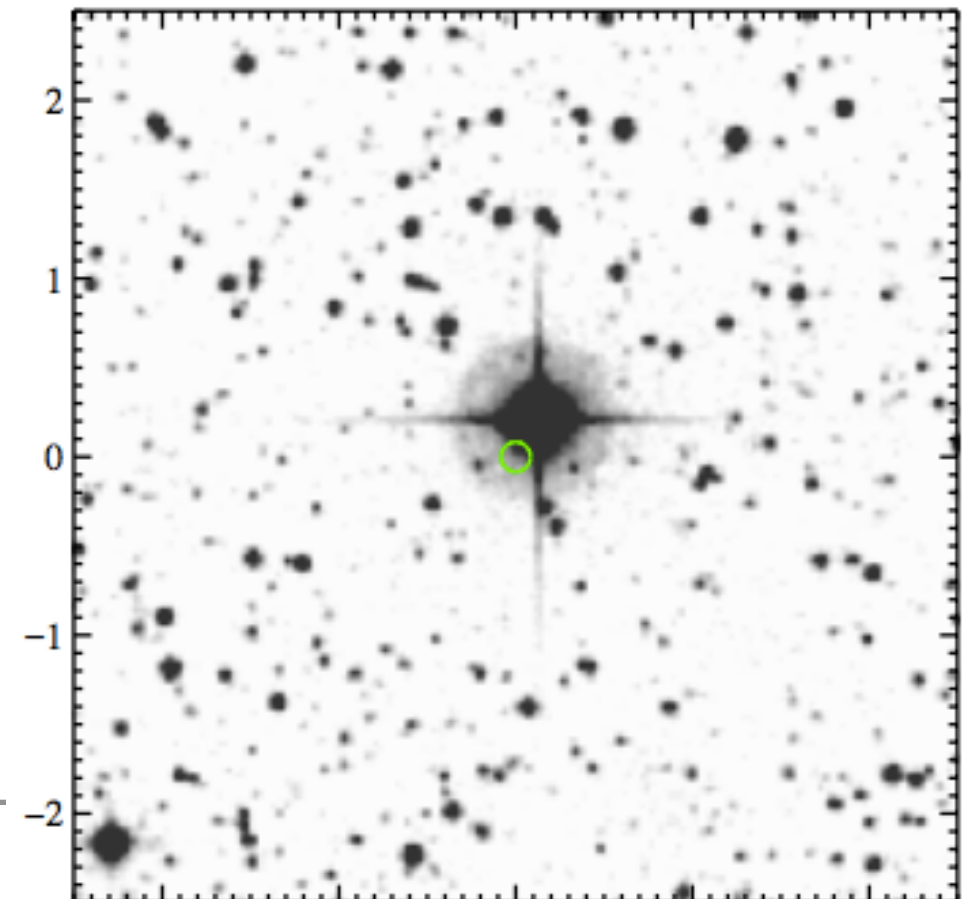
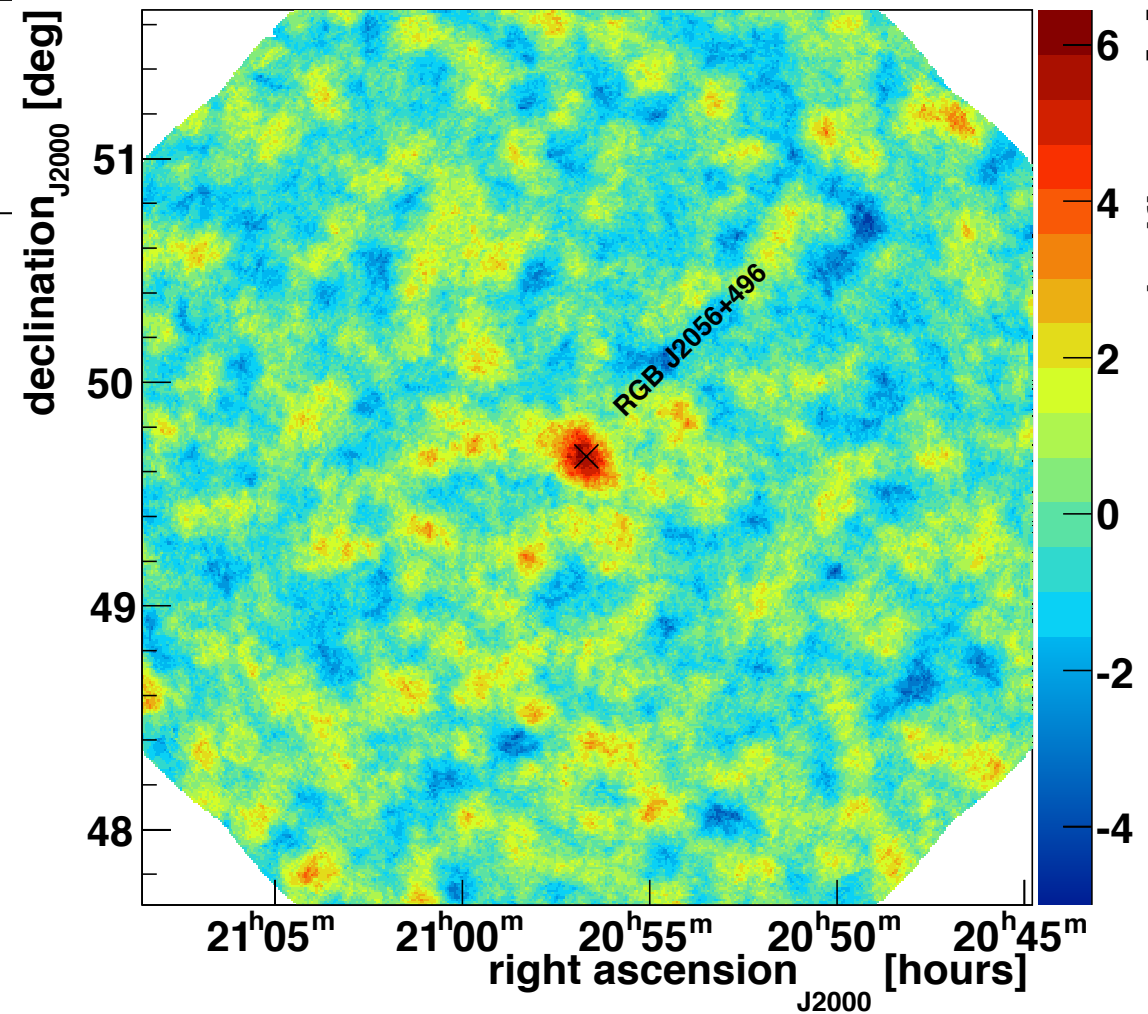
- Swift XRT flaring => 2016-17 ToO
- VHE discovery Feb 2017
ATel #10051
- 2016-17: ~50 h, 9.7σ , $\Gamma = 3.49 \pm 0.28$
- $F(>150 \text{ GeV})$
 $(4.61 \pm 0.61) \times 10^{-12} \text{ cm}^{-2} \text{ s}^{-1}$
1.3% Crab
- Copious MWL data: SED shifts





RGB J2056+496

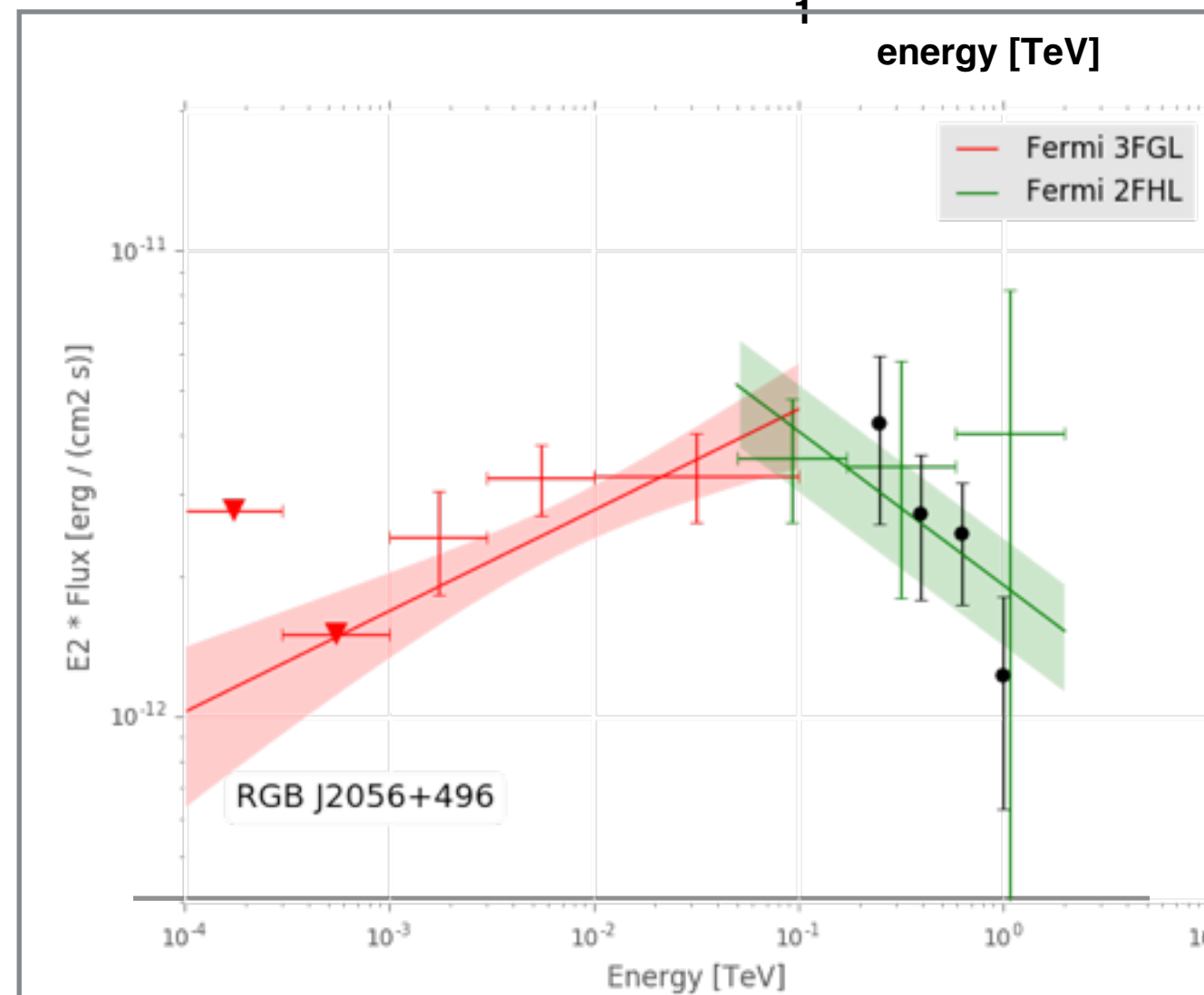
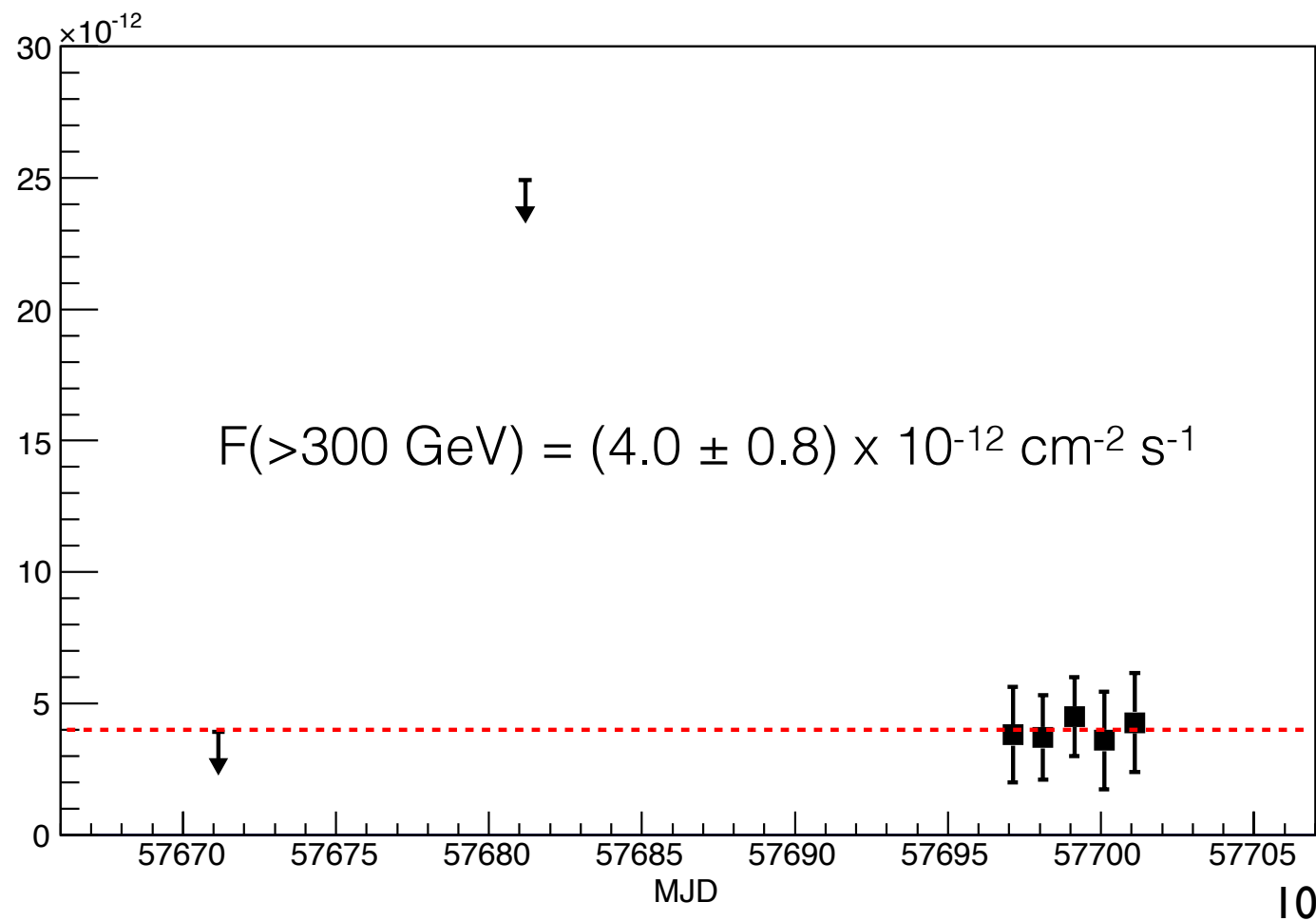
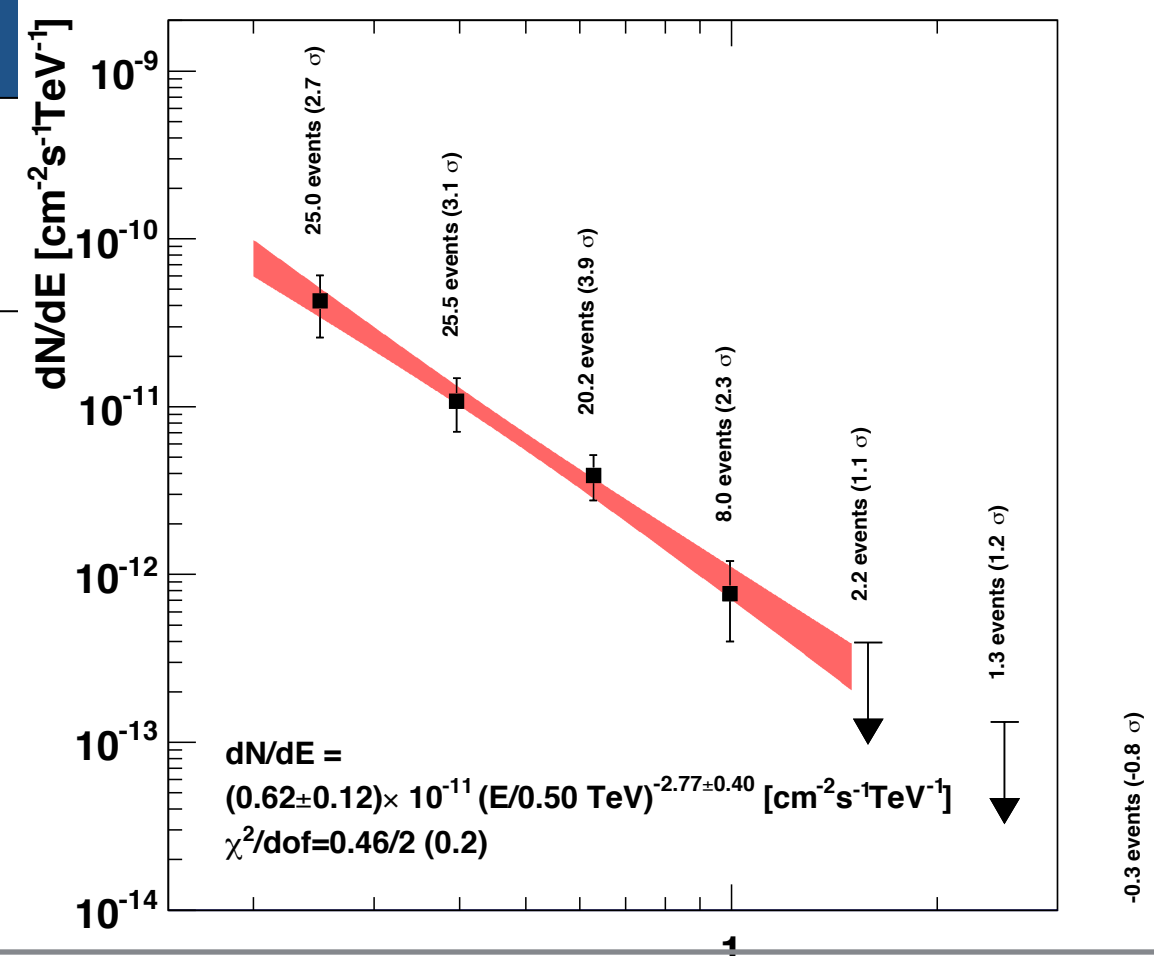
- Was the brightest 2FHL Source yet to be observed
 - $\Gamma_{2\text{FHL}} \sim 2.3$
 - $b \sim 3^\circ$
13" from LS III +49 13
 - Unknown red shift
 - Also a XMM-Newton & Swift source
- Detected first week of Nov 2016
 - ATel #9721
 - 6.3σ & 2.9% Crab Nebula





RGB J2056+496

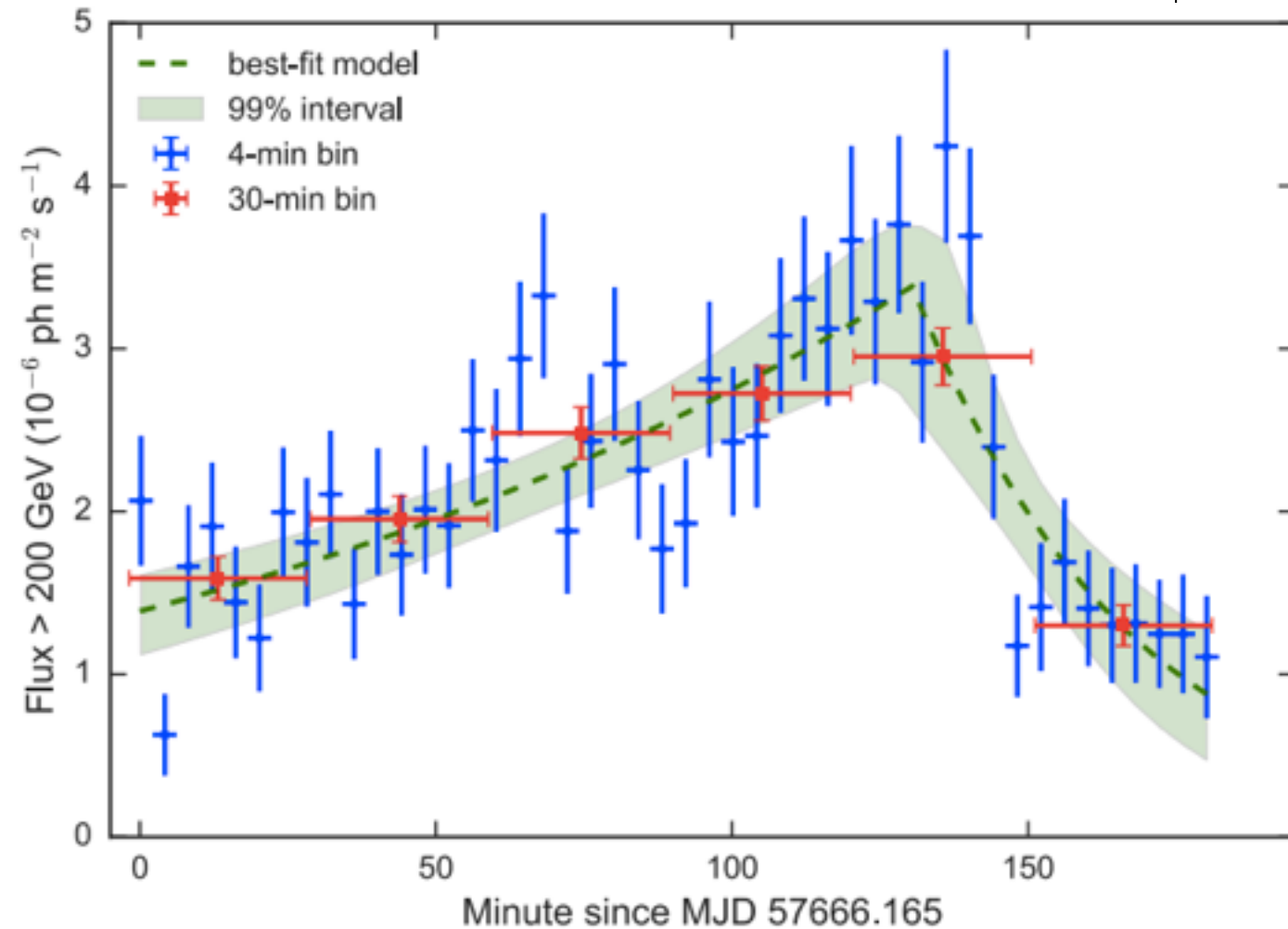
- $\Gamma = 2.77 \pm 0.40$ from 0.2 - 1.25 TeV
- 4 Swift XRT exposures taken in Nov
- Good agreement with Fermi-LAT catalogs
- Constant flux above 300 GeV for the 5 nights observed



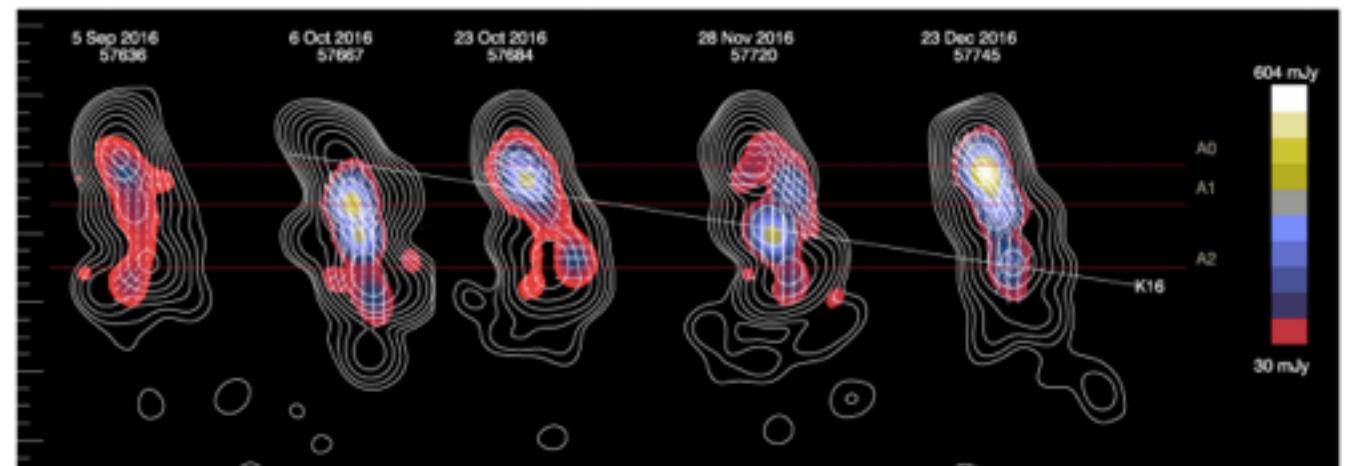


BL Lac flare 2016

- 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
 - ~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



VLBA 43 GHz Maps: Sept - Dec 2016

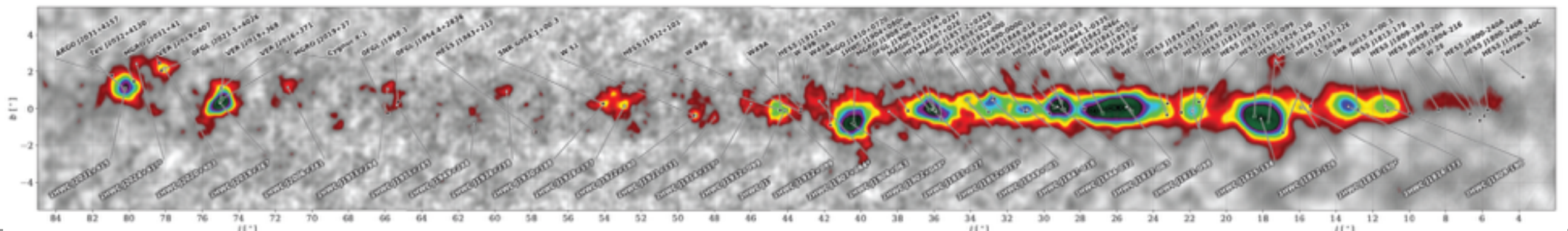
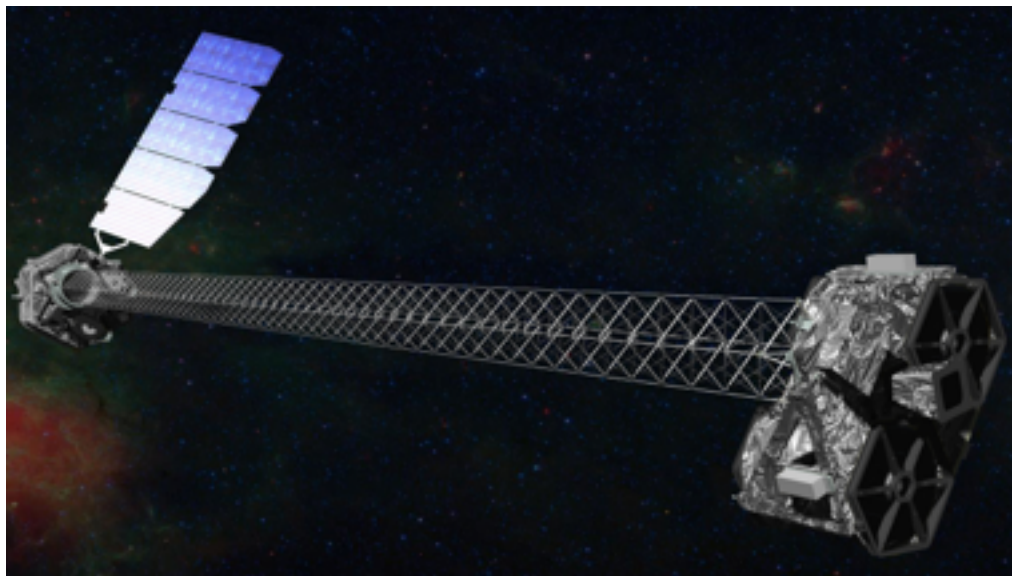
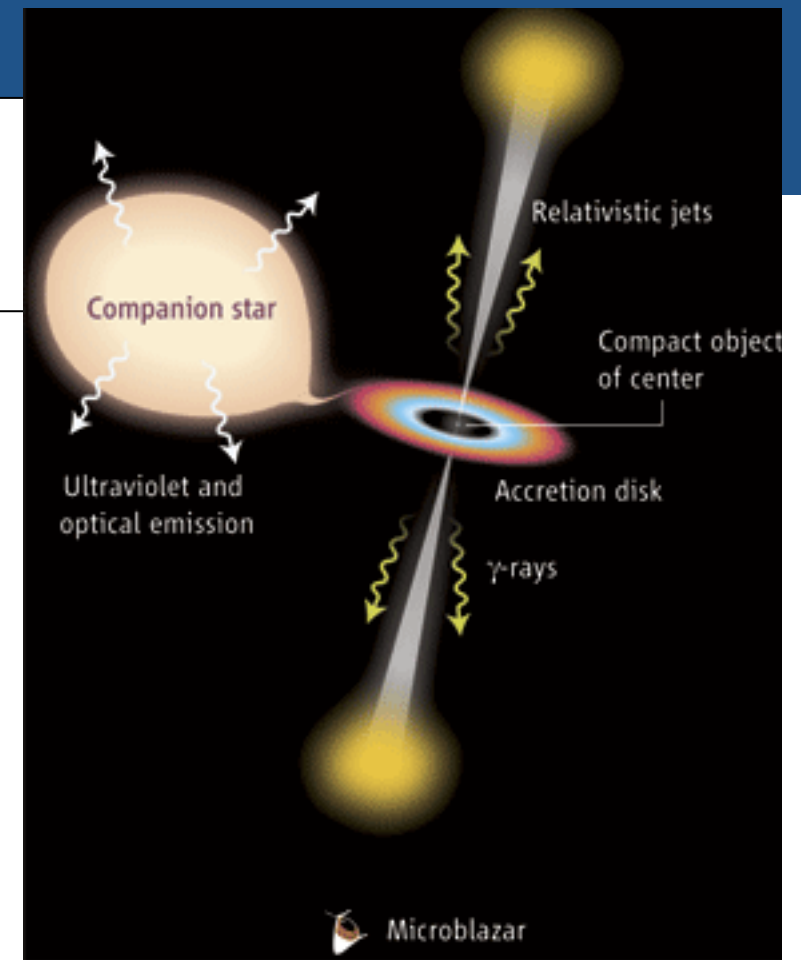


- Major flare on Oct. 5, 2016
 - Detected by monitoring 2.6 h, 71σ , Peak ~ 180% Crab
 - $T_{\text{rise}} \sim 140$ min & $T_{\text{fall}} \sim 36$ min
 - Another candidate superluminal knot appears



Galactic Program

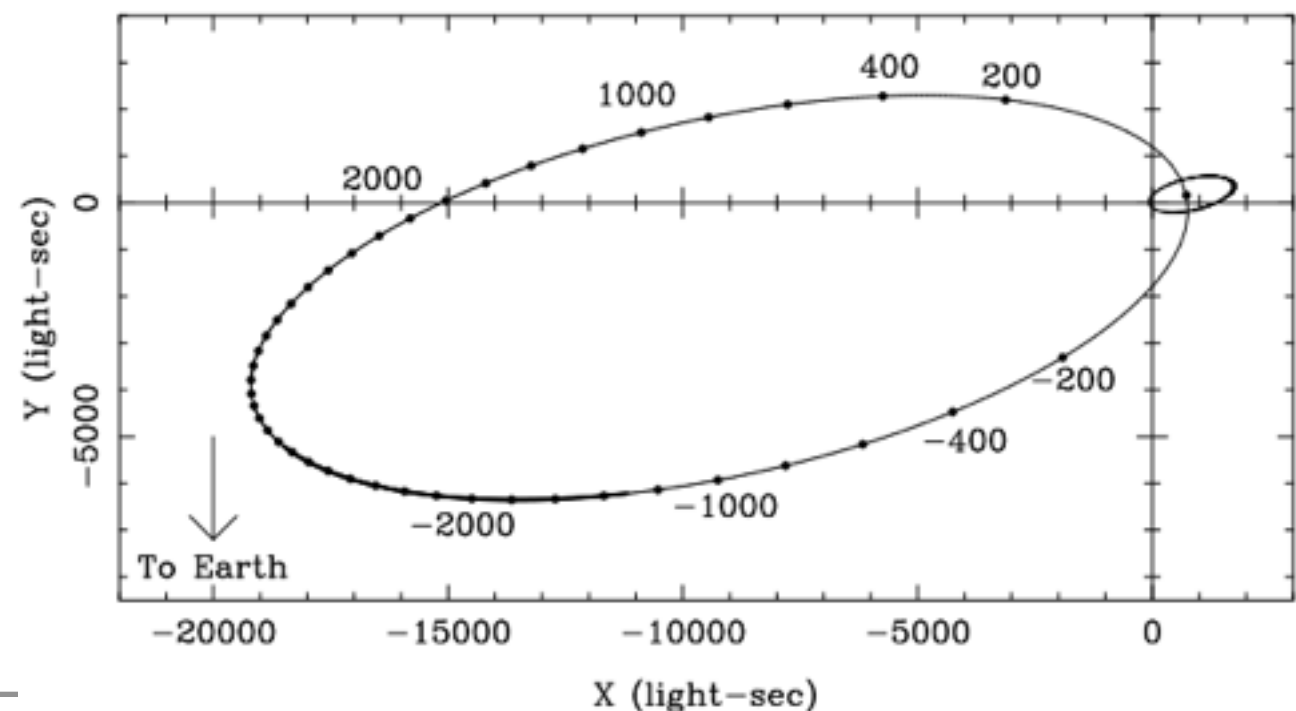
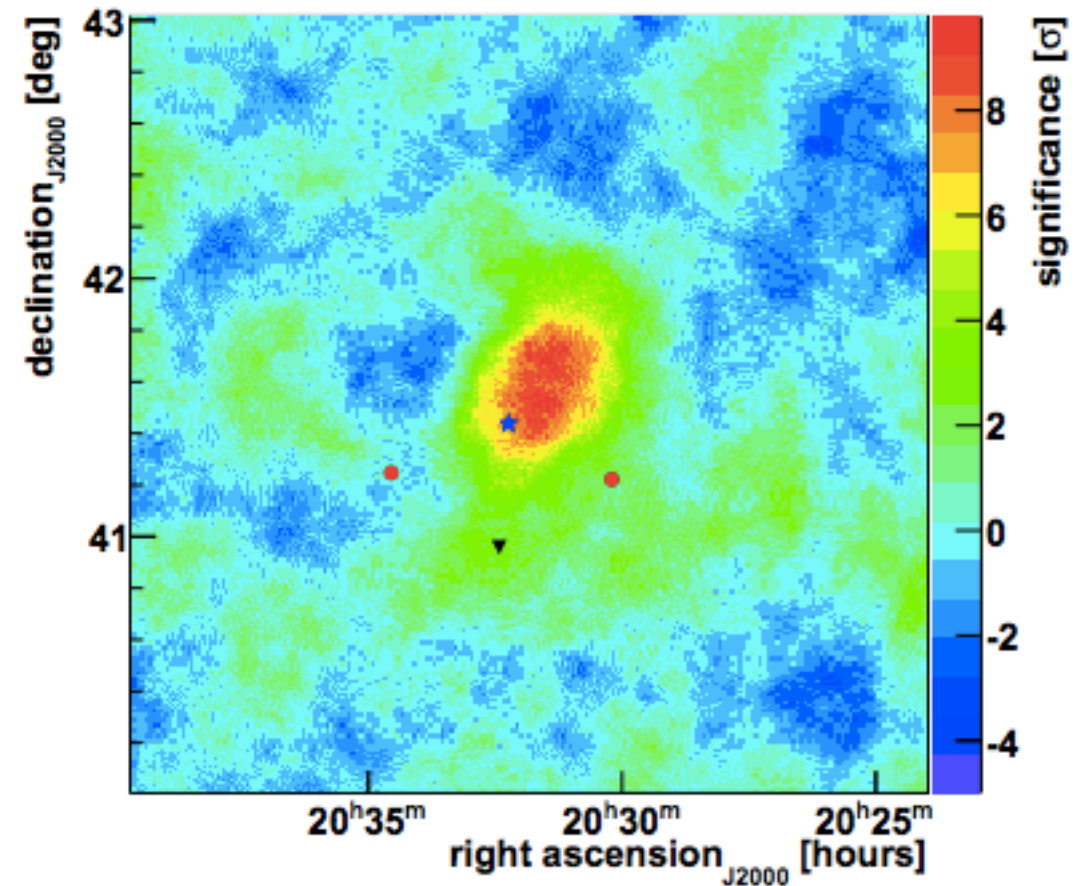
- Payel Kar: *VERITAS Observations of Galactic Binary Systems*
8 Aug 2017, 15:15
- Nahee Park: *VERITAS and Fermi-LAT observations of TeV gamma-ray sources from the second HAWC catalog*, **10 Aug 2017, 13:30**
- Michelle Hui: *Follow-up VERITAS and NuSTAR observations of Galactic HAWC gamma-ray sources*, **10 Aug 2017, 13:45**
- Amanda Weinstein: *Observations of Supernova Remnants and Pulsar Wind Nebulae*, **11 Aug 2017, 11:36**





TeV J2032+4130 / Cygnus

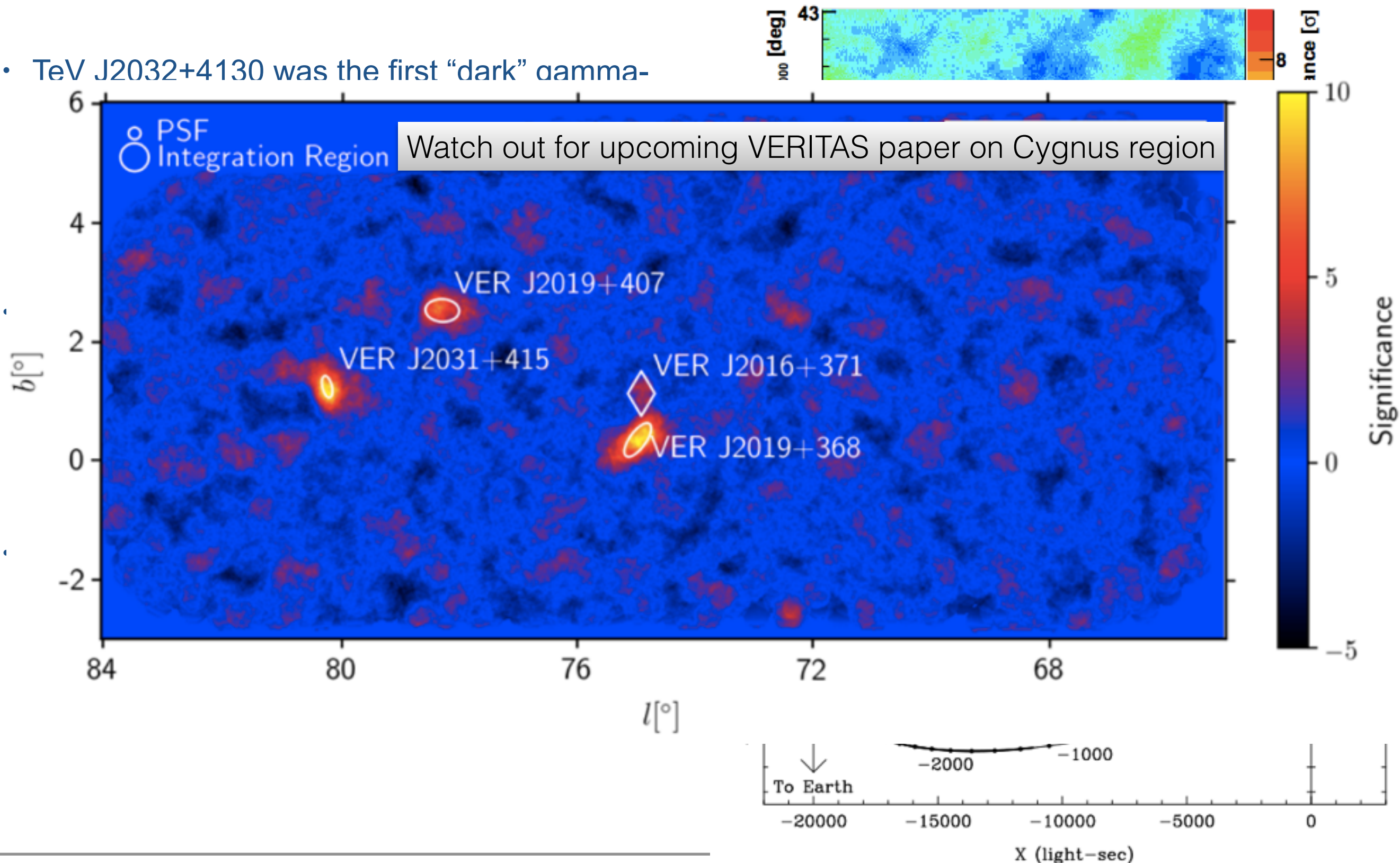
- TeV J2032+4130 was the first “dark” gamma-ray emitter
 - Discovered by HEGRA
 - 0.5° from Cygnus X-3
- Fermi-LAT discovered a pulsar 0.16° from the centre of the TeV emission
 - PWN associated with the Fermi pulsar?
 - Does not explain extension
- Recent paper suggesting the pulsar is in a binary system with a Be star (MT91 213)
 - 20-30 year period but periastron is 2018
 - Monitoring underway in conjunction with MAGIC





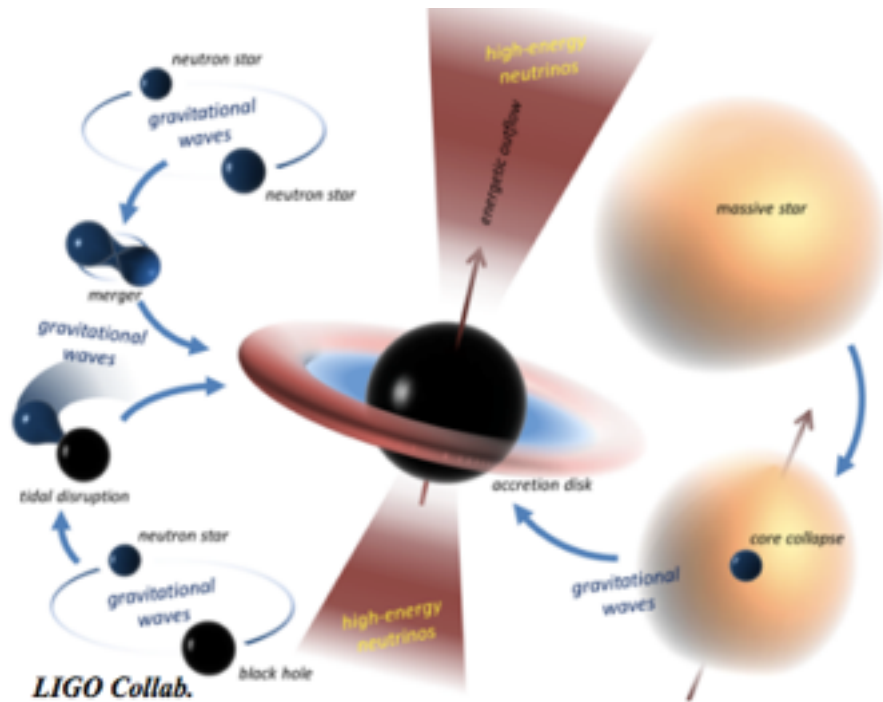
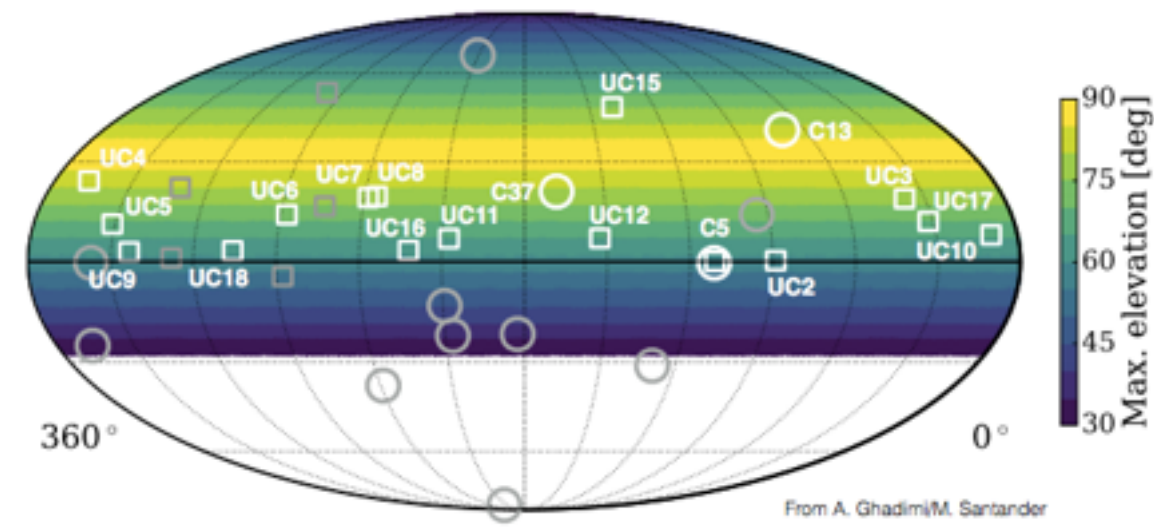
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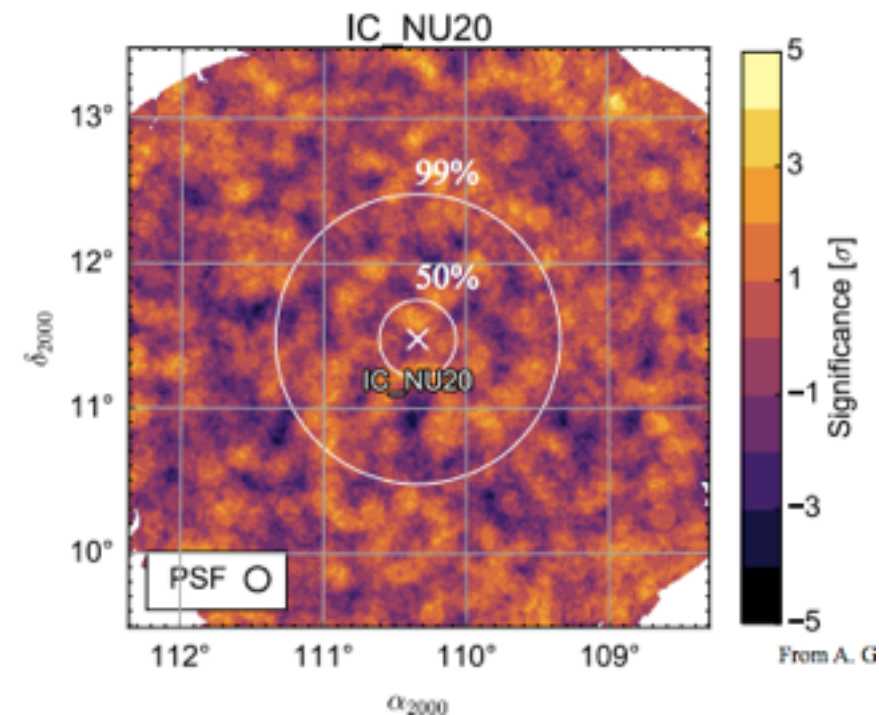
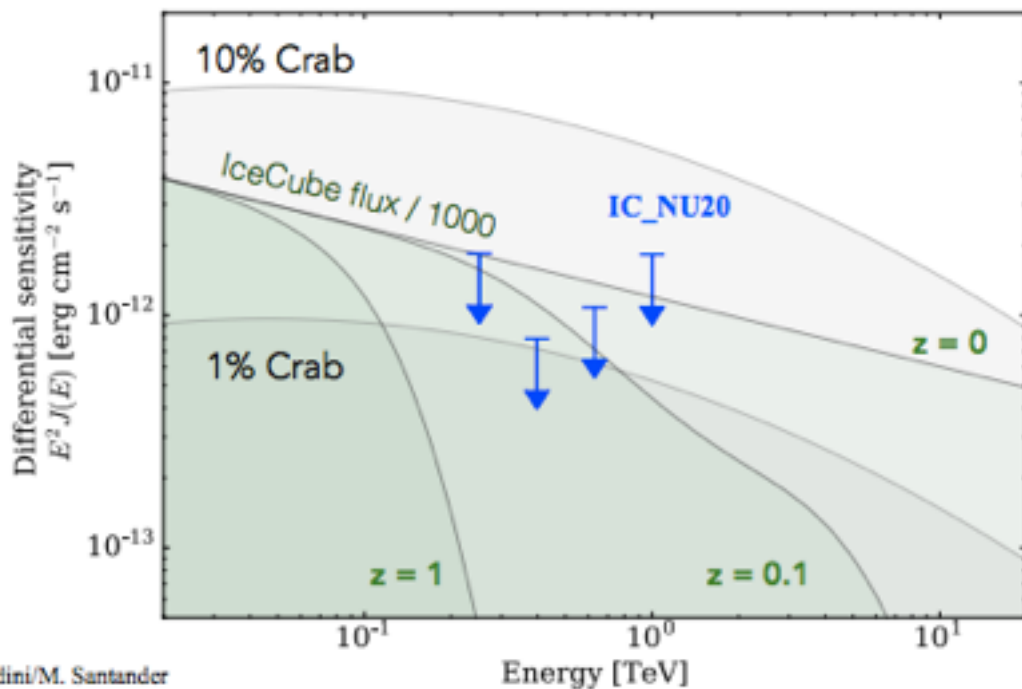




Multi-Messenger



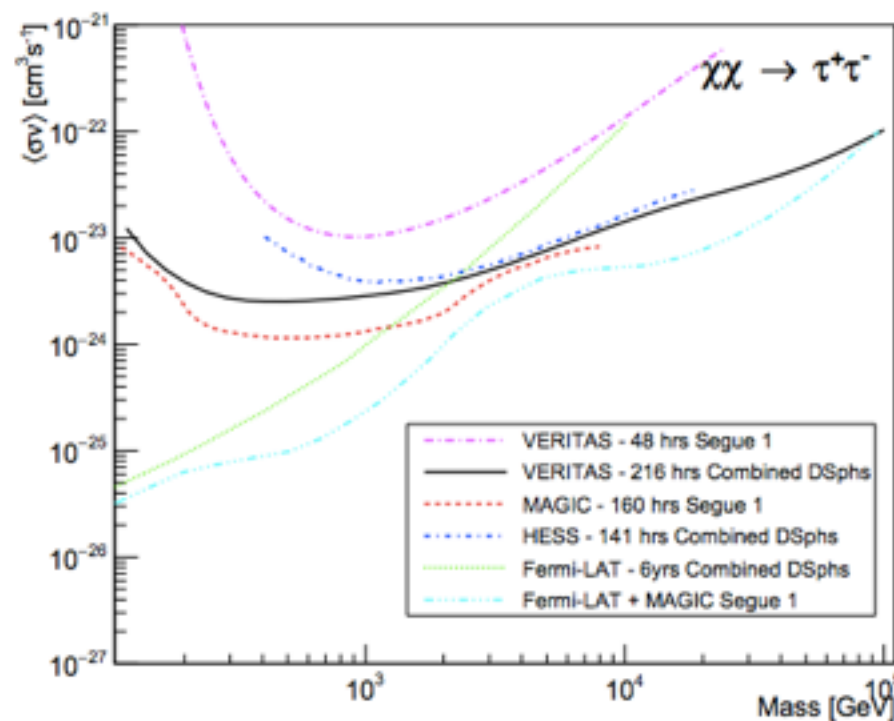
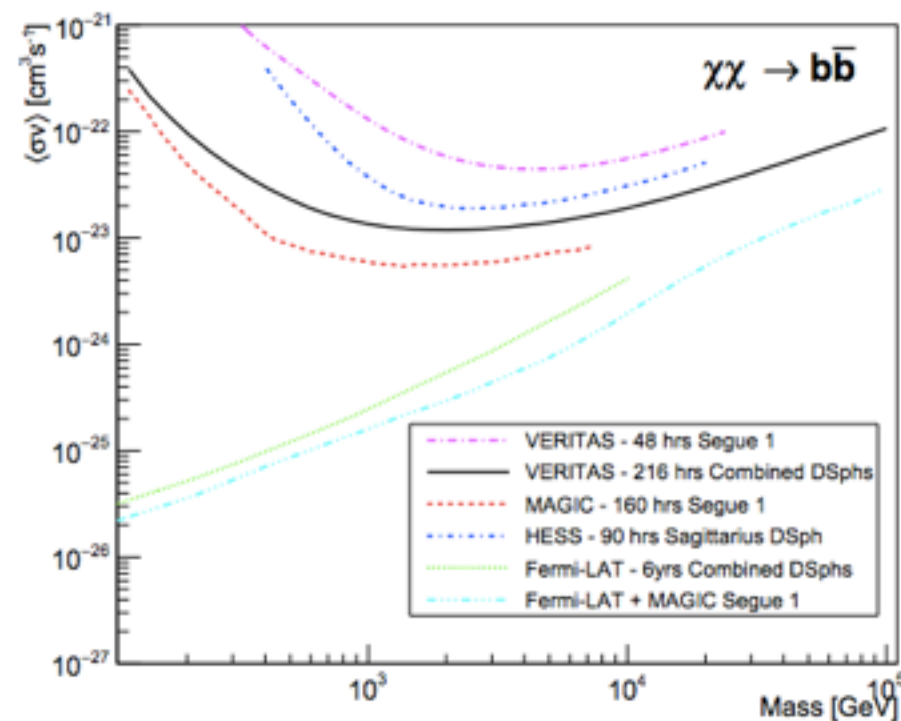
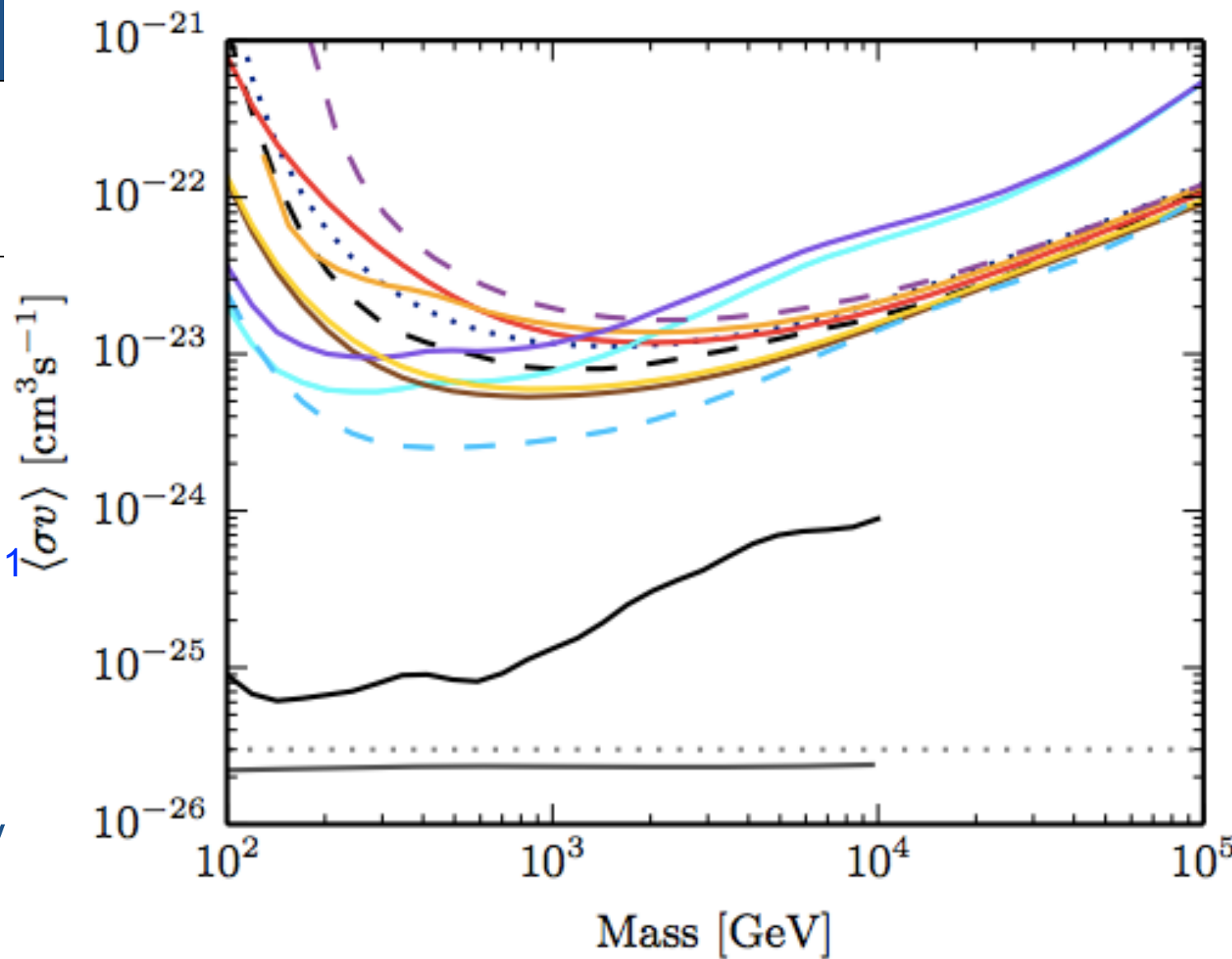
- Brian Humensky, *VHE Gamma Rays and Multi-Messenger Astrophysics: VERITAS Status and Strategies for CTA*, 11 Aug 2017, 12:15
 - Muon Neutrino follow up
 - Gravitational wave follow up
- Triplet follow up: arXiv:1702.06131





Dark Matter

- S. Archambault et al., Phys. Rev. D 95, 082001 (2017)
- 230h observations of 5 dSph galaxies
 - Segue 1, Draco, Ursa Minor, Bootes 1, Willman 1
- Stack the analysis for 216 hrs (excluding Willman 1)
- Future improvement to the analysis could improve the limits by an order of magnitude by 2019

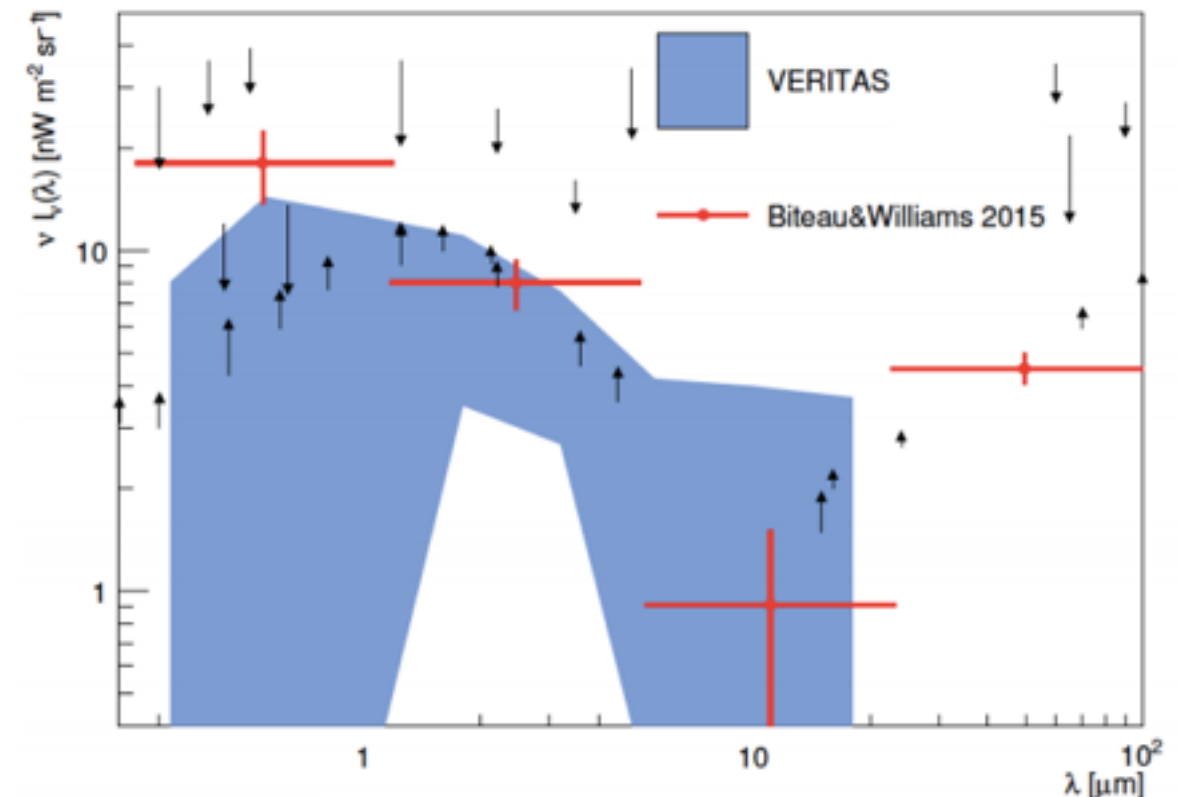
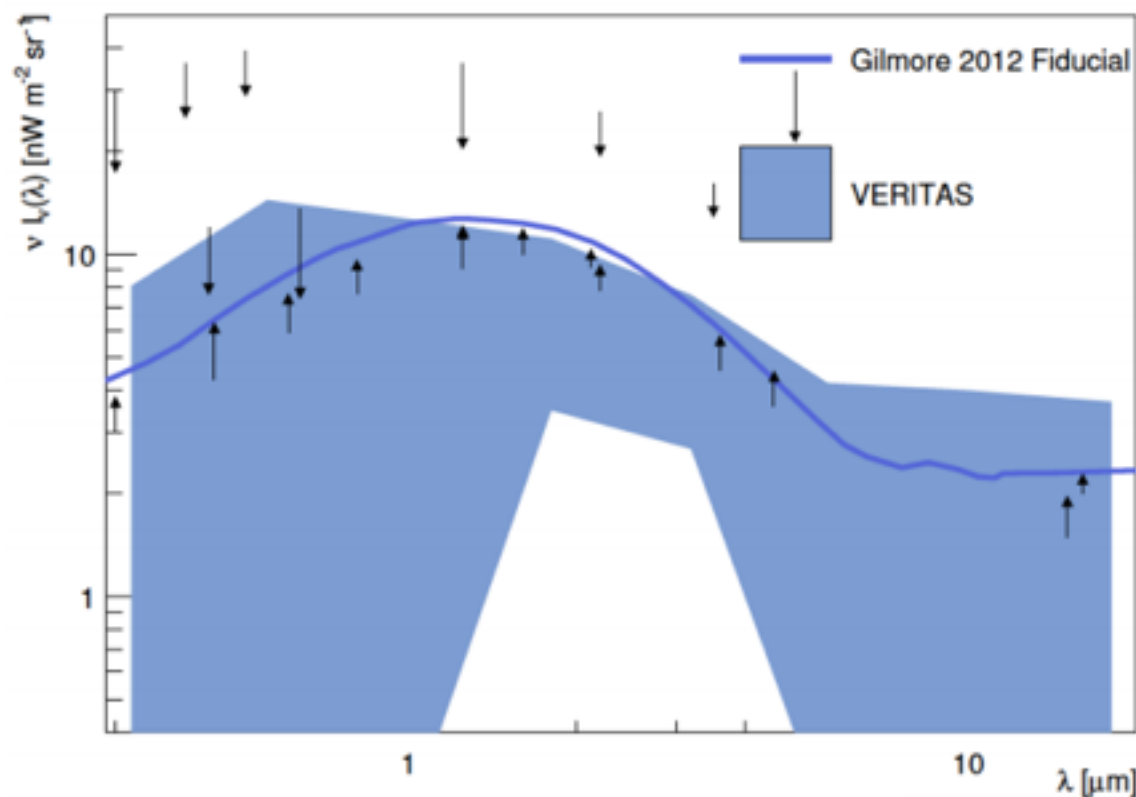


- -	W^+W^-	—	$gg, c\bar{c}$	—	$u\bar{u}, d\bar{d}, s\bar{s}$
⋯	ZZ	—	hh	- -	$\tau^+\tau^-$
—	$b\bar{b}$	—	$\gamma\gamma$	- -	$t\bar{t}$
—	e^+e^-	—	$\mu^+\mu^-$		



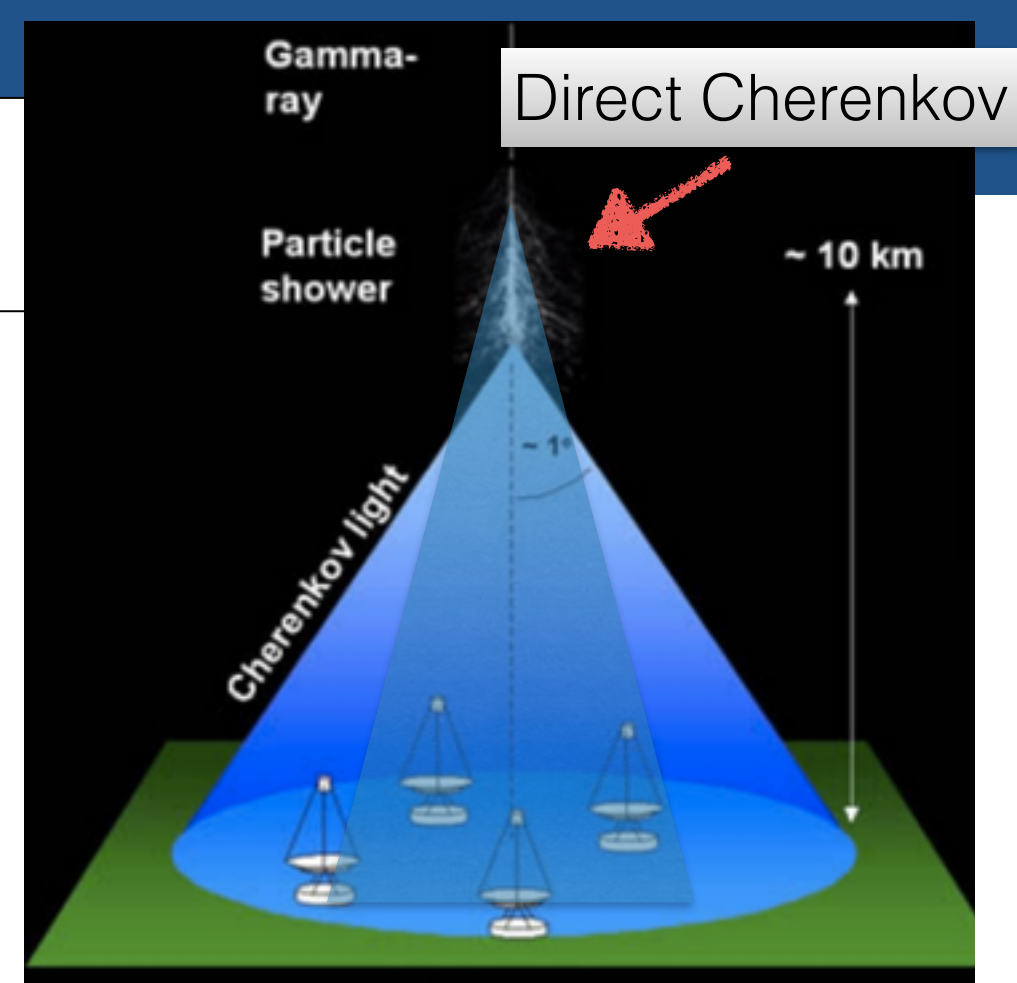
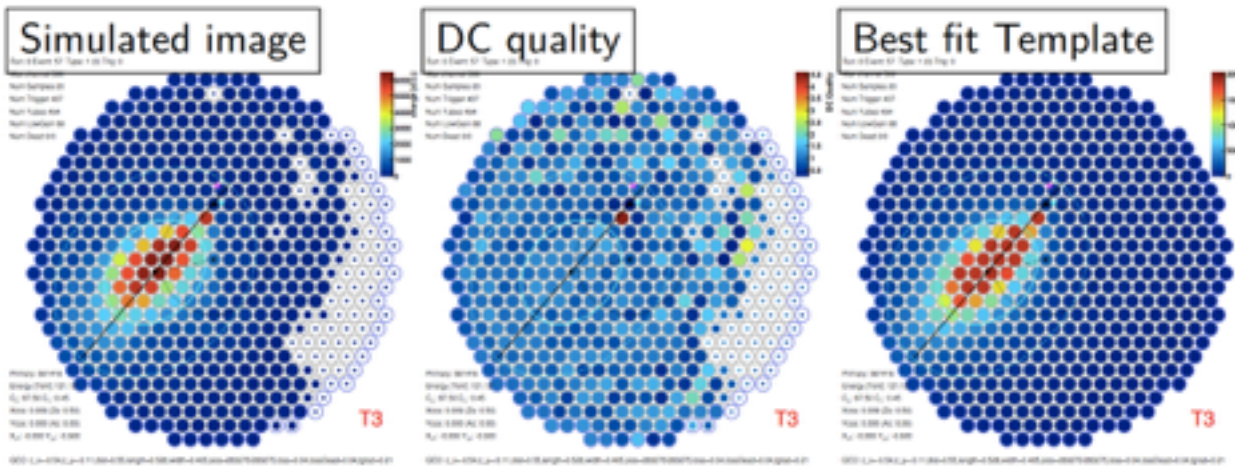
Extragalactic Background Light with VERITAS

- Imprint from reionization, star formation, galaxy evolution
- EBL modifies VHE spectra through absorption during propagation
- Deep exposures of 8 VHE blazars, with a range of red shifts
- EBL-corrected spectra fit using a power law or curved models
 - Require concavity, spectral index > 1.5
- Confidence intervals/upper limits extracted from intensity distributions at fixed points in λ_{EBL}

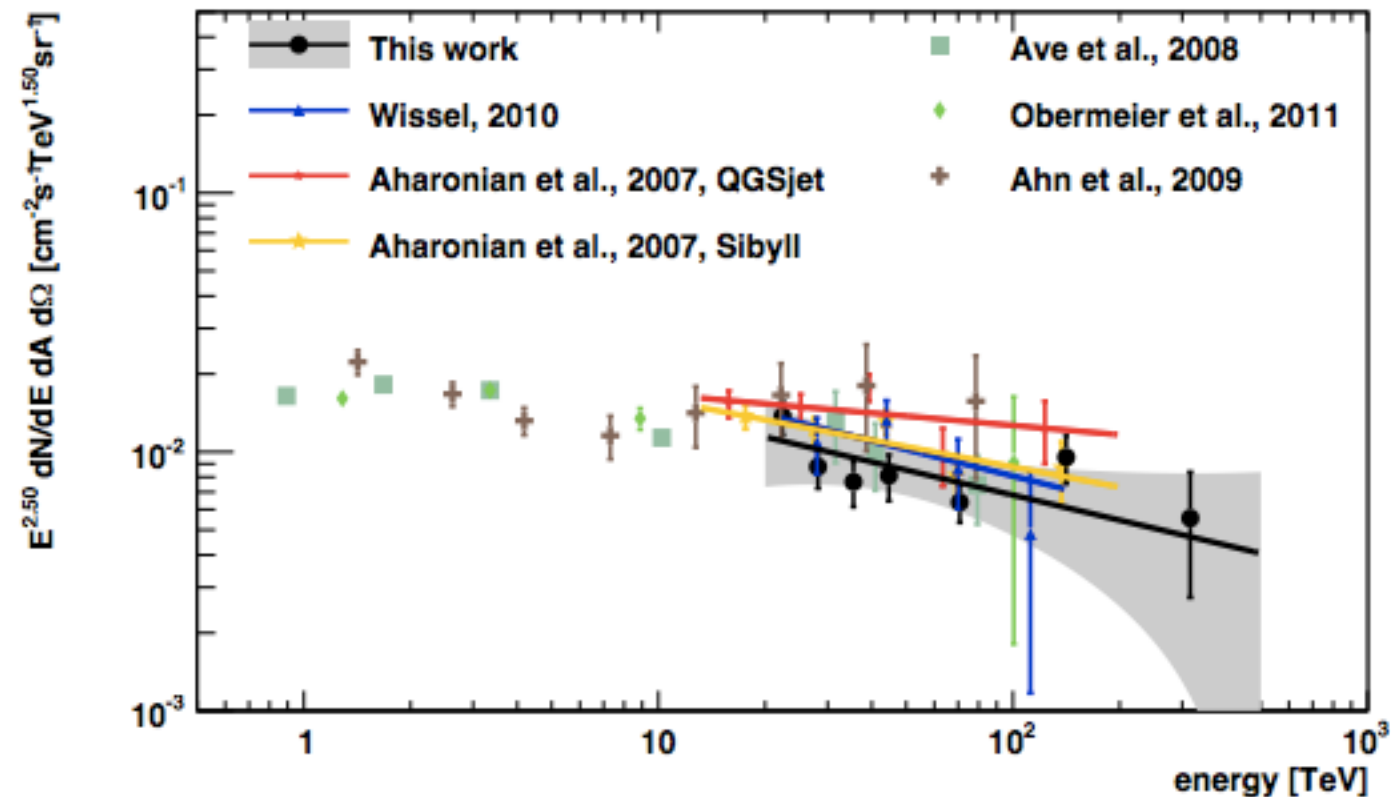




Cosmic Rays: Fe



- Cherenkov intensity $\sim Z^2$
- Therefore can detect heavy elements emit direct Cherenkov before the first interaction
- This light is concentrated in one pixel
- 71 hours of data taken on various targets.
- First-time application of template likelihood reconstruction to iron-induced showers.
 - Combination of templates and direct Cherenkov light gives good charge discrimination.
- Measurement of the iron spectrum with VERITAS from 20 TeV to 500 TeV.
- Systematic uncertainties remain, eg: atmosphere/detector model.





Summary

- VERITAS is 10+ Years Strong
 - fully funded until at least 2019
- We have a large archive of data >12,000 hours
- The VERITAS source catalog comprises of 58 sources from 8 classes
- Strong Galactic, extra-galactic and astroparticle programs

- Also go see:
Tom Brantseg, *A novel maximum likelihood method for VERITAS analysis*, **10 Aug 2017, 12:00**