

# Highlights of Galactic Observations with VERITAS



## **3<sup>rd</sup> Fermi Symposium: Rome**

Brian Humensky

University of Chicago / Columbia University  
for the VERITAS Collaboration

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

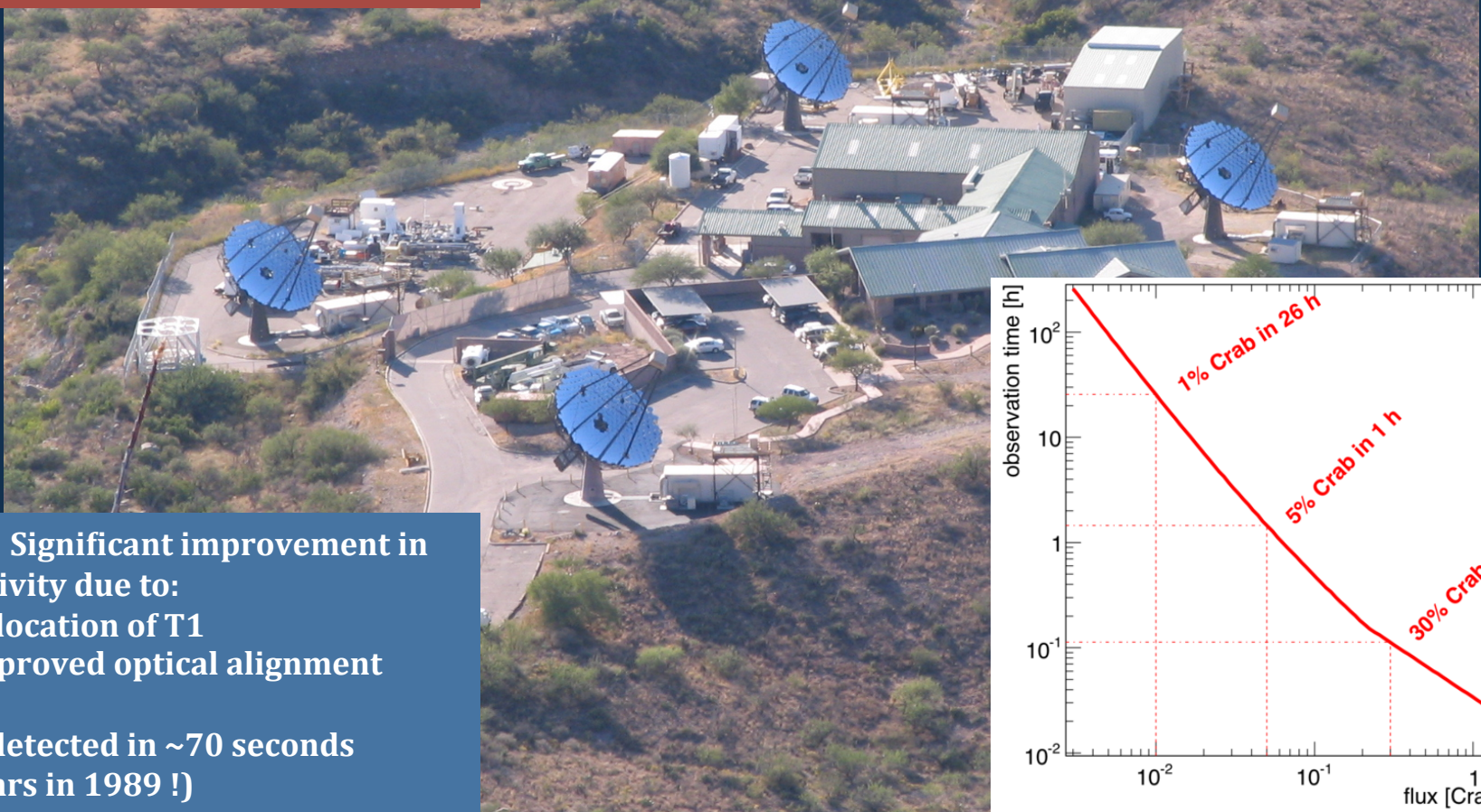
# VERITAS Status and Performance

- ❑ Energy Range: 100 GeV – 30 TeV
- ❑ Energy Resolution: 15% – 25%
- ❑ Crab  $\gamma$ -ray Rate  $\sim 50$  / min (trigger)
- ❑ Angular Resolution:  $r_{68} < 0.1^\circ$
- ❑ Pointing Accuracy:  $< 50''$

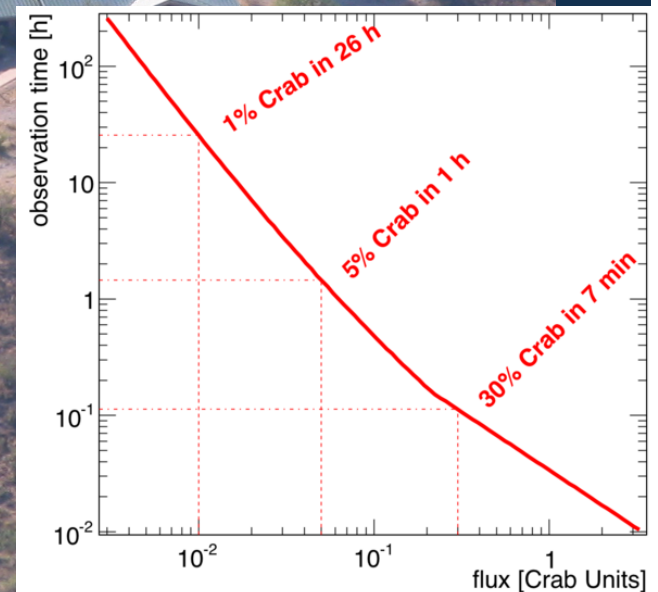
**86 Scientists:**  
22 Institutions in 5  
Countries: US, Canada,  
UK, Ireland, Germany

**+ 35 Associate  
Members**  
incl. theorists, MWL  
partners, IceCube,  
Fermi, Swift, etc.

**Support from:**  
DOE, NSF, SAO (U.S.)  
STFC (U.K.), NSERC  
(Canada)  
SFI (Ireland)



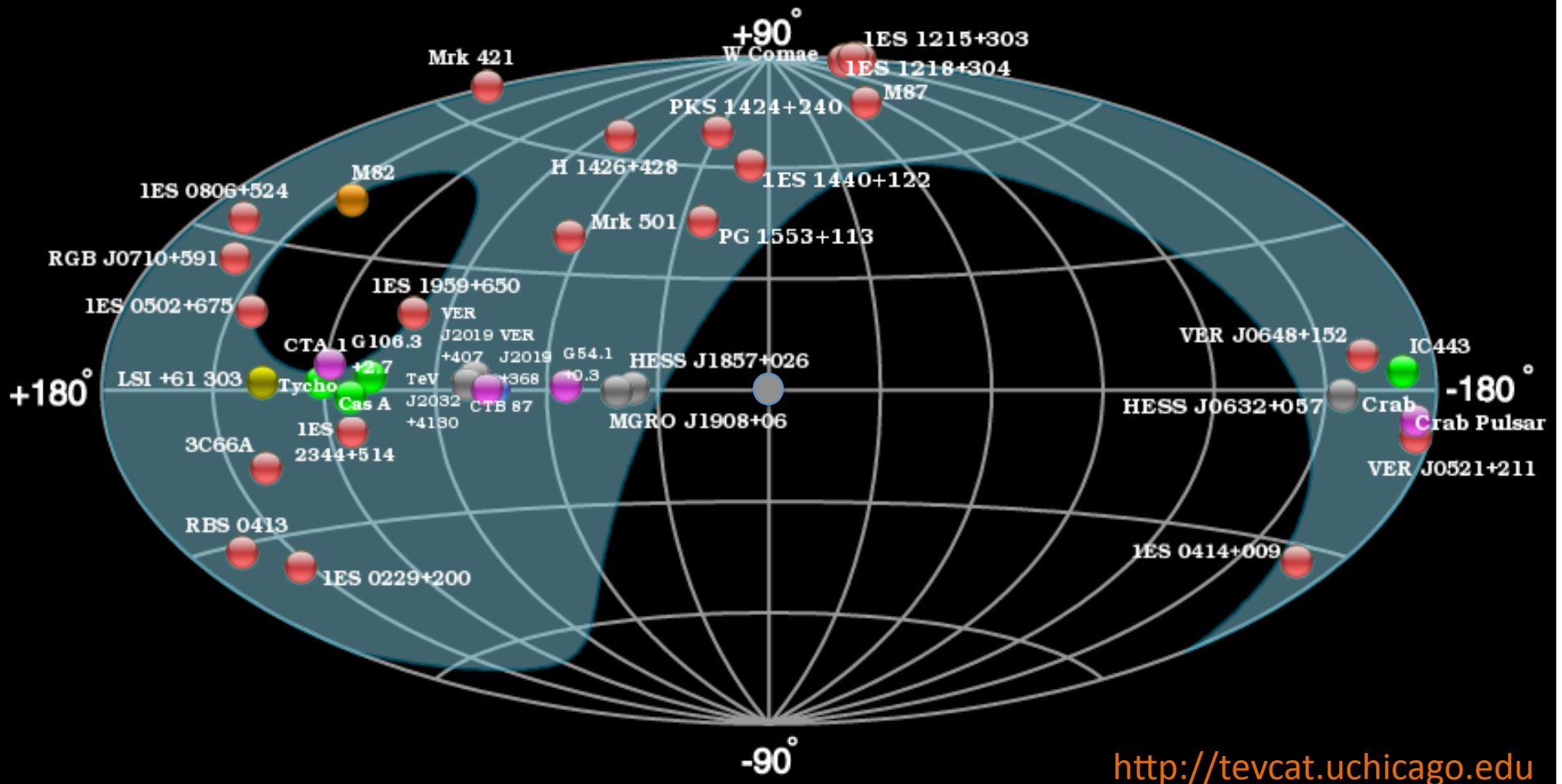
- ❑ 2009: Significant improvement in sensitivity due to:
  - 1) Relocation of T1
  - 2) Improved optical alignment
- ❑ Crab detected in  $\sim 70$  seconds ( $\sim 90$  hrs in 1989 !)





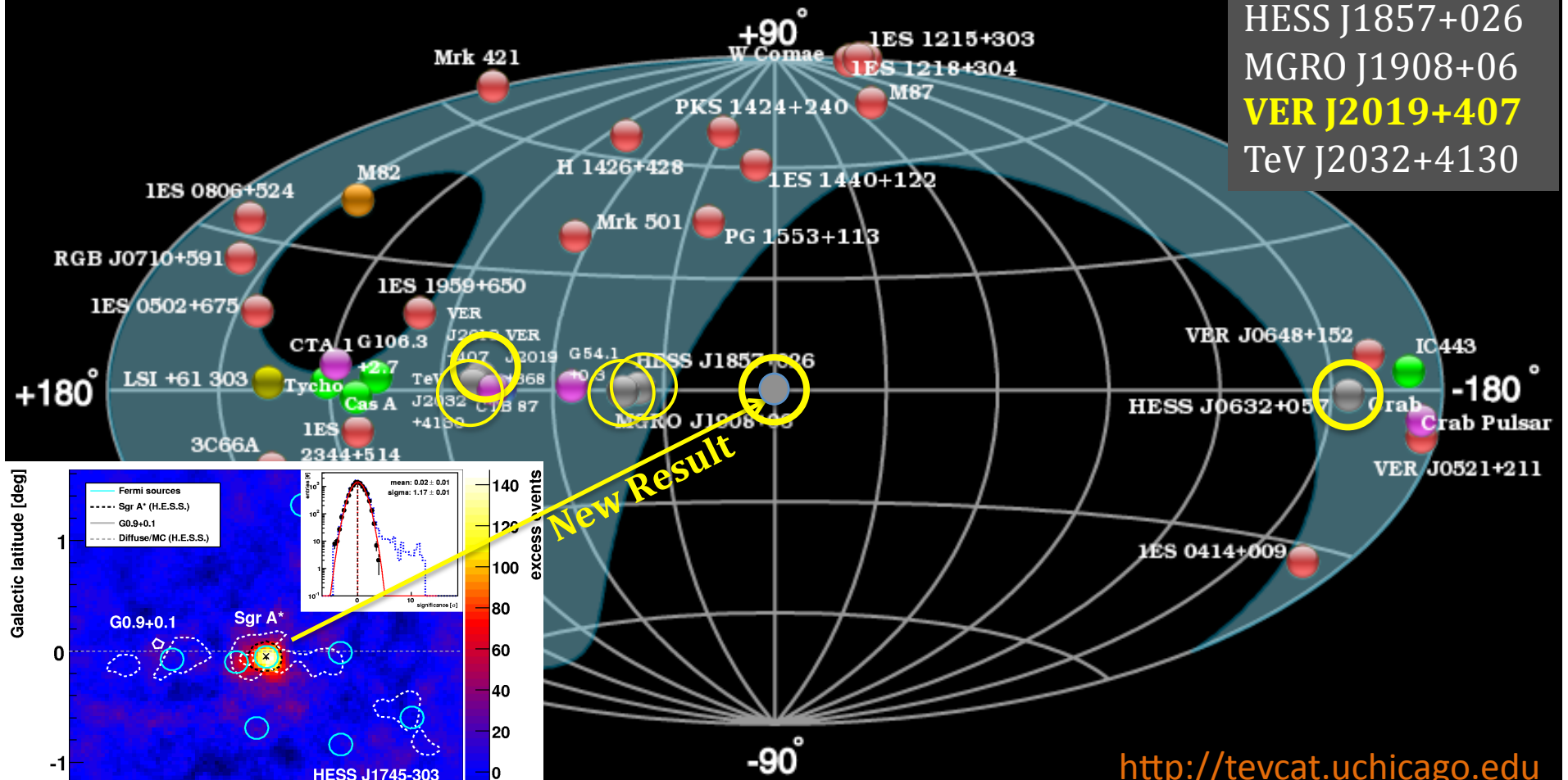
# The VERITAS Sky Map

38 sources covering 8 source classes, at least 16 of which are Galactic (SNRs, PWNe, Binaries, UnIds, Pulsars)

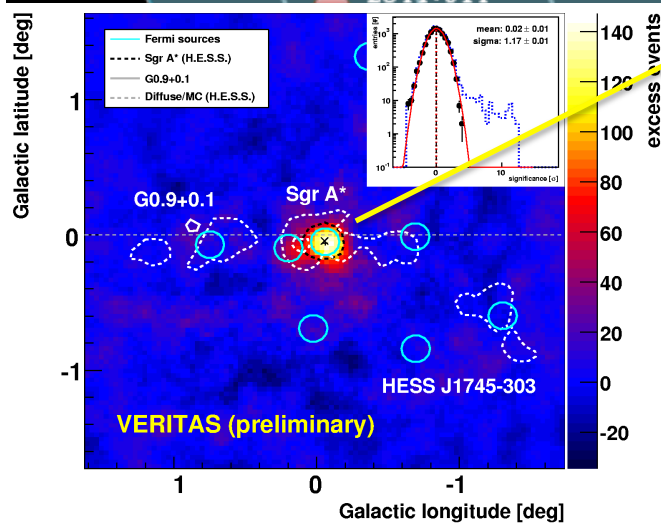


# The VERITAS Sky Map: Unidentifieds

**HESS J0632+057**  
**Galactic Center**  
 HESS J1857+026  
 MGRO J1908+06  
**VER J2019+407**  
 TeV J2032+4130



**New Result**



<http://tevcat.uchicago.edu>

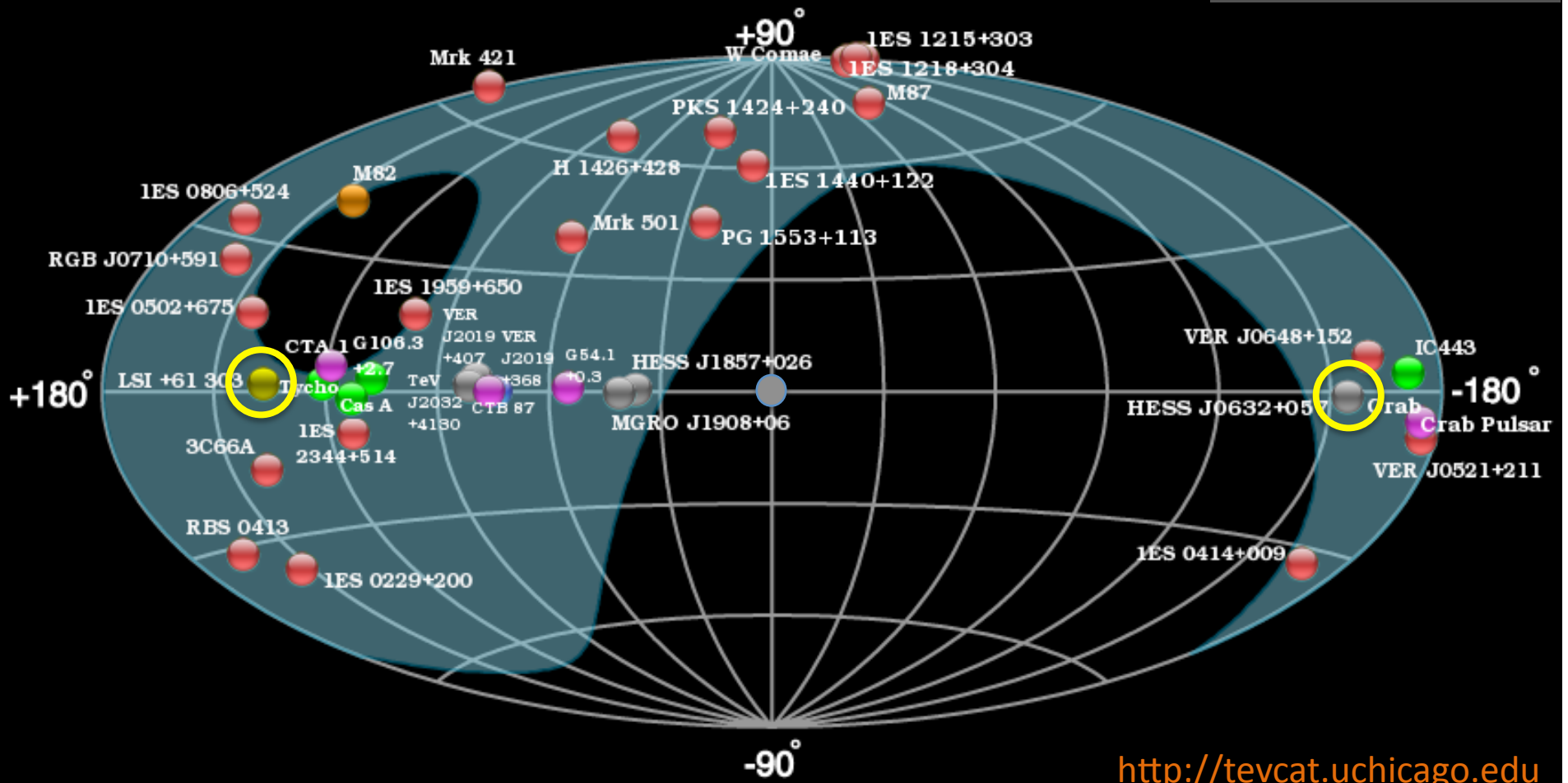
**M. Beilicke: The Galactic Center Region Imaged by VERITAS**

B Humensky: VERITAS Galactic Highlights



# The VERITAS Sky Map: Binaries

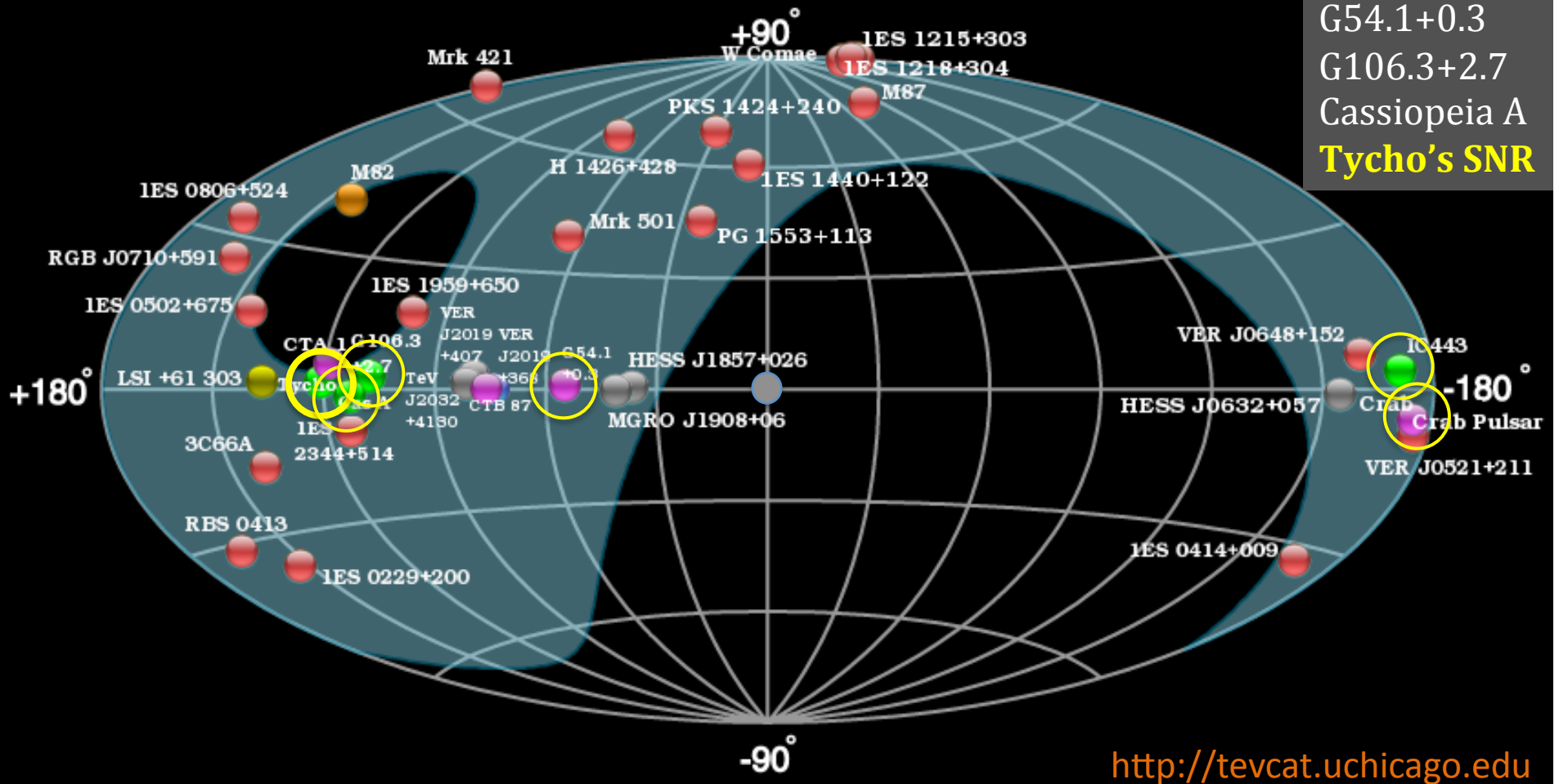
HESS J0632+057?  
LSI +61 303



<http://tevcat.uchicago.edu>

# The VERITAS Sky Map: SNRs and PWNe

Crab Nebula  
 IC 443  
 G54.1+0.3  
 G106.3+2.7  
 Cassiopeia A  
**Tycho's SNR**





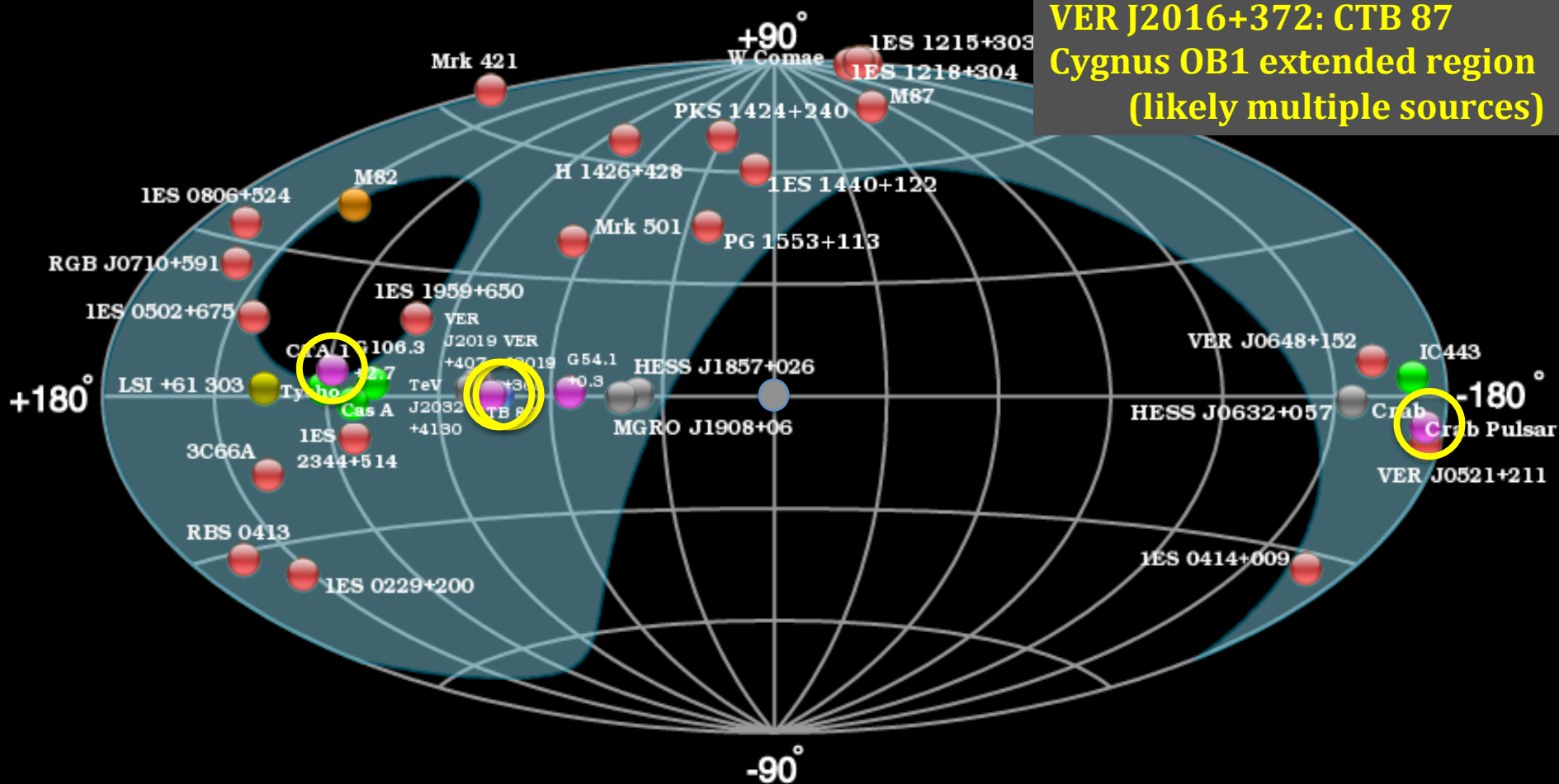
# The VERITAS Sky Map: New

Crab Pulsar

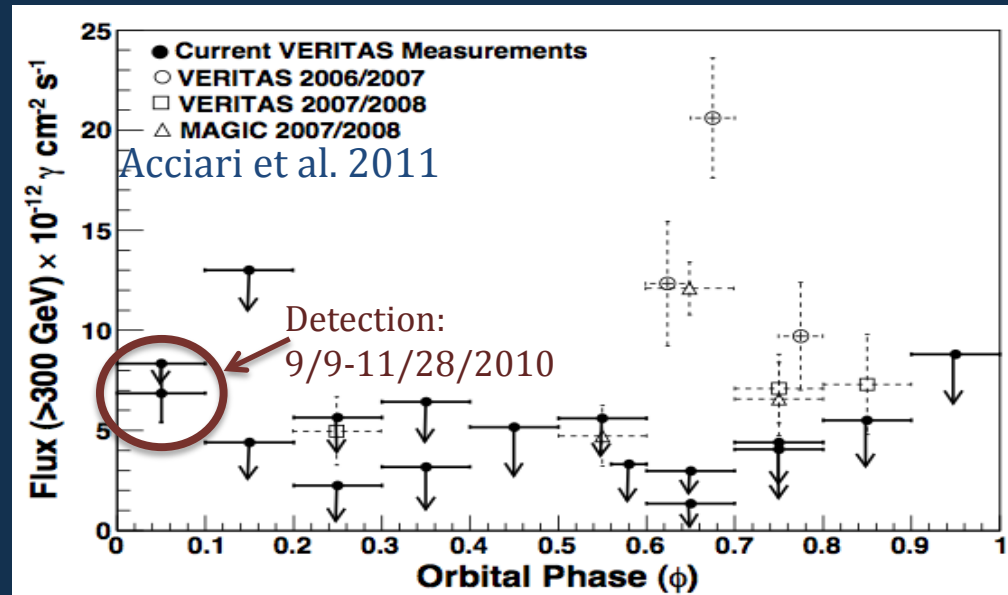
CTA 1

VER J2016+372: CTB 87

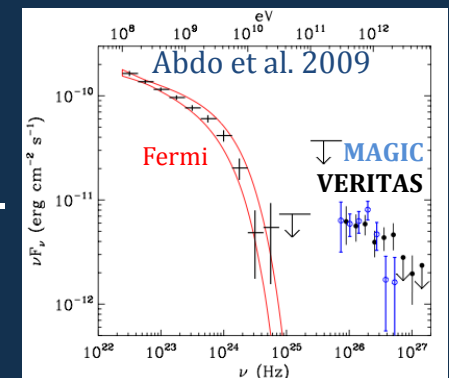
Cygnus OB1 extended region  
(likely multiple sources)



# TeV Reappearance of LS I +61 303



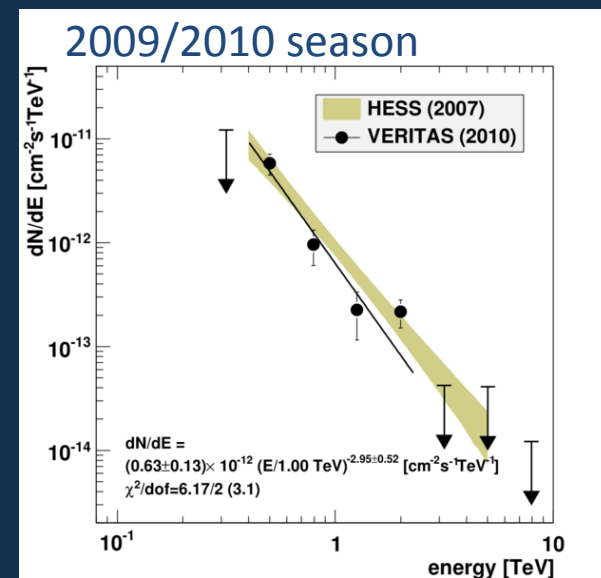
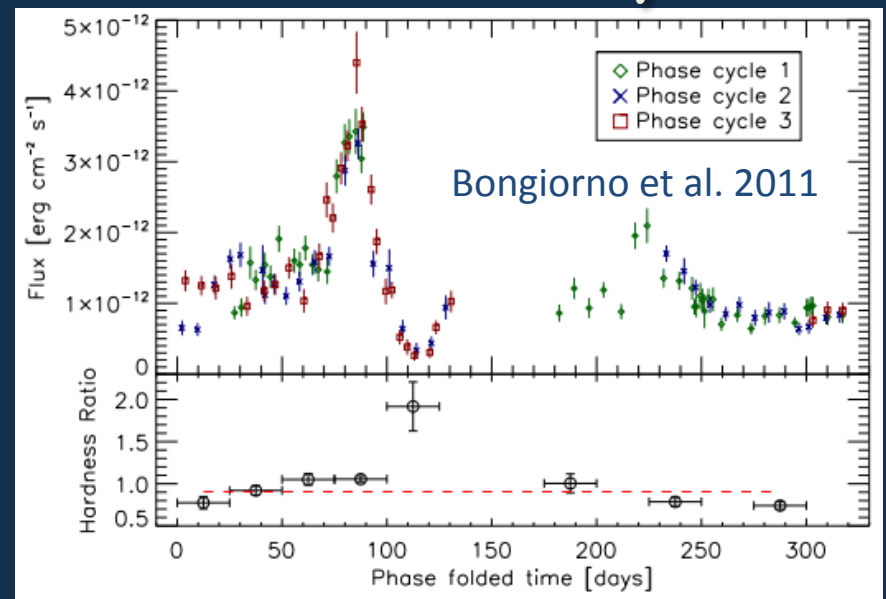
- First detected in TeV by MAGIC in 2005 (Albert et al. 2006) at **apastron**.
- Monitored by VERITAS, MAGIC in following years.
  - Detected again in 2007/08 around apastron.
  - **Silent in 2008/09 and 2009/10!**
- Fermi has detected LS I +61 303 consistently since launch.
  - But 6 GeV cut-off: different component than in TeV?
- VERITAS detection in late 2010 of TeV emission
  - near **periastron!**
- Long-term variability related to circumstellar environment of Be star?





# HESS J0632+057: New TeV Binary?

- Variable point-like TeV source in the Monoceros region.
- Swift X-ray monitoring establishes periodic behavior ( $T = 320 \pm 5$  days, Bongiorno et al. 2011).
- Atel # 3153: VERITAS Obs. Feb 7/8, 2011, triggered by X-ray activity (Atel #3152):
  - >  $8 \sigma$ ,  $F(E > 300 \text{ GeV}) \sim 4\%$  Crab Nebula.
- Confirmed by MAGIC (Atel #3161).

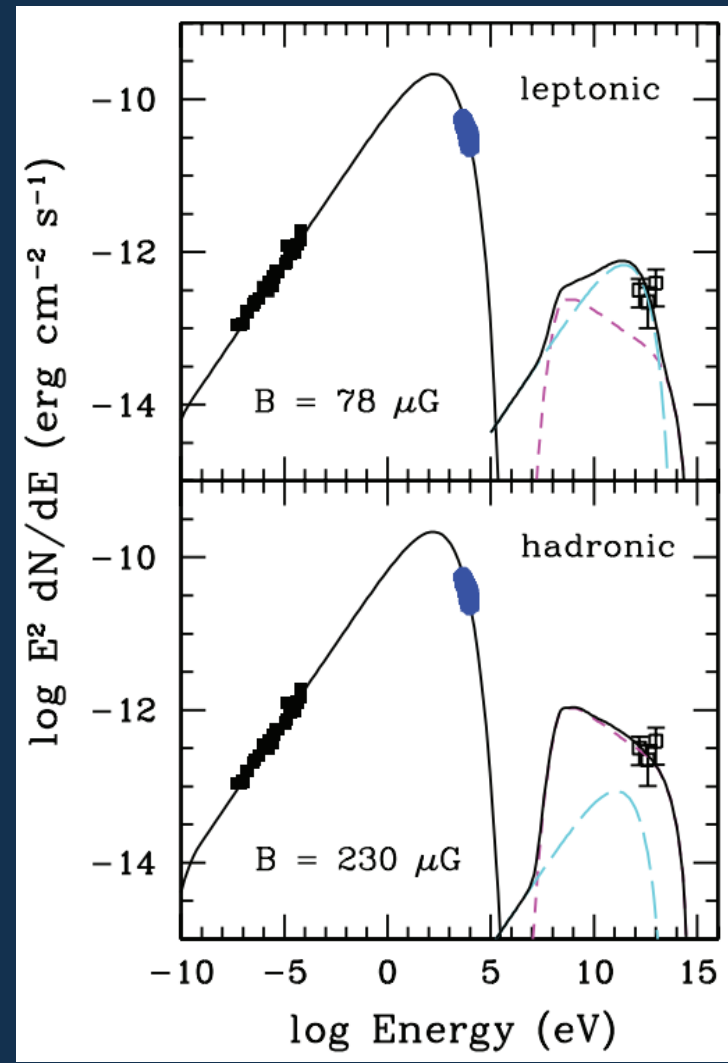
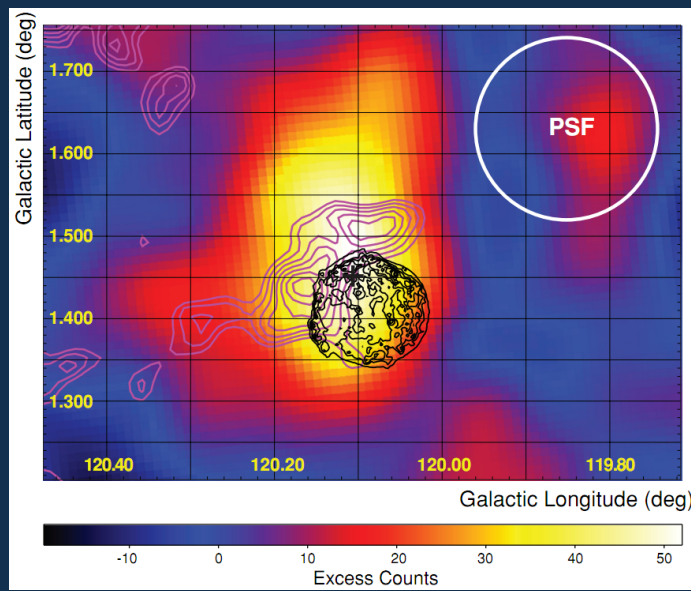


# Tycho's Supernova Remnant

A. Weinstein: Detection of VER J2019+407 (SNR G78.2+2.1) and Tycho's SNR with VERITAS

- Remnant of a Type Ia Supernova event of 1572
- X-ray morphology  $\rightarrow$  efficient hadron acceleration (Warren et al. 05)
- VERITAS:  $5\sigma$  post-trial detection in 68 hrs
- Power-law spectrum:  $\Gamma = 1.95 \pm 0.51_{\text{stat}} \pm 0.30_{\text{sys}}$   
 $F(E > 1 \text{ TeV}) = 0.9\% \text{ Crab}$
- Consistent with leptonic or hadronic models  
 $\rightarrow$  Magnetic field amplification

Acciari et al. 2010

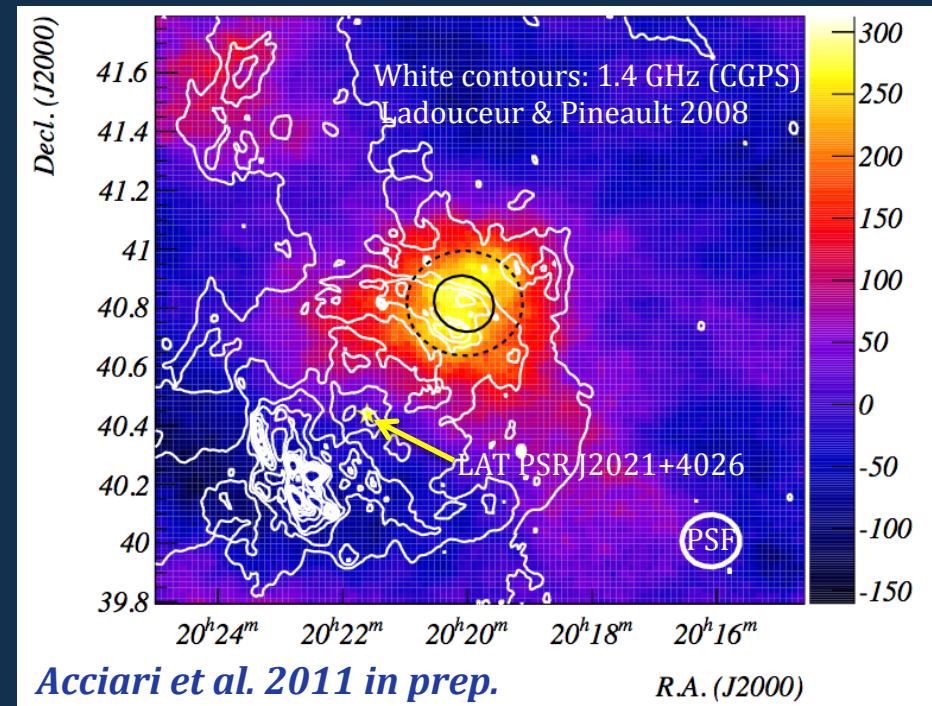




# VER J2019+407 and $\gamma$ Cygni

A. Weinstein: Detection of VER J2019+407 (SNR G78.2+2.1) and Tycho's SNR with VERITAS

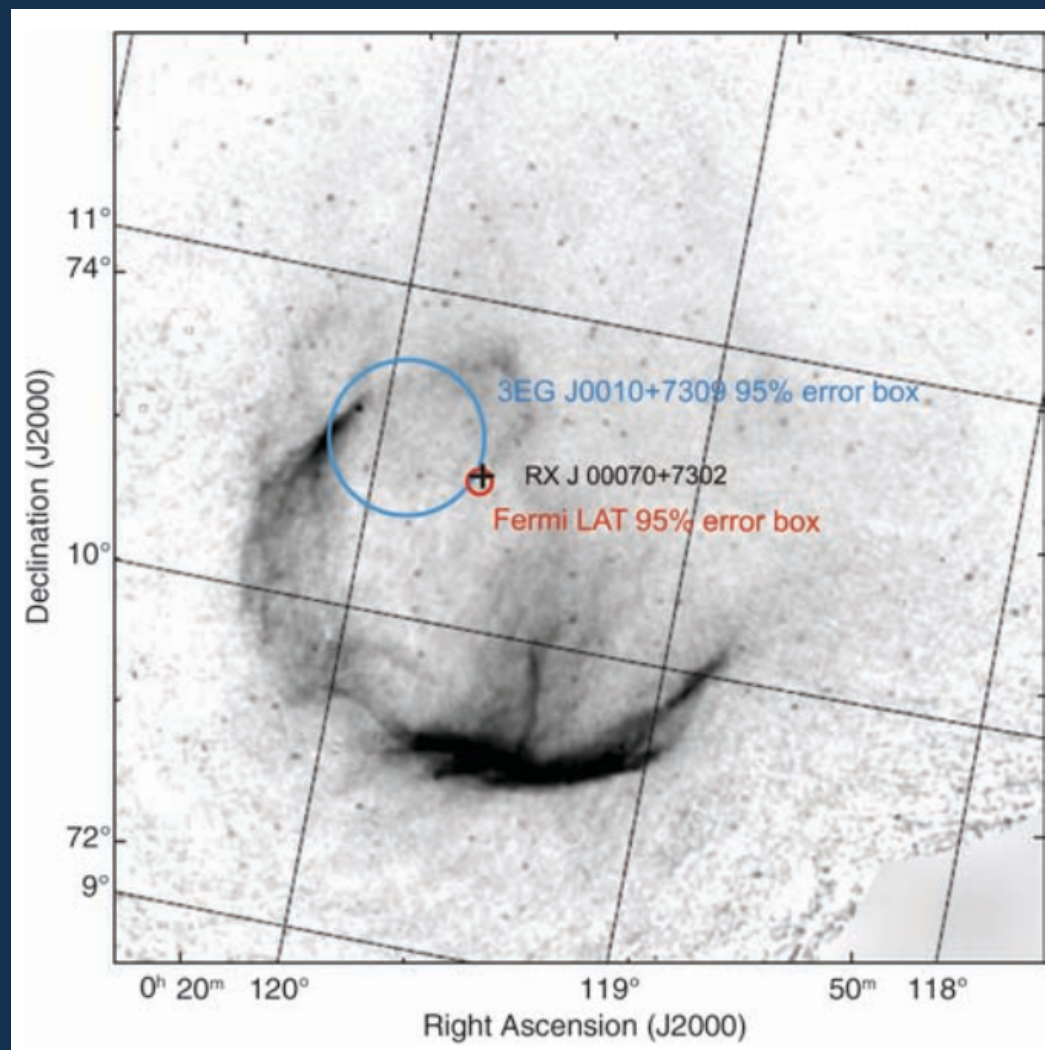
- **G78.2+2.1 ( $\gamma$ -Cygni):**
  - Distance  $\sim 1.5 - 1.8$  kpc, Age  $\sim 5-10$  kyr.
- **VERITAS: 18.6 hrs live time Sep-Nov, 2009.**
  - Detection:  $9.6$  ( $7.5$ )  $\sigma$  pre (post) trials.
  - Extended emission:  $\sigma \sim 0.18^\circ \pm 0.03^\circ_{\text{stat}} \pm 0.02^\circ_{\text{sys}}$
- ***What's driving the TeV emission?***
  - Likely SNR shock interacting with ambient material:
    - Partial HI shell encloses north, west (Gosachinskij 2001).
    - Suggests hadronic emission.
  - Lack of CO: differs from W28, W44, IC 443, W51C, ...



# CTA 1: New TeV PWN

S. McArthur: VHE observation of CTA 1 with VERITAS

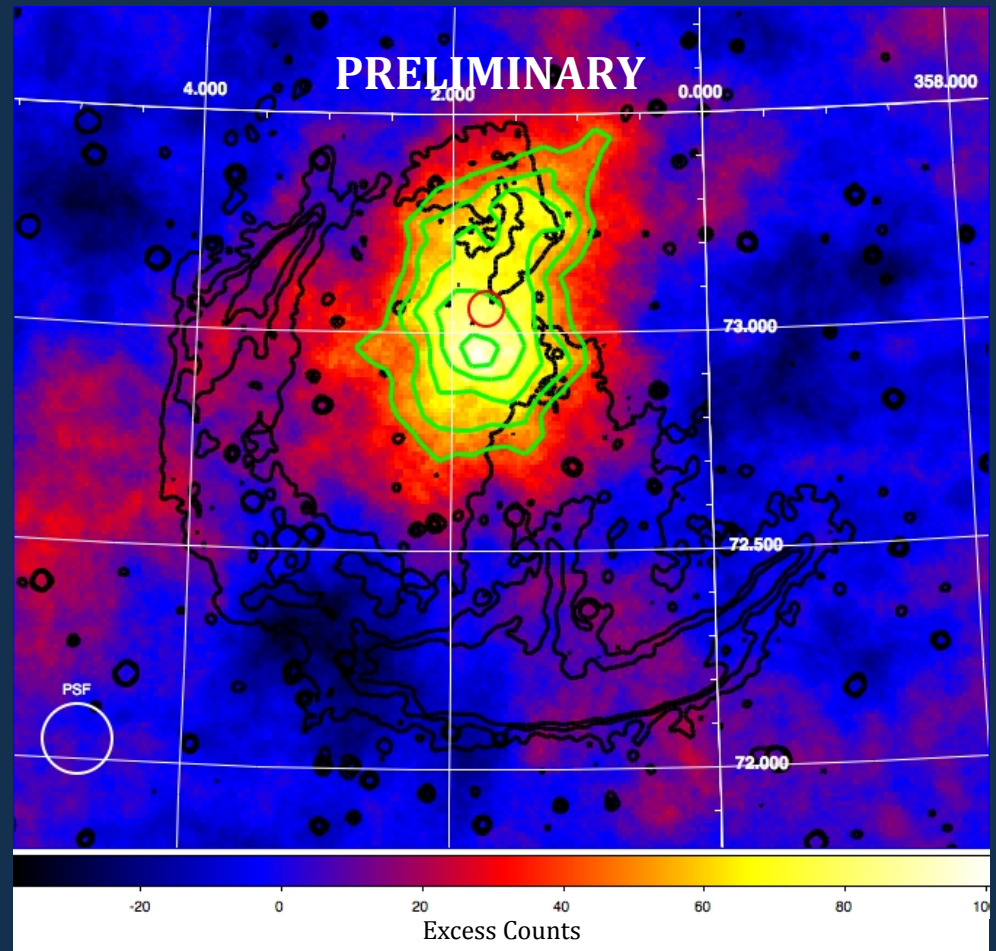
- Composite SNR: radio shell; center-filled X-ray emission.
- Distance:  $1.4 \pm 0.3$  kpc.
- Estimated age:  $\sim 13$  kyr.
- Radio shell diameter  $\sim 1.8^\circ$ .
- Fermi:  $\gamma$ -ray pulsar (1<sup>st</sup> from blind search, Abdo et al. 2008).
- Also now X-ray pulsar (Caraveo et al. 2010).



# CTA 1: New TeV Source

S. McArthur: VHE observation of CTA 1 with VERITAS

- 26.5 hrs observations Oct 2010 – Jan 2011.
- **Detection:  $7.3 \sigma$  /  $6.2 \sigma$  pre-/post-trials.**
- VERITAS excess map:
  - Black contours: Radio 1420 MHz showing SNR shell (T. Landecker).
  - Red Circle: Fermi pulsar error circle.
  - VERITAS  $3\text{-}7\sigma$  contours in green.
- Flux  $\sim 4\%$  Crab Nebula.
- Extended emission.
- **Morphology suggests young PWN.**

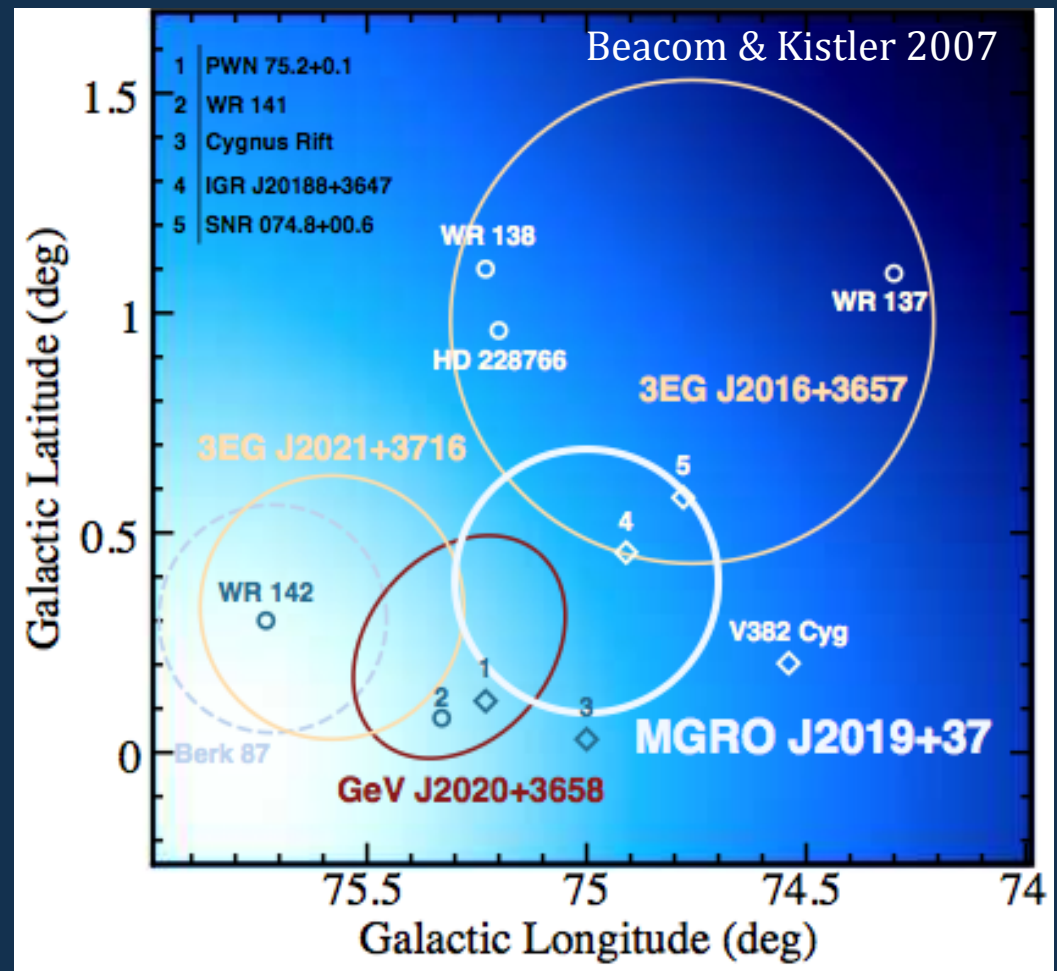




# The Cygnus Region

**E. Aliu:** Discovery of complex TeV emission towards the Cyg OB1 region with VERITAS

- MGRO J2019+37: ~90% Crab Nebula flux at 20 TeV (Smith et al. 2010).
  - **Morphology: likely extended or multiple sources (Abdo et al. 2007).**
- Lively region:
  - Energetic young pulsar PSR J2021+3651.
  - Several GeV sources in the region.
  - Several Wolf-Rayet stars.
    - Colliding winds.
- VERITAS Observations: 75 hrs May-December, 2010.
  - Follow up hints from VERITAS Sky Survey.
  - **Two new detections to report!**



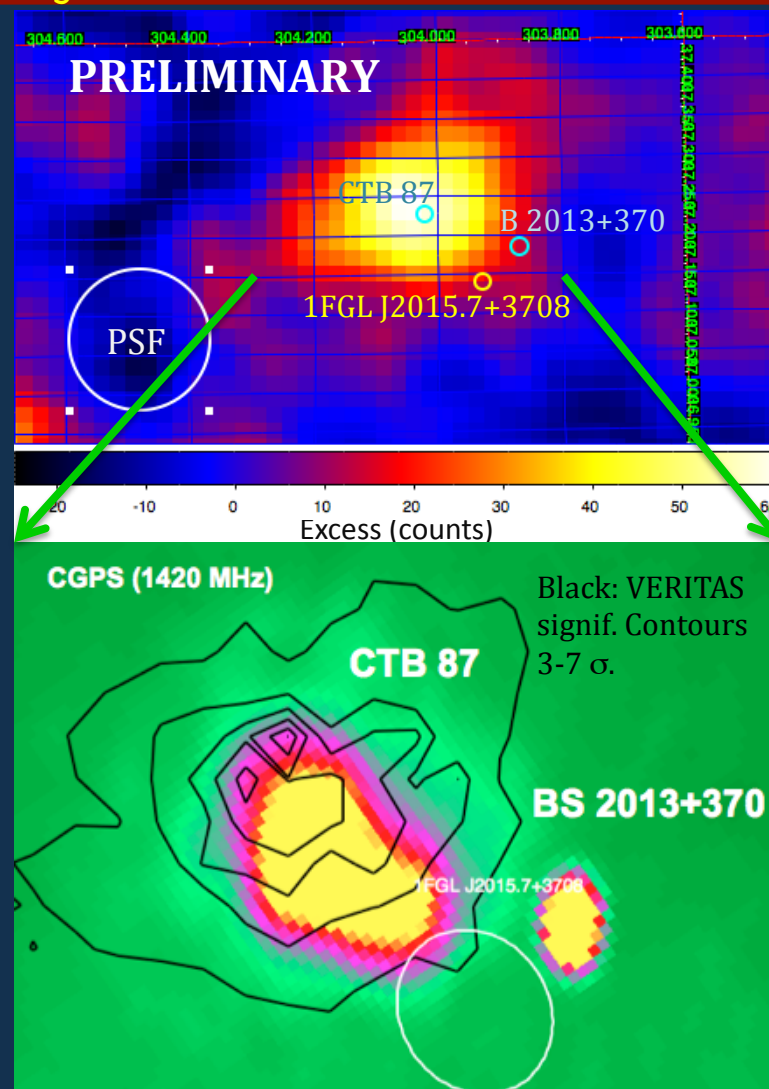


# The Cygnus Region: CTB 87

E. Aliu:

Discovery of complex TeV emission towards the Cyg OB1 region with VERITAS

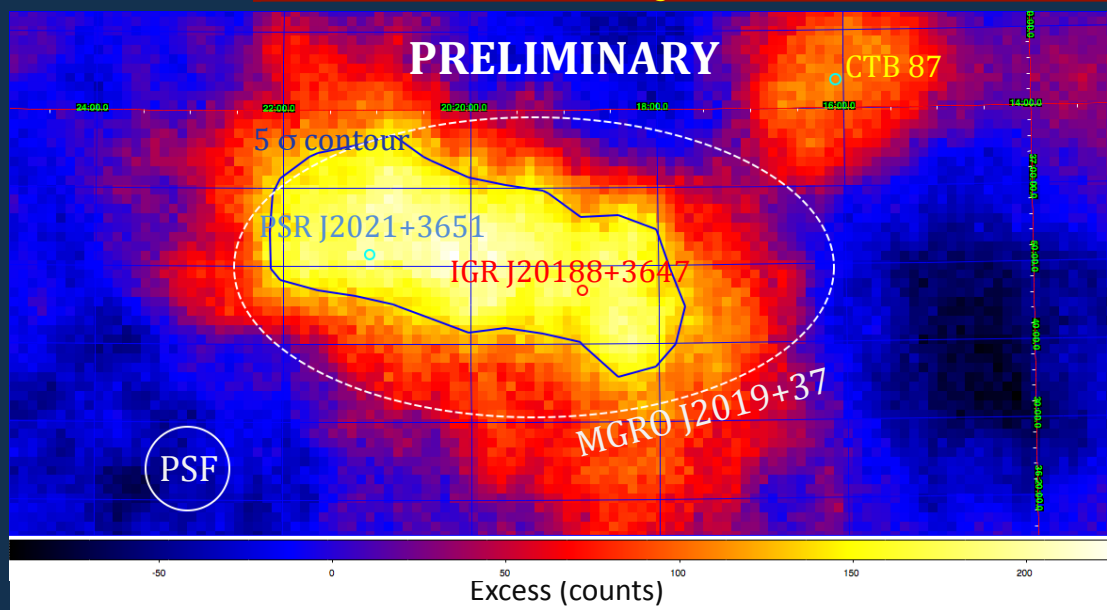
- Point-like source detected coincident with the CTB 87 PWN.
  - **VER J2016+372**:  $6.2 \sigma$  ( $6.1 \sigma$  post-trials).
- $F(E > 1 \text{ TeV}) \sim 0.8\%$  Crab Nebula.
- Can exclude at 99% level the blazar B 2013+370.
  - 1FGL J2015.7+3708 is variable  
→ likely assoc. with blazar.



# The Cygnus Region: Cyg OB1

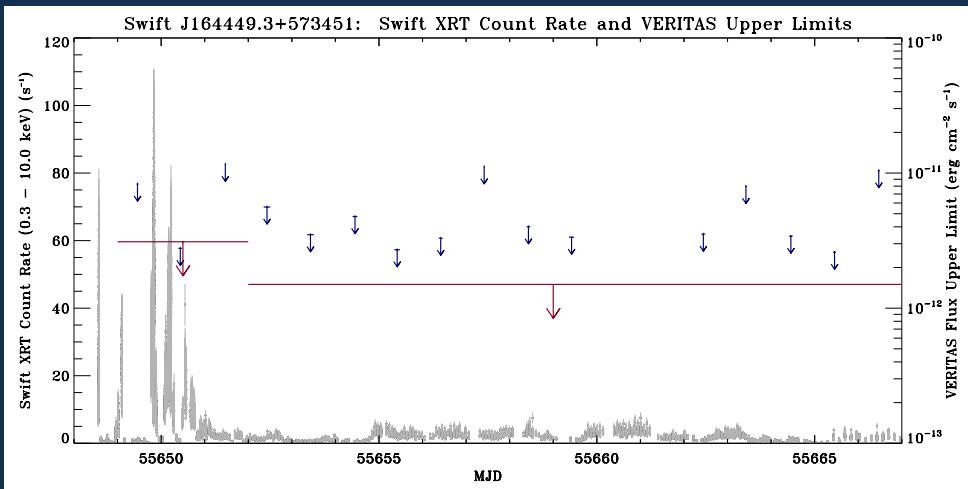
E. Aliu:

Discovery of complex TeV emission towards the Cyg OB1 region with VERITAS

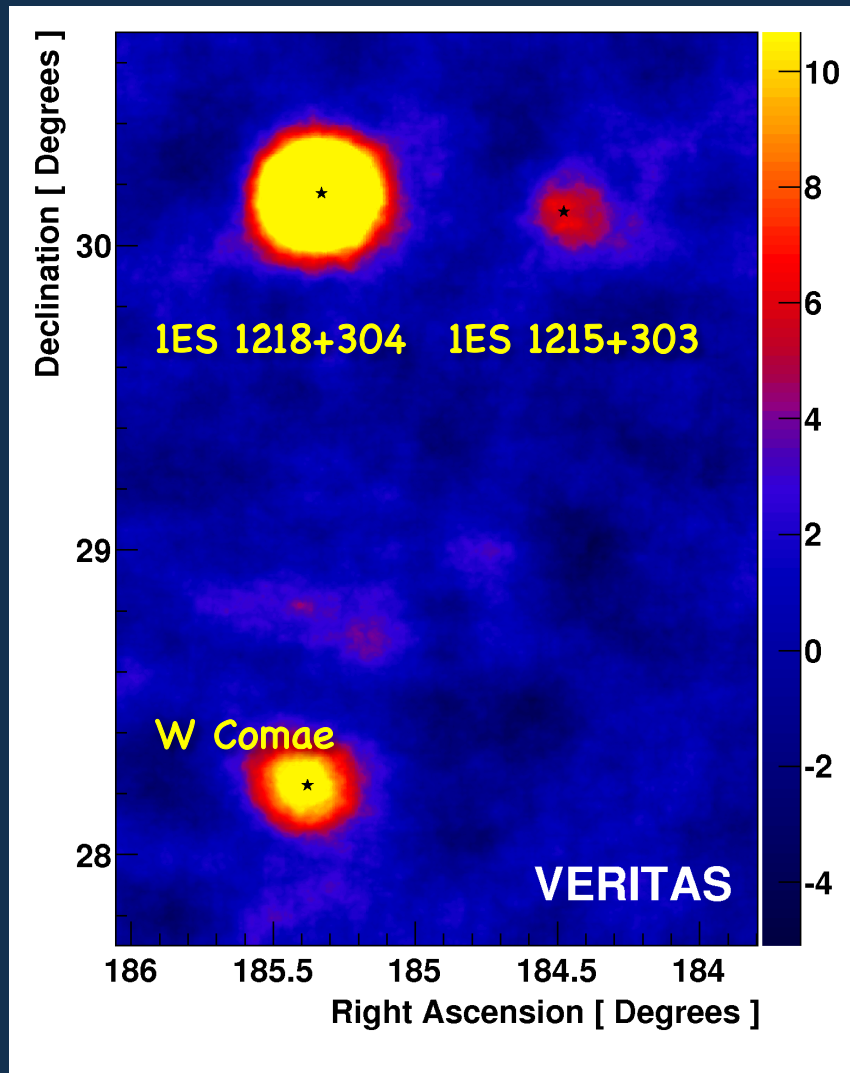


- Broad emission region detected in extended-source analysis (0.23° integration radius, 650 GeV threshold).
- **Broad TeV Excess:** 8.3  $\sigma$  peak significance (7.4  $\sigma$  post-trials).
- Coincides with MGRO J2019+37 (dashed ellipse).
- Substructure and/or multiple sources? Under evaluation.

# Tangent: Extragalactic Highlights



- **Swift J164449.3+573451:** unusual transient at  $z \sim 0.35$ :
  - VERITAS observations during flare and quiescent period following.
    - Paper to be submitted soon.
- **Crowded extragalactic region:** 3 blazars in one FoV.



# VERITAS Upgrade Plan (2010–2012)

## TRIGGER Upgrade: Fall 2011

Smaller coincidence window

Topological Trigger

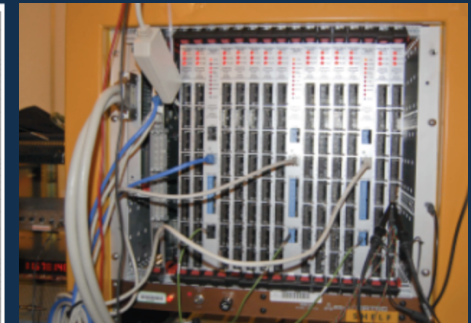
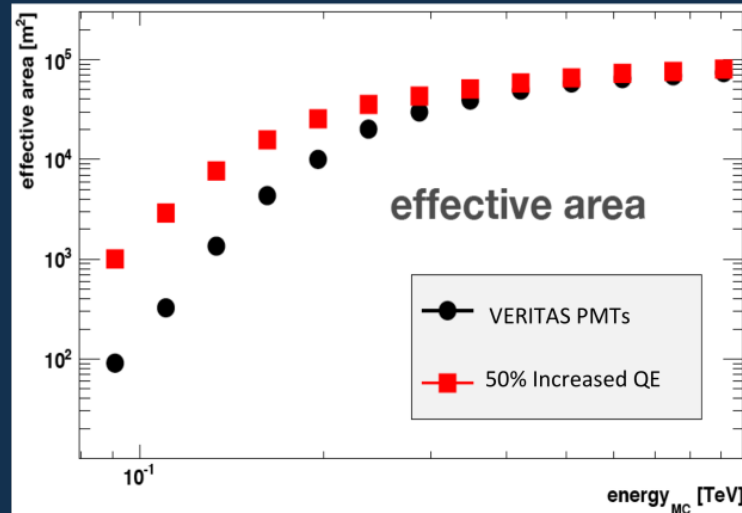
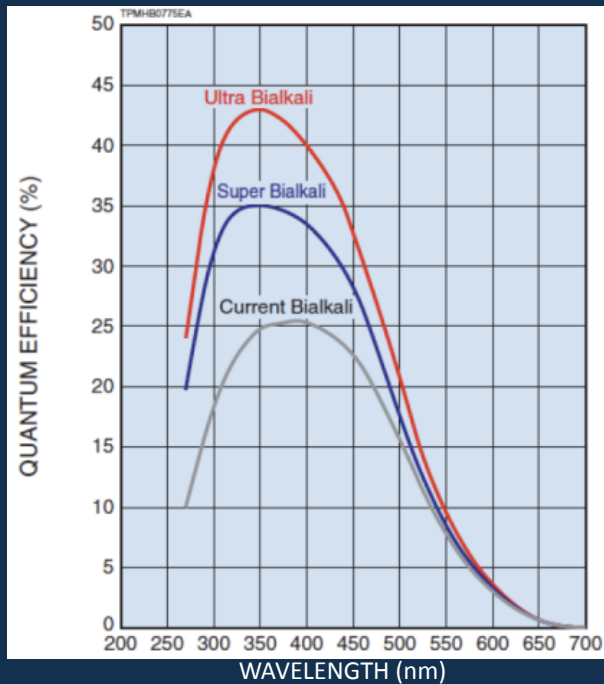
Improves  $E_{th}$  and CR event rejection.

## CAMERA Upgrade: Summer 2012

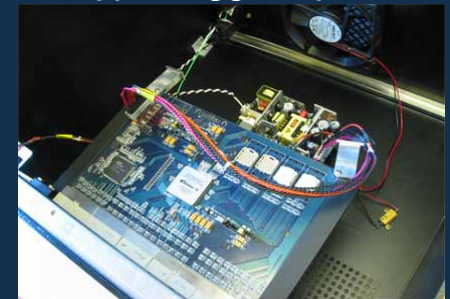
PMT replacement with high efficiency PMTs.

Increase photon collection by  $\sim 35\%$ .

Improves background rejection,  $E_{th}$ , sensitivity.



Prototype Trigger Systems



**Upgrade funded, will be completed during Summer 2012.**



# Summary

- ***New Discoveries:***

- Cygnus OB1 extended region
- CTB 87
- CTA 1

- ***Key new results for Fermi:***

- Crab Pulsar
- Galactic Center
- VER J2019+407 ( $\gamma$ Cygni), CTA 1, Tycho's SNR
- LS I +61 303

- ***VERITAS Upgrade on the horizon:***

- Lower threshold, increased effective area, improved sensitivity beginning Fall 2012.

- ***Galactic Contributions:***

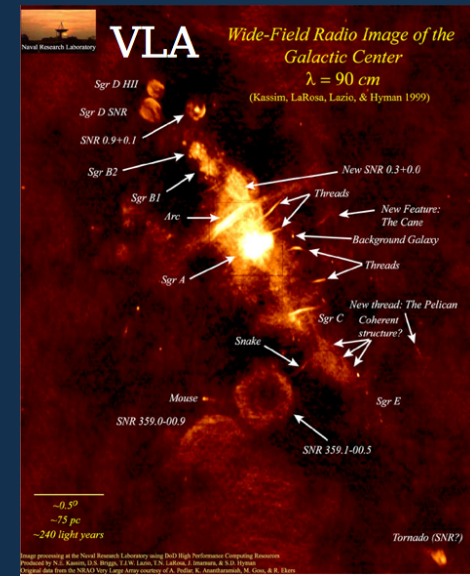
- Talk: S. McArthur, VHE observation of CTA 1 with VERITAS
- Poster: E. Aliu, Discovery of complex TeV emission towards the Cyg OB1 region with VERITAS
- Talk: M. Beilicke, The Galactic Center Region Imaged by VERITAS
- Poster: A. Weinstein, Detection of VER J2019+407 (SNR G78.2+2.1) and Tycho's SNR with VERITAS
- **VHE observation of the Crab pulsar with VERITAS**
  - **Talk: N. Otte, today at 16:30**
- ***Also extragalactic and technical posters:***
  - M. Errando, VHE observations of Fermi motivated targets with VERITAS
  - G. Senturk, GeV/TeV blazar population studies
  - N. Galante, The VERITAS extragalactic science program
  - N. Galante, VERITAS recent results on the flaring activity of M 87
  - M. Vivier, Indirect searches for DM annihilations toward dSph galaxies with VERITAS
  - E. Collins-Hughes, The Whipple 10m blazar monitoring campaign
  - G. Finnegan, Orbit Mode Observation Technique Developed for VERITAS

Backup Slides

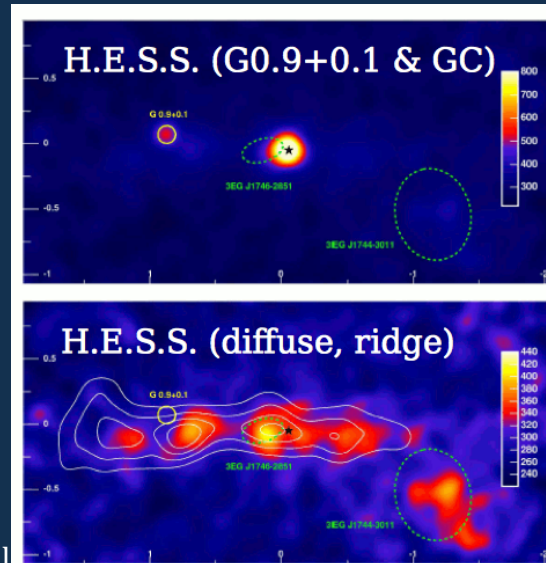
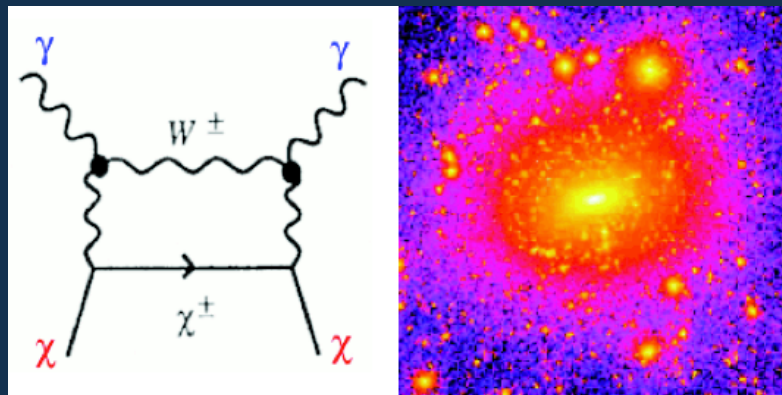
# The Galactic Center

M. Beilicke: The Galactic Center Region Imaged by VERITAS

- Galactic center:- SgrA\* (radio source):  $\sim 4 \times 10^6$  solar mass BH
- Cosmic rays, SNR & plerions:- Increased level of CR activity & MCs Aharonian et al., Nature, 439, 695 (2006)- SNRs (e.g. Sgr A East) or plerions in GC Wang et al., MNRAS, 367, 937 (2006)
- Transients:- 5 X-ray transients: 2-10 keV peak:  $\sim 10^{35}$  ergs/s- Recent flares (X-ray/MeV/GeV): Swift/XRT, MAXI/GCS, Fermi/LAT, Integral ATels: 2690, 2770, 2770, 3123, 3162, 3163, 3183
- Dark matter(?):- Neutralino annihilation: g-ray continuum+line Jungman et al., Phys.Rep., 267, 195 (1996)- g-ray flux calculations for NWF halo profile: Buckley & Jungman (1995), Bergstrom et al, Aph, 9,137(1998)



Kassim et al. (1999)

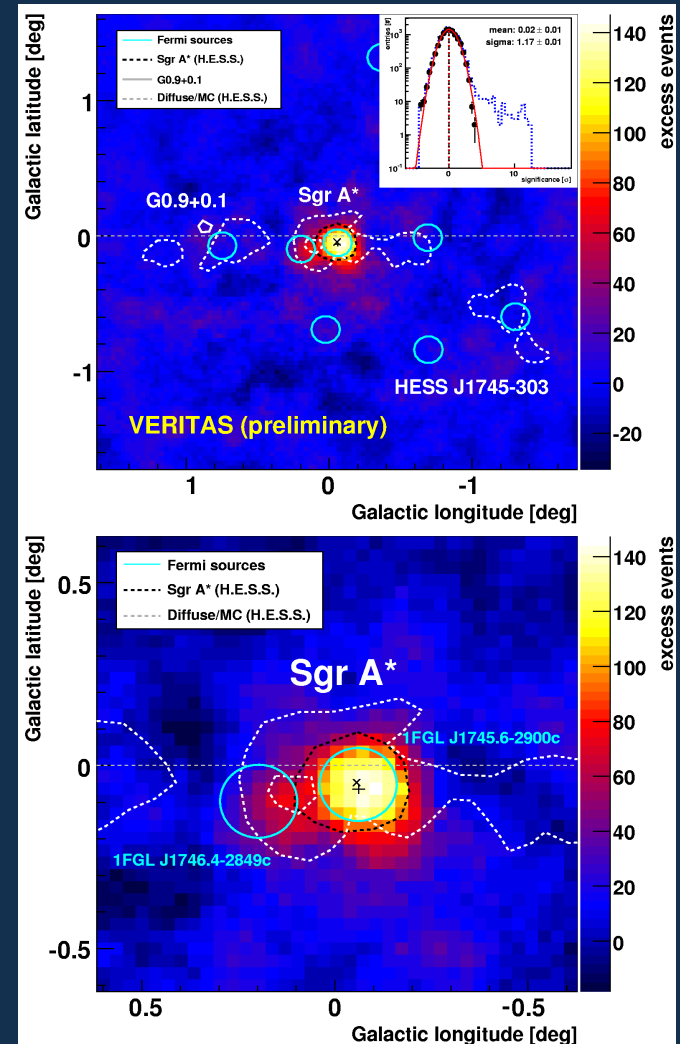
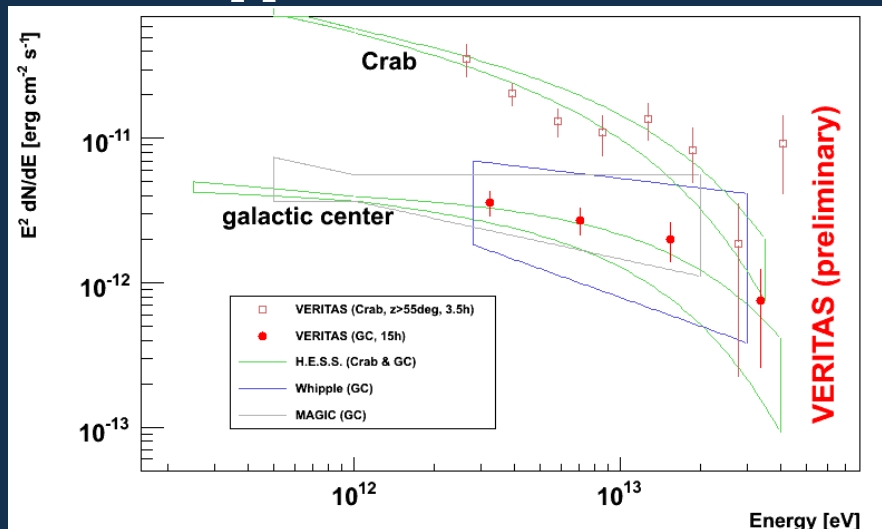


Aharonian, et al. (2006)

# The Galactic Center

M. Beilicke: The Galactic Center Region Imaged by VERITAS

- Sky map: - Excess @ GC pos.: long:  $-0.06 \pm 0.02$ , lat:  $-0.06 \pm 0.01$  - G 0.9+0.1 at the level of 2-3 std.dev.- Overlay: HESS (GC+diffuse) & Fermi sources [http://fermi.gsfc.nasa.gov/ssc/data/access/lat/1yr\\_catalog/](http://fermi.gsfc.nasa.gov/ssc/data/access/lat/1yr_catalog/)
- Energy spectrum:- Very preliminary! Use Crab LZA spectrum (~contemporary data) to estimate systematics- Compatible with H.E.S.S., Whipple & MAGIC





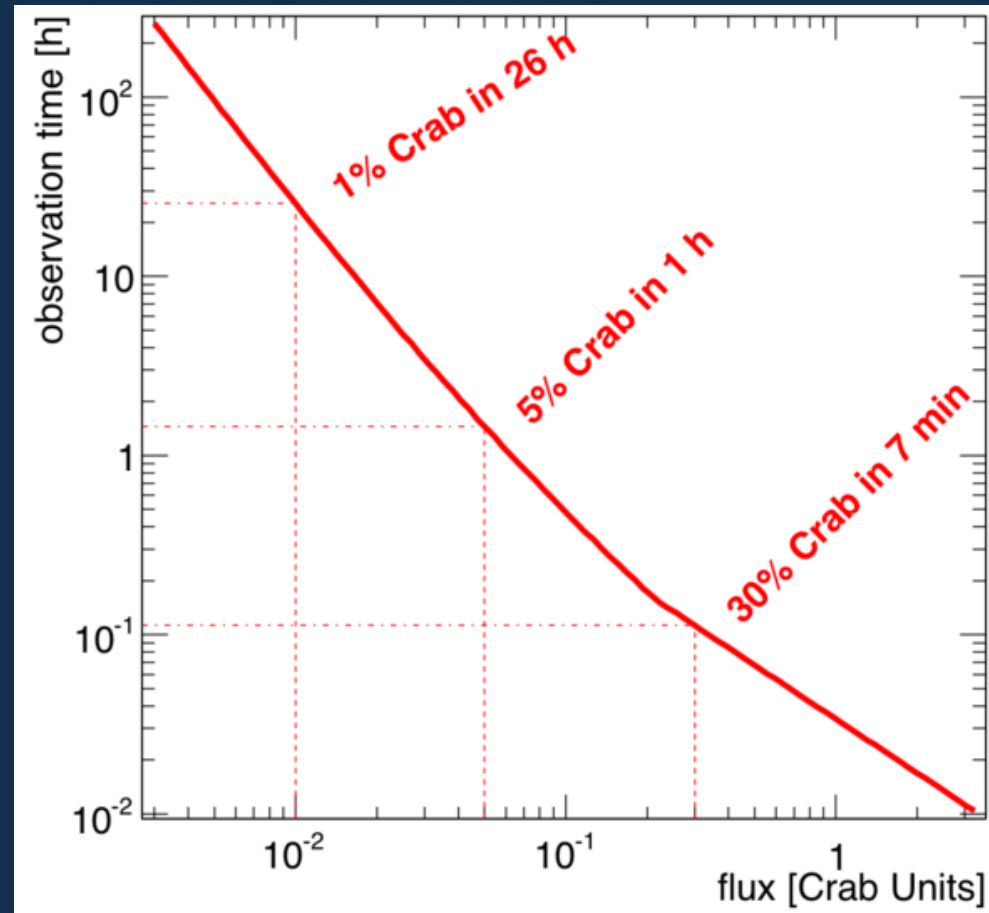
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- ❑ 2009: Significant improvement in sensitivity due to:
  - 1) Relocation of T1
  - 2) Improved optical alignment
- ❑ Crab detected in  $\sim 70$  seconds ( $\sim 90$  hrs in 1989 !)
- ❑ Fall 2011: Trigger system upgrade
- ❑ Summer 2012: PMT upgrade
  - Increase light yield by 35%



# The VERITAS Collaboration

## **86 Scientists:**

22 Institutions in 5  
Countries: US, Canada,  
UK, Ireland, Germany

## **+ 35 Associate Members**

incl. theorists, MWL  
partners, IceCube, Fermi,  
Swift, etc.

## **Support from:**

DOE, NSF, SAO (U.S.)  
STFC (U.K.), NSERC  
(Canada)  
SFI (Ireland)

