Results from VERITAS

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for the VERITAS Collaboration

SLAC Summer Institute,
Aug. 14, 2008

VERITAS Status: Complete!

- Smithsonian Astrophysical Observatory
- Purdue University
- Iowa State University
- Washington University in St. Louis
- University of Chicago
- University of Utah
- University of California, Los Angeles
- McGill University, Montreal
- University College Dublin
- University of Leeds
- Adler Planetarium
- Argonne National Laboratory
- Barnard College
- dePauw University
- Bartol Research Institute/ University of Delaware
- Grinnell College
- University of California, Santa Cruz
- University of Iowa
- University of Massachusetts
- Cork Institute of Technology
- Galway Mayo Institute of Technology
- National University of Ireland Galway

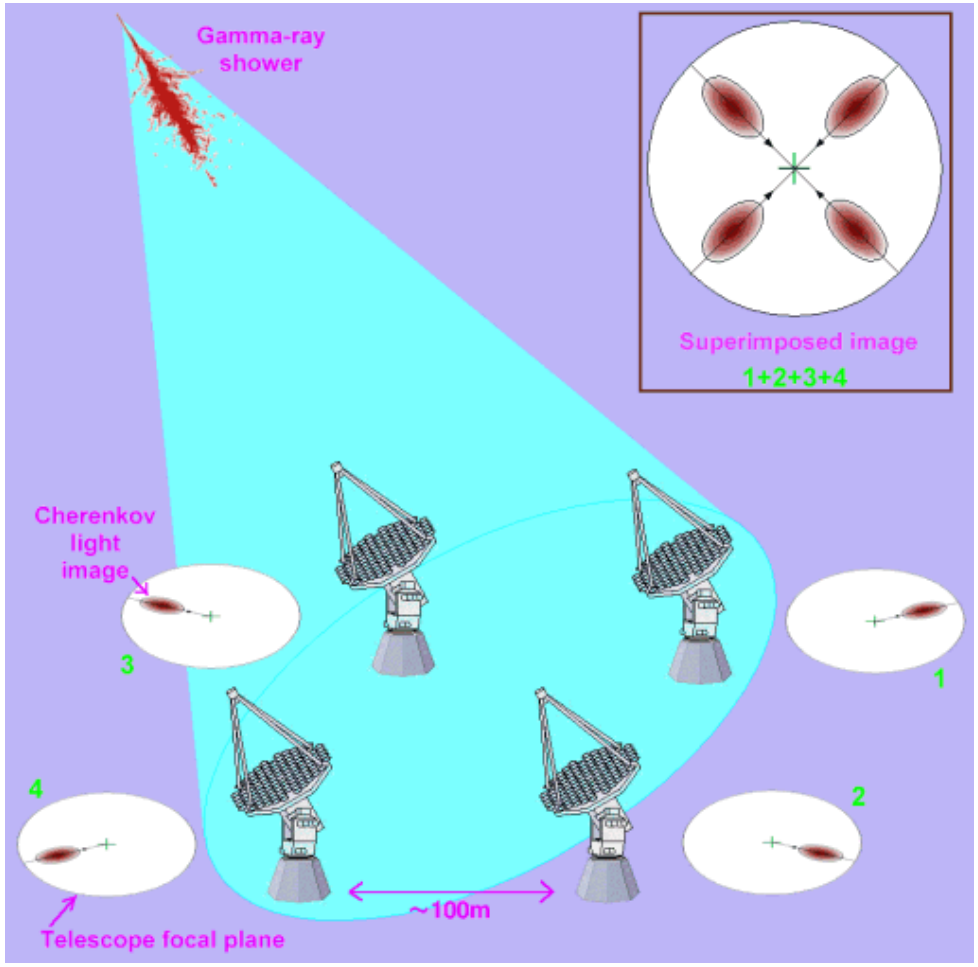
- ~25 Associate Members

Outline

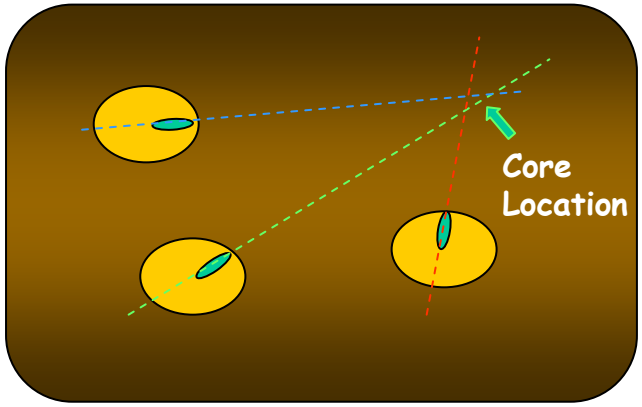
- **Introduction to VERITAS**
  - Technique
  - Instrument
    - *Design*
    - *Performance, recent operations*
  - Science Overview
- **Highlight results**
- **Summary and future prospects**

Cherenkov Telescope Arrays

IACT, ~50GeV-50TeV

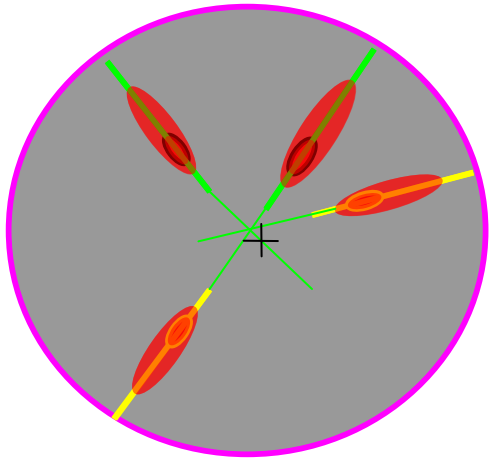


Stereoscopic viewing



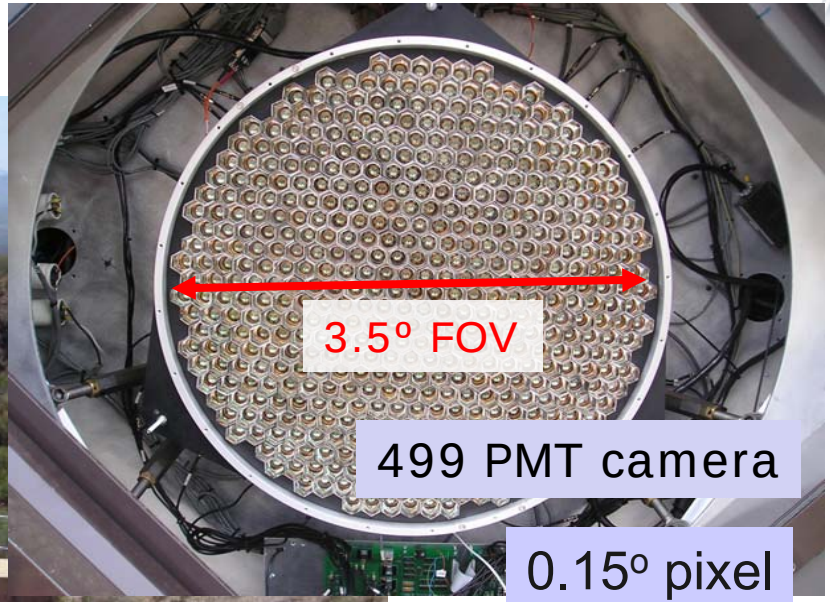
Core Reconstruction (< 15m)

Energy reconstruction



Direction Reconstruction (<0.1°)

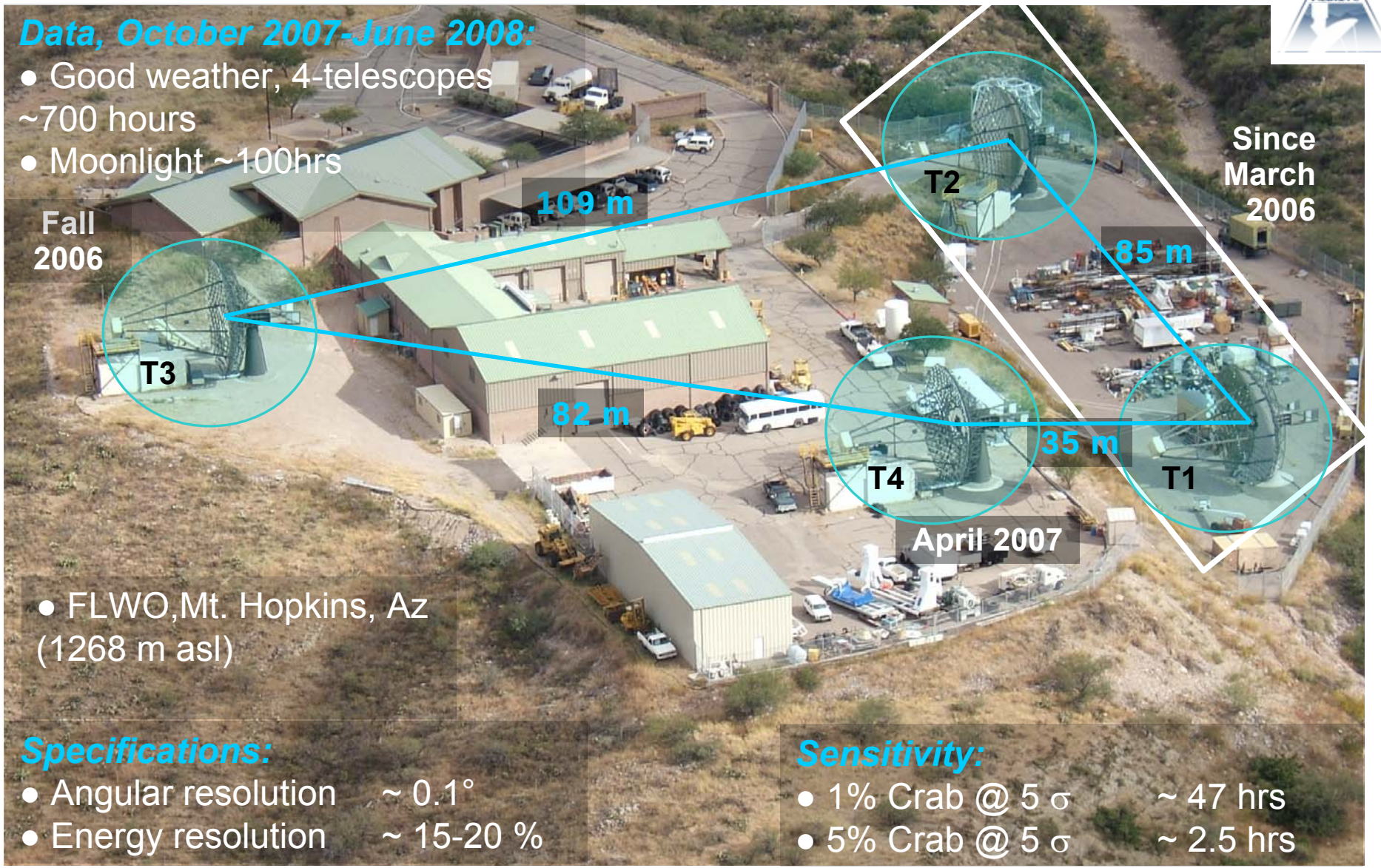
Telescope and Camera



Telescope Electronics

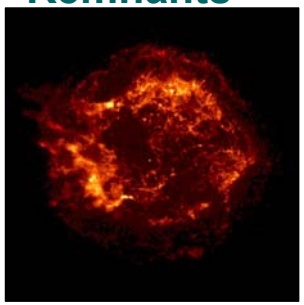
- 500 MS/s FADCs
- 3-tier trigger system

VERITAS at Whipple Observatory



VERITAS Science Program

Supernova Remnants

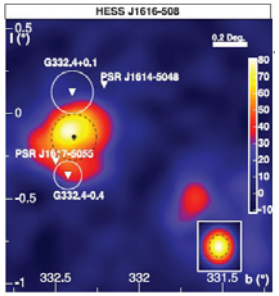


Pulsars/PWN

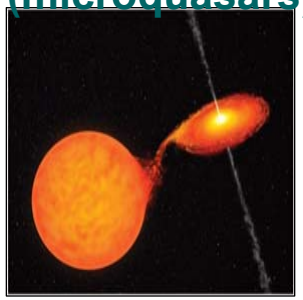
SNR/PWN Key Science Project

Cygnus Region Sky Survey (forthcoming)

Dark accelerators…

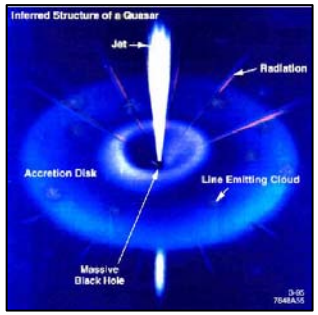


HMXBs (microquasars)



(targeted observations)

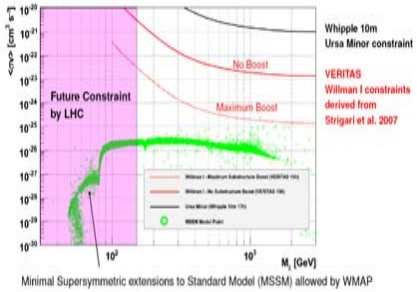
Active Galactic Nuclei



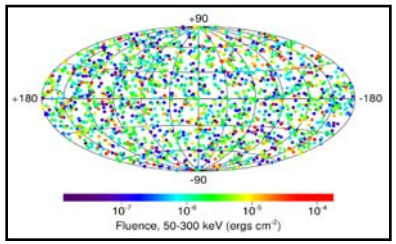
Blazar Key Science Project

Non-blazar AGN

Extragalactic non-blazars (non-blazar AGN, Auger hotspots, galaxy clusters …)



Indirect Dark Matter Searches (KSP)



Gamma-Ray Bursts

Discoveries (Mar 2008):

- 1ES0806+524 (blazar)
- W Comae (first IBL!)

Detections (Jan-Jul 2008):

- 1ES2344+514 (blazar, TeV flare correlated with X-ray)
- Supernova remnant Cas A
- MGRO J1908+06 (unidentified)

Updates:

- M87, Mrk 421 MWL campaigns
- 1ES1218+304 de-absorbed spectra
- IC443, measurement of source extension

Upper limits & constraints:

Auger hotspots, dark matter, AGILE 2021+4024

2007 observations:

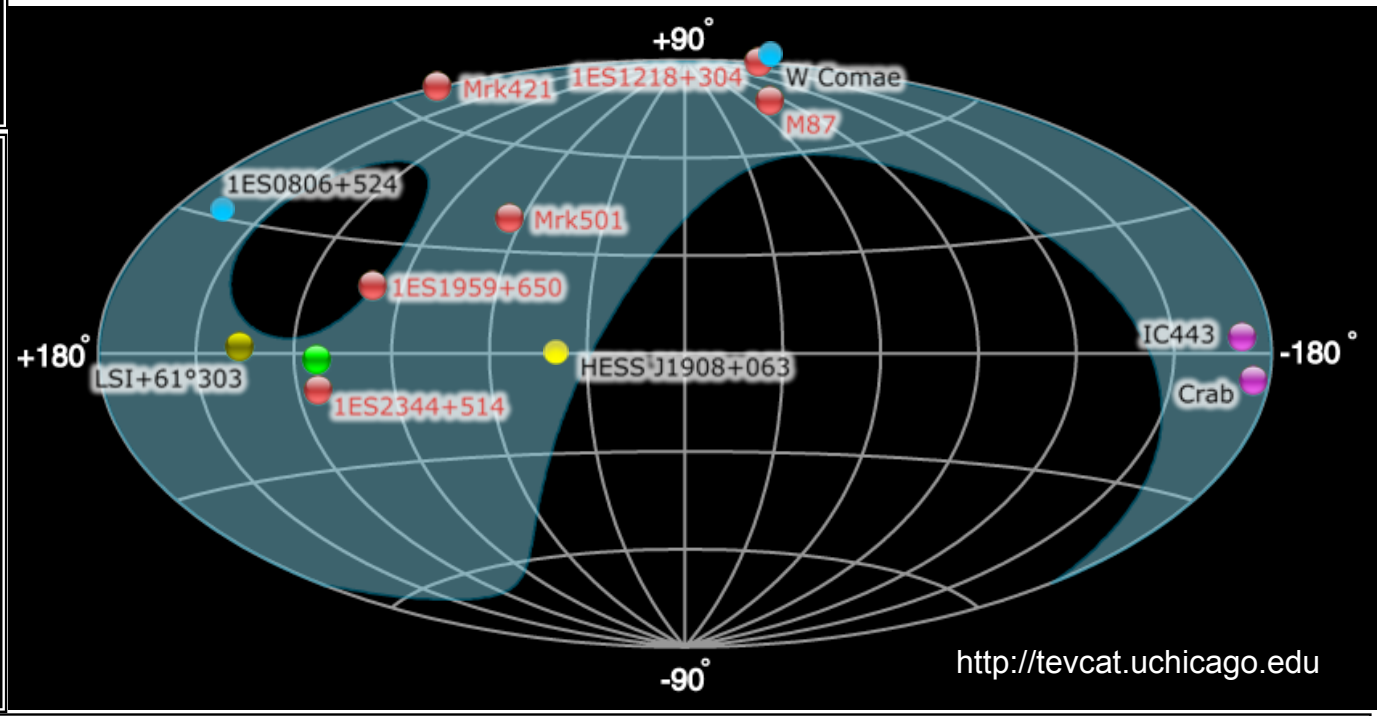
Detections (Jul 2007):

- 1ES1218+304 (distant VHE blazar)
- M87 (non-blazar AGN)
- First light! (April 2007)

Co-discovery (April 2007):

- SNR IC443

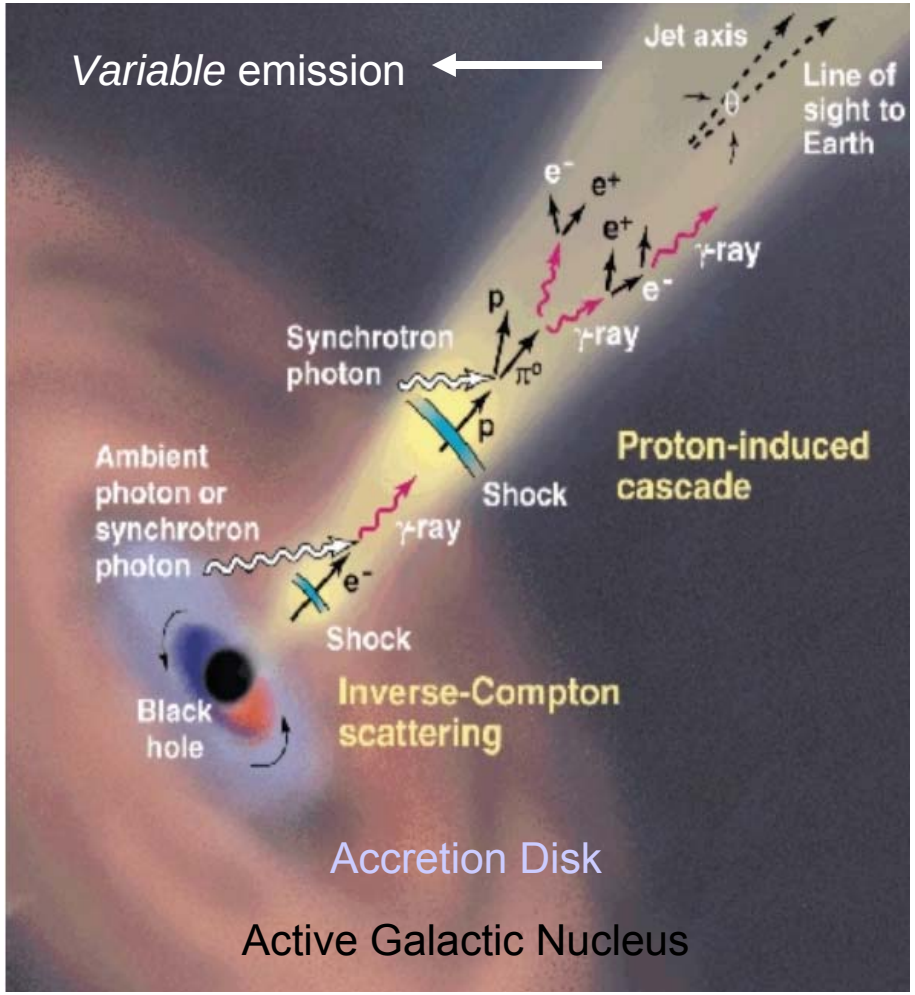
VERITAS Source Catalog (Summer 2008)



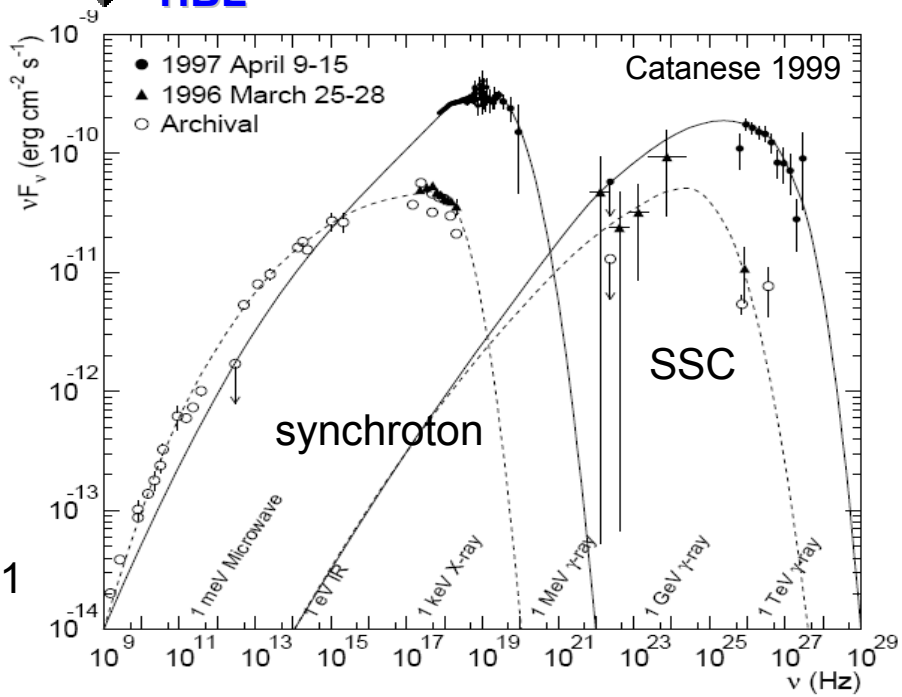
Comissioning period (2006-early 2007, 2 and 3-tel):

- XRB LSI+61 303: confirmed γ-ray variability Blazars Mrk421, Mrk501 Crab Nebula

Extragalactic Science: AGN

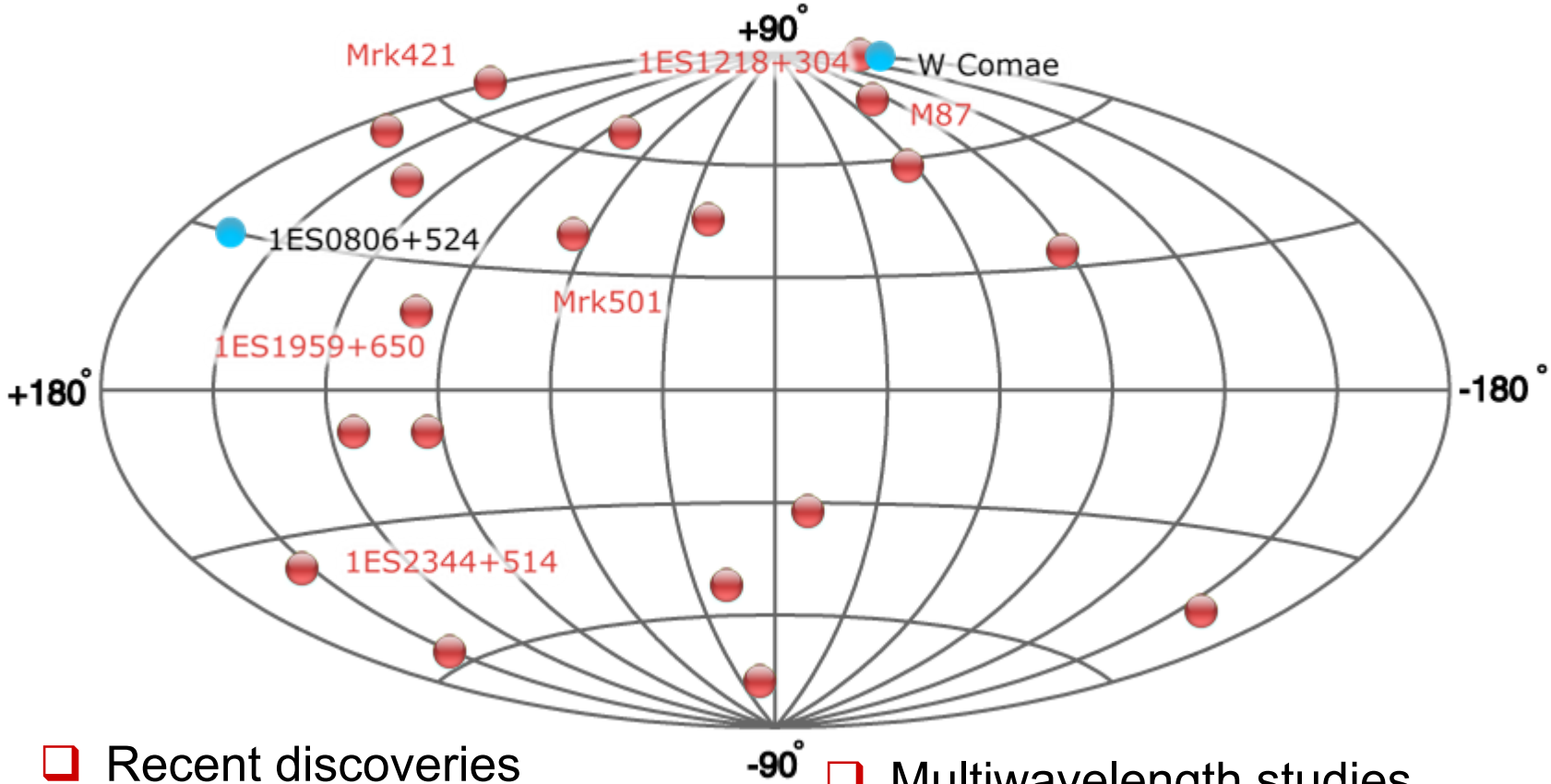


- Acceleration mechanisms, source, mechanism of γ-ray emission
  - **MWL Spectra, variability timescales**
- Can be used to probe properties of universe at large distance scales (EBL)
- AGN observed in VHE γ-rays are mostly
  - **Blazars (jets aligned with line of sight)**
  - **nearby (z < 0.35)**
  - **HBL**



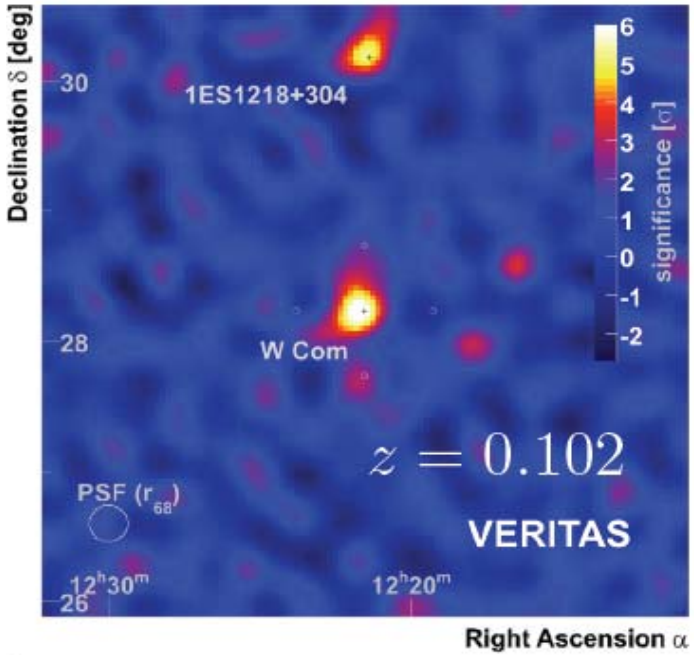
Mrk501

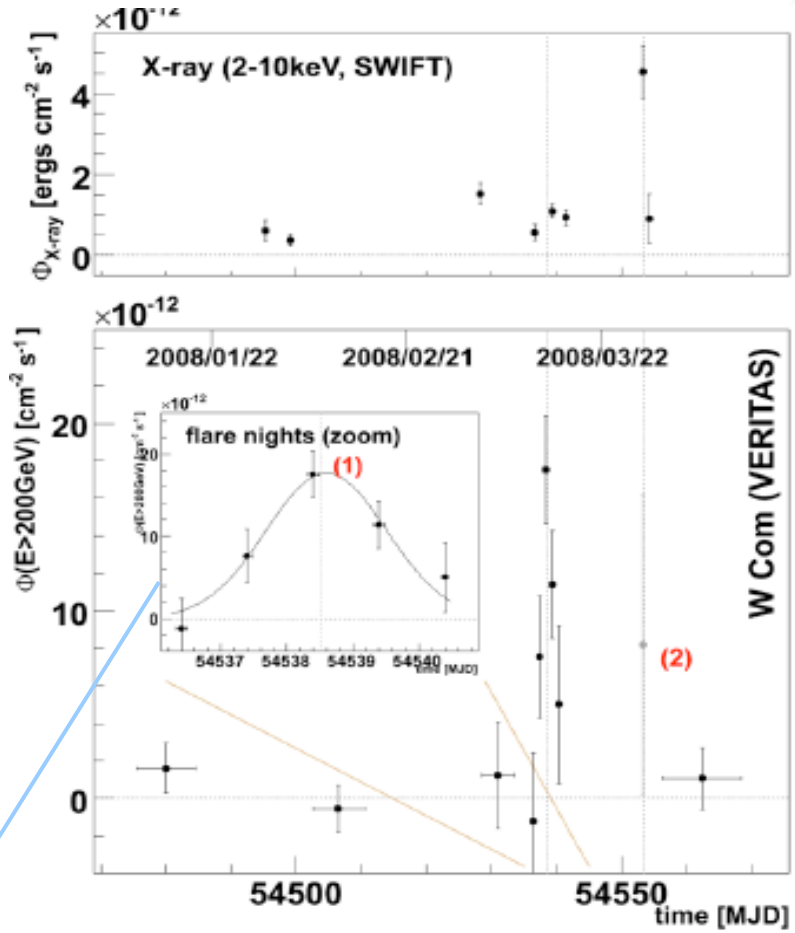
AGN and VERITAS



- Recent discoveries
  - **W Comae**
  - **1ES 0806**
- Non-blazars:
  - **M87**
- Multiwavelength studies
  - **1ES 2344+514**
  - **Mrk421**
- EBL (distant blazars)
  - **1ES1218+304**

Highlight: W Comae

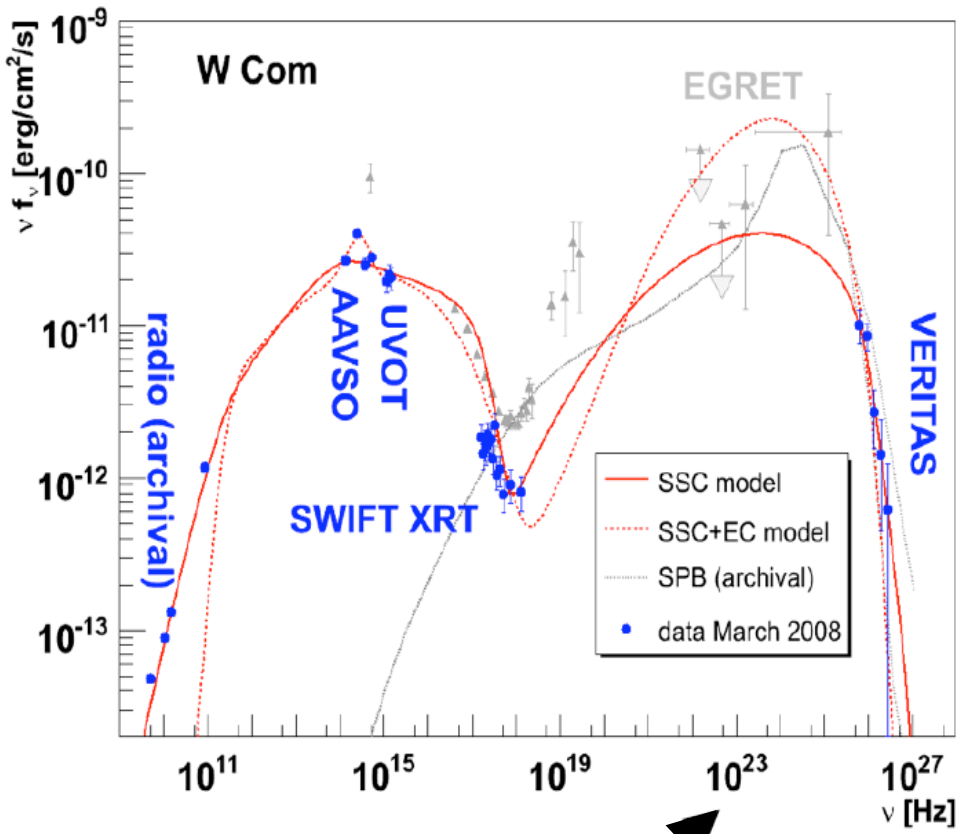




- First IBL detected at TeV energies
- 2 sources in one field!
- VERITAS discovery: (ref: ATel #1422)
  - **Triggered SWIFT follow-up observations**
  - **4.9σ, ~40 hrs**
  - **~6σ over 4 nights of flare**

- Later, stronger flare: (ref: ATel #1565)
  - **Moonlight observations**
  - **Analysis forthcoming**

Highlight: W Comae



EGRET spectrum hard (up to 25 GeV with no cutoff)

GLAST coverage important here

- Spectrum (2 peak nights):

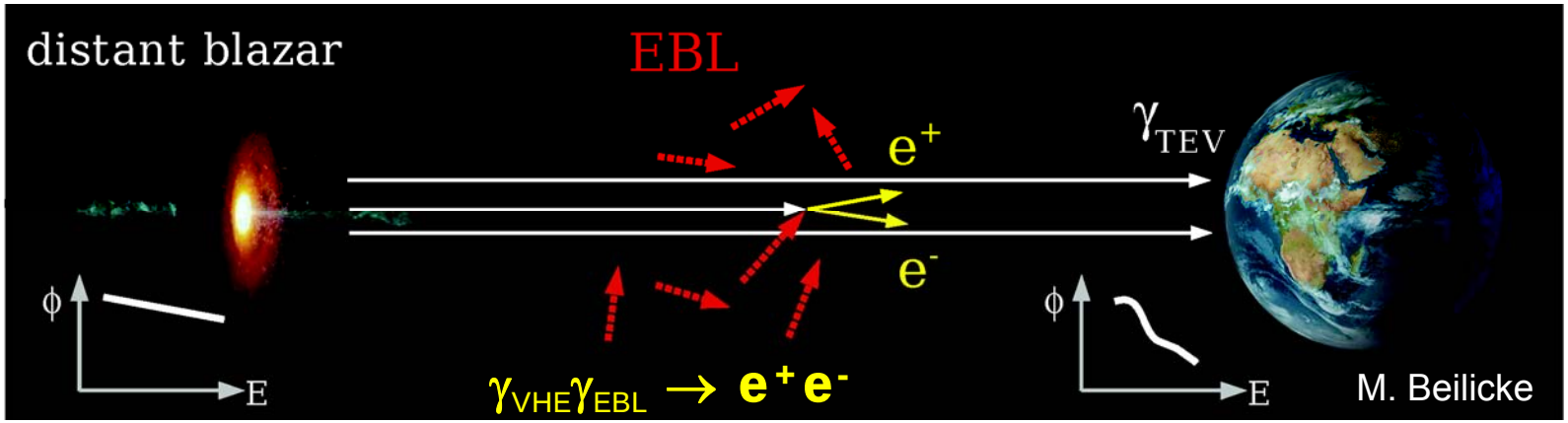
Γ=3.81±0.35(stat)±0.34(sys)

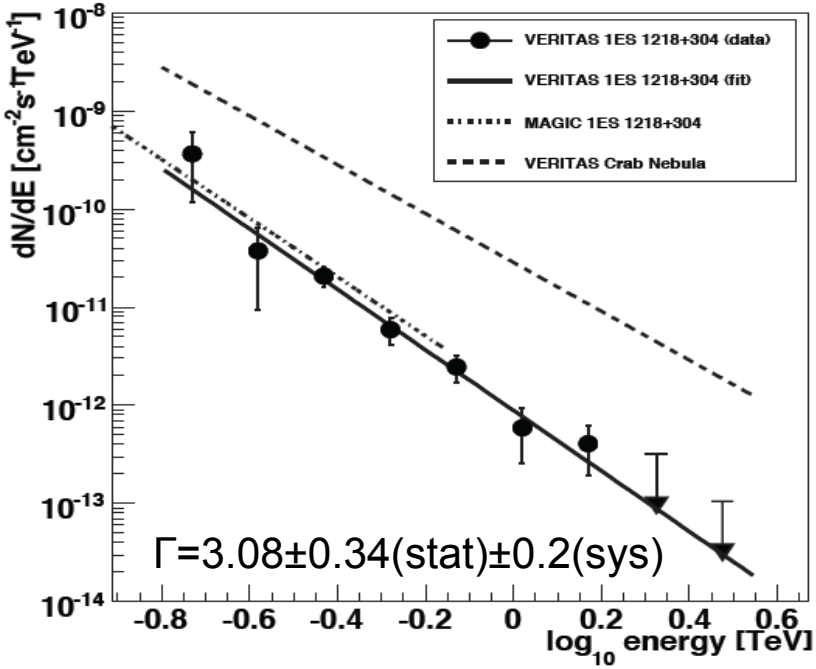
Flaring flux ~ 9% Crab Nebula above 200 GeV

Models

- Single-Zone
  - **Requires very small magnetic field (0.007 G) due to wide separation of peaks**
- External Compton
  - **Allows more natural parameters**
  - **Magnetic field 0.3 G**

Highlight: 1ES1218+304

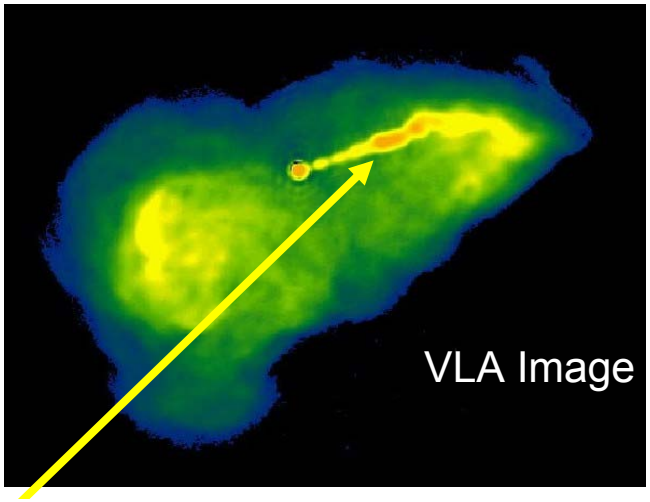




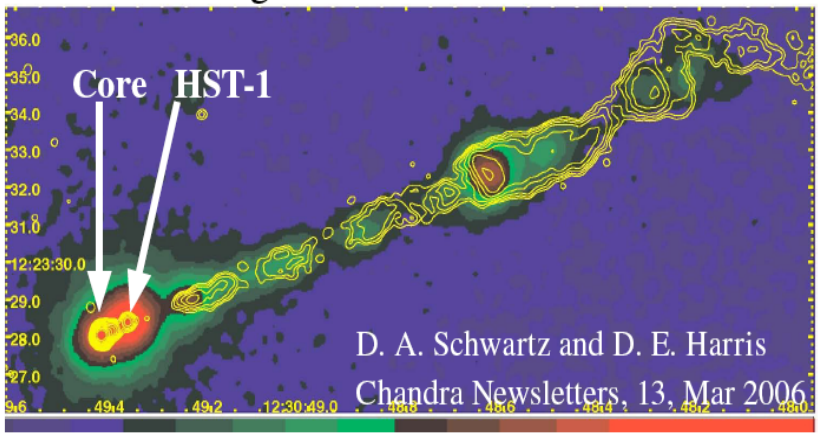
- EBL
  - **IR photons, trace history of star formation**
- 1ES1218:
  - **Distant blazar (z=0.182)**
- VERITAS:
  - **~17hrs, 10.4σ**
  - **I(E>200 GeV): ~6% Crab Nebula flux**
- Use EBL lower limits (galaxy counts), variety of EBL scenarios→deabsorbed spectra
  - **Considered alone: softest Γ=2.32±0.37**
  - **Combined with other distant blazars:**
    - ***Range of values still consistent with shock acceleration***

Highlight: M87

http://www.aoc.nrao.edu/~fowen/M87_layout.html

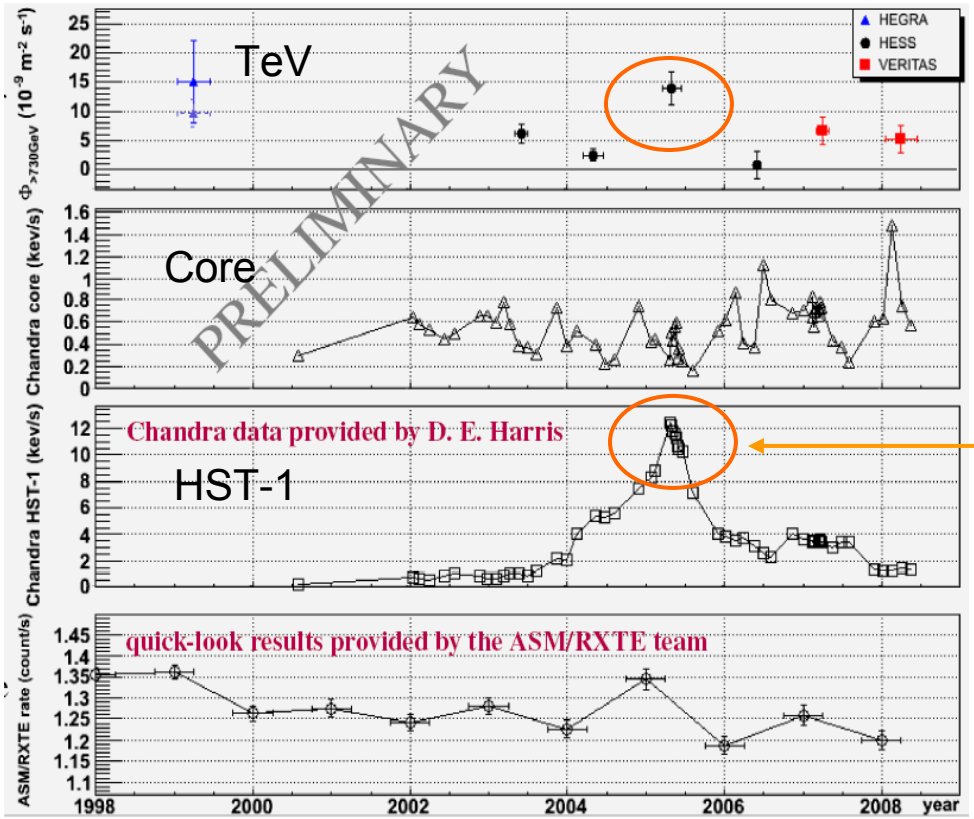


Chandra image, with radio contours overlaid



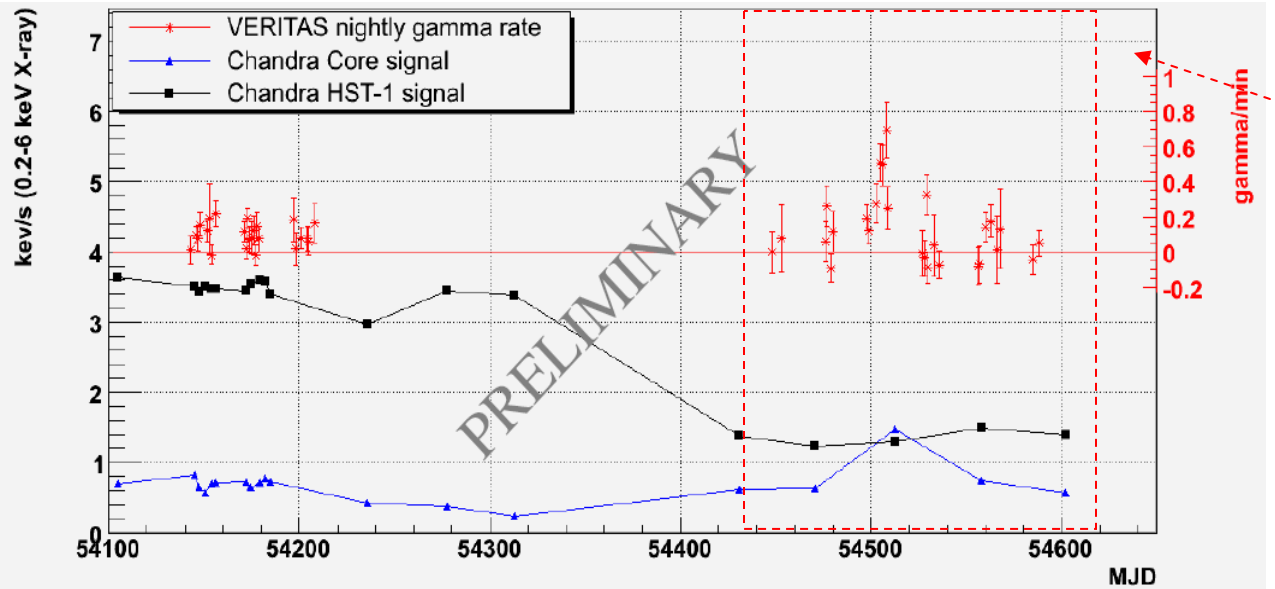
- **Giant radio galaxy**
  - 16 Mpc away (center of Virgo Cluster)
  - **jet misaligned**
  - **jet resolved in radio, optical and X-rays (similar morphologies)**
    - *Unique laboratory*
- only extragalactic non-blazar object seen in VHE γ-rays
  - **HEGRA 4.1 σ (1998-1999)**
  - **confirmed by HESS,VERITAS, MAGIC**
    - ***Day-scale variability***
    - ***Subject of joint campaign in 2008 (VERITAS, MAGIC, HESS)***

Light Curves



Elevated over long period

Light Curves



2 flares within 1 week

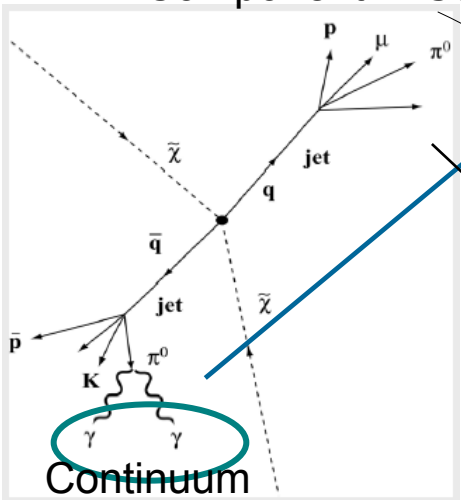
(MAGIC trigger,

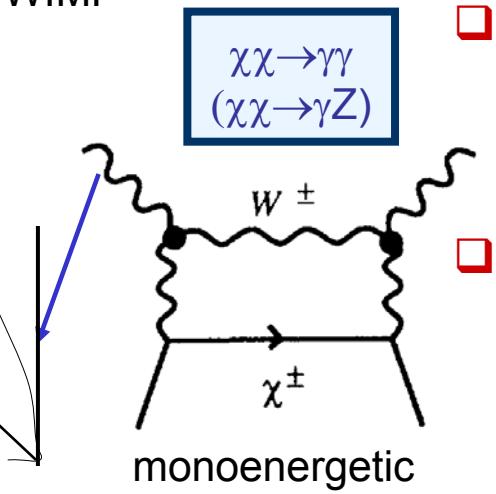
then VERITAS)

Further observations/campaigns required

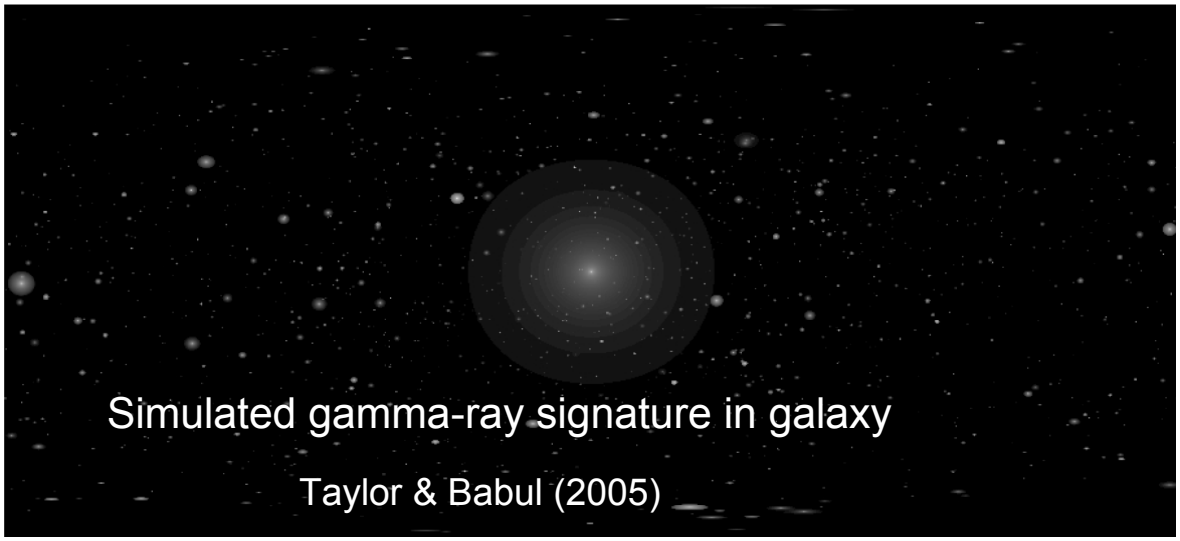
VERITAS: Indirect Dark Matter

Component 1: Self-annihlating WIMP



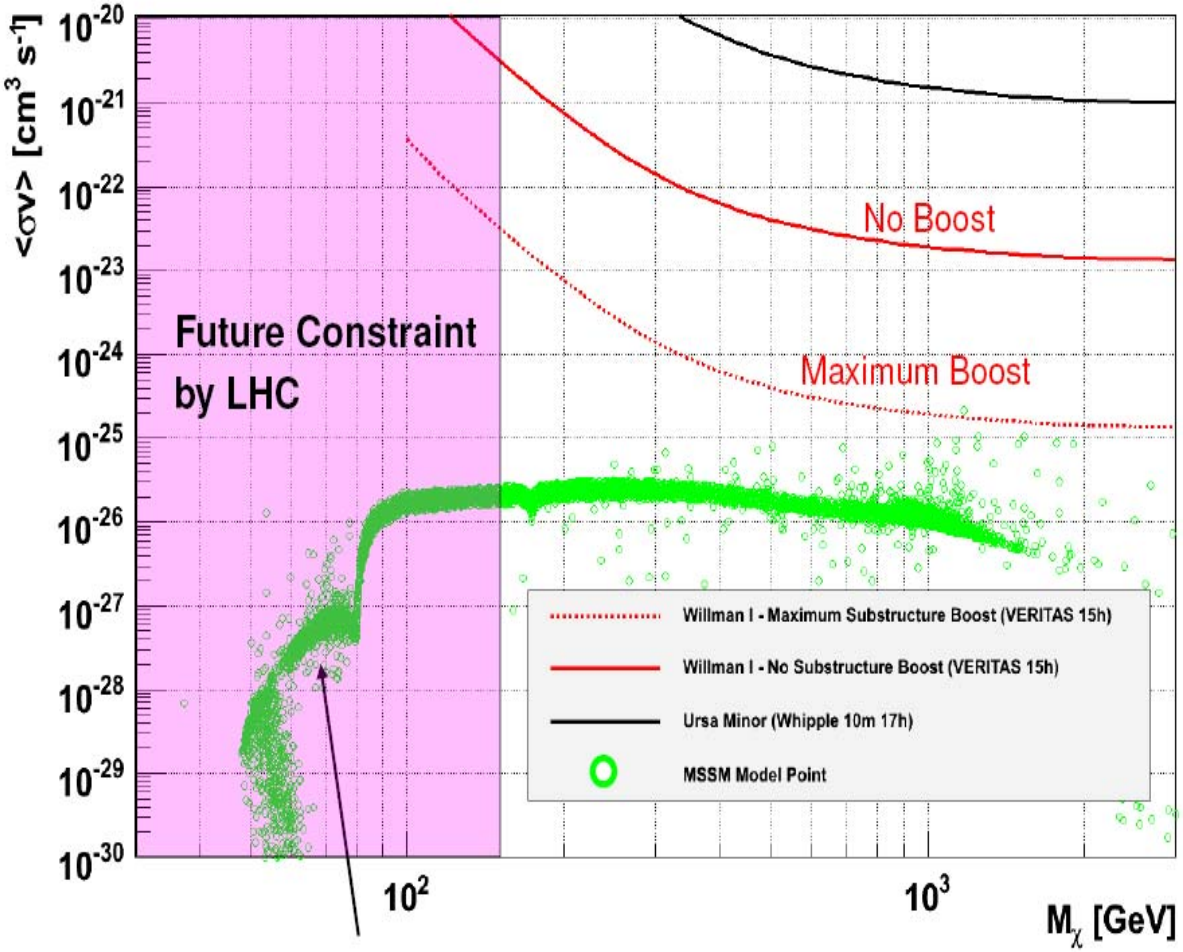


Component 2: Clumpy dark matter



- **e.g SUSY Neutralino (χ)**
  - **TeV instruments sensitive above 100 GeV**
- **VERITAS Strategy**
  - **Observe galaxies with**
    - ***favorable DM distributions***
    - ***Absence of conventional TeV emission***
    - ***Large mass-to-light ratio***
  - **Dwarf galaxies, galaxies with enhanced central DM content**

VERITAS: Dark Matter KSP



Whipple 10m
Ursa Minor constraint

VERITAS
Willman I constraints
derived from
Strigari et al. 2007 (and 15hrs data)

$<\sigma v>$:

Thermal average of product

σ: WIMP self annihilation x-sec

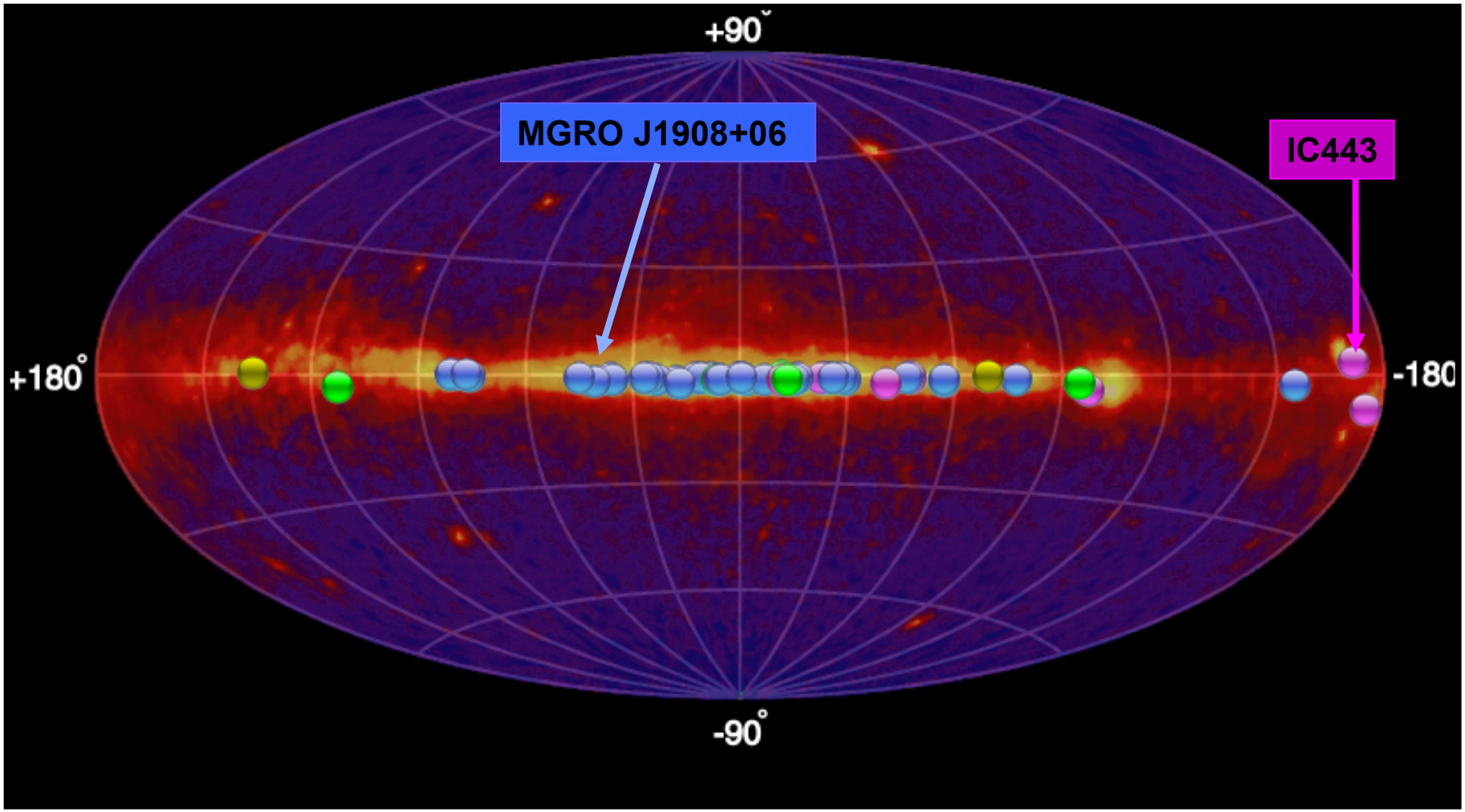
v: WIMP velocity

Recent VERITAS observations:

Draco, Ursa Minor, Willman I

Minimal Supersymmetric extensions to Standard Model (MSSM) allowed by WMAP

Galactic Science

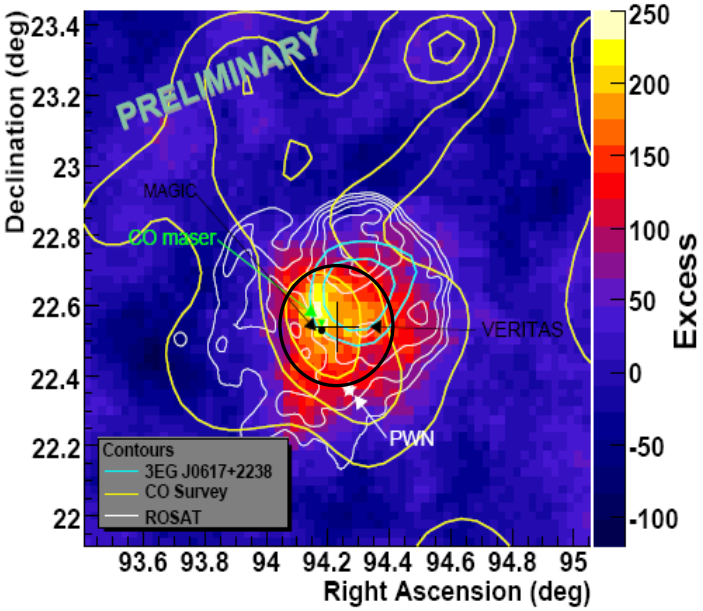


Galactic sources under discussion…

IC 443

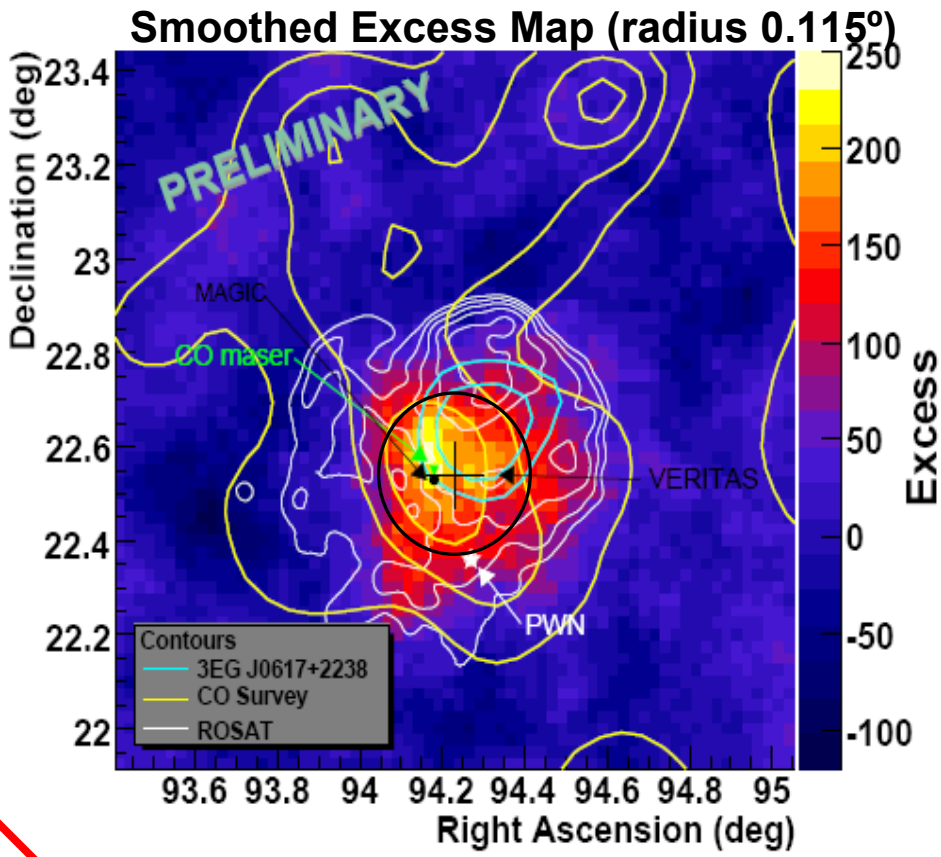
- SNR/molecular cloud interaction, PWN
- Co-discovered (MAGIC/VERITAS) in TeV in 2007
- Observed (wobble, 0.5º offset) during two epochs, for 37.1 hrs total livetime:
  - **Feb / Mar 2007 with 3 telescopes, PWN location**
  - **Oct / Nov 2007 with 4 telescopes**
    - ***Center of Feb/Mar hot spot:***
    - ***06 16.9 +22 33***
- 8.2σ peak significance pre-trials
- 2-D Gaussian profile fit
  - **Centroid:** ***06 16.9 +22 32.4 ± 0.03º(stat) ± 0.07º(syst)***
  - **Extension:** ***σ ~ 0.17º ± 0.02º(stat) ± 0.04º(syst)***

Smoothed Excess Map (radius 0.115º)



IC 443

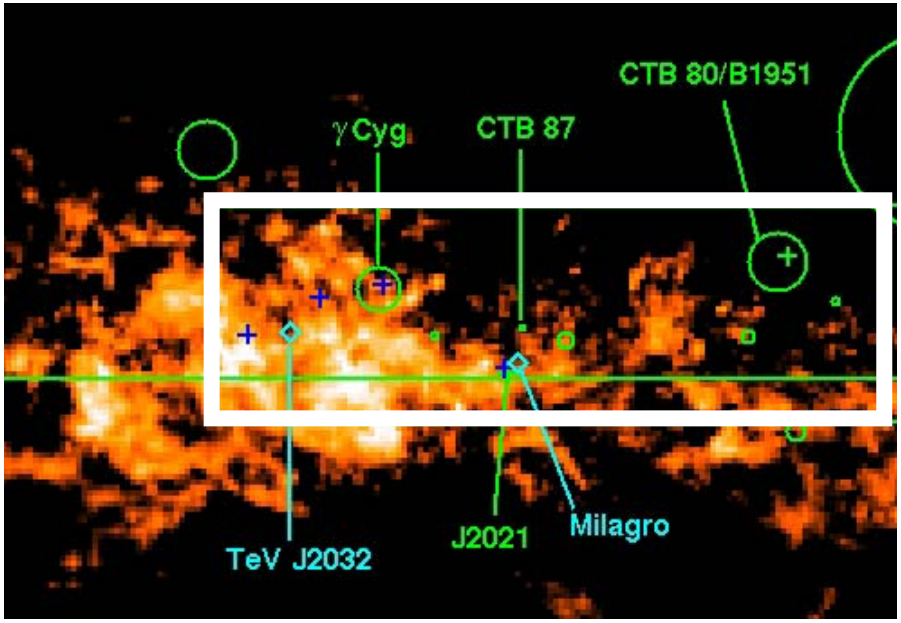
- Centroid located at 06 16.9 + 22 32.4
  - **consistent with MAGIC**
- Overlap with CO indicating molecular cloud along line of sight
- Maser emission suggests SNR shock interacting with cloud
- TeV emission could be
  - **CR-induced pion production in cloud[1,2]**
  - **associated with the pulsar wind nebula to the south[3]**



Origin of cosmic rays?

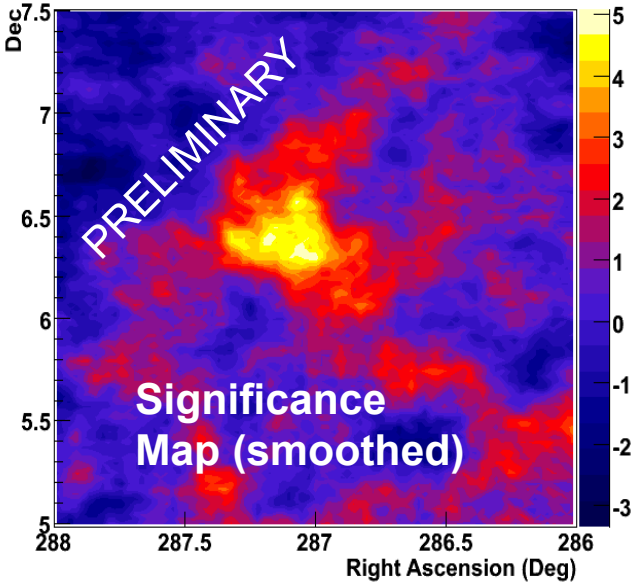
(1) Zhang, L. and Fang, J. Ap. J. **675** L21 (2008).
(2) Torres, D. F. et al. arXiv:0804.2526.
(3) Bartko, H. and Bednarek, W. arXiv:0712.2964.

VERITAS Sky Survey



- **Partial survey of Cygnus region**
  - **-1 < b < 4 and 67 < l < 82**
  - **2 year program**
    - ***Started late April 2007***
      - *3 and 4-telescope data*
    - ***Final pointings will be completed this fall***
  - **High probability of extended sources**

- **MGRO J1908+06/HESS J1908+063**
  - Under aegis of sky survey
  - ~22h of 4-telescope data
  - 4.85σ detection
  - ~0.2° extension
  - position in agreement with HESS J1908+063



Summary

- **Excellent first full year of VERITAS observations**
- **Some highlights:**
  - Blazar KSP
    - *Discovery of two new blazars including the first IBL*
    - *Detailed multi-wavelength observations, long-term light curves contribute to understanding of emission mechanisms*
    - *EBL upper limits to calculate deabsorbed Blazar spectra*
  - Extragalactic non-blazars: M87
  - SNR/PWN KSP: IC443, Cas A
  - LSI+61 303
  - Sky Survey KSP
    - *Much learned from studies of MGRO J1908+06*
    - *Full results to come*
- **More to come!**