VERITAS Observations of Supernova Remnants

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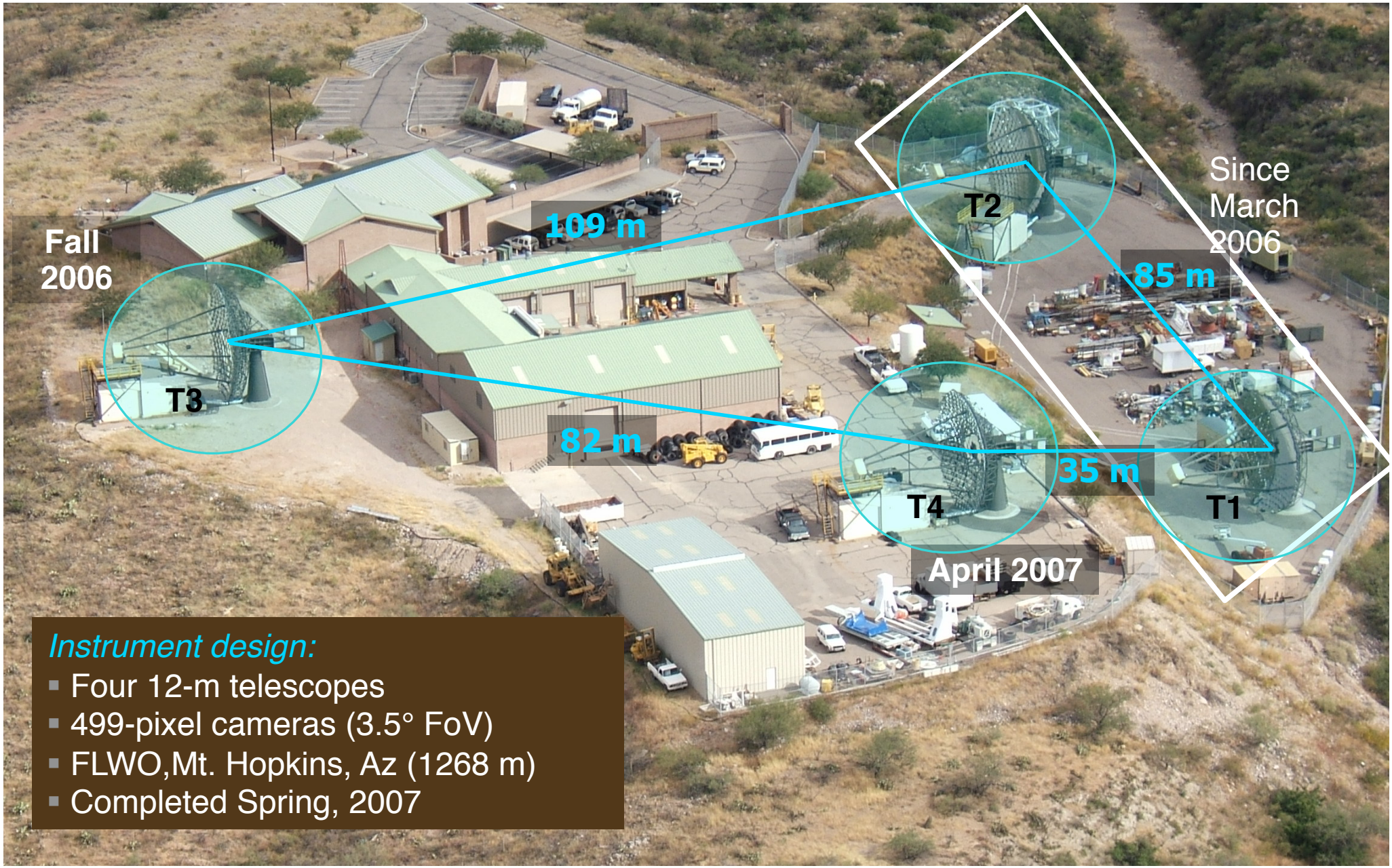
Outline

- (Quick) introduction to VERITAS
- Scientific goals & questions
- Observing program
- VERITAS γ-ray results

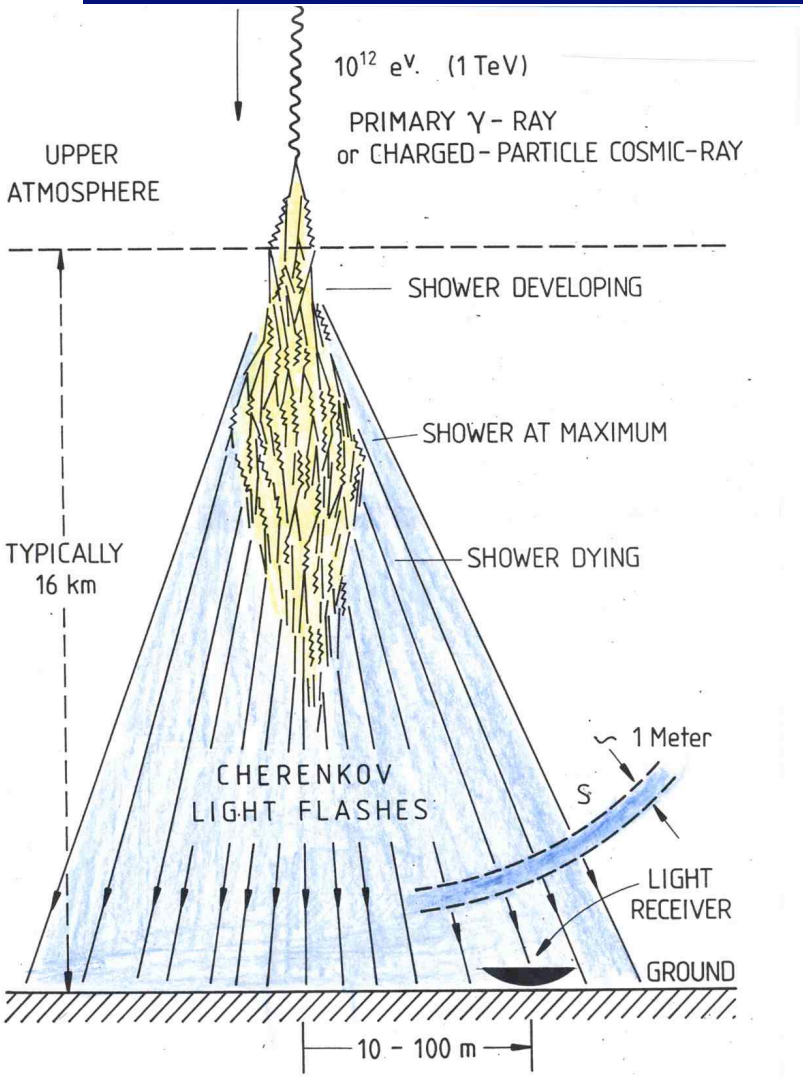
VERITAS at Whipple Observatory



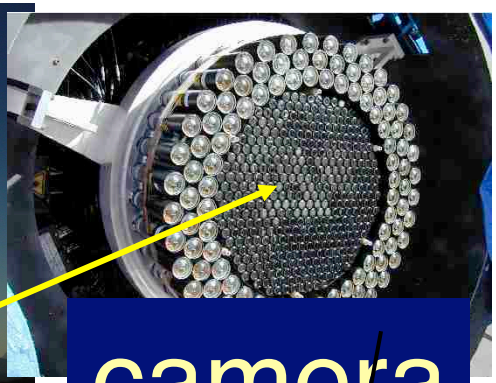
Instrument design:

- Four 12-m telescopes
- 499-pixel cameras (3.5° FoV)
- FLWO,Mt. Hopkins, Az (1268 m)
- Completed Spring, 2007

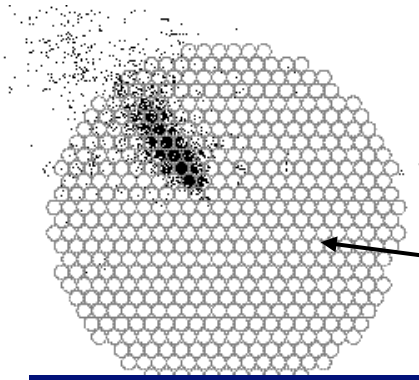
VERITAS: The Atmospheric Cherenkov Technique



Area = $10^4 - 10^5$ m^2
~60 optical photons/m^2/TeV



camera



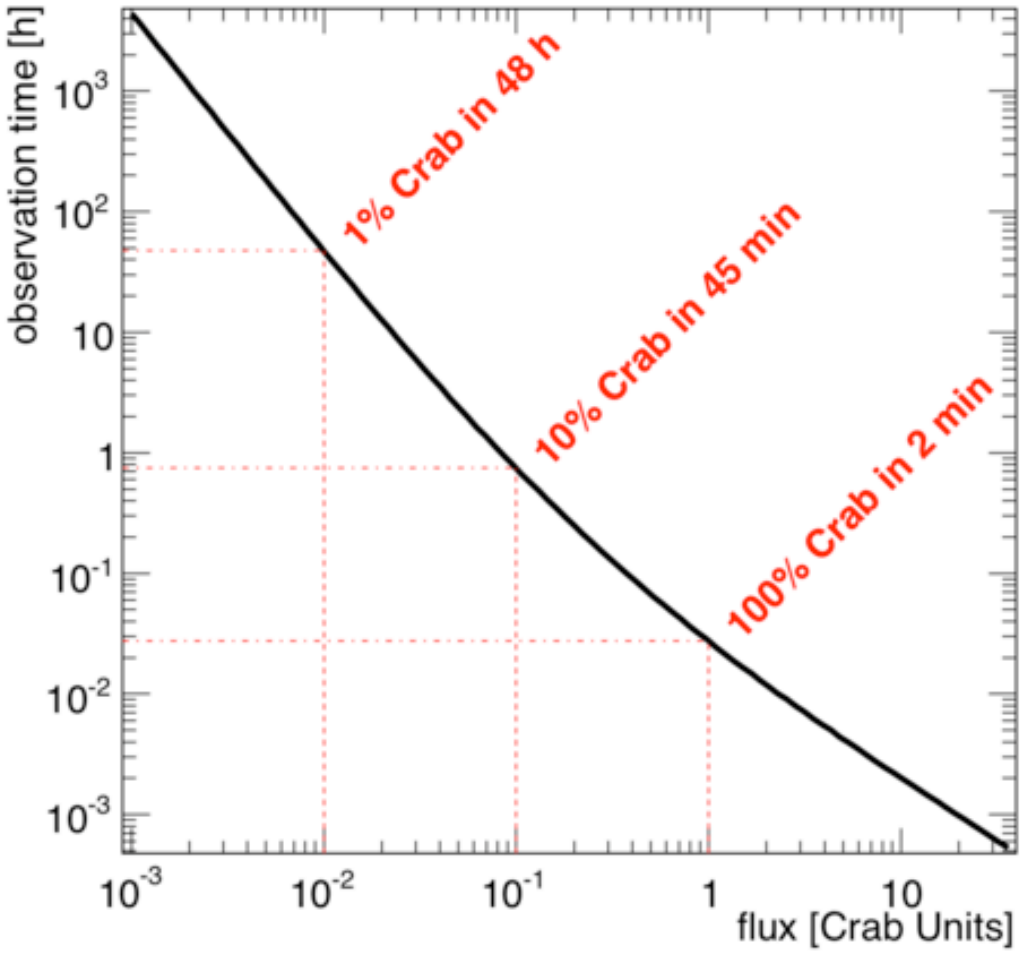
Cherenkov image

ns electronics

Imaging ACTs use the shape and orientation of the air shower image in the camera plane to distinguish between cosmic & γ-rays.

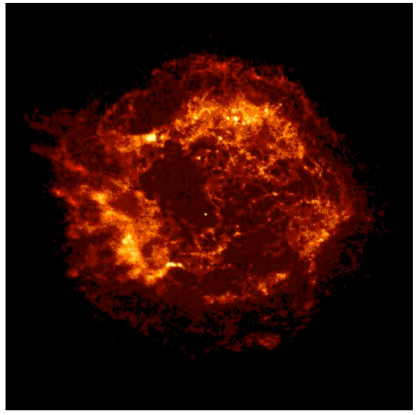
VERITAS Sensitivity

- Sensitive energy range: 100 GeV to > 30 TeV
- Spectral reconstruction begins at ~150GeV
- Energy resolution: ~15% - 20%
- Peak effective area: 100,000 m^2
- Angular resolution: 0.1º at 1 TeV, 0.14º at 200 GeV (68% values)
- 1% Crab detection (5σ) in less than 50 h, 5% crab in ~2.5 h
- Observation time per year: 750 h non-moonlight, 100 h moonlight



Galactic Science Program

- VERITAS *Key* Science Project
  - Supernova remnants/PWNe
    - Non-thermal shells
    - Shell-molecular cloud interactions
    - TeV PWNe associated with high E/d^2 pulsars



Goal of KSP: Constraints on particle acceleration and diffusion. Cosmic ray origin?
Measurement of TeV emission from SNRs could resolve the long-standing question of whether these are sites of hadronic cosmic ray acceleration.
Is there clear evidence of hadronic emission?
Is the TeV IC emission low? Can we demonstrate a robust correlation of TeV emission with target matter?

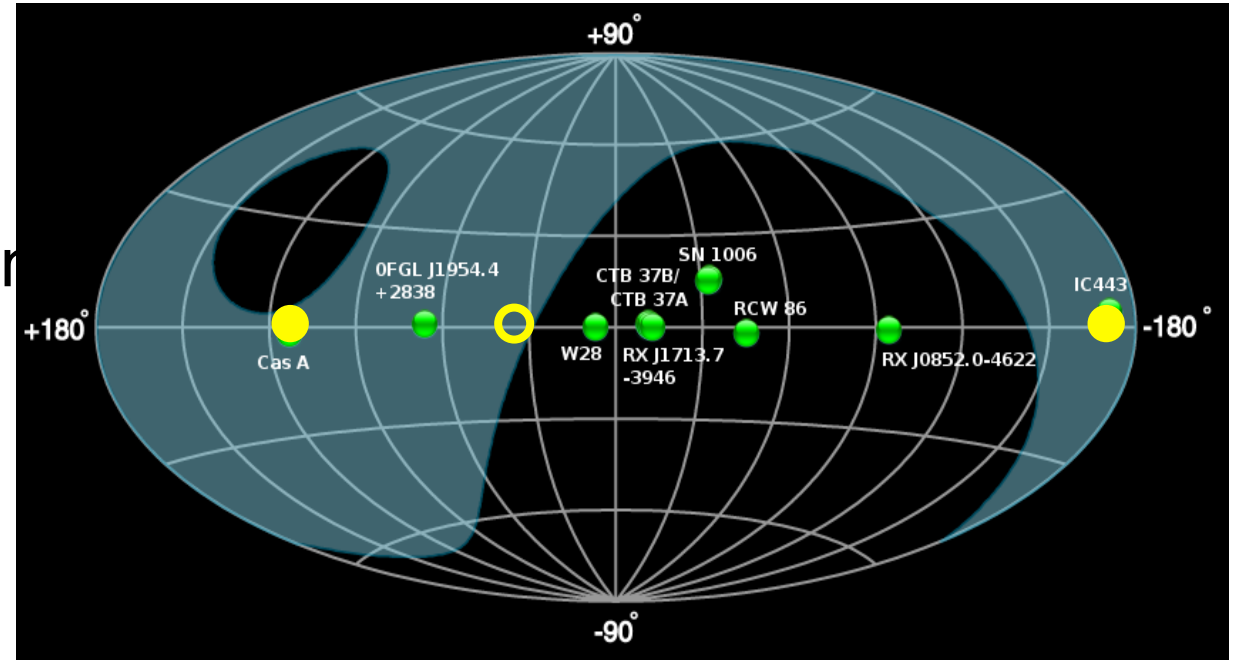
Combining the TeV spectrum with the synchrotron spectra in the radio and X-ray bands can possibly discriminate between IC and pion production/decay models, and provide strong constraints on the acceleration process.

VERITAS Observations of SNRs

- Supernova remnants are widely considered to be the strongest candidate for the source of cosmic rays below the knee at around 10^{15} eV.
- Several SNRs have been detected at TeV energies.

Here we present results on

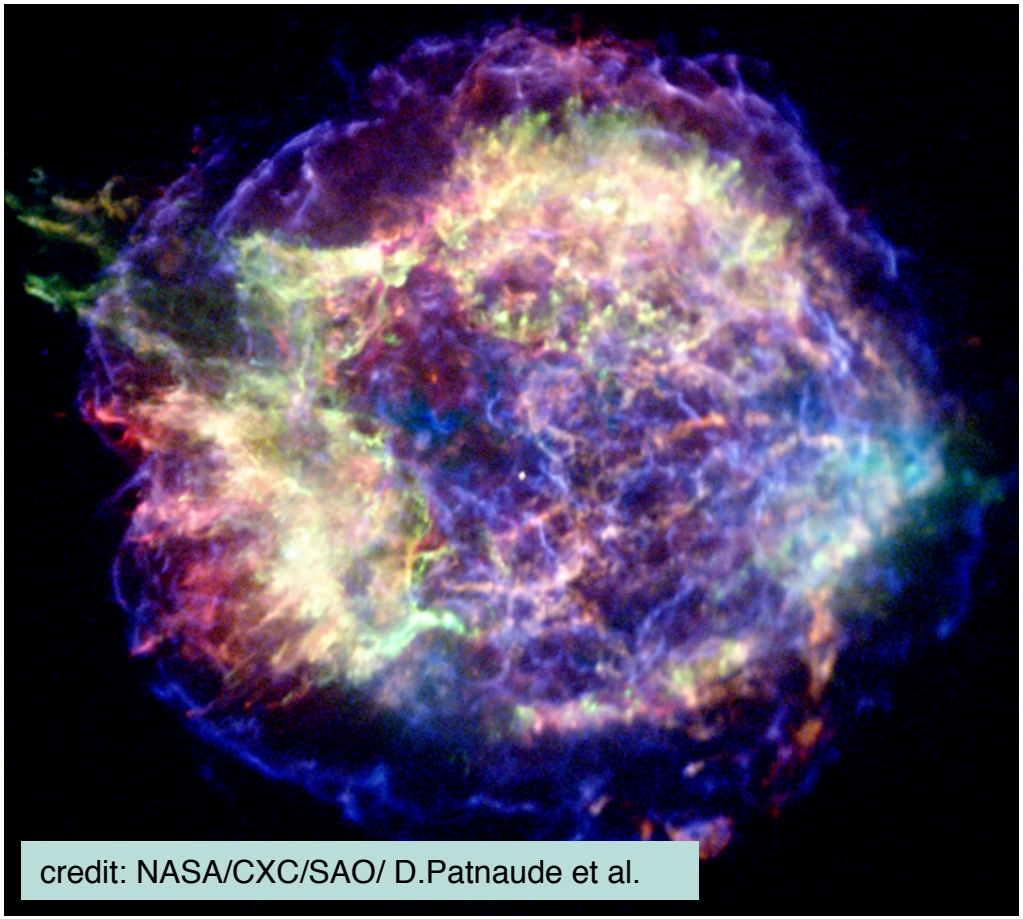
- Cas A
- IC 443
- W 44



TeVCat::://tevcat.uchicago.edu/

Results: Cas A

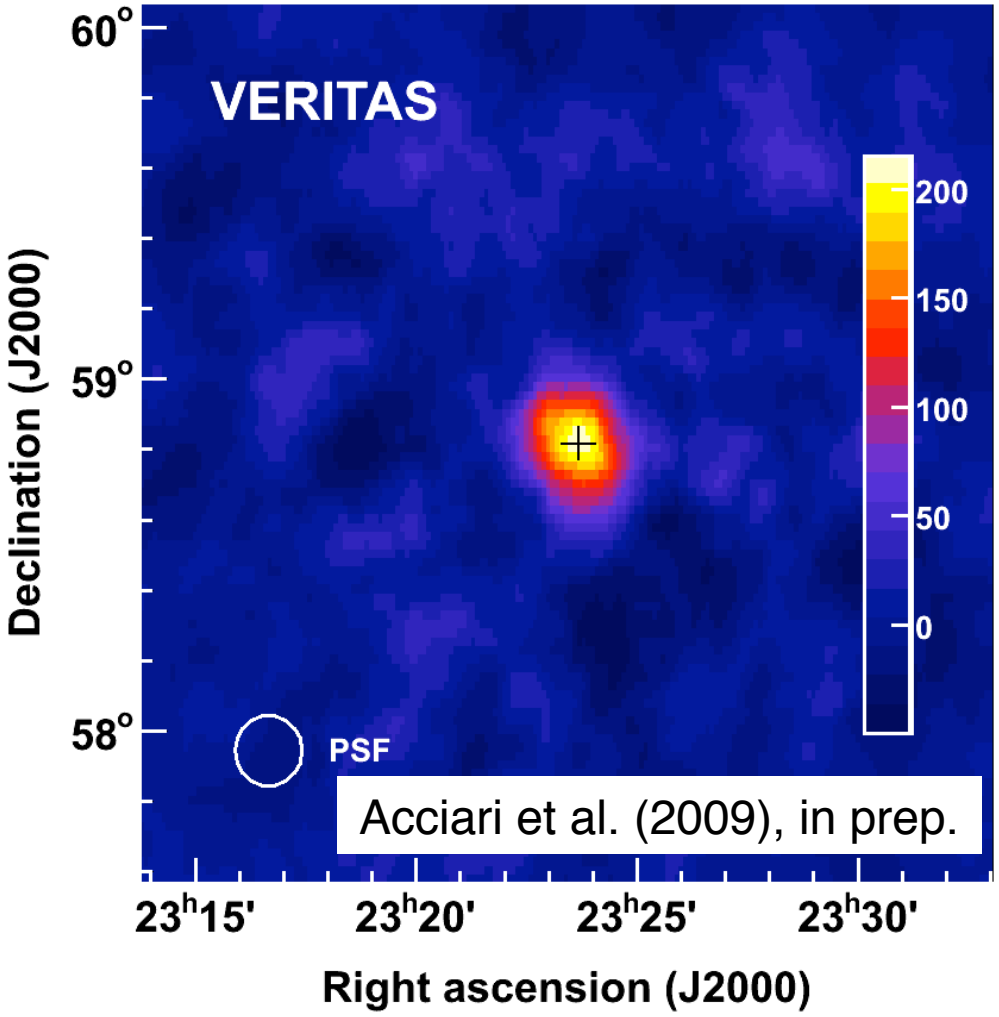
SNR & PWNe KSP:



Deep Chandra image of Cas A (7.3' by 6.4')

- Young (330 yr), shell-type SNR at a distance of ~3.4 kpc.
- Massive star progenitor
- 5' diameter (~TeV ang resolution).
- Discovered in TeV by HEGRA (232 hrs, 5 σ), confirmed by MAGIC (47 hrs, 5.3 σ)
  - Flux ~ 3.3 % Crab above 1 TeV
  - Power-law Γ: $2.3 \pm 0.2_{stat} \pm 0.2_{sys}$
- Extensive modeling of cosmic-ray acceleration and γ-ray production exists.

Results: Cas A

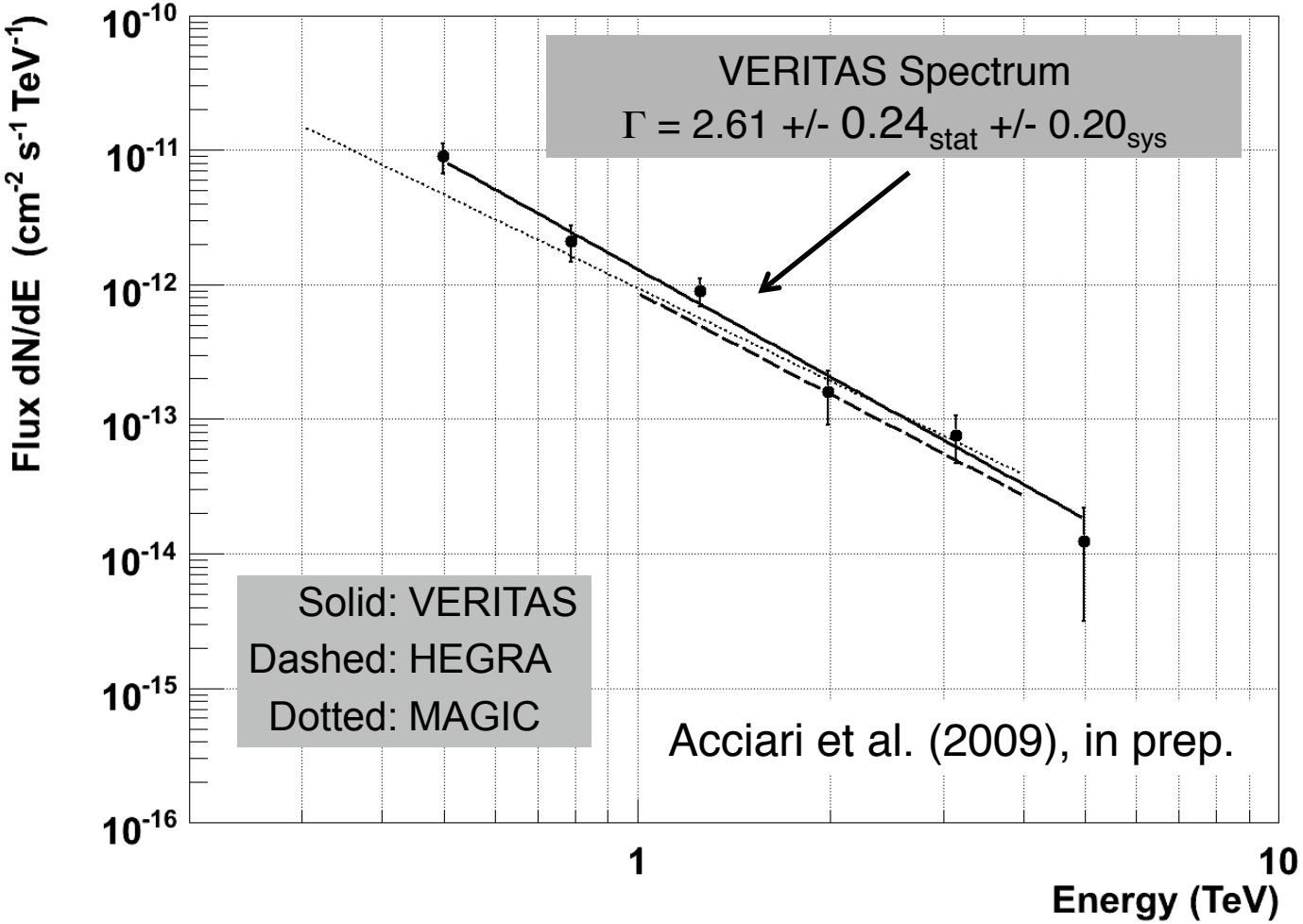


- VERITAS:

  - wobble-mode observations, 0.5º offset, during Oct/Nov 2007 with full 4 Tel. array

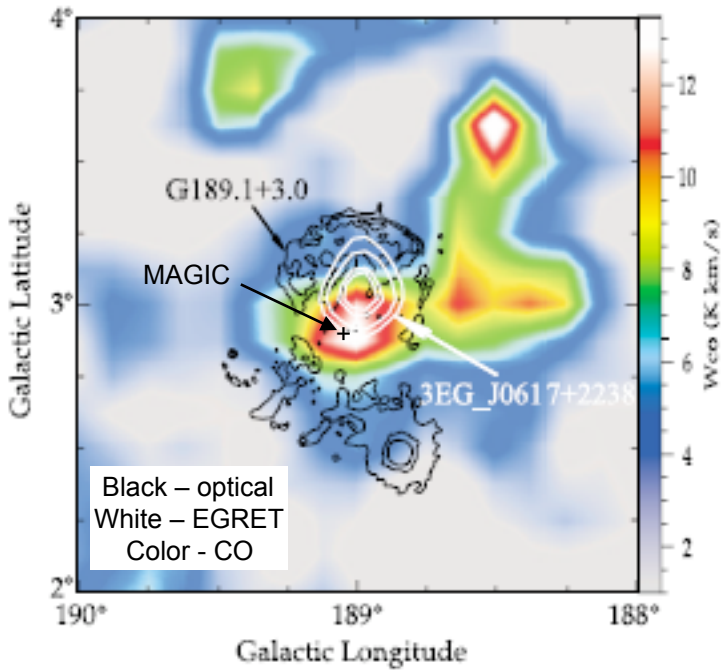
- Exposure: 22 hr: 8.3 σ detection
- Flux: ~ 3% Crab
- Consistent with a point source.

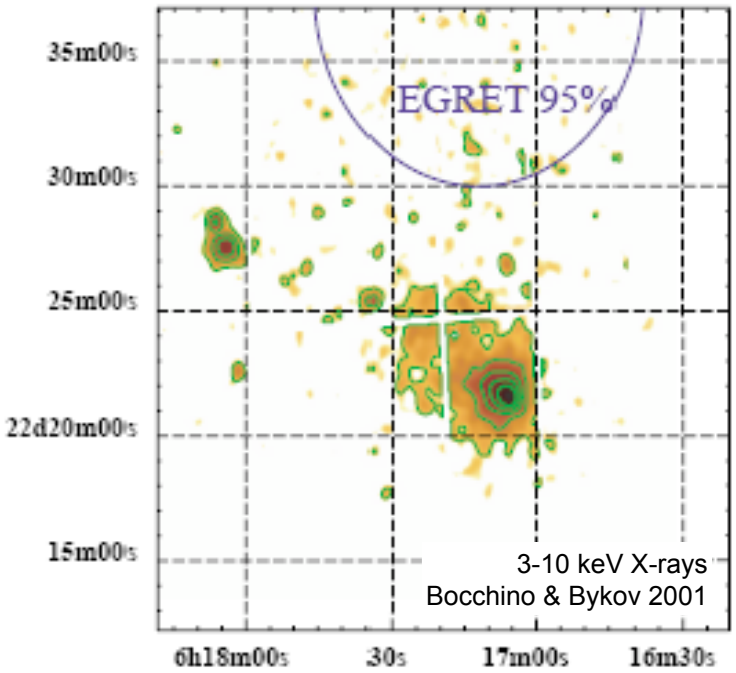
Results: Cas A



- Well-fit by power law spectrum: $dN/dE = N_0(E/TeV)^{-\Gamma}$
- Flux (E > 1 TeV): ~ 3.5% Crab $(7.76 +/- 1.10_{stat} +/- 1.55_{sys}) \times 10^{-13}$ cm^{-2} s^{-1}
- No sign of energy cut-off at high energy

Results: IC 443



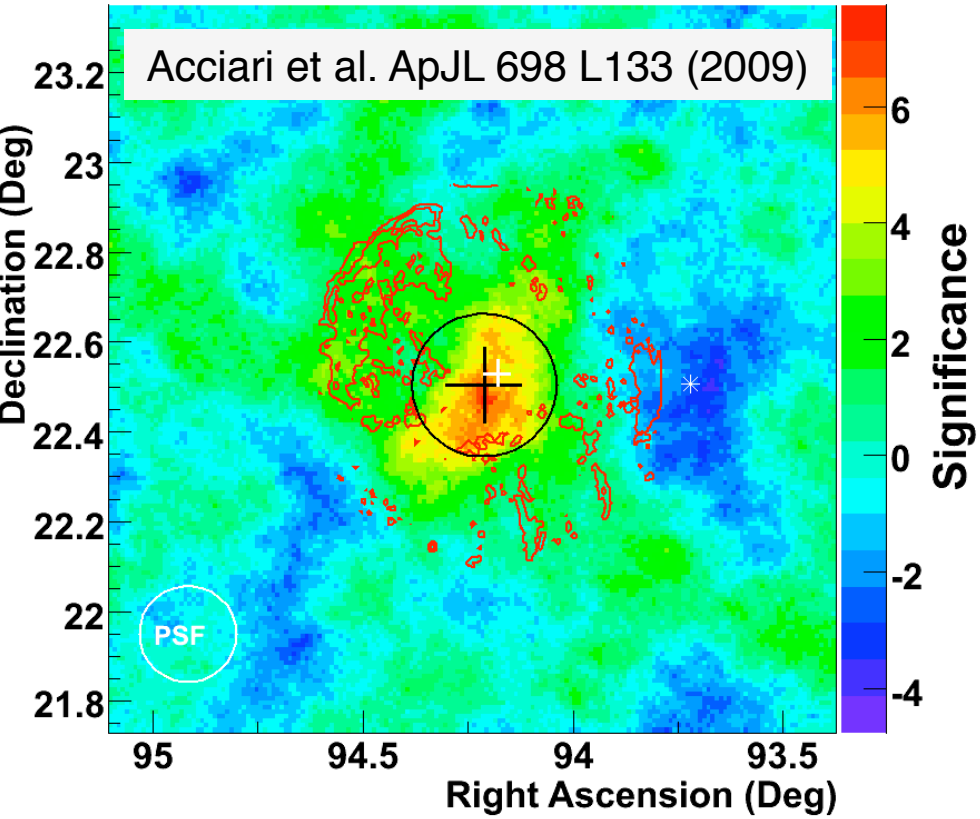


- Shell interacting with molecular cloud -> potential target material
  - EGRET emission centered on remnant, overlaps cloud
  - MAGIC emission centered on cloud
- PWN at southern edge of shell

- Distance ~ 1.5 kpc
- Age ~ 30,000 years
- Diameter 45’
- Distinct shell in radio, optical

Compelling reasons to search for TeV emission from IC 443: γs from cosmic rays, or from the PWN?

Results: IC 443



2-D Gaussian profile fit:

Centroid: 06 16.9 +22 32.4 ± 0.03°(stat) ± 0.07°(syst)

Extension: σ ~ 0.17° ± 0.02°(stat) ± 0.04°(syst)

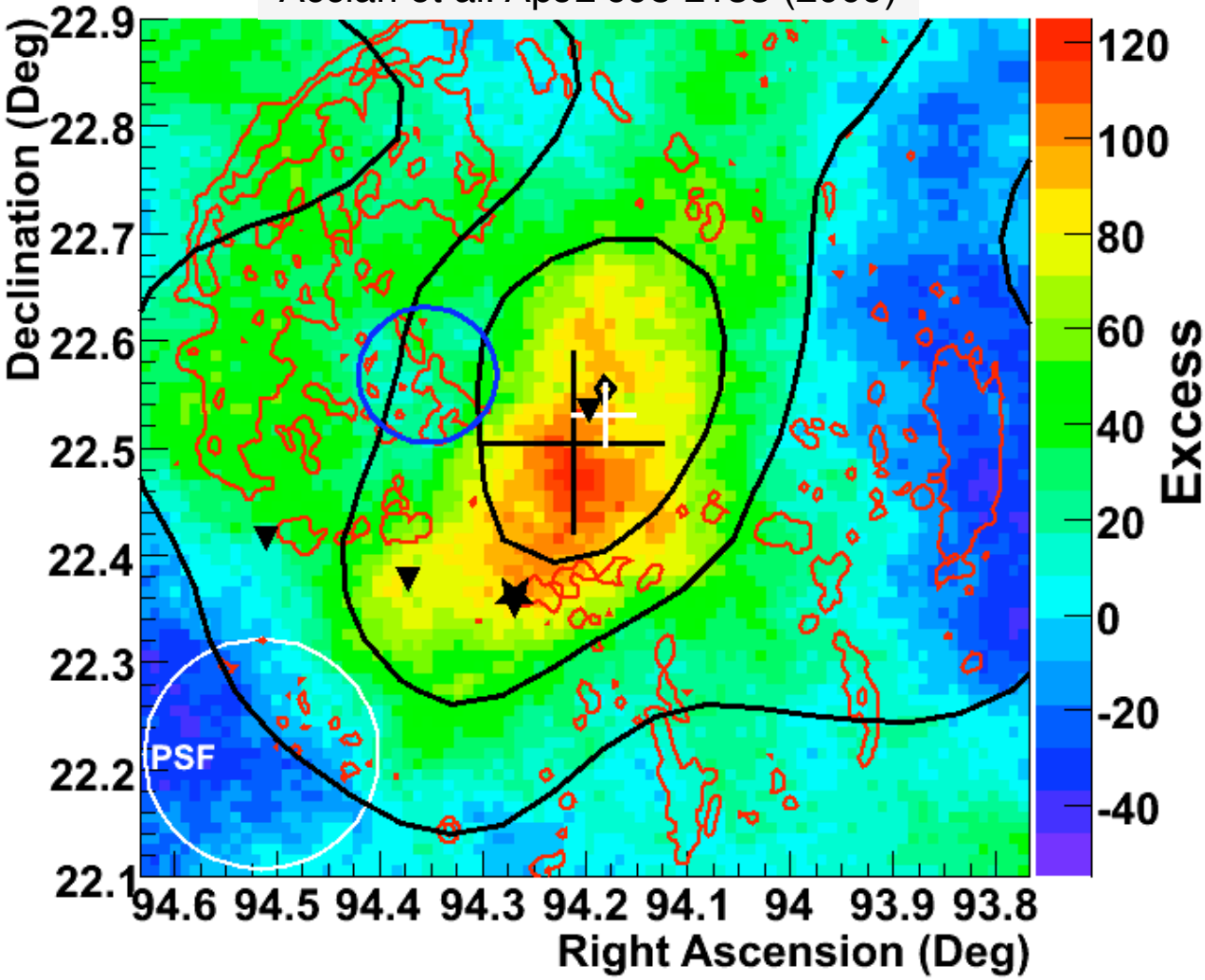
- Discovered in TeV in 2007
  - by VERITAS (7.1/6.0 σ pre/post-trials in 15.9 hrs)
  - by MAGIC (5.7 σ in 29 hrs)
- Wobble-mode observations, 0.5° offset
- Observed during two epochs:
  - Feb / Mar 2007 with 3 telescopes
    - PWN location, CXOU J061705.3+222127
  - Oct / Nov 2007 with 4 telescopes
    - Center of Feb/Mar hot spot: 06 16.9 +22 33
- Total livetime: 37.1 hrs.
- Flux ~3% Crab
- 8.2σ peak significance pre-trials

Results: IC 443

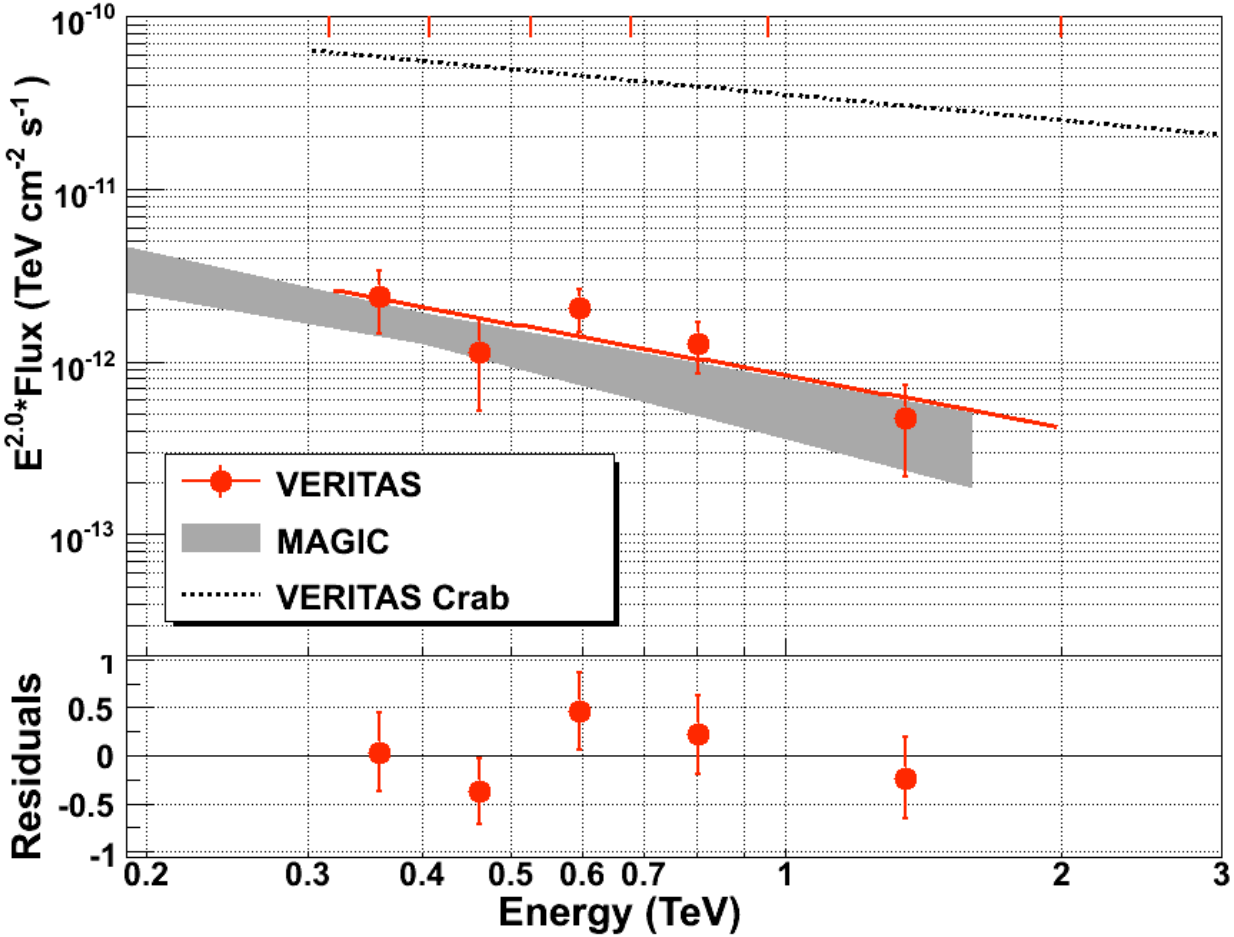
Multiwavelength Picture

- 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
  - associated with the pulsar wind nebula to the south
- GeV and TeV emission spatially separated?

Acciari et al. ApJL 698 L133 (2009)



Results: IC 443



Acciari et al. ApJL 698 L133 (2009)

- Power-law fit 0.3 – 2 TeV: $\Gamma = 2.99 \pm 0.38_{stat} \pm 0.30_{sys}$
- Threshold of energy spectrum - 300 GeV
- The integral flux above 300 GeV is $(4.63 \pm 0.90_{stat} \pm 0.93_{sys})$ X10^{-12} cm^{-2} s^{-1} (3.2% Crab), in good agreement with the spectrum reported by MAGIC

Observations of Other SNRs

- CTB 109 (G109.1-1.0): Shell-type SNR, interacting with a molecular cloud on its eastern rim. Observed briefly for 4.3 hrs (live time). No emission detected. Flux UL (E > 400 GeV) < $2.5X10^{-12}$ cm^{-2} s^{-1}

- FVW 190.2+1.1: Forbidden Velocity Wings may be the vestiges of very old SNRs. FVW 190.2+1.1 shows a clear shell-like morphology in the HI maps. Motivated by the possible association of HESS J1503-582 with an FVW. VERITAS observed for 18.4 hrs (live time) No emission detected. Flux UL (E> 500 GeV) < $0.26X10^{-12}$ cm^{-2} s^{-1} (< 1% Crab nebula flux)

- W 44: SNR promising source of π^0 induced γ-rays. 13 hr live time around W44. No emission detected around SNR. Flux UL (E > 300 GeV) < 2% Crab nebula flux.

The field of W 44

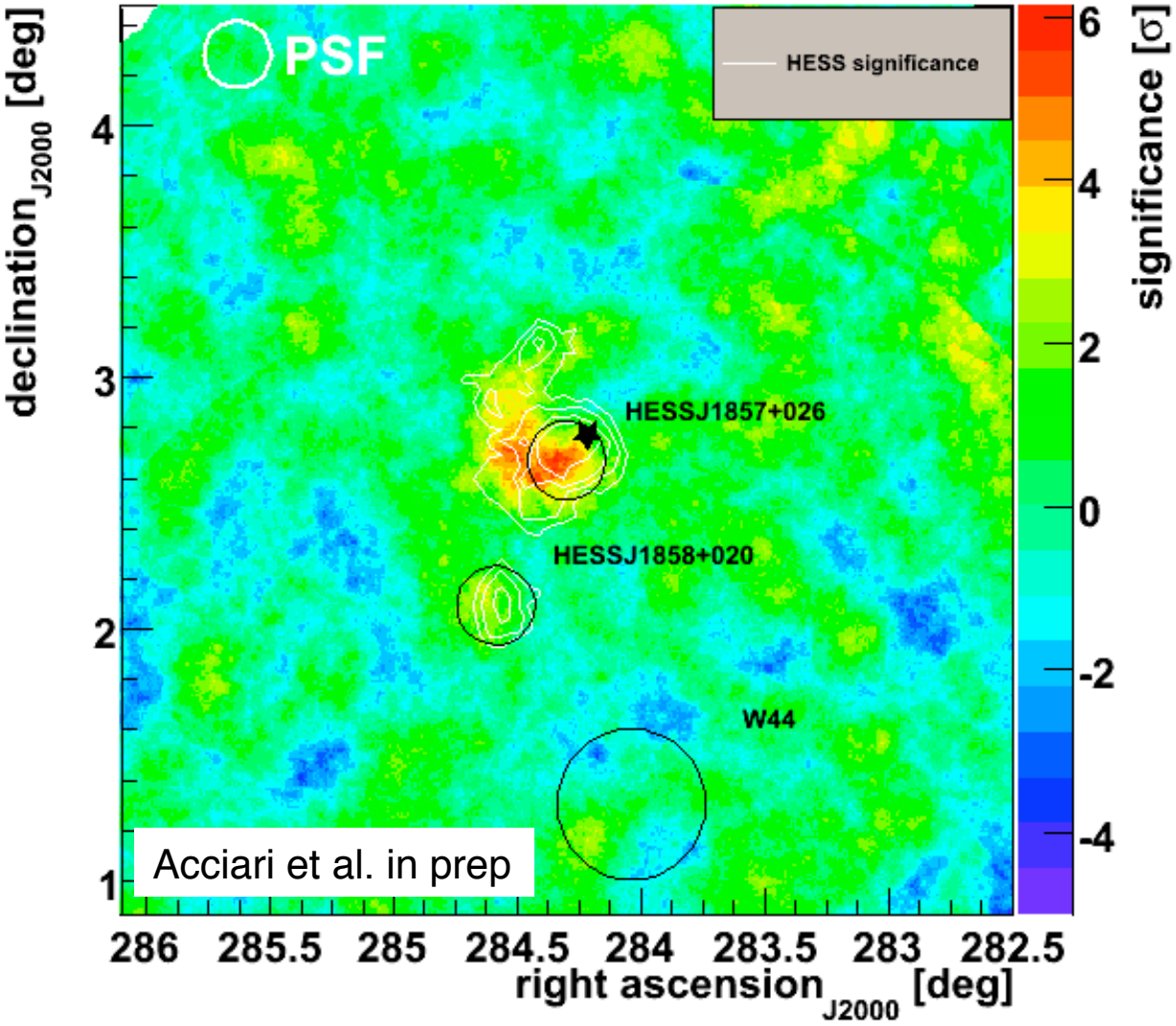
Unidentified Sources: HESS J1857+026 and HESS J1858+020

- 9.2 hrs livetime on W44 position. 6.4 hrs on UIDs
- J1857+026 possibly associated with PWN AX J185651+0245 powered by newly discovered radio pulsar PSR J1856+0245

- W44: UL ~2 % Crab
- J1857+026: 5.6 σ
- J1858+020: not detected

Agreement with HESS:

- HESSJ1857+026 is detected in the position reported by HESS.
- Morphology of HESS J1857+026 is well reproduced.



Summary

- **IC 443:** Extended and complicated
  - Extended emission; soft spectrum
  - Origin: PWN or SNR/MC interaction?
  - Strong Fermi source: broadband spectral, morphological evolution will be illuminating

- **Cas A:**
  - Detection with 8.3σ significance in 22hrs
  - Consistent with a point source
  - Power-law spectrum up to ~5 TeV; no sign of a cut-off
  - Well-measured spectrum. Boon to modelers
- **Other SNRs:** Lack of strong (>5% Crab) sources

Future Directions … Upgrade

Disassembly of T1

Relocating T1 will improve the sensitivity of VERITAS by ~15%
→ equivalent of gaining an annual 300 hr extra in obs. time.

Impacts all physics goals.

New platform for T1