The VERITAS Survey of the Cygnus Region of the Galactic Plane

A. Weinstein for the VERITAS Collaboration

University of California Los Angeles
Motivation and Context

- Efficient method of searching for new sources over a large region
- Un-biased indication of source population
- Southern hemisphere well-surveyed
  - HESS Galactic plane survey, ~14 sources in initial survey
- Best limits in northern hemisphere sky: HEGRA’s Galactic plane survey
  - $-2^\circ < l < 85^\circ$, flux upper limits: 15% Crab to several Crab
- Size and choice of region based on
  - VERITAS sensitivity and FOV
  - Material distribution, density of potential TeV γ-ray emitters (SNR, PWN, high E-dot pulsars, EGRET unidentified sources..)

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Survey Observation Strategy

Made possible by good VERITAS off-axis sensitivity

- Survey covers region $67^\circ < l < 82^\circ$, $-1^\circ < b < 4^\circ$
- Available observing period: April-June, Sep.-Nov.
- $\sim 6$ hrs effective exposure before followup.
- $\sim 112$ hours in base survey, $\sim 56$ hours followup.
One Interesting Region

- Partial survey map, generated with standard threshold extended source analysis
- Includes all data in survey region taken to this point
- Exposure uneven due to followup (more intensive followup around VER J2019+407 than around TeV J2032+4130)

- VER J2019+407
  - New VERITAS source

- TeV J2032+4130
  - Known source, first detected by HEGRA
  - Likely associated: MGRO J2031+41, 0FGL J2032.2+4122 (LAT pulsar)
  - Detection: >5σ at nominal position (no trials)

2009 Fermi Symposium
VERITAS Survey of the Cygnus Region of the Galactic Plane

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VER J2019+407

- Early follow-up candidate
- Recent (last six weeks) follow-up treated as an independent search
  - 0.25° radius search region
  - 0.6° wobble, position indicated by earlier data
- 8.5σ (~7.5σ) pre-(post-)trials in Fall 2009 data alone;

Preliminary position: RA: 304.97° ± 0.017° (stat), Dec: 40.79° ± 0.023° (stat)
Preliminary extension: 0.16° ± 0.028° (0.11° ± 0.027°) for the major (minor) axis

- Derived from 2D Gaussian (convolved with VERITAS PSF) fit to uncorrelated excess map (Fall 2009 data only)
- Flux on the order of 2-5% Crab
VER J2019+407 in context

- In northwest region of Gamma Cygni SNR (G78.2+2.1)
  - What exactly is it?
- PWN?
  - core ~0.5° away from Fermi pulsar
  - Association seems unlikely
- VERITAS emission does overlap well with radio contours in northwest
- Shock-cloud interaction?
  - Plenty of CO in southeast, not much in northwest
  - Two partial shells in HI, one in northwest (Ladouceur and Pineault 2008, A&A 490, 197)
  - Cloudlets? Enough mass in HI?
- Scenario: SNR was expanding in bubble blown by progenitor star; now hitting dense material in ISM.
VER J2019+407 in context

- Uchiyama et al. ApJ, 571:866-875, 2002
  - Soft X-ray emission belt (1-3 keV) from north to southeast
    - shock interacting with cavity wall of ambient clouds?
  - Identifies hard sources in north with shocked dense cloudlets
    - Poss. Ne IX emission lines in soft emission in north
    - Cloudlet density? (need limit on GeV emission)

ASCA X-ray map
4.85 GHz radio contours
Cygnus Region: Broad Limits

- No hotspots above $5\sigma$ post-trials in base survey

- Much stronger limits than available in the past from HEGRA

- Preliminary Flux Limits (99% CL, all points in survey below $3\sigma$)
  - $<3\%$ Crab above 200 GeV (point source)
  - $<8.5\%$ Crab above 200 GeV (0.2° radius extended source)

- New un-biased indication of northern hemisphere source population; qualitatively different
  - HESS survey: out of 14 sources in $-30^\circ<l<30^\circ$, saw 12 sources with fluxes $\geq 5\%$ Crab above 200 GeV
Summary and outlook

• Detection of 2 sources with VERITAS survey technique and followup observations
  – 1 discovery: VER J2019+407
  – TeV J2032

• Further followup observations in survey region ongoing.

• Difference in source density and strength (survey limits, current detections) indicates population difference between northern and southern hemispheres.

• Prospects for future:
  – Spectra and energy-dependent morphology studies (VER J2019+407, TeV J2032).
  – Joint analysis (morphology, cross-correlation studies) with Fermi data in the region.
VER J2019+407 in context
Analysis Strategy

• Data analysis: ring background estimation, four simultaneous, pre-defined analyses

|                      | “Standard” source                  | “Hard source”                   |
|----------------------|-----------------------------------|---------------------------------|
| Point source         | Size > 90 p.e.                    |                                 |
|                      | $\Theta^2 < 0.013^\circ$         | Size cut > 150 p.e.            |
|                      |                                   | $\Theta^2 < 0.013^\circ$       |
| Extended source      | Size > 90 p.e.                    |                                 |
|                      | $\Theta^2 < 0.055^\circ$         | Size cut > 150 p.e.            |
|                      |                                   | $\Theta^2 < 0.055^\circ$       |

• **Multiple configurations over a 2.5 year period**
  – ~30% of base survey data taken with 3-telescope configuration
  – Spring followup data taken with a different 3-telescope configuration.
  – Most recent followup data taken with new 4-telescope array configuration

• **Zenith angle variation**
  – Range of zenith angles per pointing (affects sensitivity estimates).
  – >80% of all survey pointings are at an average zenith angle <25°.
Sensitivity estimation

- Use simulated survey grid
  - average zenith angle of 20°
  - Blank survey fields for background
  - Inject simulated photons (spectra between 2.5 and 2.0, varied source extent)

- Estimates are
  - Conservative (zenith angle, configuration variations)
  - Consistent with standard VERITAS sensitivity curves/calculated “effective” exposure time.

- Sensitivity estimates based on achieving >5σ pre-trials (trigger for followup)

| Analysis type    | Spectral Index | Extension             | Flux (Crab > 200 Gev) |
|------------------|----------------|-----------------------|------------------------|
| Std point        | 2.5 (2.0)      | None                  | <0.04                  |
| Std extended     | 2.5 (2.0)      | 0.2° gaussian radius  | <0.1                   |
|                  |                |                       |                        |
|                  |                |                       | Flux (Crab > 500 Gev)  |
| Hard point       | 2.0            | None                  | <0.063                 |
| Hard extended    | 2.0            | 0.2° gaussian radius  | <0.16                  |
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VER J2019+407 in context

VERITAS excess
4.85 GHz NRAO Radio contours

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- Shock-cloud interaction?
  - VERITAS emission overlaps well with radio contours in the northwest

No visible emission to the southeast

LAT PSR J2021+4026
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**Instrument design:**
- Four 12-m telescopes
- 499-pixel cameras (3.5° FoV)
- FLWO, Mt. Hopkins, Az (1268 m)

**Specifications:**
- Angular resolution ~ 0.1° (1 TeV)
- Energy resolution ~ 15-20%  

**Prior Sensitivity:**
- 1% Crab @ 5σ ~ 50 hrs
- 5% Crab @ 5σ ~ 2.5 hrs

**Fall 2009 Sensitivity:**
- 1% Crab @ 5σ ~ 30 hrs