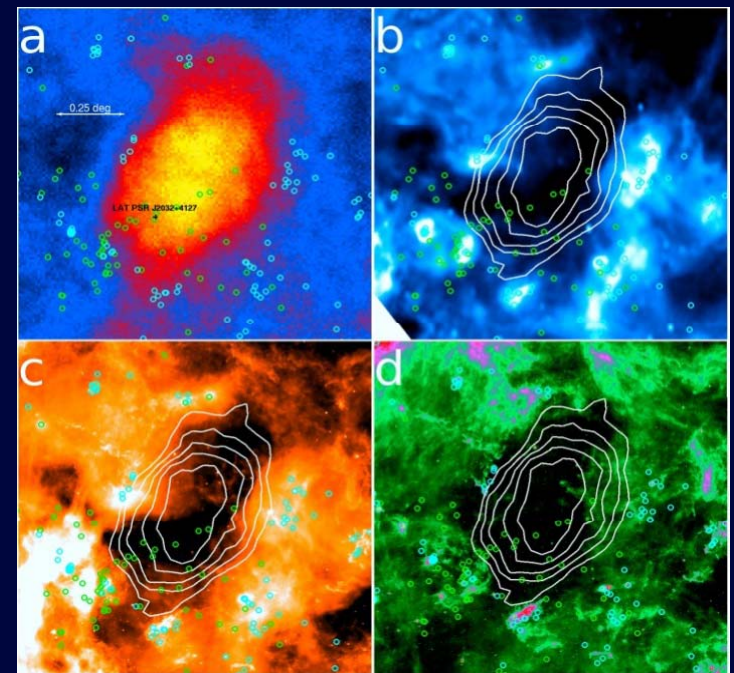


VERITAS Results on Galactic Sources in Cygnus



Rene A. Ong (UCLA)

for the VERITAS Collaboration

ICRC 2013 (Rio de Janeiro) – July 2013

OUTLINE

- VHE γ -rays as probes of Galactic CR origin
- The VERITAS Observatory
- The Cygnus region and VERITAS Sky Survey

New results on:

- VER J2019+407 (γ -Cygni)
 - TeV J2032+4130 (first Un-ID TeV source)
 - Cisne Region (MGRO J2019+37)
 - (Cygnus X-3, MGRO 1908+06)
- Summary

Rich Variety of VHE Sources → CR's

Pulsars
Pulsar Wind Nebulae



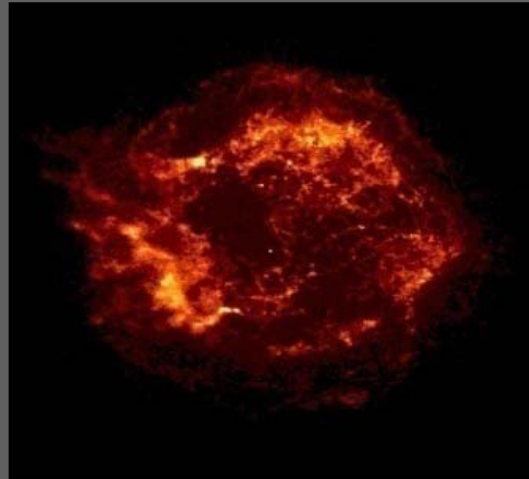
NS dynamo
Winds

Star Forming Regions



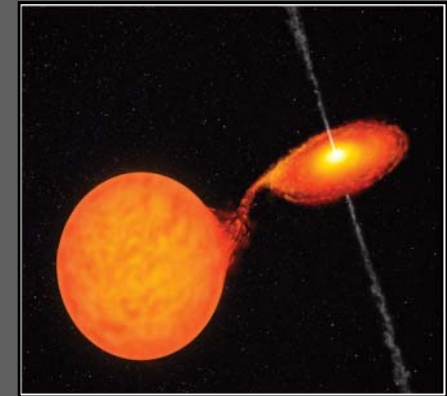
OB Assoc., WR stars,
molecular clouds, etc.

Supernova Remnants



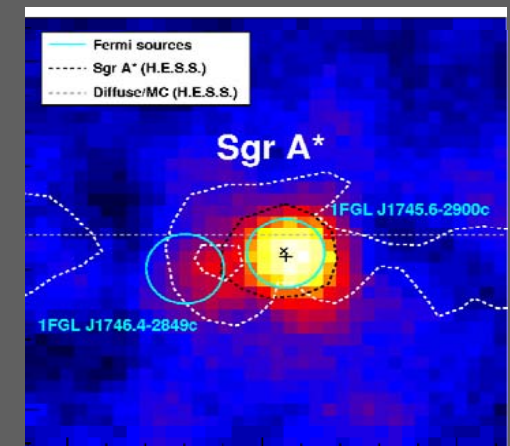
Shocks
Fermi mechanism
Origin of CRs ?

Binary systems



Accretion-powered jets,
Colliding winds, or ...?

Un-Identifieds



???

VERITAS



U.S.

Adler Planetarium
Argonne Nat. Lab
Barnard College
DePauw Univ.
Grinnell College
Iowa St. Univ.
Purdue Univ.
SAO

UCLA
UCSC
U. of Chicago
U. of Delaware
U. of Iowa
U. of Minnesota
U. of Utah
Washington U.

Canada

McGill Univ.

Ireland

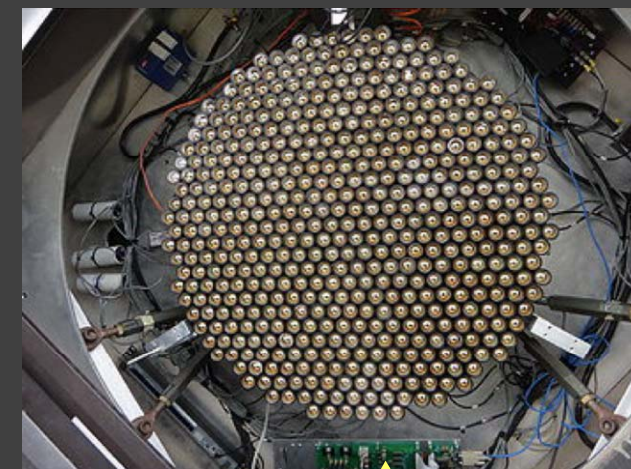
Cork University. N.U.I Galway
Galway-Mayo Inst. Univ. College Dublin

Non-Affiliated Members

Anderson Univ. DESY/Potsdam Penn State
Call Poly Georgia Tech
De Pauw Grinnell



June 2013 (Berlin)



Support from:

U.S. DOE
U.S. NSF
Smithsonian
NSERC (Canada)
STFC (UK)
SFI (Ireland)

Energy Range: 85 GeV – 30 TeV
Energy Resolution: 15-25%
Angular Resolution: < 0.1 deg (68%)
Sensitivity: < 25 hr (1% Crab)

(Summer 2012)
VERITAS Upgrade
High QE PMTs
New Tel Trigger

VERITAS Cygnus Sky Survey



HE/VHE Sky Surveys:

- **HEGRA:** North, ~25% Crab
- **HESS:** South, ~3% Crab, extended
- **Milagro (01-07):** North, ~35% Crab at $E > 10$ TeV
- **EGRET/Fermi-LAT:** GeV band

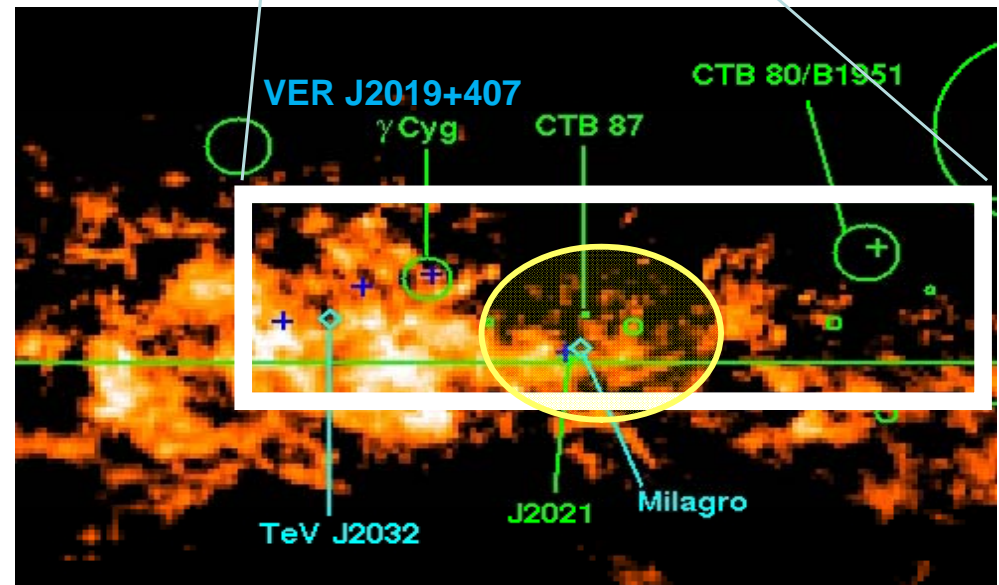
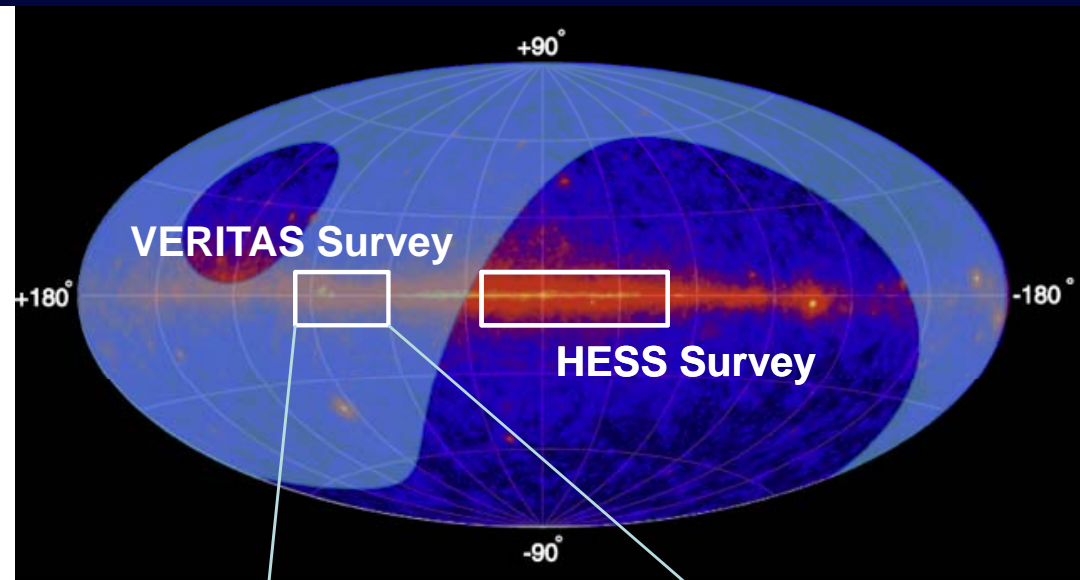
Cygnus Region:

- Rich in star forming activity
- Many potential VHE accelerators

VERITAS Sky Survey (07-09):

- N. Hemisphere – Cygnus arm.
- 115h + 55h follow-up; done before improvements to sensitivity.
- ~3% Crab (99%) for $E > 200$ GeV.

Note bright MGRO J2019+37

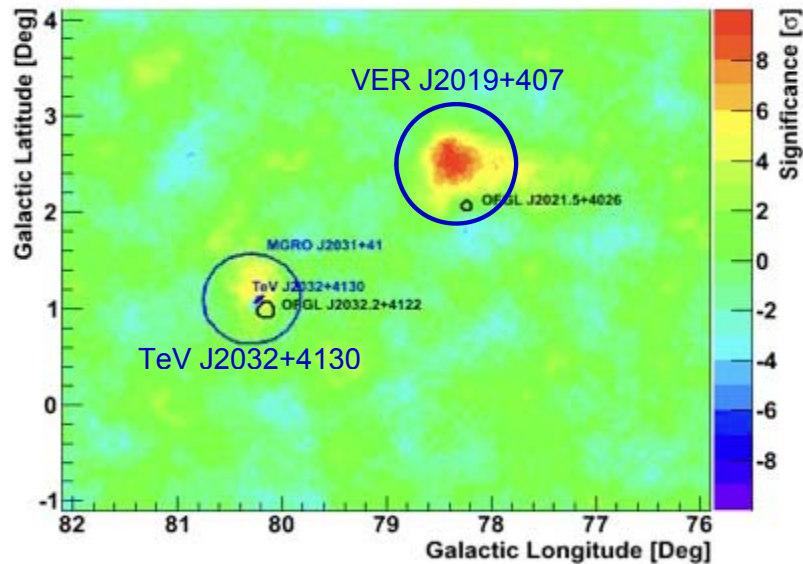


VER J2019+407 (γ -Cygni)

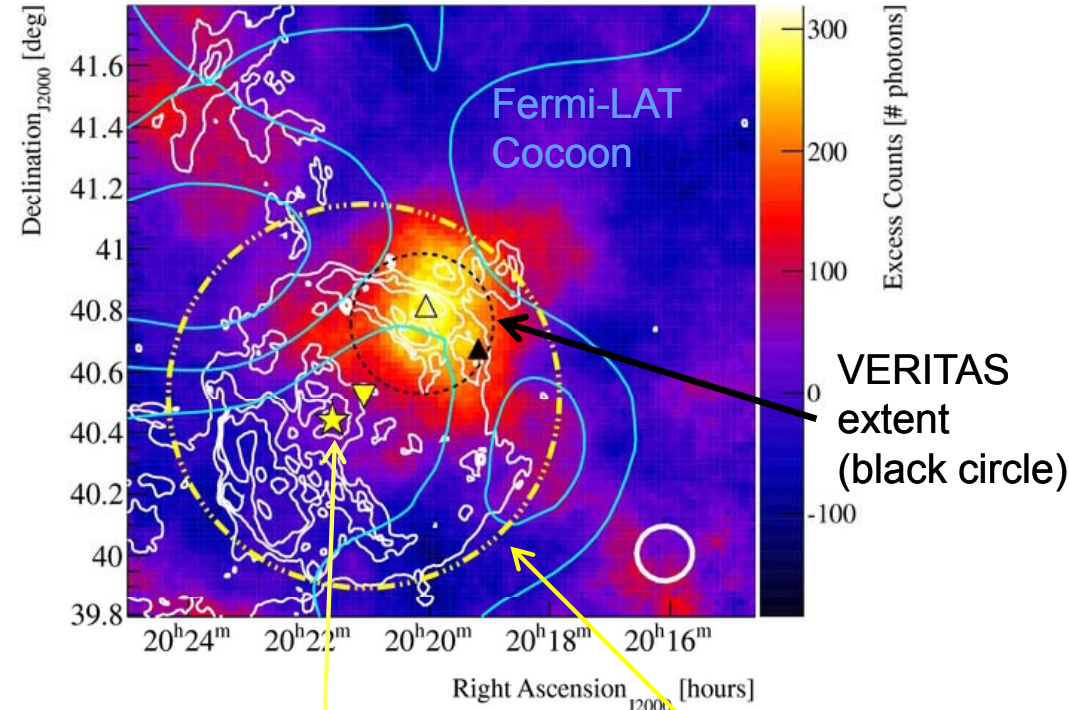


E. Aliu et al., ApJ 770, 93 (2013)

VERITAS Sky Survey (2007-09) (plus follow-up on VER J2019+407)



VERITAS Follow-up (2009)



Discovery of VER J2019+407

- 21.4 hr follow-up observations, 7.5σ post-trials
- Extension of $0.23 \pm 0.03_{\text{stat}} (+0.04_{-0.02})_{\text{sys}}$ deg
- Source at NW rim of G78.2+2.1 (γ -Cygni) in region of enhanced radio emission
- Pulsar and *Fermi*-LAT emission displaced from VERITAS source

PSR J2021+4026
(yellow star)

Fermi-LAT
>10 GeV emission
(yellow circle, center
at inverted triangle)

CGPS 1420 MHz
(white contours)

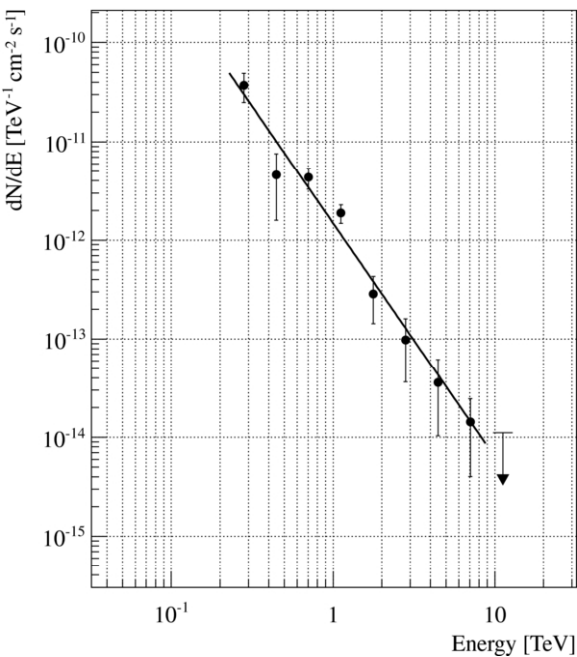
VERITAS
extent
(black circle)

VER J2019+407 (γ -Cygni)



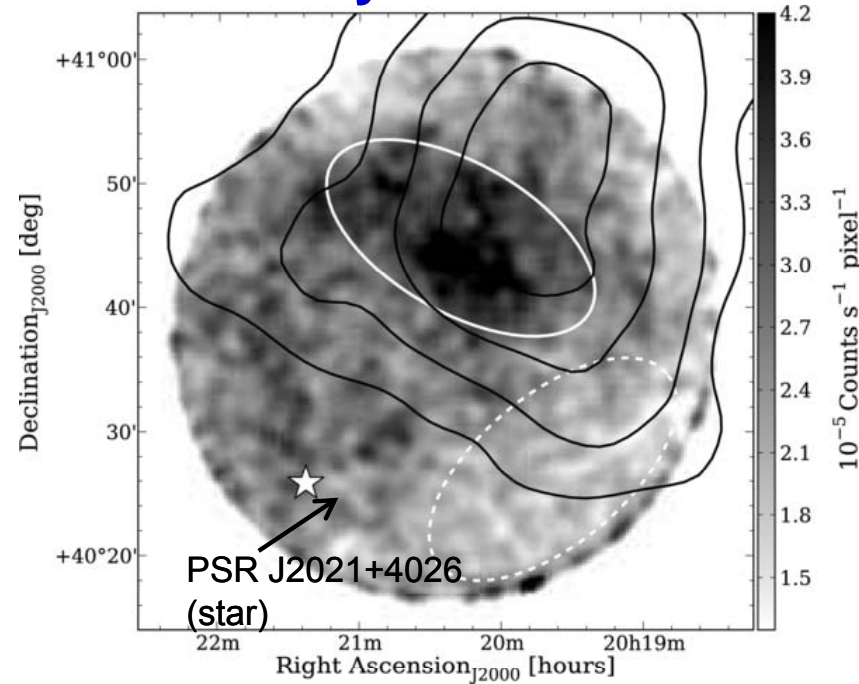
E. Aliu et al., ApJ 770, 93 (2013)

VERITAS Spectrum



- Single power-law form
- $\Gamma = 2.37 \pm 0.14_{\text{stat}} \pm 0.20_{\text{sys}}$
- 3.7% Crab $E > 320$ GeV

X-ray & VERITAS



- ASCA 1-3 keV, enhanced emission, fitted by Raymond-Smith model
- No evidence for non-thermal X-ray emission

Interpretation

PWN ?

Pulsar offset

SNR ?

Shock interaction of ejecta with dense HI shell

Required density (ρ) ~ 1.0 - 5.5 cm^{-3}
(similar to/less than inferred from optical)

TeV J2032+4130



TeV J2032+4130

- First un-identified TeV source (HEGRA)
- Confirmed by MAGIC, Whipple
source extension of ~ 6 arc-mins
- MGRO J2031+41: bright emission over a much larger area
- No clear picture of its nature

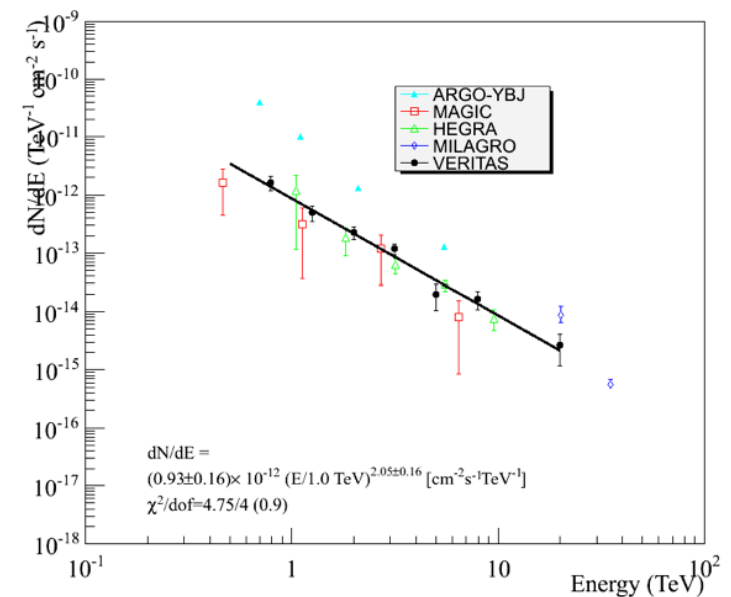
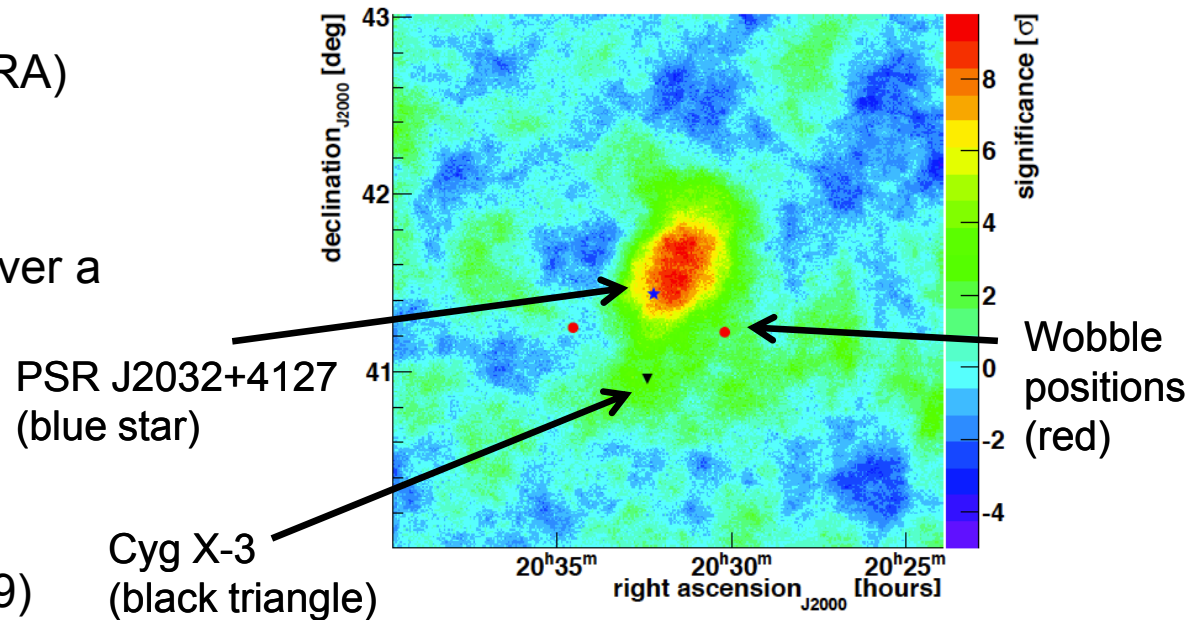
VERITAS Observations

- Detected in the Sky Survey (2007-09)
- Follow-up of 48.2 hr, 8.7σ significance
- Position consistent with previous ones
- Asymmetric extension
major axis: 0.16 ± 0.02 degs (NW)
minor axis: 0.066 ± 0.009 degs
- No evidence for E dependent morphology
- Hard spectrum, single power-law form

$$\Gamma = 2.05 \pm 0.16_{\text{stat}} \pm 0.21_{\text{sys}}$$

$$N_0 = 9.3 \pm 1.6_{\text{stat}} \pm 2.2_{\text{sys}} \times 10^{-13} \text{ TeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$$

E. Aliu et al. (in preparation, 2013)



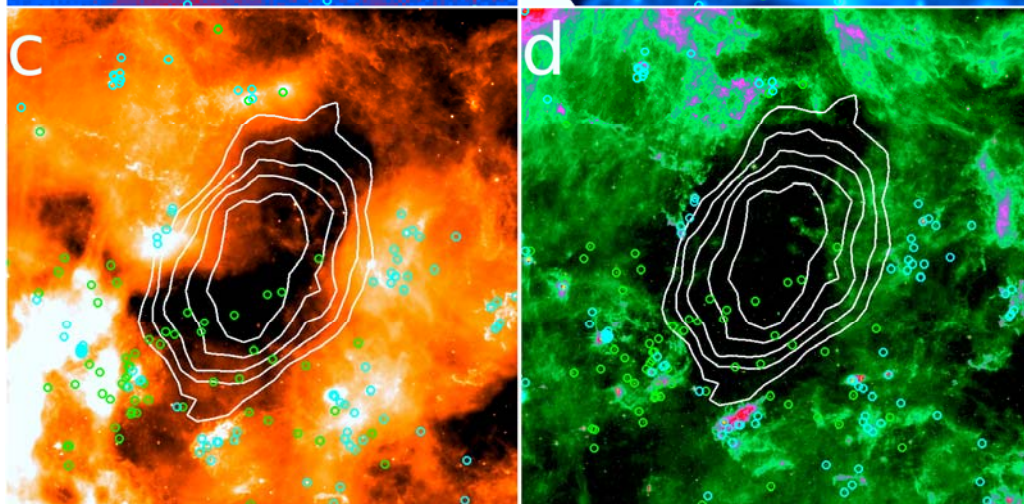
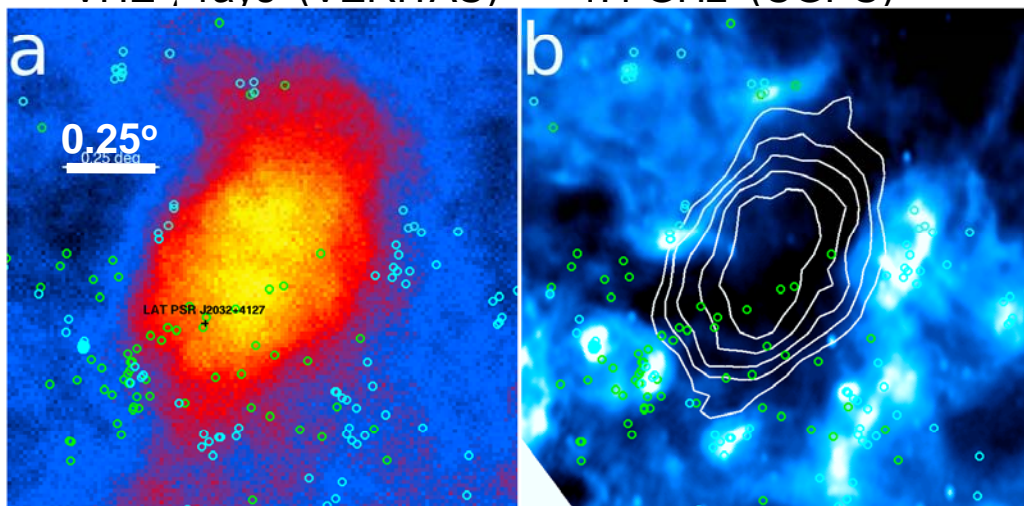
TeV J2032+4130 → VER J2032+415



E. Aliu et al. (in preparation, 2013)

VHE γ -rays (VERITAS)

1.4 GHz (CGPS)



24 μm
(Spitzer MIPS)

8 μm
(Spitzer GLIMPSE)

MWL Picture

- Fermi-LAT pulsar (blind search)
PSR J2032+4127, $P=142$ ms
→ relatively old and weak.
- No un-pulsed *Fermi*-LAT emission seen (our analysis).
- MGRO source has softer spectrum, but integrates over larger size

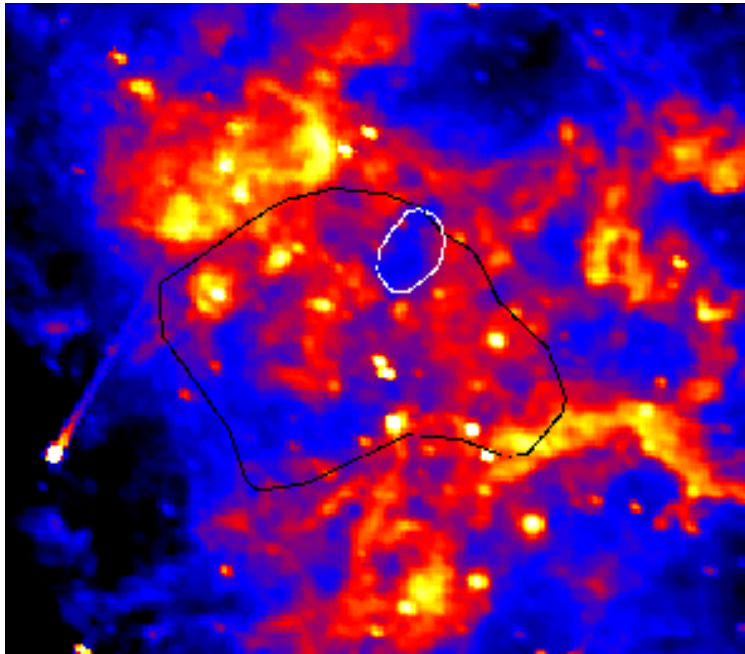
Interpretation: PWN

- TeV source is in void of generally bright emission at longer wavelengths.
- No SNR shell detected, but VHE emission consistent with pulsar wind powered by *Fermi*-LAT pulsar .
- Characteristics of PSR J2032+4127 are consistent with TeV PWN population.

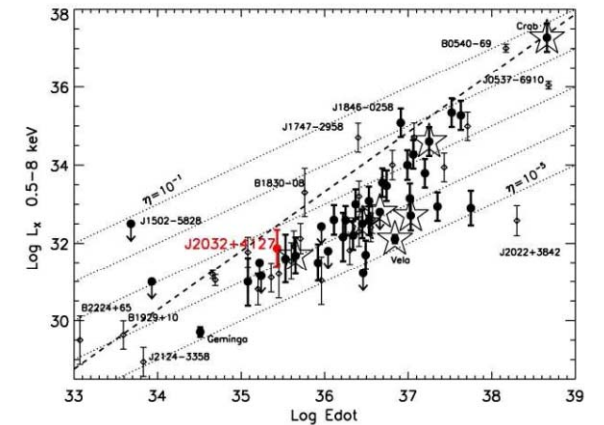
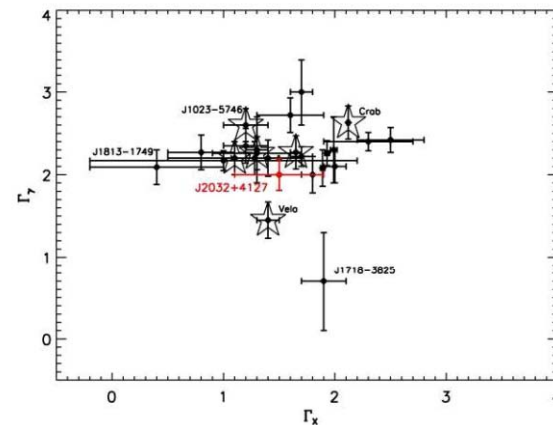
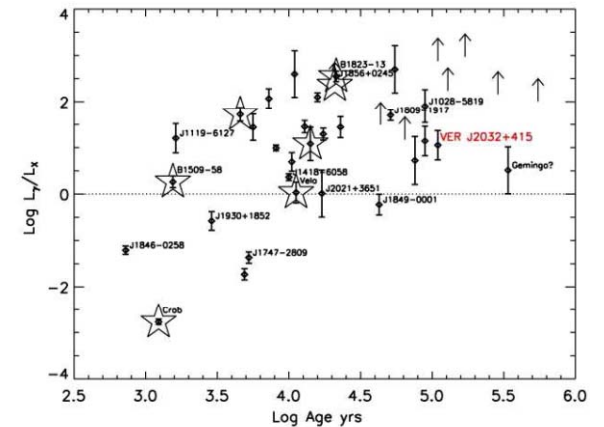
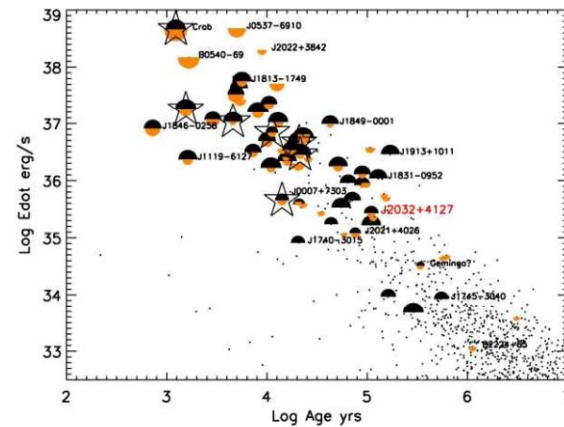
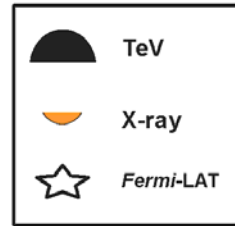
TeV J2032+4130



E. Aliu et al. (in preparation, 2013)



MSX $8\mu\text{m}$ survey
 VERITAS = white line
 Milagro = Black line



Characteristics of PSR J2032+4127

Cisne Region (MGRO J2019+37)



MGRO J2019+37

- One of three bright sources detected by Milagro, broad ($1.2^\circ \times 0.7^\circ$), not resolved
- Excellent angular resolution of VERITAS allows for a sharper image

VERITAS Observations (2010)

- 71 hr \rightarrow complex sky map, with multiple sources
- VER J2016+371: point source, consistent with CTB 87
- VER J2019+368: extended emission, possibly multiple sources covering ~ 1 deg

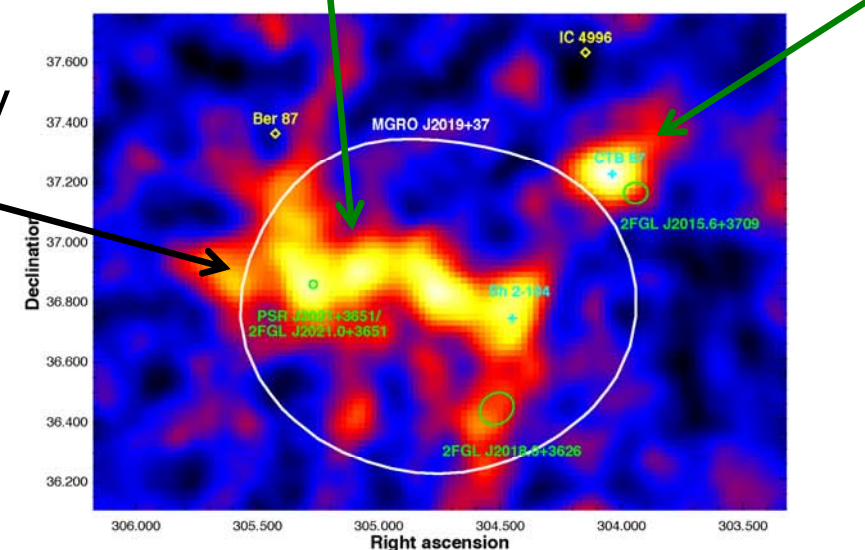
VER J2019+368

VER J2016+371

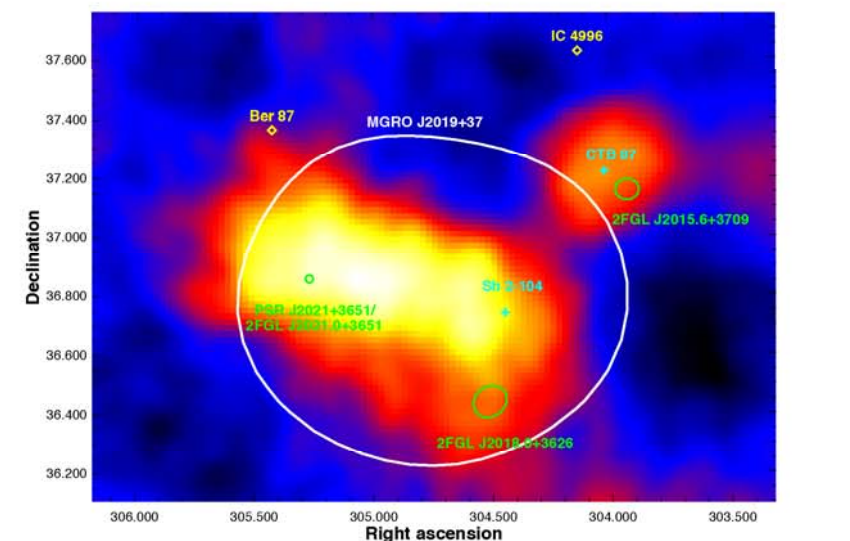
E. Aliu et al. (in preparation, 2013)

MGRO
 $E > 20$ TeV
white

Fermi
2FGL
green
circles



Integration $\theta^2 < 0.008 \text{ deg}^2$



Integration $\theta^2 < 0.055 \text{ deg}^2$

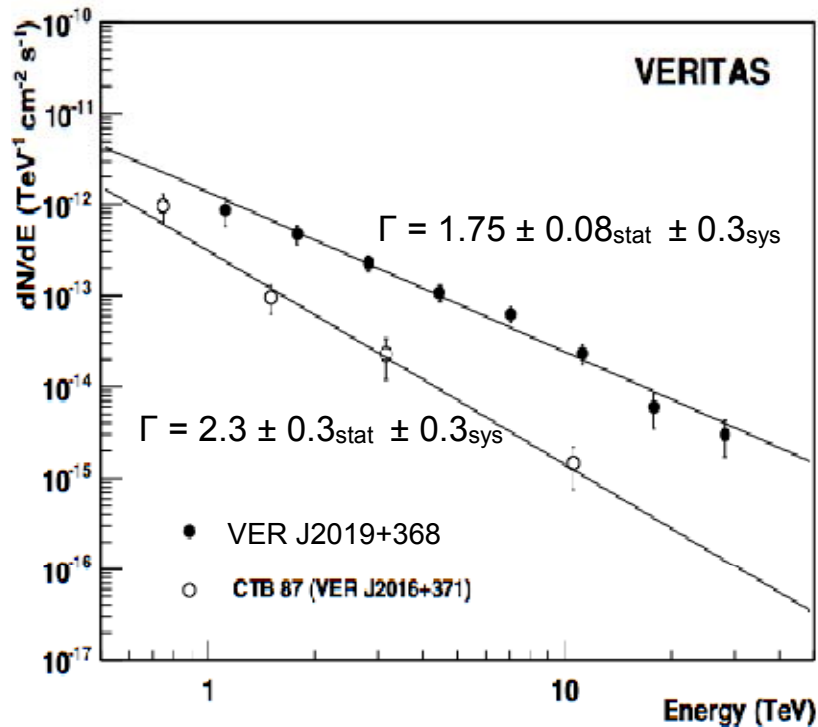
Spectra and CTB 87



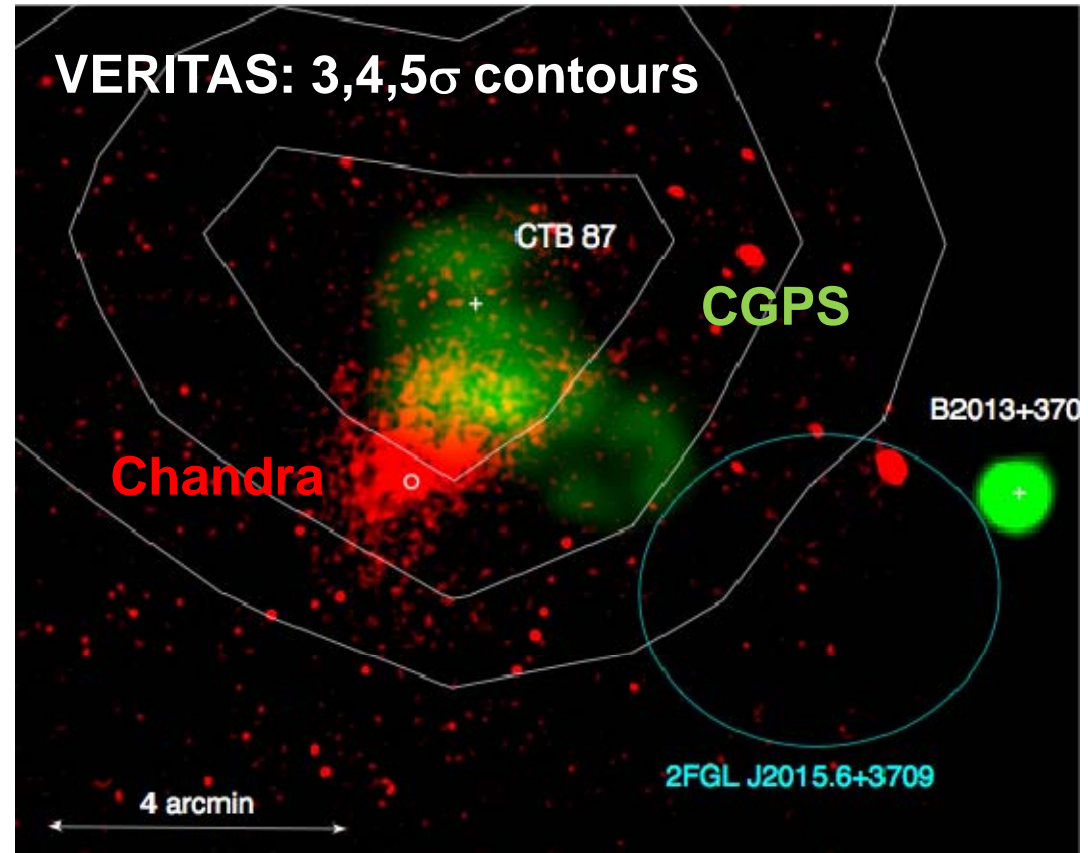
CTB 87 Region

E. Aliu et al. (in preparation, 2013)

VERITAS Spectra

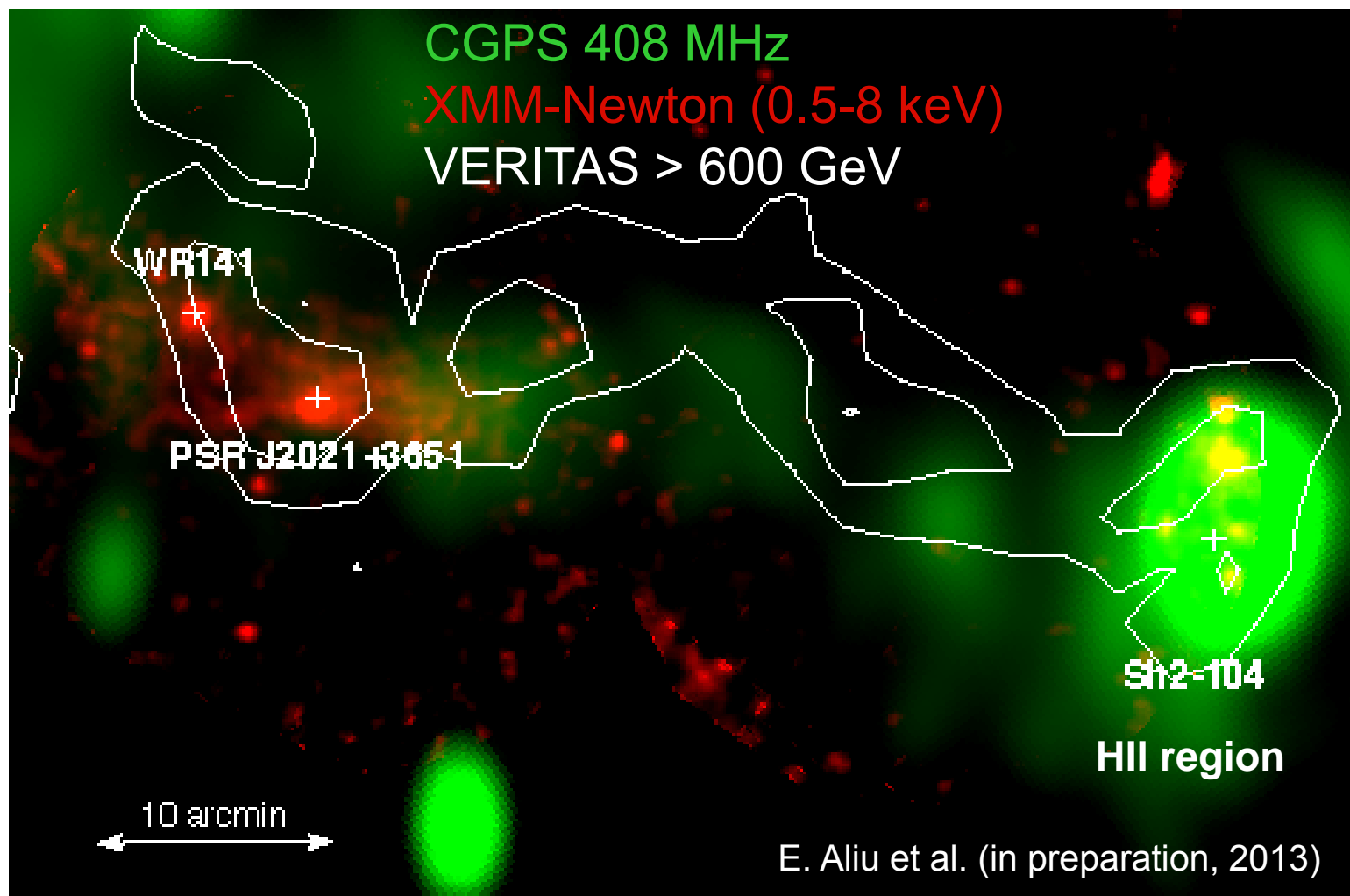


- VER J2016+371 (CTB 87) is weaker & softer
- VER J2019+368 is compatible with MGRO



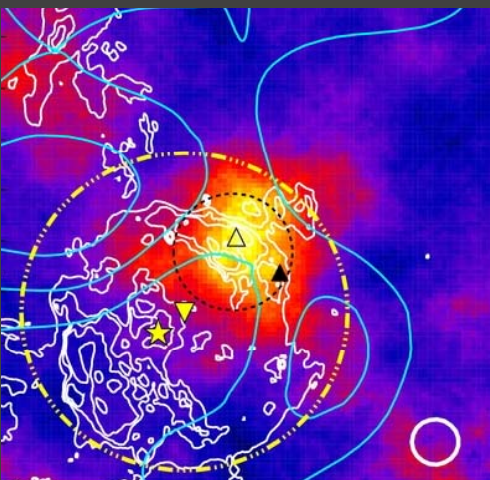
- VER J2016+371 point source emission at location of CTB 87.
- X-ray/radio suggest PWN, no pulsar yet detected
- 2FGL source probably not related

Sharper View of MGRO J2019+37

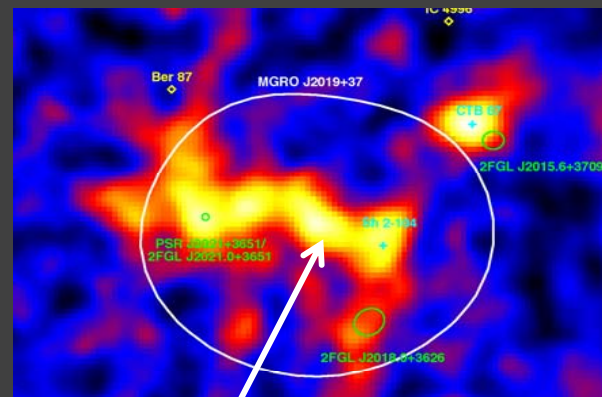


- VHE emission appears to follow ridge of diffuse radio emission
- Signif. fraction (~50%) VHE could derive from PWN powered by PSR J2021+3651
- Remainder of VHE is still unattributed (unknown nebula ? winds in HII region ?)

The VERITAS view of Cygnus

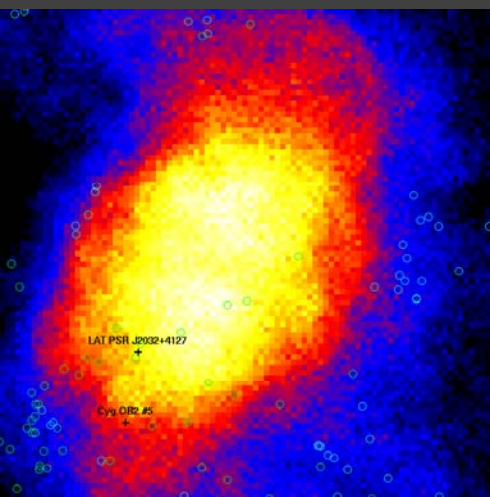


VER J2019+407
(SNR shock)

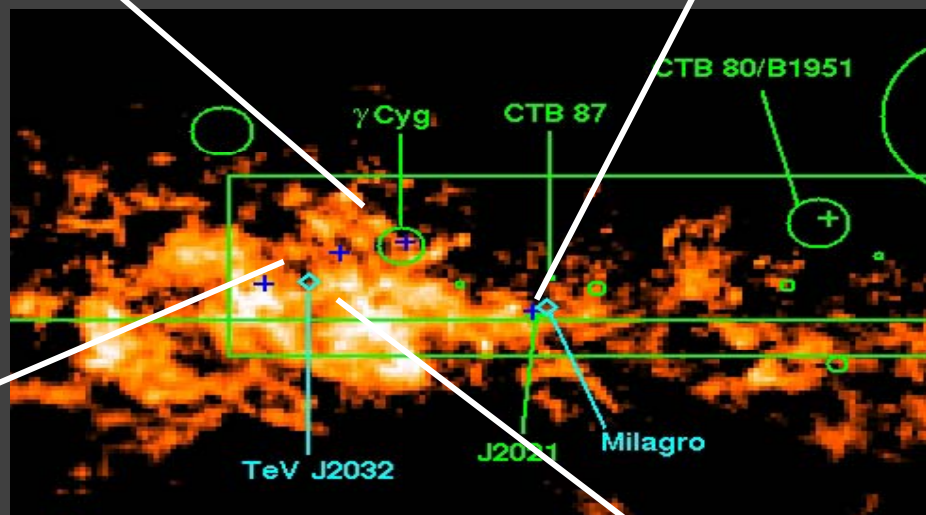


VER J2016+371
(Pulsar Wind)

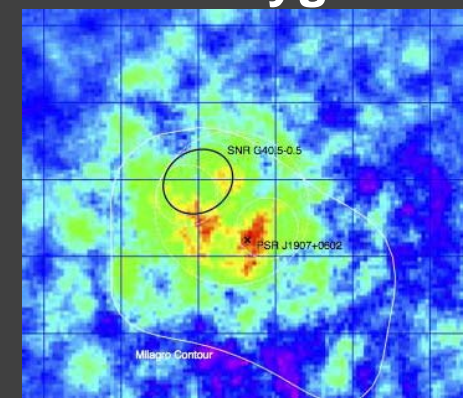
VER J2019+368
(Unknown)



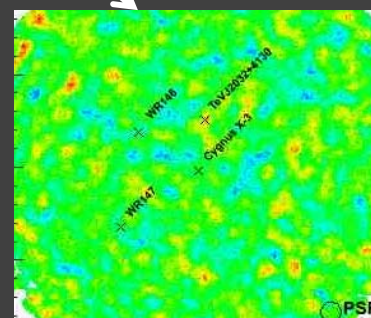
VER J2032+415
(Pulsar wind)



In Gal plane,
not in Cygnus



MGRO 1908+06
(stay tuned)



Cyg X-3
(Not seen at TeV)

All five papers to be published In 2013

Summary



Cygnus is a rich, complex region in VHE γ -rays.

VERITAS has taken ~ 250 hr of data in Cygnus over 2007-2012, leading to:

- discovery of new sources
- a sharper view, compared to previous surveys

2013 Results:

- **VER J2019+407**: (SNR interaction)
- **TeV J2032+4130**: (PWN)
- **Cisne: CTB 87** (PWN)
MGRO J2019+37 (complex, not understood)
- **Cyg X-3**: not yet detected

Extending knowledge of TeV Galactic sources \rightarrow origin of CR's