The VERITAS Survey of the Cygnus Region

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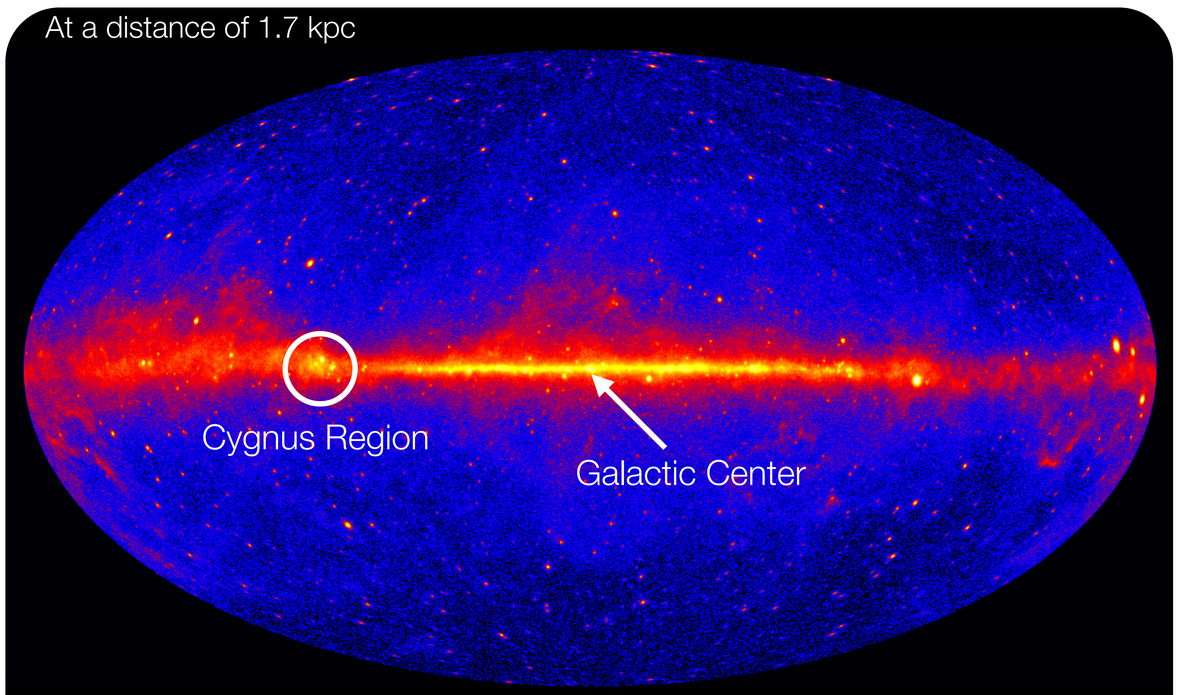
The VERITAS Observatory

- Array of four imaging atmospheric Cherenkov telescopes [1]
- Location: Fred Lawrence Whipple Observatory in southern Arizona (30°40'N 110°57', 1.3 km a.s.l)
- Scientific aim: study astrophysical sources of gamma-ray emission
- Energy range of about 85 GeV up to 30 TeV
- Field of view of 3.5°

The current layout of the VERITAS array.

Motivation - The Cygnus Region in a Nutshell



The gamma-ray sky as seen at energies above 1 GeV in Galactic coordinates.
Image credit: NASA/DOE/Fermi LAT Collaboration.

The Cygnus region is a star-forming region of our Galaxy seen in the northern sky, with a large number of known GeV-TeV γ-ray emitters. The total stellar mass is as high as $>10^6$ $M_\odot$. The emitted γ-rays from the Cygnus region provide insights into the mechanisms responsible for the acceleration and propagation of cosmic rays in our Galaxy. The best studied OB association within the Cygnus region to date, OB2, contains more than 2600 stars and is a great tool to study the interplay between star formation and cosmic rays which could then be accelerated by supernova remnants.

- Objects found in the Cygnus region: pulsar wind nebulae (PWNe), supernova remnants (SNRs), binary systems, many OB star associations and molecular clouds
- Yet unresolved puzzles:
  - ➡ What are the origins of the extensive TeV emissions in this region?
  - ➡ What are the mechanisms responsible for the acceleration and propagation of cosmic rays?
  - ➡ Are the acceleration of cosmic rays and emission of γ-rays associated with massive star-forming regions?

Survey of the Cygnus Region

- 2007-2009: VERITAS survey of the Cygnus region
  - ➡ Area: about 15ºx5º from 67º to 82º Galactic longitude and from -1º to 4º Galactic latitude
- 2008-2012: follow-up observations of about 150 hours
- In total: 300 hours (Figure 1) of quality-selected live time
- Elevation angles of observations: between 50º and 85º

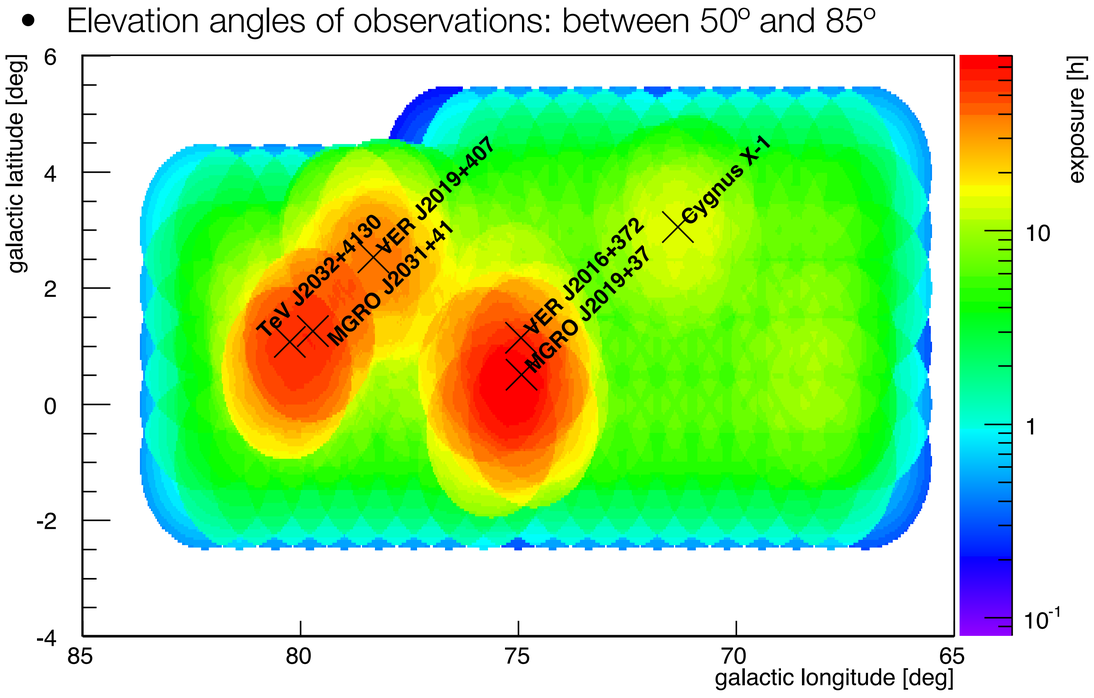
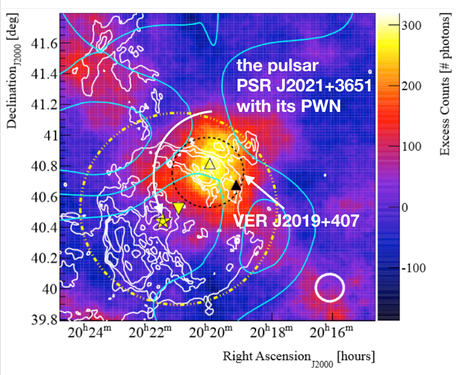


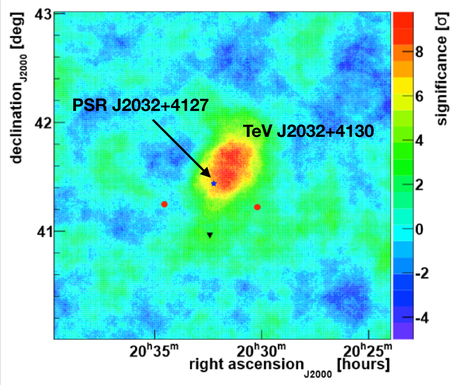
Figure 1: The exposure map of the VERITAS observations from 2007 to 2012.

TeV Sources in the Cygnus Region

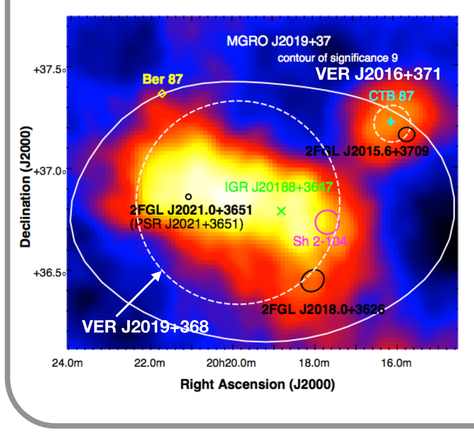
The previous analysis led to the detection of two new sources and greatly improved the information of already known sources [2,3,4]. The TeV γ-ray emission of these sources has various physical origins.



- Clear signal around region of SNR G78.2+2.1: post-trial-significance of 7.5σ
- Related to presence of shocks interacting between the supernova ejecta and the surrounding medium
- Might be also a line-of-sight coincidence between the SNR and an unassociated PWN [2]



- TeV J2032+4130: first unidentified gamma-ray source at very high energies (above 100 GeV)
- VERITAS analysis: 8.7σ
- MWL studies in gamma-ray, infrared and radio regimes
- Emission from a pulsar wind powered by PSR J2032+4127 or due to OB associations in this field [3]



- MGRO J2019+37: brightest source within the Cygnus-X region first seen by MILAGRO
- Better angular resolution of VERITAS → sharper view → two separate sources
- Point-like source VER J2016+371: consistent with the radio SNR CTB 87
- Extended emission of VER J2019+368: main contributor of this source seems to be the pulsar with its PWN [4]

Conclusion and Outlook

The Cygnus region has been identified to be active in very-high-energy γ-rays with four sources detected by VERITAS. It is furthermore a region for active inquiry at GeV-TeV energies with a large number of unidentified sources. Ongoing analysis efforts excluding already known sources and using an improved algorithm of gamma/hadron separation are being made, and can help untangle the origins of γ-ray emission in this region. Deep observations of this region with HAWC, VERITAS and in the future CTA will determine whether other yet unidentified sources exist. The combination of the sensitivity of HAWC with the deeper, higher angular resolution of VERITAS and CTA observations and the cross correlation of the *Fermi* sky maps provides the most efficient way to study the Cygnus region at GeV-to-TeV energies.

Acknowledgements
This research is supported by grants from the U.S. Department of Energy Office of Science, the U.S. National Science Foundation and the Smithsonian Institution, and by NSERC in Canada. We acknowledge the excellent work of the technical support staff at the Fred Lawrence Whipple Observatory and at the collaborating institutions in the construction and operation of the instrument. The VERITAS Collaboration is grateful to Trevor Weekes for his seminal contributions and leadership in the field of VHE gamma-ray astrophysics, which made this study possible. M.K. acknowledges support through the Young Investigators Program of the Helmholtz Association.

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[1] N. Park (VERITAS Collaboration), 34th ICRC in The Hague, 2015.
[2] E. Aliu et al., Astrophys.J. 770(2):93, 2013.
[3] E. Aliu et al., Astrophys.J. 783:16, 2014.
[4] E. Aliu et al., Astrophys.J. 788:78, 2014.