TeV-band galactic science

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Introduction

Galactic science is rich!

- Supernova remnants
- Pulsar wind nebulae
- Pulsars
- Binaries
- The Galactic center

The Galactic center

VERITAS is particularly sensitive to multi-TeV gamma rays

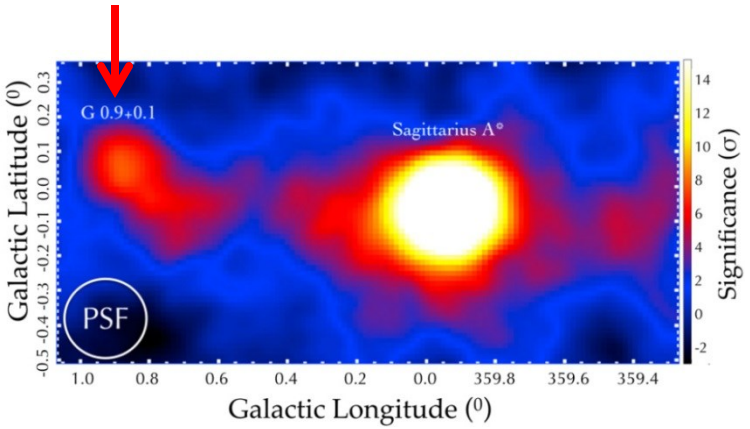
No evidence for variability

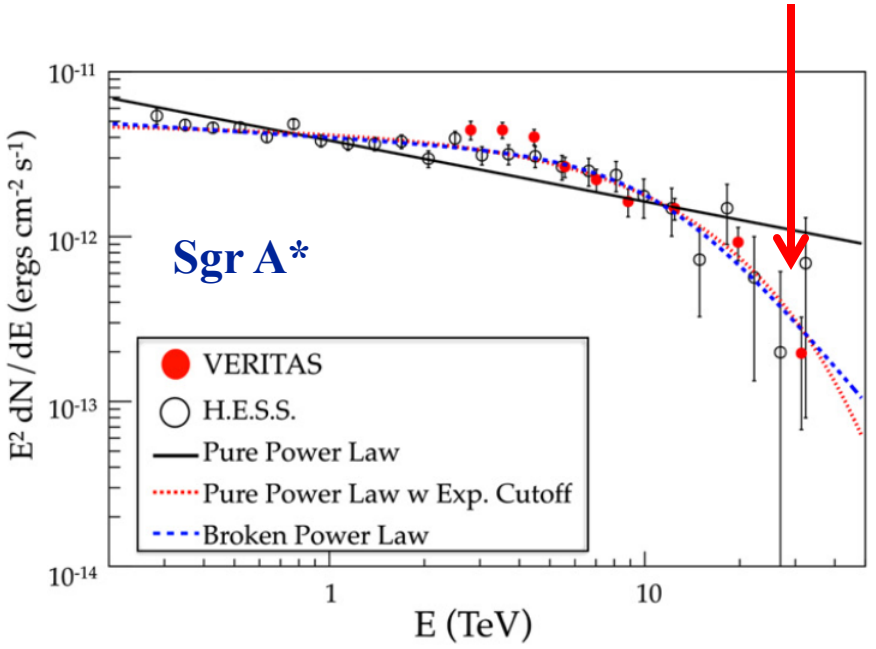
→ Do we really see Sgr A*?

High statistical accuracy above 10 TeV

Precise measurement of cut off

Power-law spectrum extends to 20 TeV





The Galactic center

Extended emission (first seen with H.E.S.S.)

Sgr A* subtracted

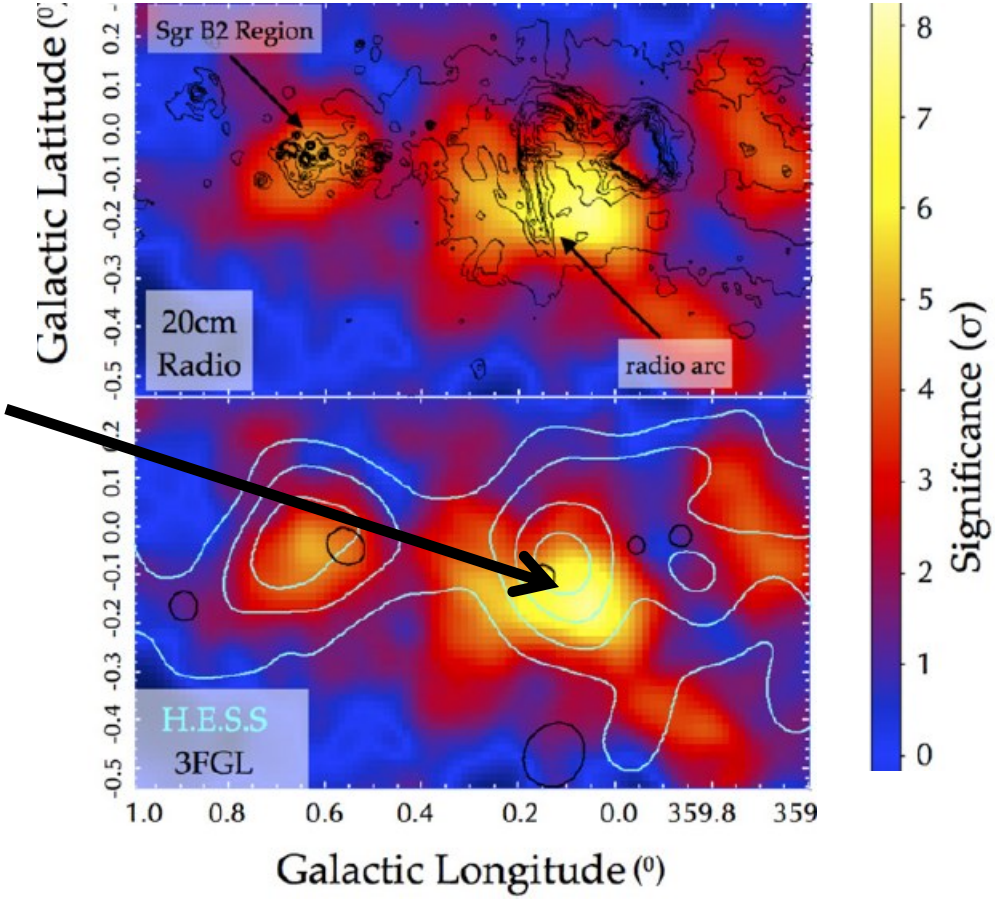
G0.9+0.1 subtracted

Extended source VER J1746-289

Appears point-like in HESS data

Possibly associated with radio arc

Energy-dependent extent?



Supernova remnants

In the early 2000‘s we knew for certain

- Galactic supernova remnants accelerate to PeVs
- Cosmic-ray spectra are hard in the TeV band
- We can distinguish leptonic and hadronic γ rays

Supernova remnants

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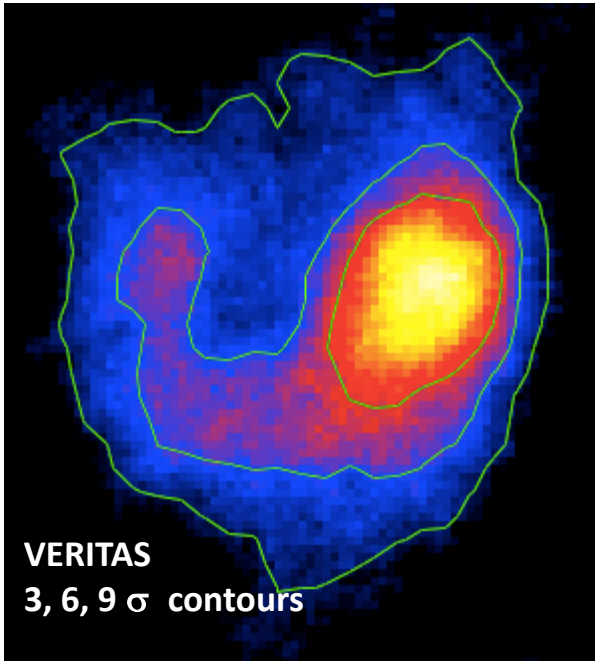
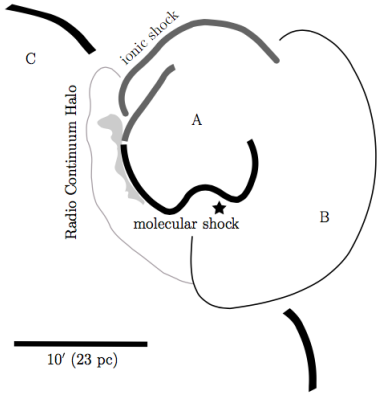
Now we know better …

Supernova remnants

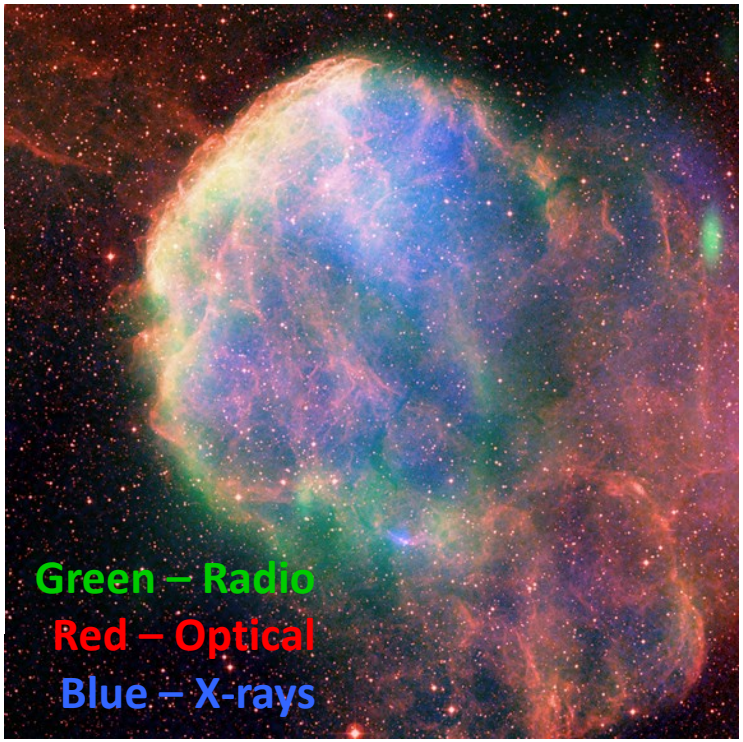
IC 443: The messy supernova remnant

Little, if any, spectral variation





Lee at al. 2012



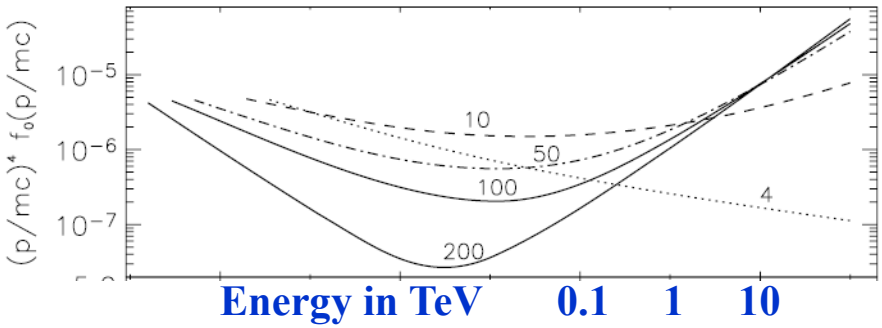
Supernova remnants

Hard spectra expected in the TeV band

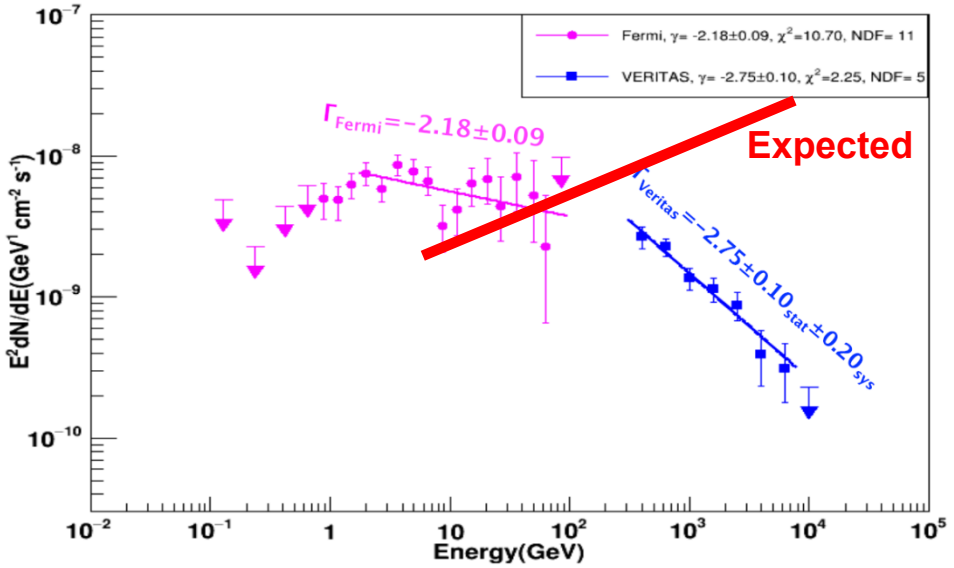
… not really seen, spectra tend to be soft

Cosmic-ray spectra

From a paper published in 2006



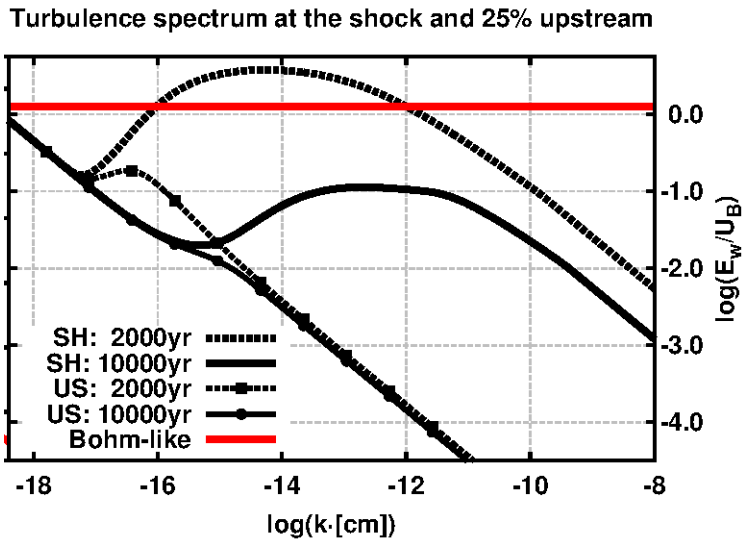
Gamma-ray spectra

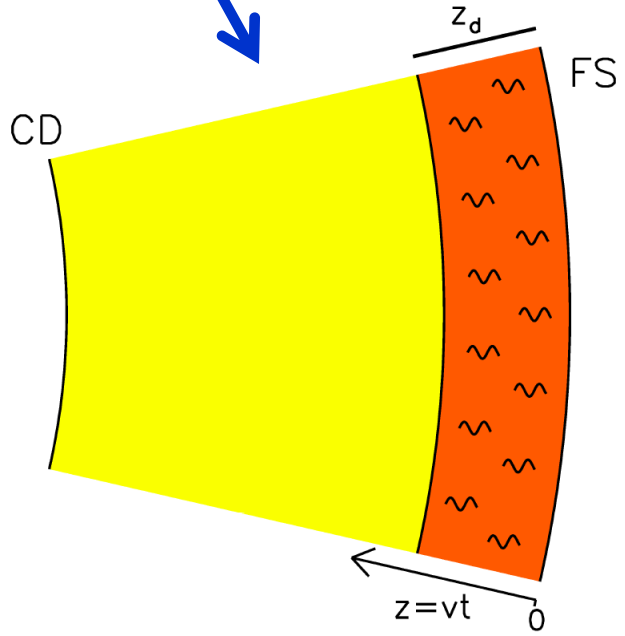


Supernova remnants

Model refinements are explored.

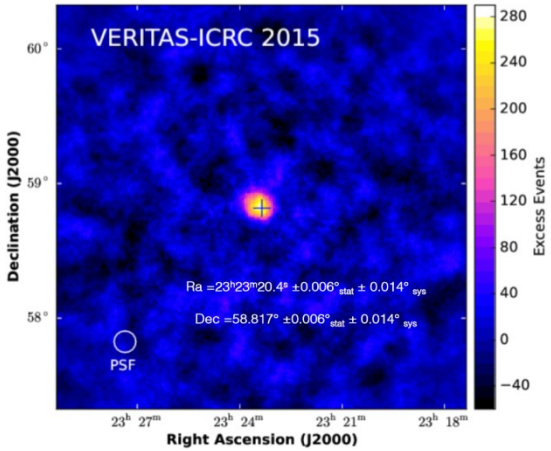
- Motion of scattering turbulence
- Secondary acceleration by turbulence
- Imperfect build-up of turbulence

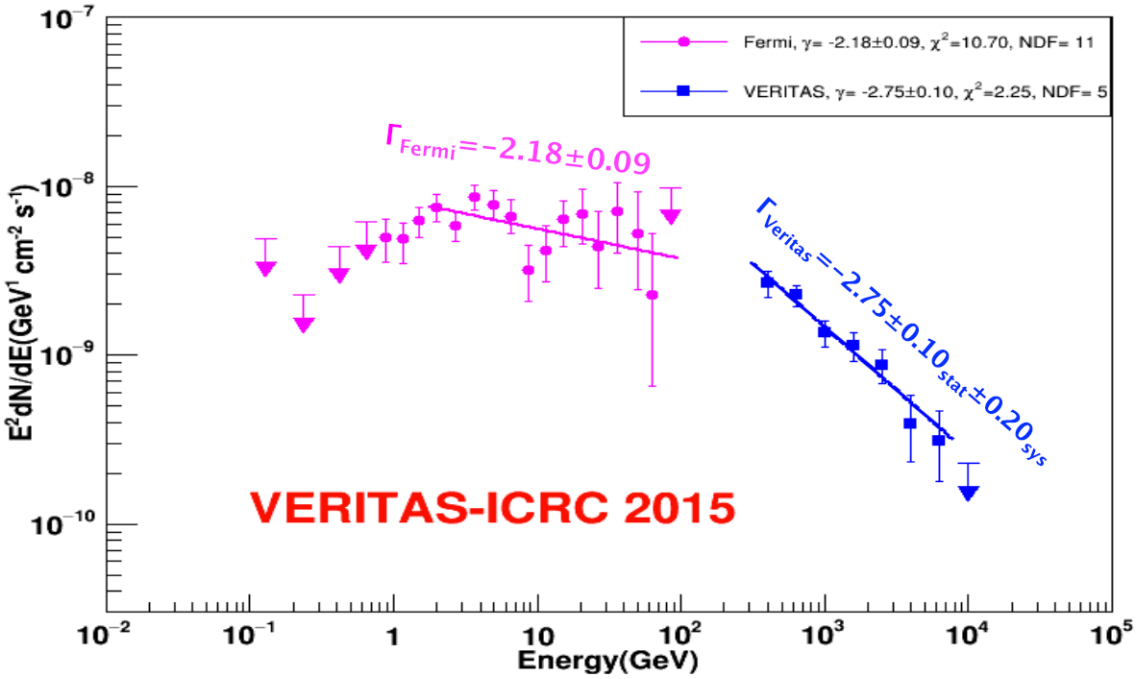




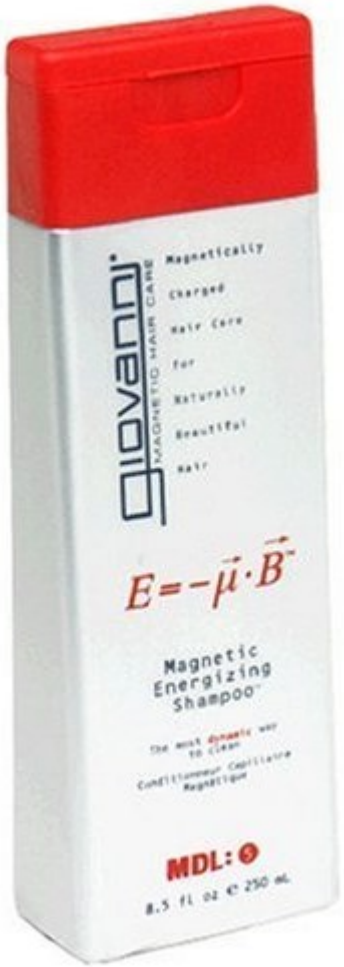
Supernova remnants: Cas A

How to make sense of that?

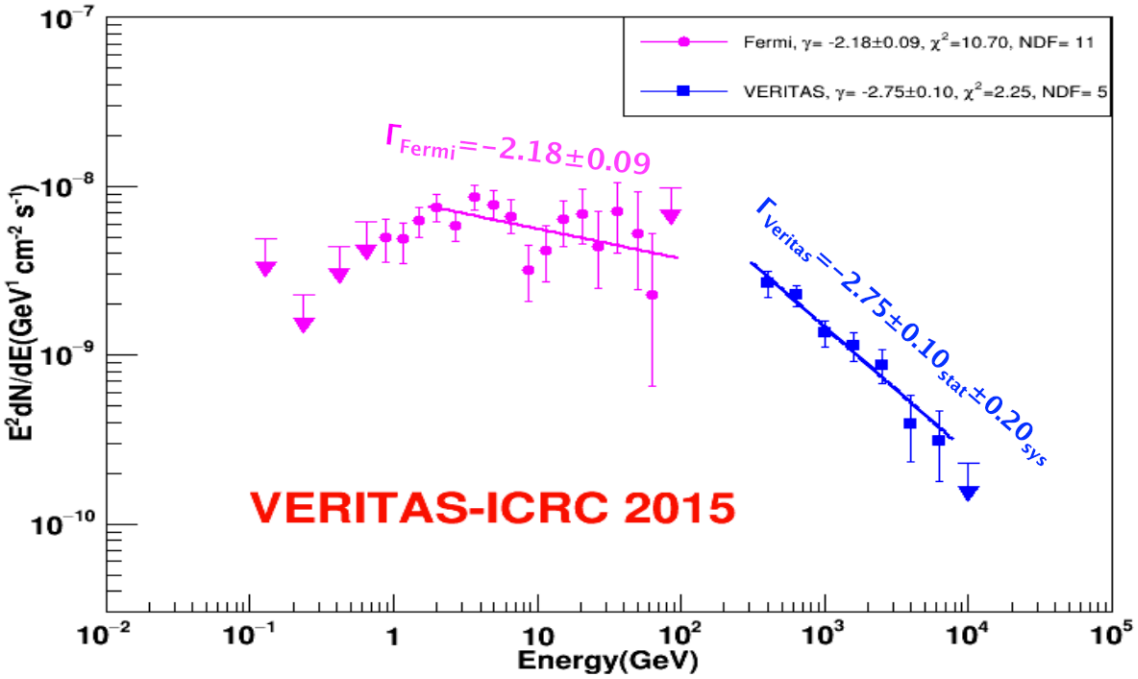




Supernova remnants: Cas A

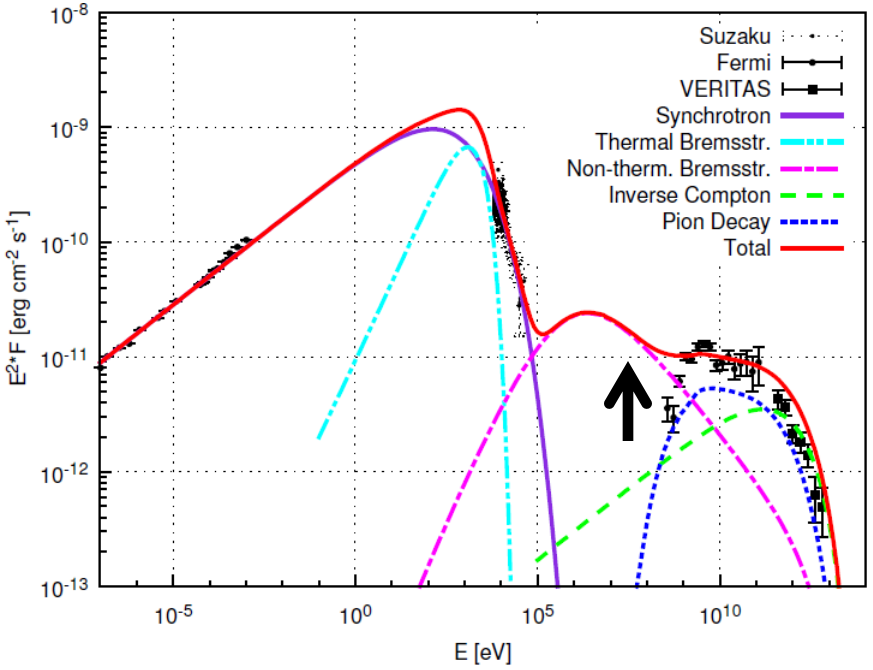


It‘s the magnetic field, stupid!

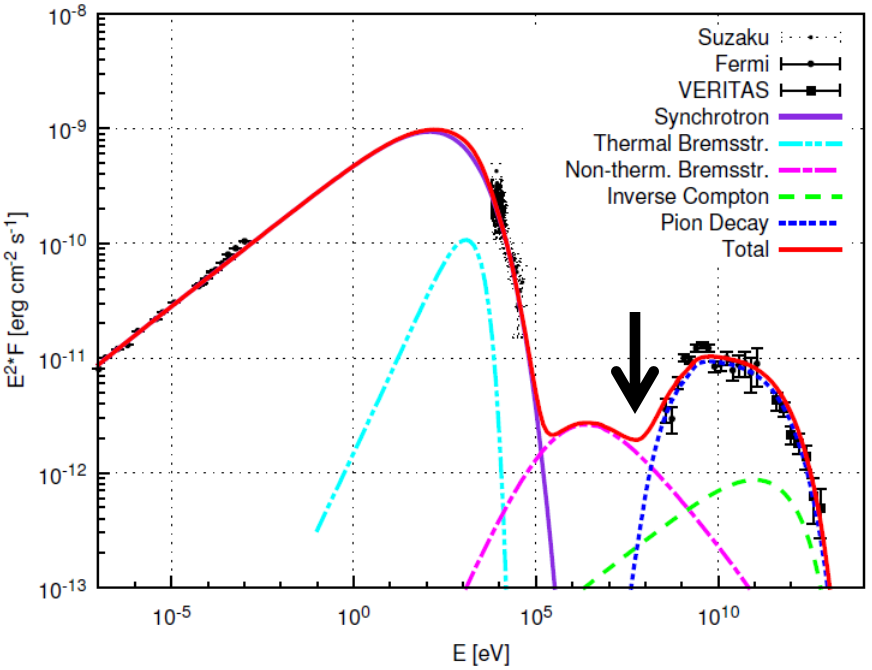


Supernova remnants: Cas A

Weaker magnetic field



Stronger magnetic field



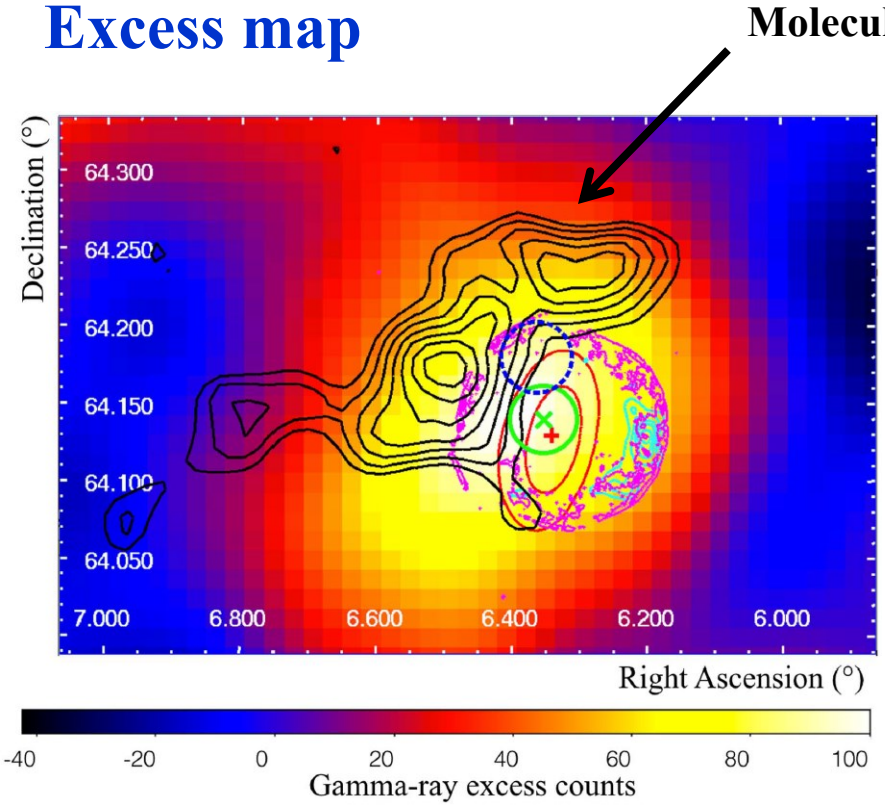
Electrons: magenta and green **Hadrons: blue**

Distinguishing requires information at 1-400 MeV

Tycho‘s Supernova remnant

Type Ia Supernova → clean environment

Excess map



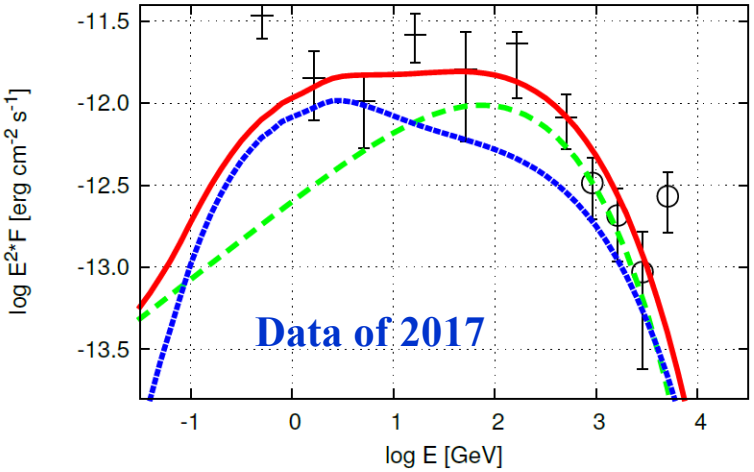
Statistical analysis:

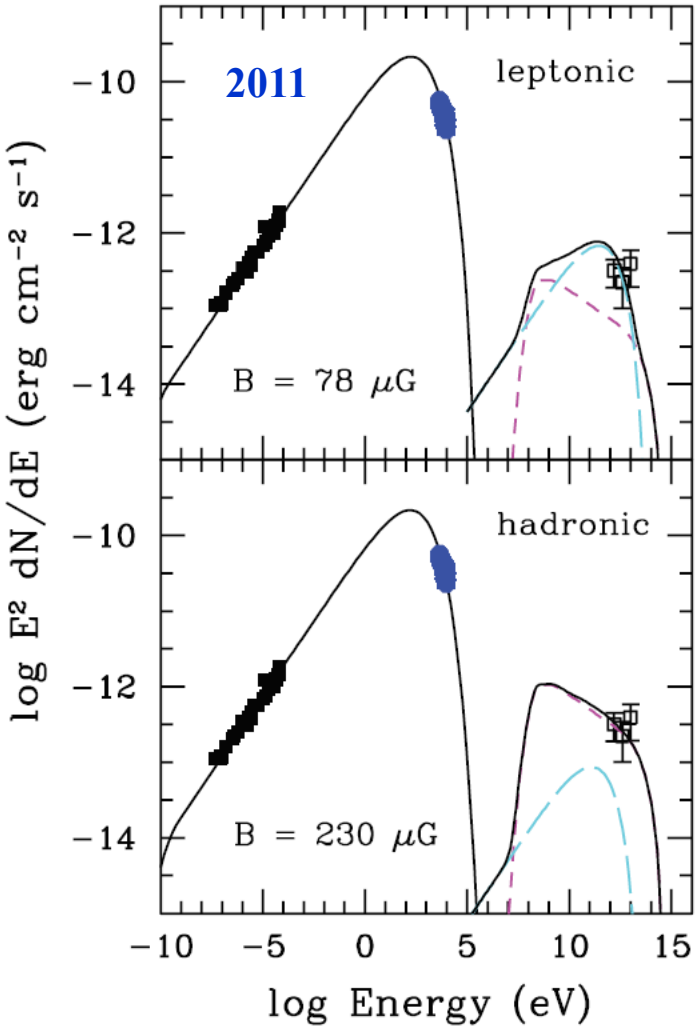
Signal comes from remnant itself

Tycho's Supernova remnant

Direct, model-independent assessment of average magnetic field

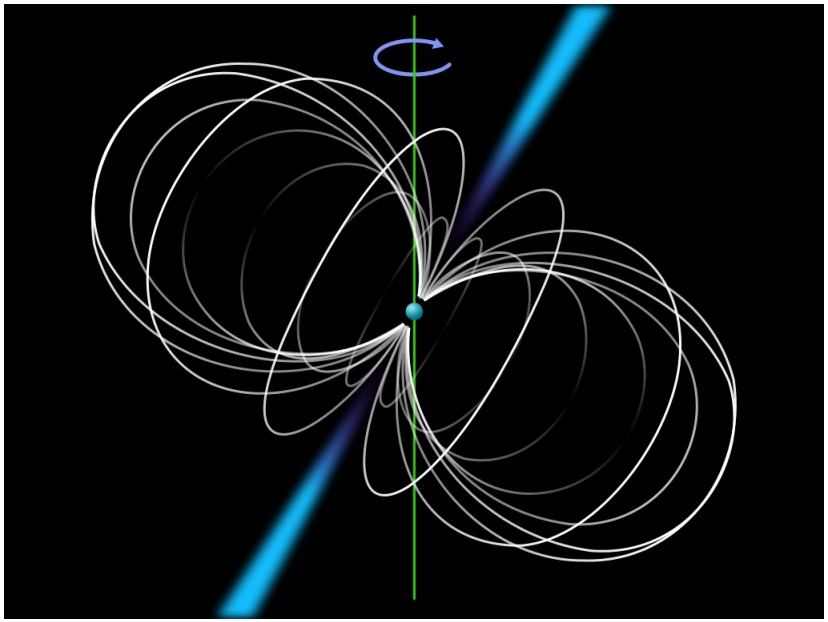
With damping B>170 μG



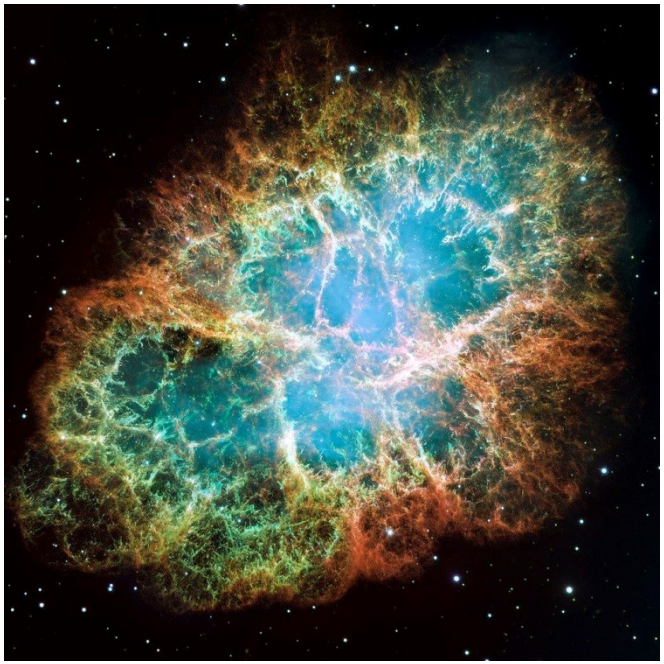


Pulsars

Some supernovae leave behind a pulsar

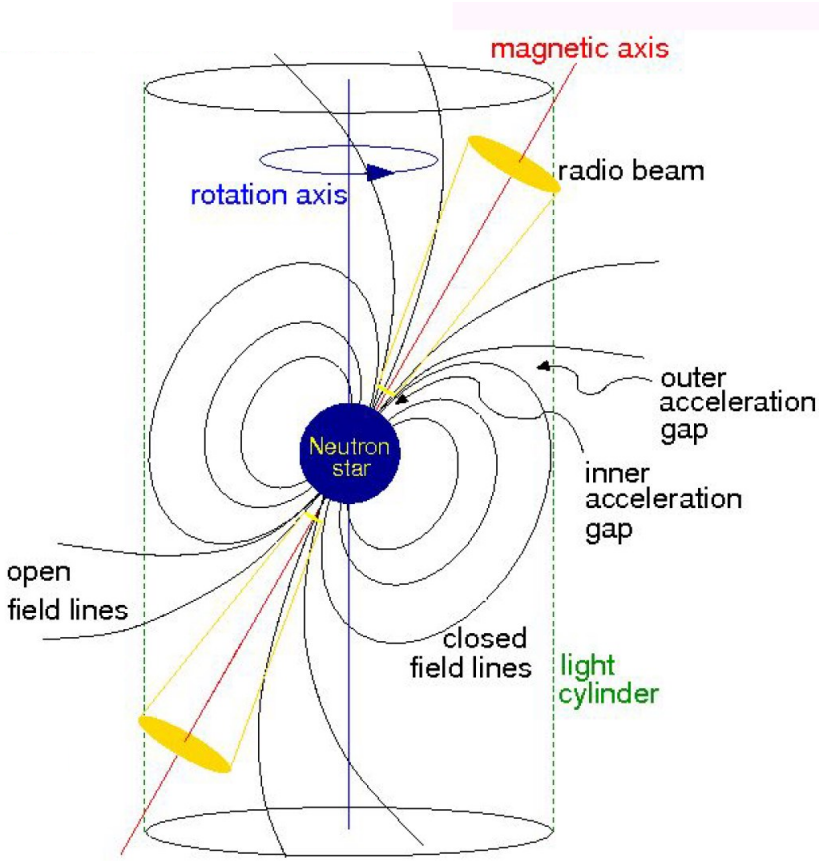


Crab nebula and pulsar

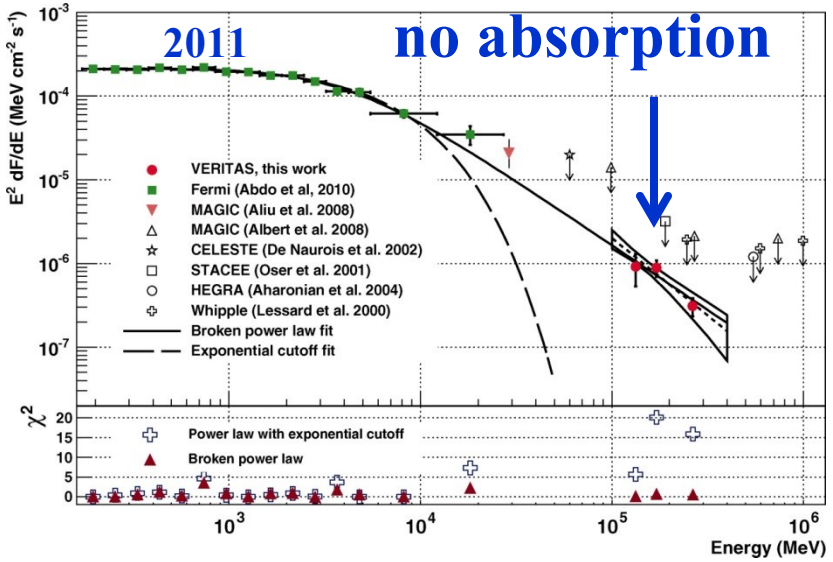


Crab pulsar

Gamma-ray not produced at inner acceleration gap



but rather close to or beyond the light cylinder



Pulsar wind nebula

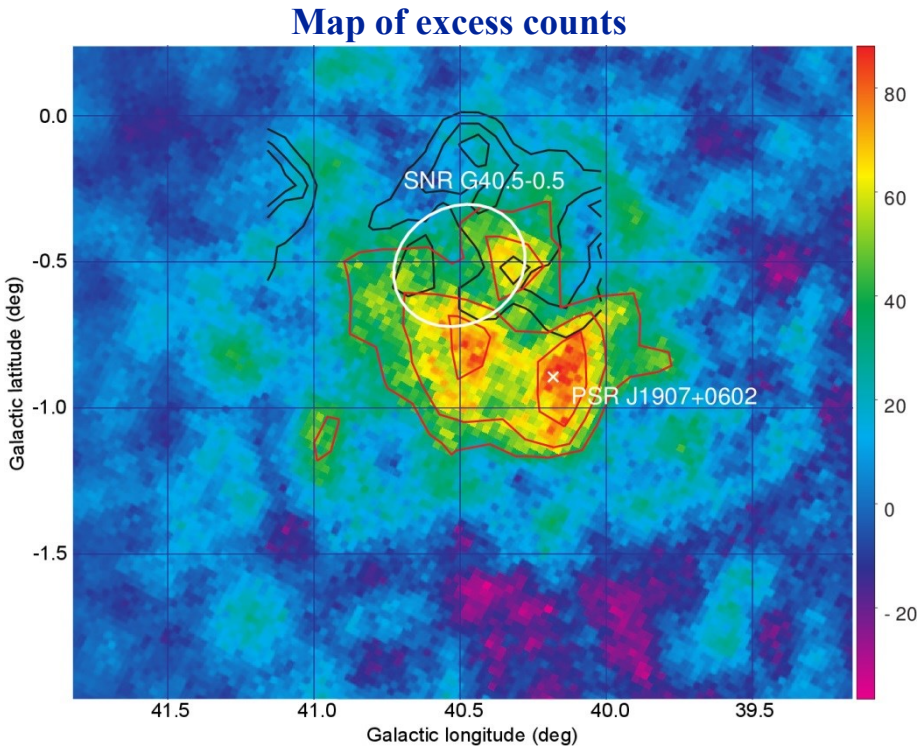
MGRO J1908+06 resolved with VERITAS

A pulsar outside the remnant of its parent supernova

No evidence
of spectral variation

Complex interaction
between PWN and SNR?

Black contours: CO

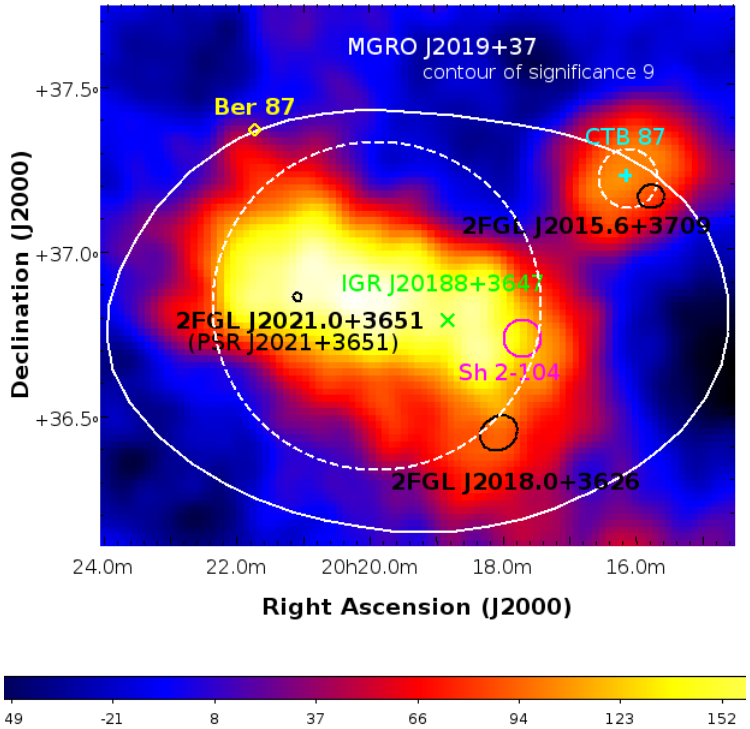


Pulsar wind nebula

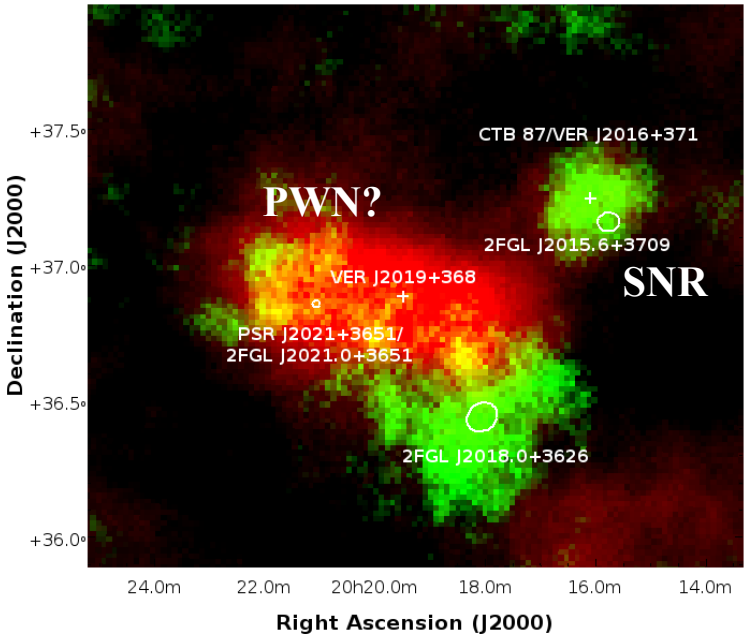
Spectral variability is normal in composite sources

Example: MGRO J2019+37 resolved with VERITAS

Map of excess counts



> 1 TeV < 1 TeV



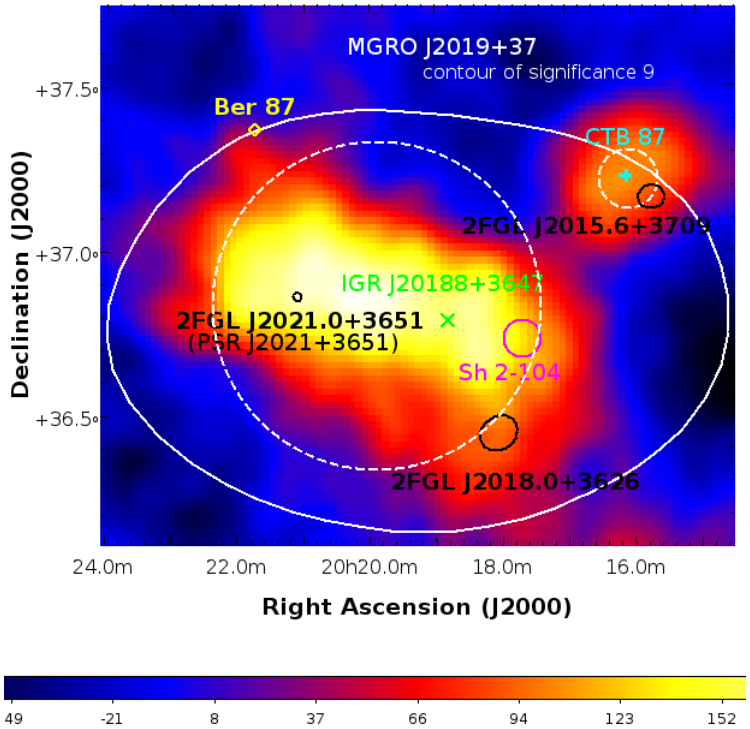
Jun 28-29, 2017

10 years VERITAS

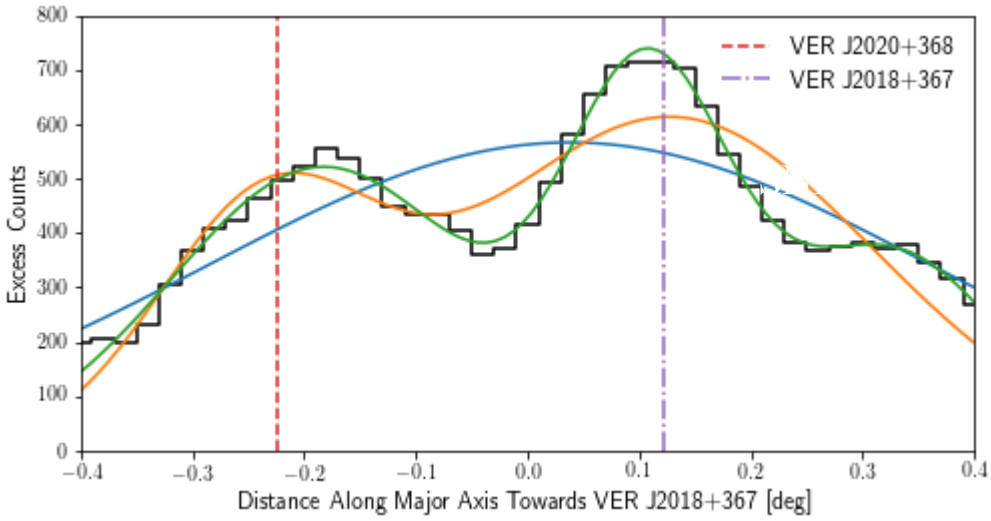
Pulsar wind nebula

How many sources make up MGRO J2019+37?

We identified CTB87 and a large extended region



Brightness profile: 2 or 3 sources?



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10 years VERITAS

Gamma-ray binaries: HESS J0632-057

Originally an unidentified TeV source

Initial non-detection with VERITAS → variability

Periodicity found in X rays, confirmed in γ-rays

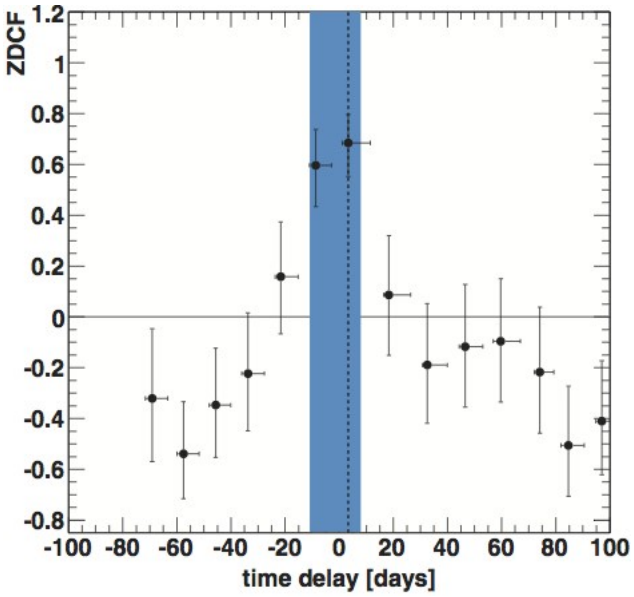
No detection yet in GeV band with Fermi LAT

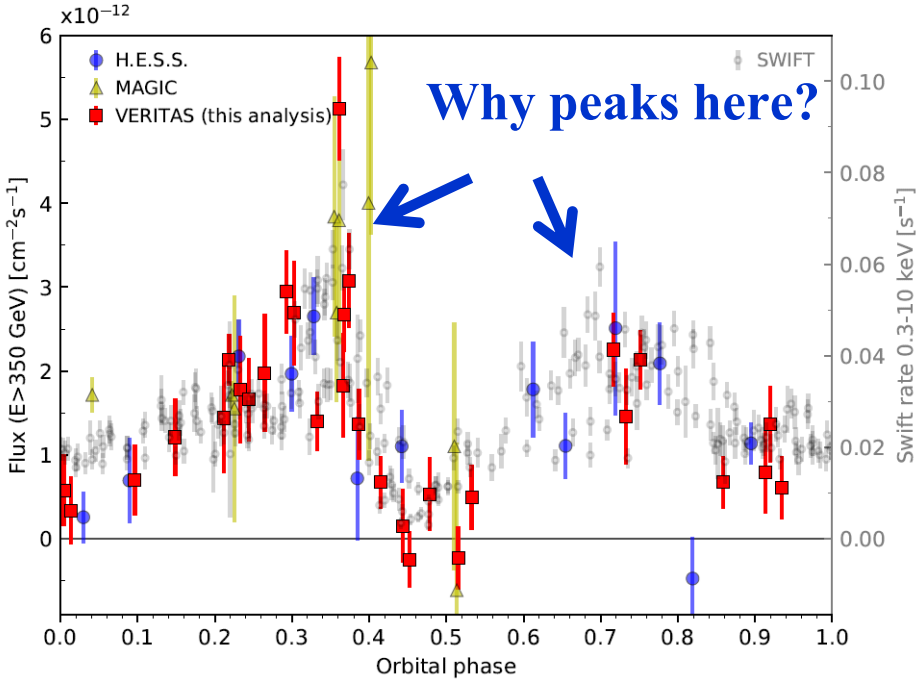
Gamma-ray binaries: HESS J0632-057

Correlated variability in X rays and TeV gamma rays

Two peaks in light curve … an effect of orbit eccentricity?

X rays vs. TeV gamma rays



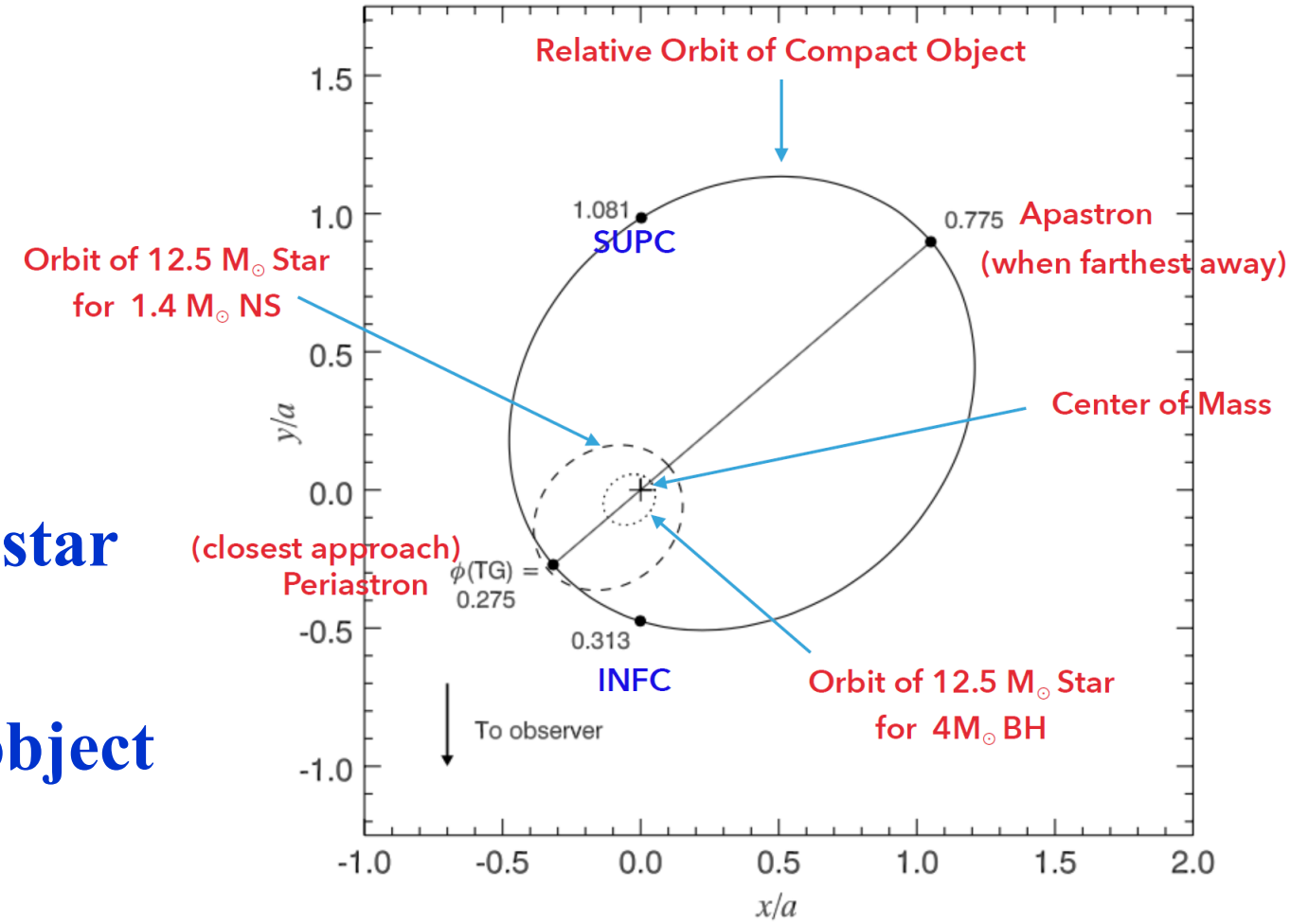


Gamma-ray binaries: LS I +61 303

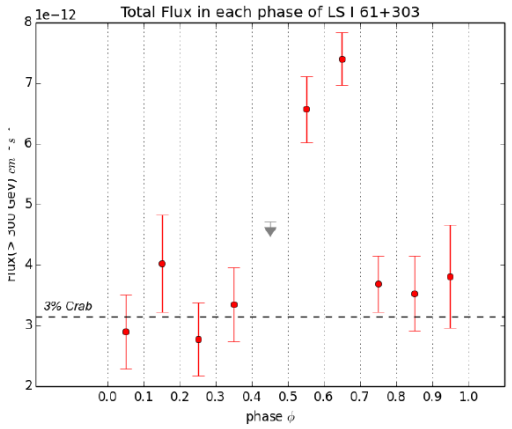
A B0 Ve 25 star

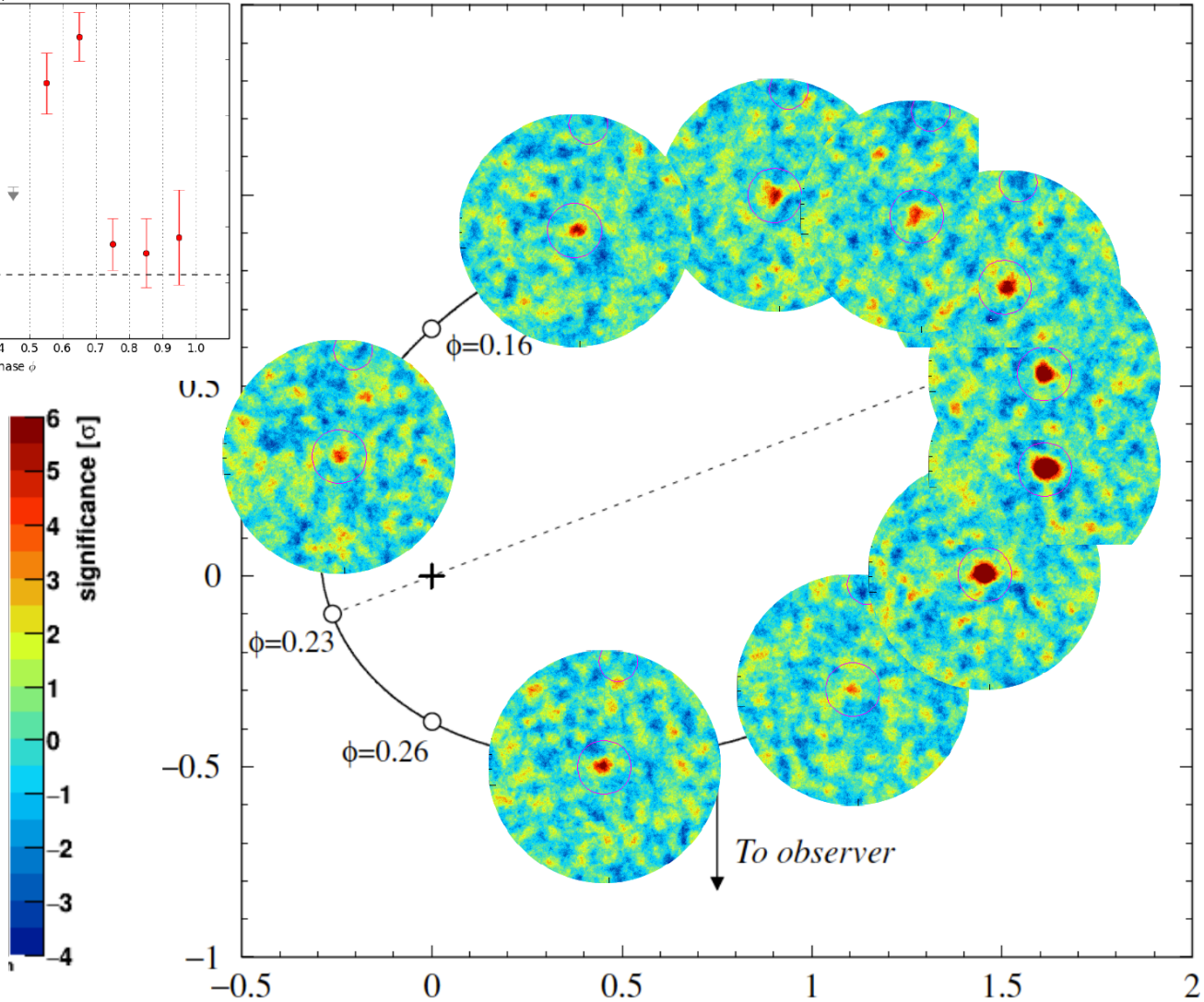
and

a compact object



Gamma-ray binaries: LS I +61 303





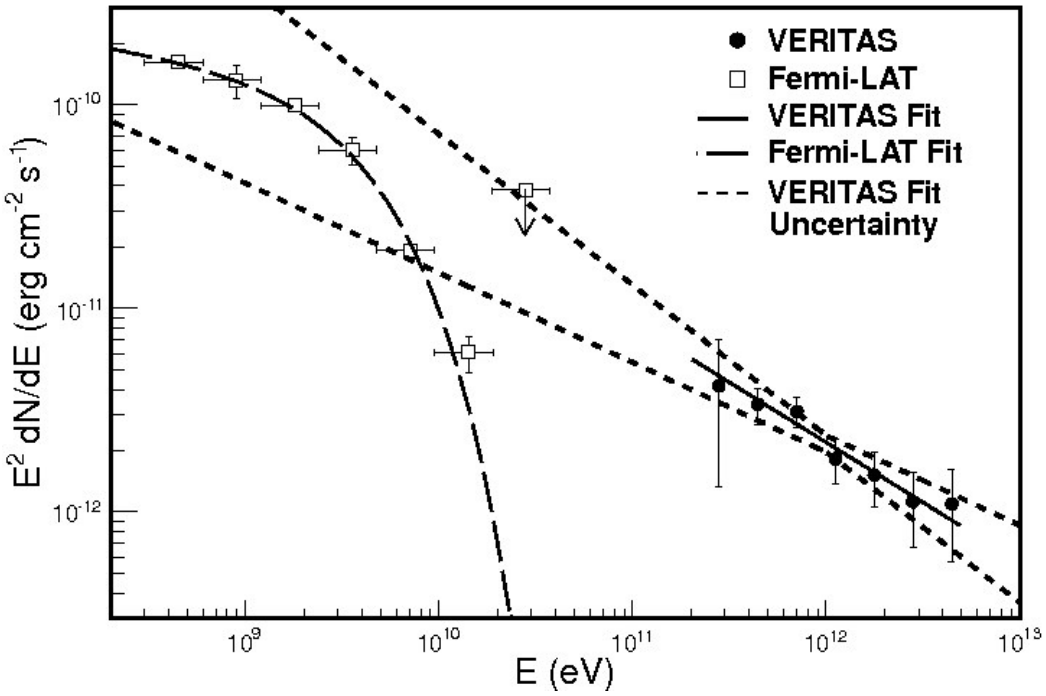
Gamma-ray binaries: LS I +61 303

A massive B0 Ve 25 star and a compact object

Nightly TeV variability

Uncorrelated GeV and TeV emission

GeV spectrum similar to that of a pulsar

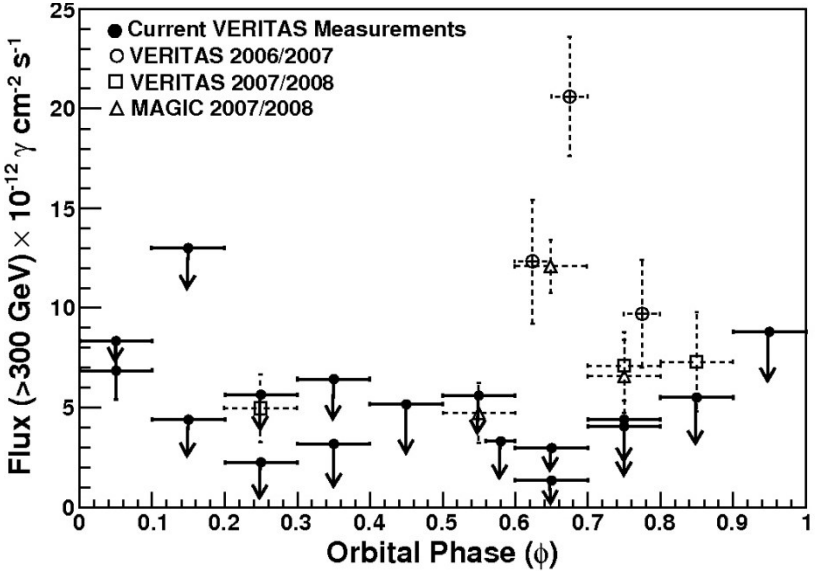


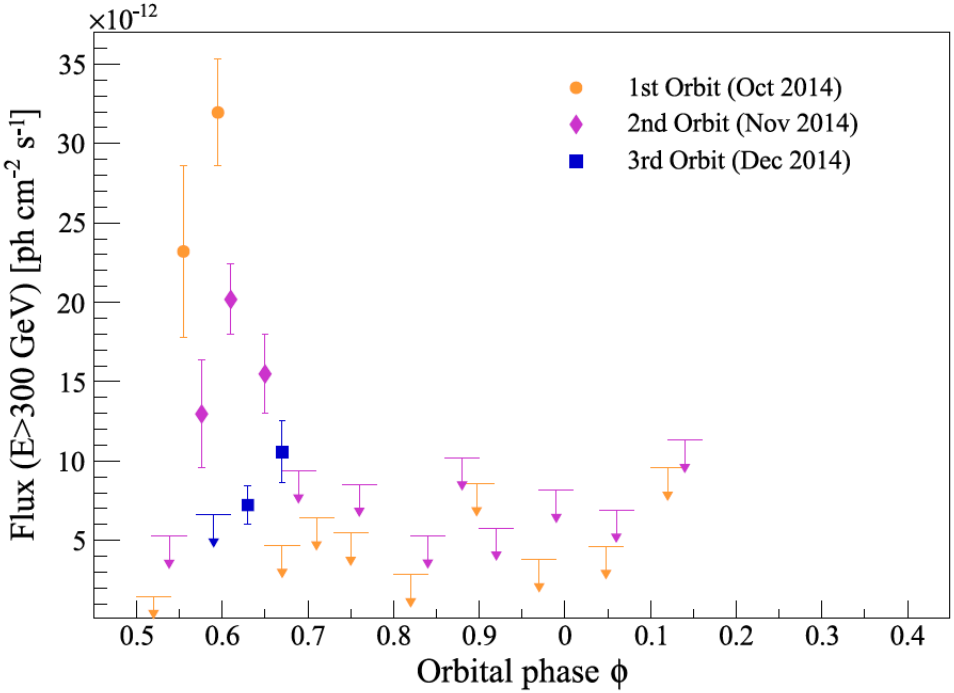
Gamma-ray binaries: LS I +61 303

Baseline TeV emission seen throughout entire orbit

Strong gamma-ray flares in some orbits

Little spectral variation



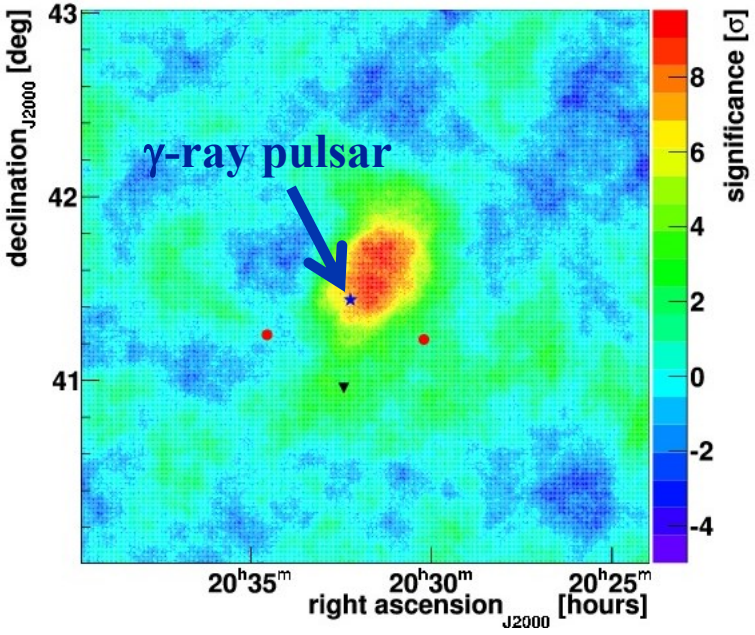


Gamma-ray binaries: TeV J2032+4130

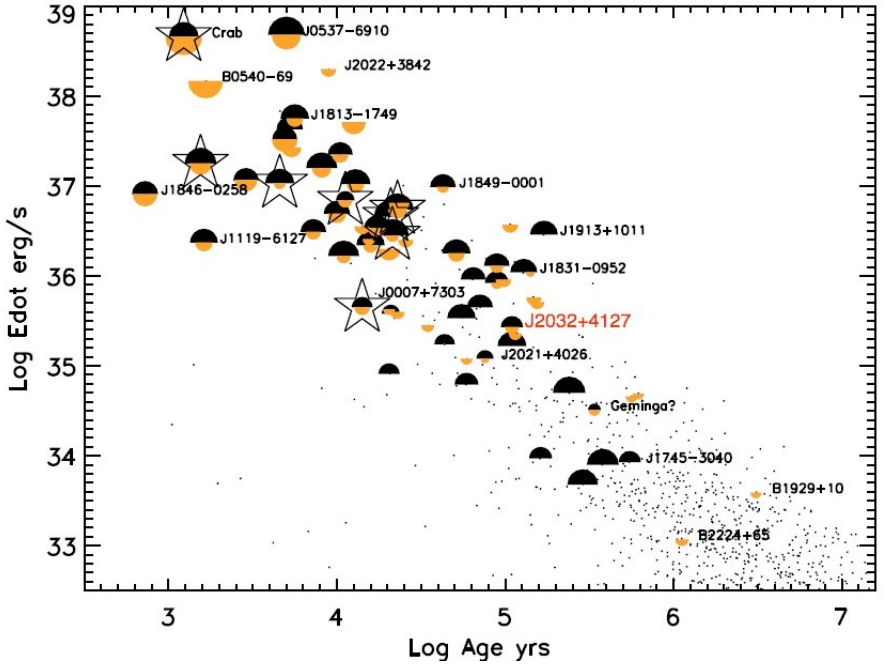
First unidentified TeV source (1990s, HEGRA)

2014: Association with pulsar

A pulsar wind nebula?



Fits to know pulsar wind nebulae



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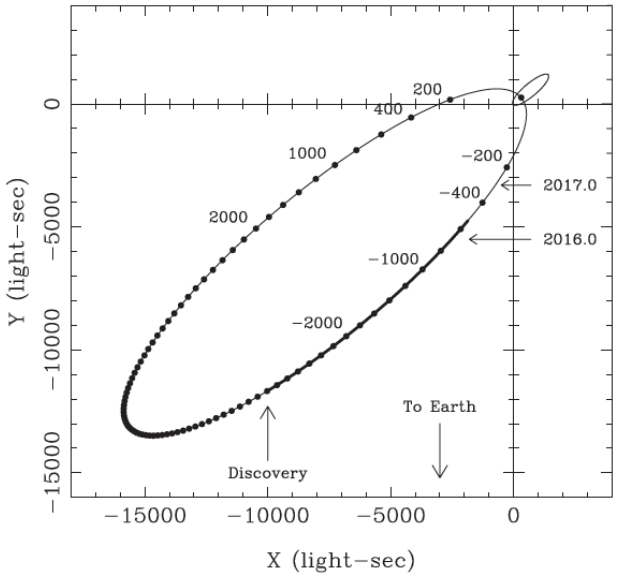
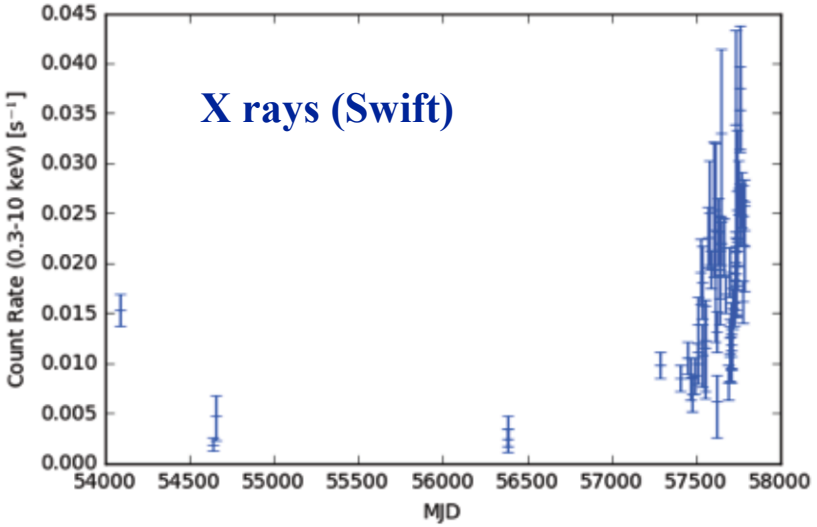
Gamma-ray binaries : TeV J2032+4130

A possible partner in a long-period binary shortly approaching periastron



(Lyne et al. 2015)



X-ray flux increases significantly

What will the gamma-ray flux do?

Conclusion

10 years of VERITAS operation

- A rich harvest of Galactic science
- Fundamental advances in understanding
- Physics interpretation combines all messengers
- There is more to come …