Highlights from VERITAS studies of TeV astroparticle physics

Nahee Park
For The VERITAS Collaboration

THE UNIVERSITY OF CHICAGO

The VERITAS Collaboration

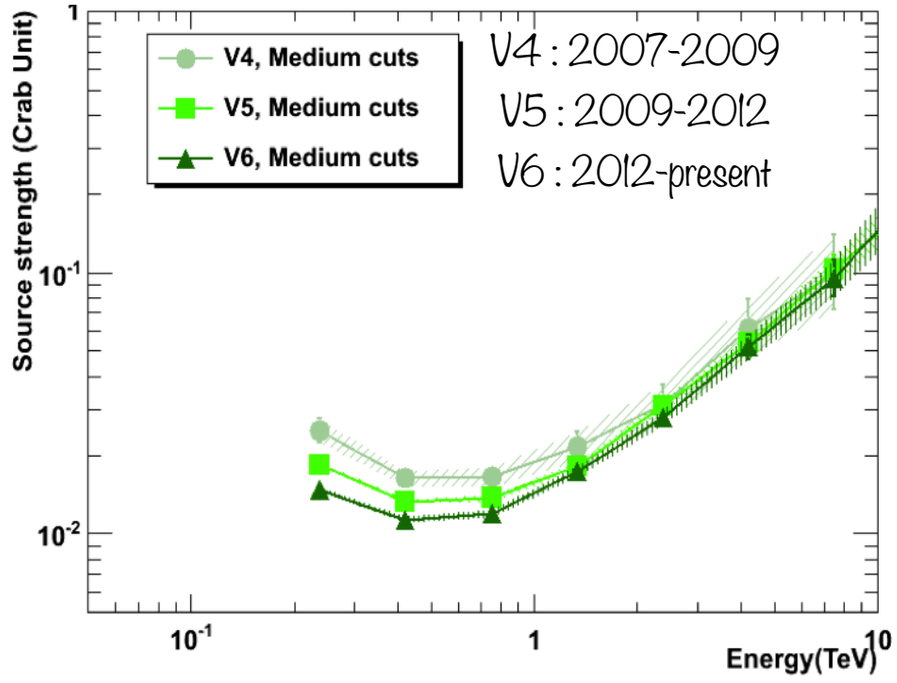
- **~100 members, 20 institutions**
  - 24 non-affiliated members
  - +35 associate members
- Managing Organization: Smithsonian Astrophysical Observatory
- Adler Planetarium
- Argonne National Lab
- Barnard College / Columbia University
- Bartol Research Institute / University of Delaware
- Georgia Institute of Technology
- Iowa State University
- Purdue University
- University of California, Los Angeles
- University of California, Santa Cruz
- University of Chicago
- University of Iowa
- University of Minnesota
- University of Utah
- Washington University in St. Louis
- McGill University, Montreal
- University College Dublin
- Cork Institute of Technology
- Galway-Mayo Institute of Technology
- National University of Ireland, Galway

VERITAS : Observatory Overview

Study VHE γ-rays(~80 GeV to ~ 30 TeV) from astrophysical sources

Fully operational since 2007

- Continuous improvement in performance with two major upgrades (2009 & 2012)
- Sensitive to detect 1% Crab Nebula signal in ~25 hr with angular resolution of <0.1 degree at 1 TeV
- ~ 1000 hours/yr in "dark time" observation, ~300 hours of bright moonlight data (moon illumination > 30%)



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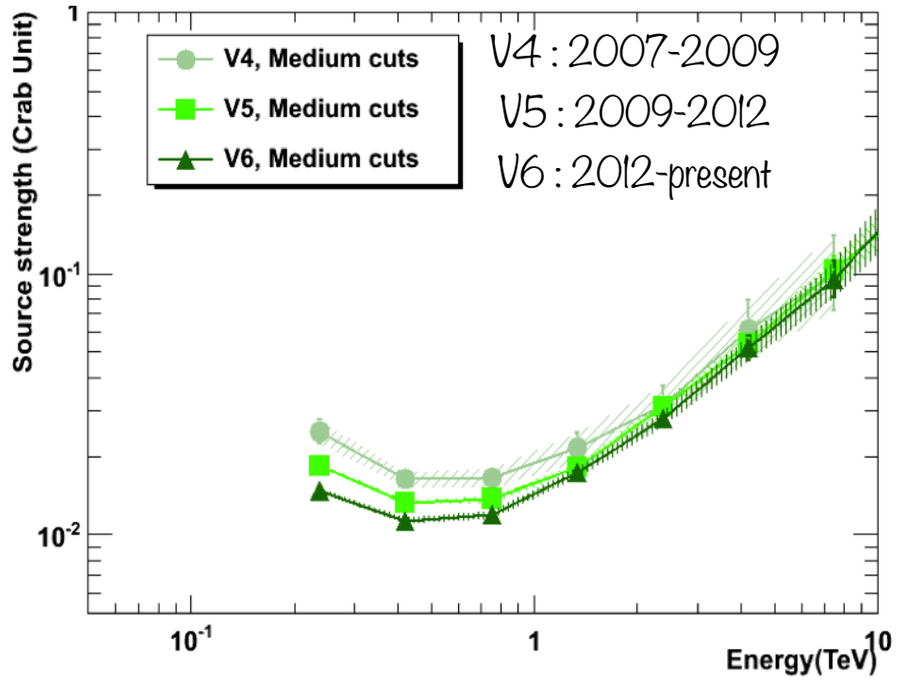

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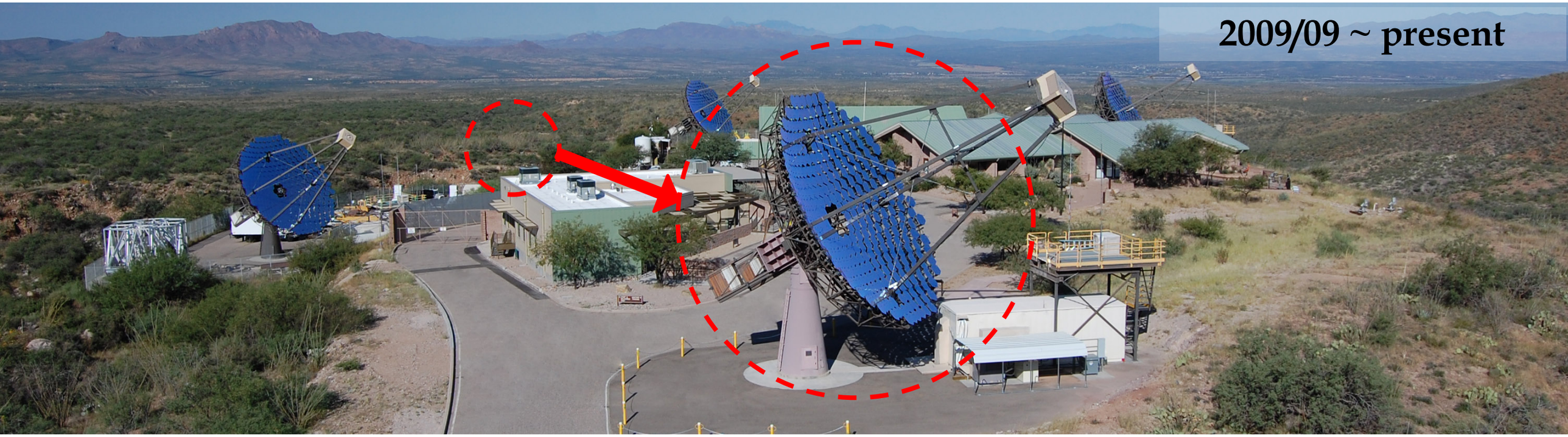

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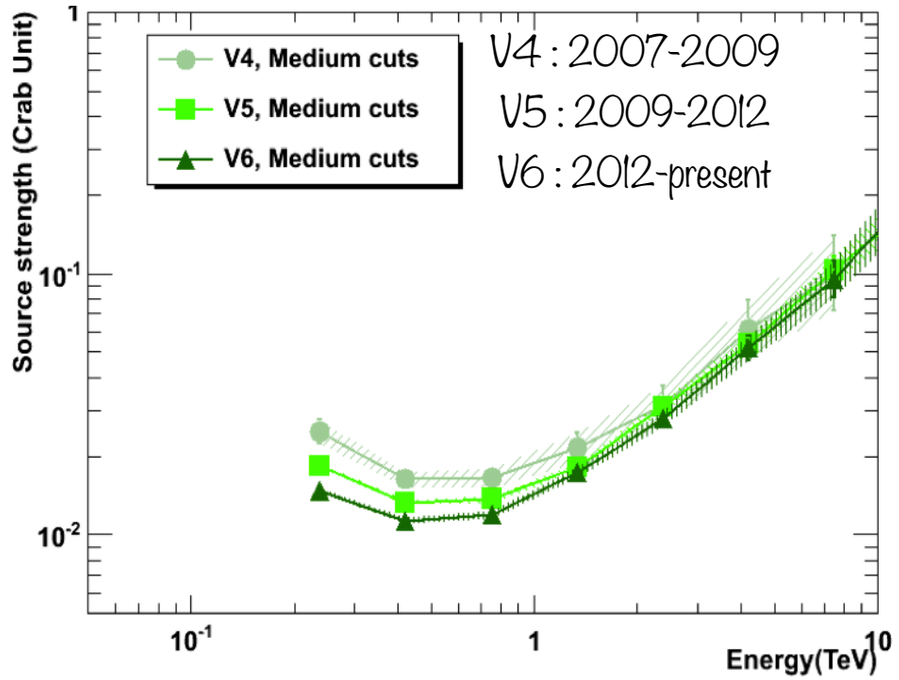

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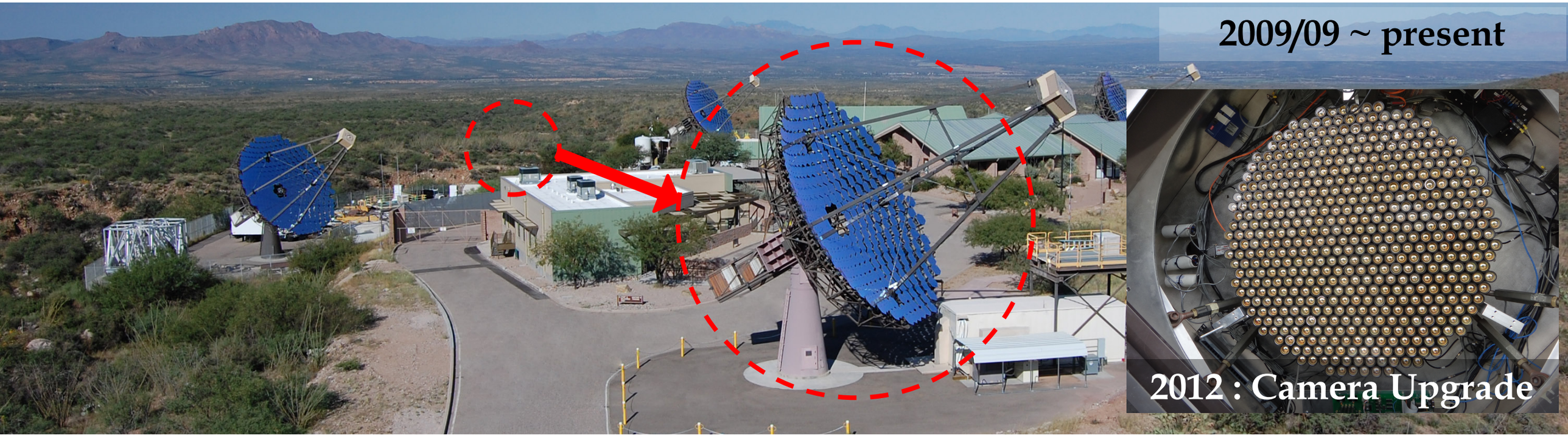

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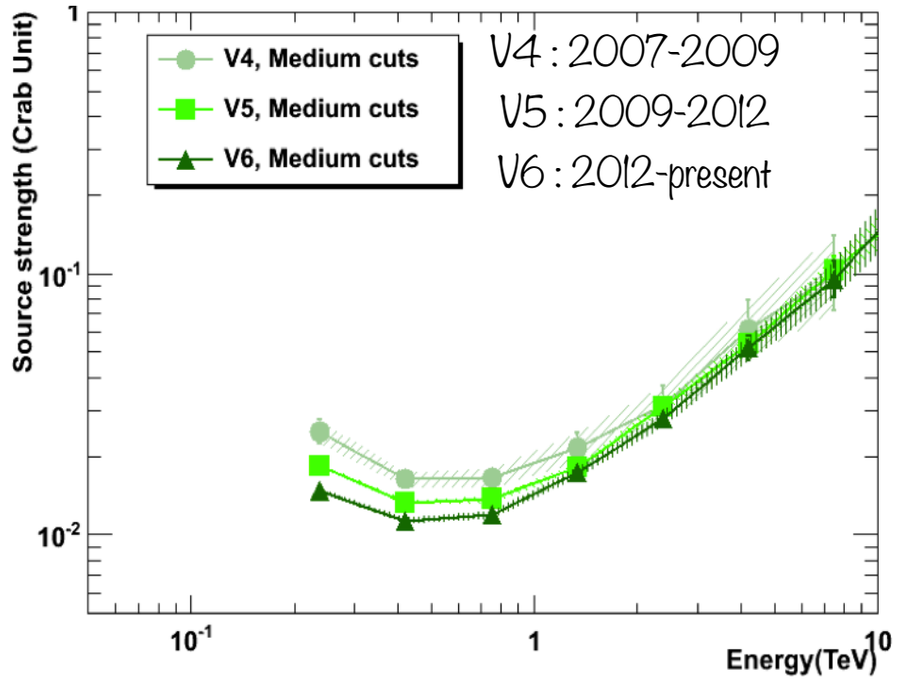
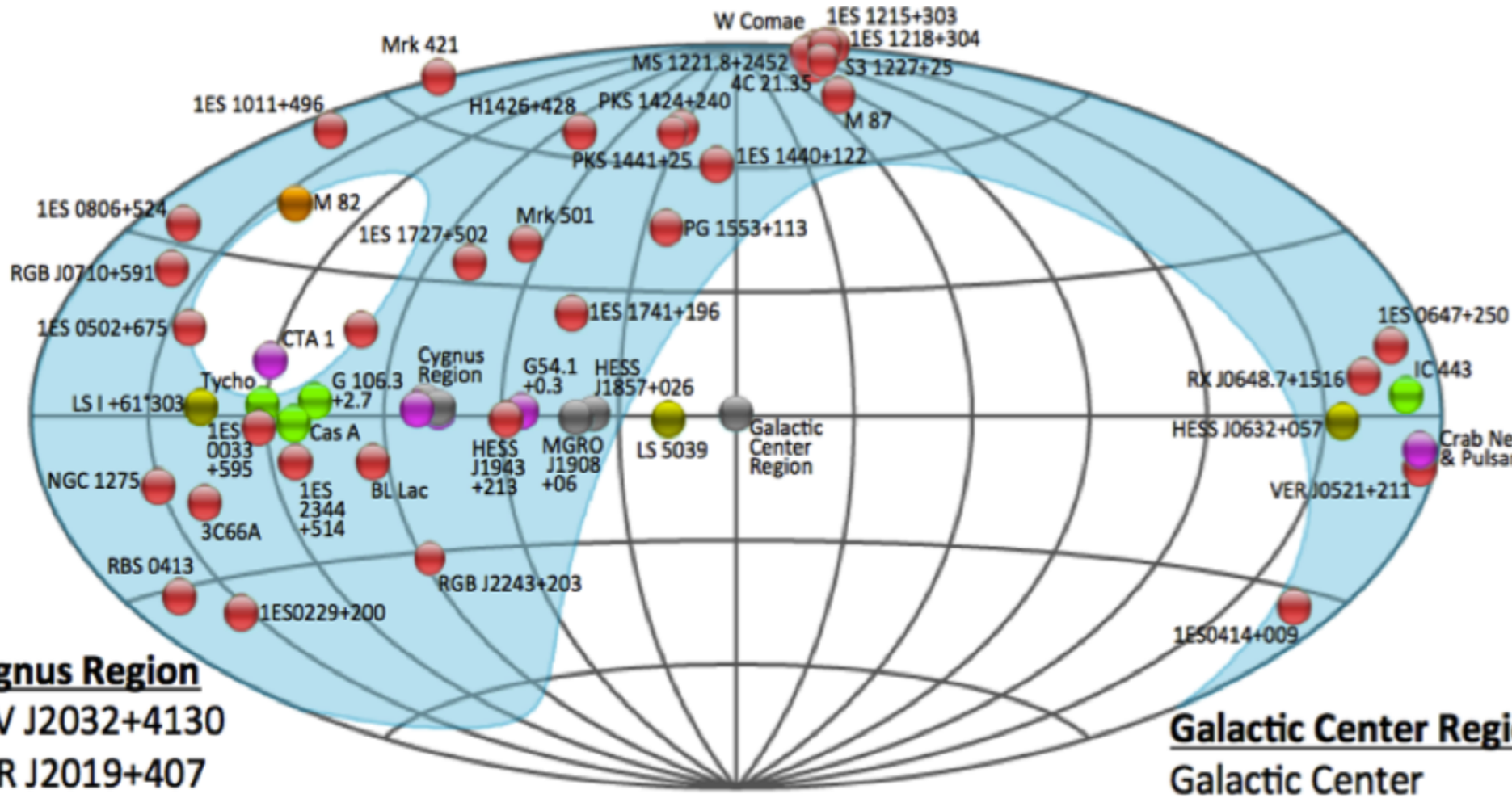


VERITAS Catalog

54 detections, with at least 8 source classes



Cygnus Region
TeV J2032+4130
VER J2019+407
VER J2019+368
VER J2016+372

http://tevcat.uchicago.edu

Galactic Center Region
Galactic Center
Galactic Center Ridge
G 0.9+0.1

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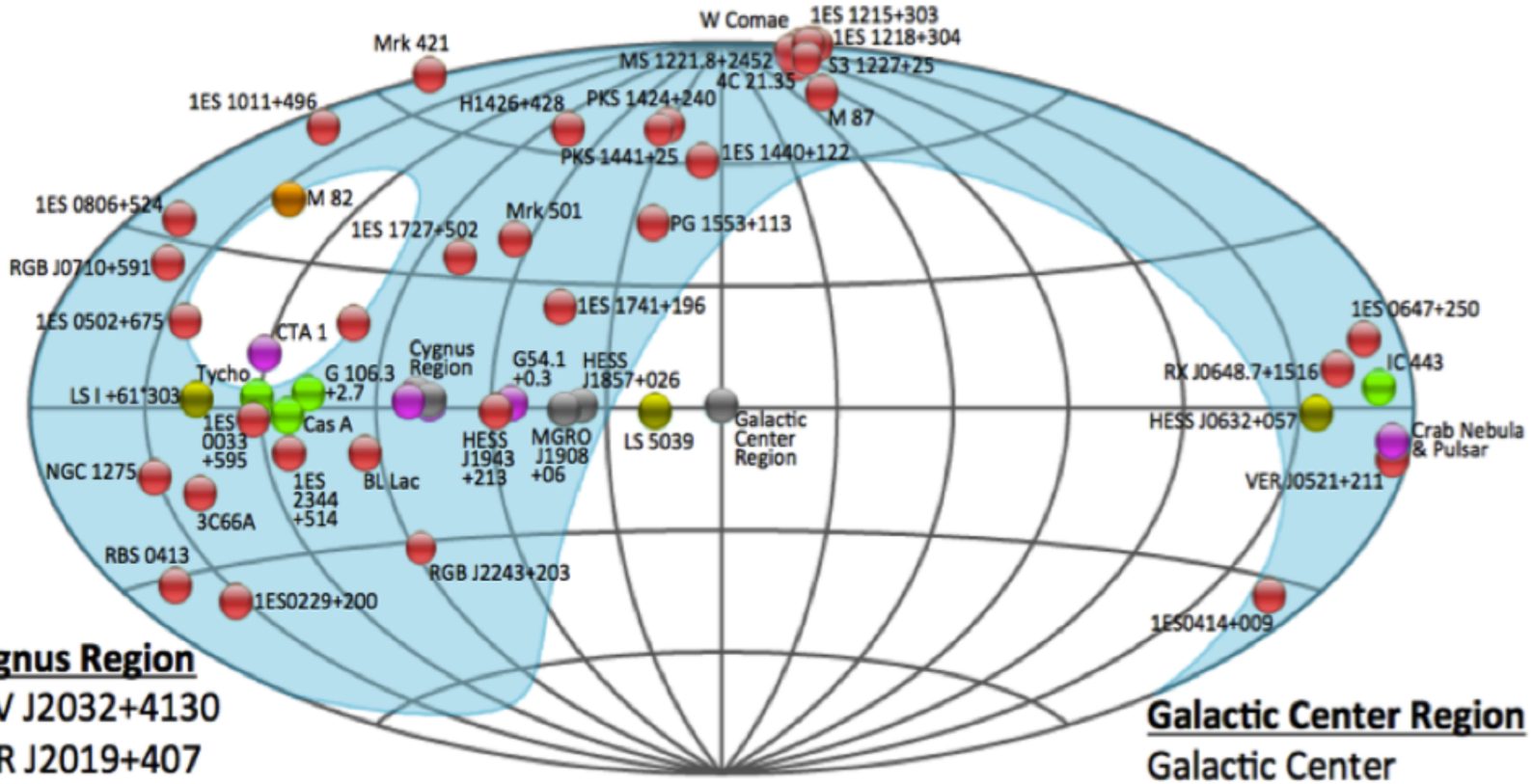

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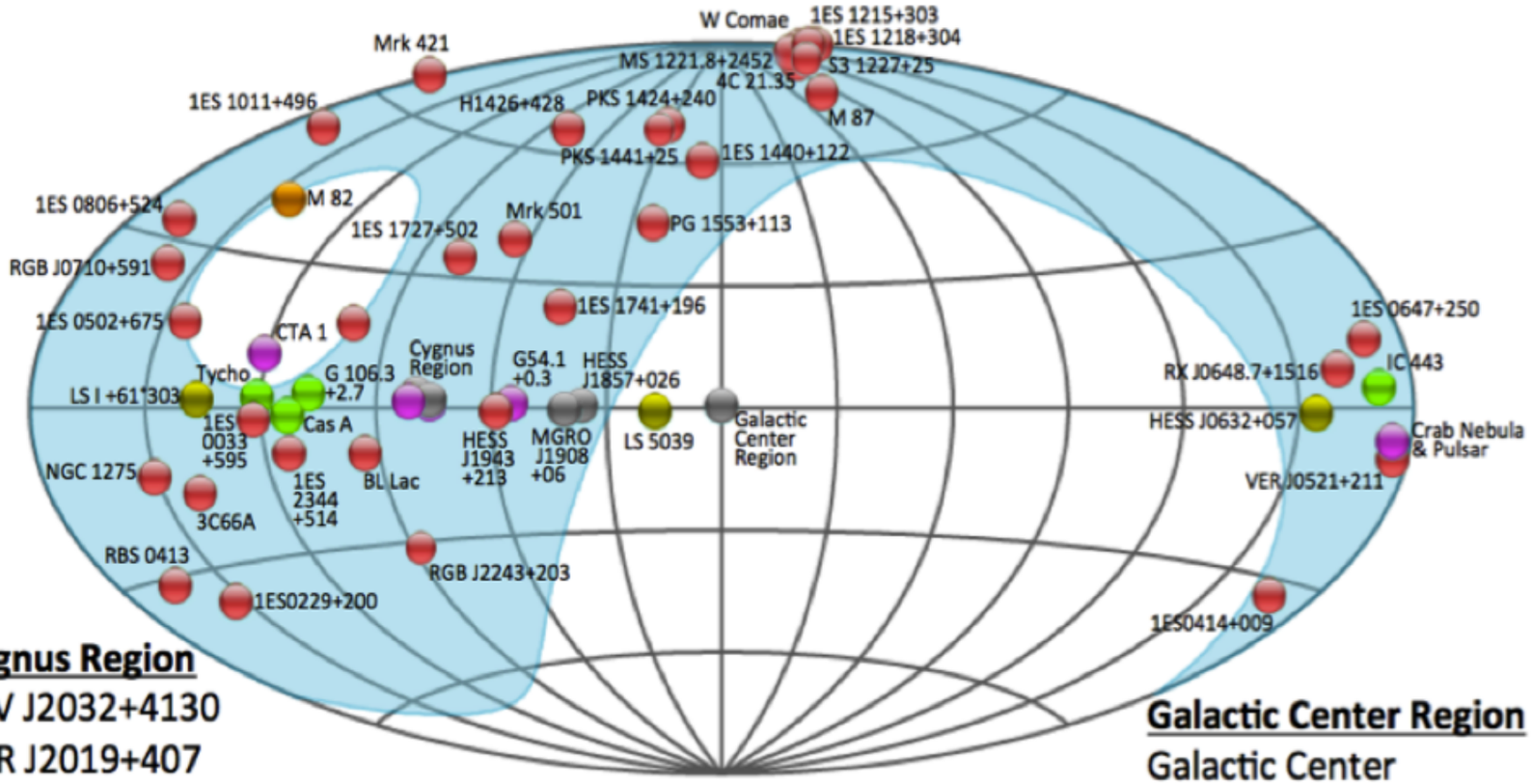

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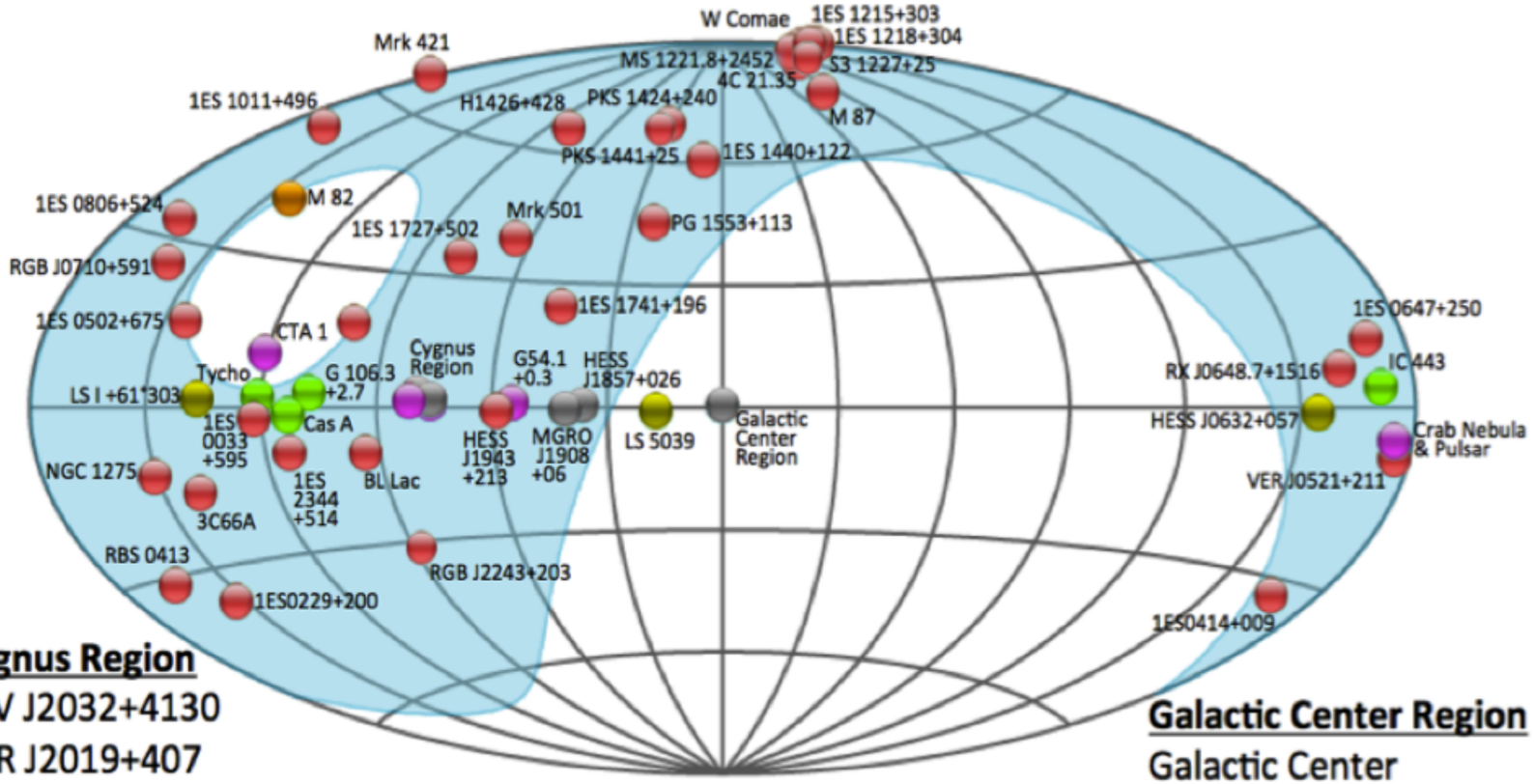

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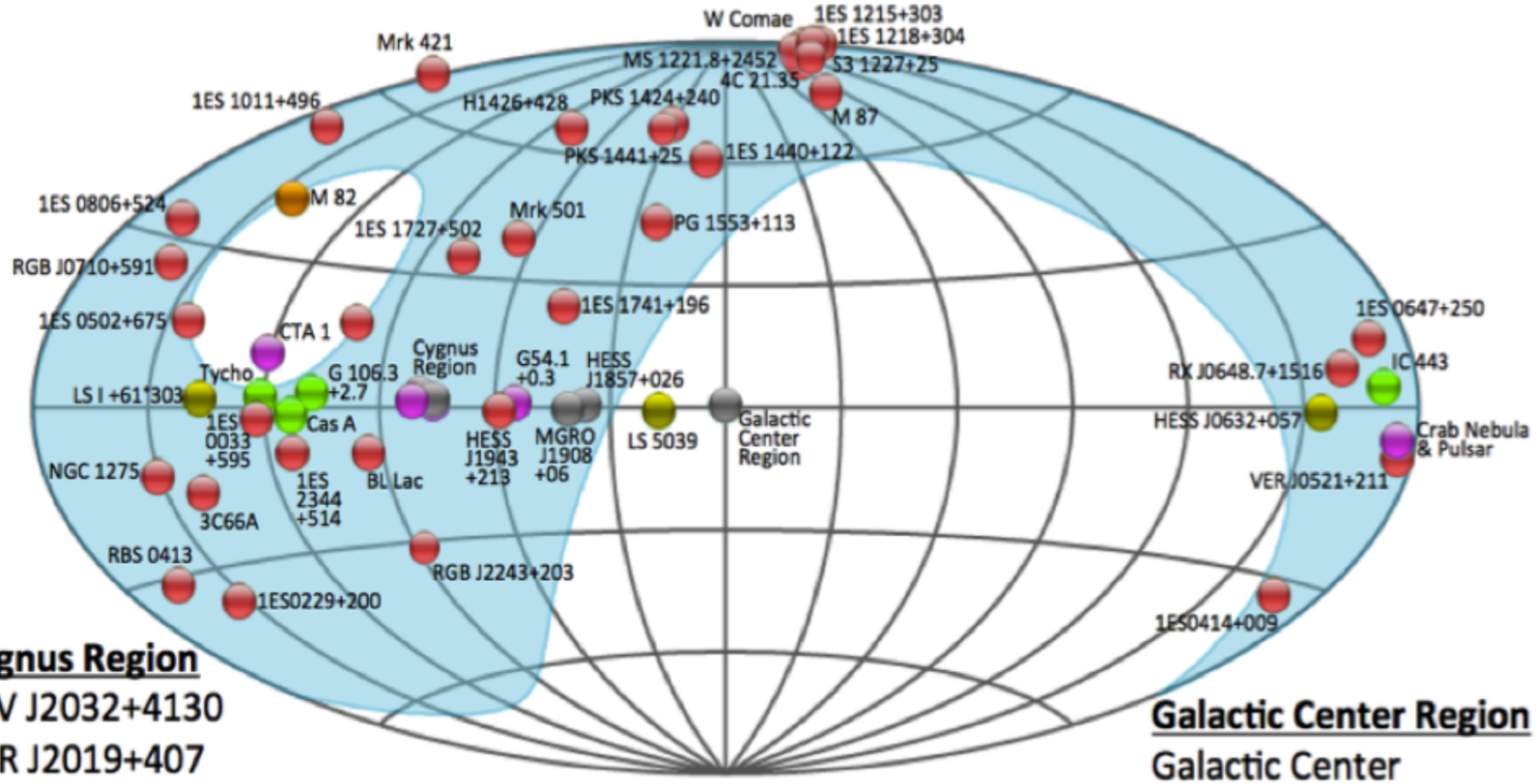

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Other Astroparticle Studies

Dark Matter Search,
Intergalactic Magnetic Field Studies,
Cosmic-ray electron measurement,
IceCube followups,
Lorentz Invariance Violation,
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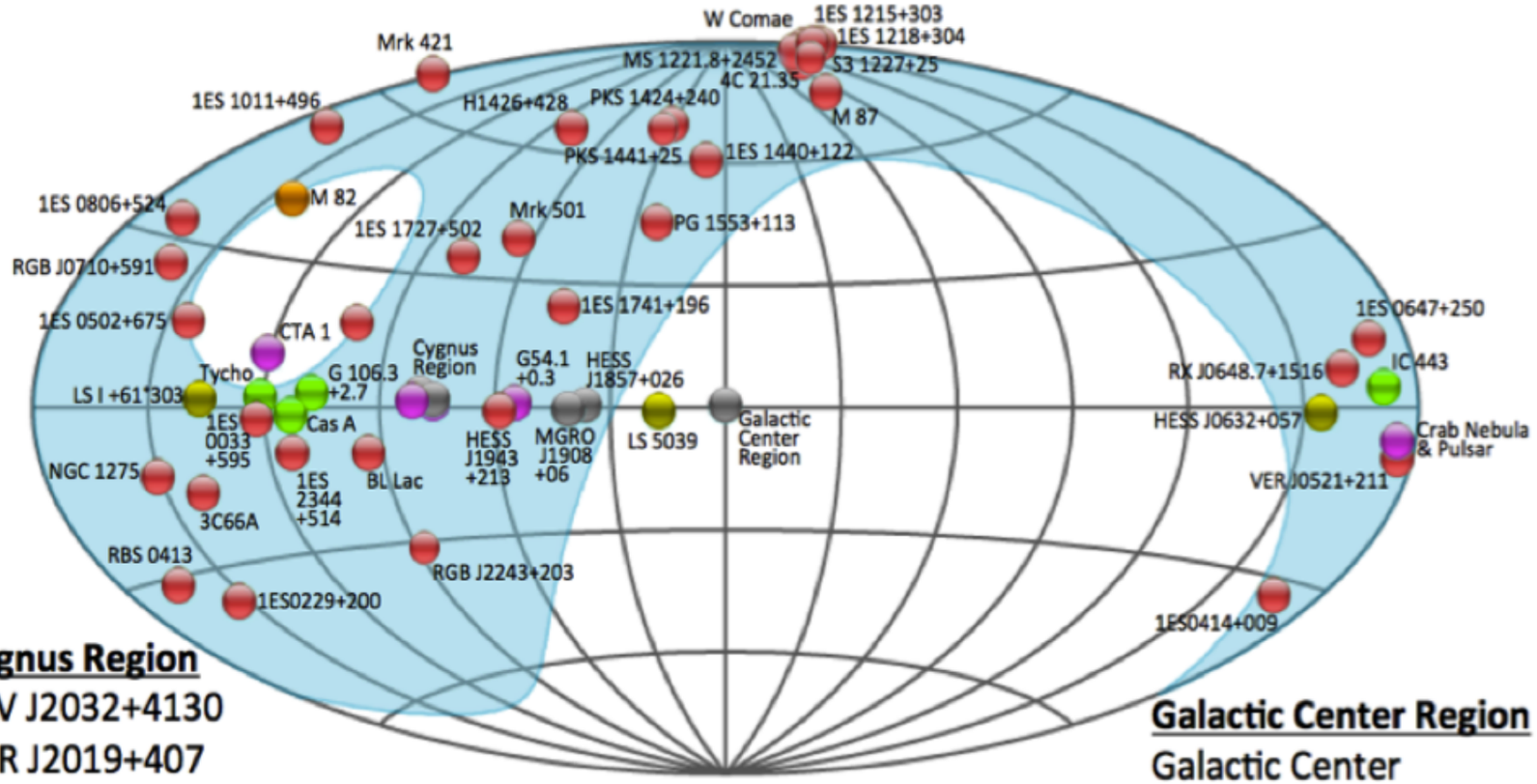

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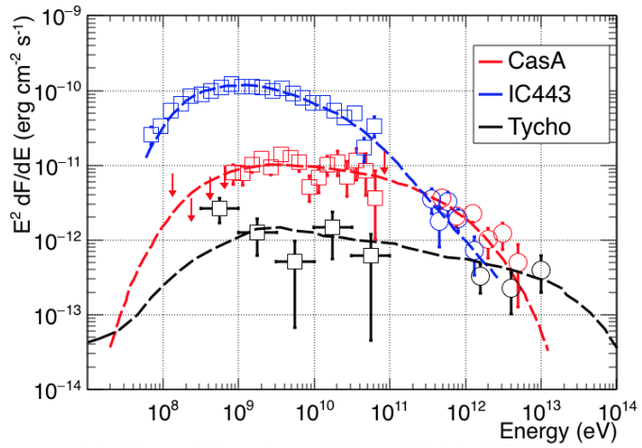
➥ **Focused talk by Ben Zitzer today 18: 12 in Dark matter search session**

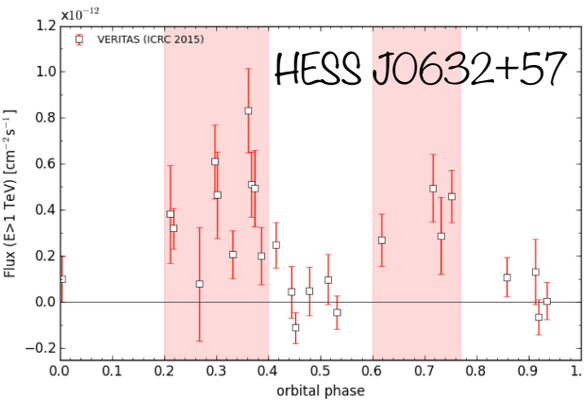
Galactic Highlights

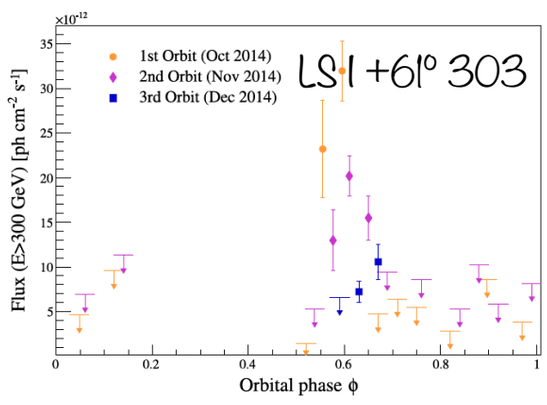
Deep observations on known SNRs

Cassiopeia A, IC 443 & Tycho

- Studying acceleration in different environments & evolutionary stages







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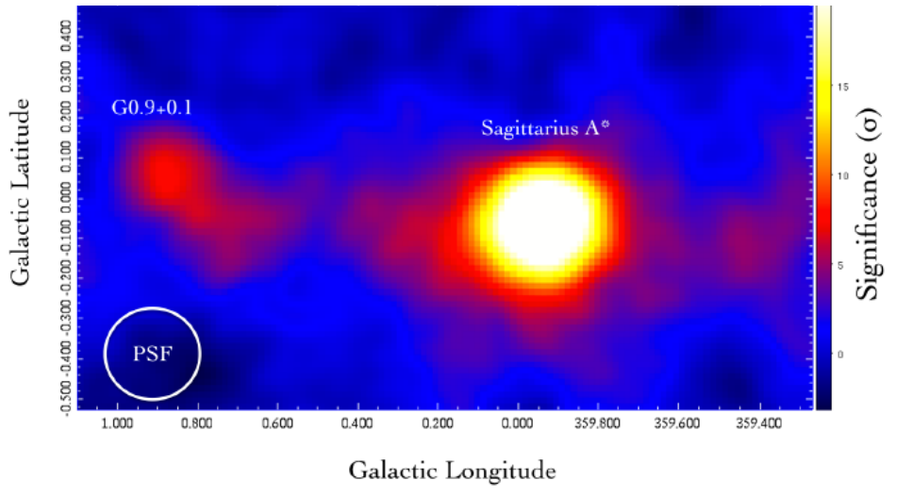
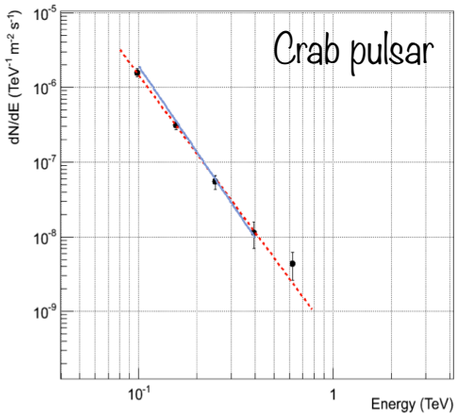
HESS J0632+57: detected at phase ~ 0.35 & 0.75

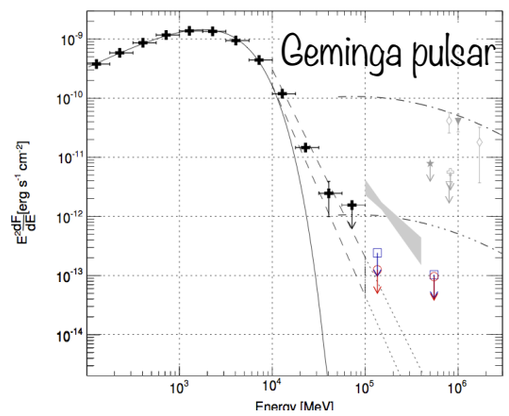
LS I +61° 303: bright flare around apastron, 2014

E>2TeV observations on Galactic Center

Detection of diffusive emissions and point sources in the rich star forming regions







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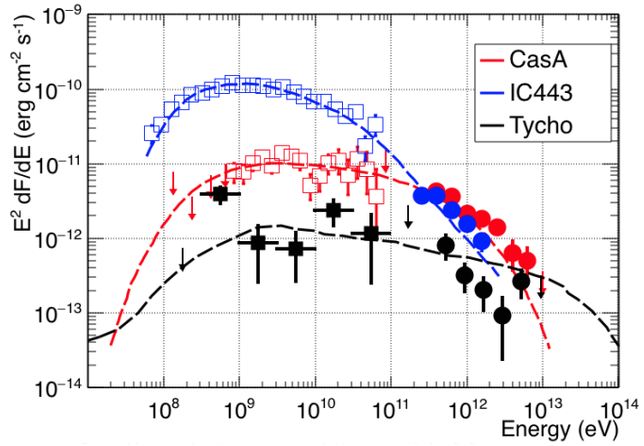

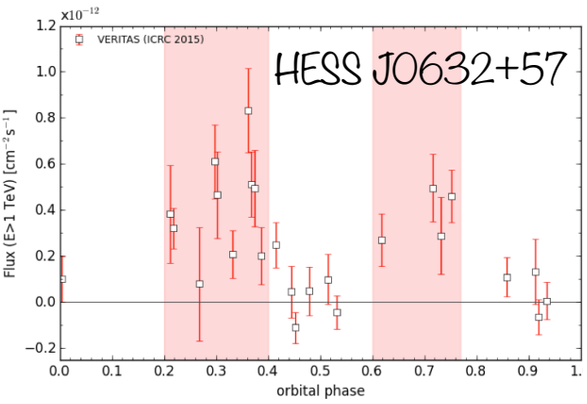

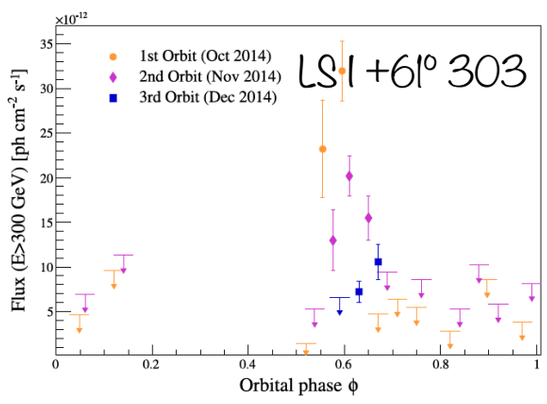

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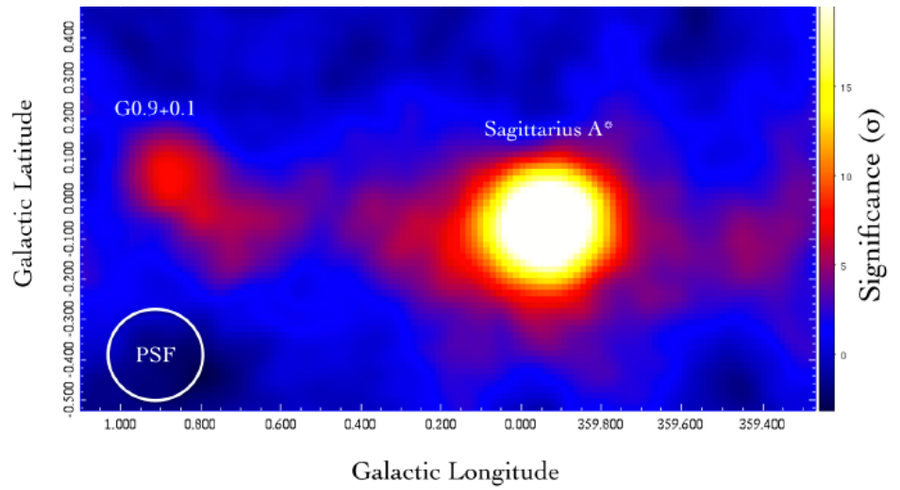

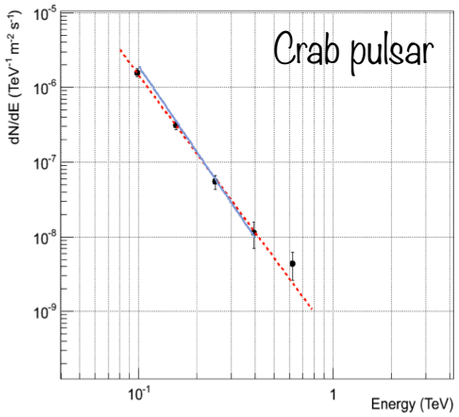

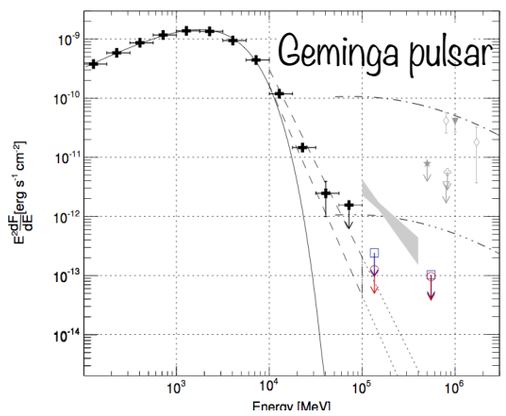

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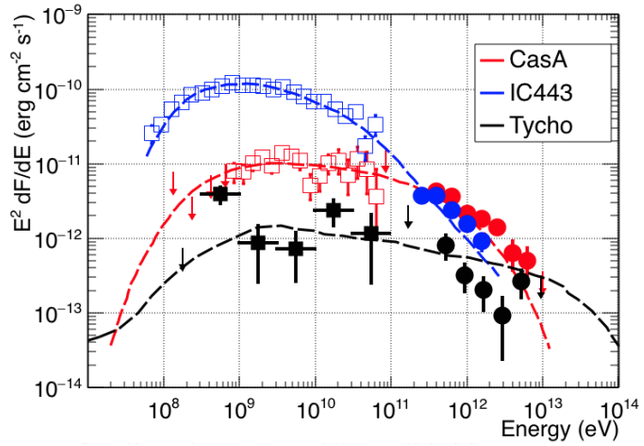

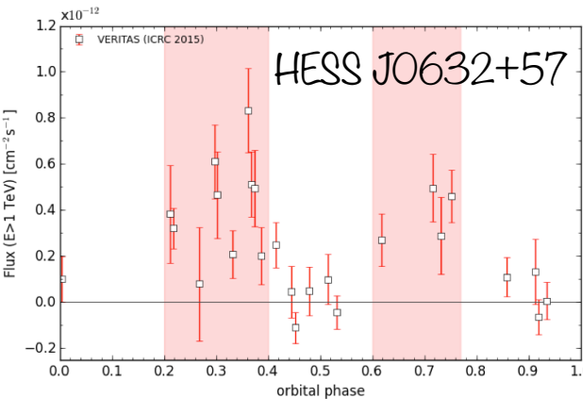

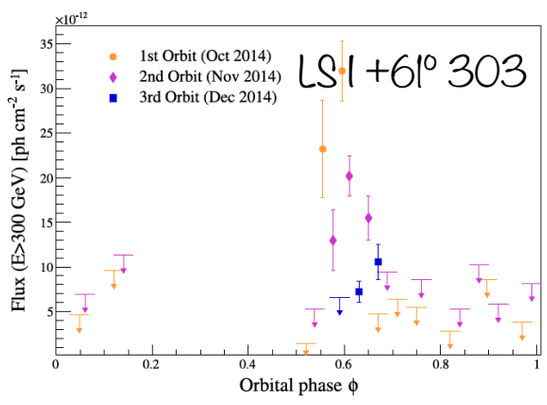

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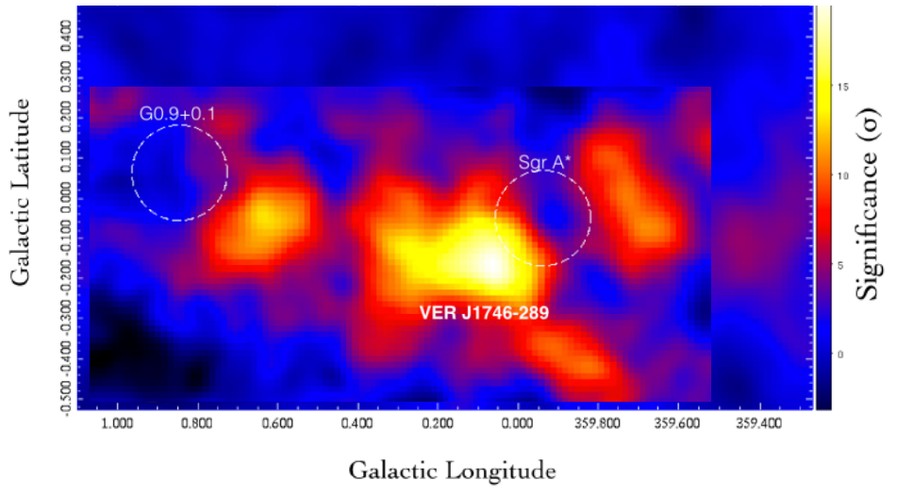

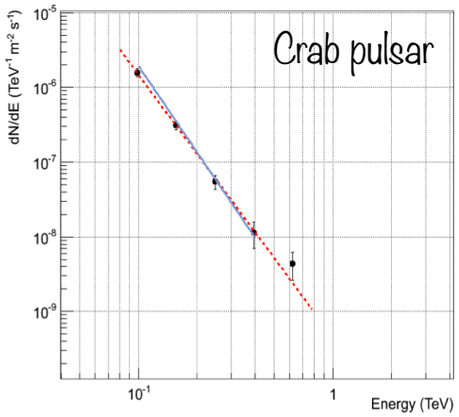

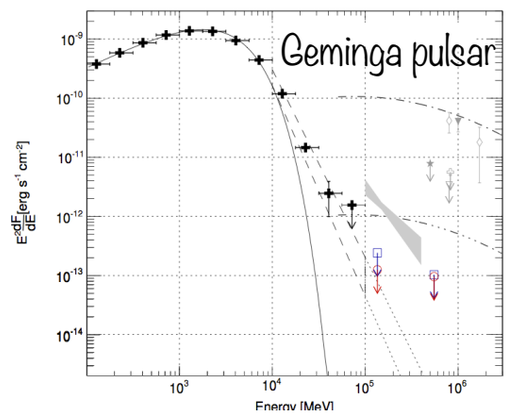

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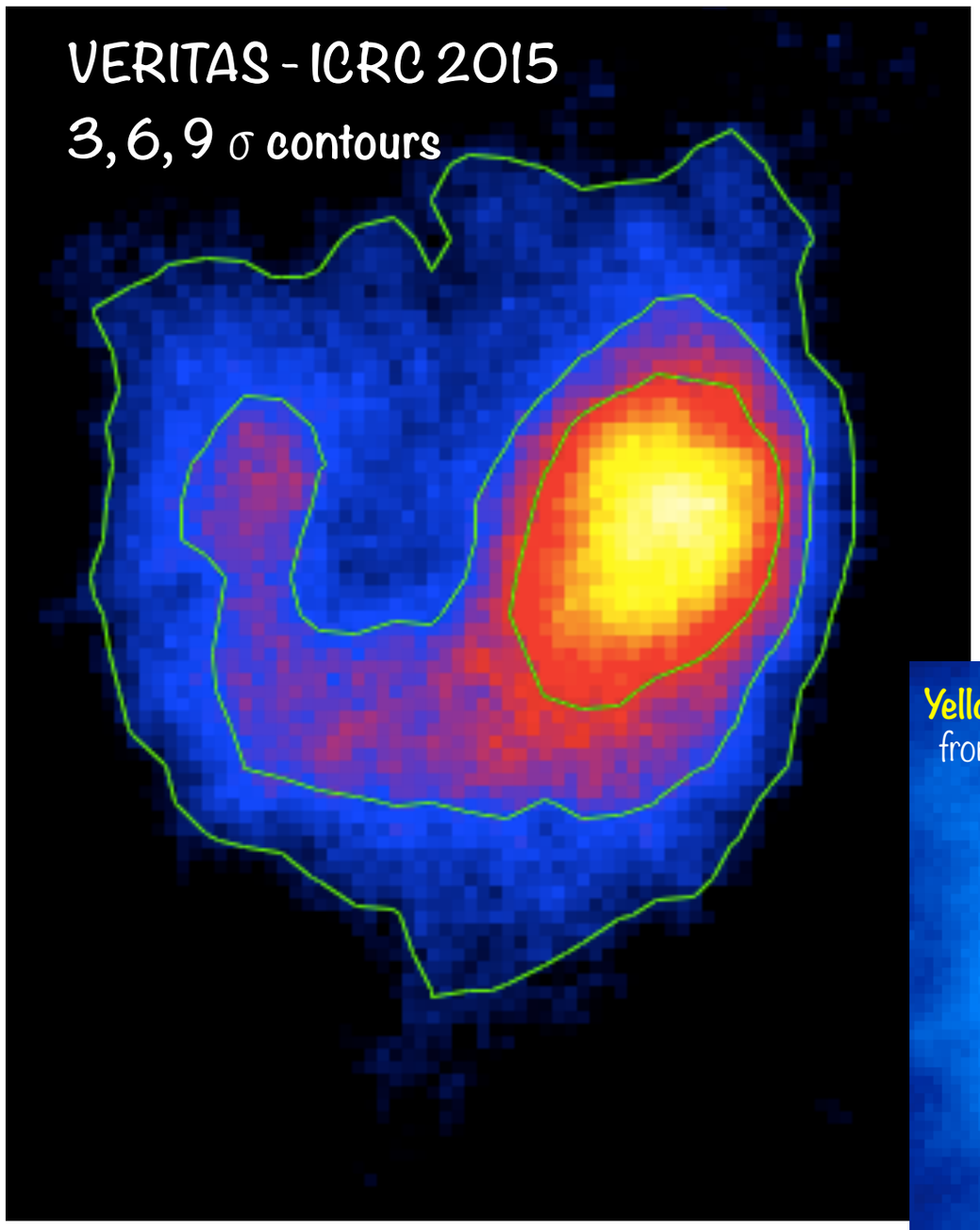
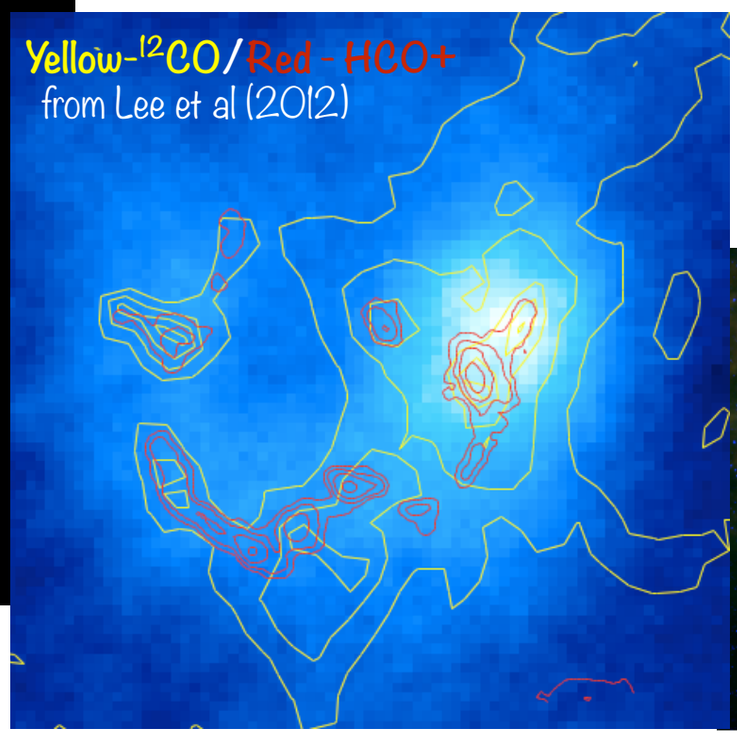
Resolving shell morphology of IC 443

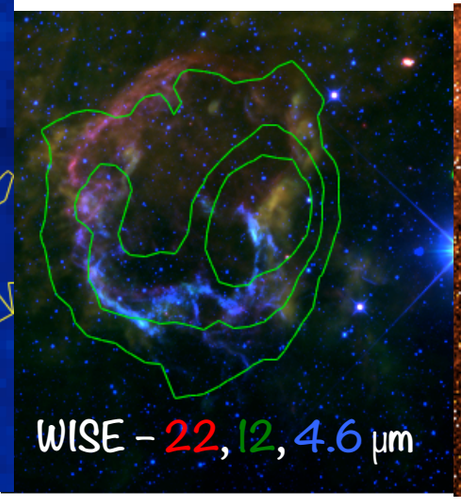


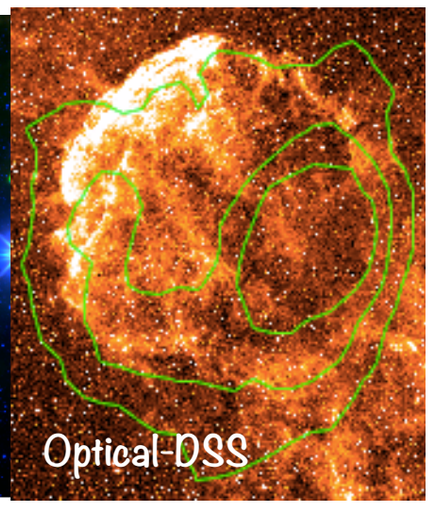
Deep observation of IC 443 with VERITAS has resolved significant VHE emissions from the entire NE lobe

Emission correlated most strongly with shocked gas

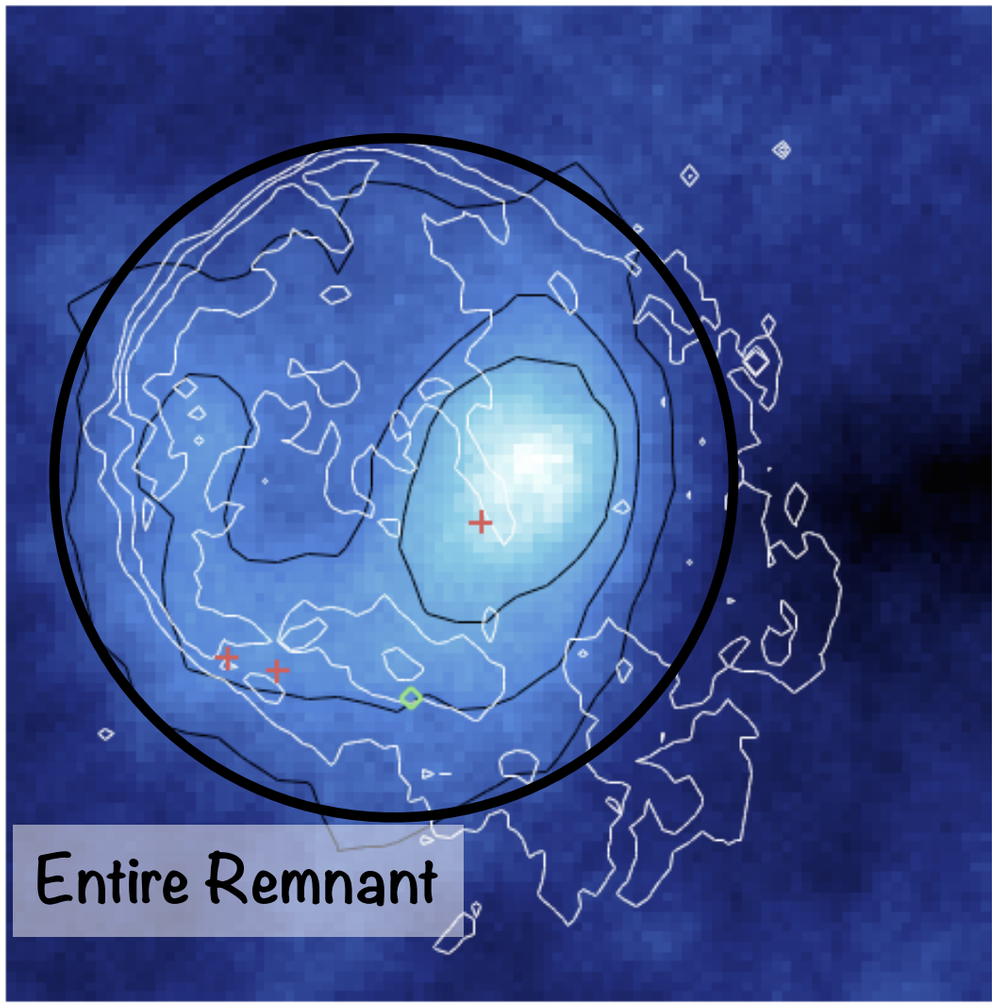
- Emission dominated by CRs interacting with gas in contact with shock front

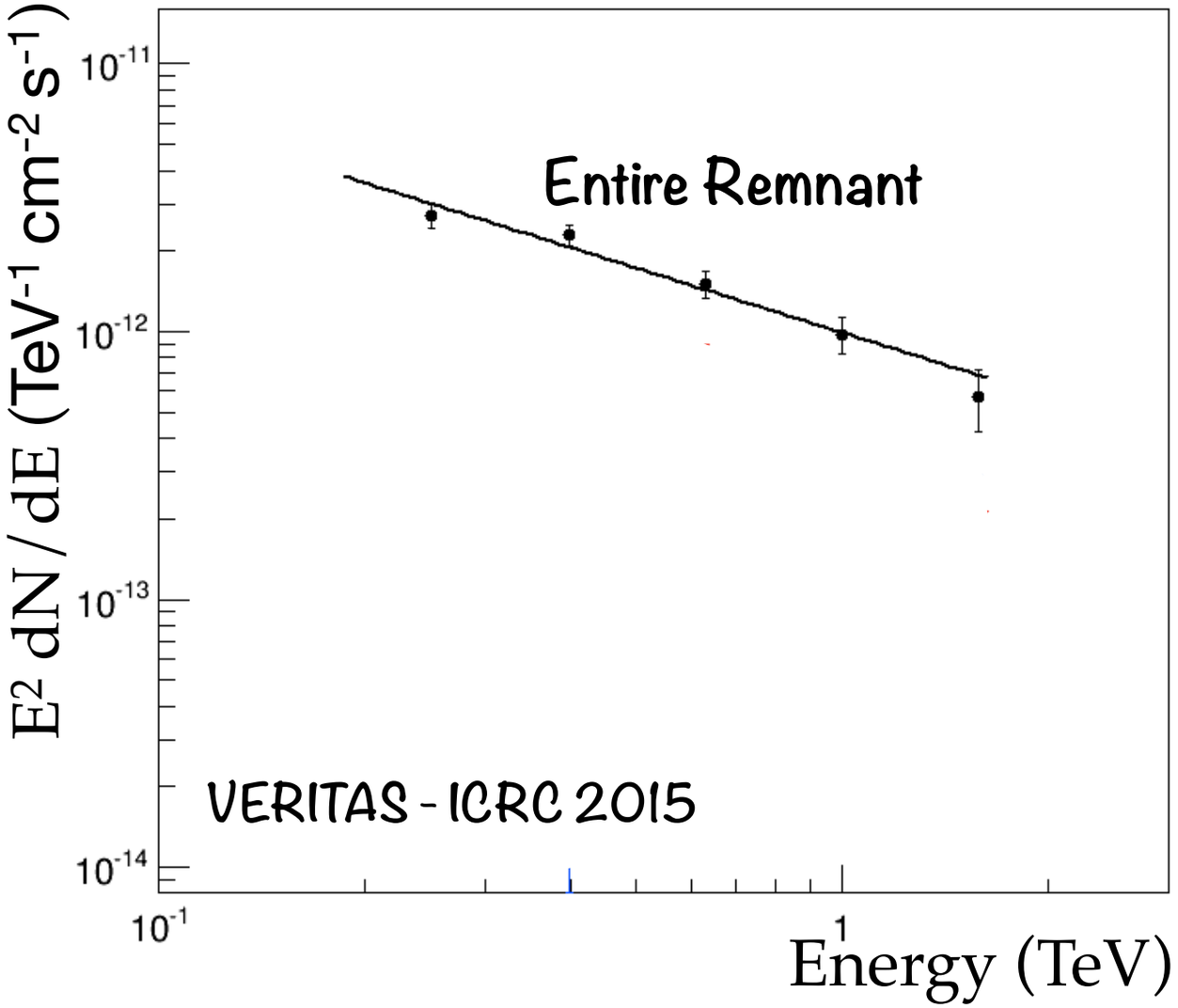






Flux & spectra measurement in IC 443





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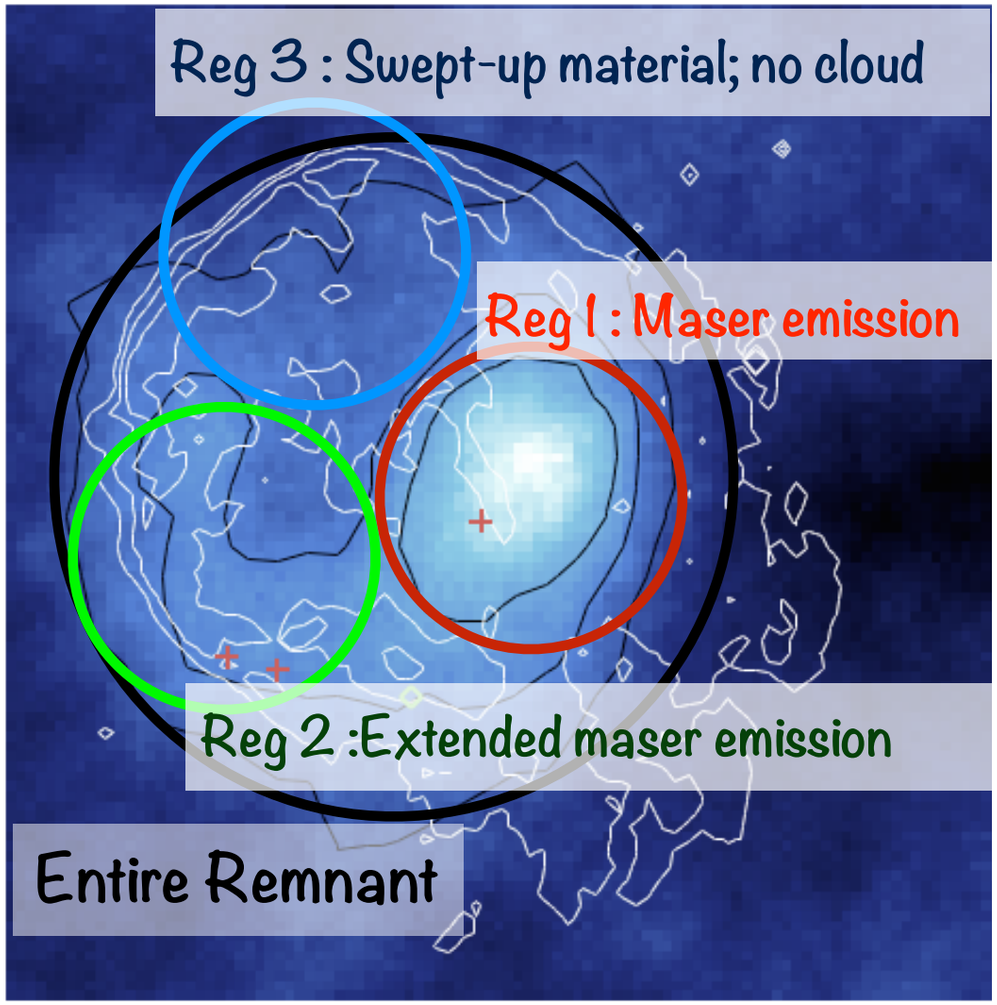
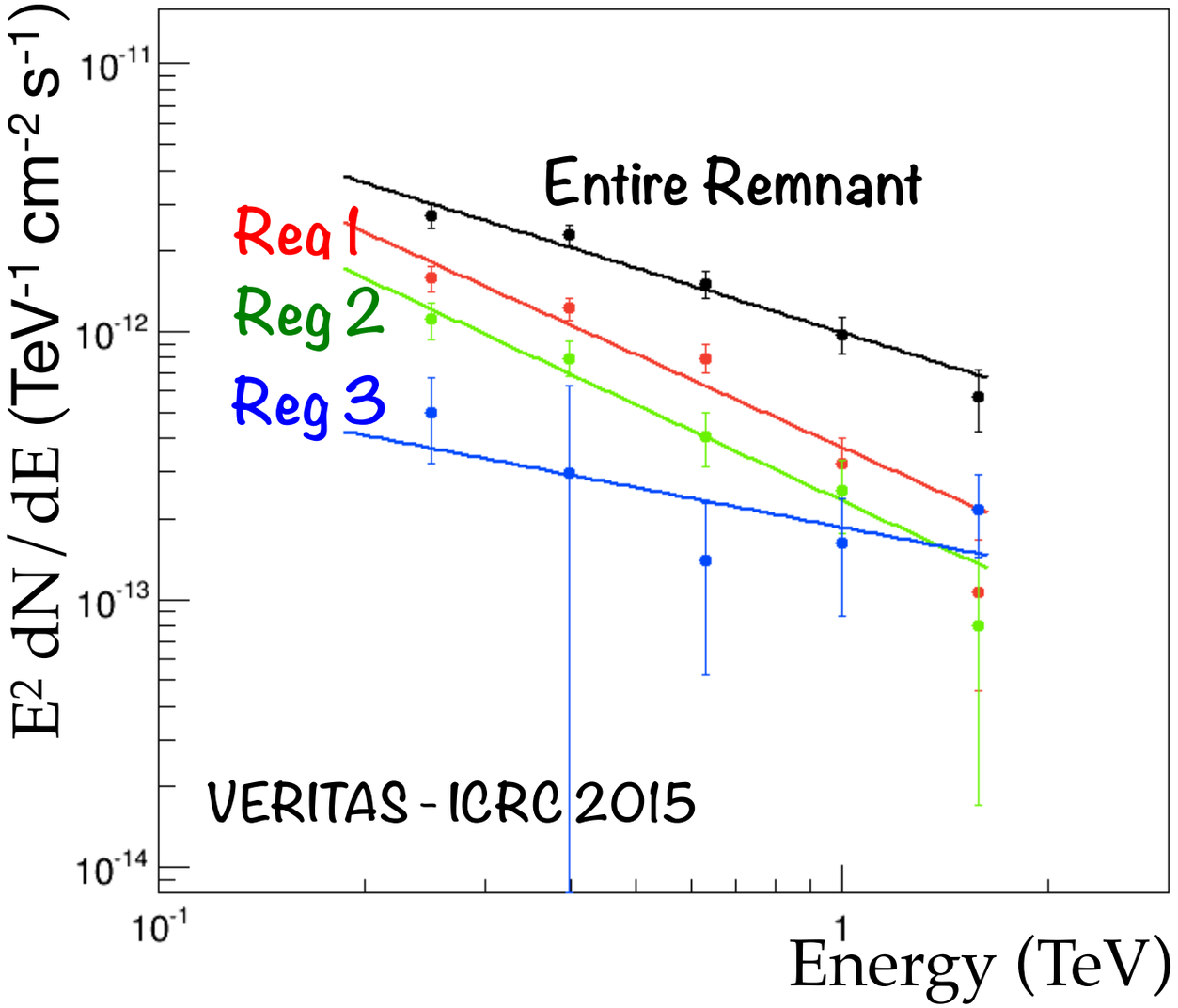
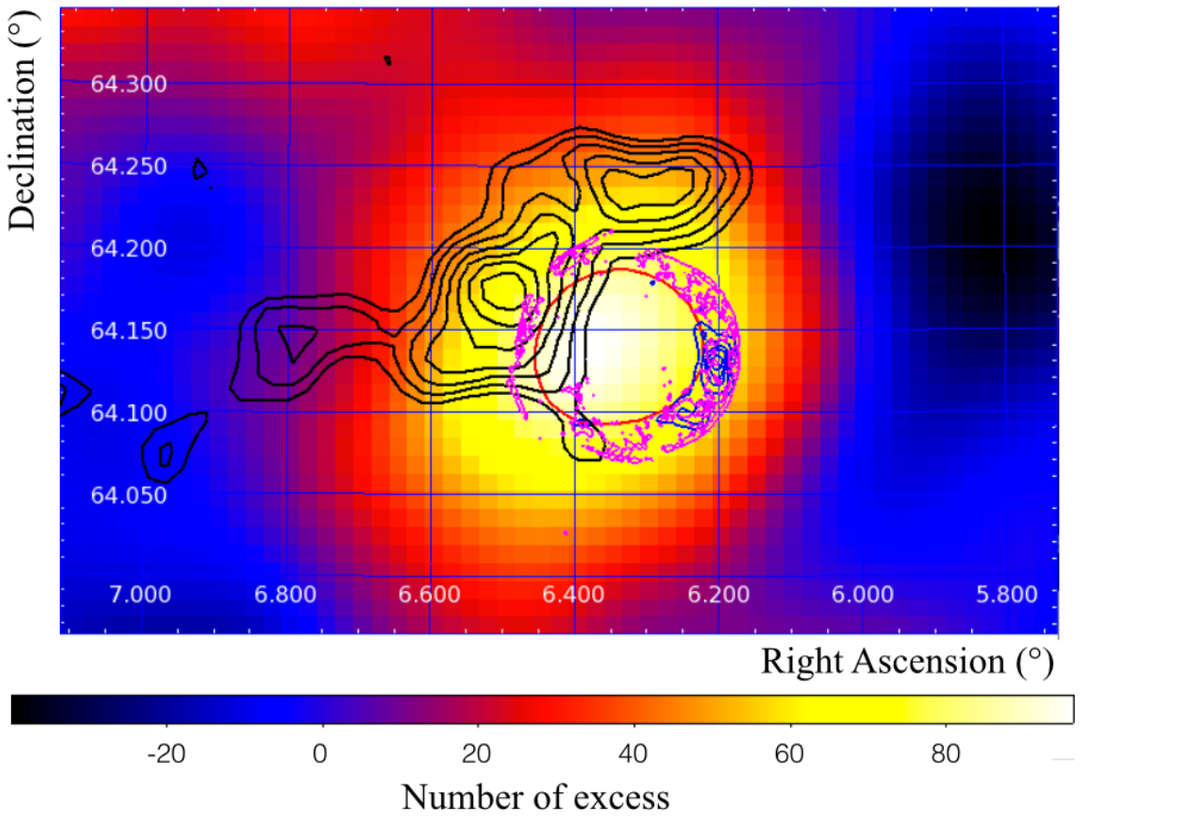




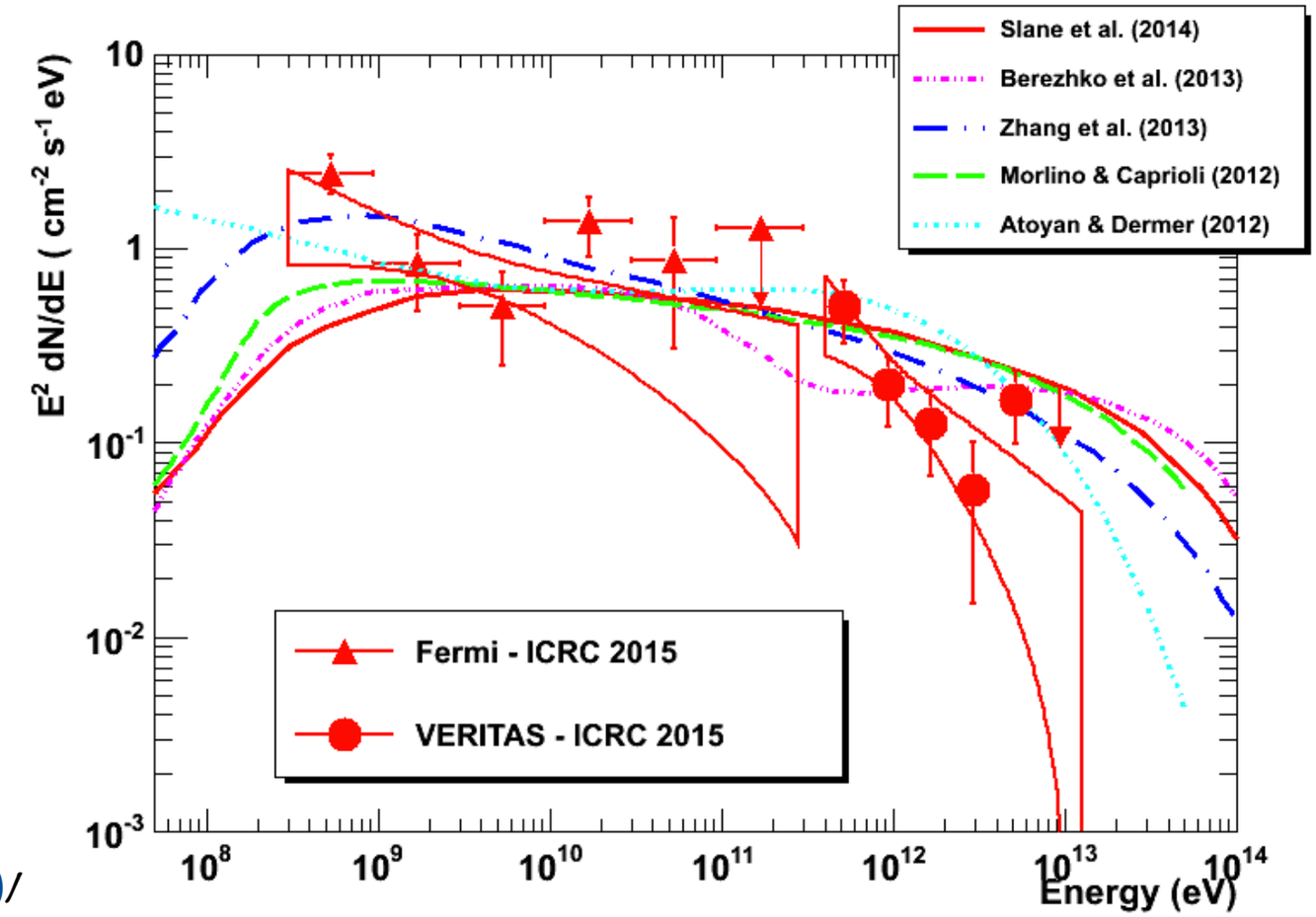
Power-law fit results:

Region	Norm (/550 GeV) * 10^{-13} TeV^{-1} cm^{-2} s^{-1}	Index	χ^2 / ndf
Entire Remnant	9.92 ± 0.90	-2.80 ± 0.09	2.76 / 3
Region 1	3.69 ± 0.42	-3.15 ± 0.11	9.98 / 3
Region 2	2.33 ± 0.42	-3.19 ± 0.17	1.85 / 3
Region 3	1.86 ± 0.49	-2.49 ± 0.42	2.64 / 3

Deep exposure on Tycho



CO cloud / X-ray (Chandra, E>4.1 keV) / X-ray (NuSTAR, 20 keV<E<40 keV)/
Red (Fermi, 95% C.L. centroid, this study)



Extended TeV energy measurements to cover 400 GeV - 10 TeV

A power-law index of TeV shows softer tendency

- PL index = 2.92 $\pm 0.42_{stat}$

No clear illumination of molecular clouds in GeV-TeV energy ranges

Extragalactic Highlights

Flaring activities provide a unique chance to study the dynamics of relativistic particles in blazars

Also, a highly elevated flux increases the chance to get a glimpse of the extragalactic γ-ray horizon, enabling cosmological studies and the propagation studies of γ-rays

Recent VERITAS ATELs

8148 VERITAS observation of a bright very-high-energy gamma-ray flare from 1ES 1959+650
RESHMI MUKHERJEE FOR THE VERITAS COLLABORATION
10 OCT 2015; 01:21 UT

7516 VERITAS Detection of Very High-Energy Gamma-Ray Emission from S3 1227+25
RESHMI MUKHERJEE
16 MAY 2015; 21:46 UT

7433 Very-high-energy gamma-ray emission from PKS 1441+25 detected with VERITAS
RESHMI MUKHERJEE
23 APR 2015; 03:37 UT

6849 VERITAS Discovery of Very High-Energy Gamma-Ray Emission from RGB J2243+203
JAMIE HOLDER
24 DEC 2014; 23:09 UT

5981 Detection of Persistent VHE emission from PKS 1222+216 (4C +21.35) with VERITAS
J. HOLDER FOR THE VERITAS COLLABORATION
14 MAR 2014; 18:34 UT

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JAMIE HOLDER
24 DEC 2014; 23:09 UT

5981 Detection of Persistent VHE emission from PKS 1222+216 (4C +21.35) with VERITAS
J. HOLDER FOR THE VERITAS COLLABORATION
14 MAR 2014; 18:34 UT

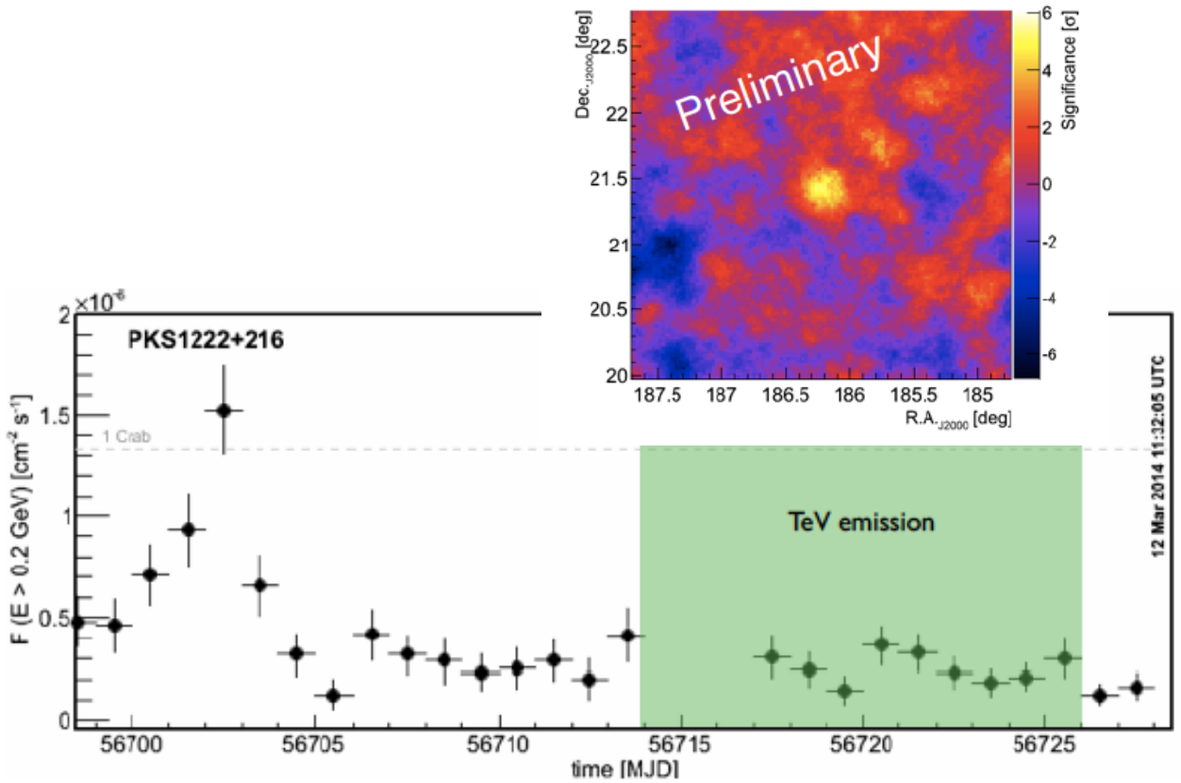
Extragalactic Highlight (2)

Detection of PKS 1222+216 (z=0.432)

FSRQ

March 2014 detection
w/ 6 hours over 10 nights,
clearly delayed from LAT flare

Steady, persistent flux of 3% Crab flux



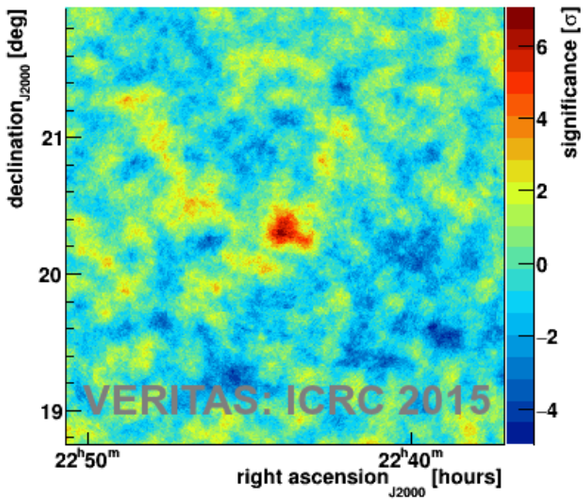
Discovery of RGB J2243+203 (z>0.39)

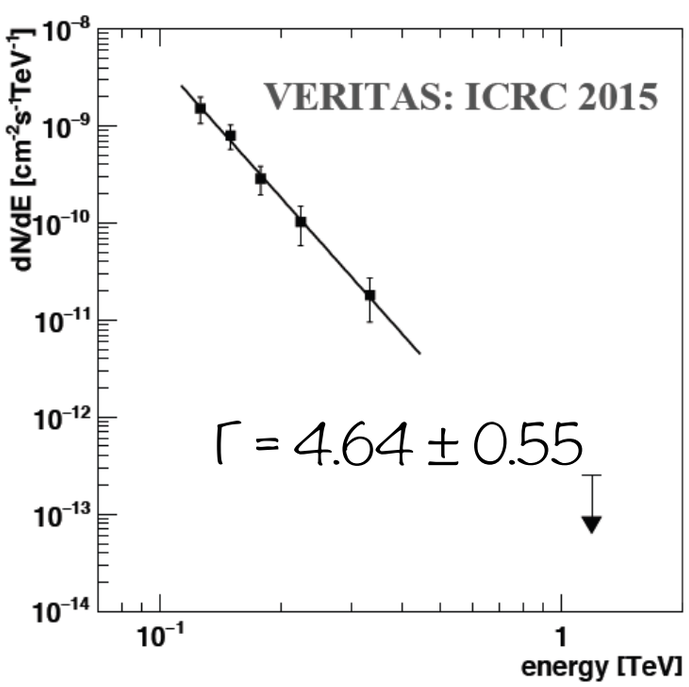
Fermi-detected IBL

- $\Gamma_{2FGL} \sim 1.75$; $\Gamma_{1FHL} \sim 2.4$

December 2014 detection

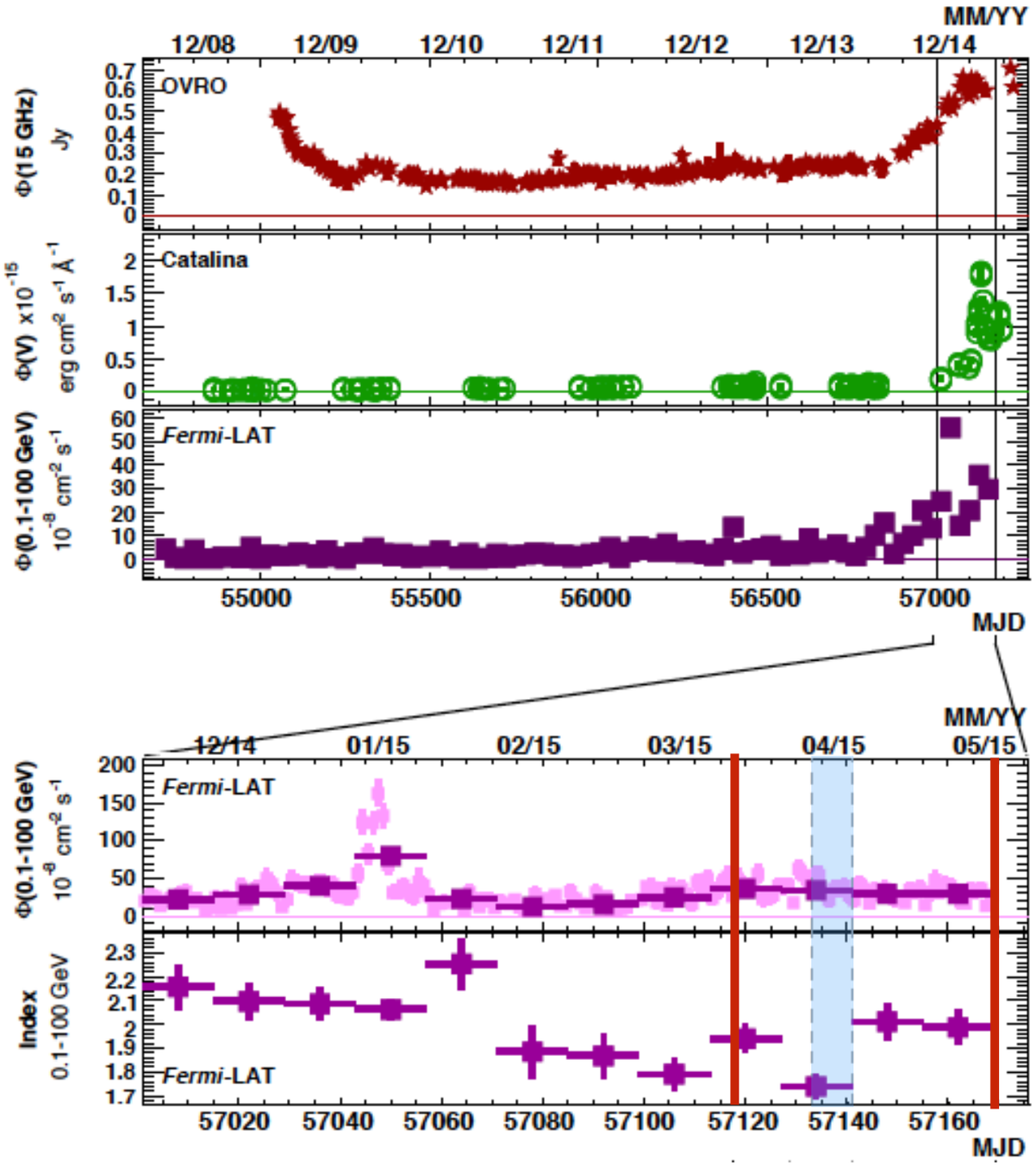
- 20th : triggered by elevated flux
  from Fermi-LAT
- 21-24th : Detection with ~ 6% Crab above 160 GeV

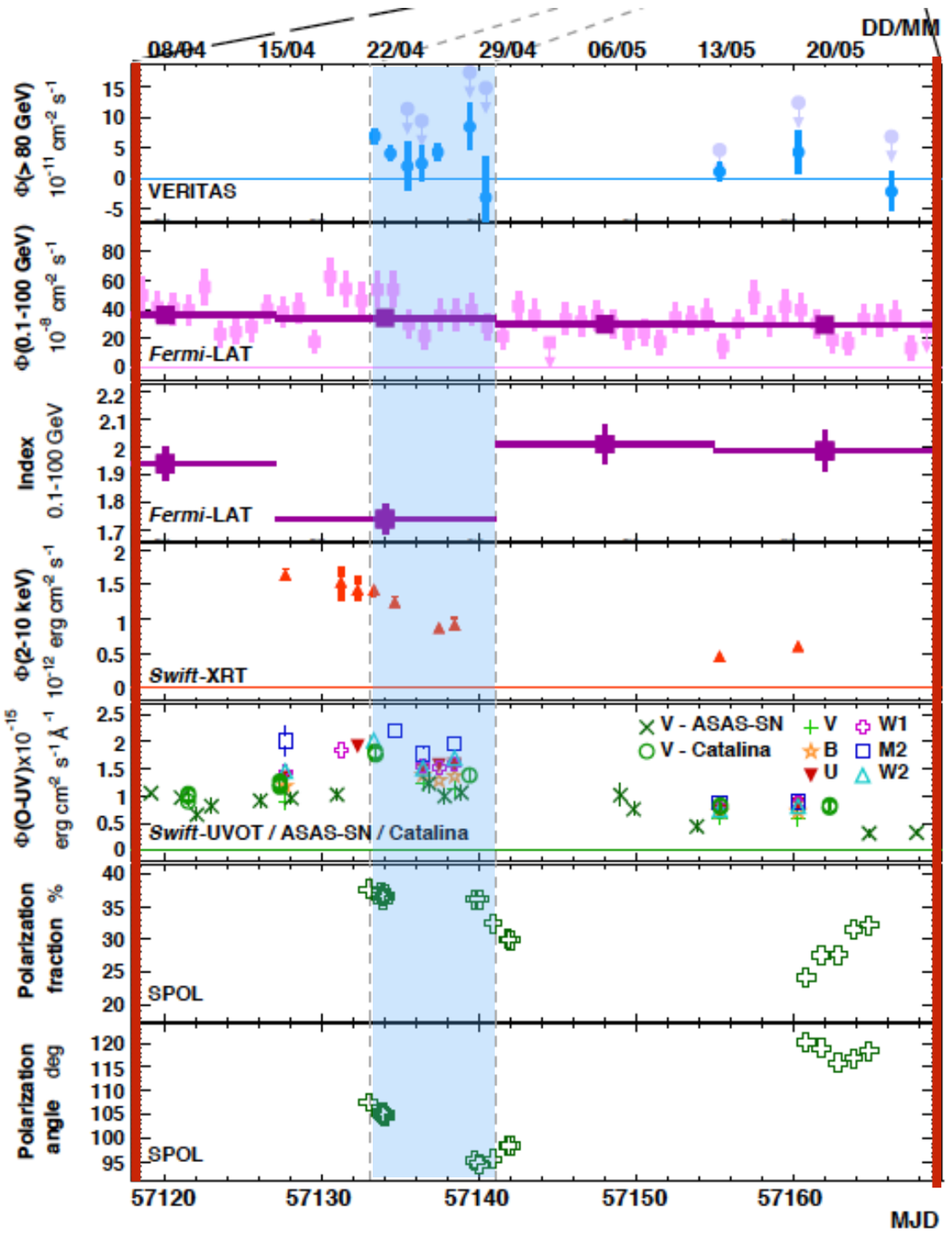




Detection of PKS 1441+25 (z=0.939)

A very distant FSRQ detected at VHE during exceptional outburst



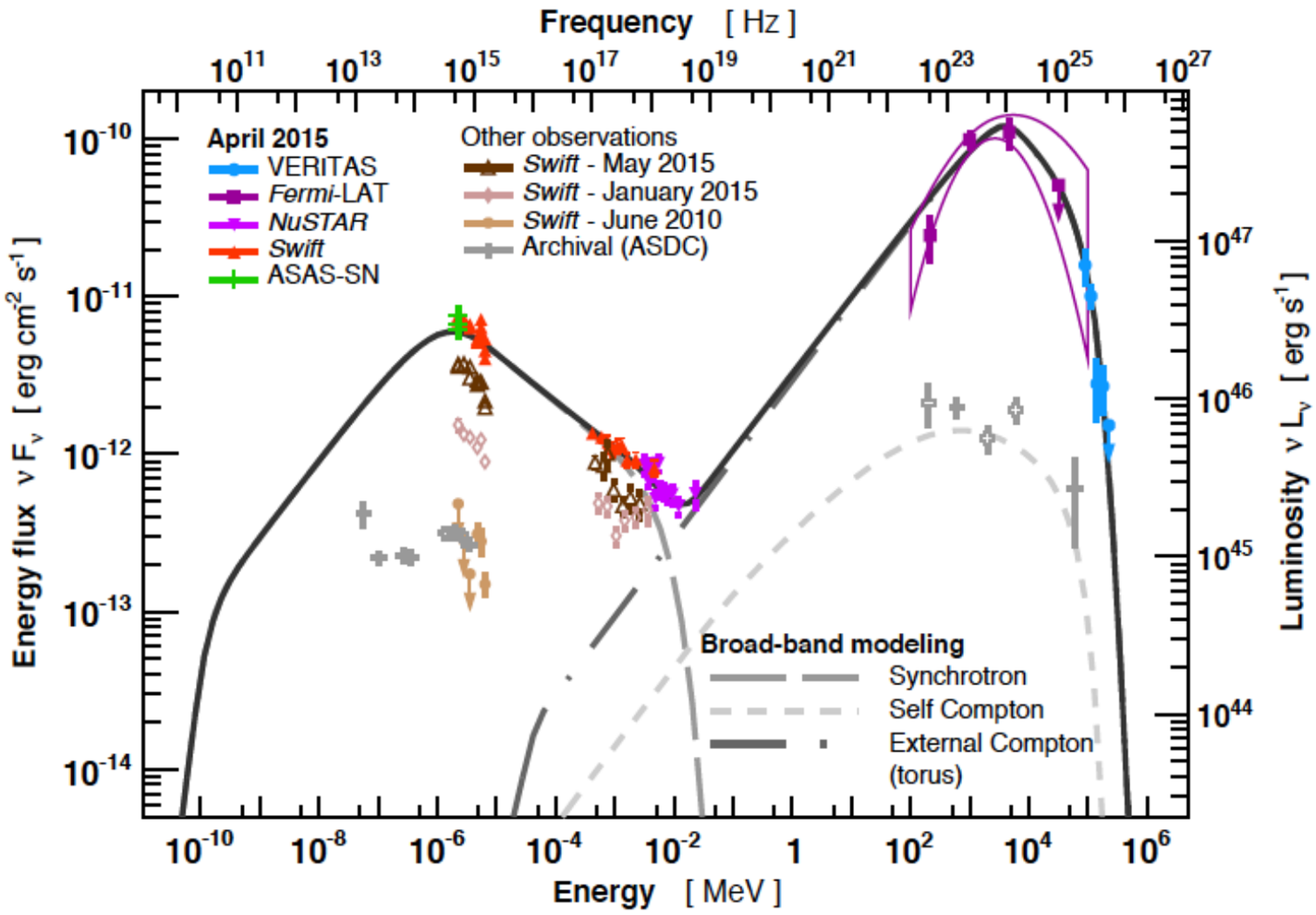


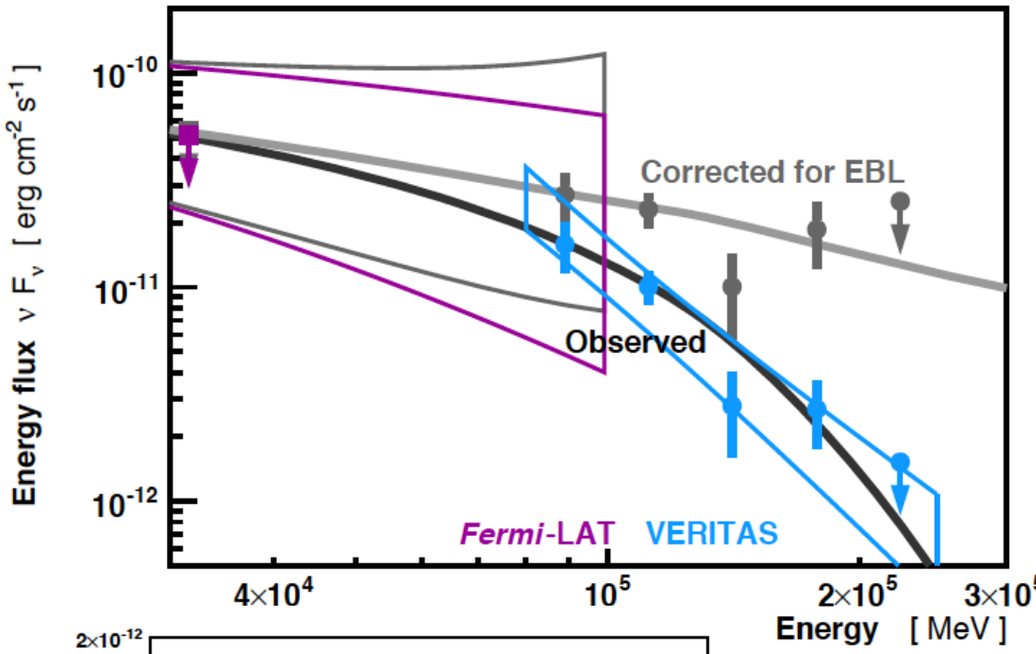
Detection of PKS 1441+25 (z=0.939) (2)

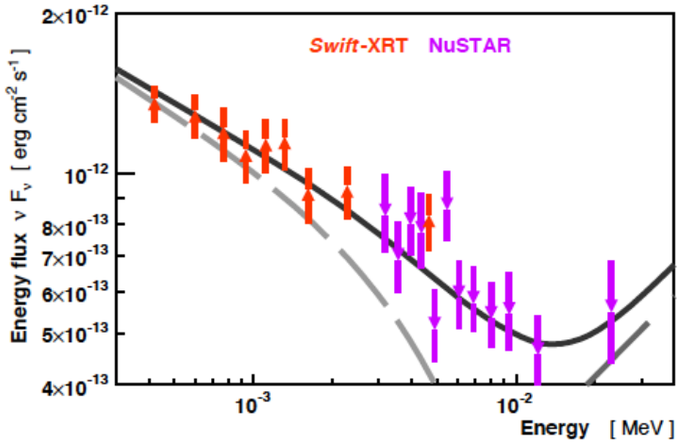
A very distant FSRQ detected at VHE during exceptional outburst

Detection of γ-ray up to 200 GeV, elevated radio state correlated with optical & GeV brightening

→ Emission region is beyond broad line region,
Distance between black hole & emission region is estimated to be > 5000 Schwarzschild radii





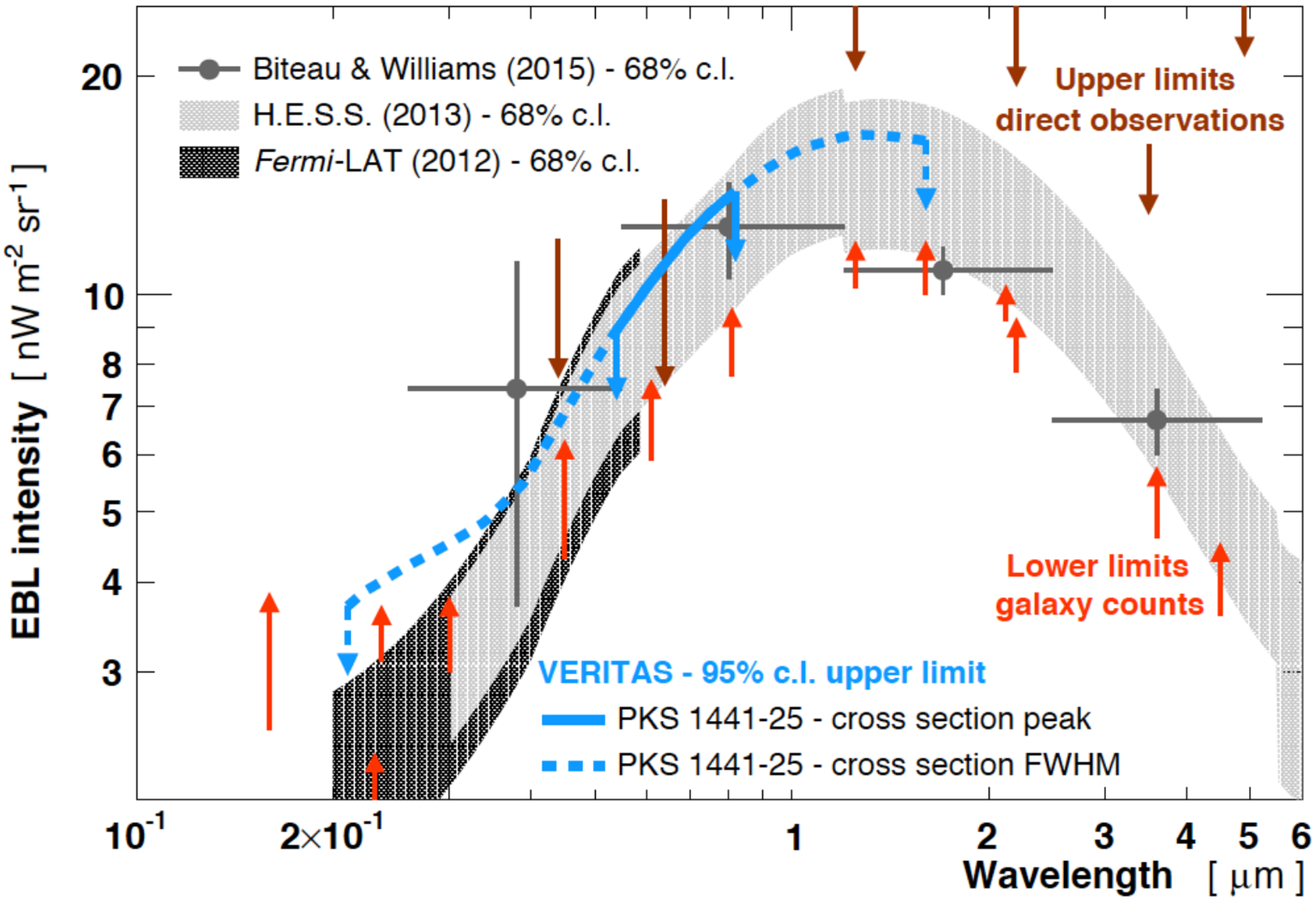


Detection of PKS 1441+25 (z=0.939) (3)

A very distant FSRQ detected at VHE during exceptional outburst

Setting stringent upper limit on the near-ultraviolet to near-infrared EBL just from a single source!

- Competitive below 1 um with combined analysis
- No significant tension with local constraints



Summary

VERITAS has been operated successfully for over seven years.

The sensitivity of VERITAS has been improved with two major upgrades

The scientific goals of VERITAS include understanding the acceleration, interactions, and propagation of TeV particles by observing very high energy gamma-rays from extreme environments in both Galactic and extragalactic sources.

- IC 443 : middle-aged SNRs, VERITAS resolved shell morphology & spectra from different regions of the SNR
- Tycho : historic SNR, softer index was resolved with deep exposure
- Detection of two new VEH blazars - RGB J2243+203 & S3 1227+25
- Detection of flaring activities on PKS 1222+216 & 1ES 1959+650
- Detailed MWL studies on the most distance FSRQ - PKS 1441+25 (z=0.94), providing constraining EBL limit
- And many more interesting results