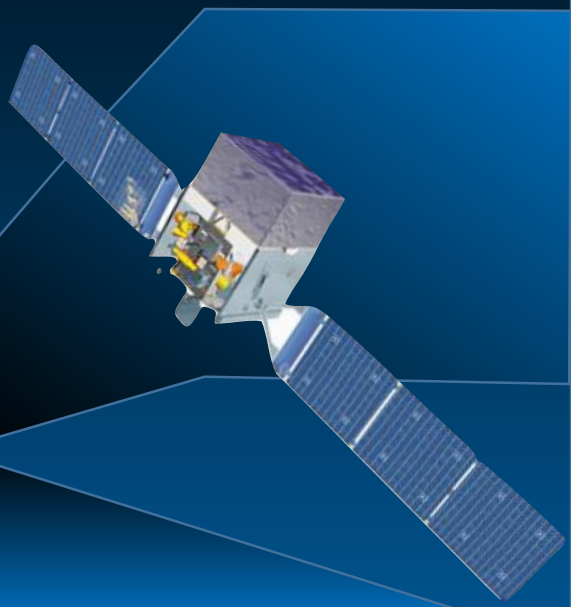
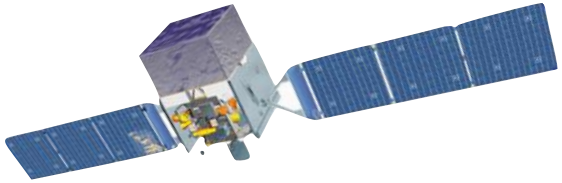
VERITAS and *Fermi*-LAT observations of TeV gamma-ray sources from the 2HWC catalog



Nahee Park for VERITAS, Fermi, and HAWC collaboration

Coverage of gamma-ray observations

We currently have instruments covering seven orders of energy range in γ-ray observations



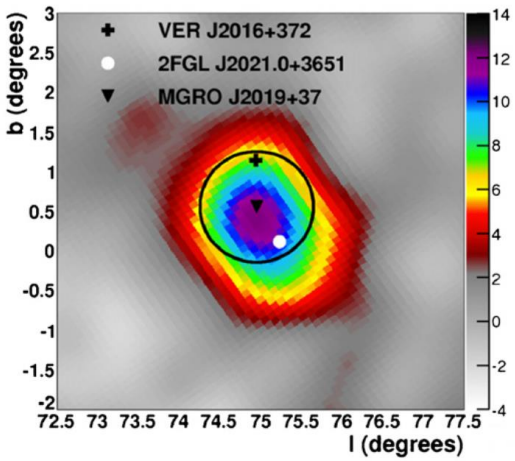
	GeV satellite (e.g. Fermi-LAT)	IACT (e.g. VERITAS)	Air shower array (e.g. HAWC)
Energy range	Few 10s of MeV- 500 GeV	85 GeV - > 30 TeV	100 GeV - 100 TeV
Type	Survey	Pointing (<5 degree)	Survey (~2/3 of sky)
Time to detect Crab Nebula (E>100GeV)		~1 min.	~1 day

Coverage of gamma-ray observations

The most powerful approach is combining all of data

- e.g. MGRO J2019+37

Detection by Milagro (Abdo2007b)



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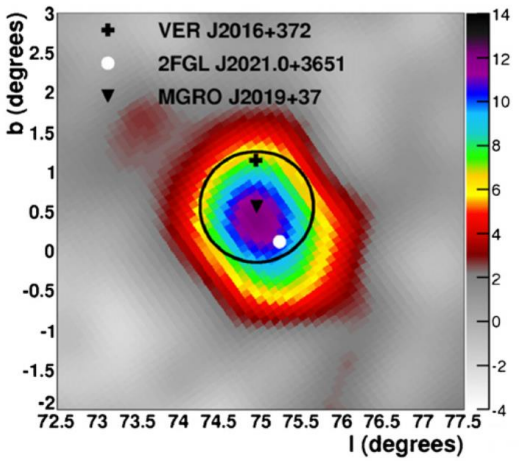
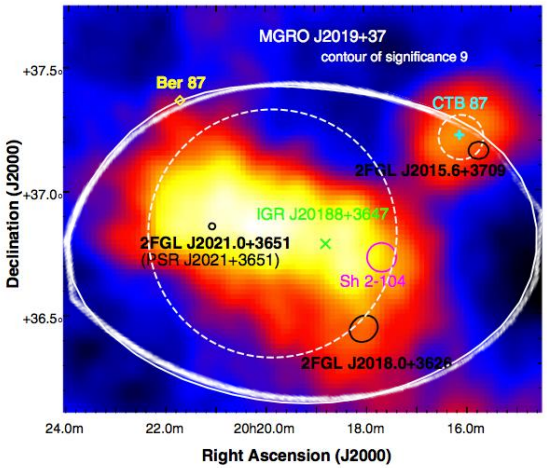


Followup by VERITAS (Aliu 2014)



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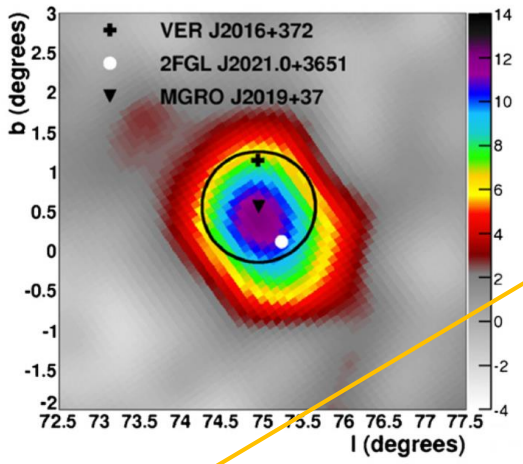

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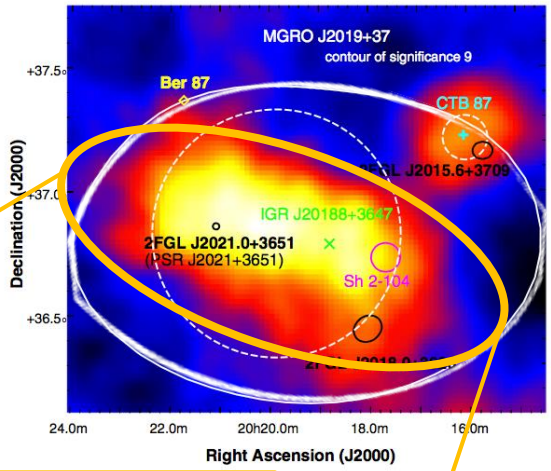

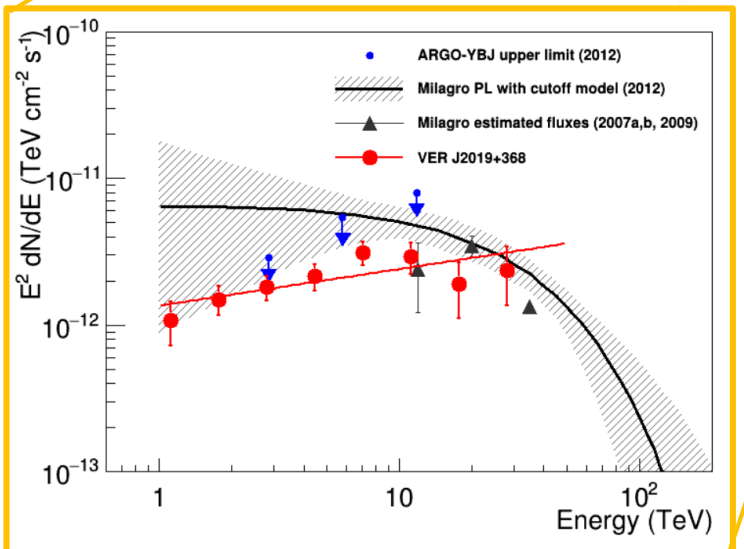

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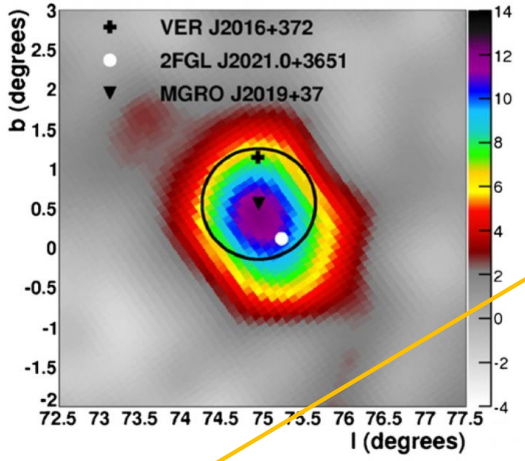

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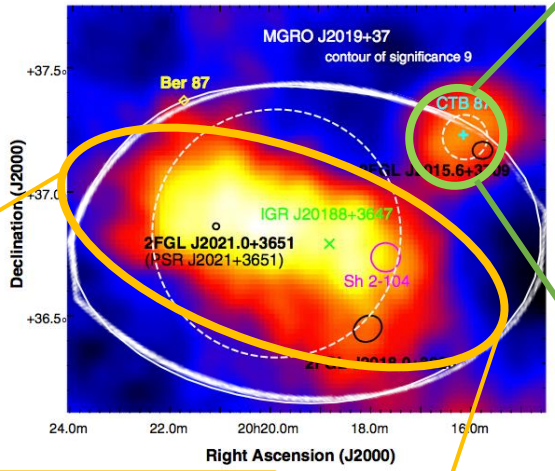
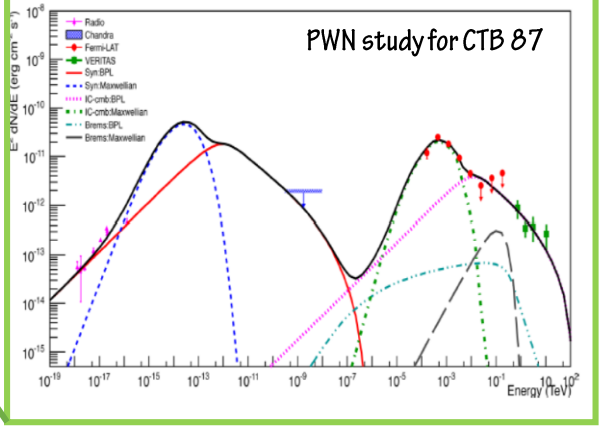
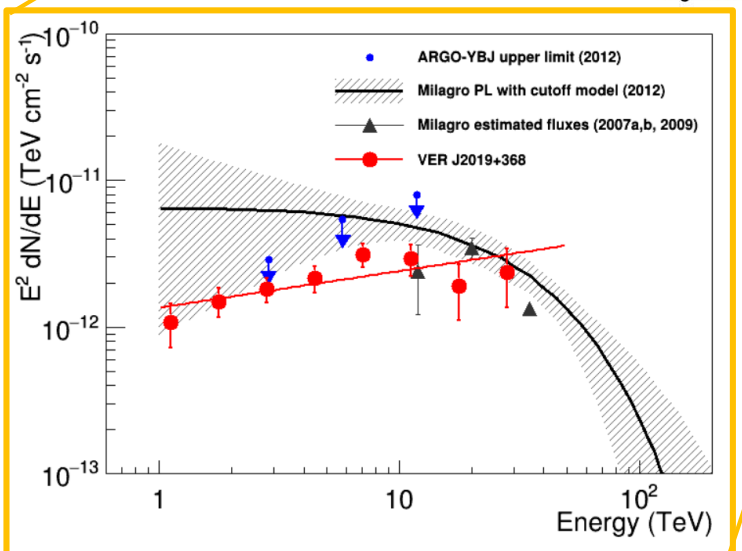


Followup w/ Fermi-LAT (Saha2016)





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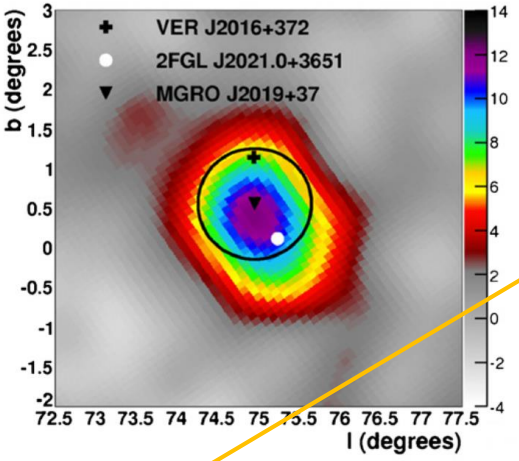

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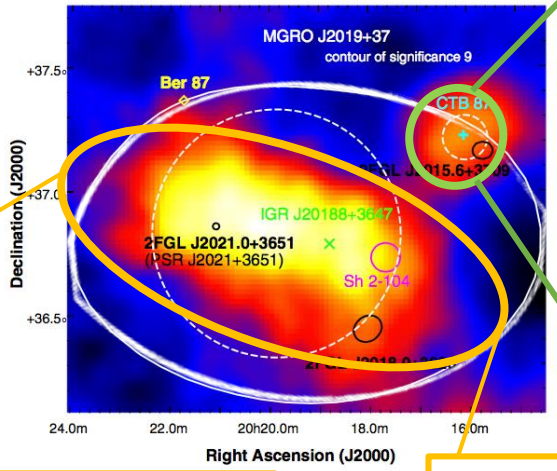

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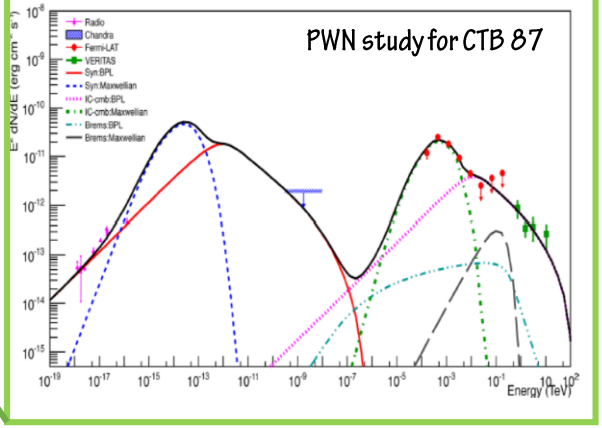
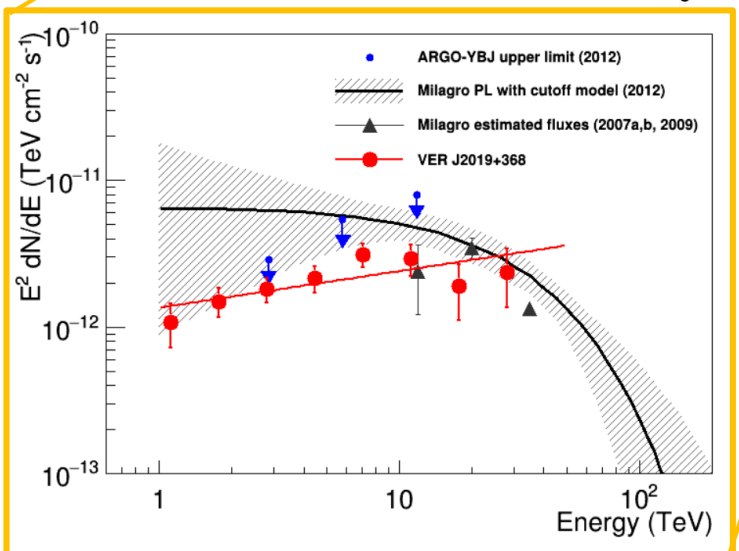
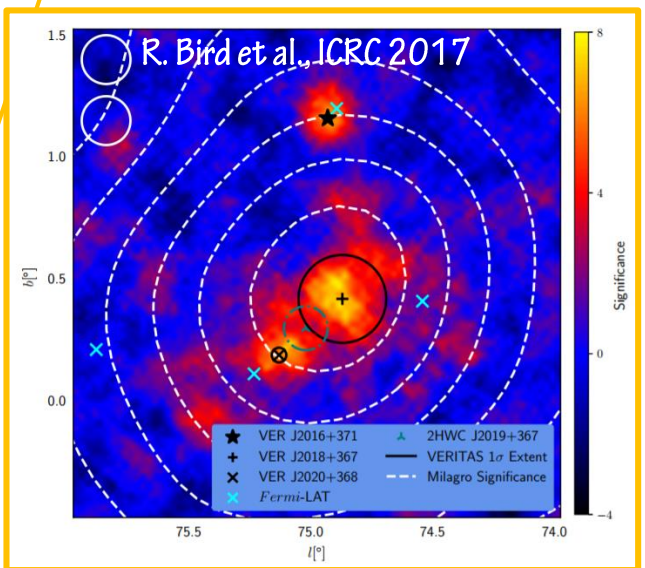
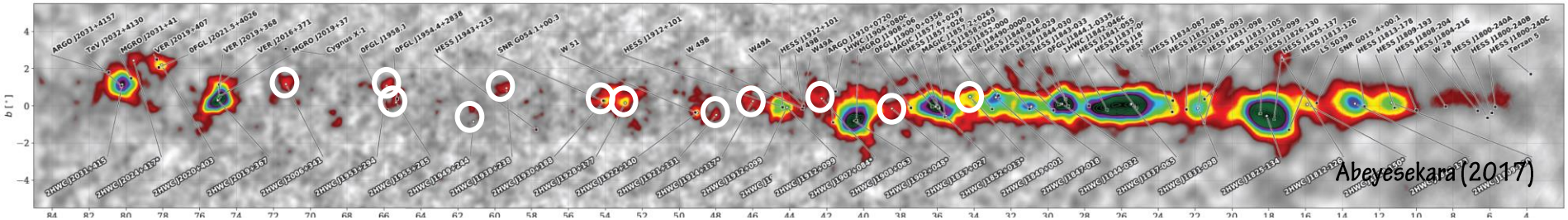






HAWC Second Catalog

507 Days of observation with HAWC found 39 Gamma-ray sources



- 19 sources are 0.5° away from known TeV gamma-ray sources
- Follow-up studies by using VERITAS & Fermi-LAT data
  - VERITAS has 187 hours of exposure on 13 out of 19 sources
  - Fermi accumulated 8.5 years of exposure over all sky, improved sensitivity with Pass 8 (E>10GeV)

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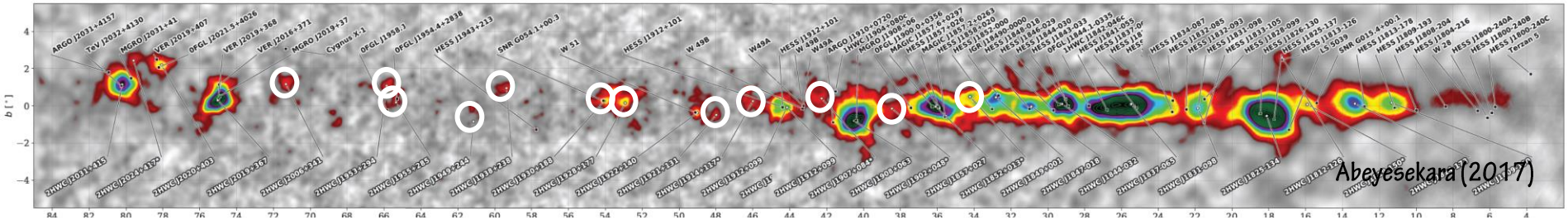
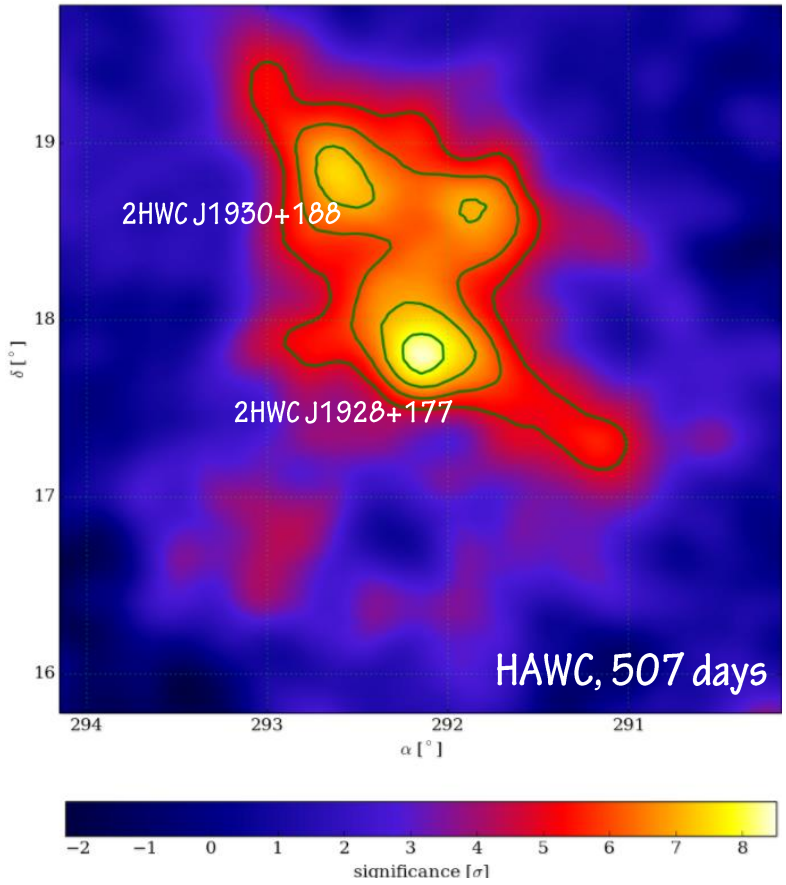
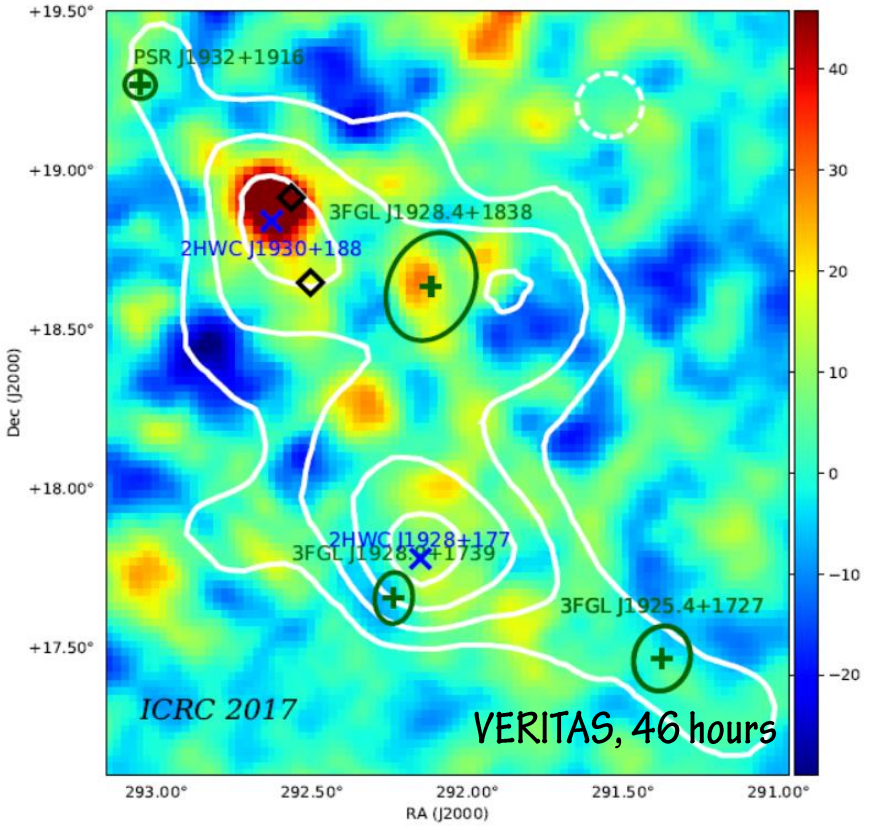


- 19 sources are 0.5° away from known TeV gamma-ray sources
- Follow-up studies by using VERITAS & Fermi-LAT data
  - VERITAS has 187 hours of exposure on 13 out of 16 sources
    - Non-detection on 12 sources
    - 1 detection – 2HWC J1953+294
  - Fermi accumulated 8.5 years of exposure over all sky, improved sensitivity with Pass 8 (E>10GeV)
    - Non-detection for 13 sources
    - Detection of a known TeV source, SNR G54.1+0.3

SNR G54.1+0.3 region

Two 2HWC sources
– 2HWC J1930+188 & 2HWC J1928+177

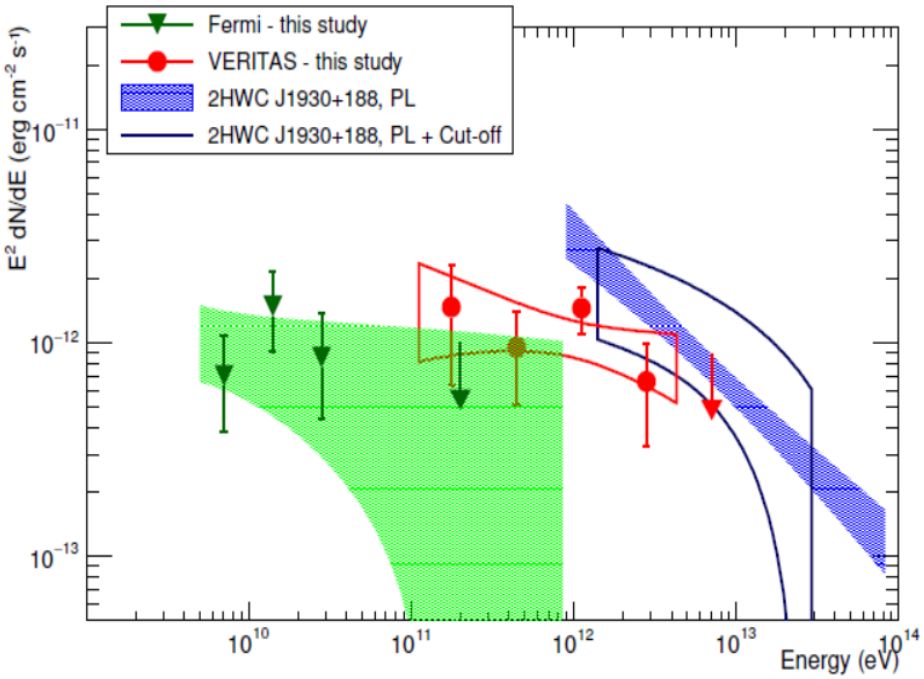


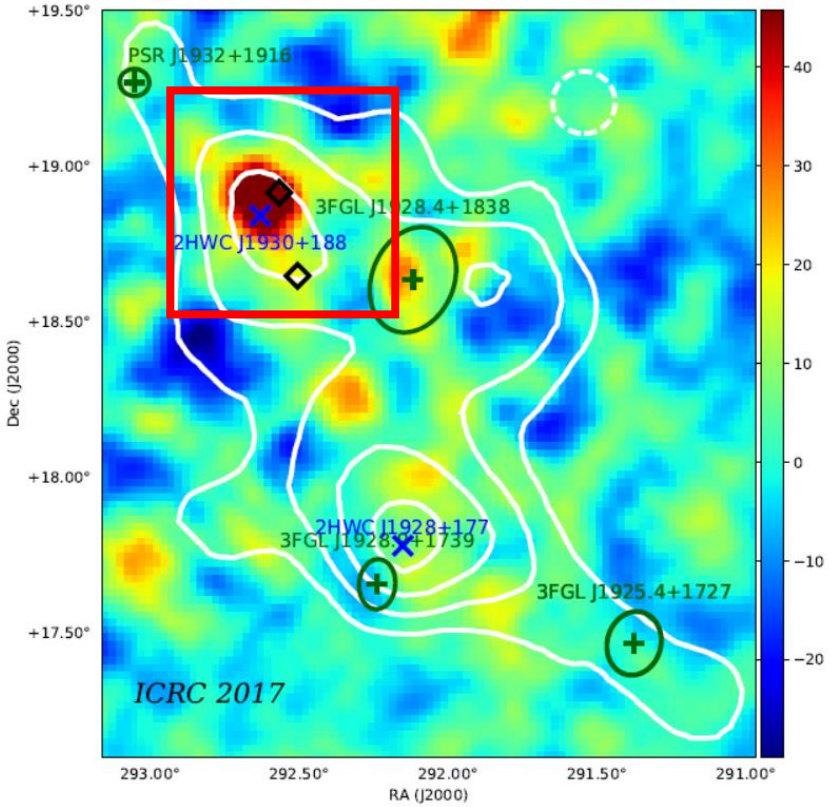


SNR G54.1+0.3 region (2)

Detection of Fermi coincident with known TeV source, VER J1930+188, and 2HWC J1930+188

- SNR G54.1+0.3 is likely the counterpart
- Fermi, VERITAS & HAWC combined, the overall SED is more consistent with PL + cut-off hypothesis

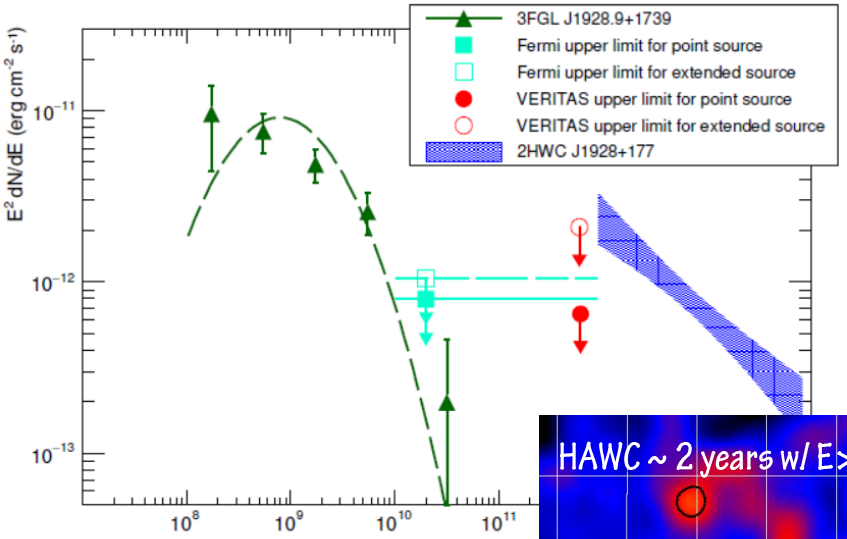


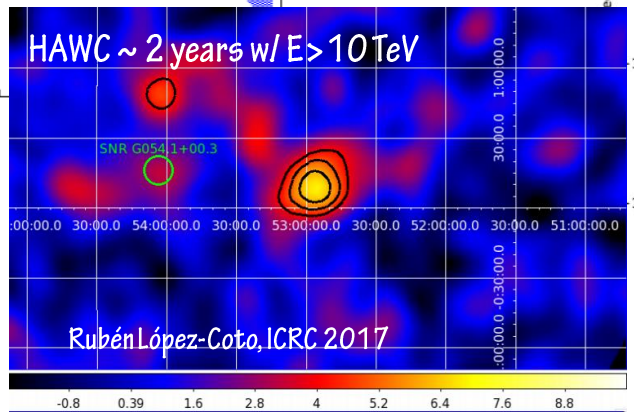


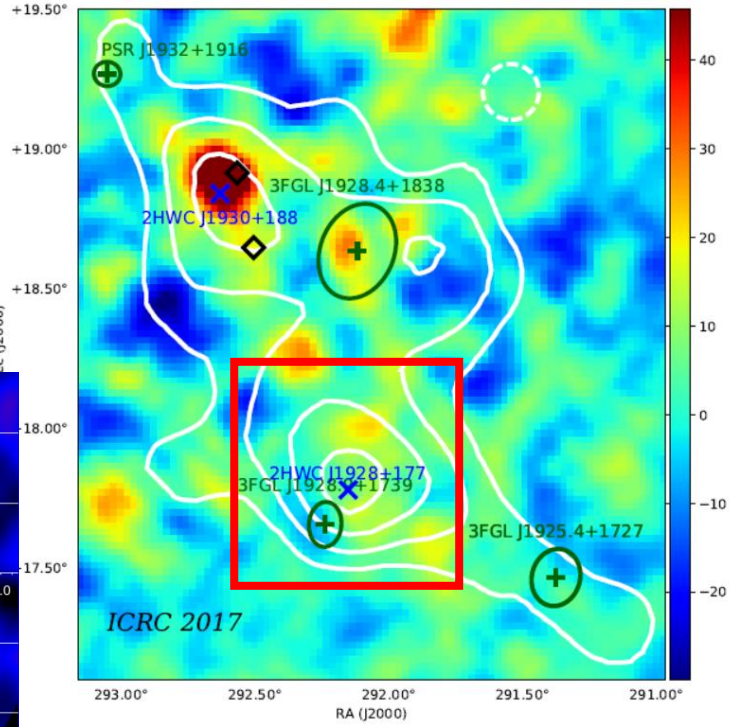
SNR G54.1+0.3 region (3)

2HWC J1928+177

- Coincide with pulsar, PSR J1928+1746
- Equally strong source w/ 2HWC J1930+188 for HAWC
  - Stronger than 2HWC J1930+188 for E>10 TeV
- VERITAS upper limit excludes a point source hypothesis assuming the same PL distribution

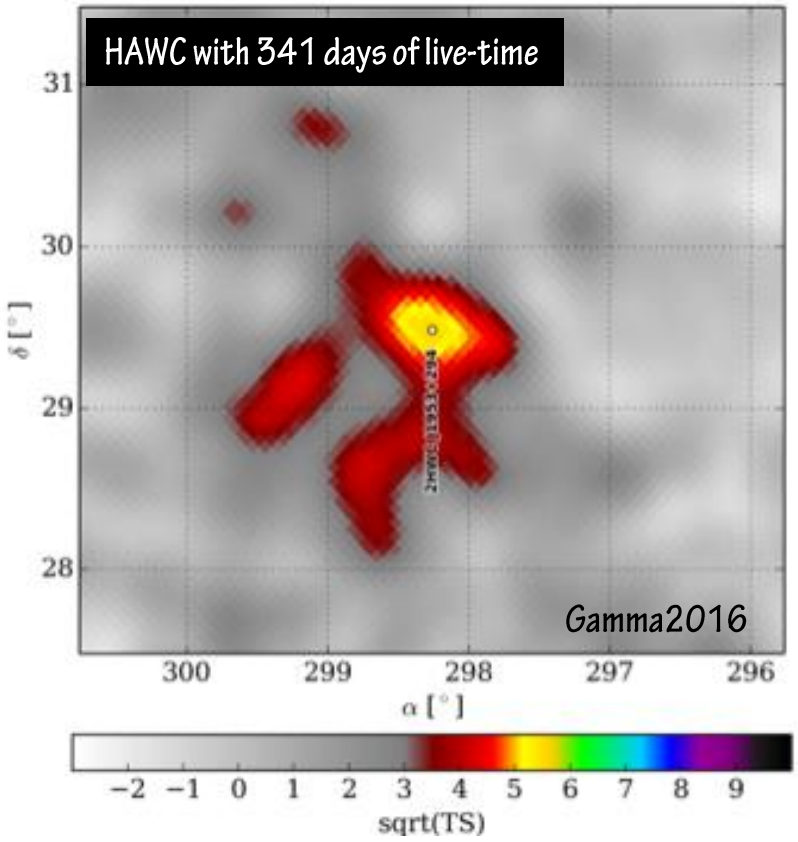


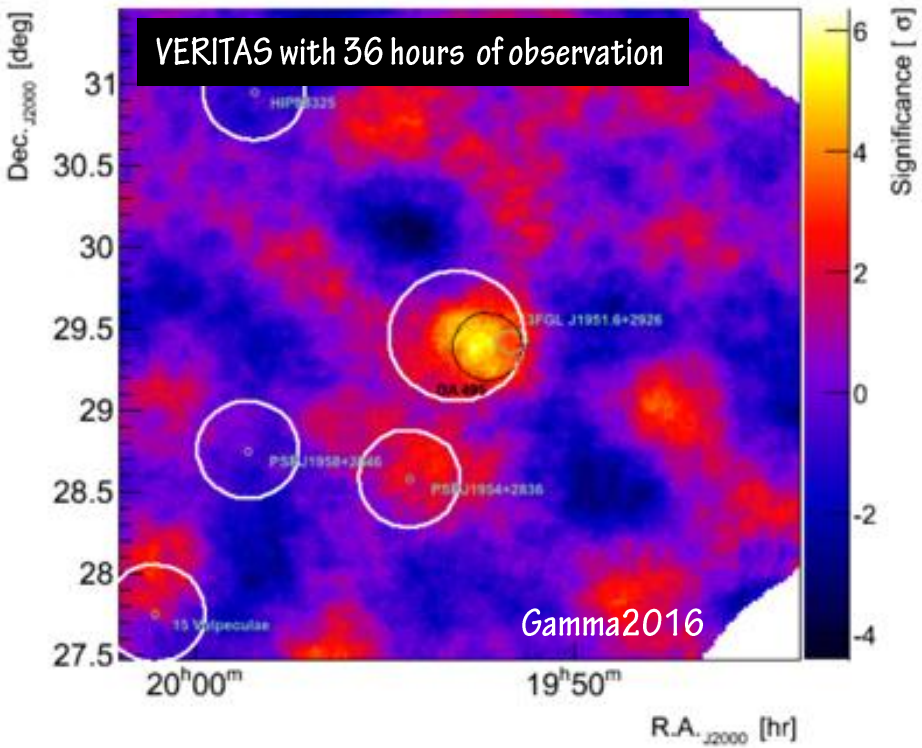




DA 495 region

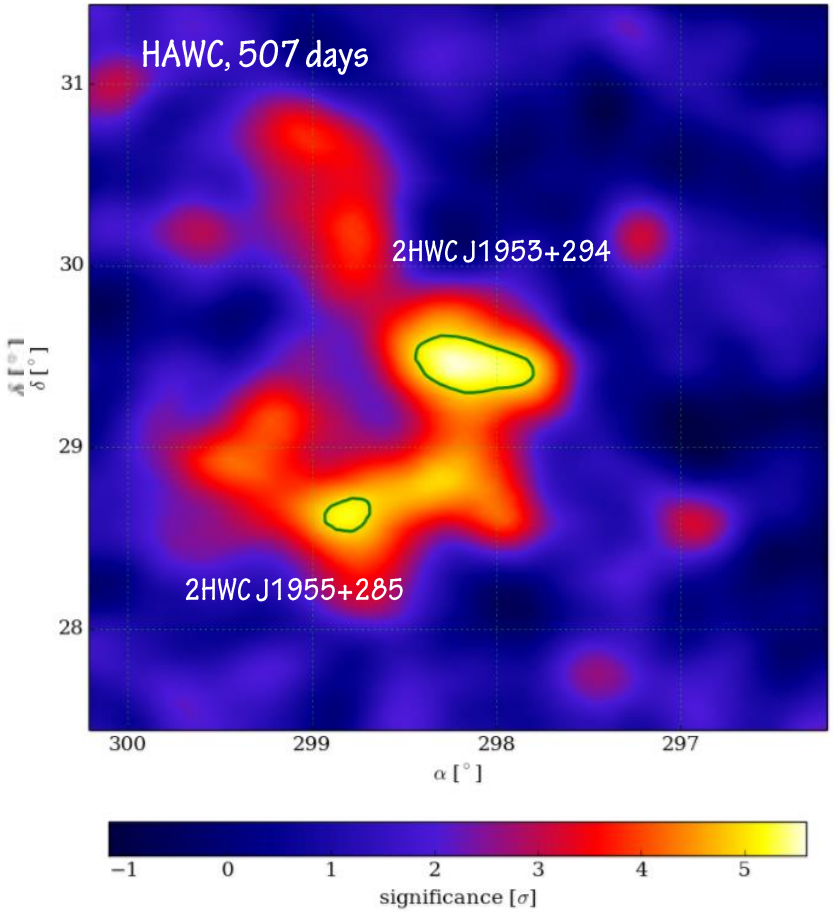
VERITAS confirmed gamma-ray emission from 2HWC J1953+294 at 2016 Heidelberg meeting

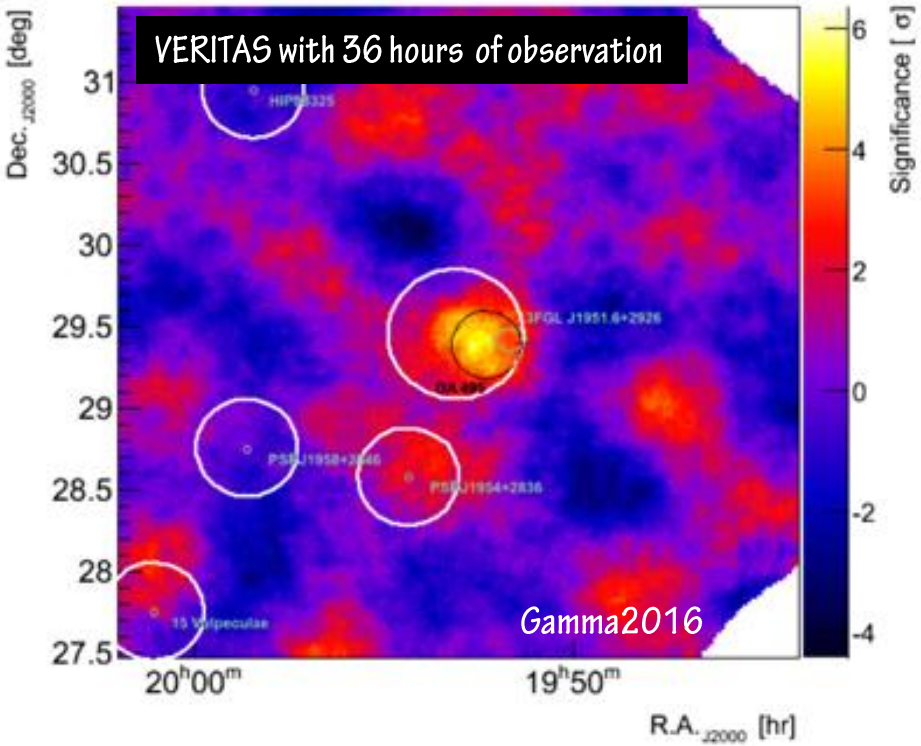




DA 495 region

Two 2HWC sources
– 2HWC J1953+294 & 2HWC J1955+285





DA 495 region

Two 2HWC sources
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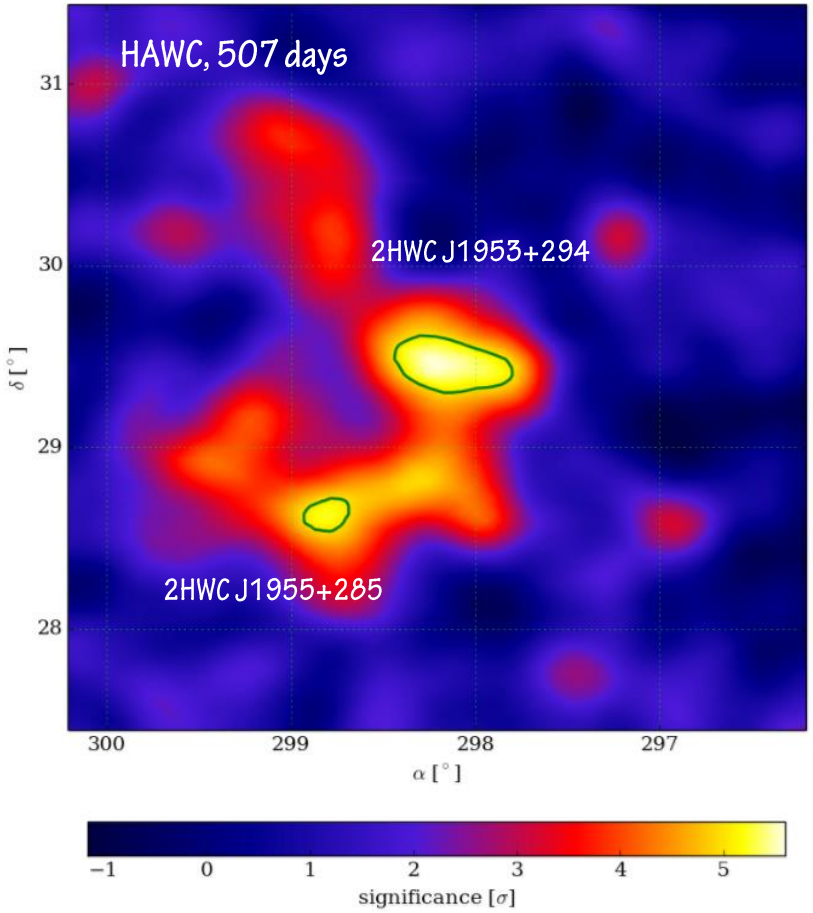
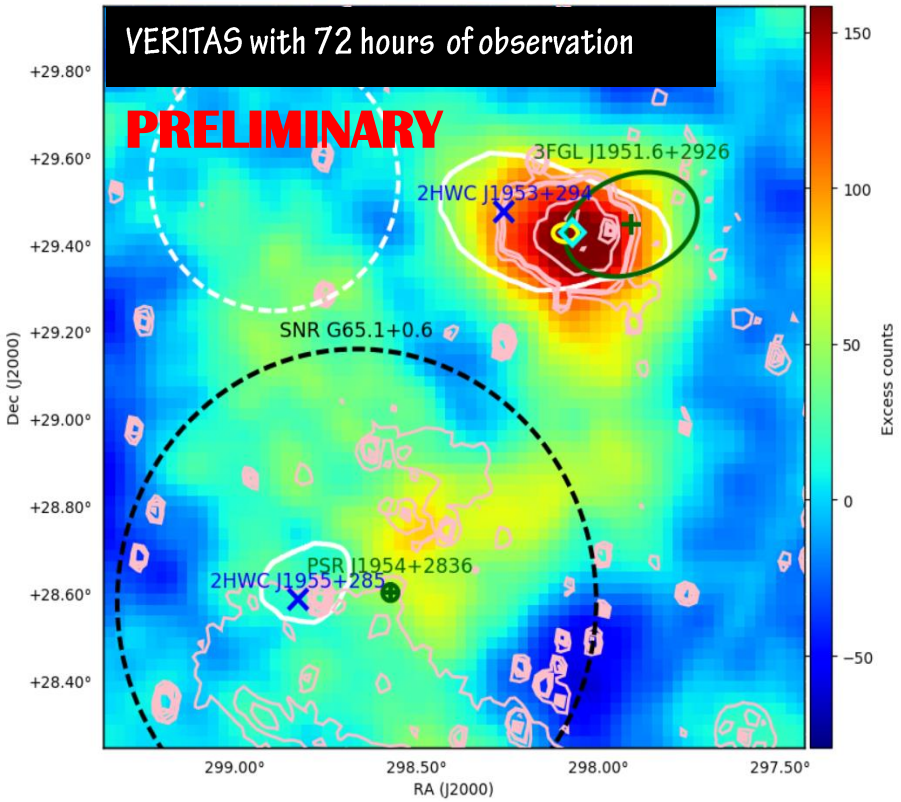
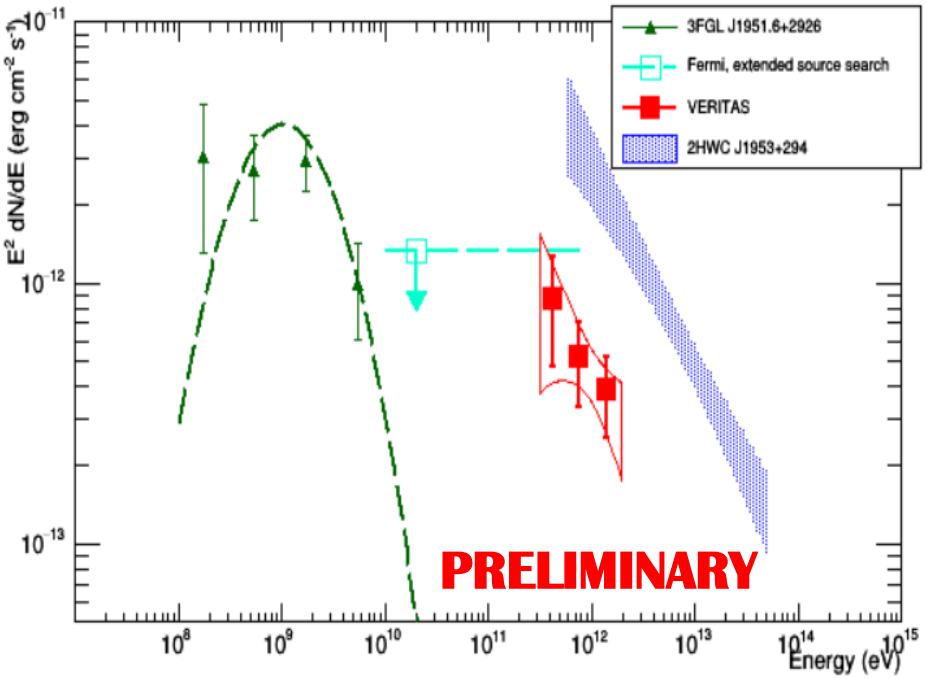


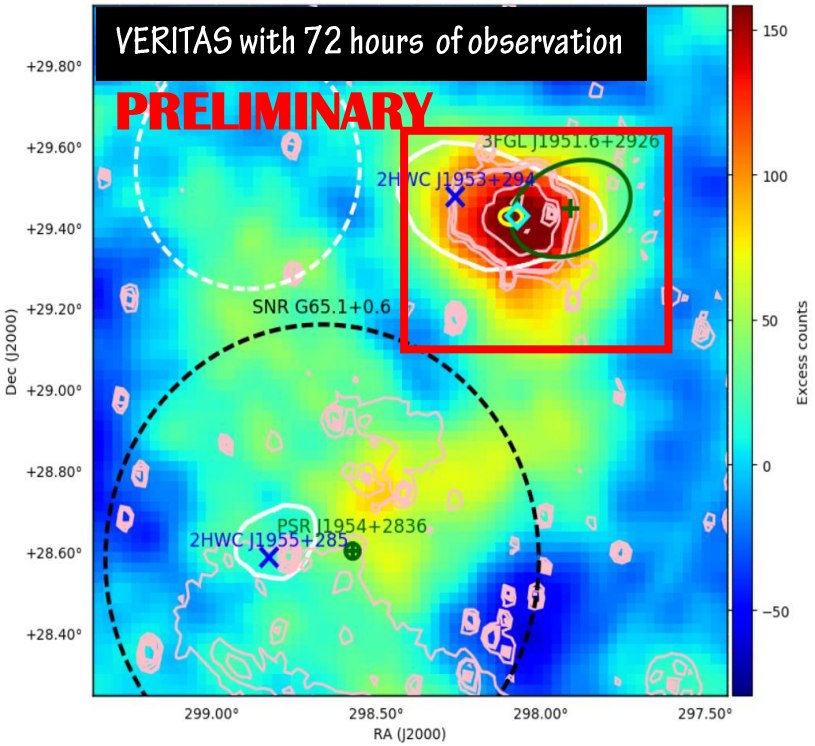


DA 495 region (2)

2HWC J1953+294

- VERITAS detection, VER J1952+294
- Likely counterpart is PWN DA 495
  - X-ray : A compact central object surrounded by non-thermal diffuse emission (no pulsation detected)
  - GeV gamma-ray : 3FGL source (no pulsation detected)

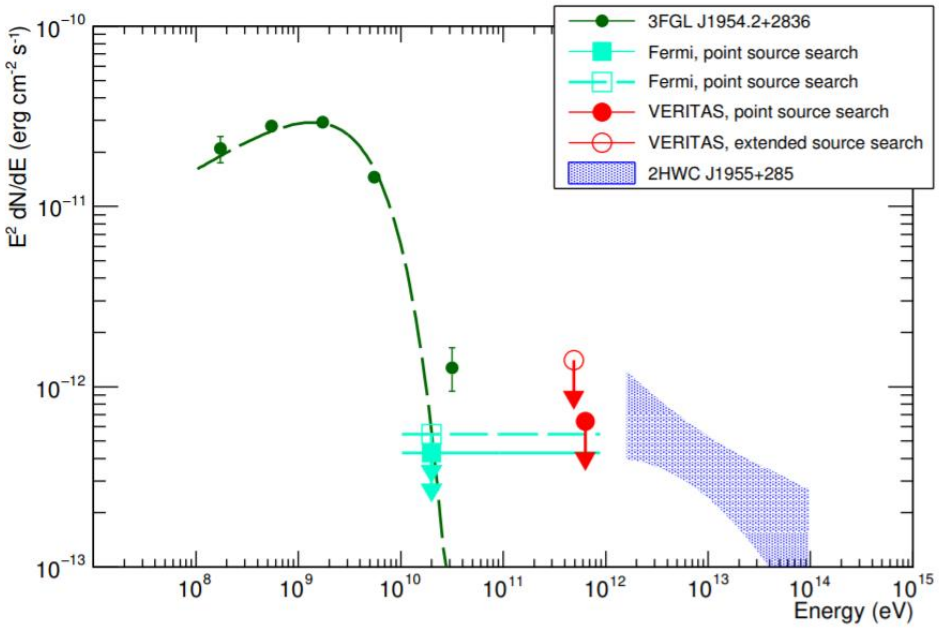


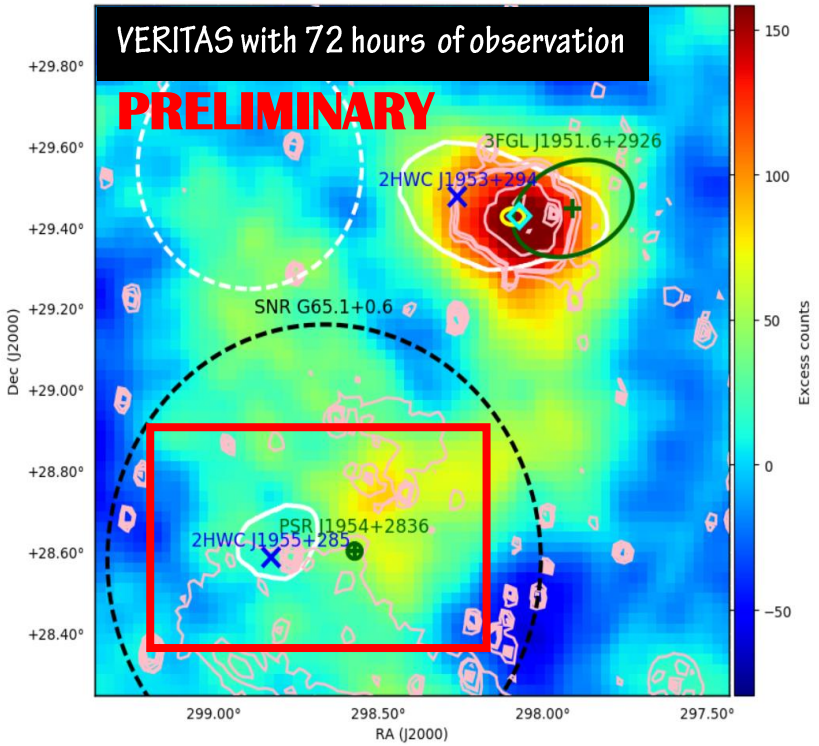


DA 495 region (3)

2HWC J1955+285

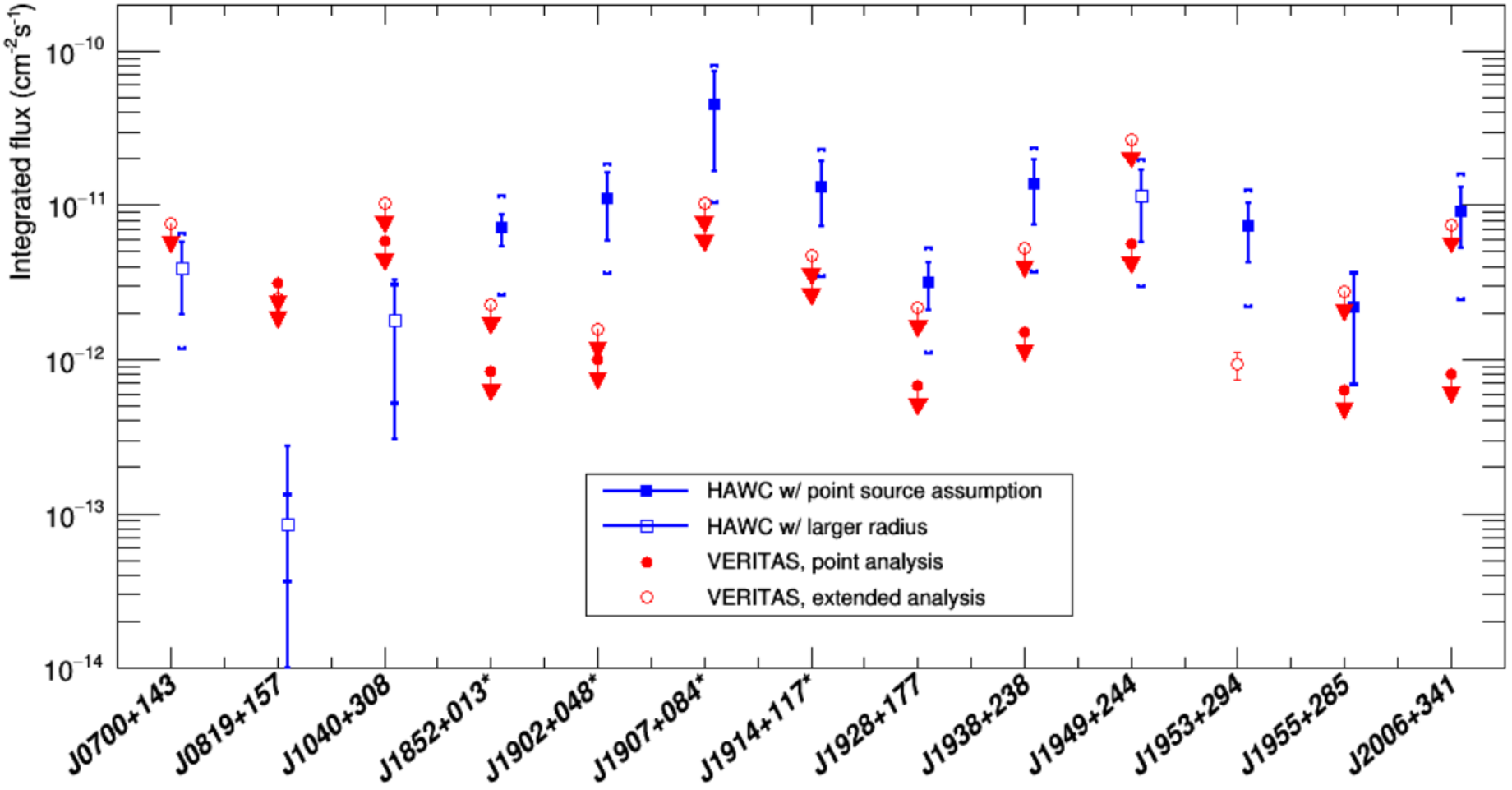
- ~1 degree away from nearby HAWC source, 2HWC J1953+294
- 2 σ away from LAT pulsar, PSR J1954+2836
- Within faint radio SNR G65.1+0.6
- No detection by VERITAS w/ point & extended source search





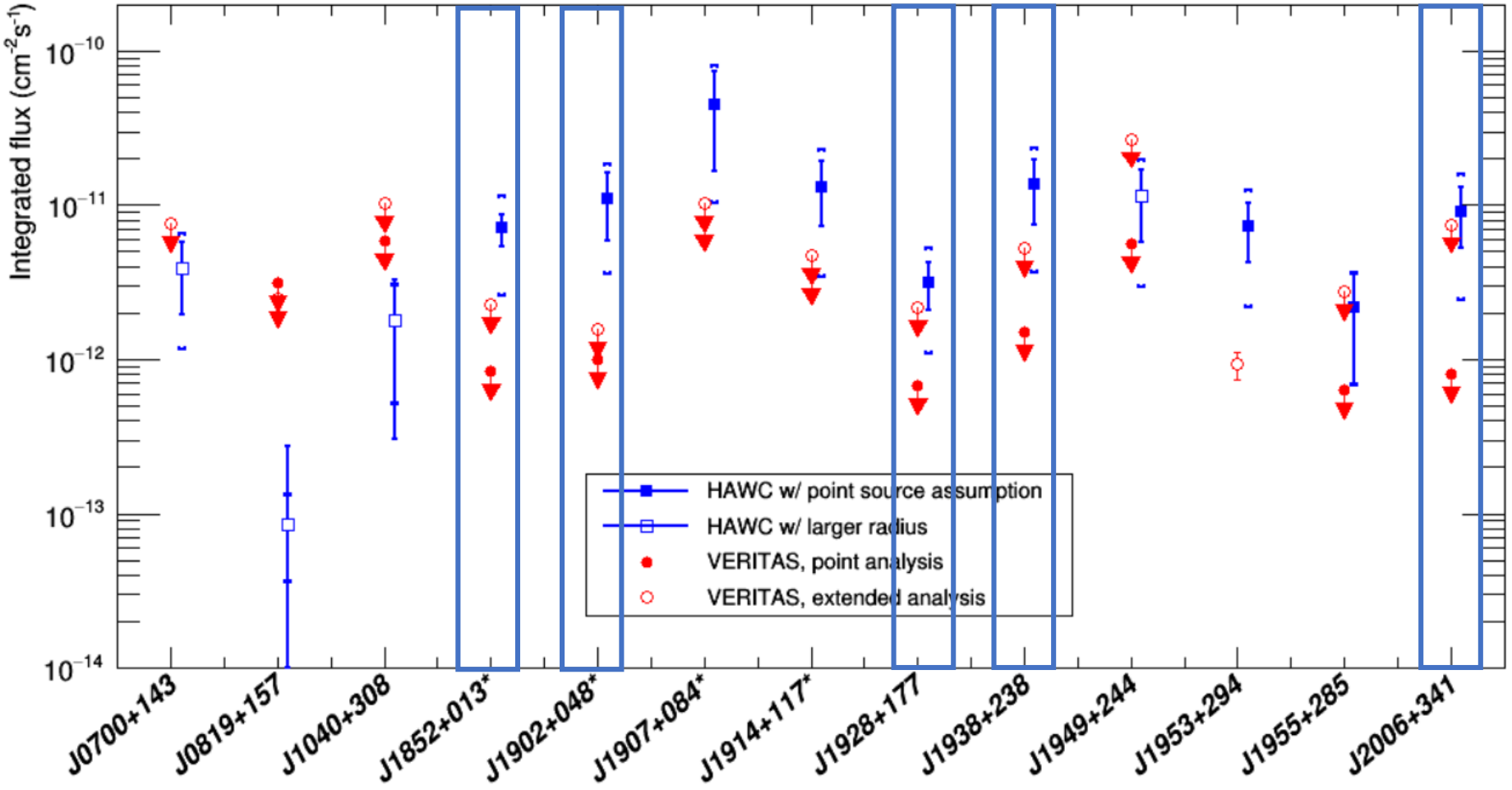
Comparison between VERITAS & HAWC

VERITAS : 99% C.L. Upper limits for non-detection



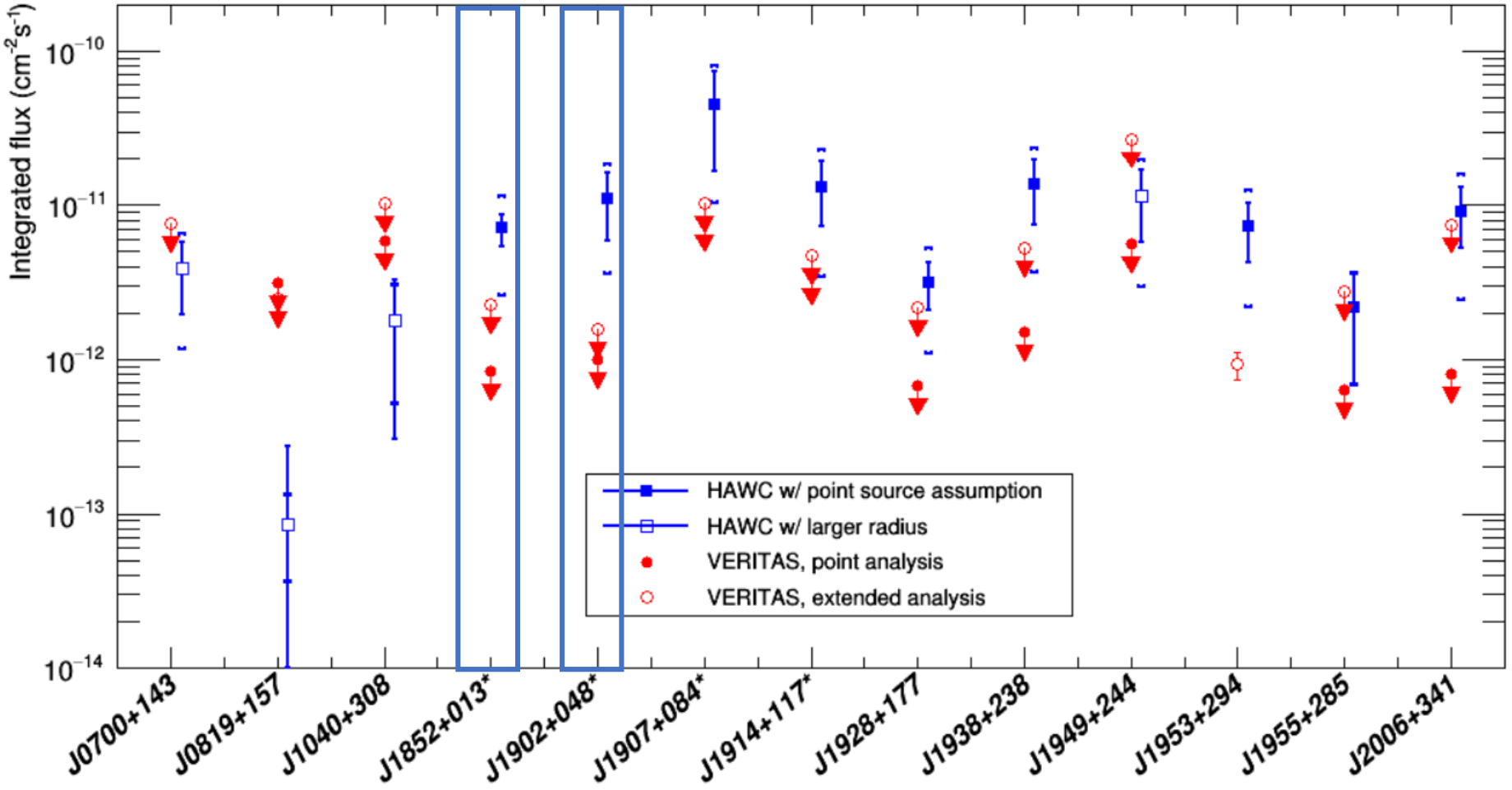
Comparison between VERITAS & HAWC

VERITAS exclude a point source hypothesis for 5 sources w/ 95% C.L.



Comparison between VERITAS & HAWC

VERITAS exclude an extended source hypothesis (w/ radius of 0.23 degree) for 2 sources



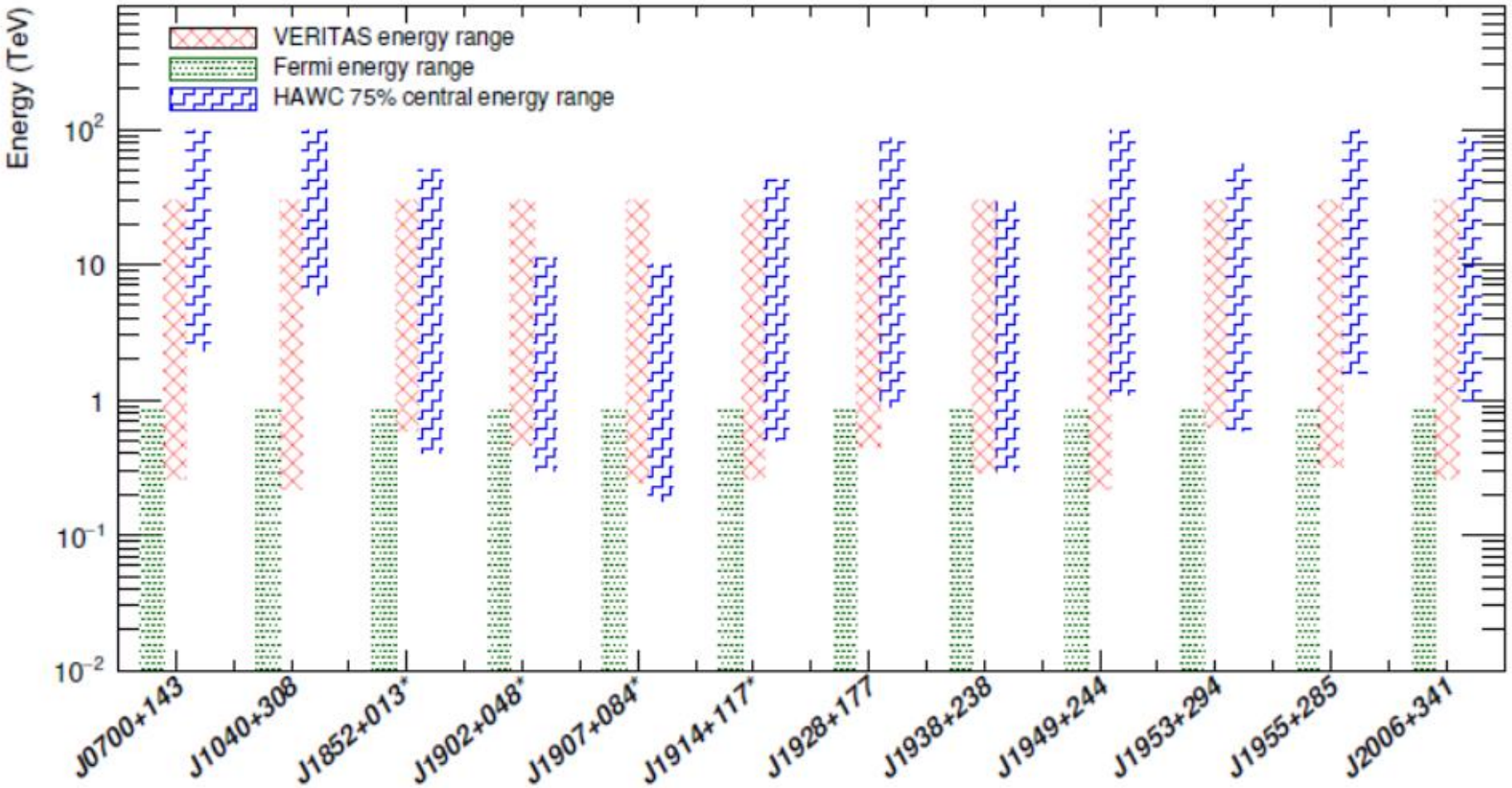
Summary

VERITAS & Fermi-LAT follow-up study on 13 out of 16 HAWC unassociated sources.

- VERITAS detection on DA 495
- Fermi-LAT detection on SNR G54.1+0.3
  - Fermi-VERITAS-HAWC spectrum is better describe with PL+cut-off
- Non-detection of the VERITAS & Fermi-LAT still provide interesting data to study the source
  - There is no obvious systematic difference between IACT & HAWC flux measurements for known, isolated sources
  - For five sources, our upper limits provide lower limit for the source extension with 95% confidence level
- Caveats
  - HAWC analysis for the catalog analysis is a simple, single source likelihood analysis
    - Possible flux over-estimation due to nearby source or diffuse emission
  - Possible to have a spectral change within HAWC energy range

Backup slides

Energy range comparisons



Flux comparisons for known sources

1. Crab PWN flux comparison
2. Isolated 2HWC sources w/ known TeV counterparts