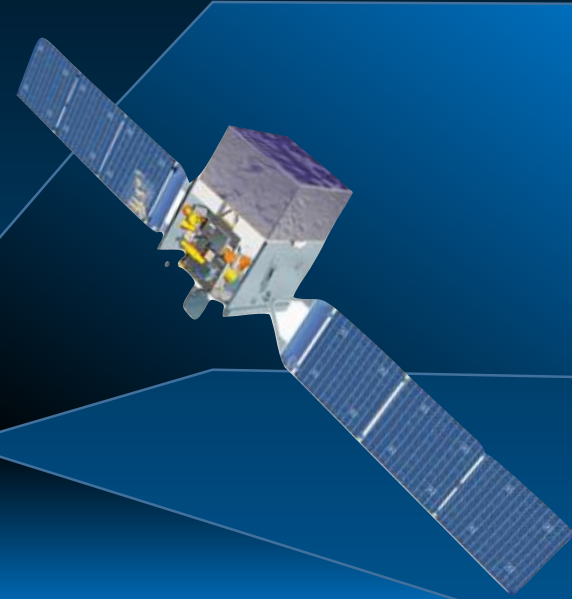


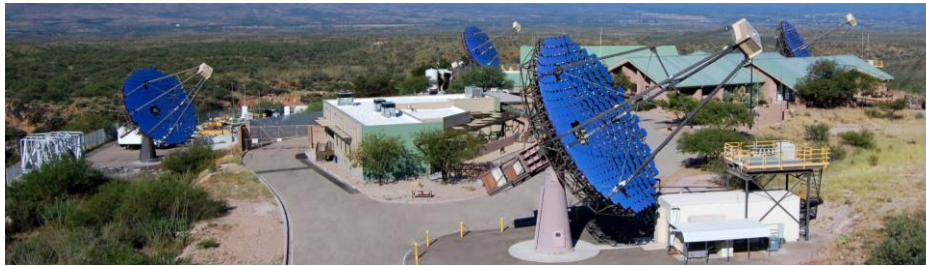
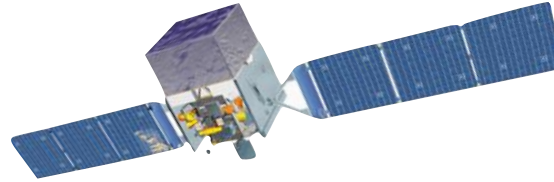
VERITAS and *Fermi*-LAT observations of TeV gamma-ray sources from the 2HWC catalog



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



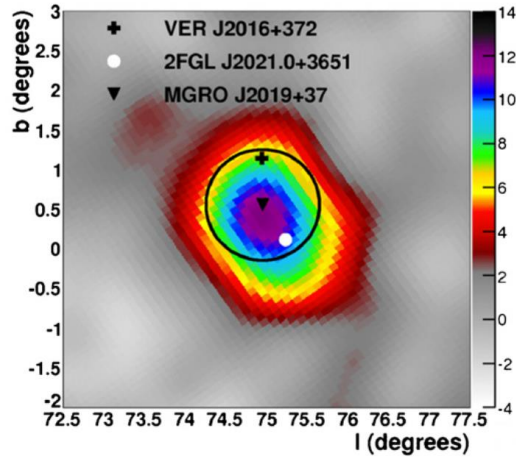
| | GeV satellite (e.g. Fermi-LAT) | IACT (e.g. VERITAS) | Air shower array (e.g. HAWC) |
|--|--------------------------------|----------------------|------------------------------|
| Energy range | Few 10s of MeV- 500 GeV | 85 GeV - > 30 TeV | 100 GeV - 100 TeV |
| Type | Survey | Pointing (<5 degree)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

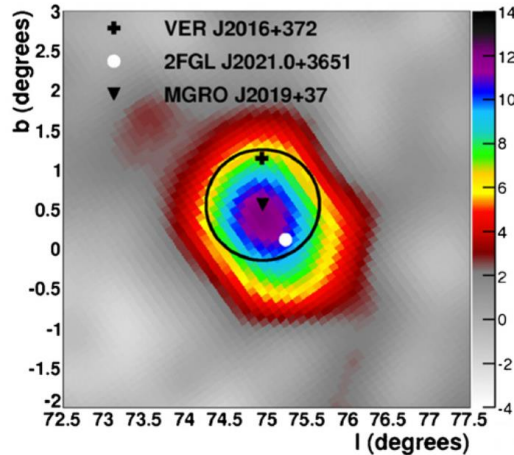


Coverage of gamma-ray observations

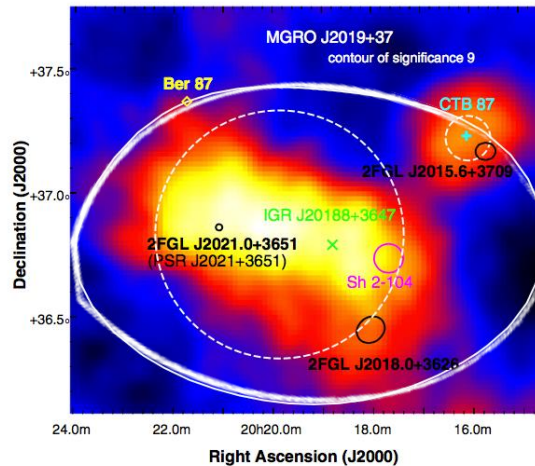
The most powerful approach is combining all of data

- e.g. MGRO J2019+37

Detection by Milagro (Abdo2007b)



Followup by VERITAS (Aliu 2014)

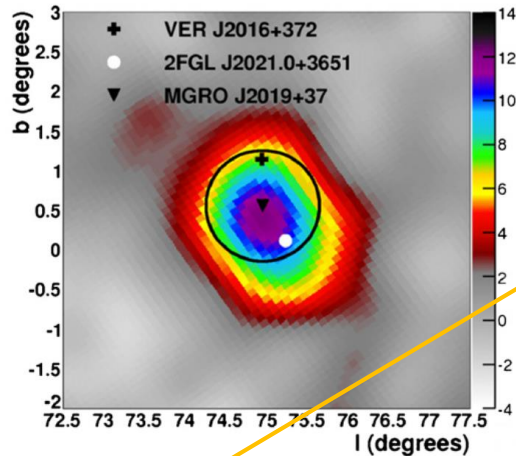


Coverage of gamma-ray observations

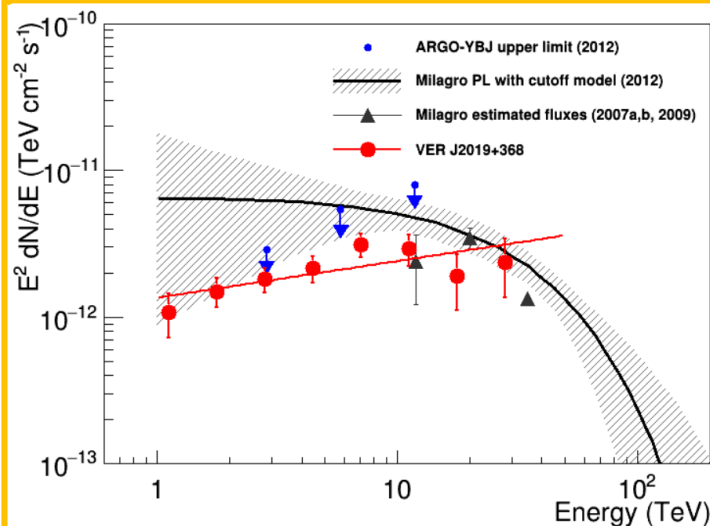
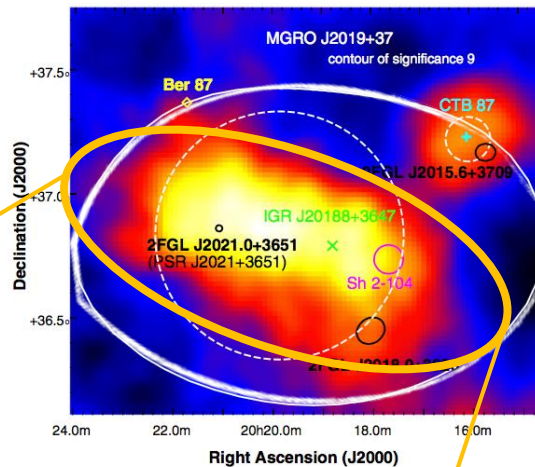
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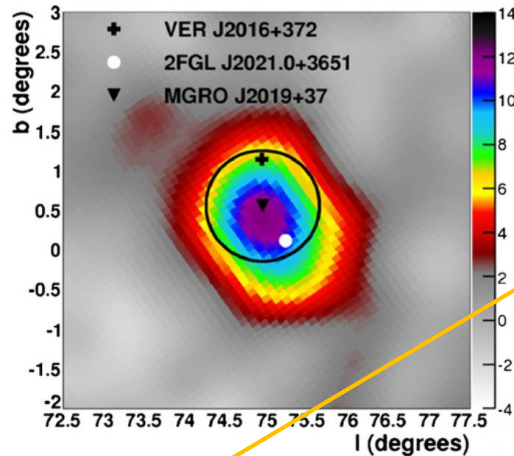


Coverage of gamma-ray observations

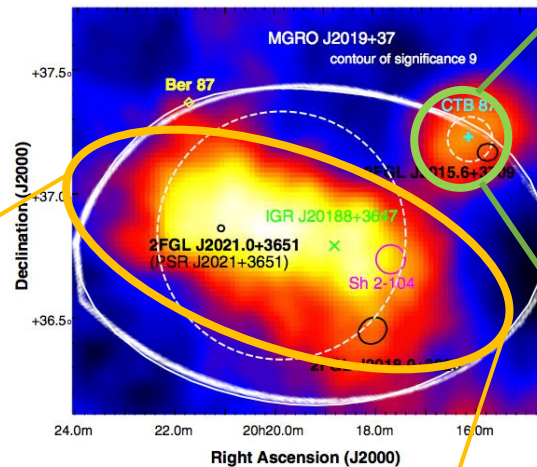
The most powerful approach is combining all of data

- e.g. MGRO J2019+37

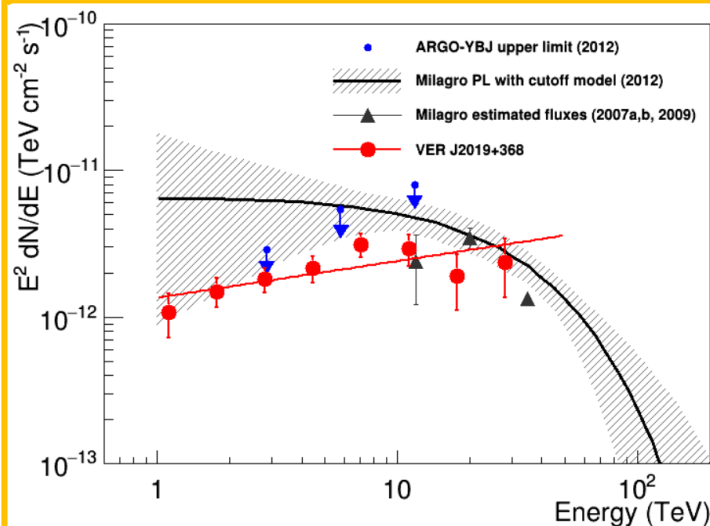
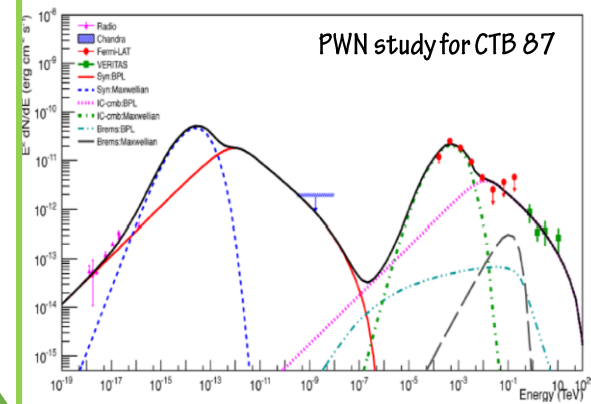
Detection by Milagro (Abdo2007b)



Followup by VERITAS (Aliu 2014)



Followup w/ Fermi-LAT (Saha2016)

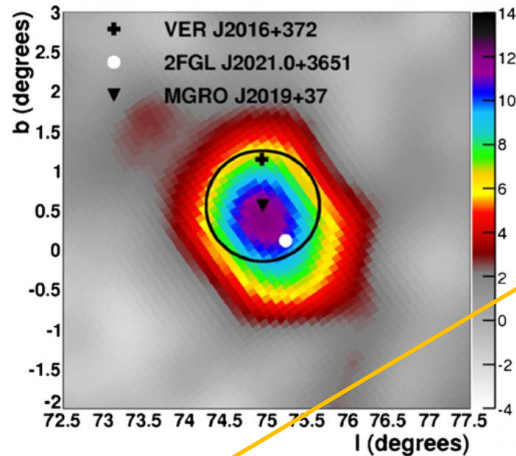


Coverage of gamma-ray observations

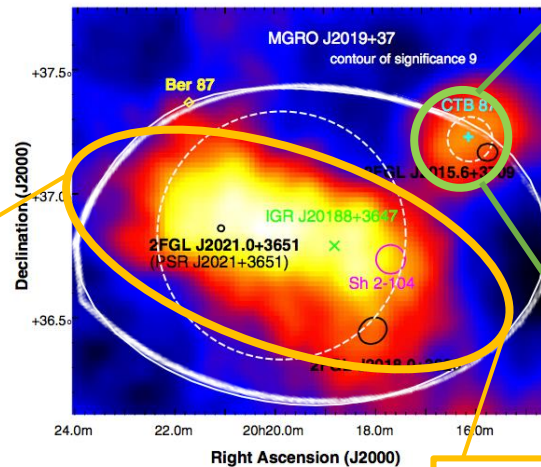
The most powerful approach is combining all of data

- e.g. MGRO J2019+37

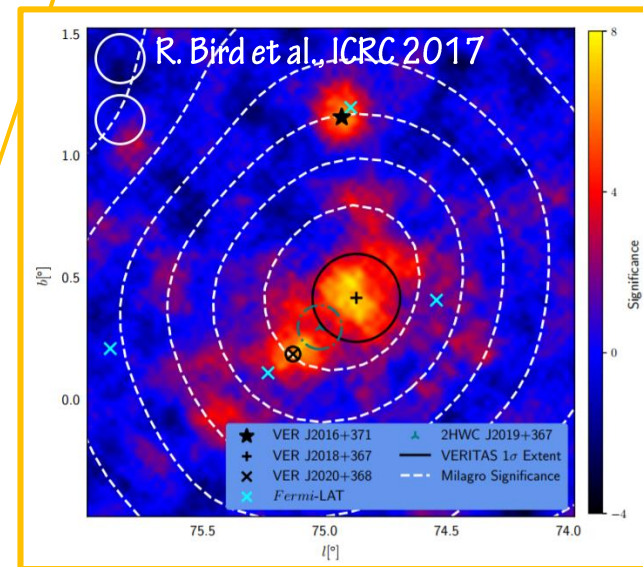
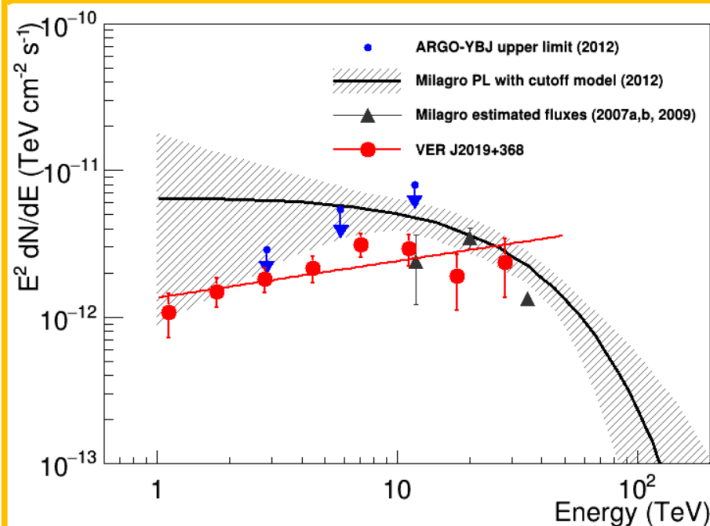
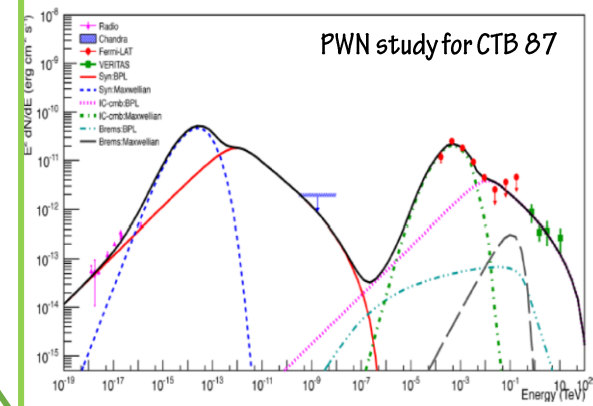
Detection by Milagro (Abdo2007b)



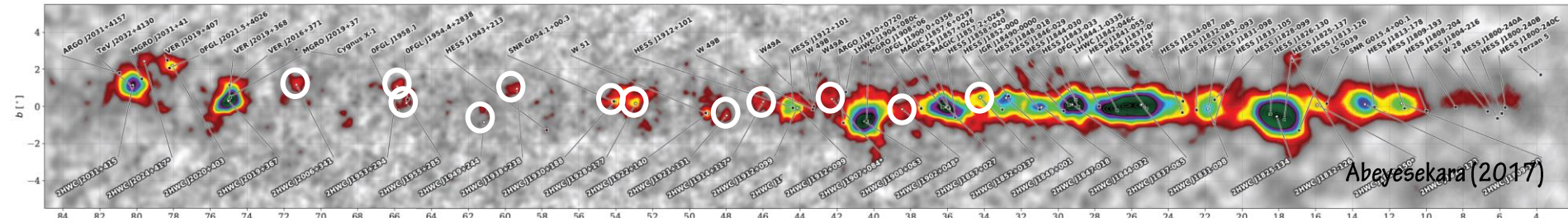
Followup by VERITAS (Aliu 2014)



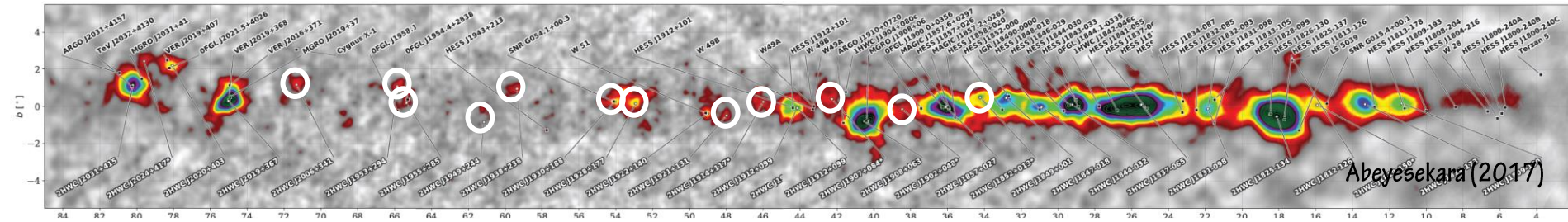
Followup w/ Fermi-LAT (Saha2016)



HAWC Second Catalog



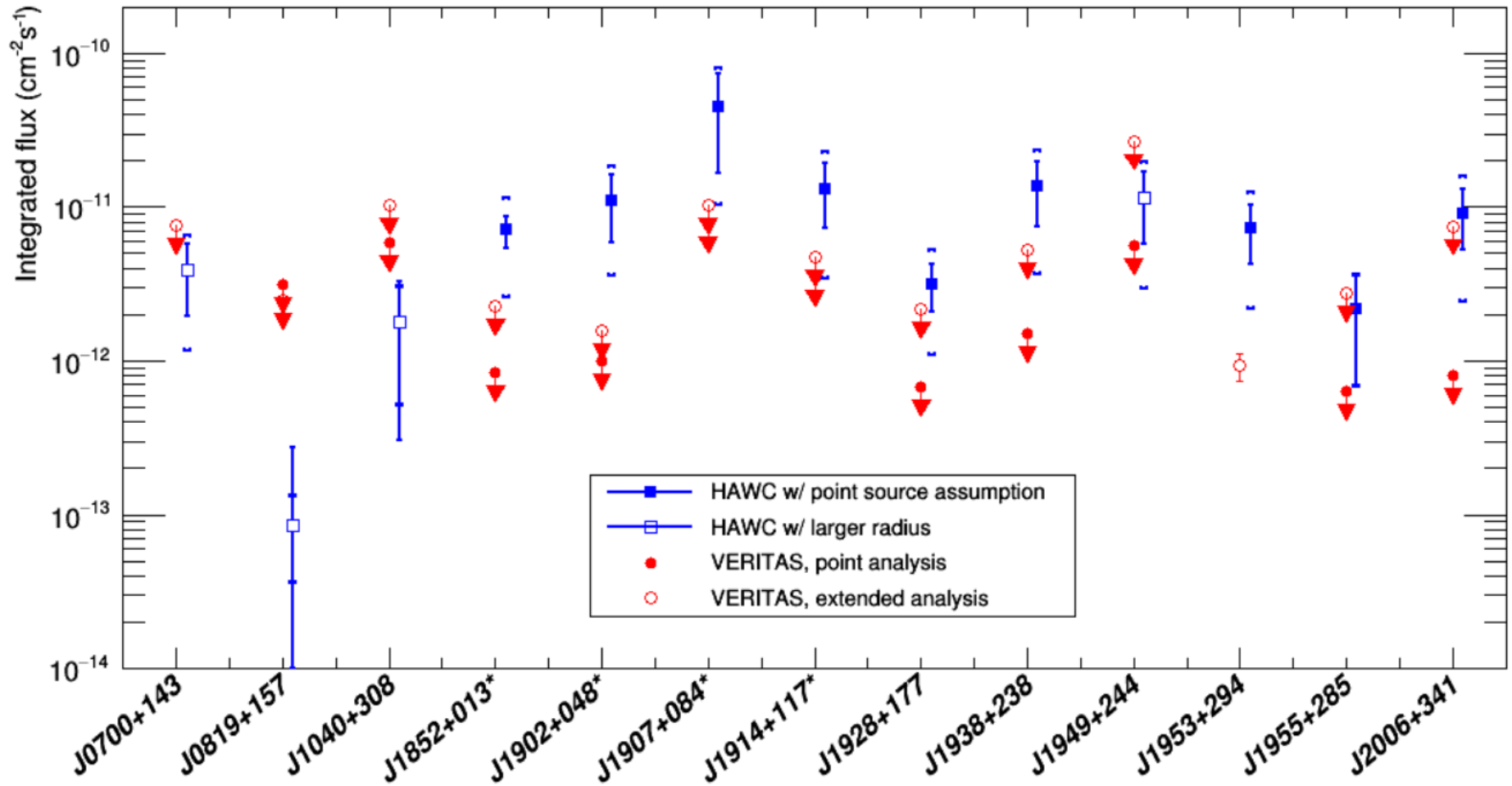
HAWC Second Catalog



- 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 ($E > 10 \text{ GeV}$)
 - Non-detection for 13 sources
 - Detection of a known TeV source, SNR G54.1+0.3

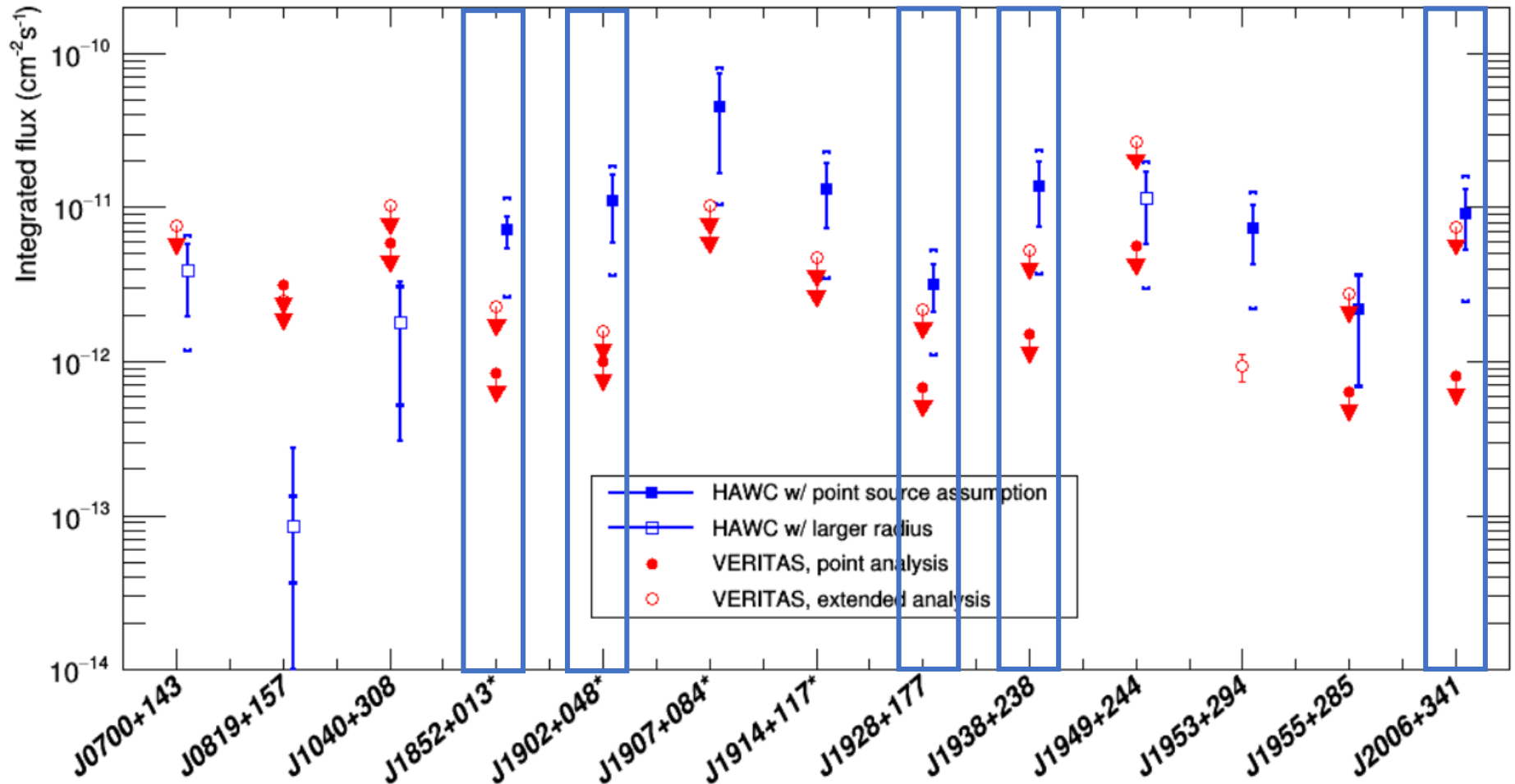
Comparison between VERITAS & HAWC

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



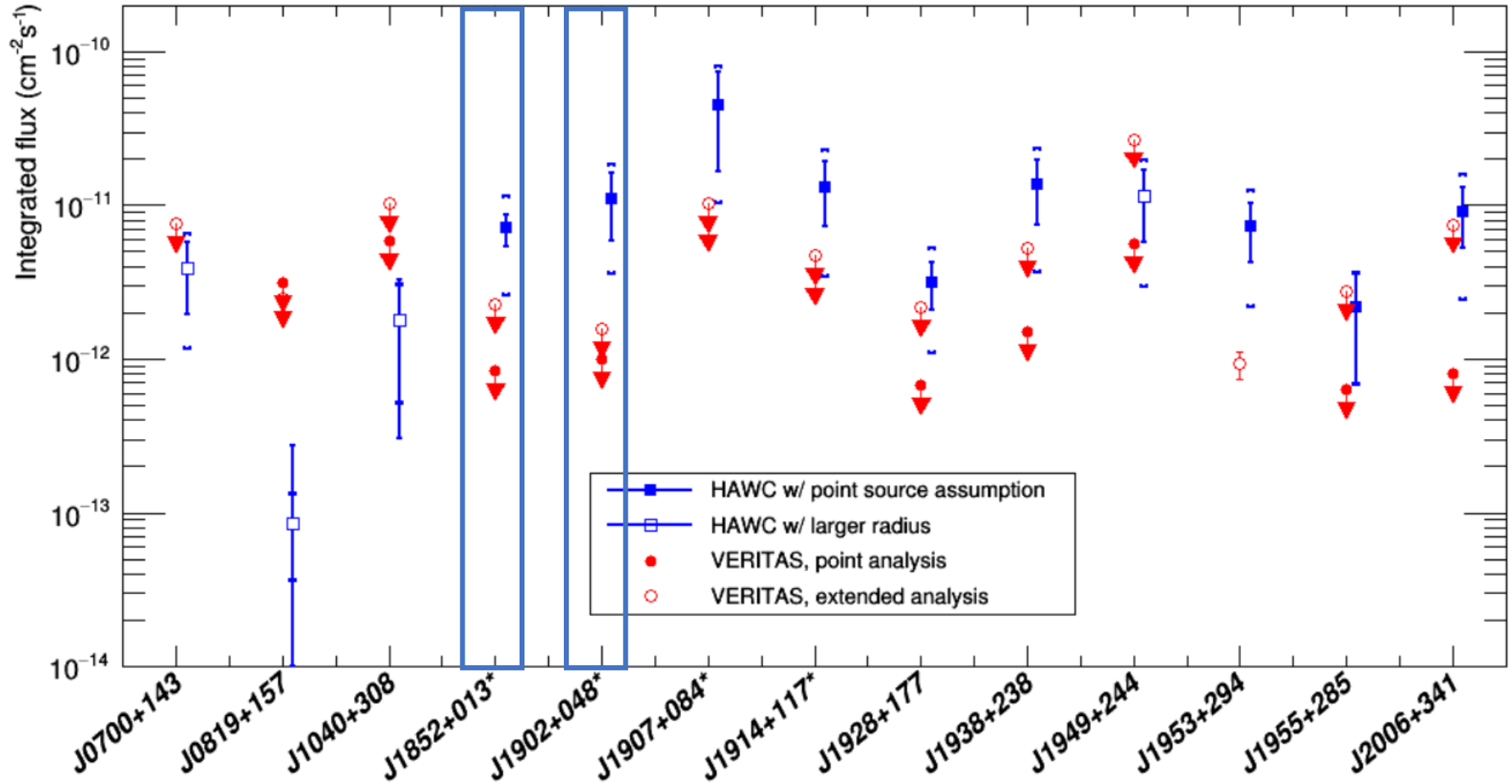
Comparison between VERITAS & HAWC

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



Comparison between VERITAS & HAWC

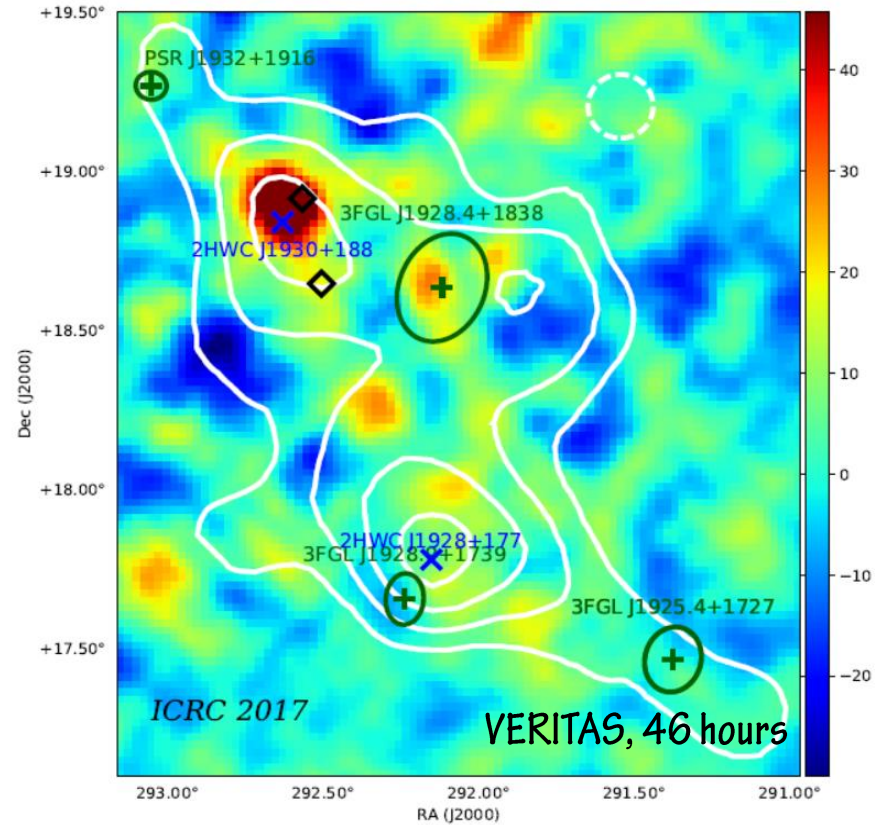
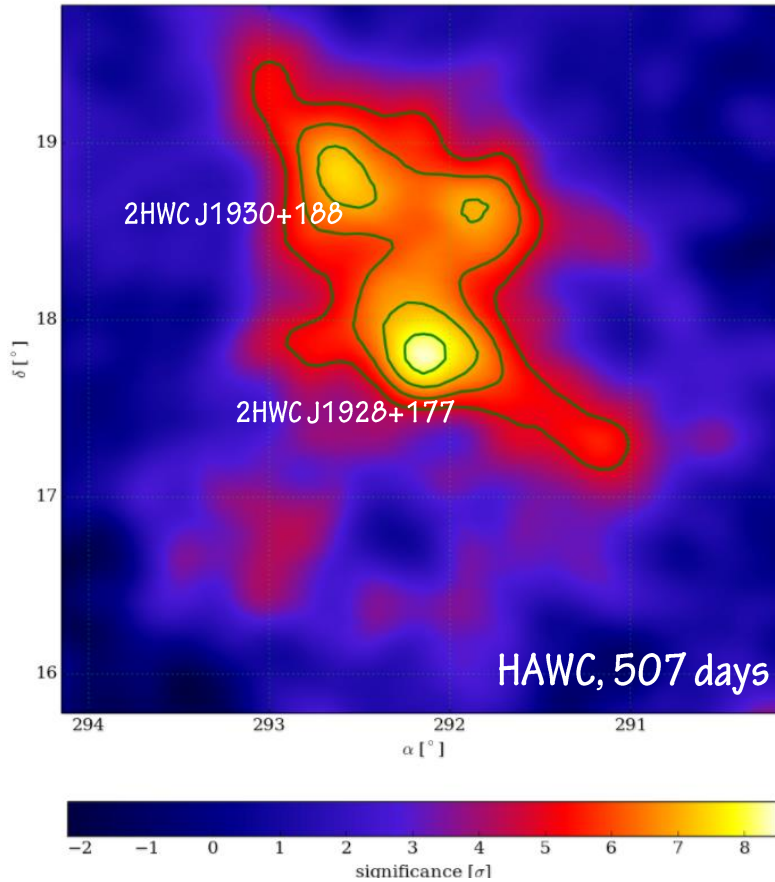
VERITAS exclude an extended source hypothesis (w/ radius of 0.23 degree) for 2 sources



SNR G54.1+0.3 region

Two 2HWC sources

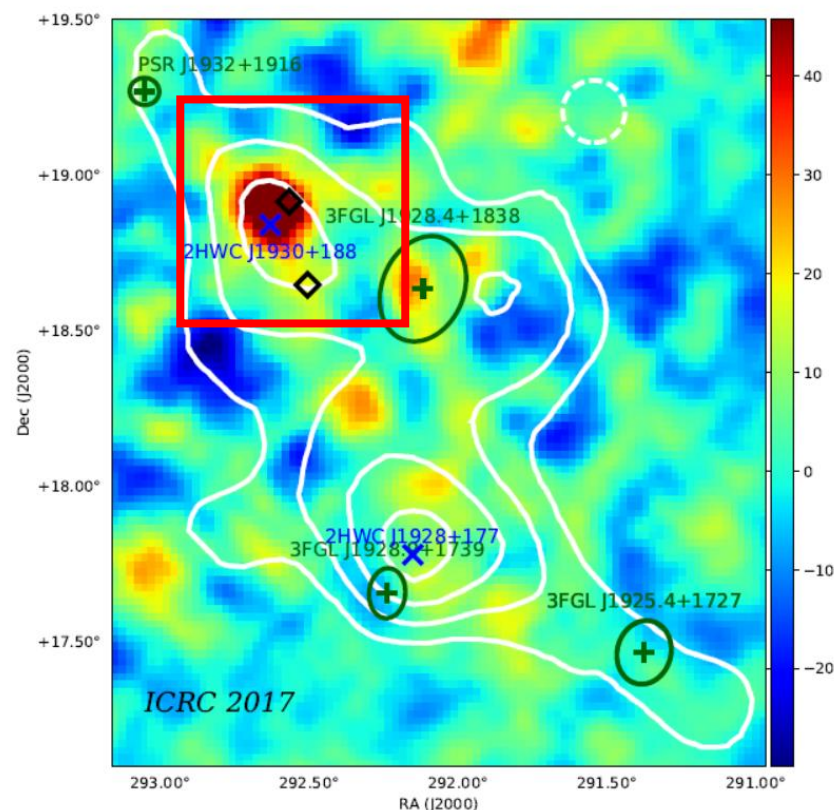
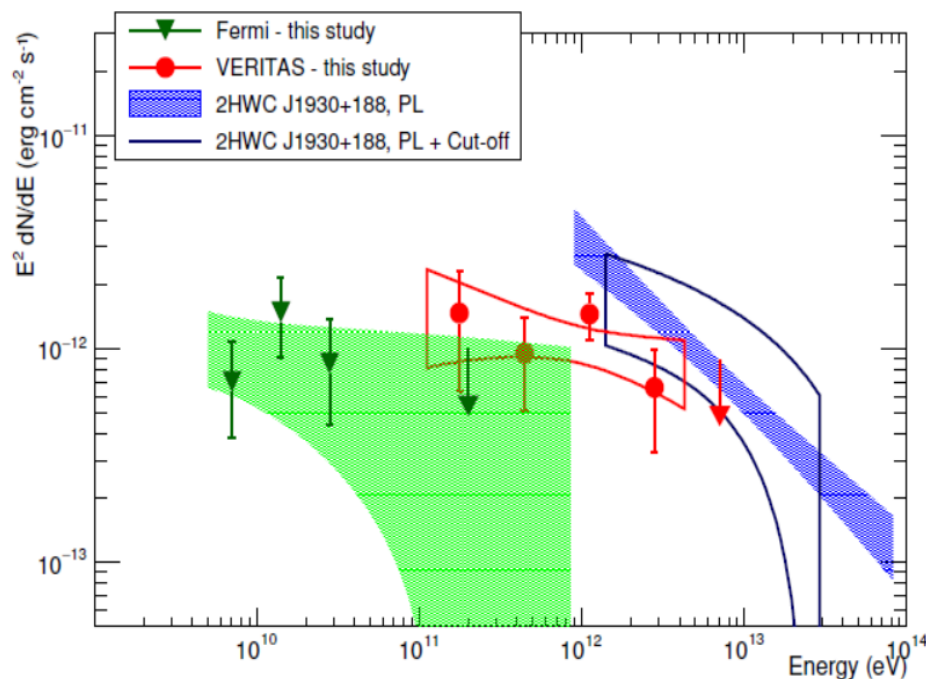
– 2HWC J1930+188 & 2HWC J1928+177



SNR G54.1+0.3 region (2)

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

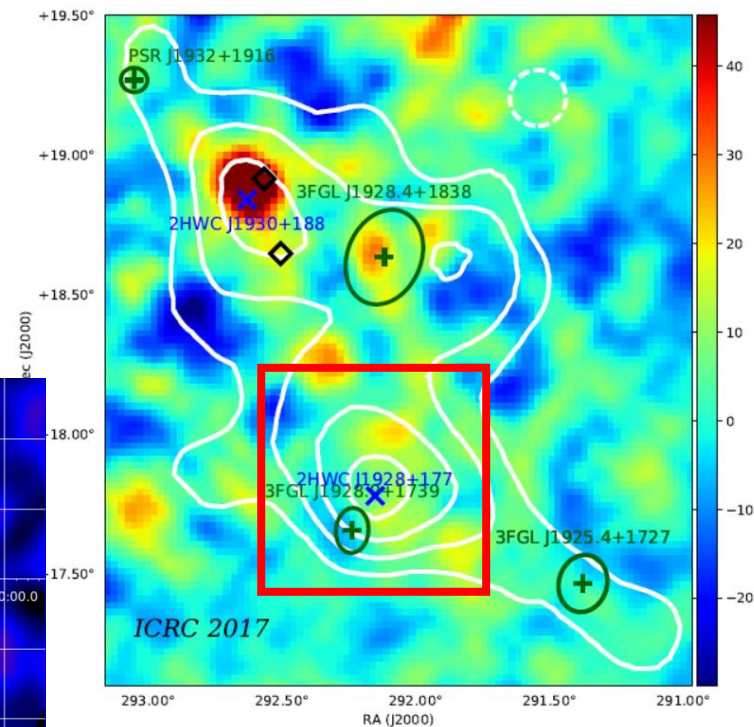
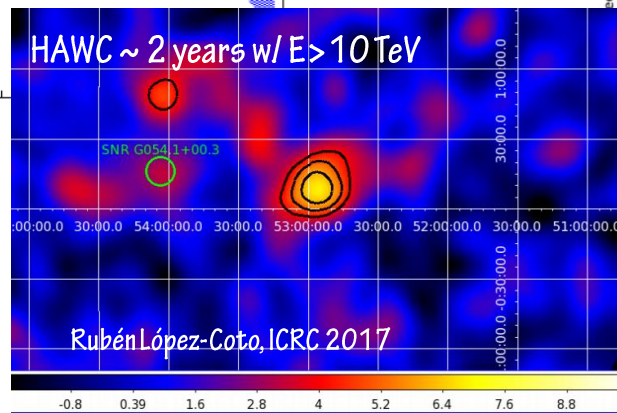
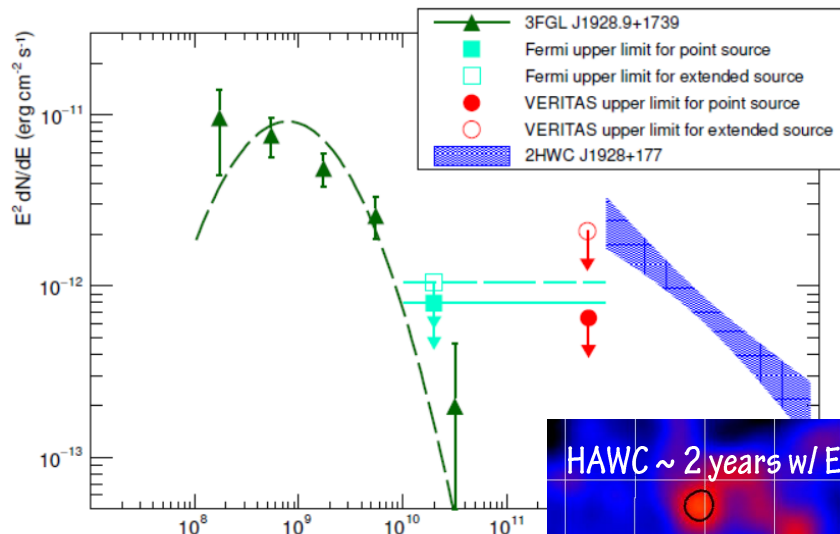
- SNR G54.1+0.3 is likely the counterpart
- Fermi, VERITAS & HAWC combined, the overall SED is more consistent with PL + cut-off hypothesis



SNR G54.1+0.3 region (3)

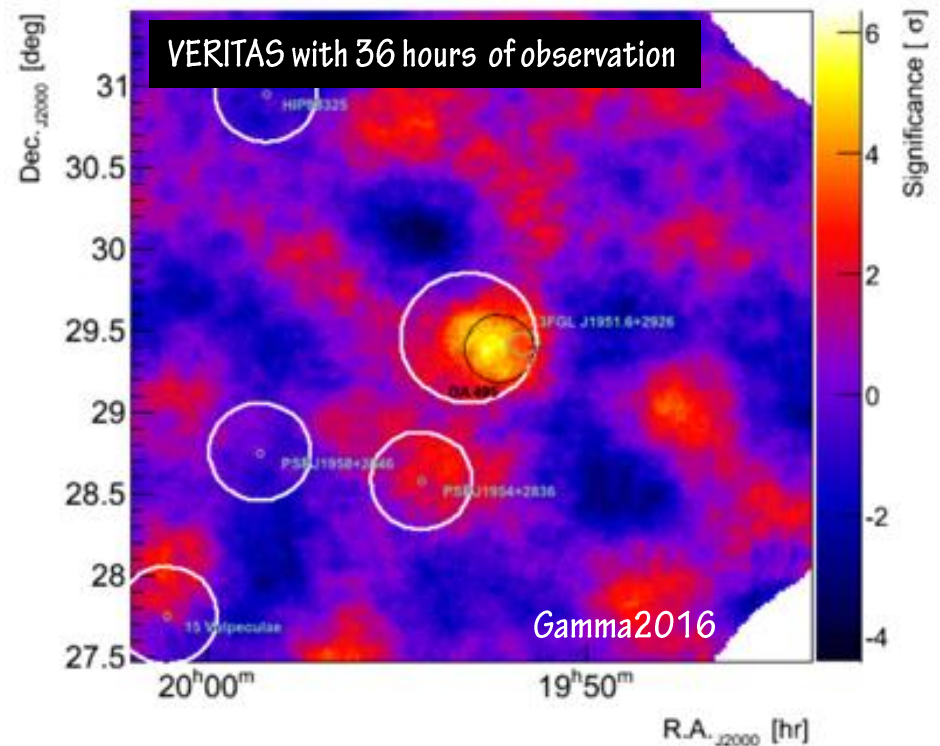
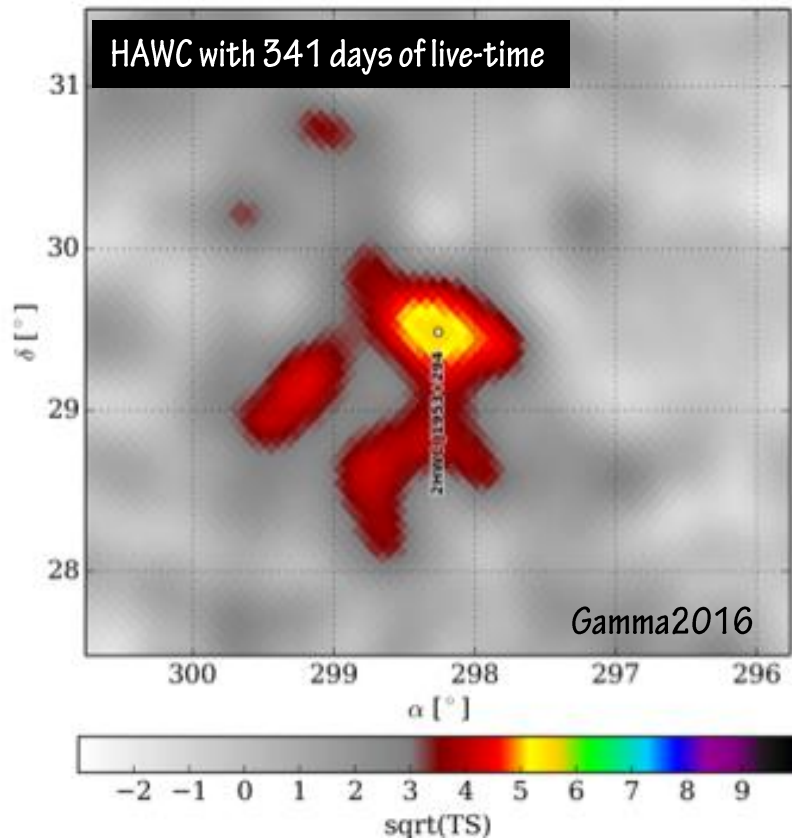
2HWC J1928+177

- 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

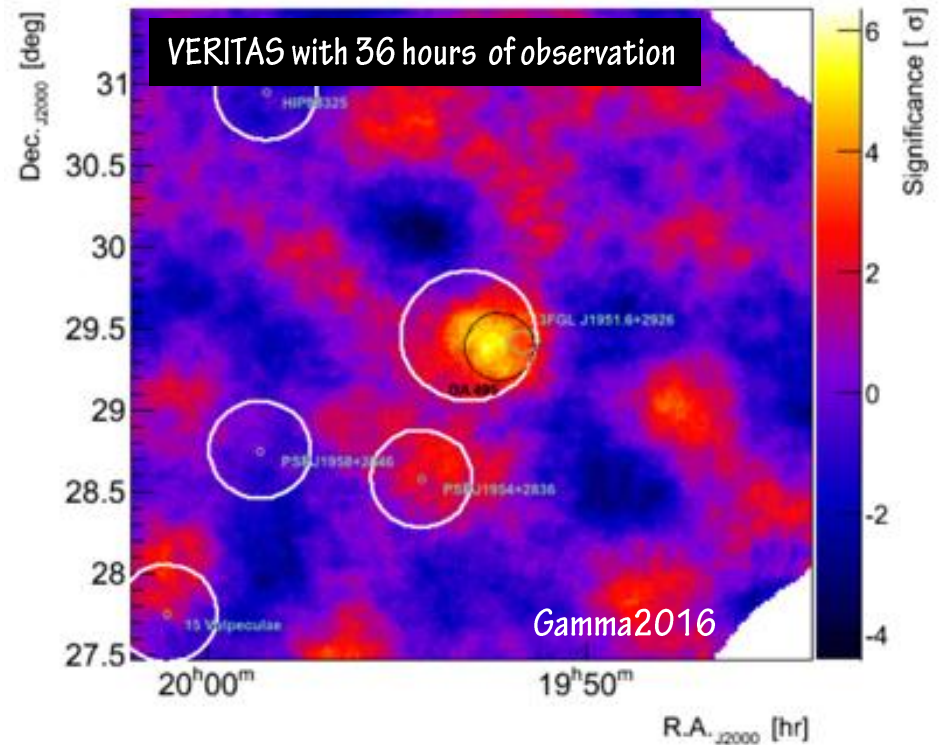
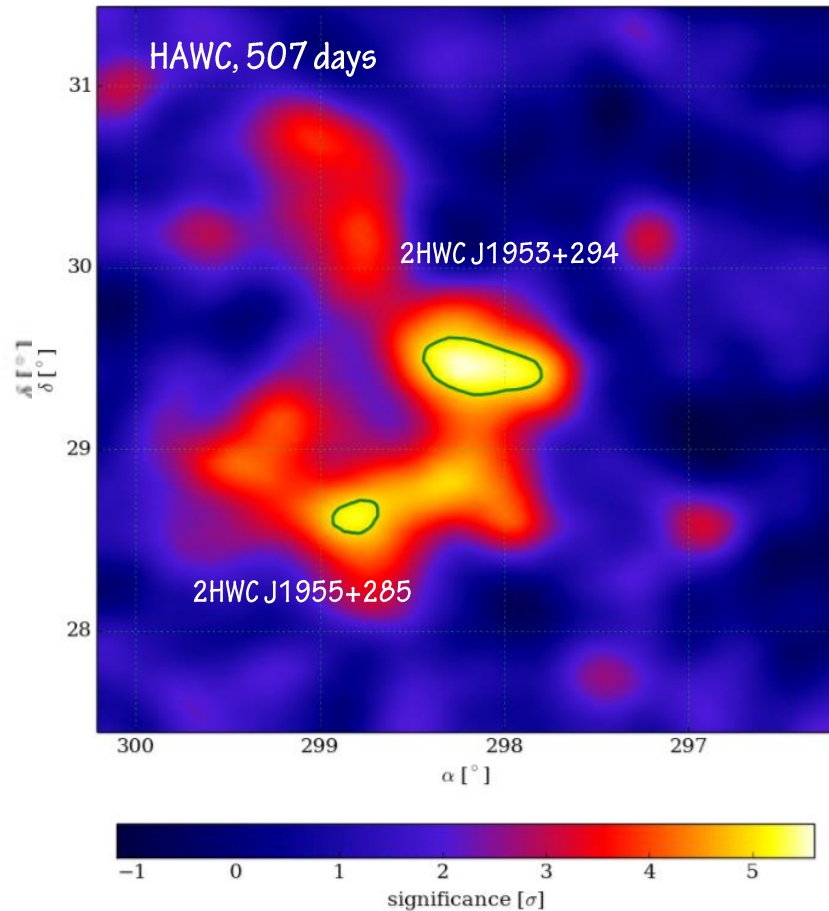
VERITAS confirmed gamma-ray emission
from 2HWC J1953+294 at 2016 Heidelberg meeting



DA 495 region

Two 2HWC sources

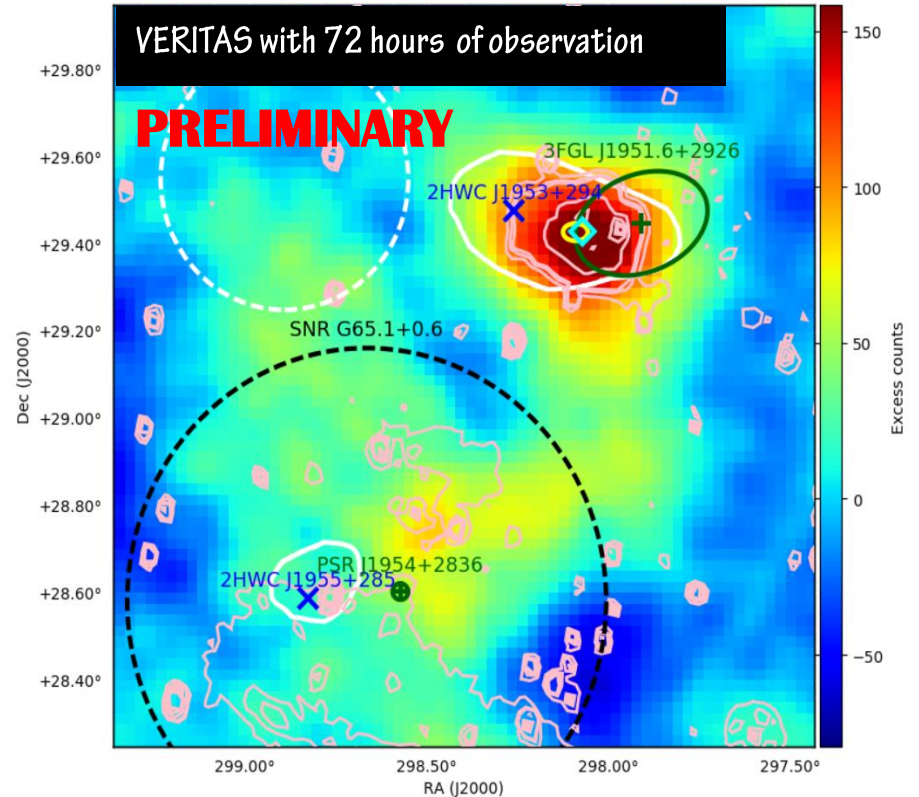
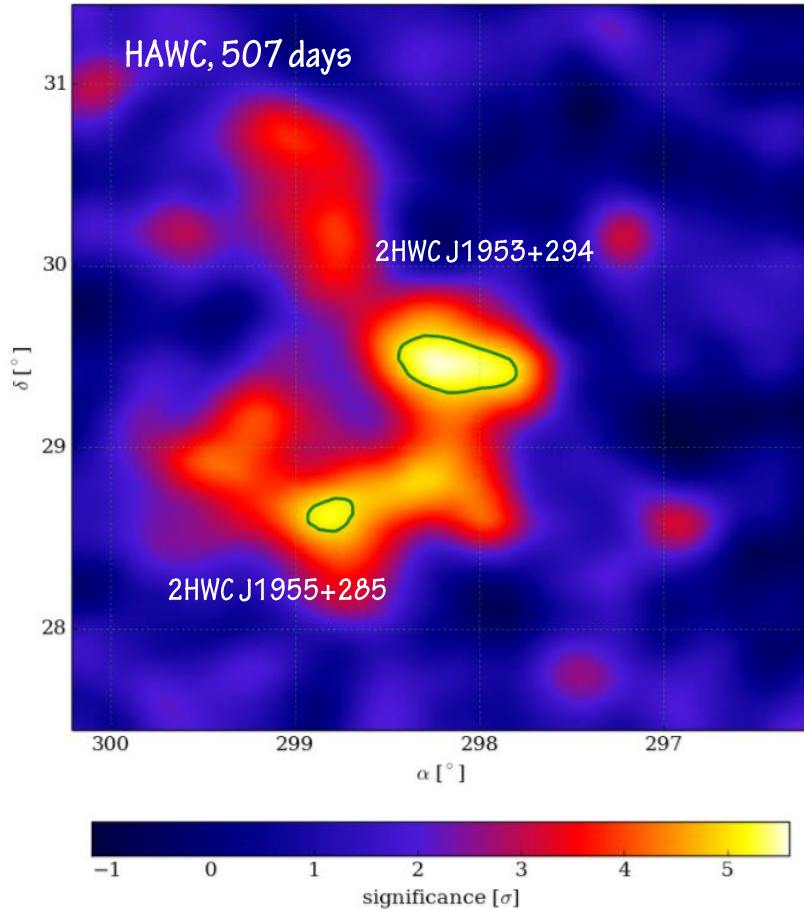
- 2HWC J1953+294 & 2HWC J1955+285



DA 495 region

Two 2HWC sources

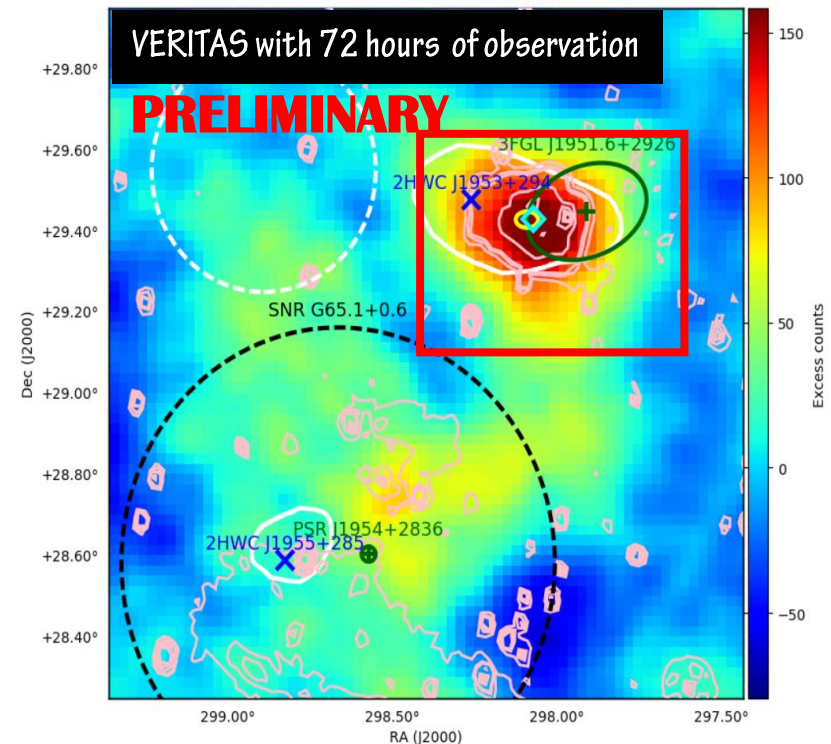
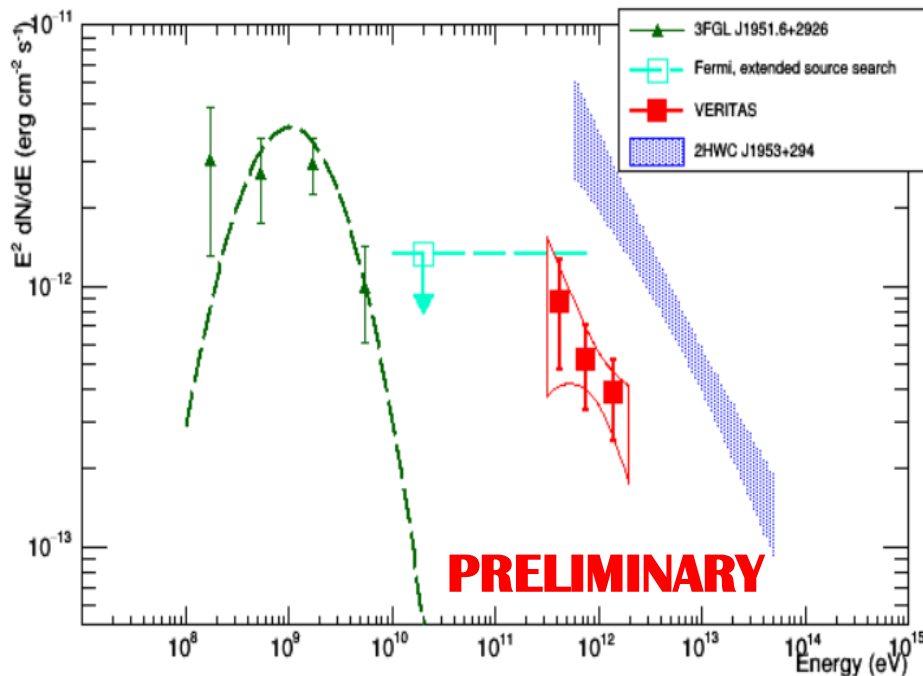
– 2HWC J1953+294 & 2HWC J1955+285



DA 495 region (2)

2HWC J1953+294

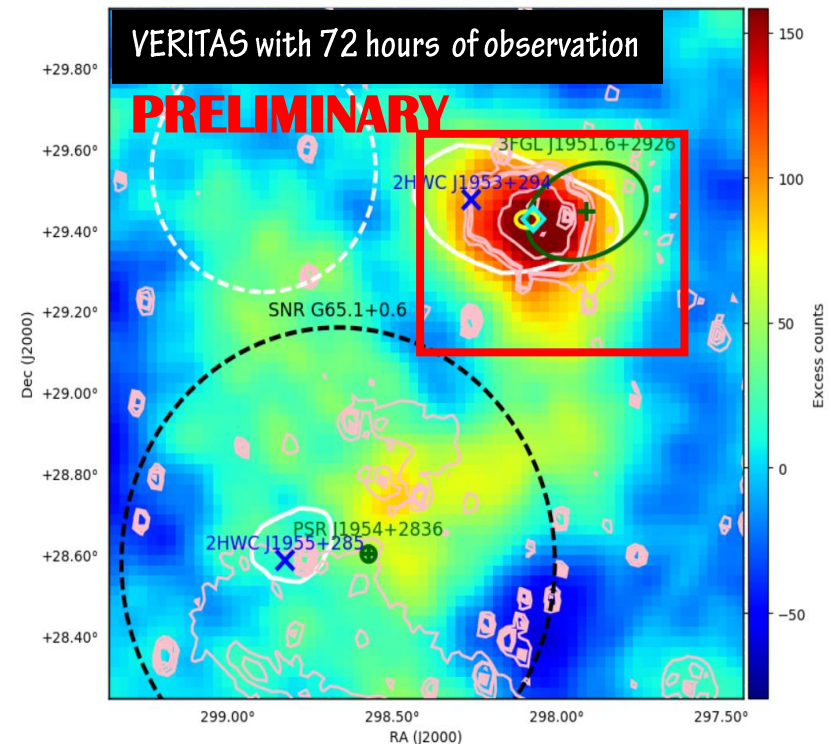
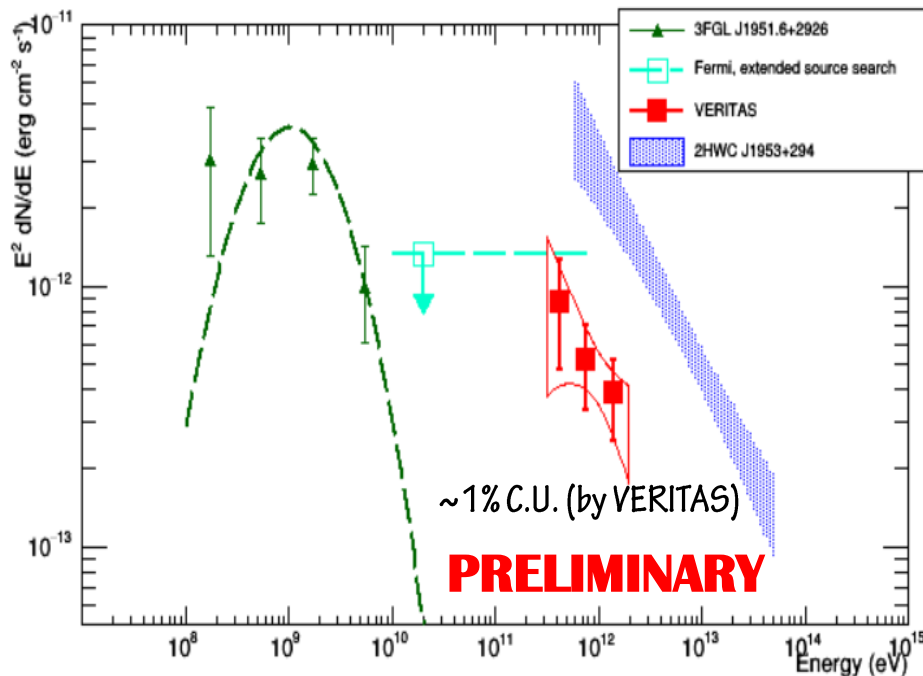
- VERITAS detection, VER J1952+294
- Likely counterpart is PWN DA 495
 - X-ray : A compact central object surrounded by non-thermal diffuse emission (no pulsation detected)
 - GeV gamma-ray : 3FGL source (no pulsation detected)



DA 495 region (2)

2HWC J1953+294

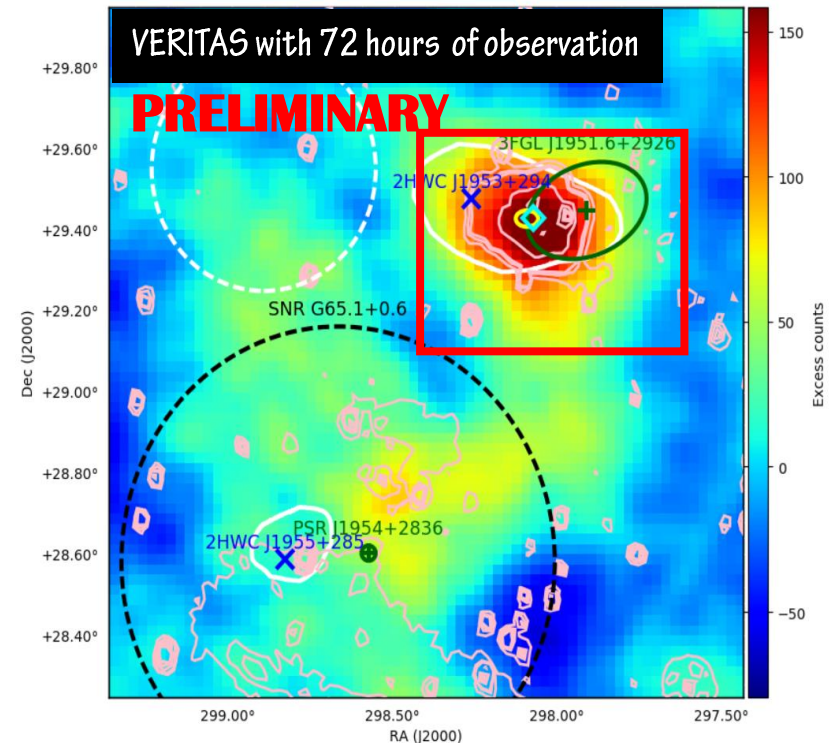
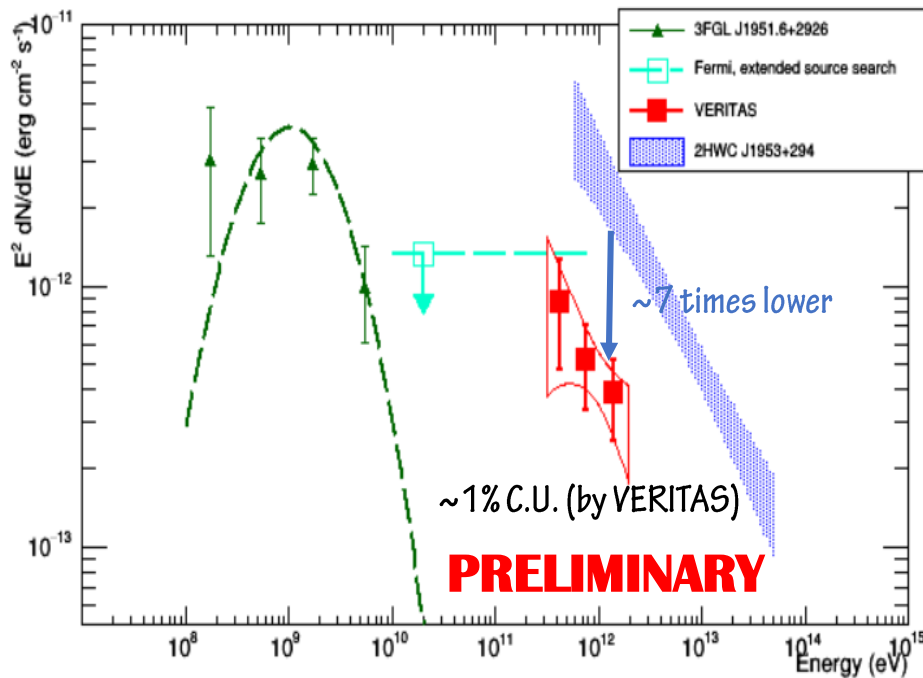
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DA 495 region (2)

2HWC J1953+294

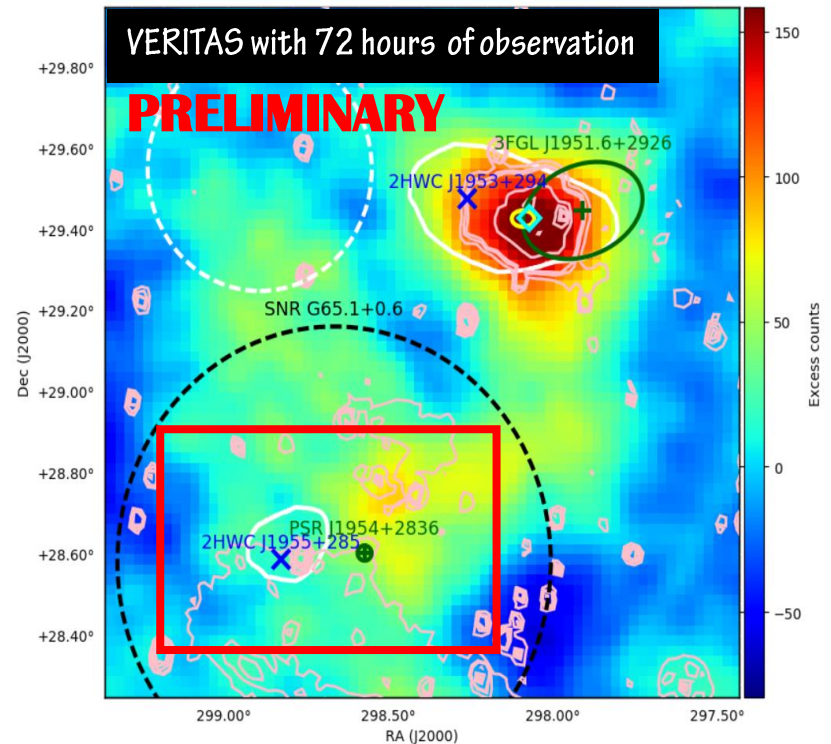
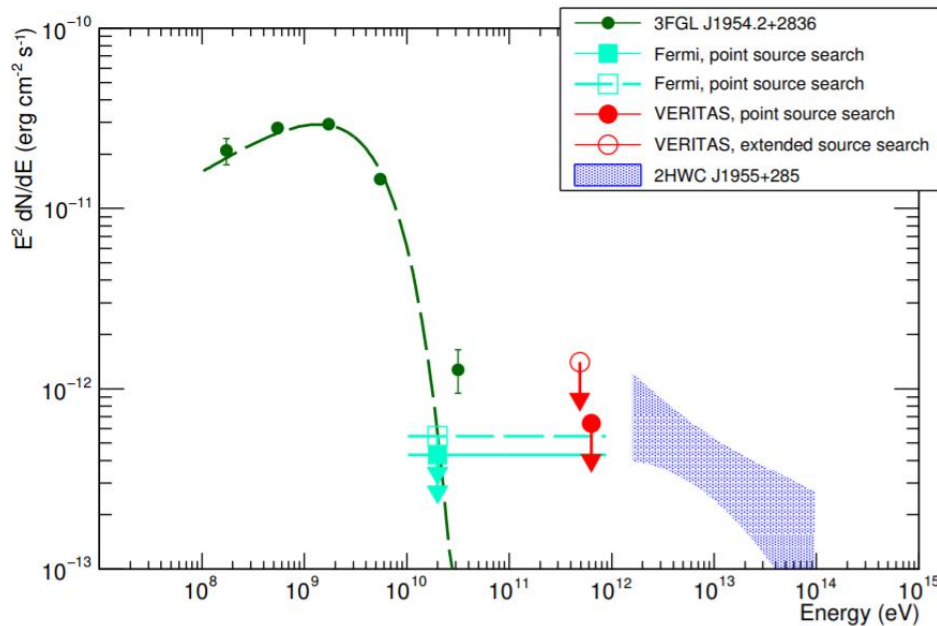
- VERITAS detection, VER J1952+294
- Likely counterpart is PWN DA 495
 - X-ray : A compact central object surrounded by non-thermal diffuse emission (no pulsation detected)
 - GeV gamma-ray : 3FGL source (no pulsation detected)



DA 495 region (3)

2HWC J1955+285

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



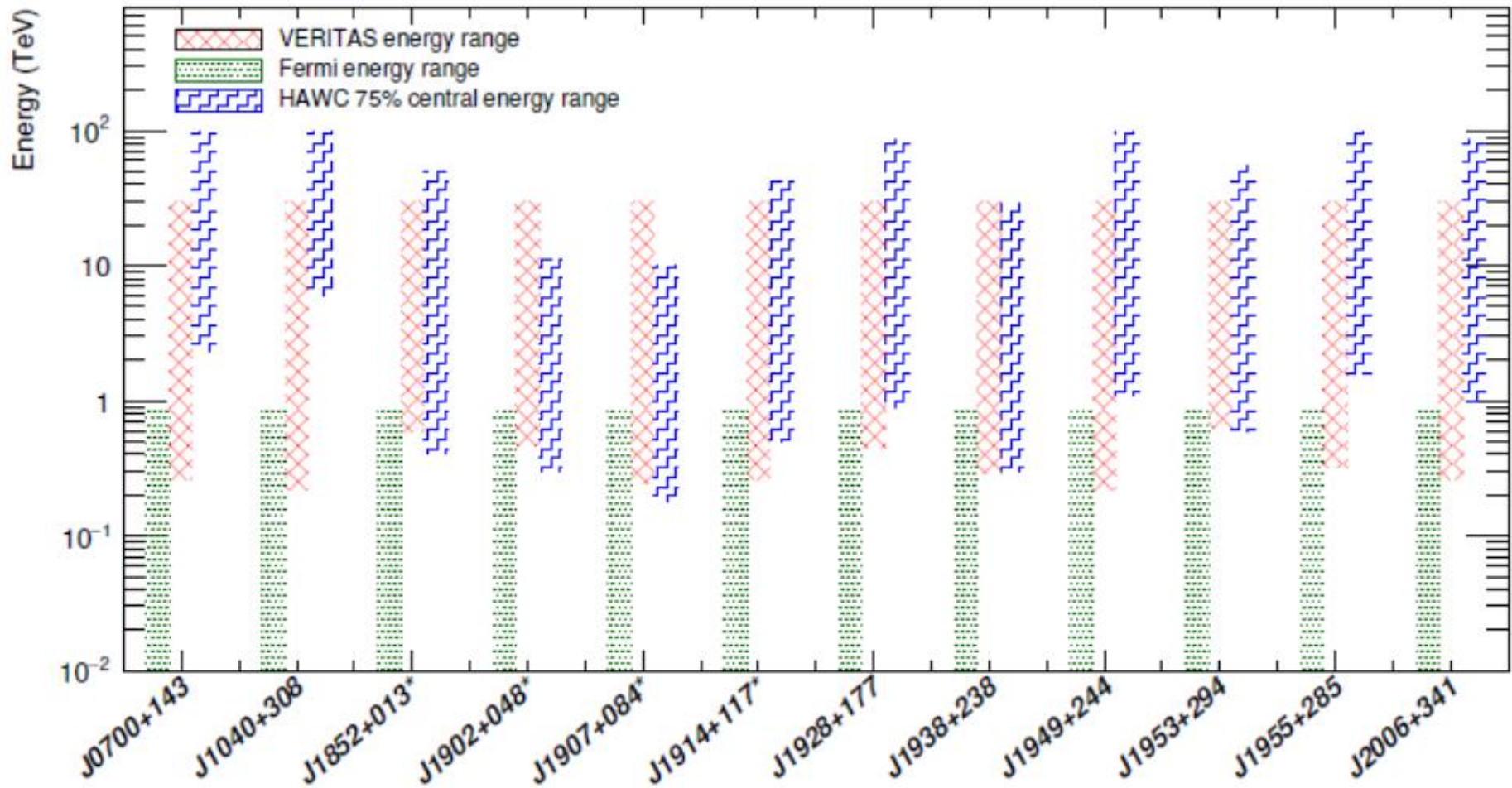
Summary

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

