Dark Matter Subhalo Observations with VERITAS

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What makes a good DM source?

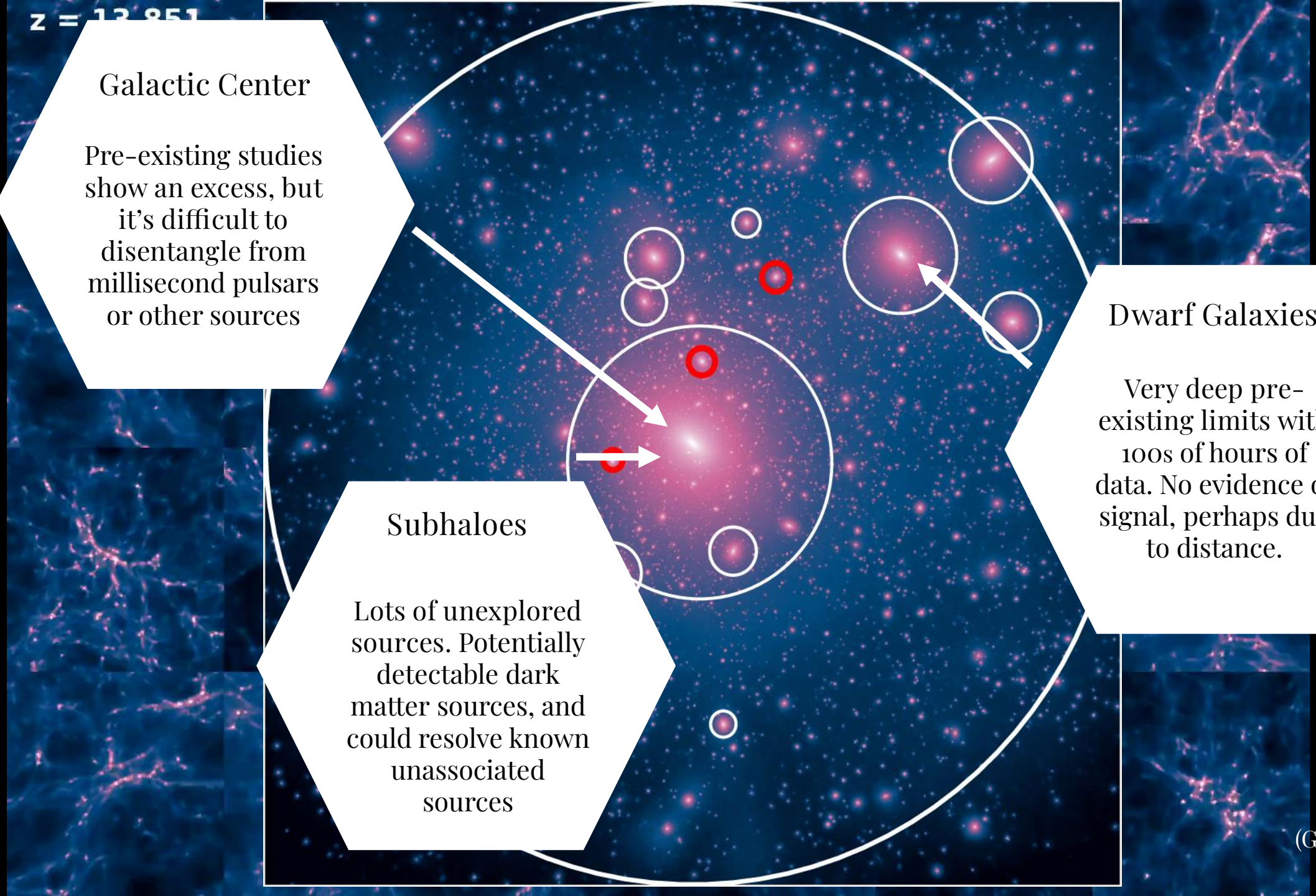
Estimated flux on Earth

Particle physics model parameter. ***This is model dependent and fixed*** *for a given limit.*

$$\textbf{Flux}(\chi\chi \rightarrow ?) = \frac{< \sigma v >}{2m_\chi^2} J_{factor} N_\gamma$$

The ***thermally averaged cross-section.*** This will determine the flux of a given source, but it's treated as the unknown during an indirect search and constrained.

The astrophysical parameter representing the integral of the dark matter along the line of sight. Sources with a high J-factor are more visible for the same DM models. ***This is what we use to select sources.***



Galactic Center

Pre-existing studies show an excess, but it's difficult to disentangle from millisecond pulsars or other sources

Subhaloes

Lots of unexplored sources. Potentially detectable dark matter sources, and could resolve known unassociated sources

Dwarf Galaxies

Very deep pre-existing limits with 100s of hours of data. No evidence of signal, perhaps due to distance.

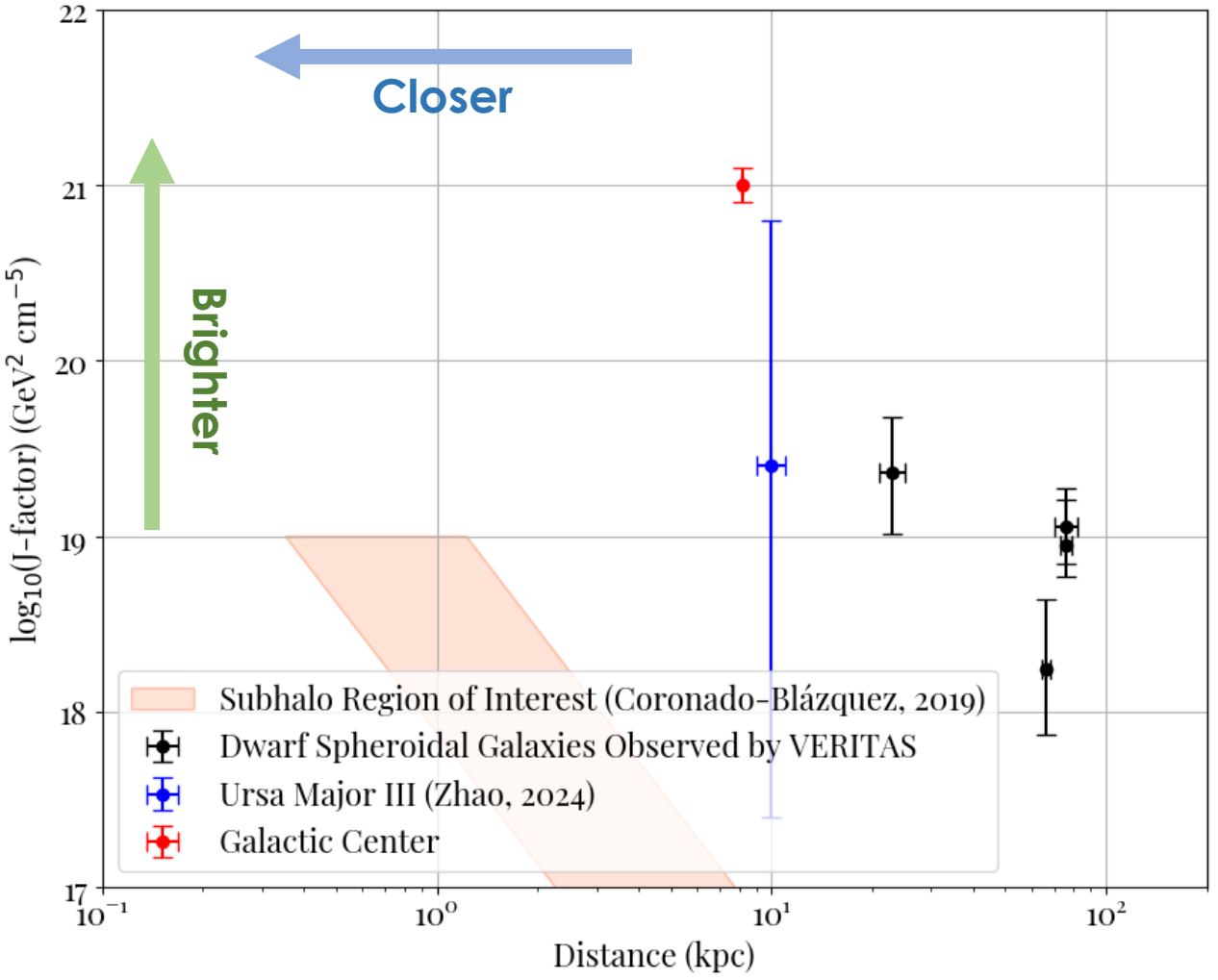
(Griffen,2016)

Are they bright enough?

Even though the subhaloes that we are interested in aren't very massive (~10^5 $M_\odot$) they are **extremely close** (<~2 kpc).

Although the emission is expected to be fainter than the galactic center emission, the level could be comparable to previously observed **dwarf spheroidals**.

Some newer ultrafaint galaxies may prove promising sources in the future, but uncertainties in their J-factors make current predications of their expected flux volatile.



Will they be confused for other sources?

The benefit to looking at subhaloes is that due to their lack of baryonic matter, they have unique spectral and spatial signatures making them:

- **Extended** (> ~0.1 degree)
- **Show DM spectral shape**
- **No multiwavelength counterparts**

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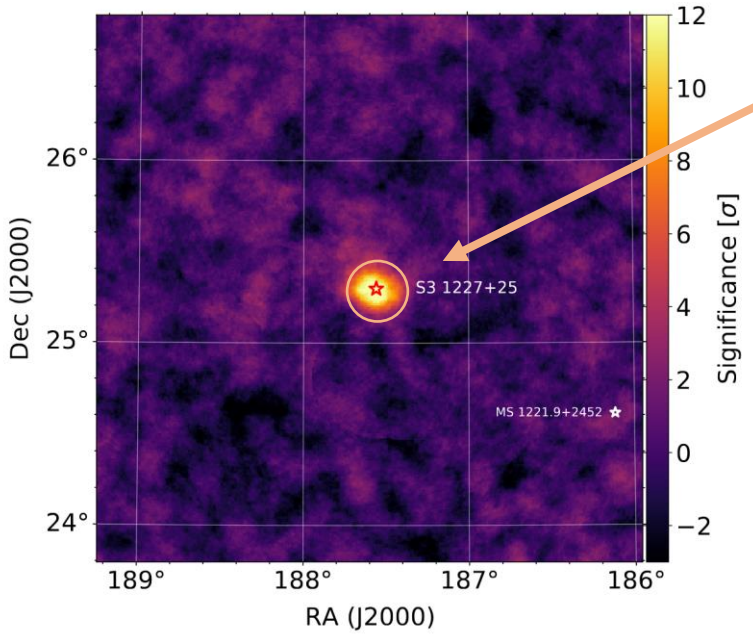
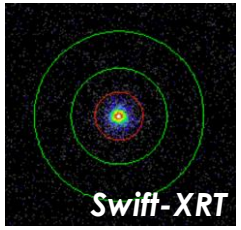
Toy Example of Non-Subhalo



Not Extended <0.1 degrees

~SSC emission with no clear DM model

Clear X-ray Counterpart



TeV emission is clearly associated with an *extragalactic* source, in this case the blazar S3 1227+25

…which you can see in Acharyya+ (2023).

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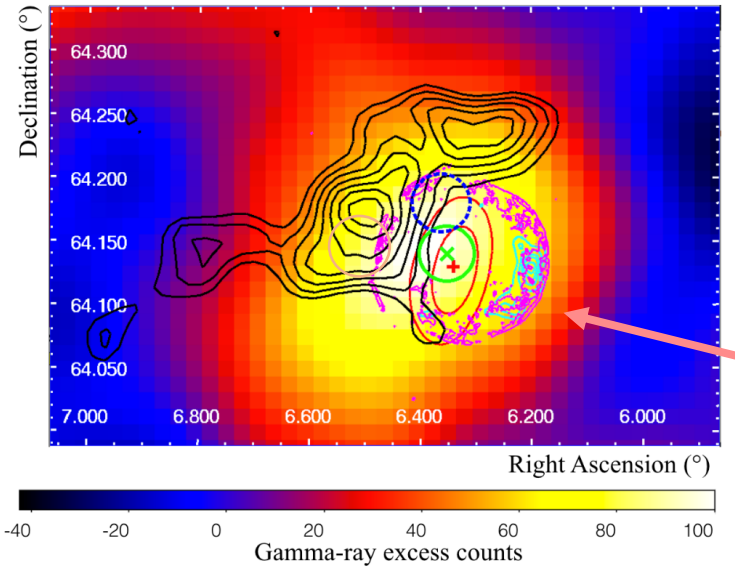


Very extended

No evidence for spectra favouring DM

Very Bright Radio Counterpart(contours)

TeV emission is clearly associated with a *galactic* source, in this case the SNR Tycho.

…which you can see in Archambault+ (2017).

IACT/pair production synergy

FERMI-LAT

- Wide FoV, survey instrument (2.4 sr)
- Coarse angular resolution (3.5-0.15˚)
- 20 MeV - 300 GeV Energy range
- **Good for identifying candidates**

VERITAS

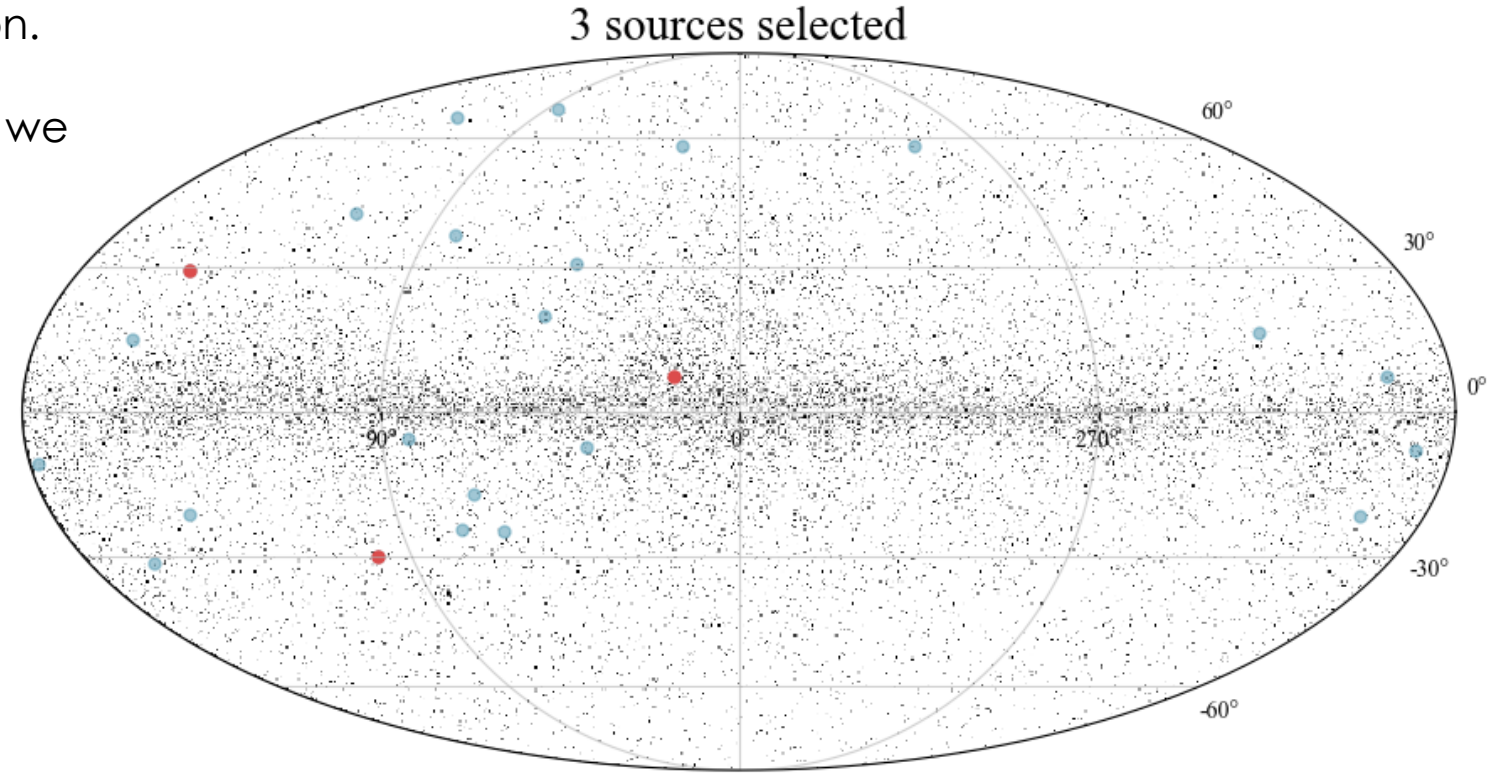
- Pointed Instrument (3 ˚ diameter)
- Good angular resolution (0.08 ˚ at 1 TeV)
- 85 GeV- 30 TeV Energy range
- **Good for confirming DM origin**

How do we parse the catalog?

Previous searches that only used Fermi-LAT require a stricter set of source selection cuts due to not having the additional IACT information. Since we are just looking for **plausible DM sources,** we can have loose criteria. In 3FHL we search for sources that:

- Are located in the Northern Hemisphere (visible to VERITAS)
- Are "unassociated"
- Are located outside the galactic plane
- Are non-variable
- Have a spectrum with a power-law harder than an index of 2
- Have no counterpart obvious in the literature, or in public follow-up X-ray observation (AI or ML categorizations are removed from consideration)

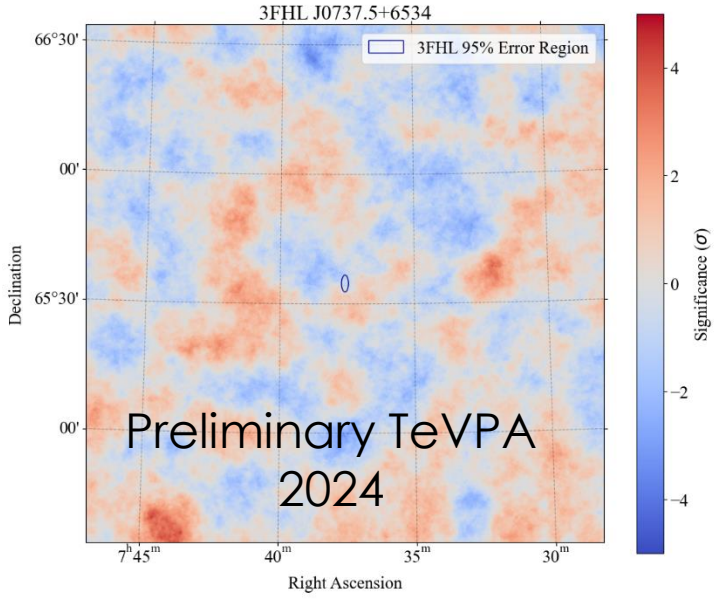
The 23 sources were sorted by estimated flux, and the 3 brightest sources were observed with VERITAS



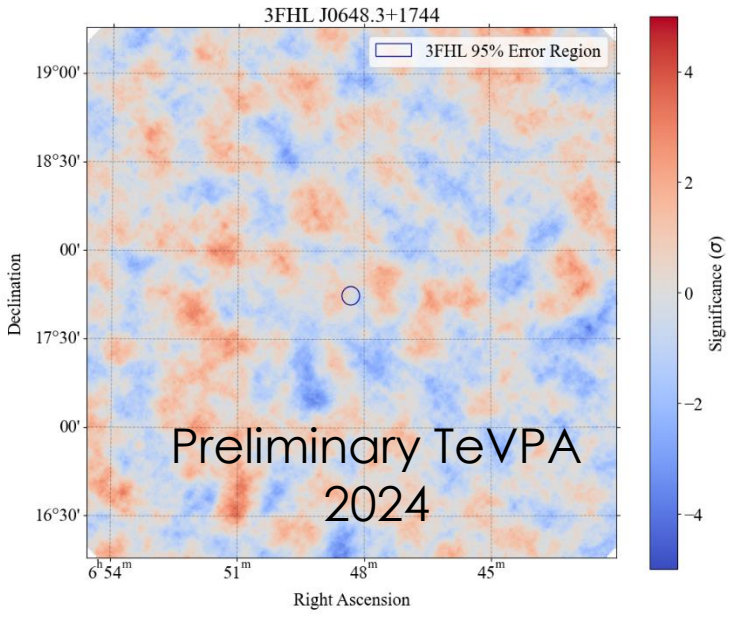
Observations

No significant TeV emission is seen by VERITAS spatially coincident with any canidate source. As such, we place constraints on the emission at TeV energies.

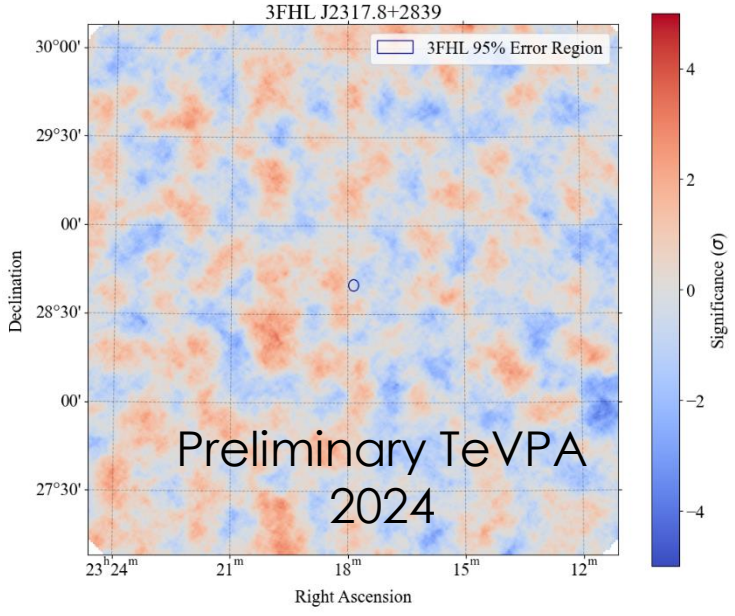
-1.0σ : 11h



-0.15σ : 9h



-0.8σ : 12h

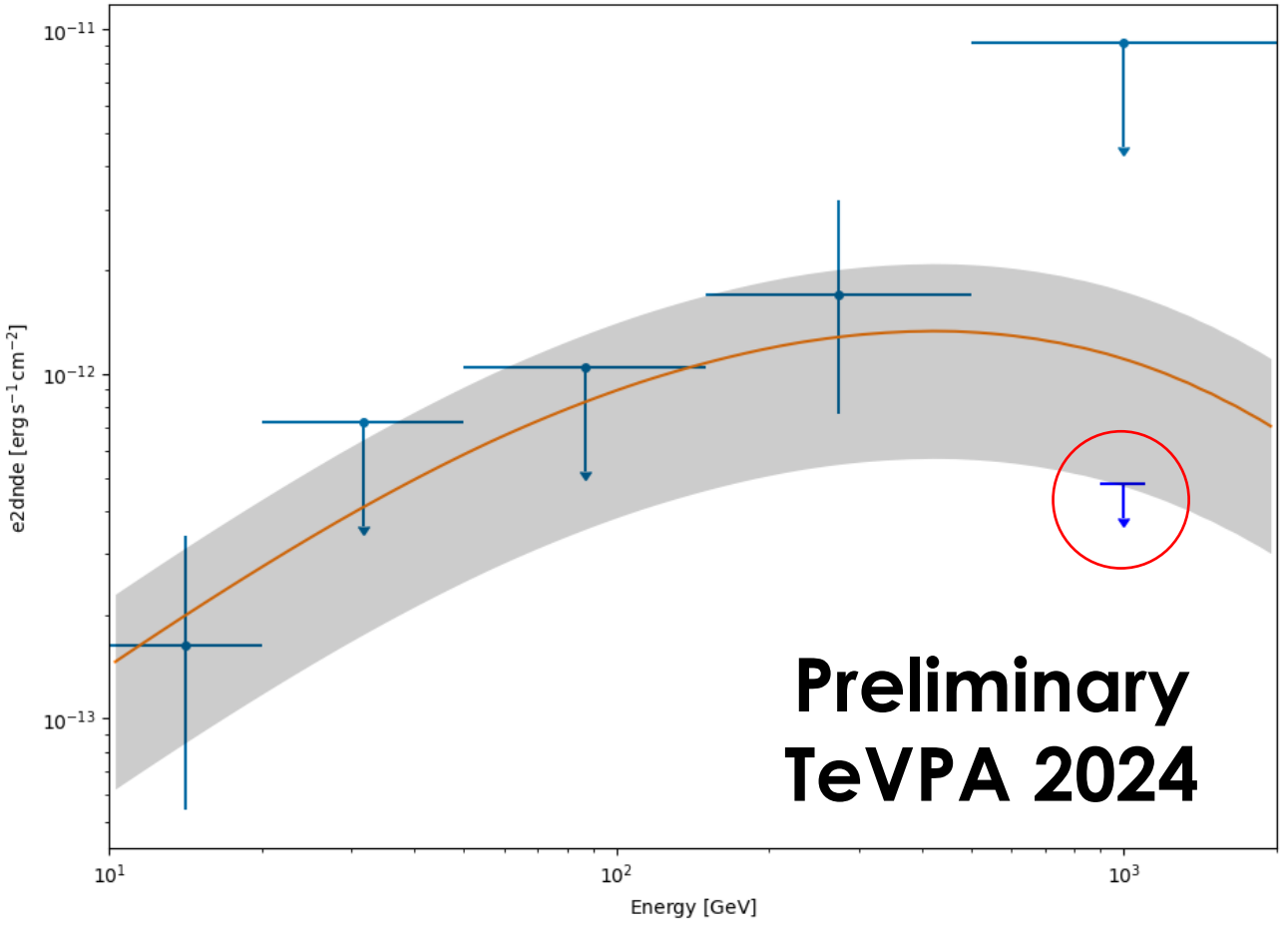


Interpreting non-detections

Non-detections constrain many astrophysical and DM models, as sources were selected based on their extrapolated TeV flux.

If the source is astrophysical, our limits could imply a **strong GeV scale cut-off,** or it may imply that the source has previously un-cataloged **variable emission.**

For 3FHL J0737.5+6534, there has been multiple suggested counterparts such as the starburst NGC 2403, and emission related to fading supernova (Abdollahi+, 2020; Ajello+, 2020; Xi+, 2020). Due to the likely variable emission and the lack of a strong cut-off expected for NGC 2403, we **tentatively favor a supernova interpretation.**



Fermi-LAT Observations

VERITAS Observations

Future potential IACT follow-up

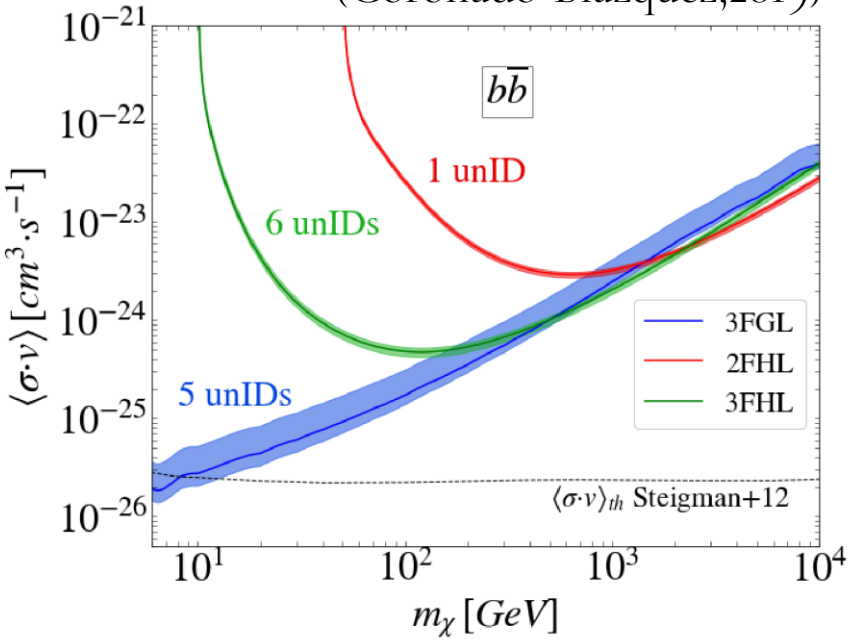
Leveraging the statistics with Fermi-LAT to make statements about the **total population of subhaloes** will continue to benefit from the rejection of the handful of sources which exist as plausible DM candidates.

Unfortunately, due to **the faint nature of many of the remaining sources**, current generation Northern Hemisphere instruments may struggle to make progress without large exposures (>50 hours).

This process will become easier and more powerful with **CTAO** due to the **~10x sensitivity, and ~2x the angular resolution**.

Many of these candidates may be observed during the CTAO extragalactic survey.

(Coronado-Blázquez,2019)



Credit: CTAO

Question & Discussion

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