Investigating TeV Gamma-ray Emission around GRS 1915+105 with HAWC

Minji Shin, Chang Dong Rho

Microquasars

***Micro*quasars**

- X-ray binary system with relativistic outflows
- Compact object: neutron star or black hole

High-mass microquasars (HMMQs)

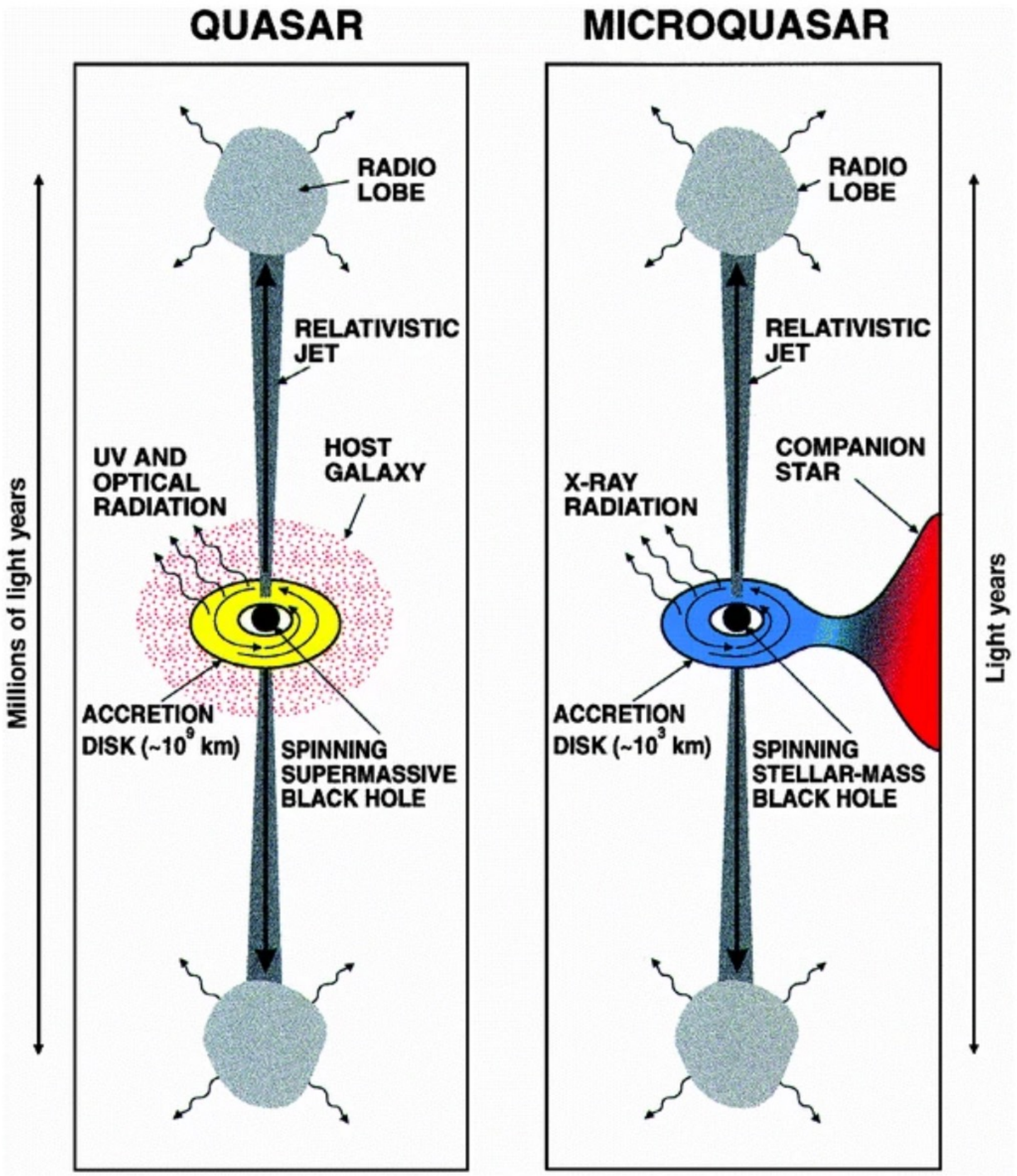
Massive, early-type companions ($M_* \gtrsim 10M_\odot$)

Dense stellar winds and strong photon fields

Low-mass microquasars (LMMQs)

Late-type or evolved companions ($M_* \lesssim 1M_\odot$)

External photon and matter densities are low



Nature **392**, 673–676 (1998)

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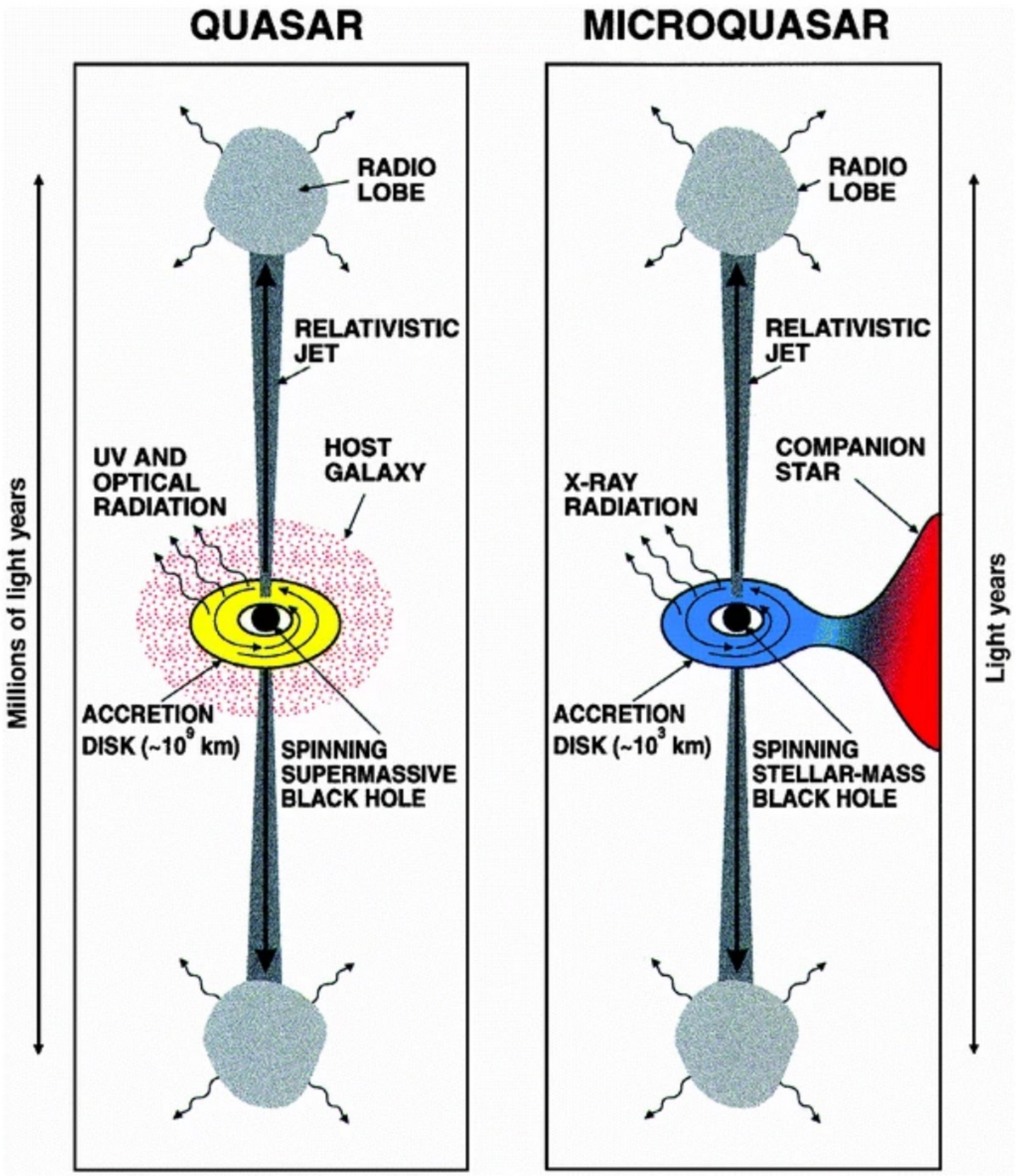
GRS 1915+105 is a well-known **low-mass microquasar hosting a black hole**



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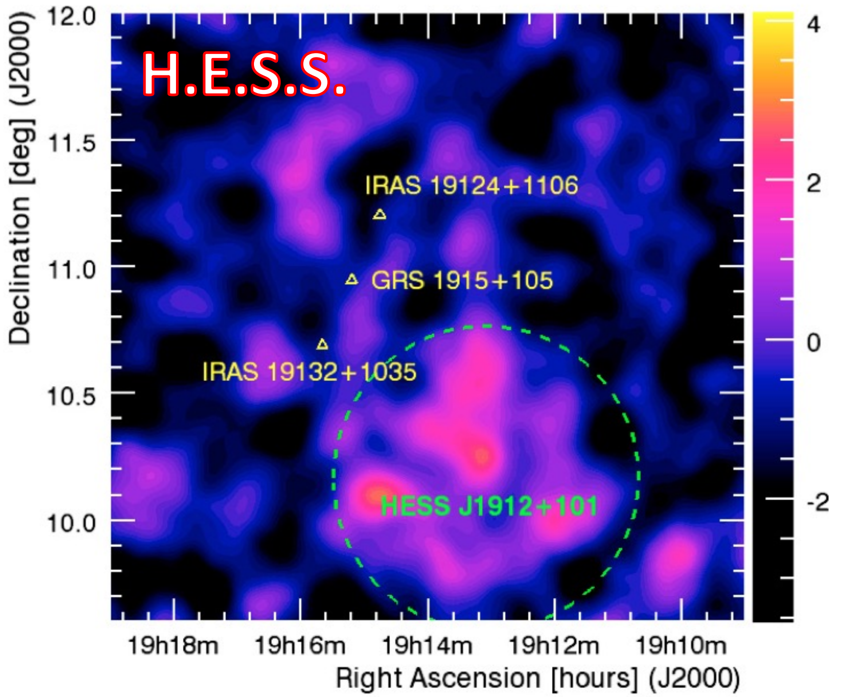
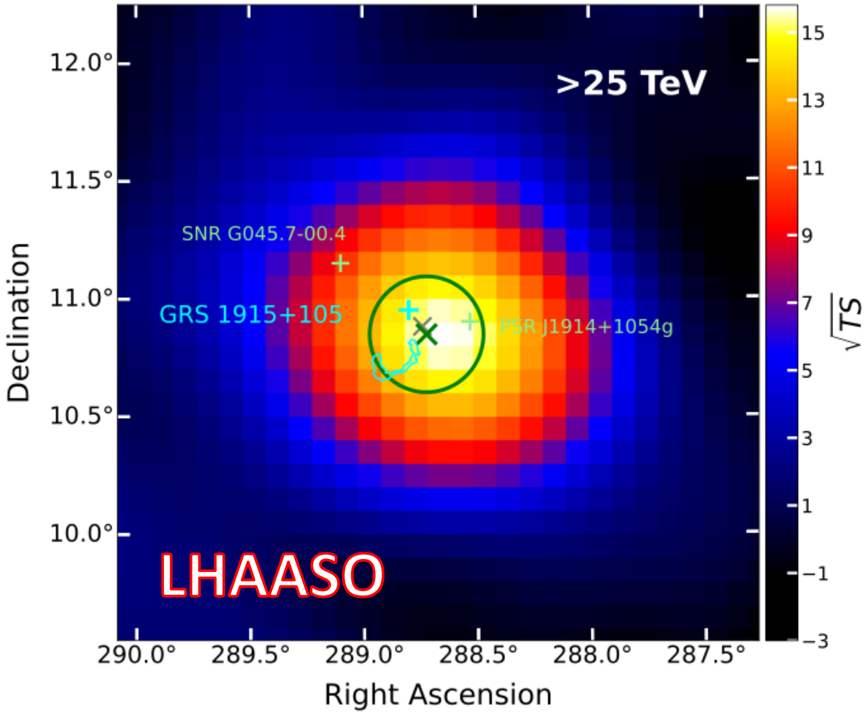
GRS 1915+105

- Low-mass microquasar
  Black hole mass: 12.4 $M_{\odot}$
  Companion star: K-type star (0.5 $M_{\odot}$)

- Distance: 8.6 kpc
- (l, b) = (45.37°, -0.22°)
- (RA, dec.) = (288.80°, 10.95°)

- VHE γ-ray studies
  - H.E.S.S placed a flux upper limit on VHE emission
    A&A 508, 1135-1140 (2009)
  - LHAASO detected a source associated with GRS 1915+105
    https://arxiv.org/pdf/2606.25054





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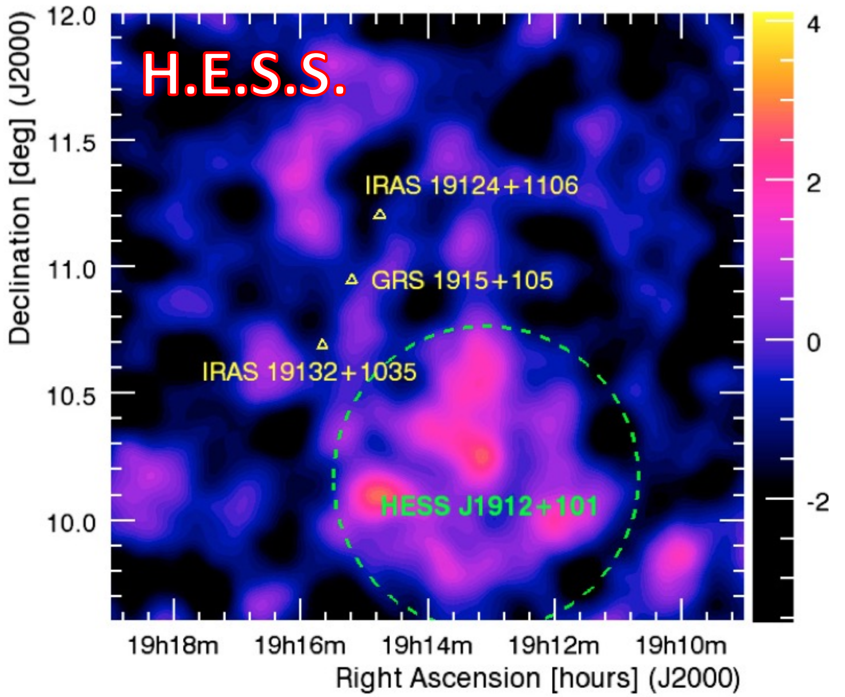
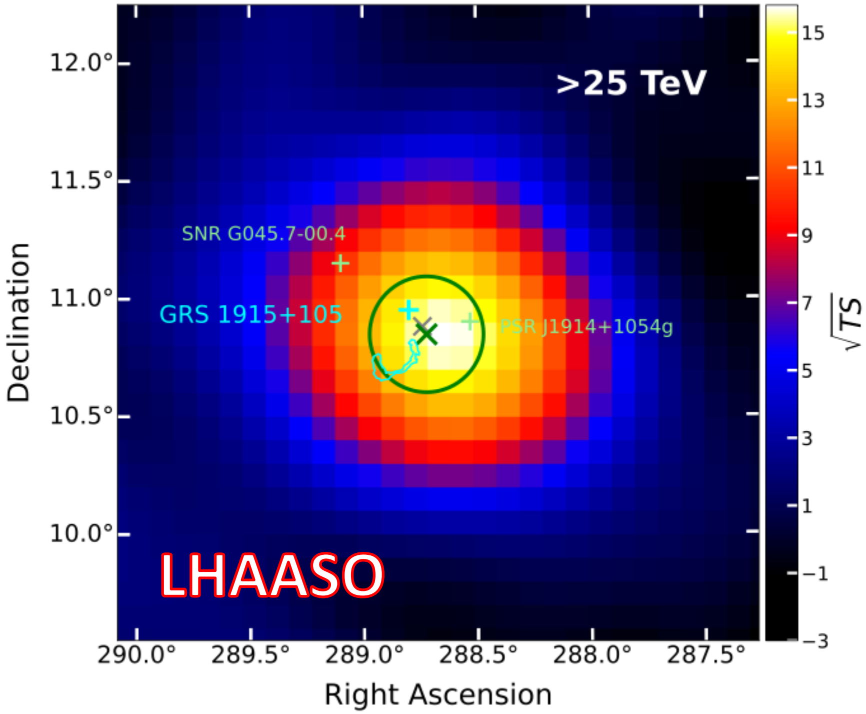




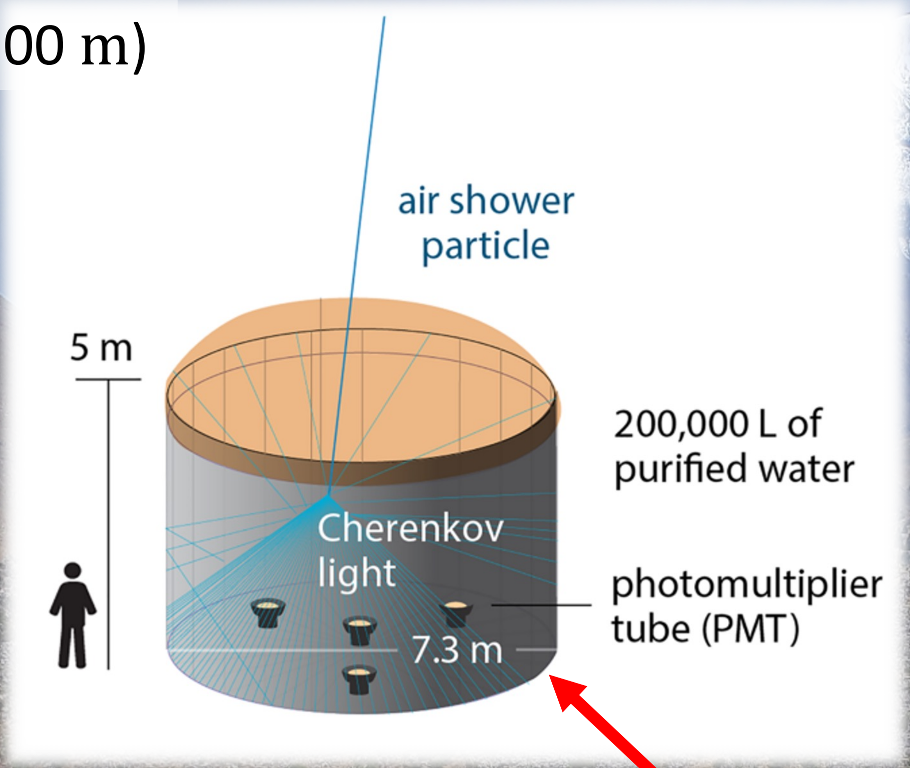
What does this region look like with HAWC data?
We present preliminary results for the GRS 1915 region

High-Altitude Water Cherenkov (HAWC) Observatory

High-Altitude Water Cherenkov (HAWC) Observatory

Sierra Negra, Mexico (4,100 m)

- 300 GeV – hundreds of TeV
- Instantaneous field of view of 2 sr
- Duty cycle ~95%
- Angular resolution: ≥ 0.1°



Main array

300 water Cherenkov detectors (WCDs)

22,000 m^2

HAWC data

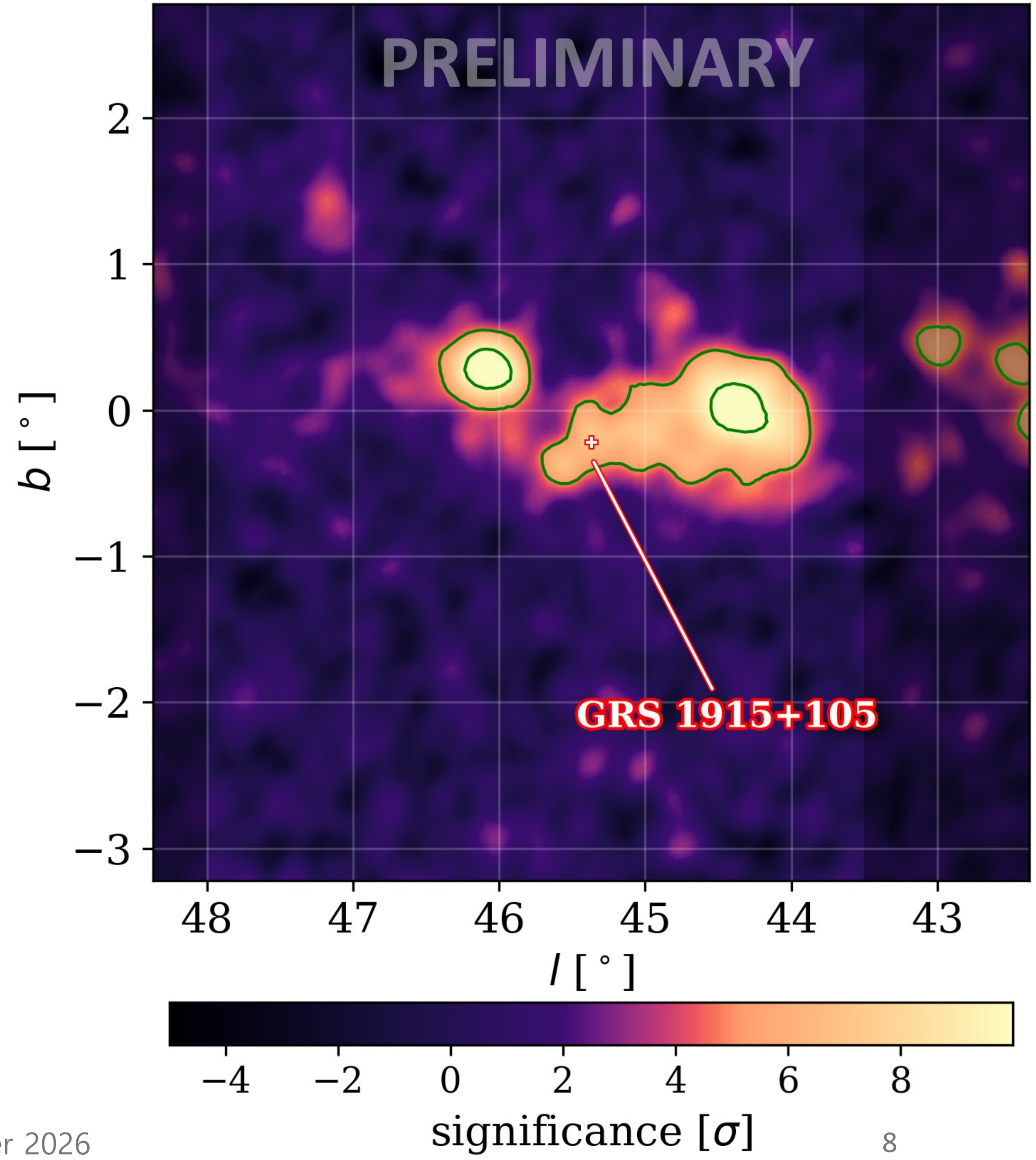
- ~2886 days of main array data
  - Neural network energy estimator
  - ML approach for background rejection
  - Above ~5 TeV

- Region of interest (ROI):
  $l = (43.5°, 48.0°)$ & $b = (-5.0°, 5.0°)$

- Pre-trial significance: $\sigma \simeq \sqrt{\text{test statistic (TS)}}$

- 6.95σ at GRS 1915+105 position, ***BUT …***
  Diffuse background emission (DBE)
  Possible contamination from nearby sources

We need dedicated analysis for this region!



Modeling GRS 1915+105 region

1. Number of sources in our ROI? Extended or point-like?

- Model DBE using Hermes (High-Energy Radiative MESsengers) template

- **Add point source** with power-law spectrum in our ROI until

$$\boldsymbol{\Delta}\mathbf{TS} = \mathbf{2}(\mathbf{ln}\boldsymbol{L}_{\mathbf{alt}} - \mathbf{ln}\boldsymbol{L}_{\mathbf{null}}) < \mathbf{25}$$

L_{null} : likelihood value for the null hypothesis (previous model)
L_{alt} : likelihood value for the alternative hypothesis (updated model)

- Test each point source with an **extended morphology**, in descending order of TS

If $\boldsymbol{\Delta}\mathbf{TS} > \mathbf{16}$, the source is accepted as extended

Note. Weak sources with $\mathbf{TS} < \mathbf{25}$ **are removed** during this step

Modeling GRS 1915+105 region

2. Spectral model test

Power-law: $\frac{dN}{dE} = K\left(\frac{E}{E_{\mathrm{piv}}}\right)^{\alpha}$

Log-parabola: $\frac{dN}{dE} = K\left(\frac{E}{E_{\mathrm{piv}}}\right)^{\alpha-\boldsymbol{\beta}\log(E/E_{\mathrm{piv}})}$

Power-law with exponential cutoff: $\frac{dN}{dE} = K\left(\frac{E}{E_{\mathrm{piv}}}\right)^{\alpha}\exp\left(-\frac{E}{\boldsymbol{E_c}}\right)$

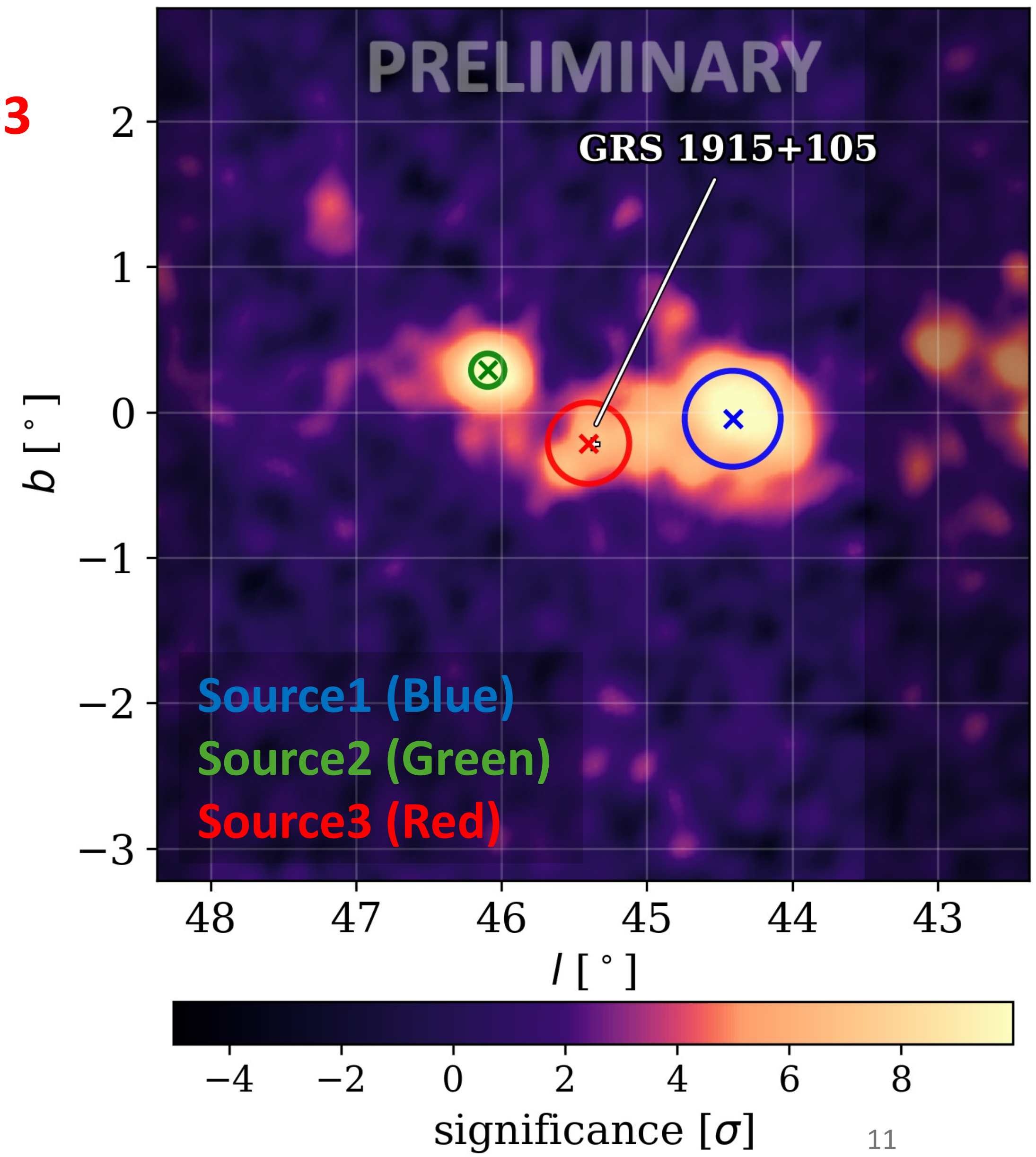
- Test all possible combinations of three spectral models

- Compare spectral models using AIC
- Significant statistical improvement ⟶ accept curvature

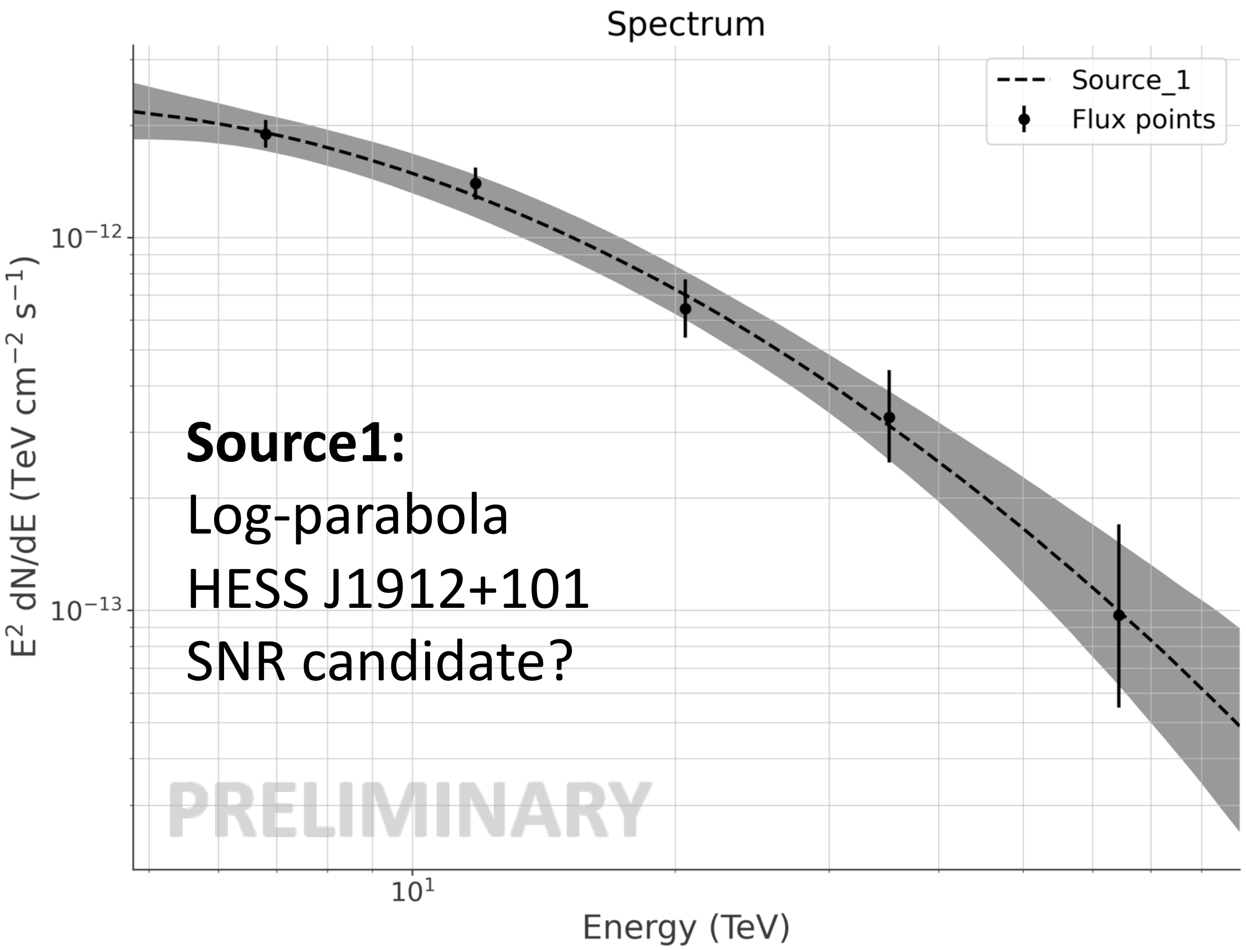
Modeling results: three extended sources

- Following the order in which sources were added, they are referred to as Source1, Source2 and Source3
- GRS 1915+105 position: (RA, Dec.) = (288.80°, 10.95°)

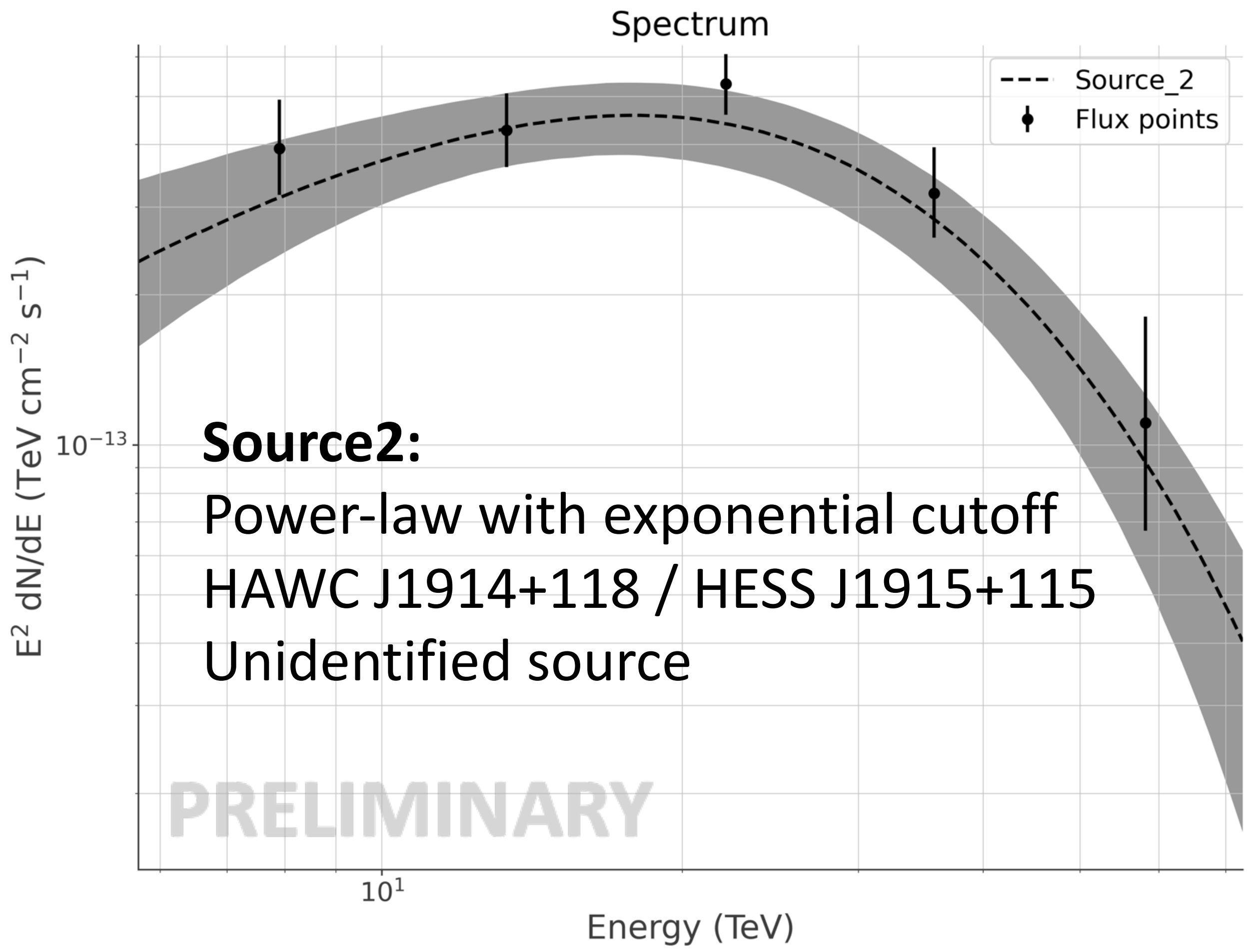
Source1	RA	288.194° +/- 0.032°	TS = 57
	Dec.	10.18° +/- 0.04°	
	Extension	0.338° +/- 0.027°	
Source2	RA	288.687° +/- 0.020°	TS = 82
	Dec.	11.834° +/- 0.021°	
	Extension	0.131° +/- 0.023°	
Source3	RA	288.82° +/- 0.06°	TS = 50
	Dec.	10.99° +/- 0.07°	
	Extension	0.27° +/- 0.06°	



Modeling results: Sources 1 and 2 (nearby sources)

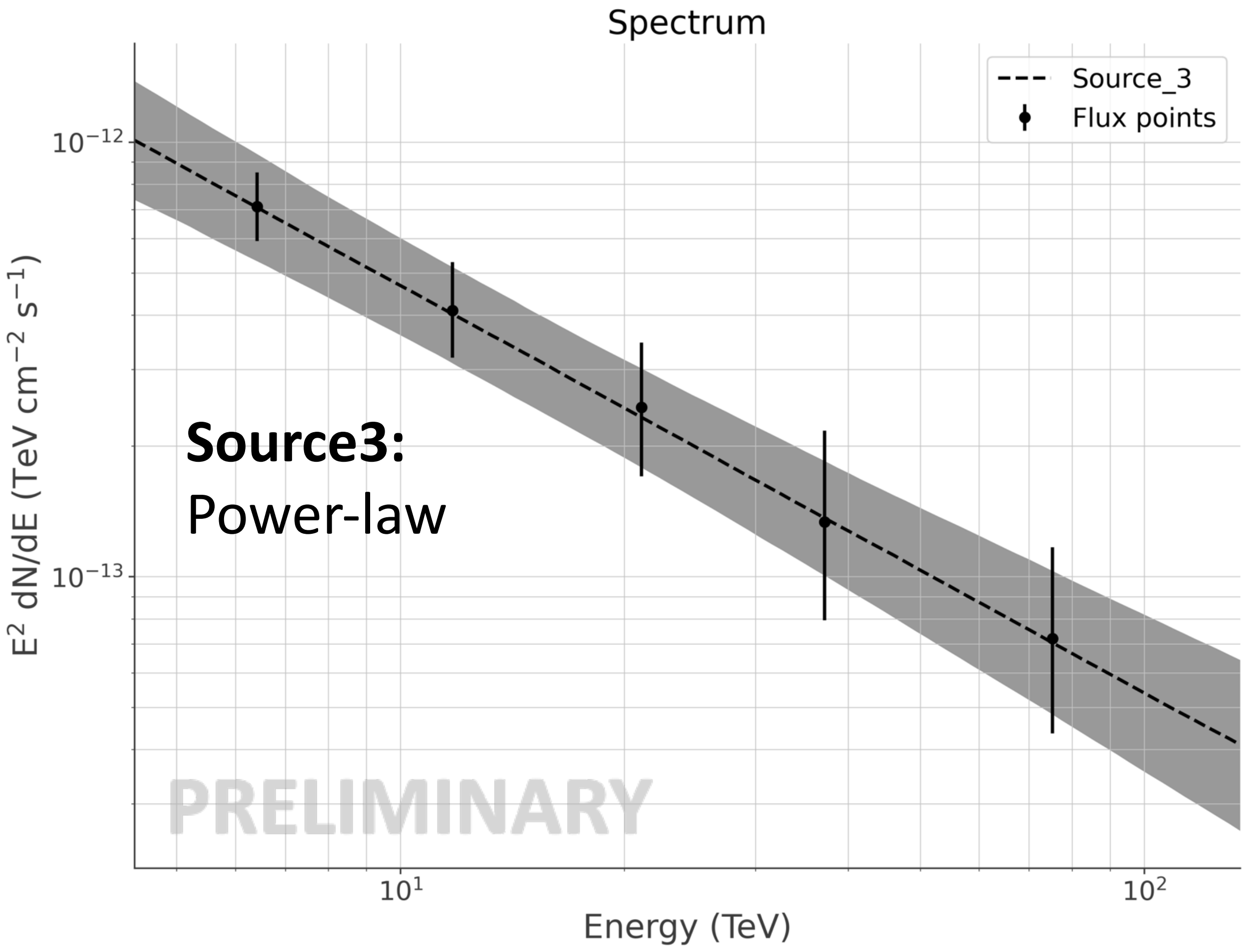


Source1:
Log-parabola
HESS J1912+101
SNR candidate?



Source2:
Power-law with exponential cutoff
HAWC J1914+118 / HESS J1915+115
Unidentified source

Modeling results: Source3 (GRS 1915+105 candidate)

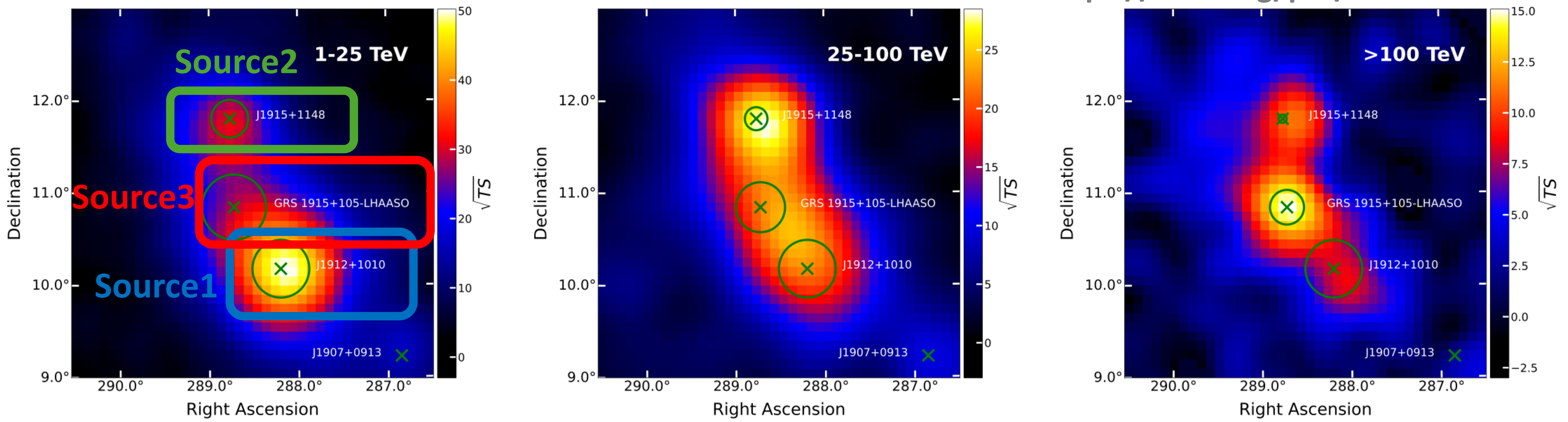


- **Source3** is a candidate spatially associated with GRS 1915+105, the best-fit positions ~0.032° away

- No strong evidence of curvature

Comparison with LHAASO results

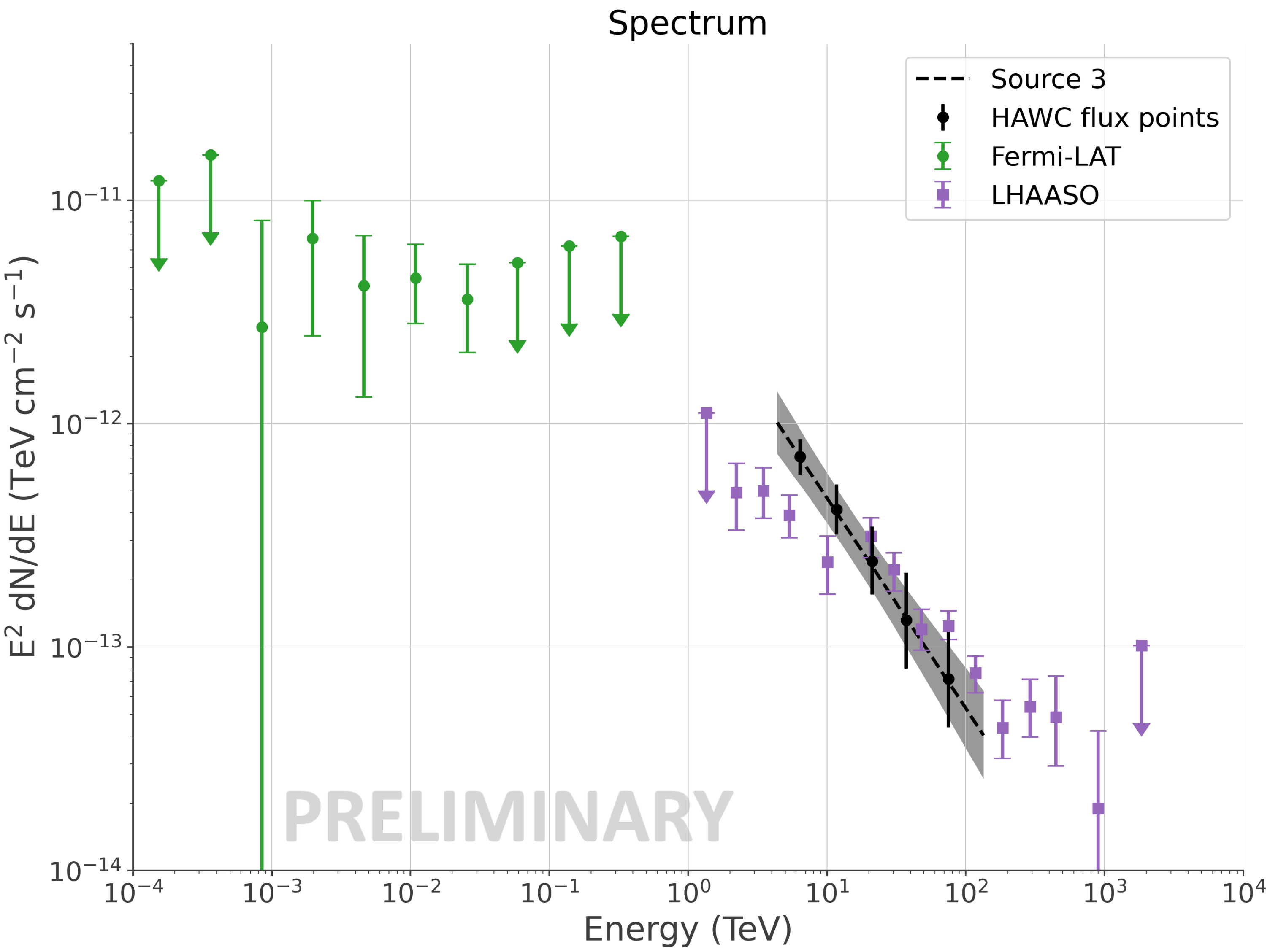
https://arxiv.org/pdf/2606.25054



- LHAASO also reported three extended sources in this region
- LHAASO J1912+1010 and LHAASO J1915+1148 correspond to Source1 and Source2, respectively
- LHAASO J1915+1148 and GRS 1915+105 LHAASO were modeled with energy-dependent morphologies → **Does HAWC observe the same feature? (future work)**

Comparison with LHAASO results

- Other data points are taken from https://arxiv.org/pdf/2606.25054
- HAWC results are broadly consistent with LHAASO above 10 TeV
- HAWC and LHAASO adopted different morphological models



Summary and future work

- We identified three extended source in the region around GRS 1915+105 using 2886 days of HAWC data above ~5 TeV

- Among three sources, Source3 has a best-fit position only 0.032° away from GRS 1915+105

- Above 10 TeV, Source3 spectrum shows a broadly similar trend to that reported by LHAASO

▪ Energy-dependent morphology study

▪ Multi-wavelength analysis

Thank you for your attention!

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