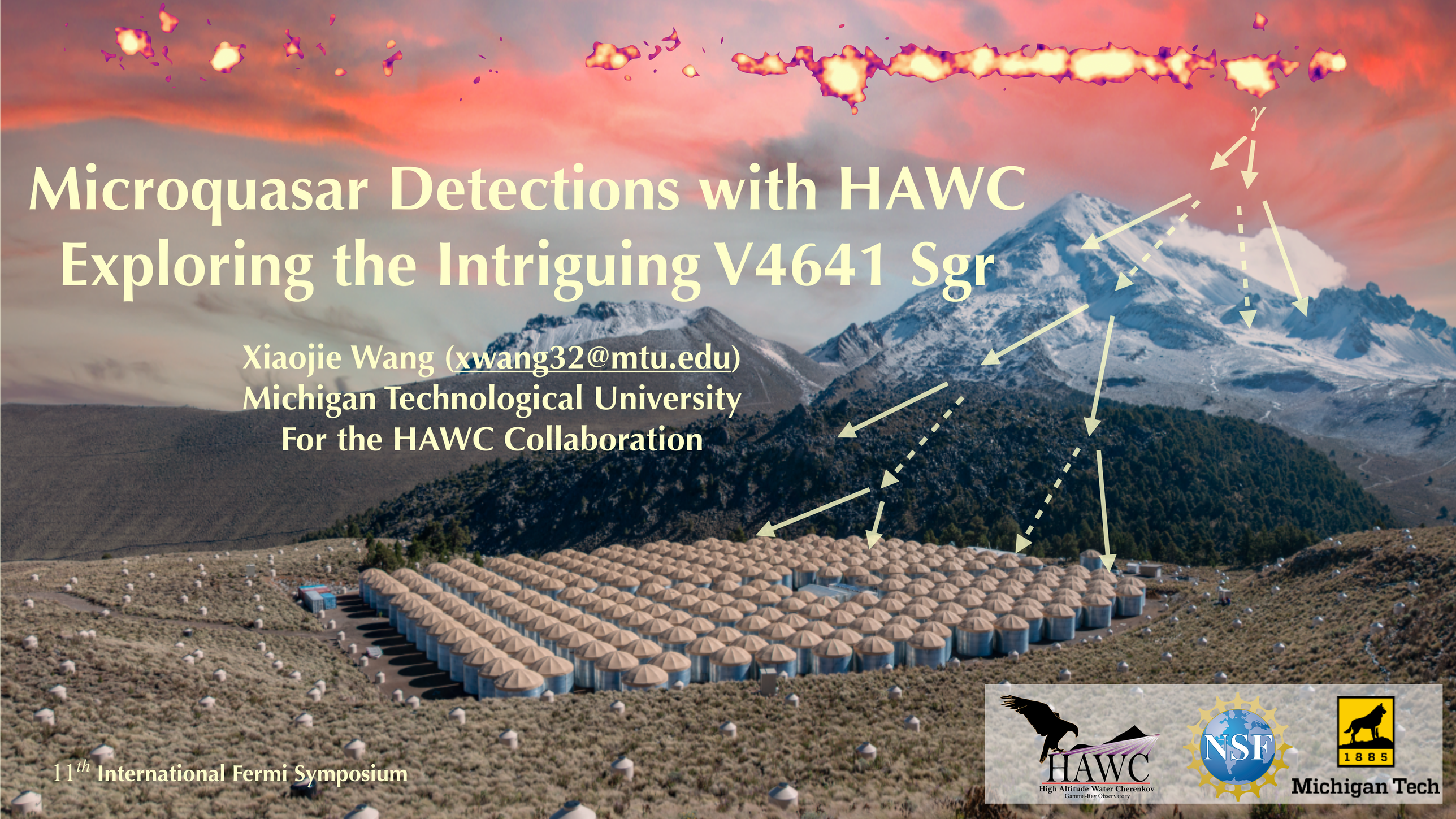

Microquasar Detections with HAWC
Exploring the Intriguing V4641 Sgr

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Michigan Technological University
For the HAWC Collaboration

11th International Fermi Symposium

HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

NSF

1885
Michigan Tech

HAWC Site

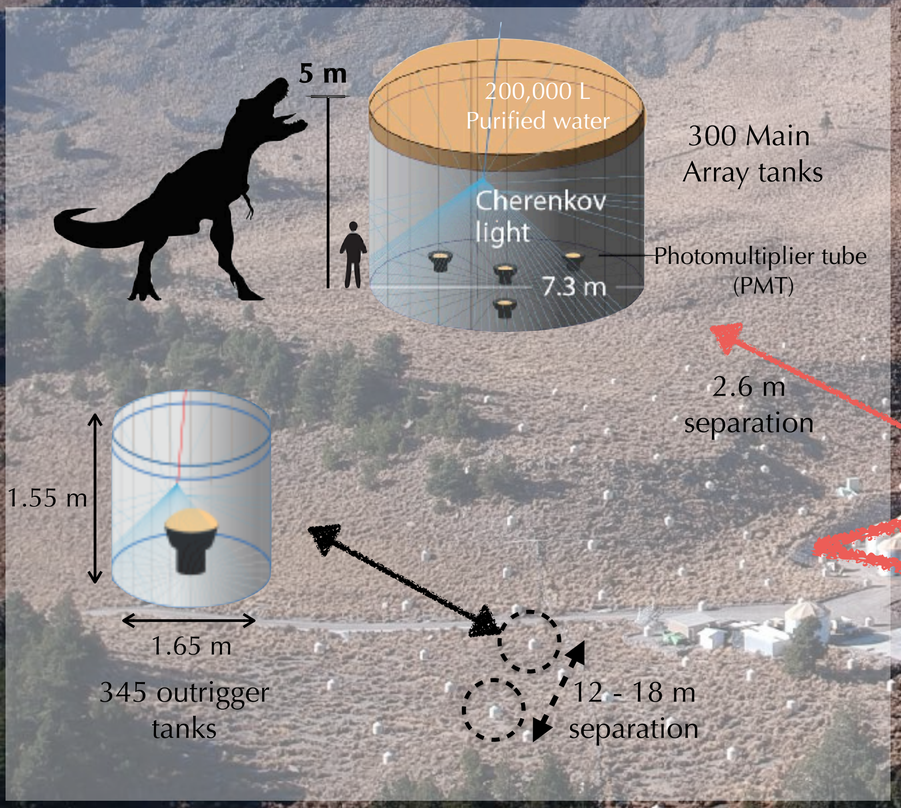
Latitude: 18°59.7′N
Longitude: 97°18.6′W

- HAWC is located on the flanks of the Sierra Negra volcano near Puebla
- 4,100 meters (13,500 feet) above the sea level

High Altitude Water Cherenkov (HAWC) Observatory

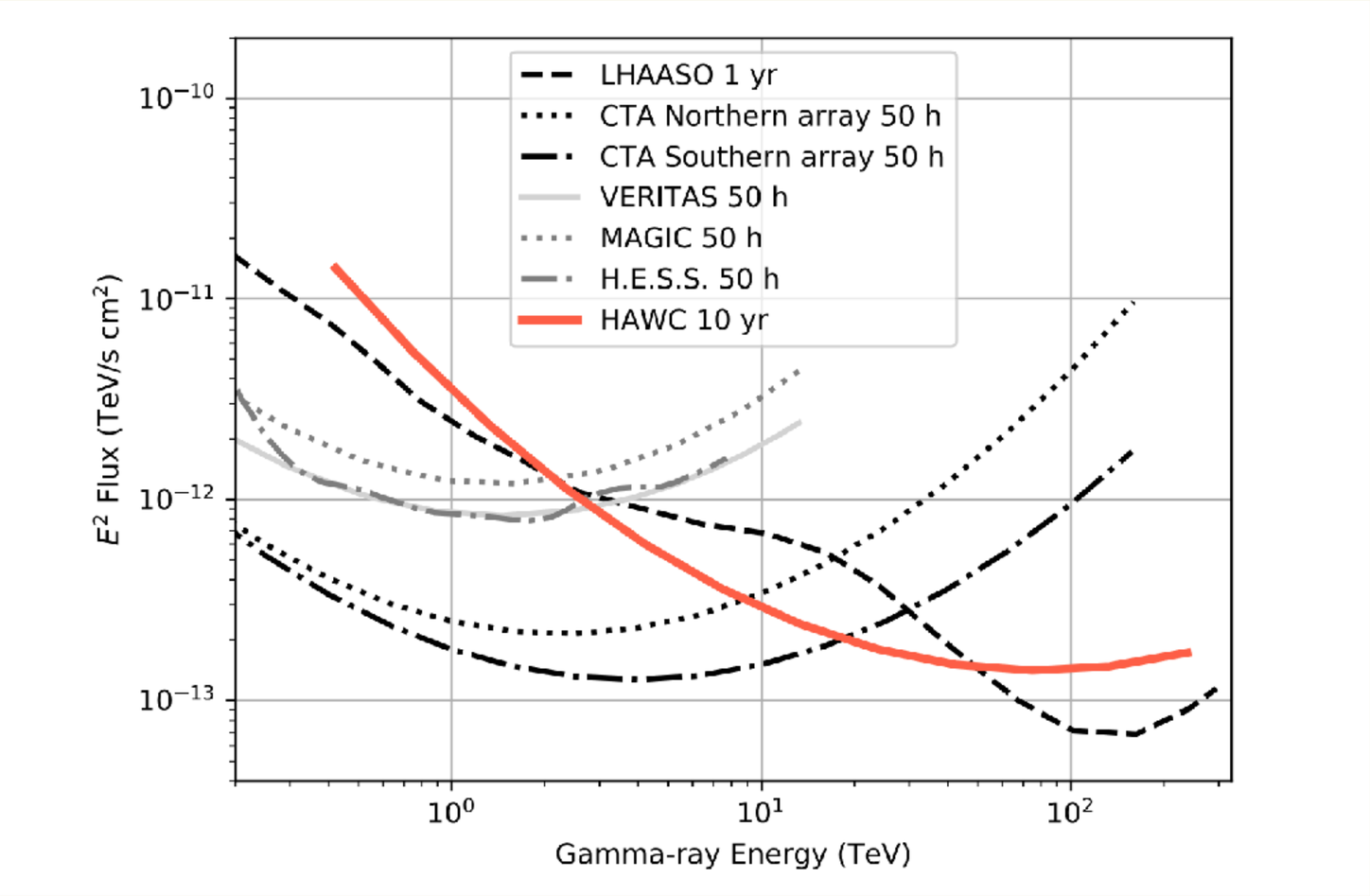
Large Millimeter Telescope

- **300 main array plus 345 outrigger WCDs covering ~100,000 m^2 effective area**
- **Large field of view: instantaneous field of view: ~ 2sr**
- **High duty cycle: > 95%**
- **Great sensitivity at high energies: 100 GeV to more than 100 TeV**



4100 m
a.s.l.

Sensitivity - Pass 5 Improvement

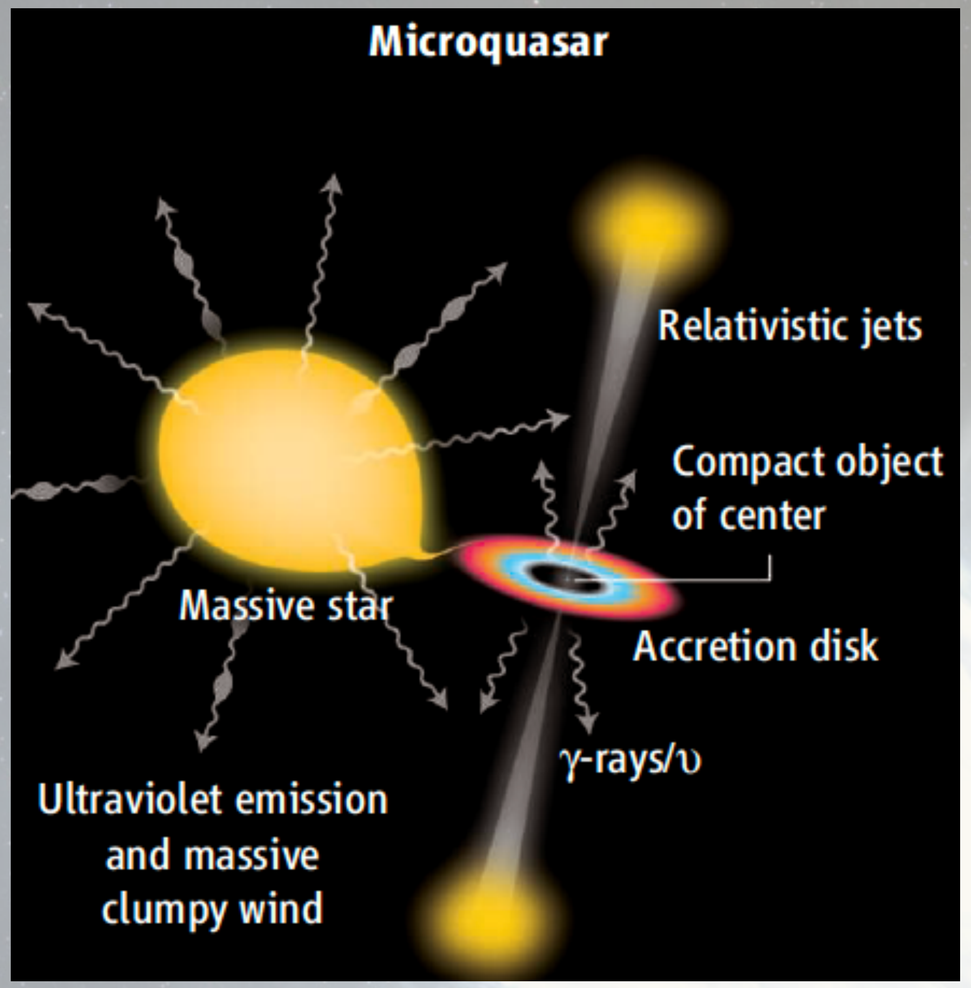


New Improved Reconstruction: Pass5

https://arxiv.org/pdf/2405.06050

- Improved background rejection
- Better angular resolution
- Improved sensitivity at low energy (hundred GeVs)

Microqusars



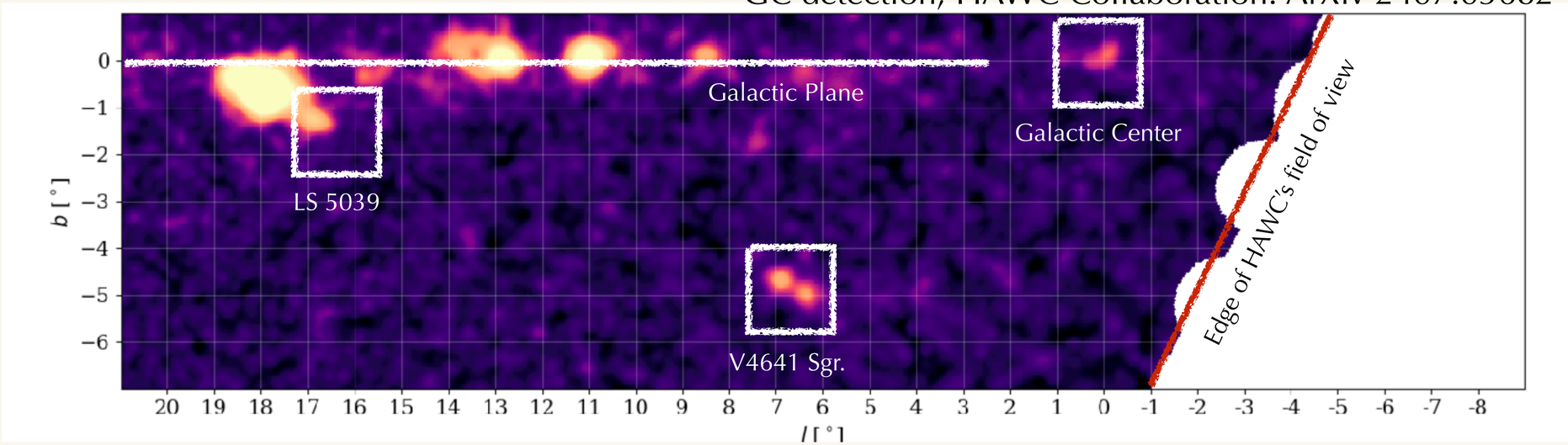
I.F. Mirabel 2012

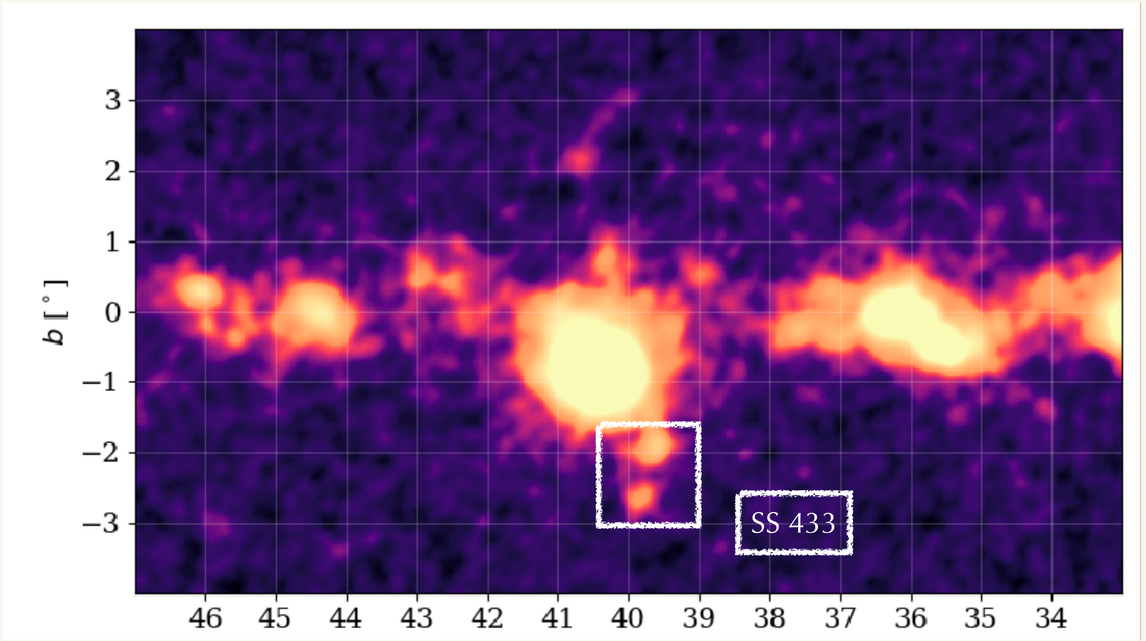
- Smaller version of a quasar
- Consist of a compact object and companion star
- Jet-ejecting X-ray binaries

Image credit: L. Calçada / ESO.

Multi-TeV Microquasars with HAWC

GC detection, HAWC Collaboration: ArXiv 2407.03682

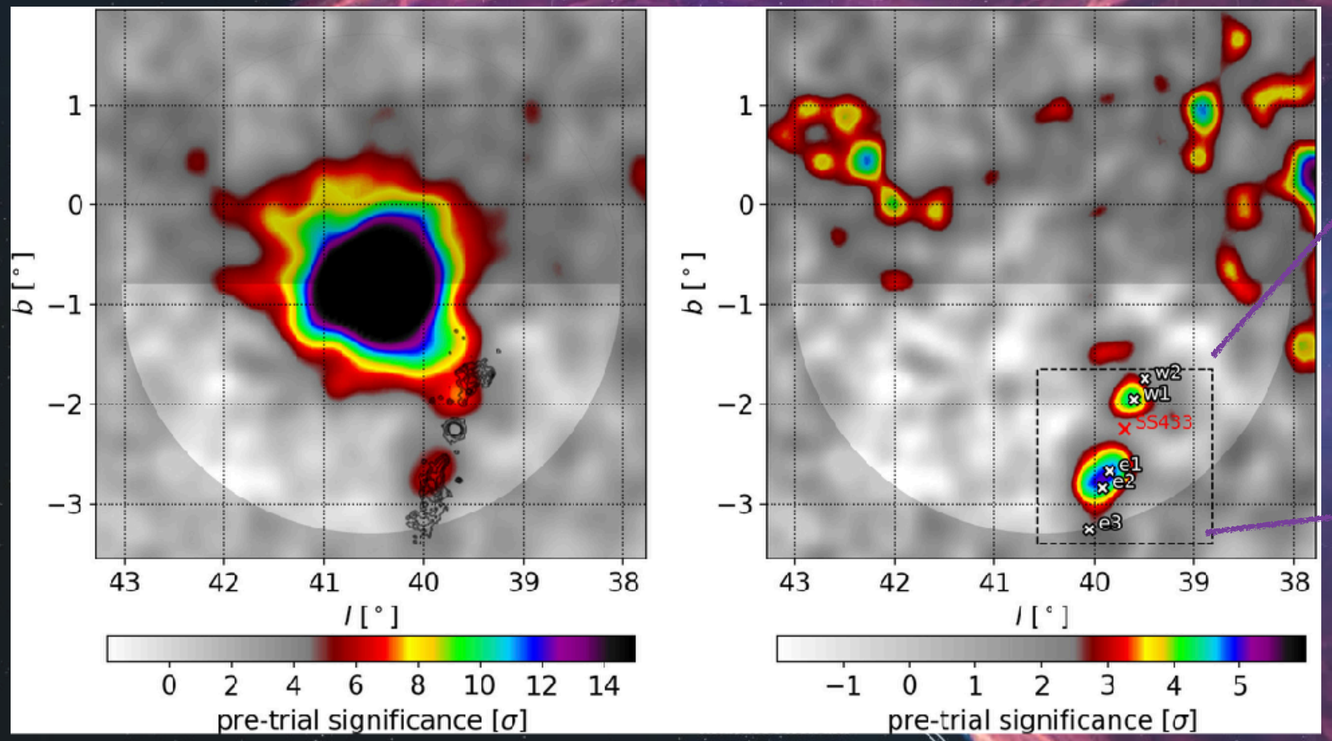


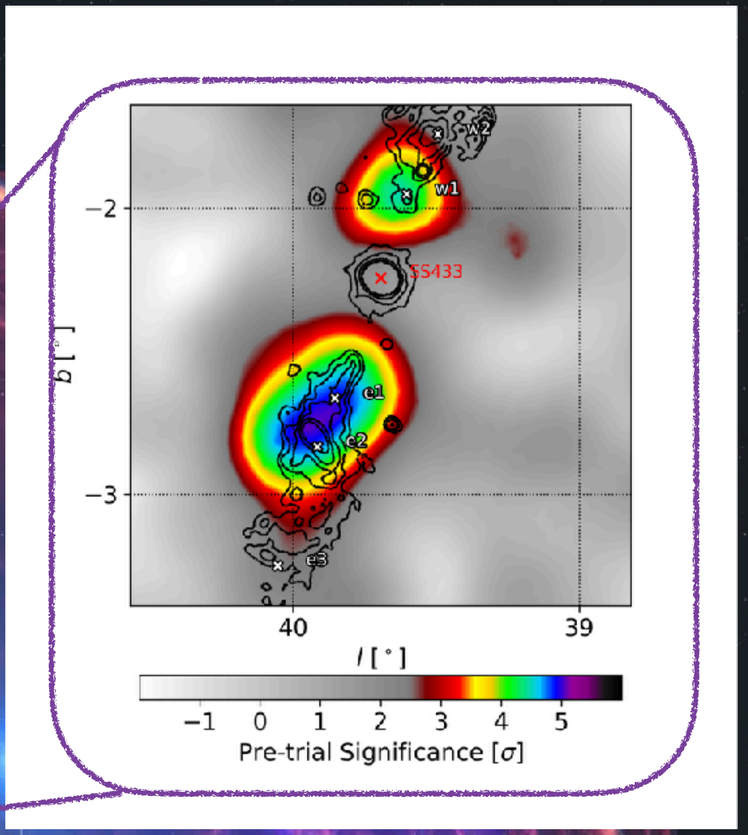


	Distance (kpc)	Companion star mass ($M_\odot$)	Compact star mass ($M_\odot$)	Orbital period (days)	Orbital axis inclination (°)
V4641 Sgr	6.2 ± 0.7	2.9 ± 0.4	6.4 ± 0.6	2.817 ± 0.002	72. 3 ± 4.1
SS433	~ 5.5	>10	8	13.082	79
LS5039	~2.5	22.9 +3.4 -1.3	3.7 +1.3 -1.0	3.90603 ± 0.00017	24.9 ± 2.8

Microquasar SS 433

Nature 562, 82–85 (2018)
https://doi.org/10.1038/s41586-018-0565-5

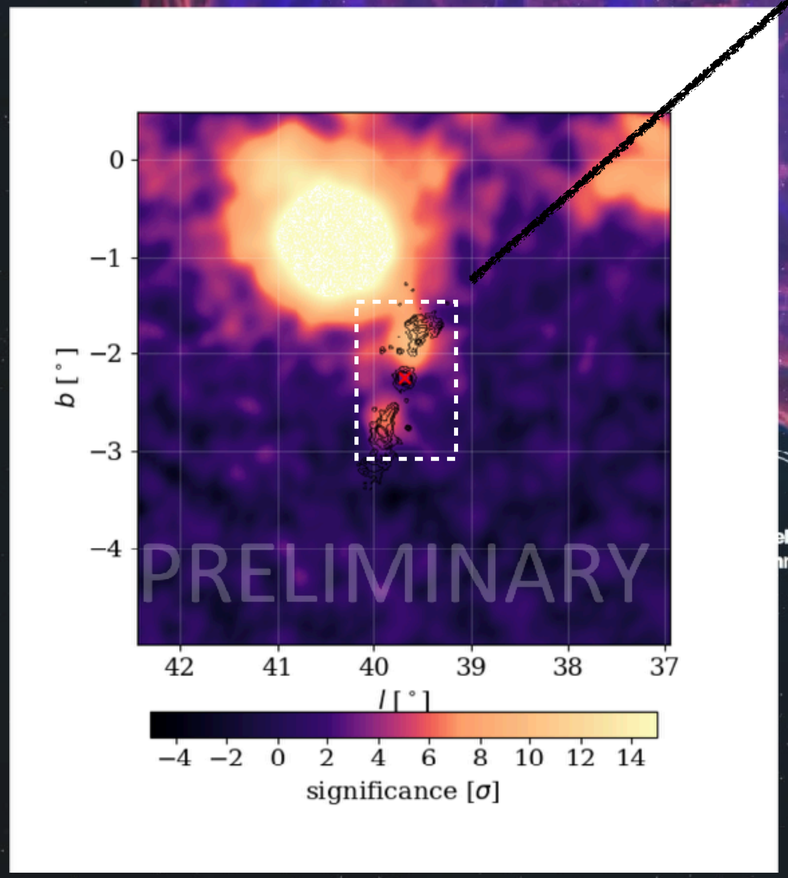


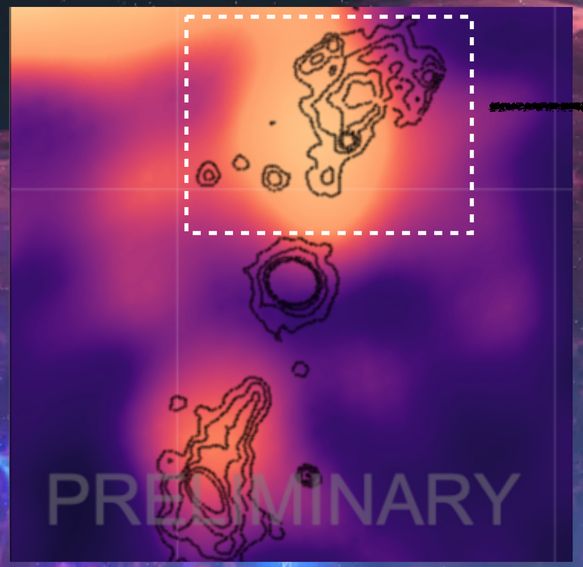


- Distance: ~5.5 kpc
- Compact object with 8 $M_\odot$, companion star mass > 10 $M_\odot$
- Orbital period of ~13.1 days

- The first microquasar HAWC detected
- Near the bright MGRO J1908+06
- With 1017 days of HAWC observations
- Post-trial 5.4 σ
- The TeV emission from the east and west lobes shows that powerful jets can accelerate particles beyond 20 TeV

Recent Updates from SS 433





West jet only after subtract emission from adjacent MGRO J1908 +06

discontinuity particle acceleration site

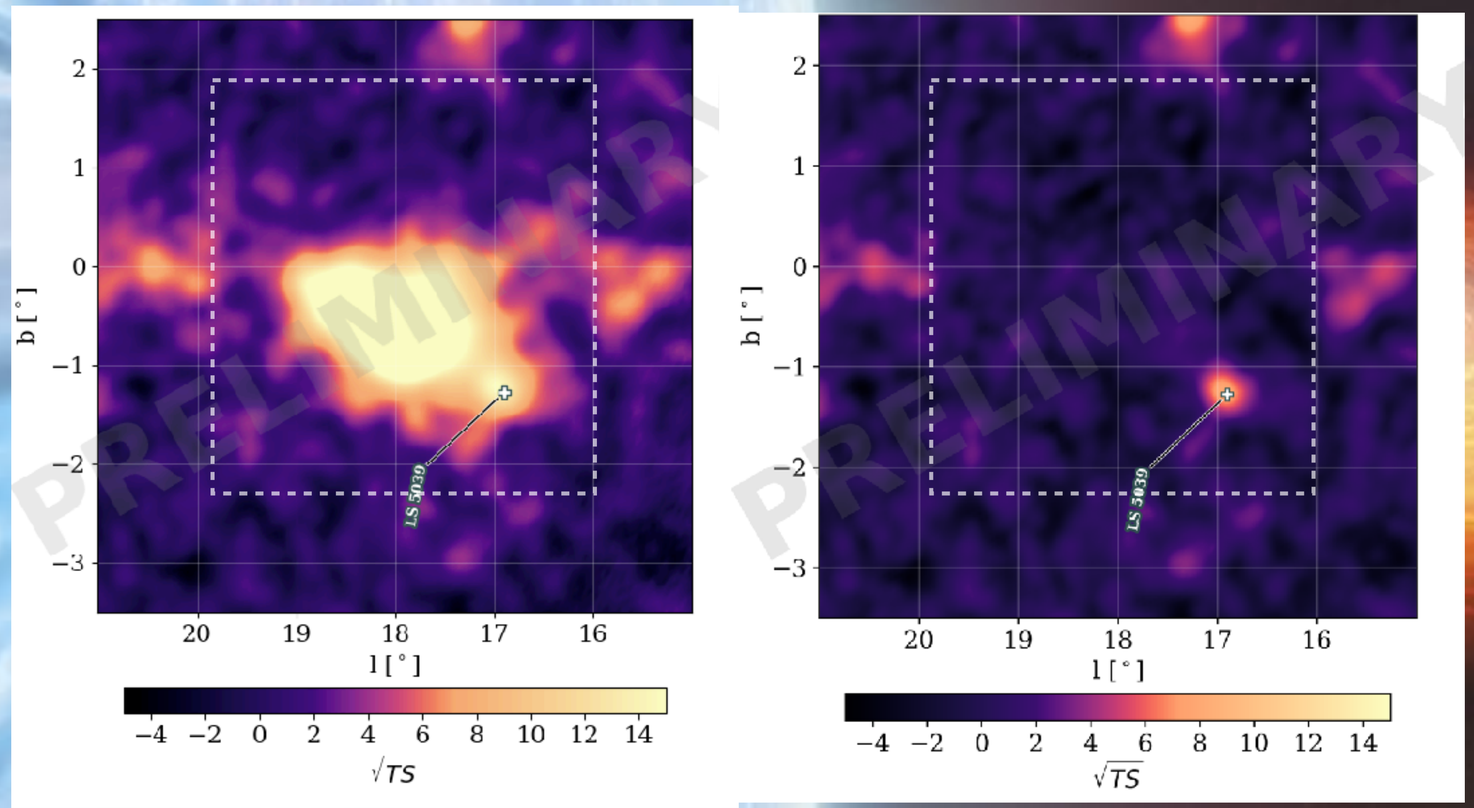
microquasar SS433

discontinuity particle acceleration site

- 1910 days of data
- Better Reconstruction algorithm
- More separate with MGRO J1908 +06
- Lobs have enough significance to do the individual analysis
- The spectrum from both jets reaching 100 TeV

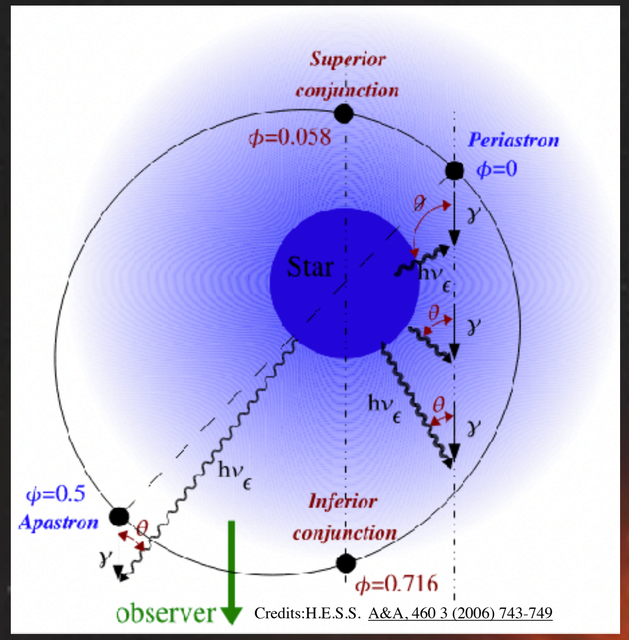
CREDIT: Science Communication Lab for MPIK/H.E.S.S.

Gamma-Ray Binary LS 5039



- Unable to disentangle LS 5039 in Pass4 data
- LS 5039 can be disentangled from J1825 region
  - About 8 σ detection
- Use multi-source fitting procedure to get best-fit model for the whole J1825 region

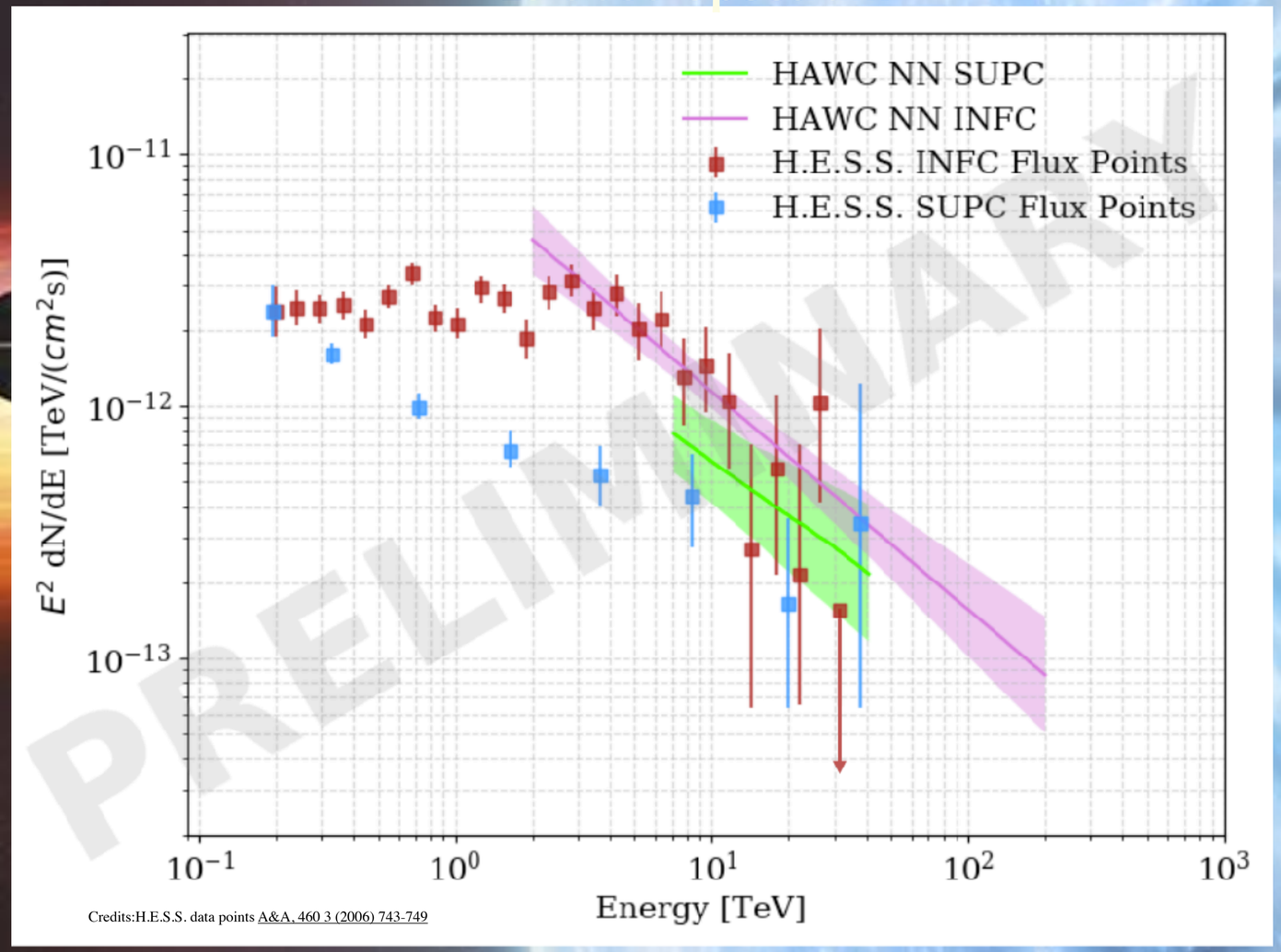
Gamma-Ray Binary LS 5039



Credits:H.E.S.S. A&A, 460 3 (2006) 743-749

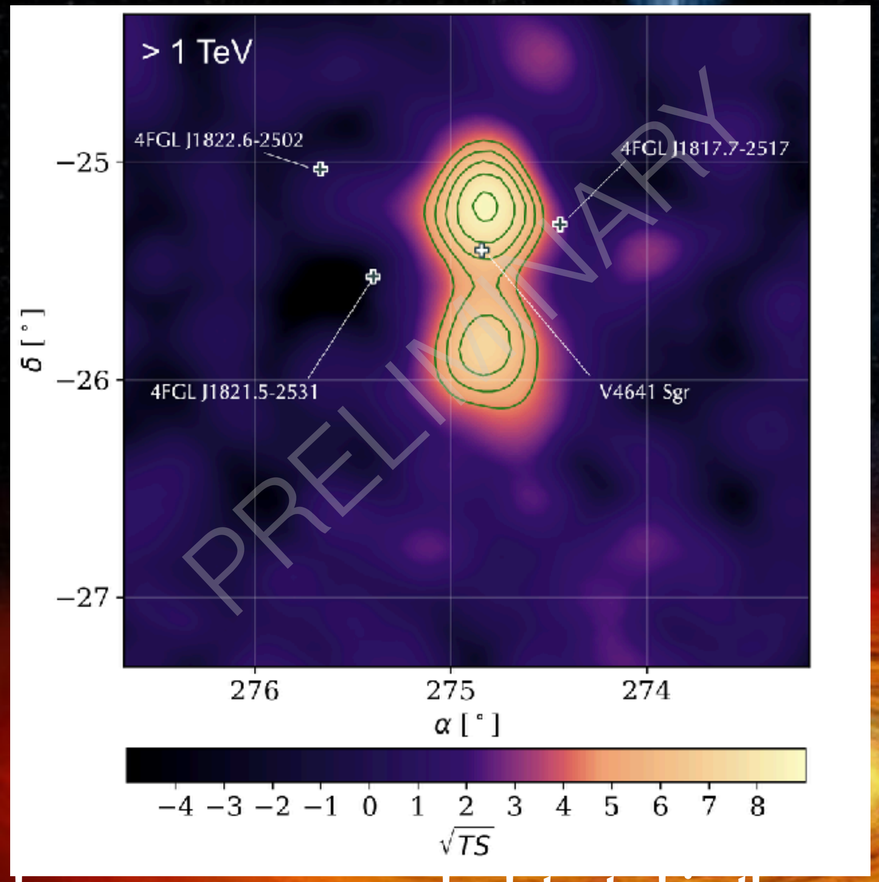
- HAWC see flux modulation at LS5039
- Inferior conjunction (INFC) $0.45<\phi\leq0.9$
- Superior conjunction (SUPC) $\phi \leq 0.45$or ϕ >0.9
- INFC flux have a factor of two compare to SUPC flux, similar power law indices
- No cutoff found in both low state and High state maps yet

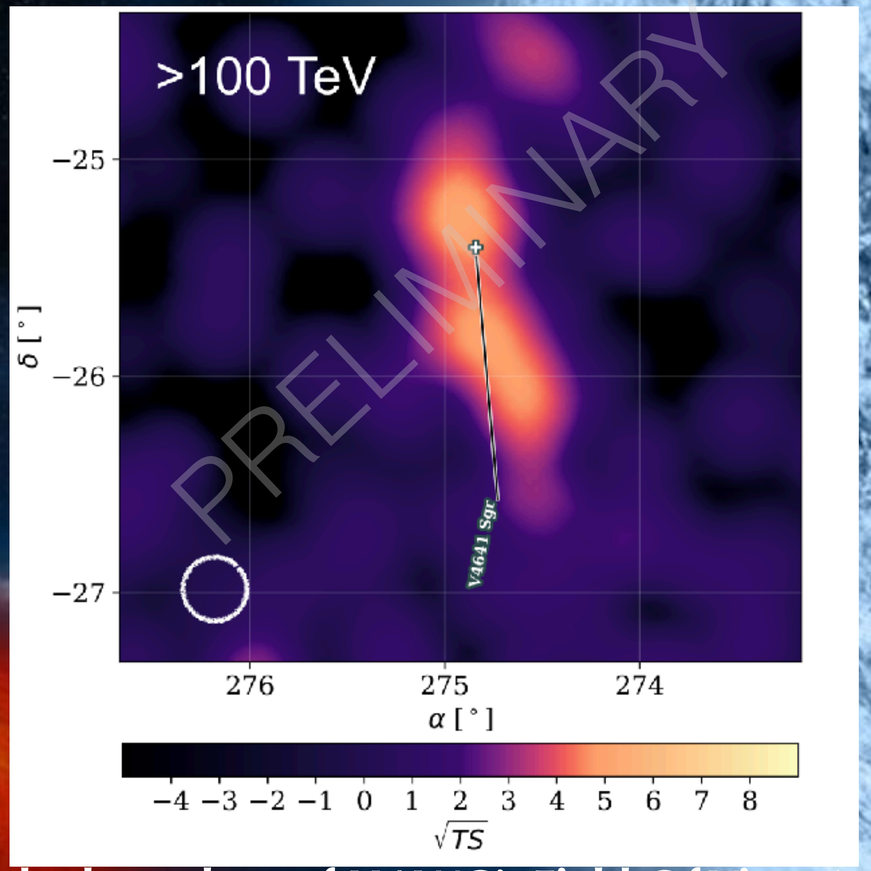
LS 5039 Spectrum



Credits:H.E.S.S. data points A&A, 460 3 (2006) 743-749

Microquasar V4641 Sgr.





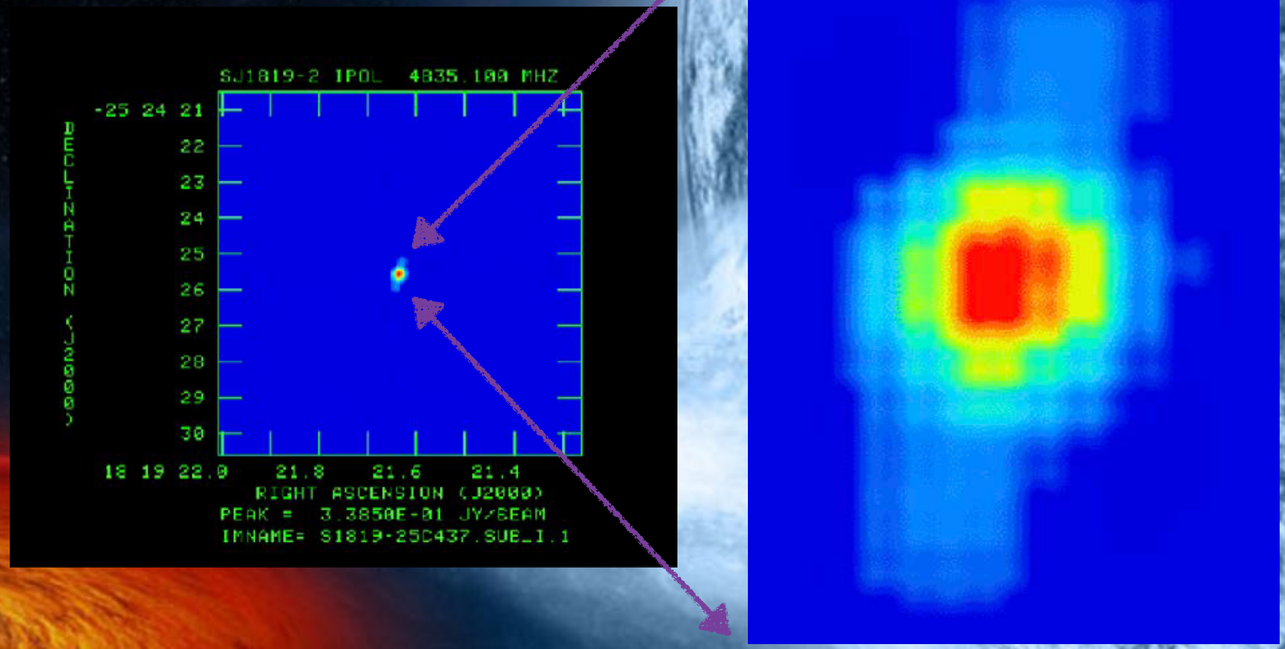
- A off-plane source was newly detected in the southern sky near the boundary of HAWC's Field Of View (~ 45° zenith)
- The excess is over the background at a 8 sigma pre-trail significance in all energy range and 5.2 sigma above 100 TeV
- The source position is coincident with V4641 Sgr.
- One of the fastest superluminal jets in the Milky Way galaxy

HAWC Collaboration, Nature (in press), 2024

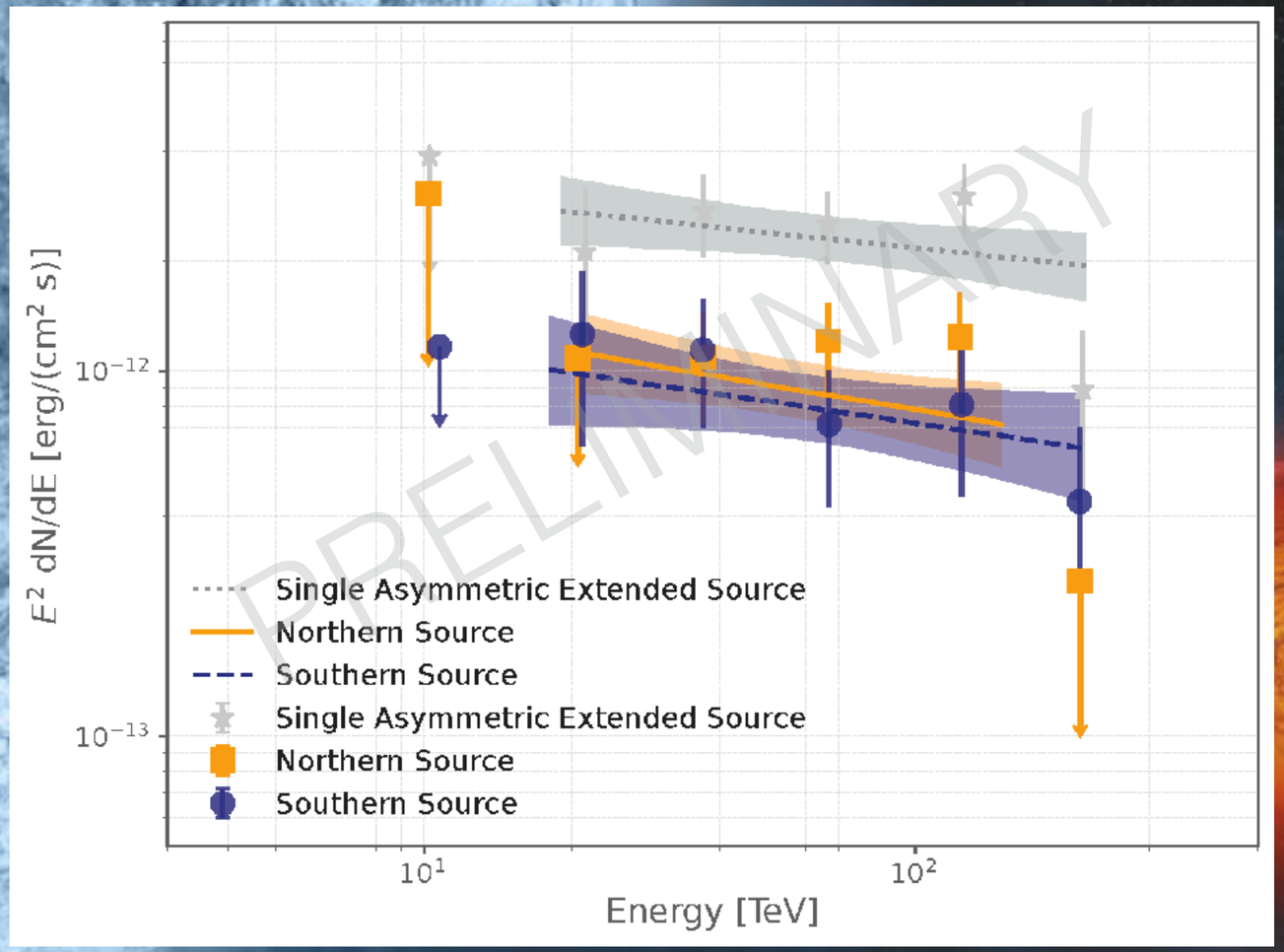
Microquasar V4641 Sgr.

- Distance is 6.6 kpc away from us
- Have a Companion star ~ 2.9 $M_{\odot}$
- Compact object should be a black hole with the mass ~ 6.4 $M_{\odot}$
- Orbital period ~ 2.8 days
- Stand out for it's violent X-ray outburst in September 1999
  - X-ray flux reached to 12.2 Crab in 8 hours
- Jet-like structure observed by VLA (0.25″)
  - Jet axis inclination: <16 °
  - Superluminal jets: apparent velocity 9.5 c

Credit: (R.M. Hjellming, NRAO, VLA, Associated Universities, Inc.)



Microquasar V4641 Sgr.

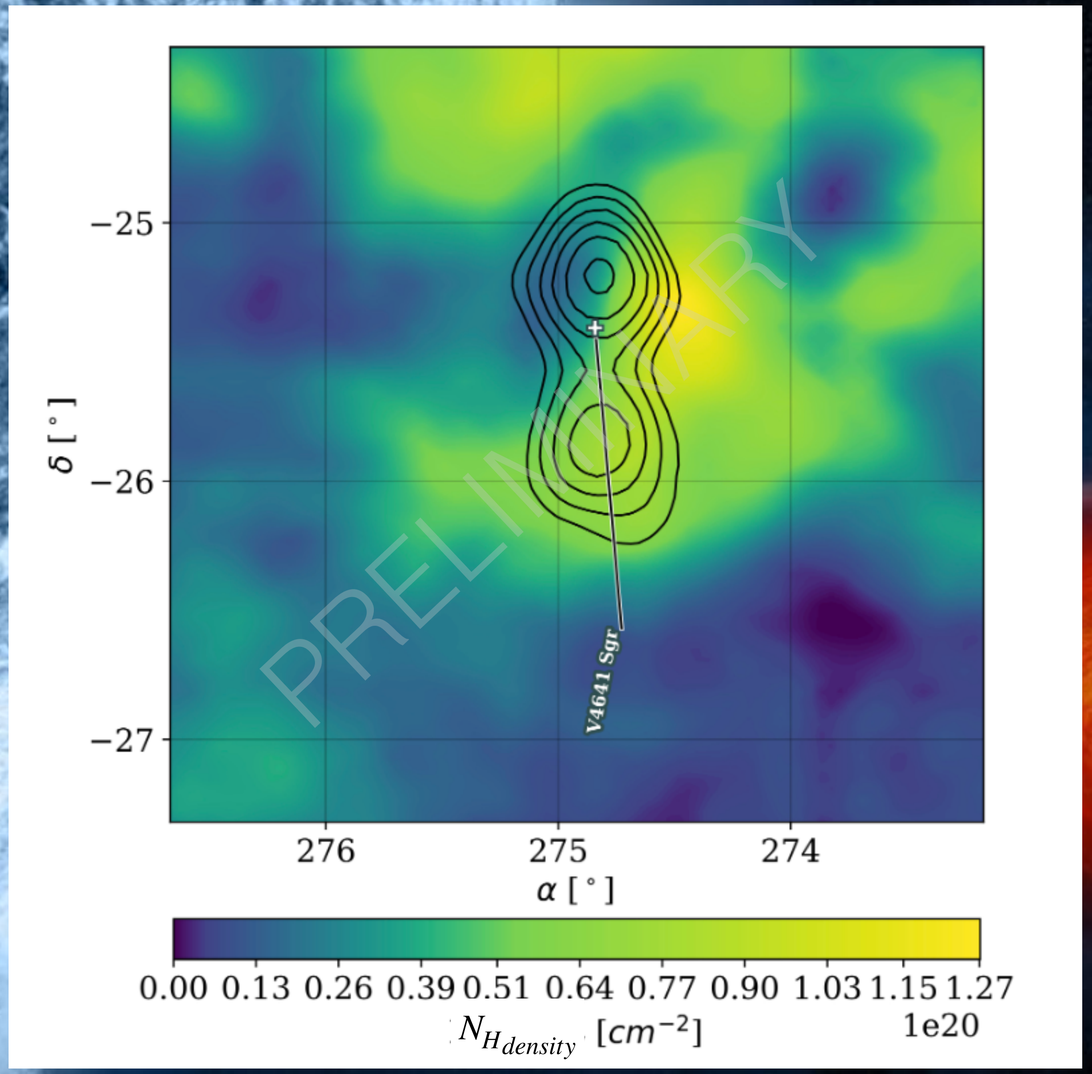


Nature (in press), HAWC, 2024

- Two-point source model or one elongated extended source
  - Similarity of spectral properties for two sources, likely share the same origin
  - Elongated source: ~70 pc
- Maximum energy >200 TeV

Microquasar V4641 Sgr.

Nature (in press), HAWC, 2024



The column density of atomic hydrogen

- Microquasars could be PeVatrons ?
- Leptonic scenario is challenging
- Multi-wavelength and multi-messenger follow up observations is needed to fully understand the nature of gamma-ray emissions

Upcoming Insights: Stay Tuned for More Results

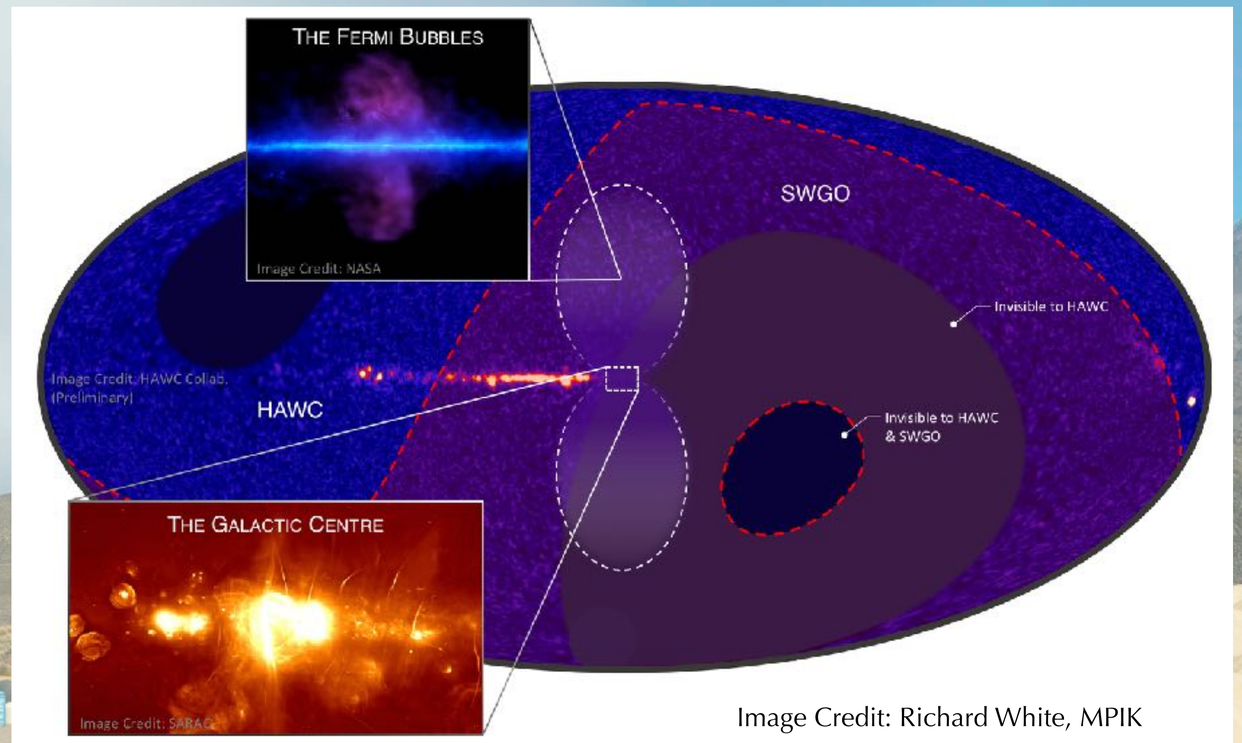
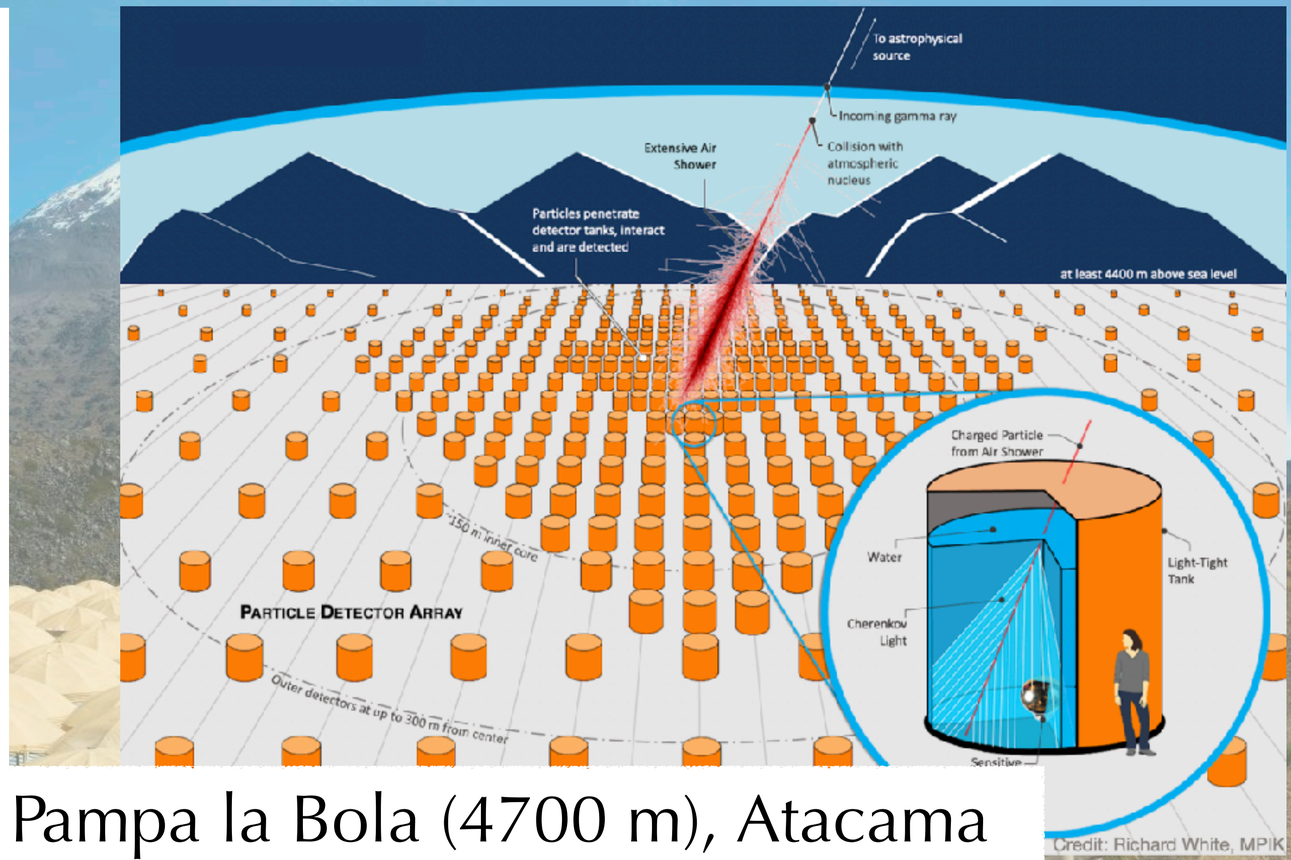


Image Credit: Richard White, MPIK



Credit: Richard White, MPIK

Breaking News: SWGO Site Chosen at Pampa la Bola (4700 m), Atacama Astronomical Park, Chile. [Press release]

Acknowledgments

NSF · Department of Energy, United States of America · CONACYT · Michigan Tech