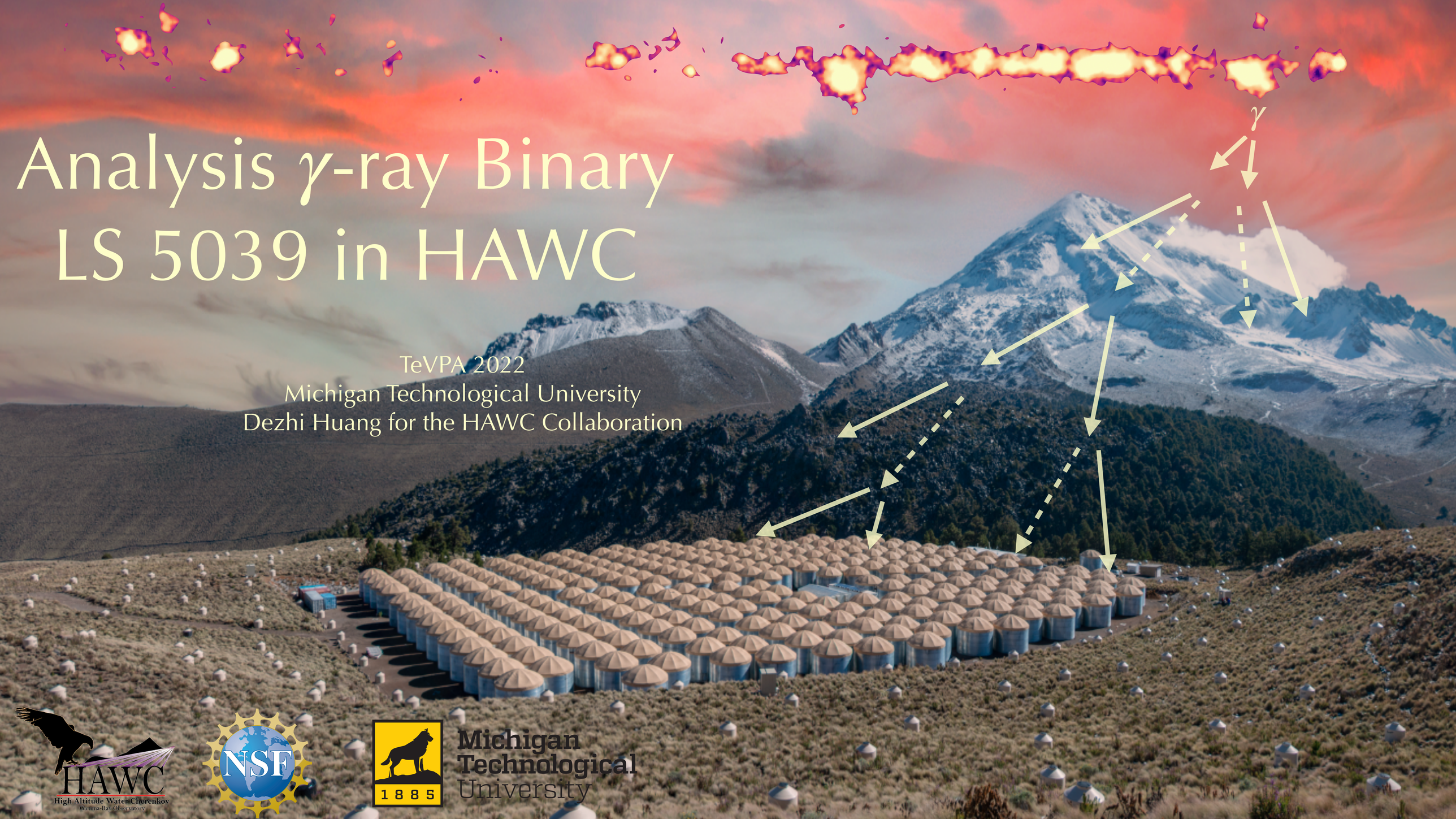
Analysis γ-ray Binary LS 5039 in HAWC



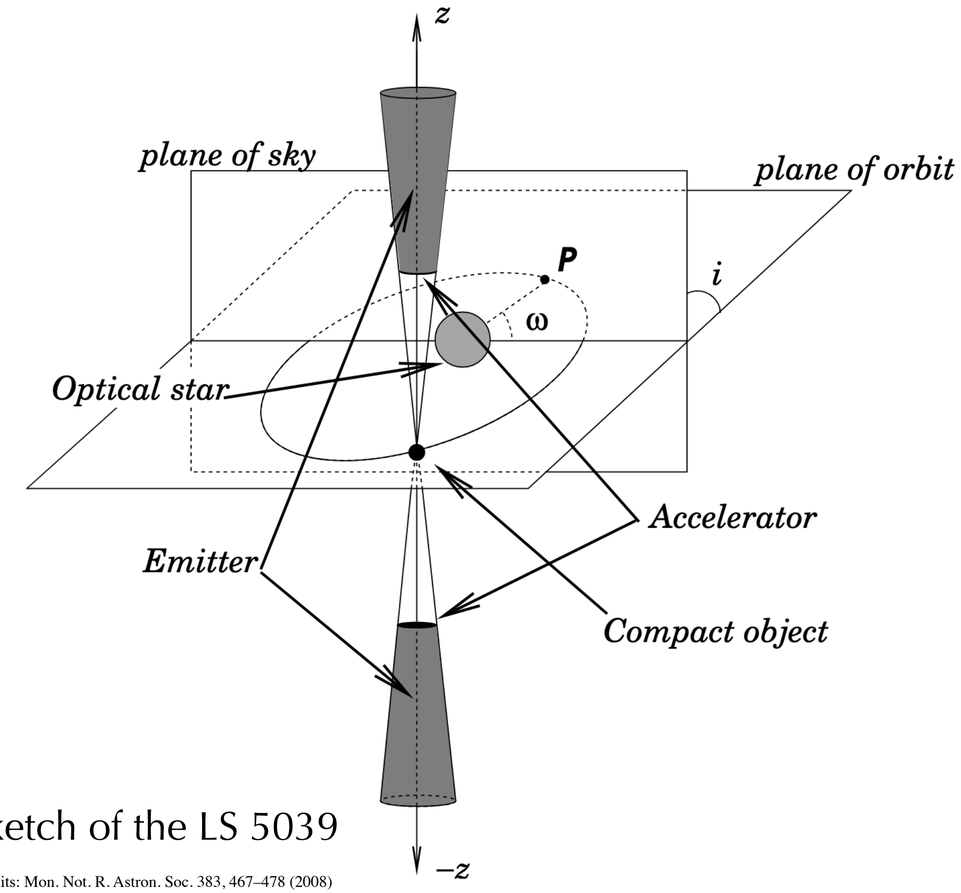
TeVPA 2022
Michigan Technological University
Dezhi Huang for the HAWC Collaboration

HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

NSF

1885
Michigan
Technological
University

High-mass γ-ray Binary LS 5039



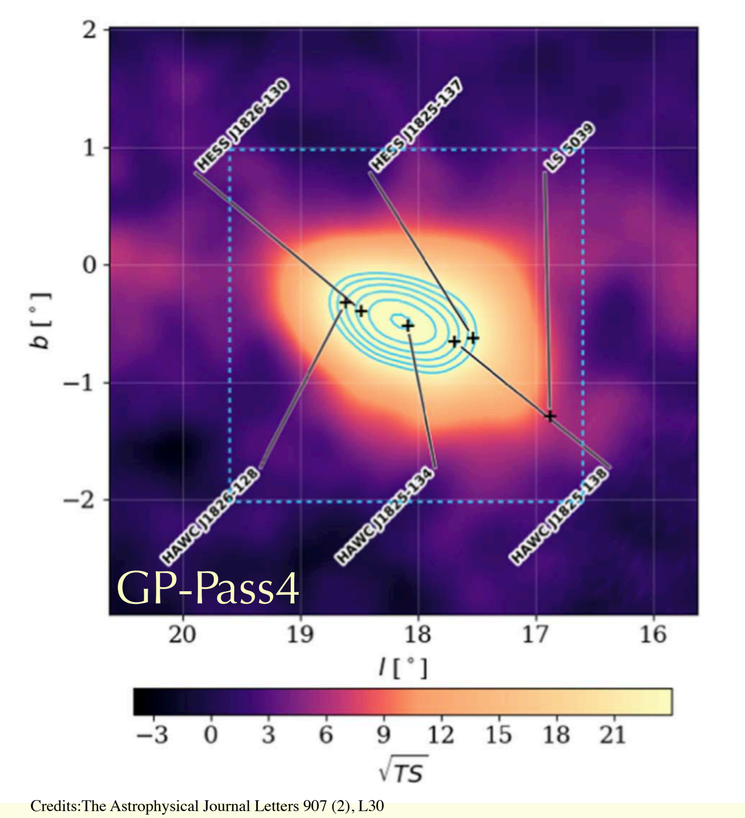
Sketch of the LS 5039

Credits: Mon. Not. R. Astron. Soc. 383, 467–478 (2008)

- Optical type O star has the mass ~ 22.9 (+ 3.4, -2.9) $M_\odot$
- The compact object 3.7 (+ 1.3, -1.0) $M_\odot$ Pulsar? Black Hole?
- The orbit period is ~ 3.9 days
- Located ~ 1.5° from galactic plane

LS 5039 at HAWC

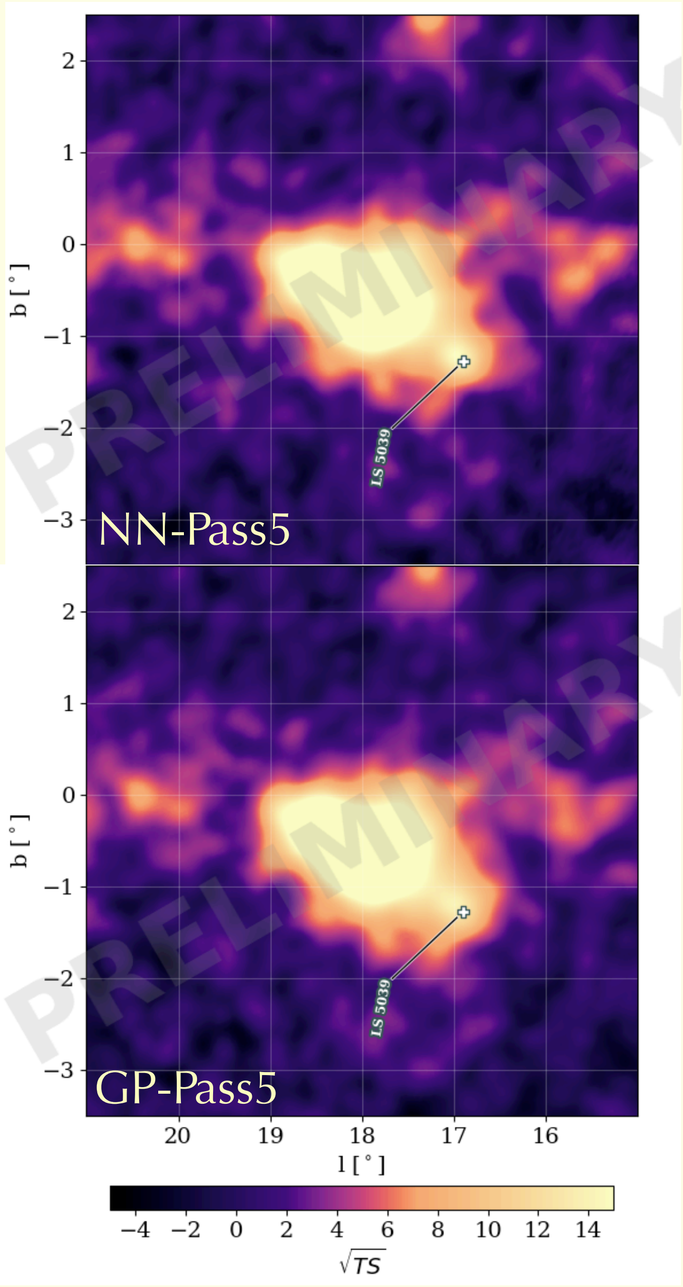
- We are unable to resolve LS 5039 in HAWC Pass4 maps



Credits:The Astrophysical Journal Letters 907 (2), L30

Pass4 → Pass5

Improvement of angular resolution



Two independent energy estimators

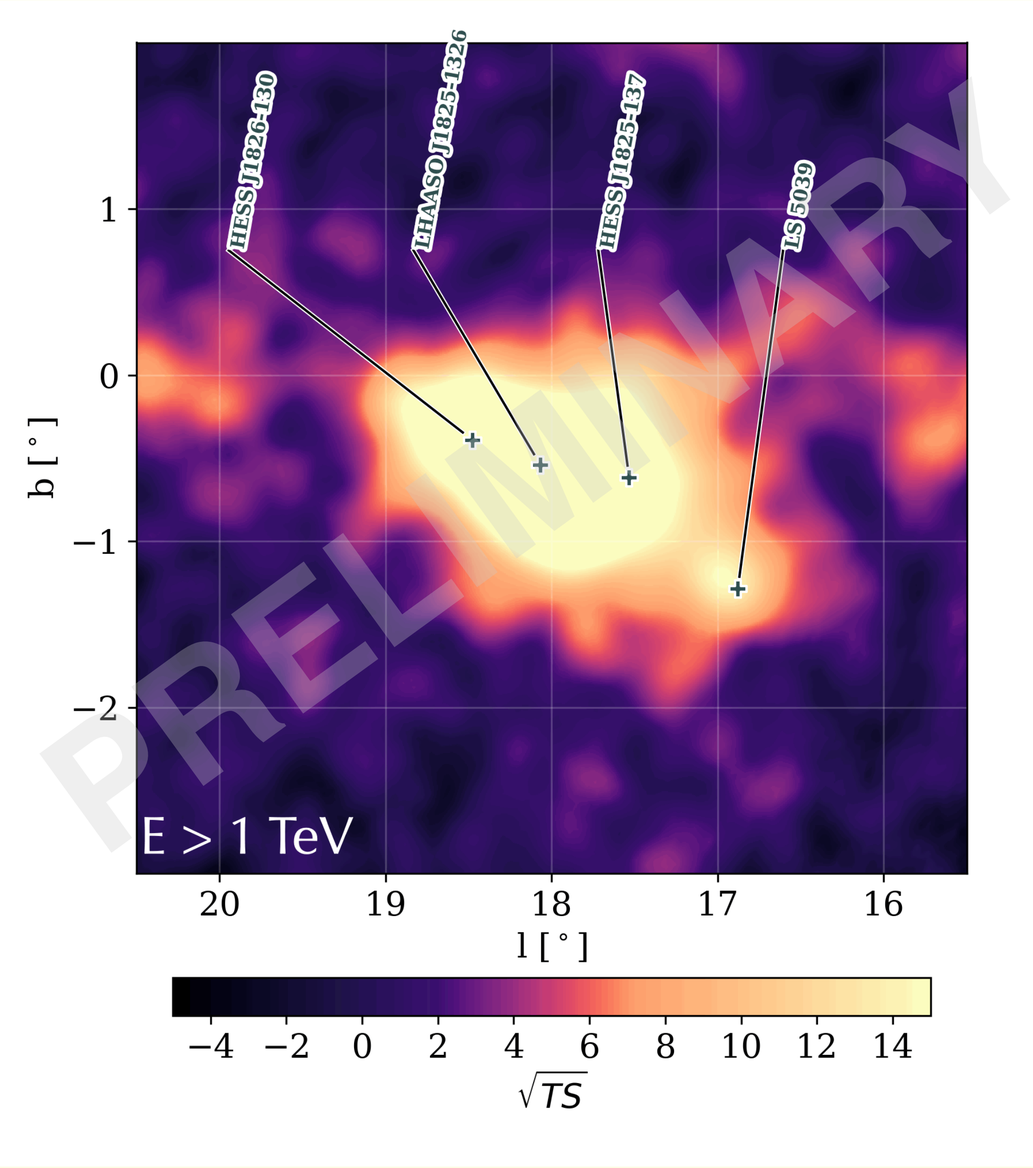
Neural network(NN)

- Using artificial neural network to estimate the energy of primary gamma-rays

Ground Parameter(GP)

- Using charge density at certain distance from shower axis to estimate the energy of primary gamma-rays

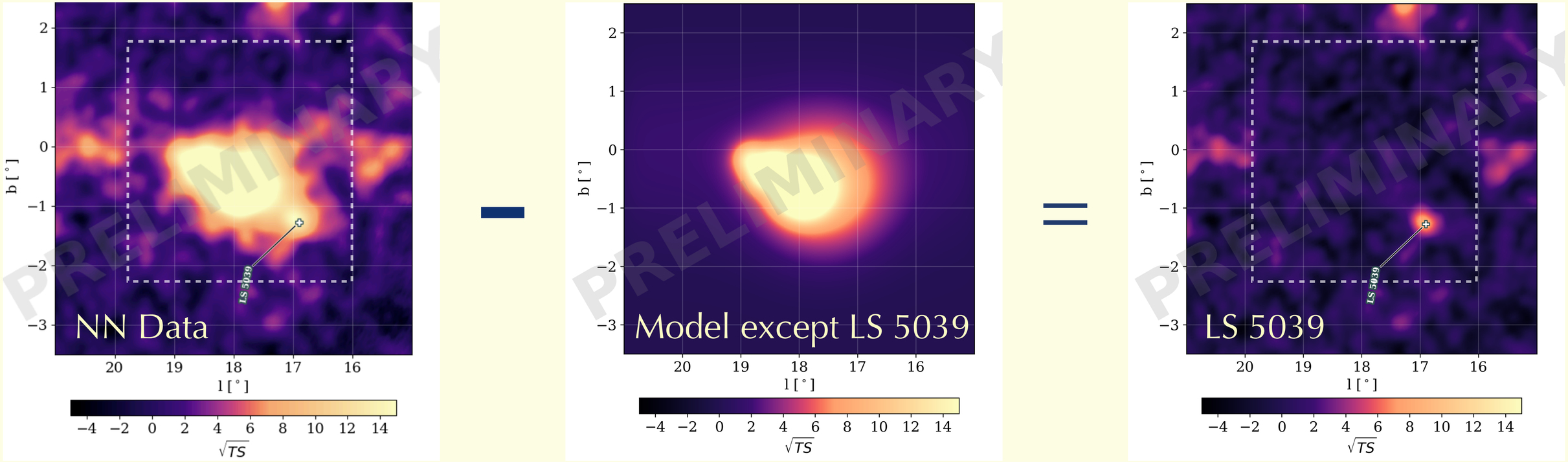
LS 5039 at HAWC



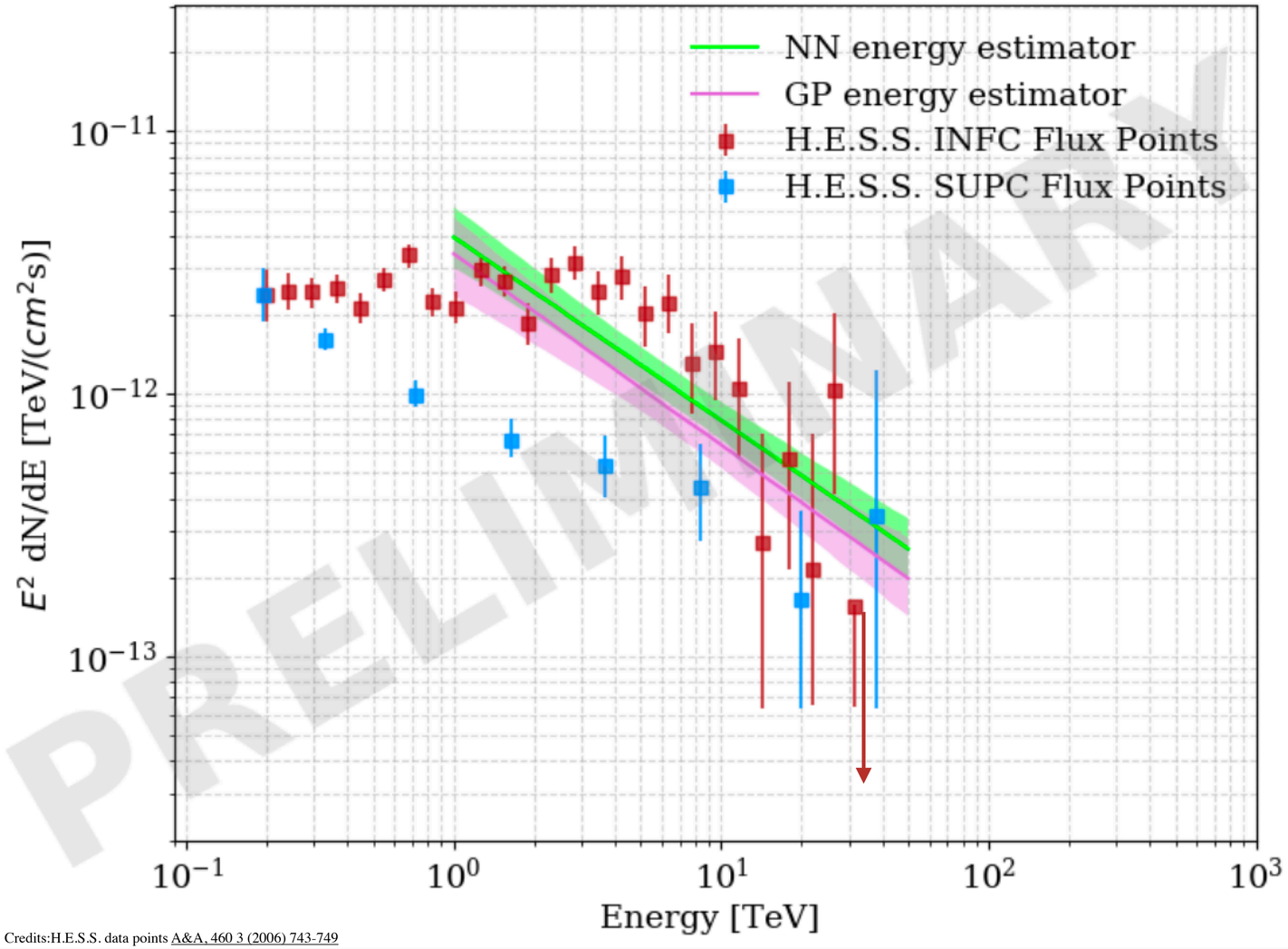
- Hotspot found in the LS 5039 location
- Hotspot start separate from J1825 region when we move to high energy
- To isolate the LS 5039 from this complex region:
    1. Diffuse background emissions
    2. J1825 contamination

Modeling the Region

- Simultaneously likelihood fit performed inside the region of interest
- Model includes diffuse background emission and all background sources
- Same analysis repeated using GP map



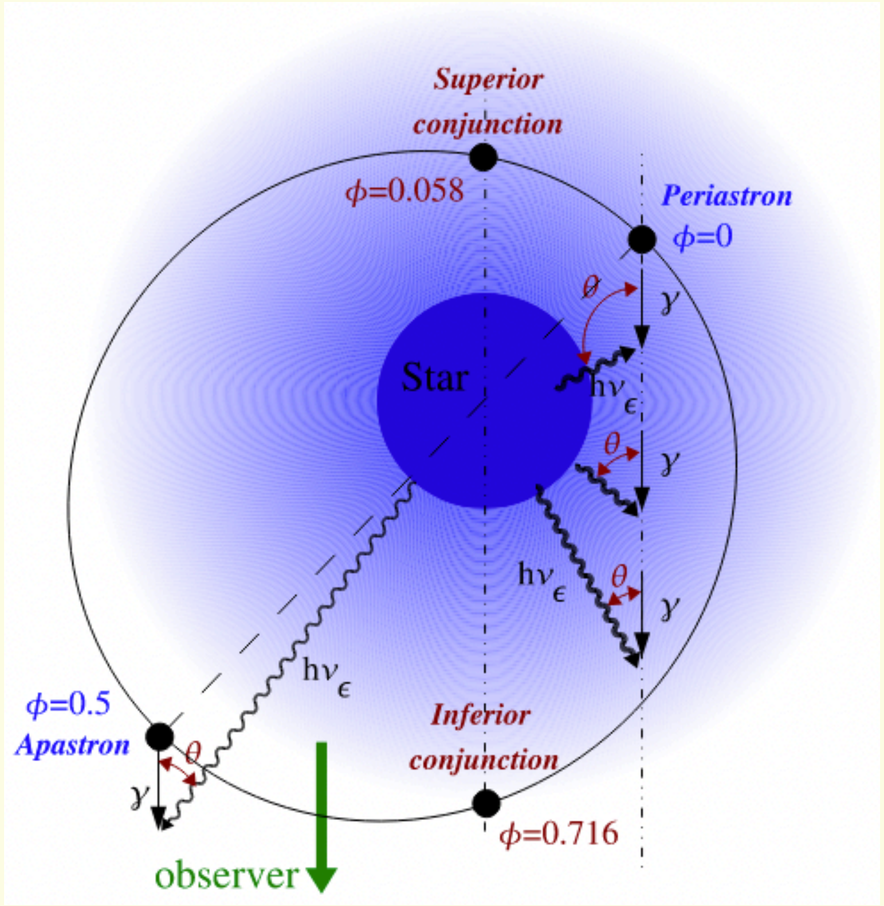
Spectrum Analysis



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

- Pure powerlaw is preferred in both of HAWC maps
- HAWC spectrum is located in between of H.E.S.S. INFC and SUPC
- Can we distinguish high and low states HAWC ?

Analysis Procedure



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

HAWC Data Using NN Energy Estimator

Inferior conjunction (INFC) | Superior conjunction (SUPC)

High State $0.45<\phi\leq 0.9$ | Low State $\phi \leq 0.45$ or $\phi>0.9$

Separate HAWC data

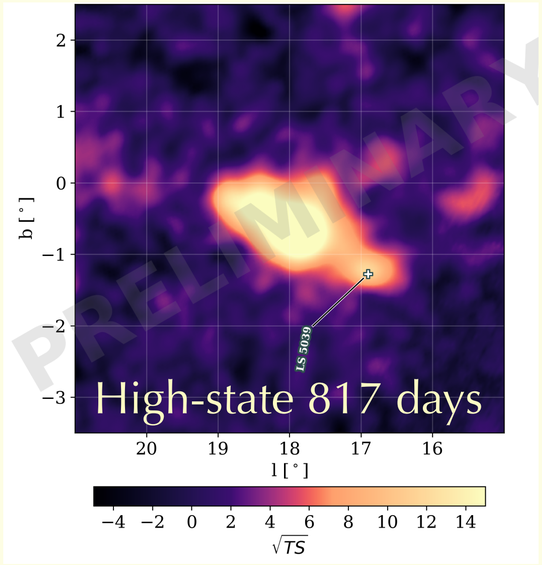
High State Data | Low State Data

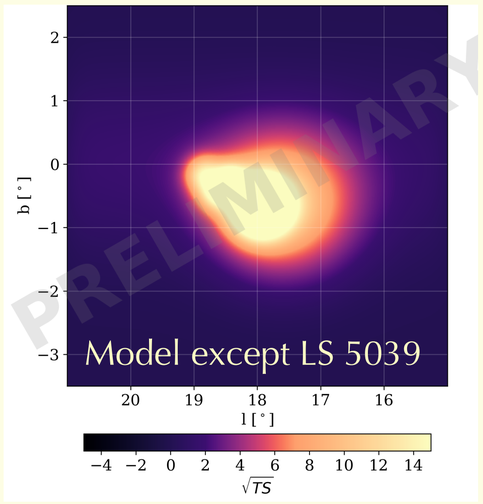
Map Maker

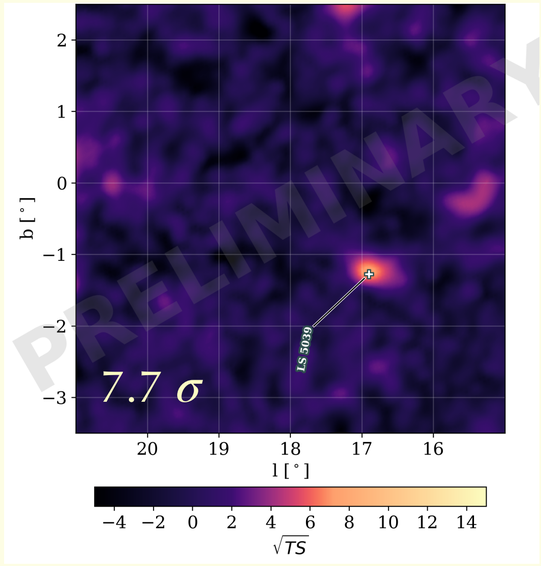
High State Map 817 Days | Low State Map 1003 Days

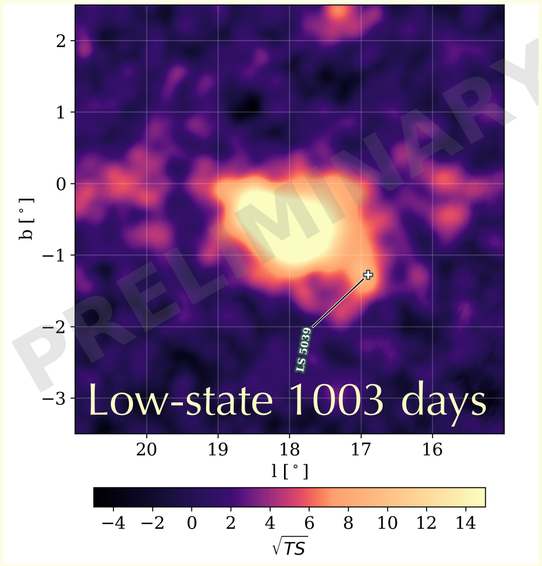
Analysis

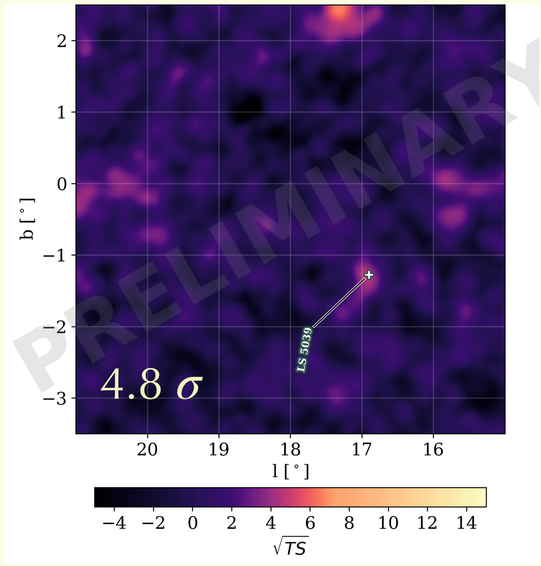
Study the Flux Modulation





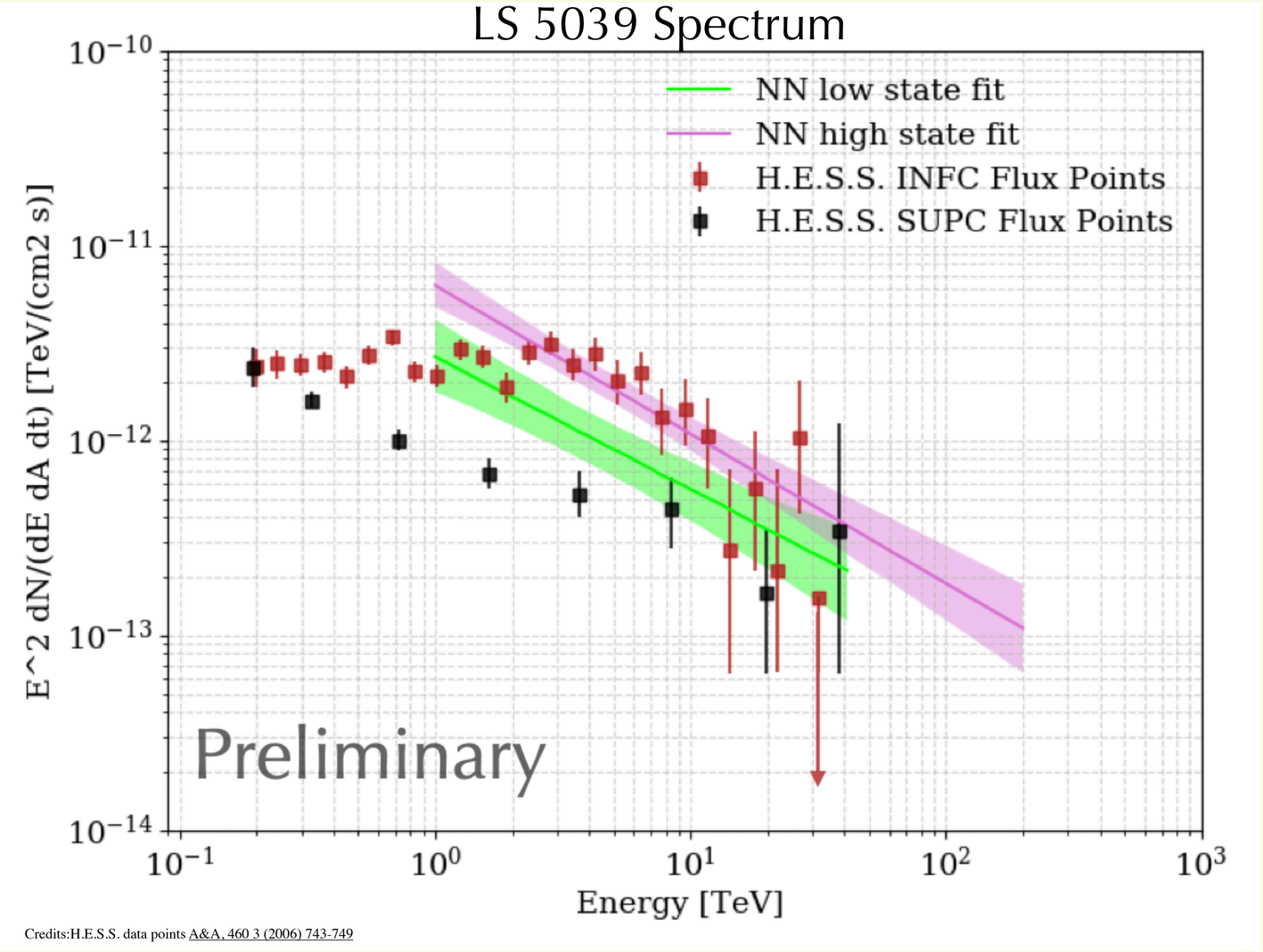






- High state accumulate data at ~ 0.27σ per day
- Low state accumulate data at~ 0.15σ per day

Spectrum Analysis

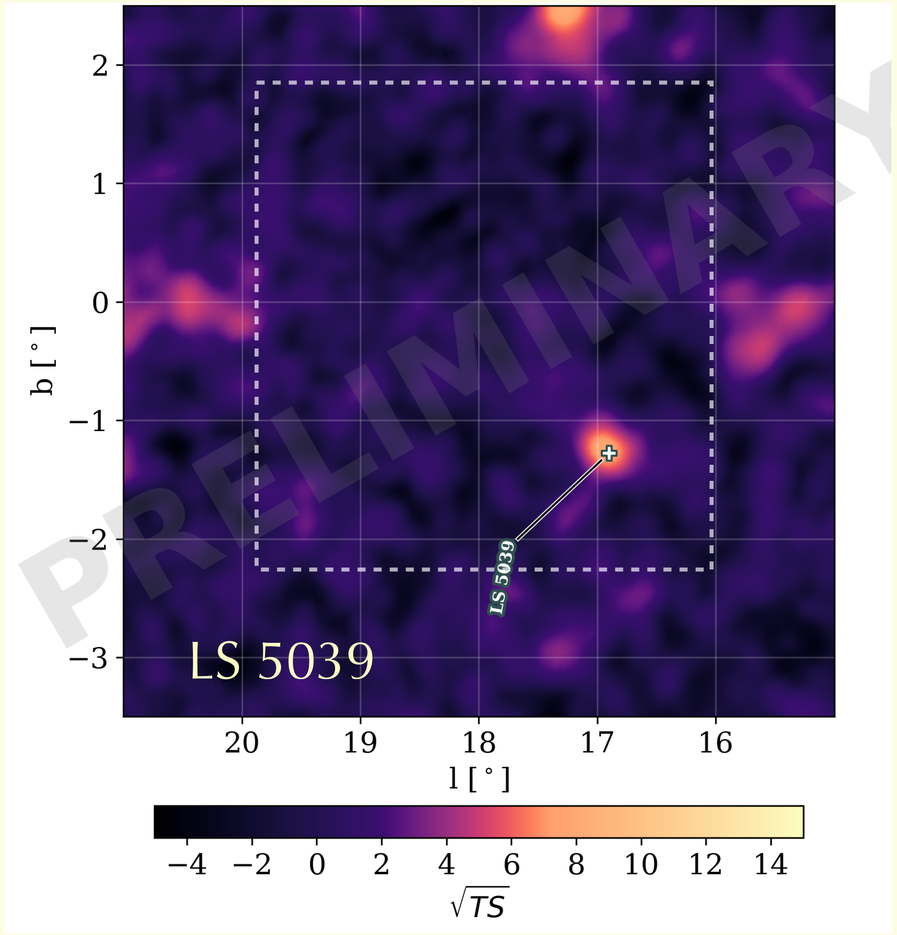


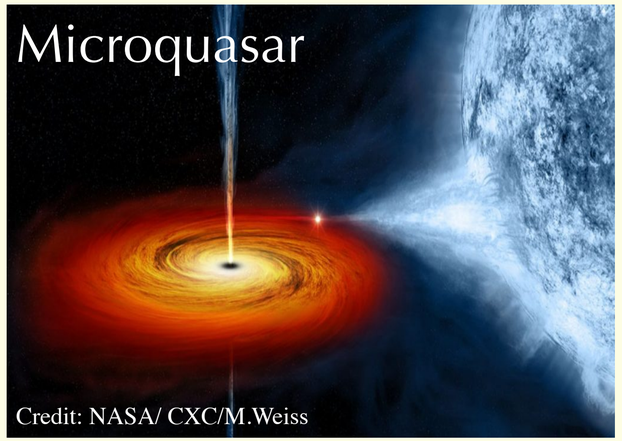
Credits:H.E.S.S. data points A&A, 460 3 (2006) 743-749

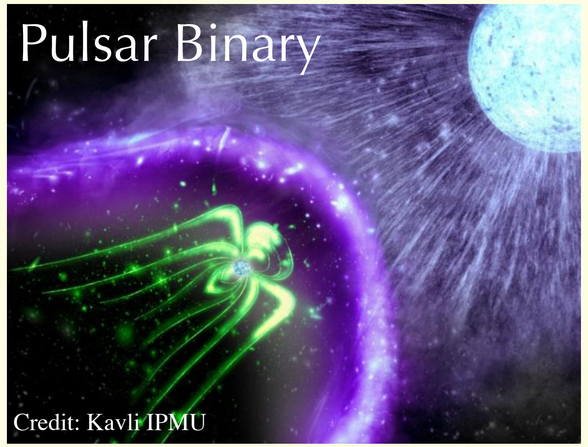
- HAWC see flux modulation at LS5039
- High state flux have a factor of two compare to low state flux
- High and low state have similar powerlaw index
- No cutoff found in both low state and High state maps yet

High Energy Emission from LS 5039

HAWC Observation







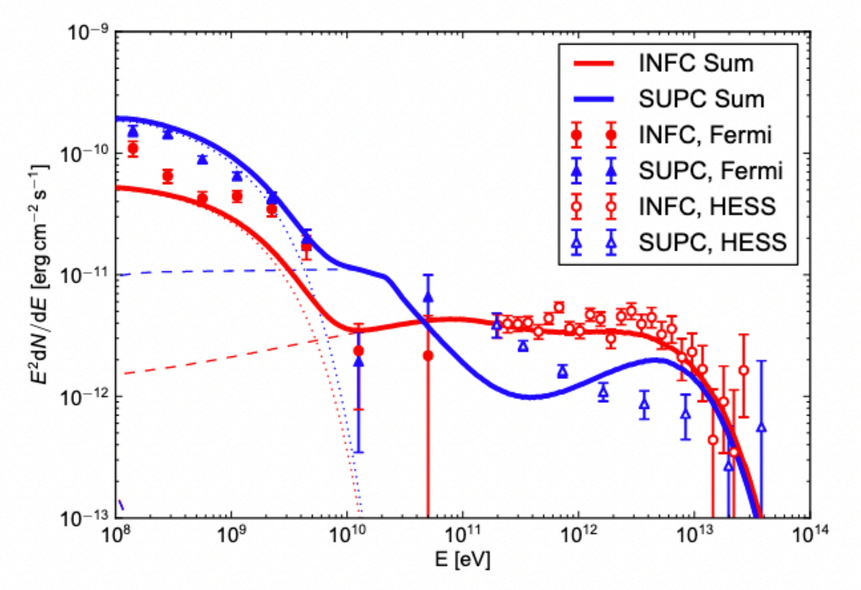
Powerful Outflows

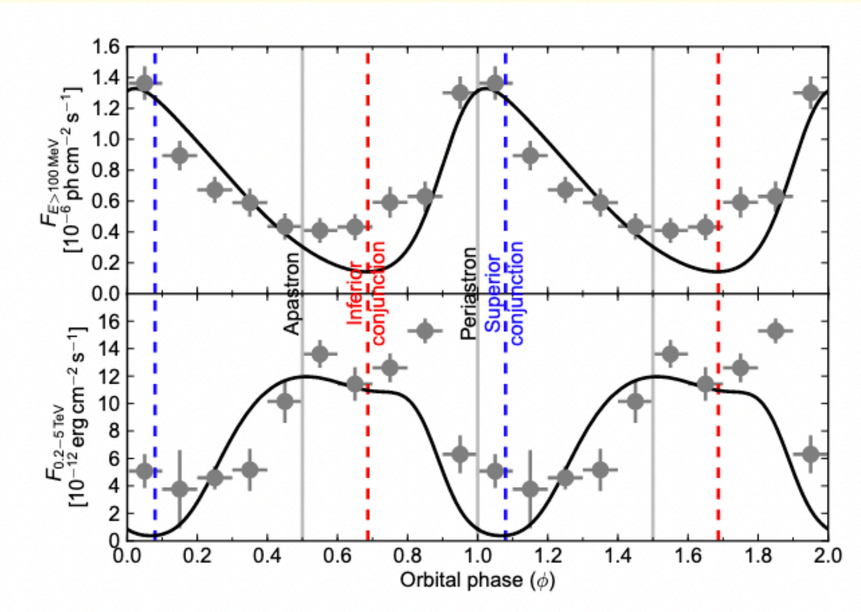
Acceleration

Jet formation through matter accretion

Interaction between pulsar wind and star wind

Mirrored Modulation

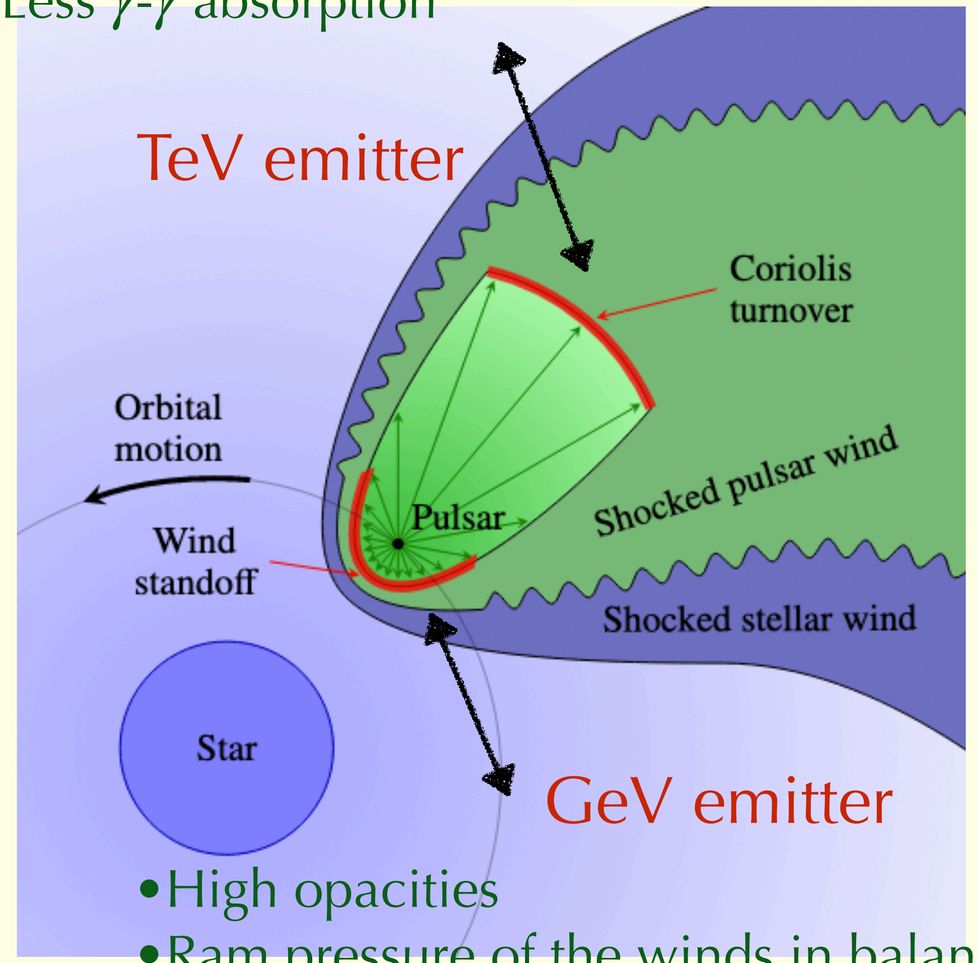




Fermi
100 MeV to 30 GeV

H.E.S.S.
200 GeV to 5 TeV

- Ram pressure of the stellar wind owing to Coriolis forces
- Less γ-γ absorption

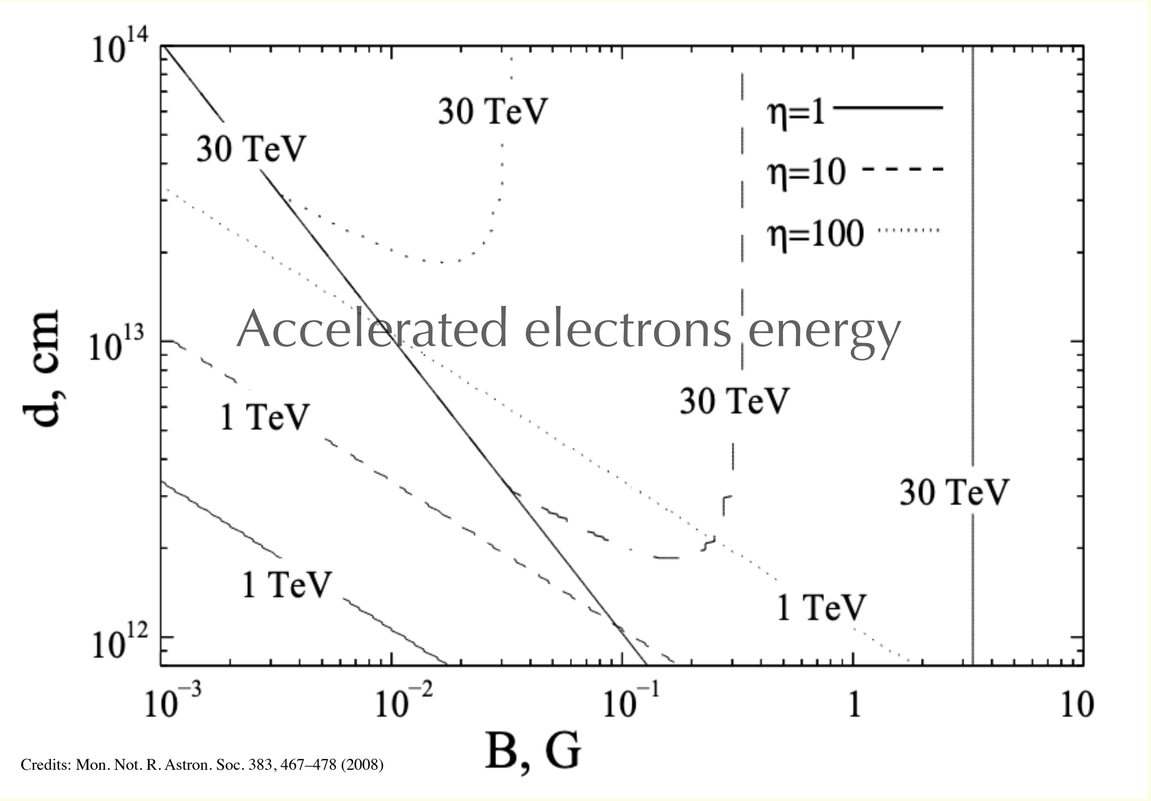


- High opacities
- Ram pressure of the winds in balance

A&A 551, A17 (2013)

High Energy Emission from LS 5039

Maximum γ-ray energy from HAWC can constrain



Credits: Mon. Not. R. Astron. Soc. 383, 467–478 (2008)

How efficient the accelerator is?

Very efficiently with η even < 10

Where is γ-ray produced?

Not be located deep inside the binary

What is the magnetic field?

B < 0.1 G? Cannot explain if X-ray emission modulated as TeV emission

Conclusion & Outlook

- HAWC able to disentangle the LS 5039 from complex J1825 region with improved angular resolution
- HAWC see flux modulation at LS 5039 respect to different orbital phase
- Spectrum analysis in both high and low states prefer pure powerlaw and similar index without cutoff
- Detailed studies at highest energy will help us understand the nature of LS 5039
- More results will come in our up coming publication

Acknowledgments:

Thanks for your attention!

Question are welcome!

Backup