The Peanut

One of the most significant and mysterious discoveries by LHAASO

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On behalf of LHAASO collaboration

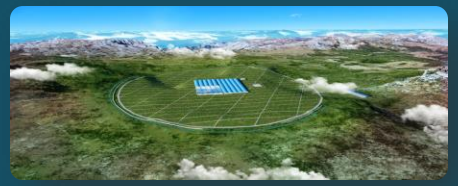
The *TAUP2025*, Xichang, 27 August

Outline

1. The LHAASO experiment
2. Discovery of Peanut
3. How is Peanut formed?
4. Conclusion

1 The LHAASO experiment

Key Science
Origin of Cosmic-ray



VHEγ Astronomy
LHAASO、CTA

EHE cosmic ray
AUGER、JEM-EUSO

VHE/UHE neutrino astronomy
ICECube

LHAASO, 1.3km^2, 4410m a.s.l

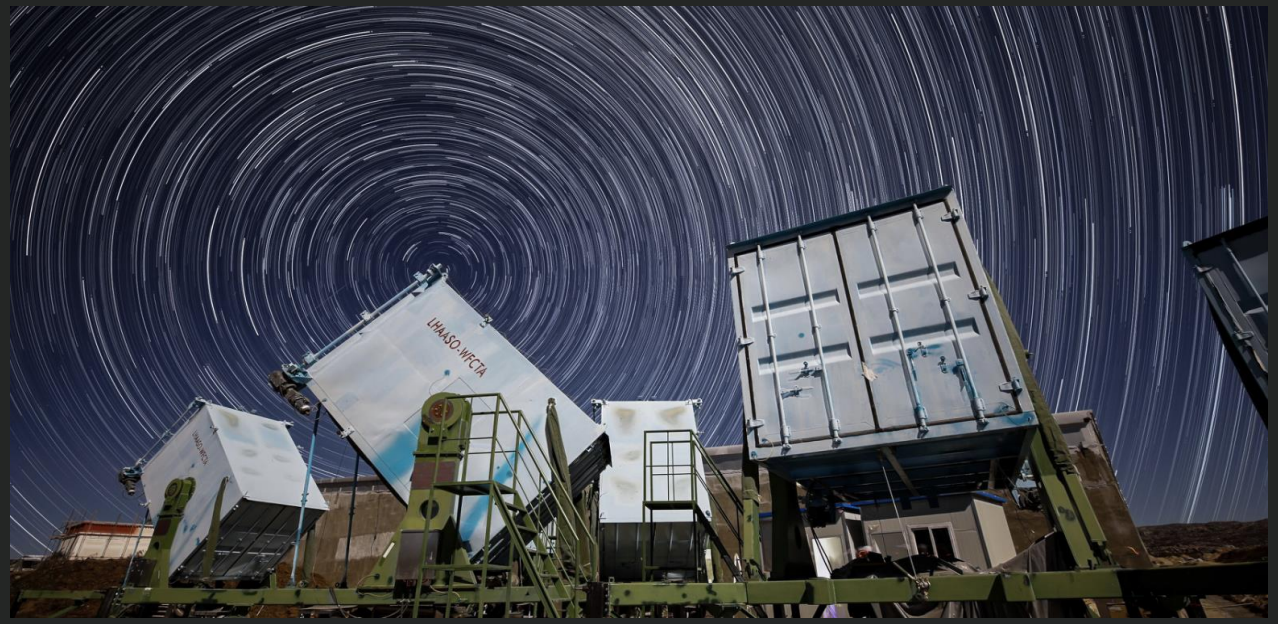
Daocheng, Sichuan, China
the southeastern edge of the Qinghai-Xizang Plateau

since 2021

The KiloMeter Square Array (KM2A)

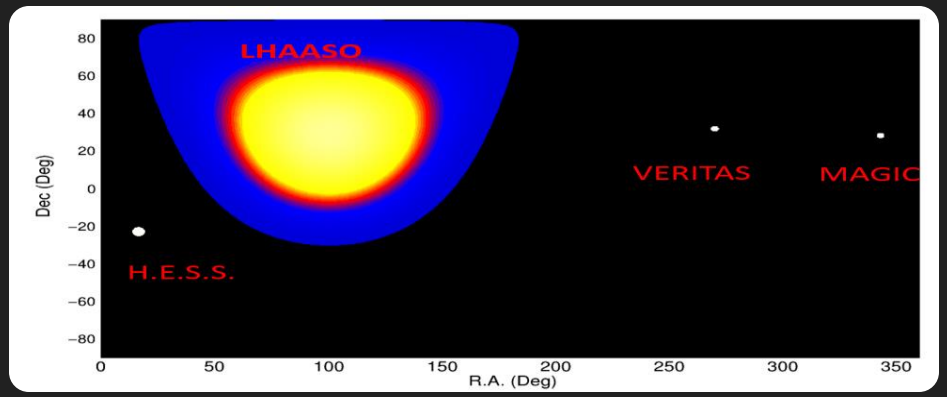
The largest water Cherencov detector array (WCDA)

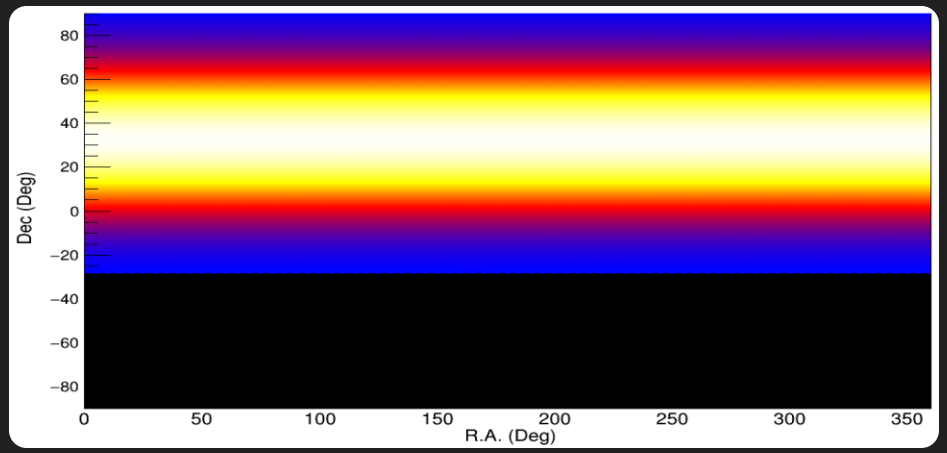
Wide field-of-view Cherenkov Telescope Array (WFCTA)

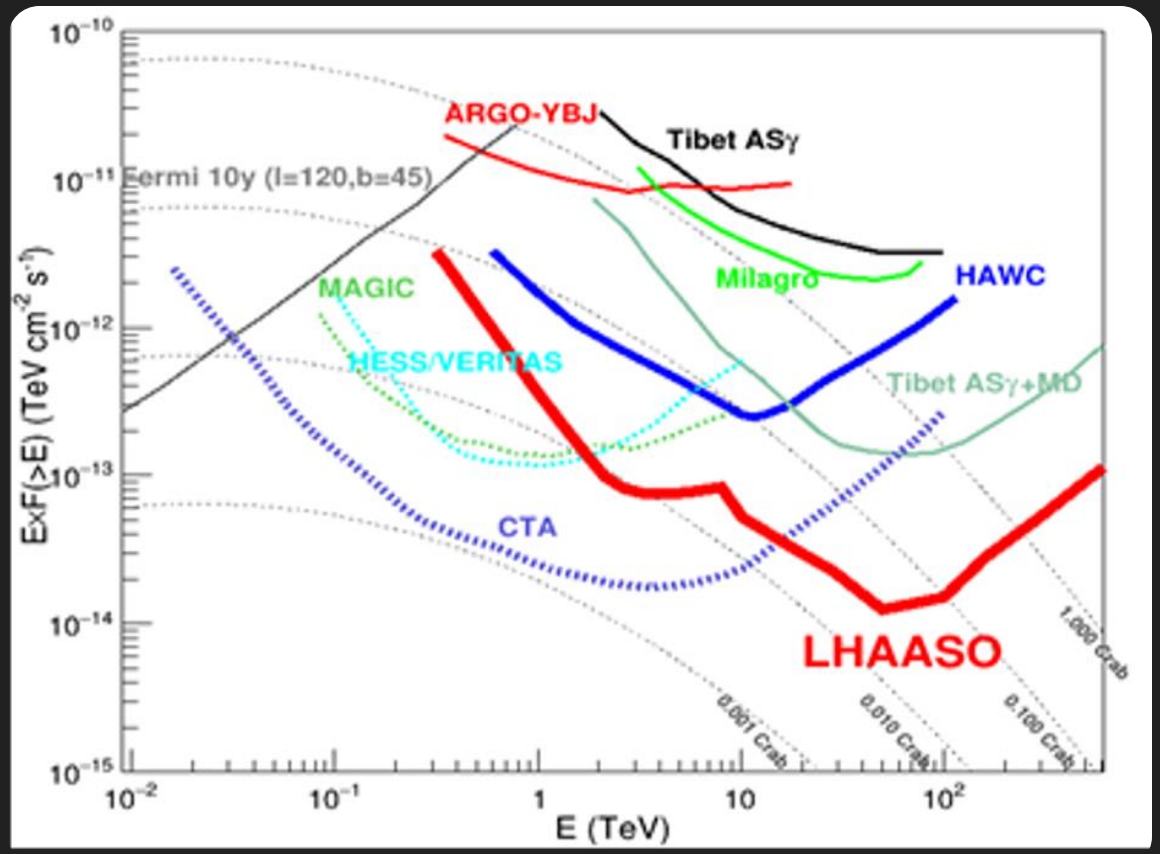


LHAASO: 0.3TeV-100000TeV

LHAASO can monitor 1/7 of the entire sky at any given time

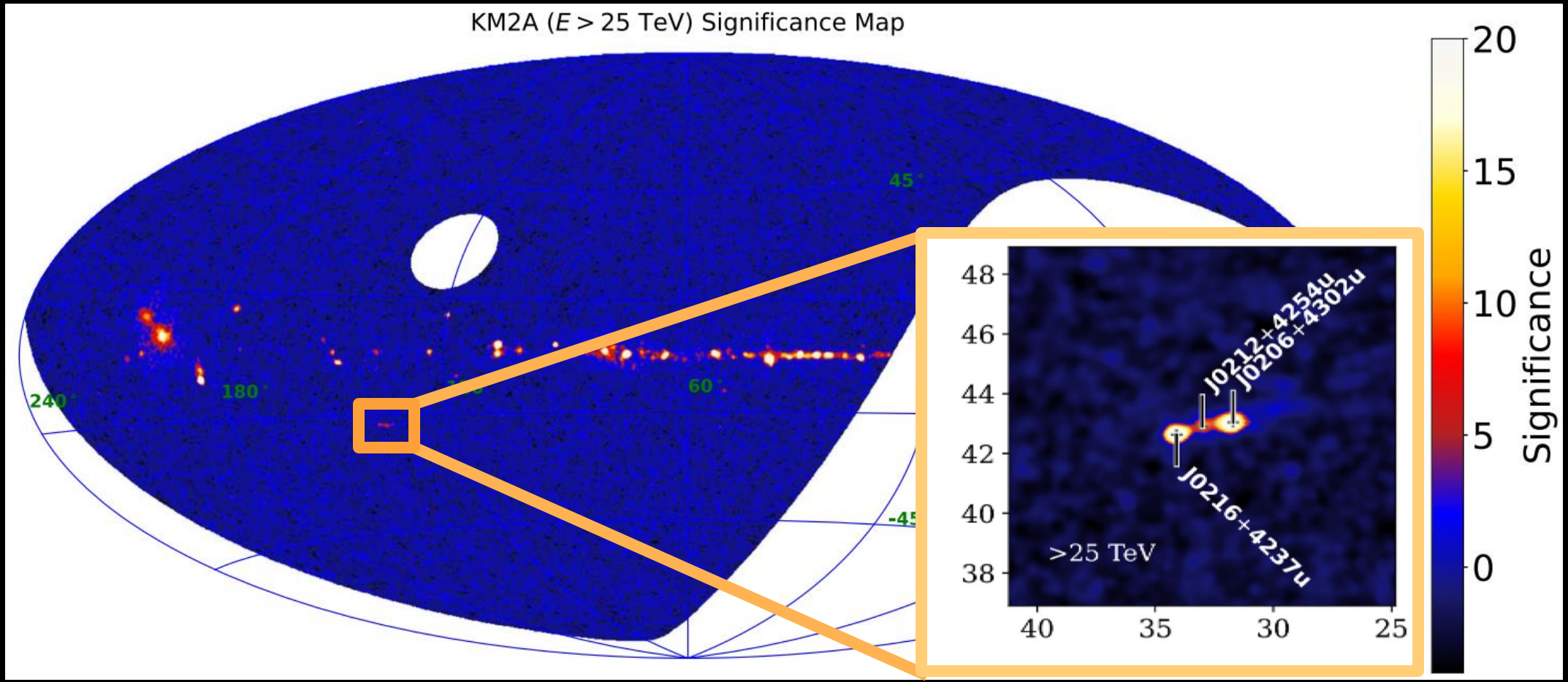






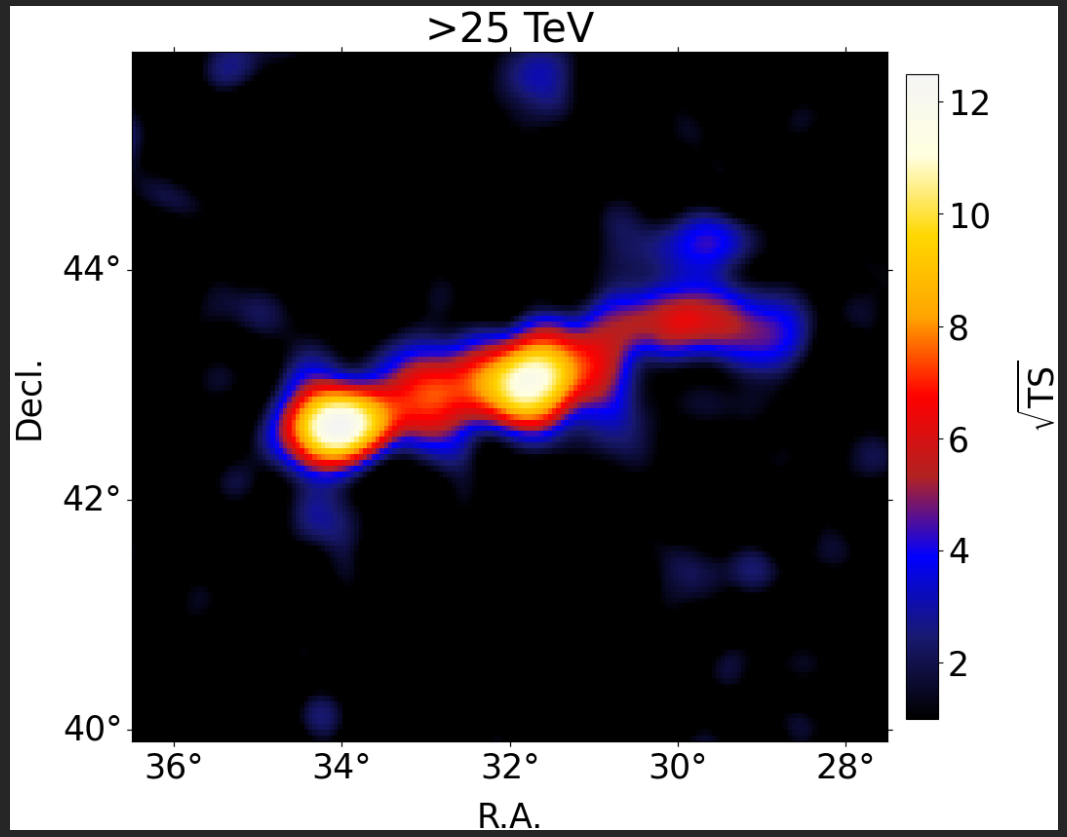
2 Discovery of Peanut

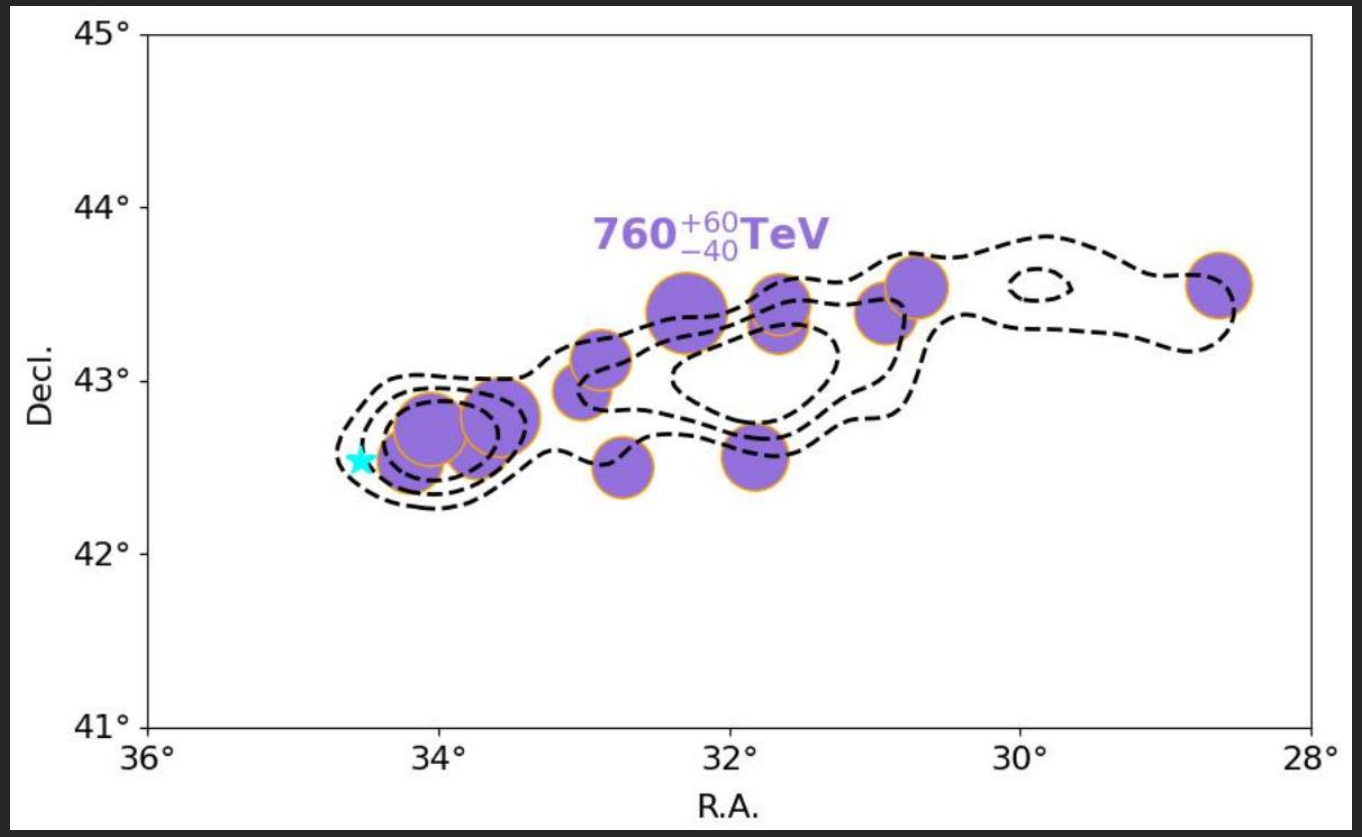
The significance map of gamma-ray radiation above 25 TeV



ApJS, 2024, 271:25

The Peanut ——1384 days observation by KM2A

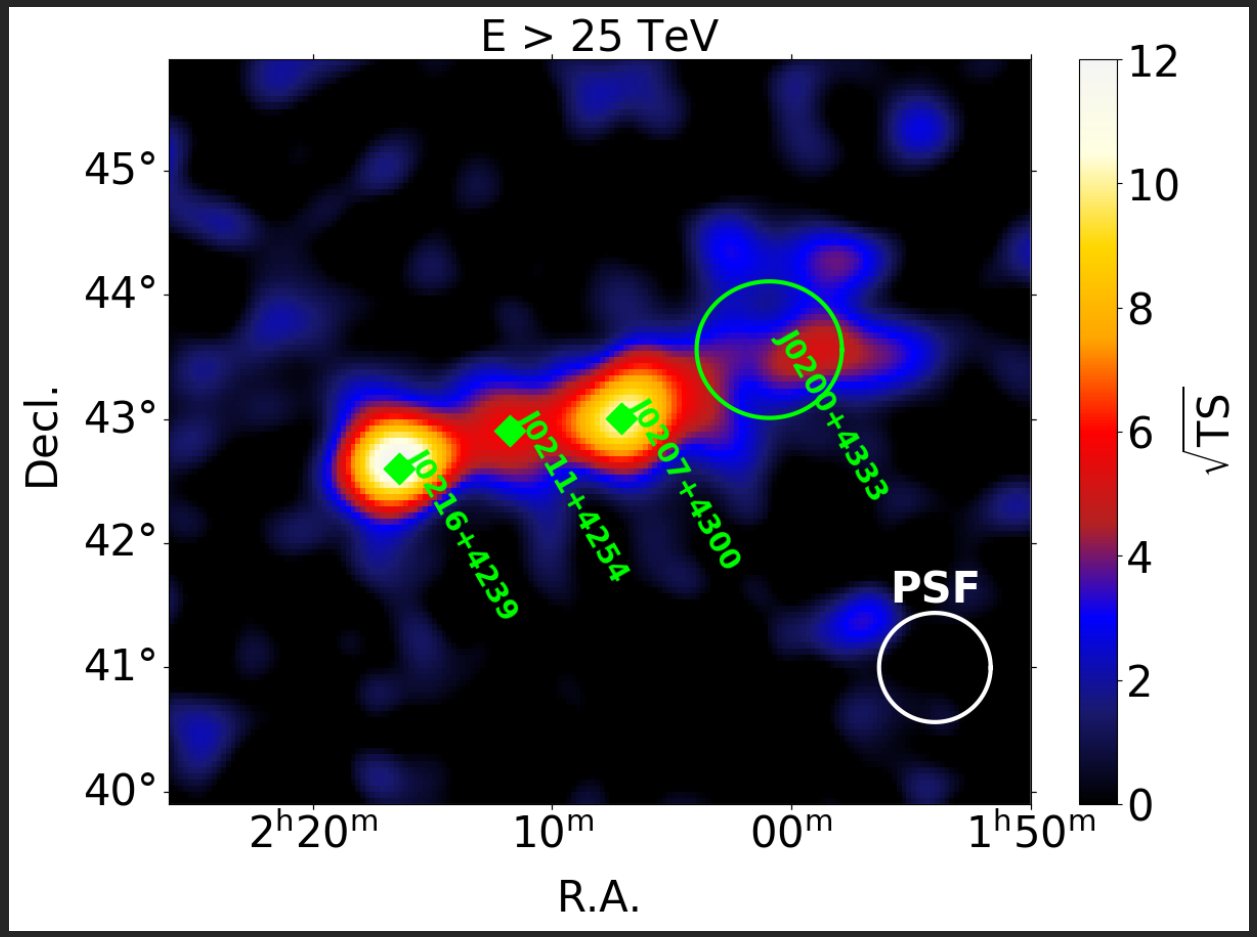




≃5° in length, ≃ 0.5 ° in width

E_γ> 400TeV

What's the connection hidden in the radiation?



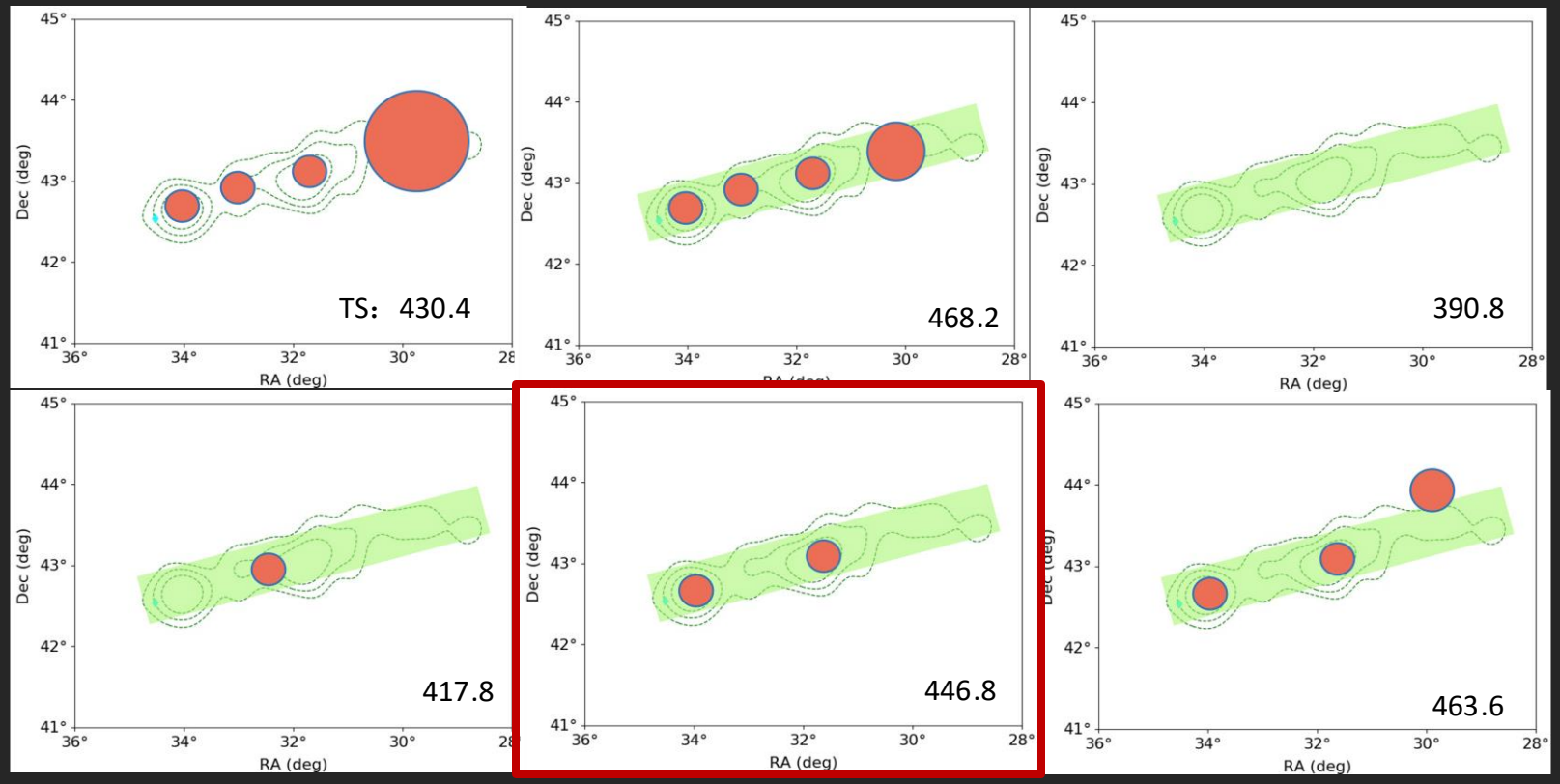
$$\frac{dN}{dE} = J_0(\mathrm{E}/E_0)^{-\Gamma}$$

Γ: 2.68±0.15
2.57±0.17
2.66±0.16
2.60±0.14

They have a similar spectrum behavior!

$p_{ch} \simeq 8 \times 10^{-7}$ ***!***

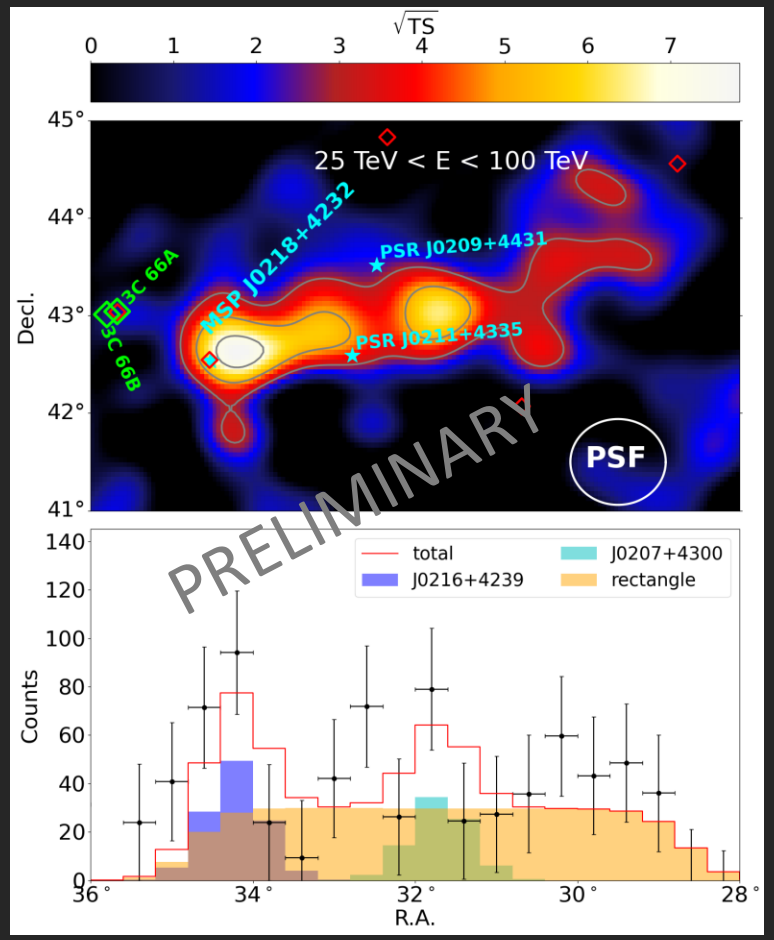
What exactly is the morphology?

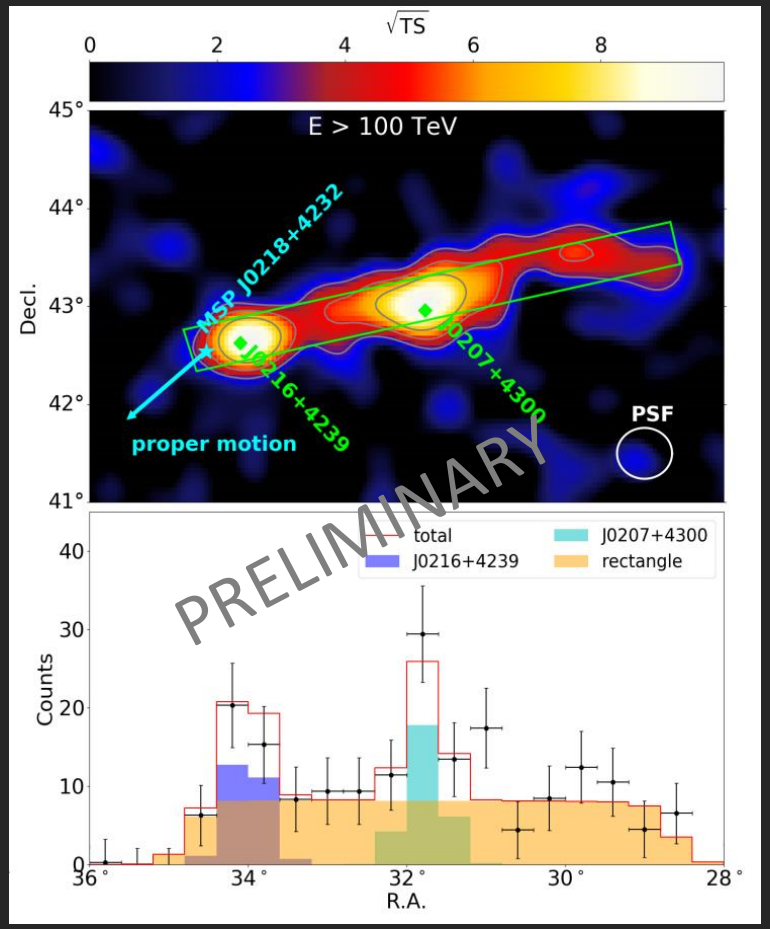


Favor three components:

Two point-like + one strip

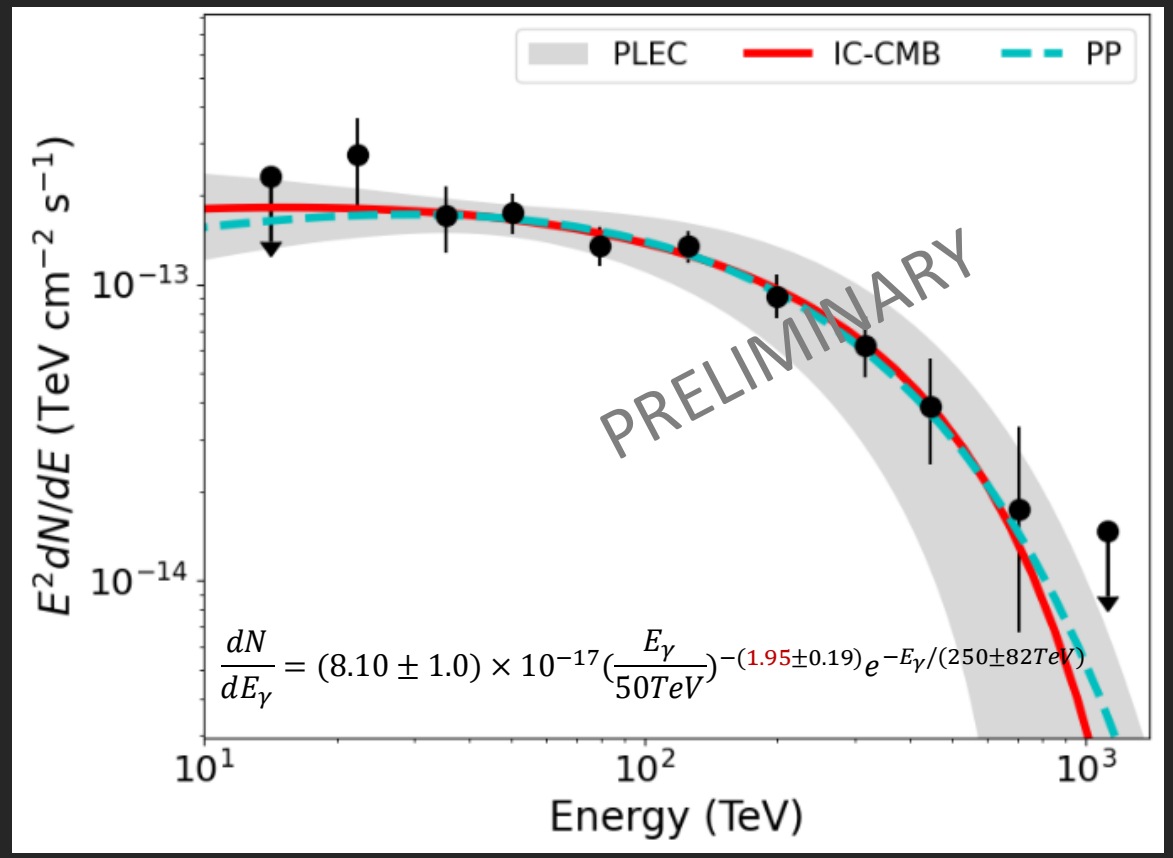
Morphology evolution with energy is not evident





the strip accounts for ≃70% of the total observed flux

General requirement of leptonic and hadronic scenarios



❖ $e^{\pm}$ Inverse Compton(IC) scattering of CMB

$$\frac{dN}{dE_e} = (\frac{E_e}{1TeV})^{-2.48} e^{-(E_e/0.77PeV)^2}$$

$W_e \approx 1.2 \times 10^{45}$erg

$E_{e,max} \approx$ 2PeV

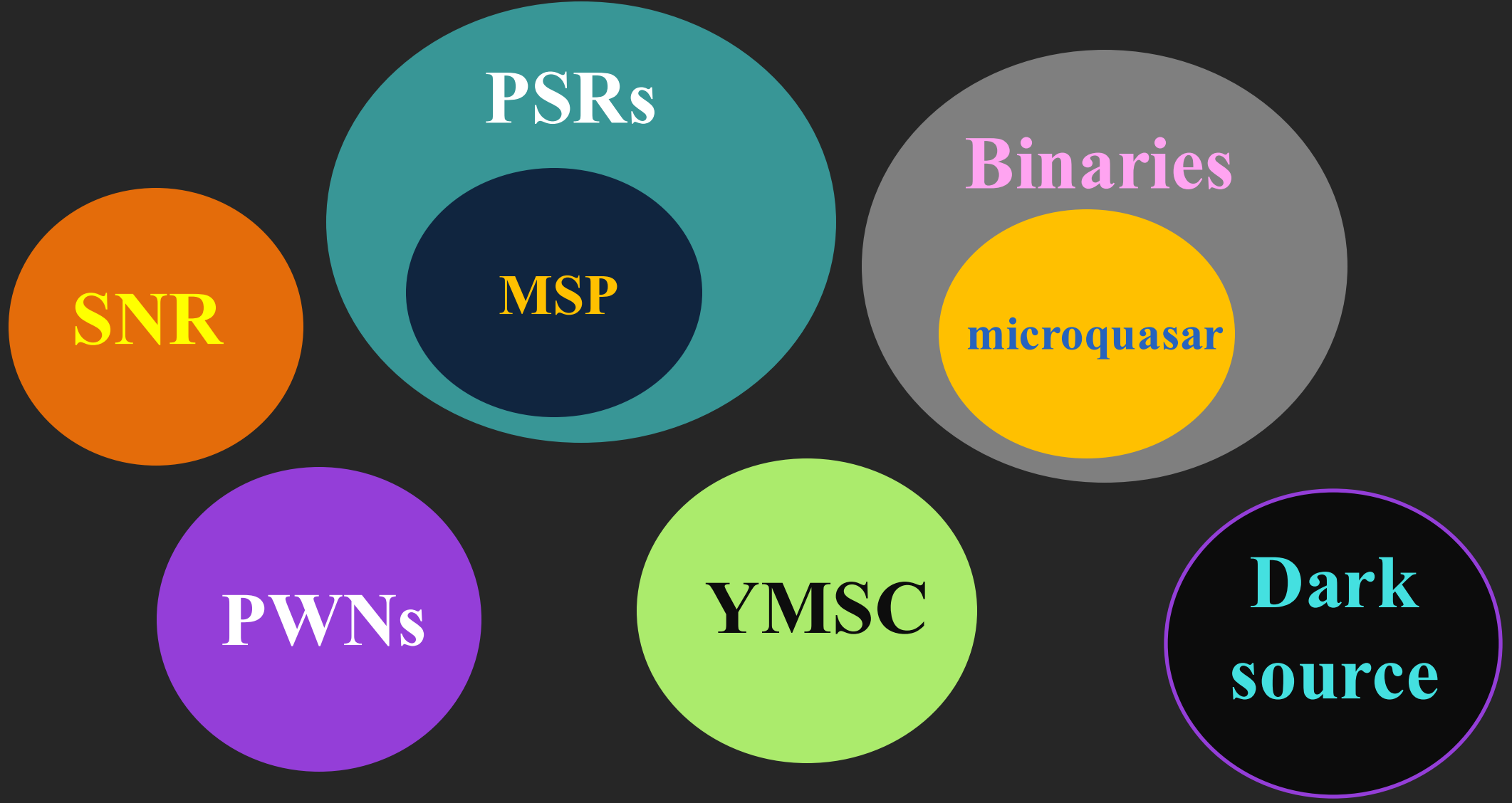
❖ Proton-proton interaction

$$\frac{dN}{dE_p} = (\frac{E_p}{1TeV})^{-1.71} e^{-(E_p/1.81PeV)^2}$$

$W_p \approx 3.6 \times 10^{48}$erg

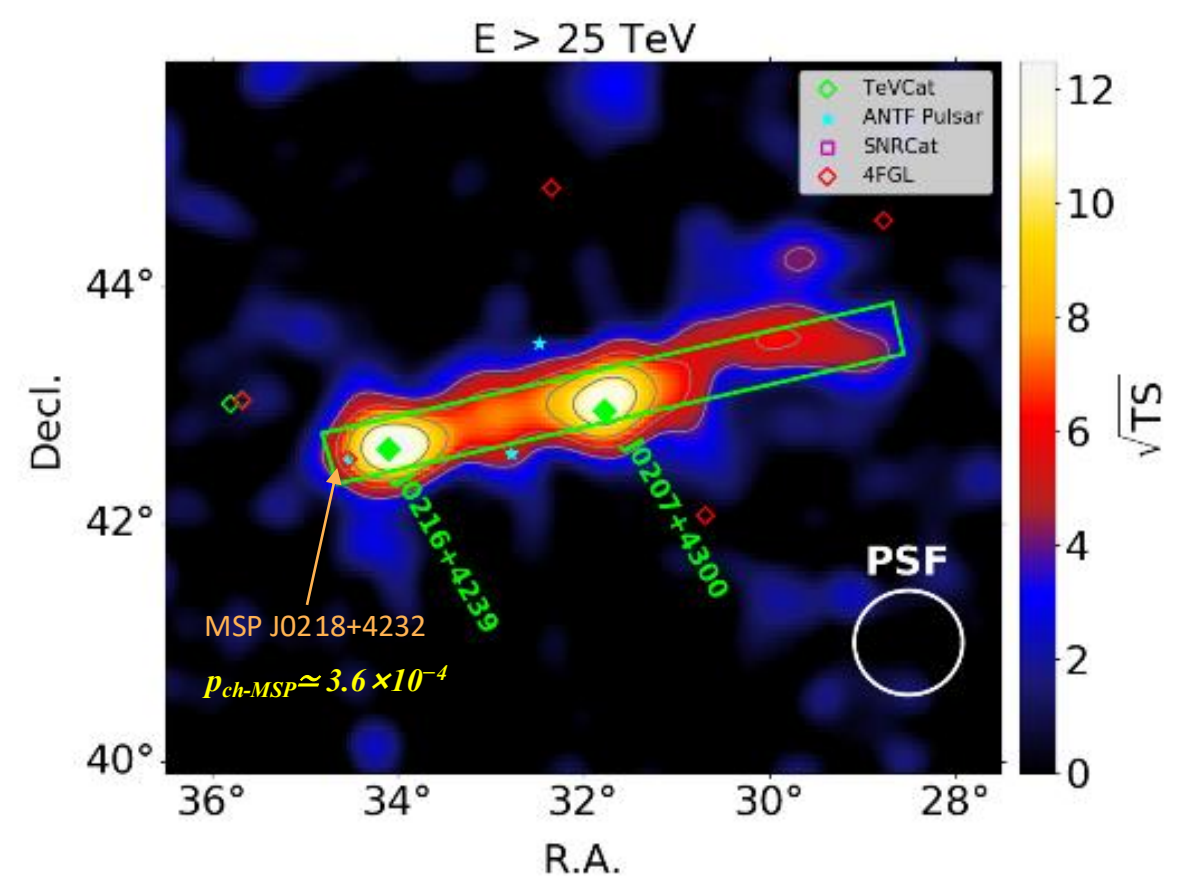
$E_{p,max} \approx$ 7PeV

3 How is Peanut formed?



What kind of accelerator it could be from?

The first evidence that MSPs can act as PeVatron!



Peanut luminosity at 3.15 kpc :

9.36×10^{32}erg s^{-1}

MSP J0218 +4232 can supply sufficient power:

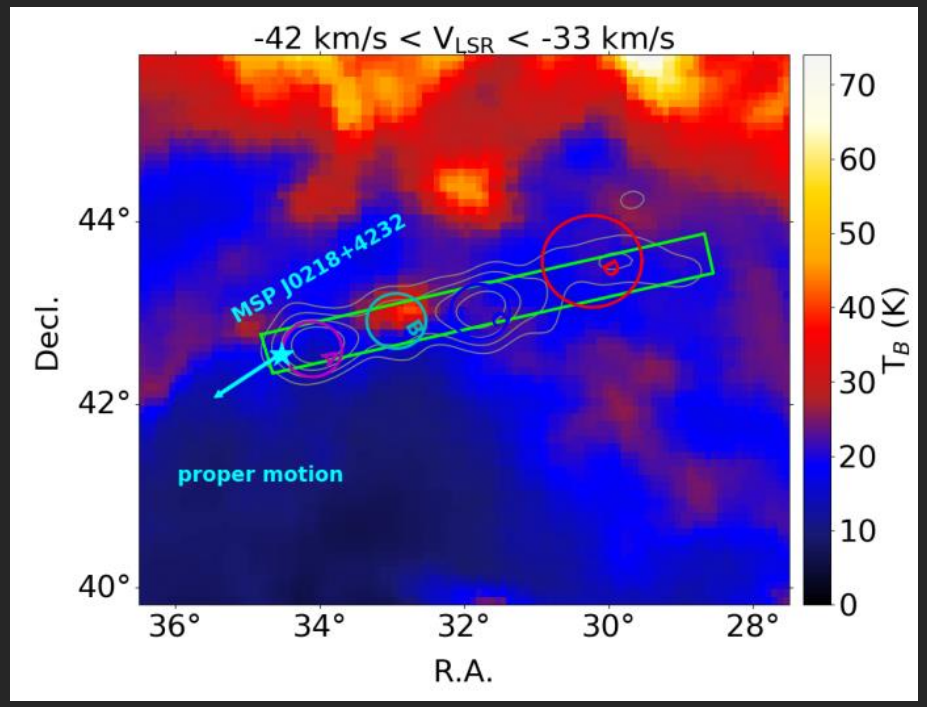
$\dot{E} \approx 2.44 \times 10^{35}$erg s^{-1}

$\kappa_{UHE} \approx 0.4\%$

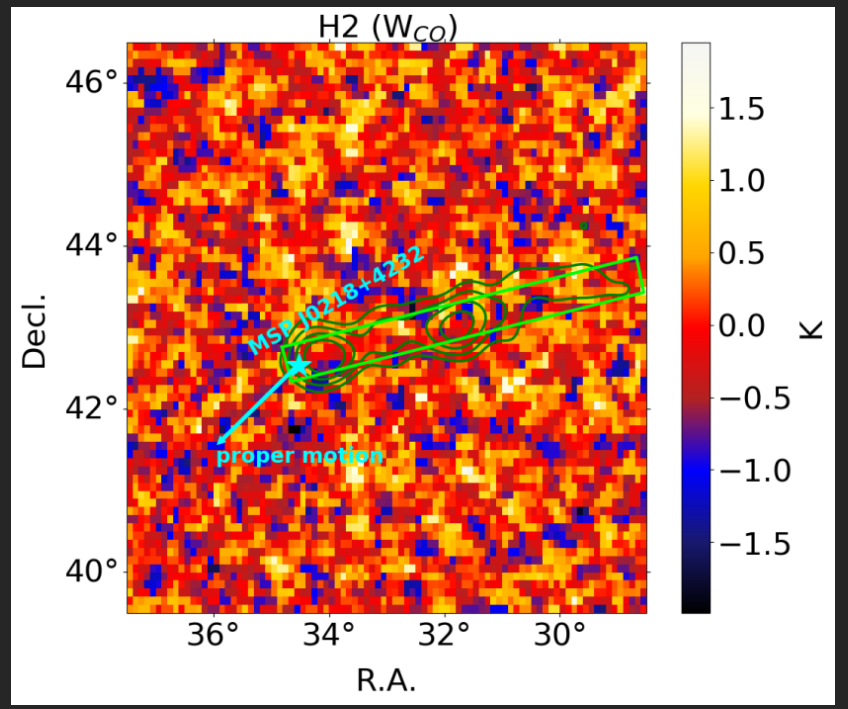
Hadronic scenario is challenging!

reason 1 : $\frac{W_p}{\kappa_{UHE}\dot{E}} \approx 55\ Myr$, means the angular distance ≃90°

reason 2:



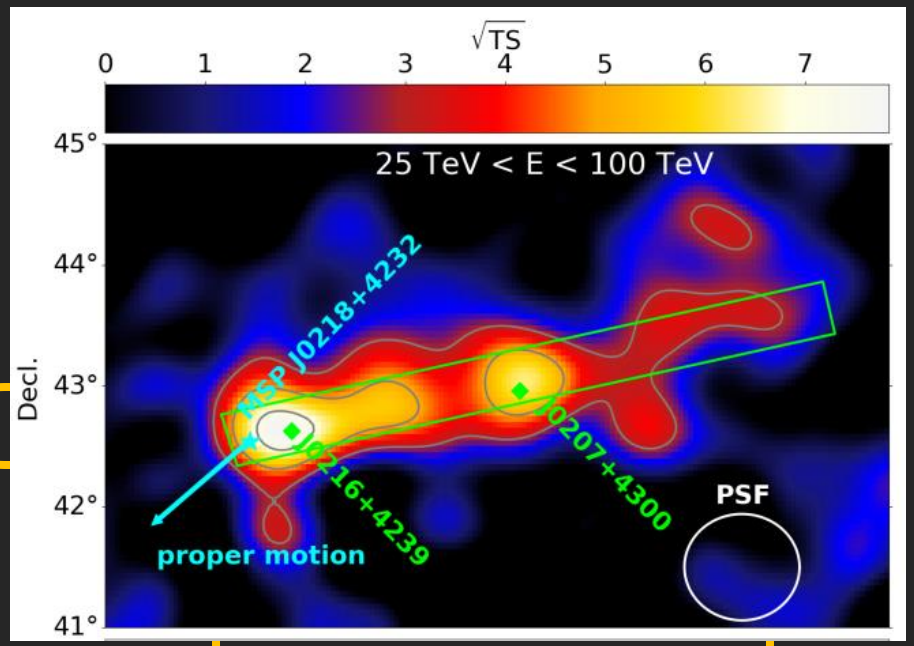
neutral atomic gas



molecular gas

Leptonic scenario is more compelling!

$\frac{W_e}{\kappa_{UHE}\dot{E}} \approx 16\ kyr$, angular distance $\simeq 2'$



$r_{d,\perp} \approx 12.5pc$

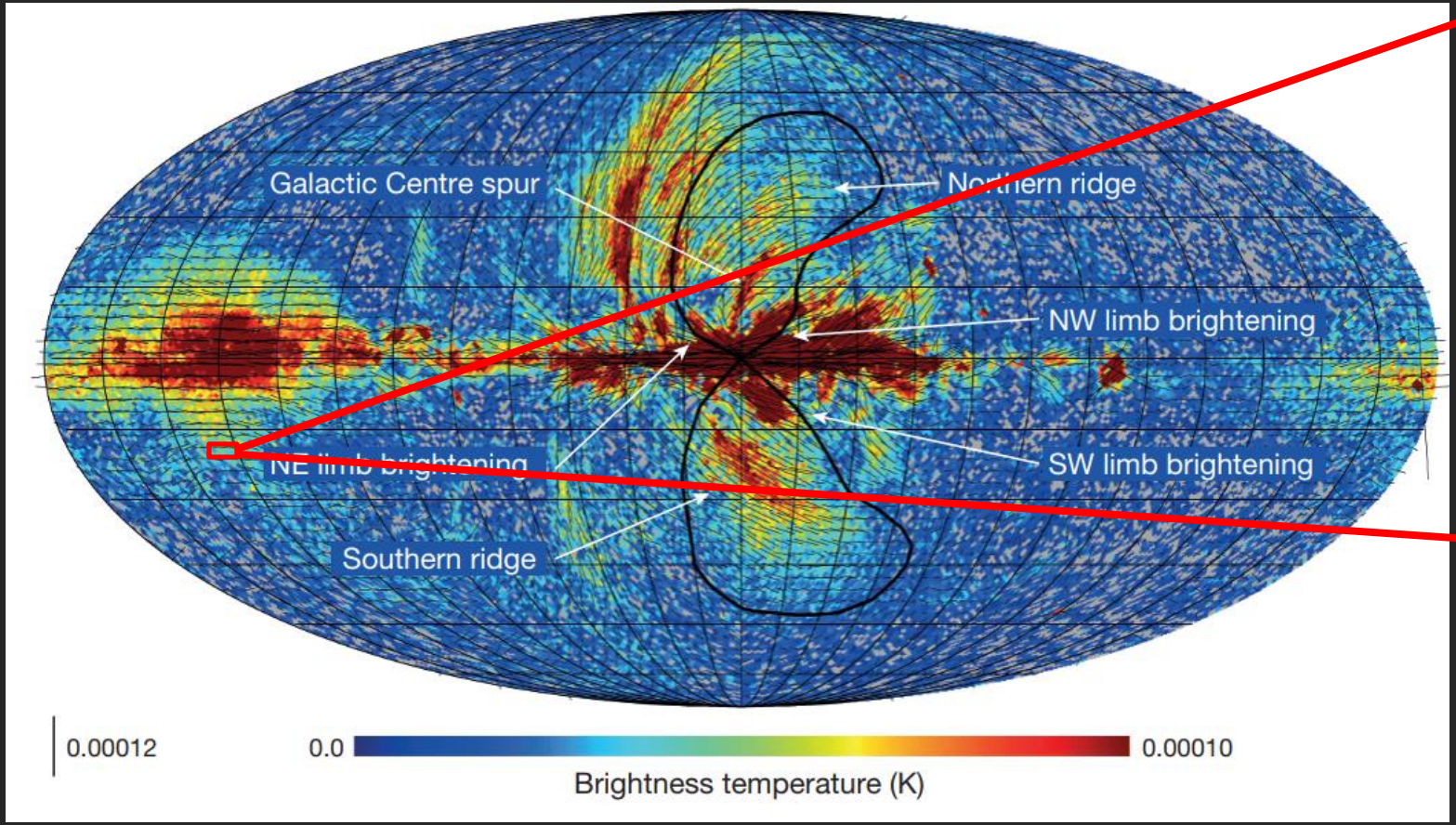
$D_\perp \approx D_{||}/400$

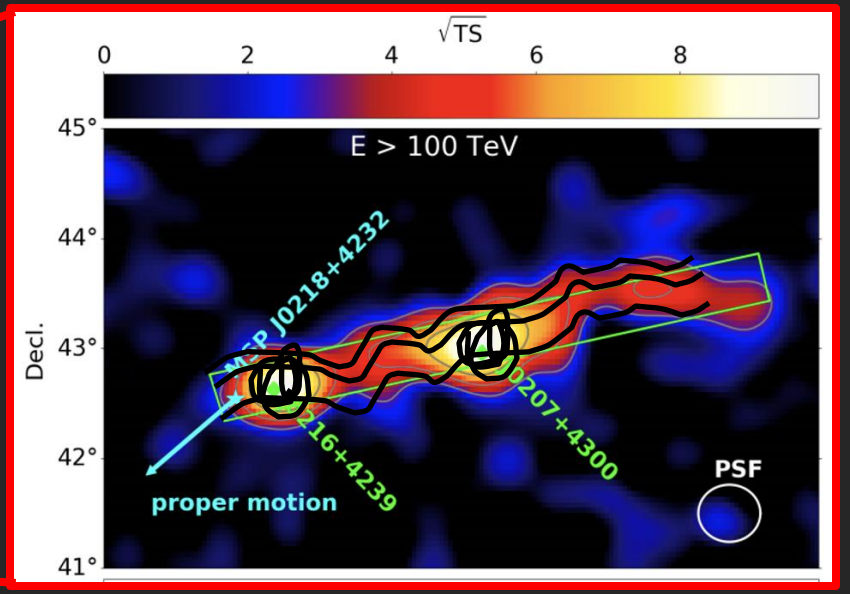
$r_{d,||} \approx 250pc$

$D_{||} \approx 3 \times 10^{29}$ cm^2 s^{-1}

- The cooling time of 1PeV $e^{\pm}$ constrains the magnetic field in Peanut region $\leq 1\mu$G
- *Anisotropic **d**ifussion is the dominated transport mechanism.*

Indication to Galactic large-scale magnetic field





Peanut structure may provide insights into the orientation of the magnetic field lines.

Ettore Carretti, et al., *Nature*,2013

Conclusion

- **LHAASO discovered the giant enigmatic region—Peanut**
- **This discovery provides *the first evidence* that the *particle acceleration by MSPs proceeds very efficiently*, *MSP can act as PeVatron***
- **Leptonic scenario is more compelling, Peanut represents a novel anisotropic particle transport mechanism.**
- **the shape of the Peanut further provides unique constraints on the magnetic field structure and strength of the interstellar medium in the Galactic halo.**

Thank you!

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