SST-1M
Single-Mirror
Small Size Telescope

Probing the PeVatron Candidate VER J2019+368 in the Cygnus Region with the SST-1M Stereoscopic System

Ana Laura Müller[1], Jakub Juryšek[1], Thomas Tavernier[1]
on behalf of the SST-1M Collaboration

[1]FZU-Institute of Physics of the Czech Academy of Sciences

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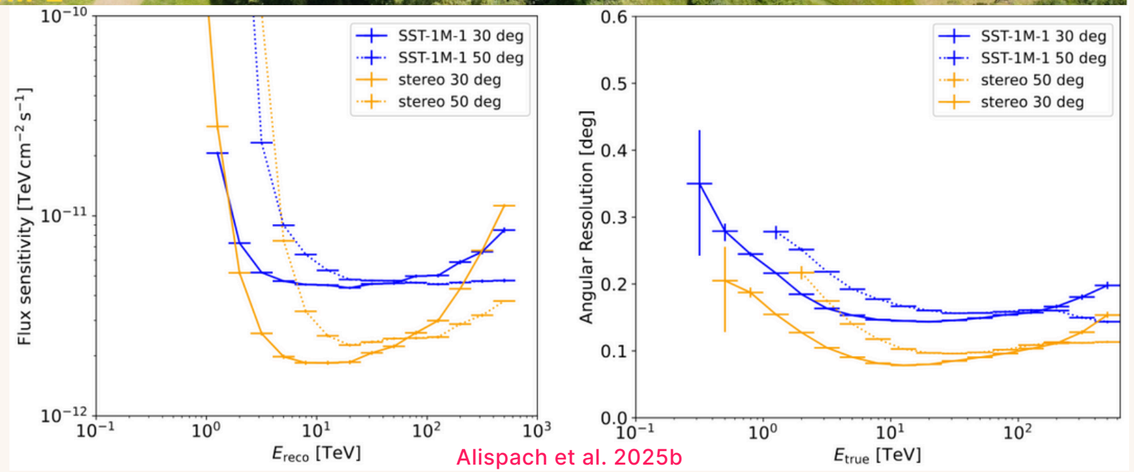
The SST-1M Project

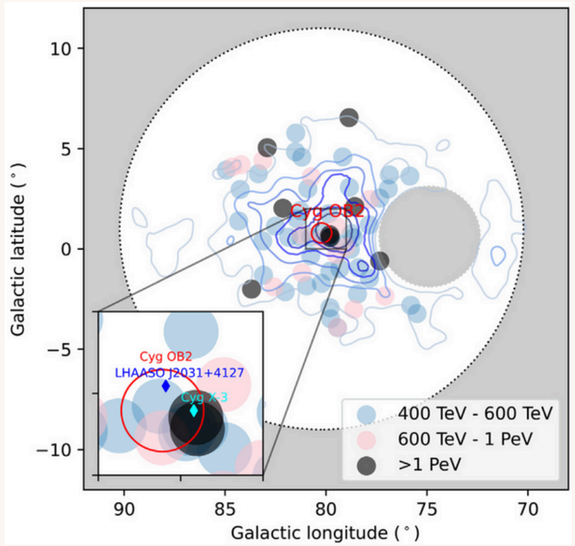
- Collaboration integrated by 63 scientists from 17 Institutions in 3 countries (Czech Republic, Poland, and Switzerland)
- Two 4-m diameter IACTs in the Ondřejov Observatory (510 m a.s.l.), Czech Republic
- Davies-Cotton optical design, SiPM camera, digital readout, stereo baseline = 155 m (Alispach et al. 2025a)
- Large FoV (9°), good off-axis response → ideal for extended sources (Alispach et al. 2025b)
- Sensitivity at very high energies (>1 TeV)
- Stereo trigger managed with SWAT, White Rabbit synchronization of the timestamps
- Commissioned system validated on Crab Nebula (Alispach et al. 2025b)



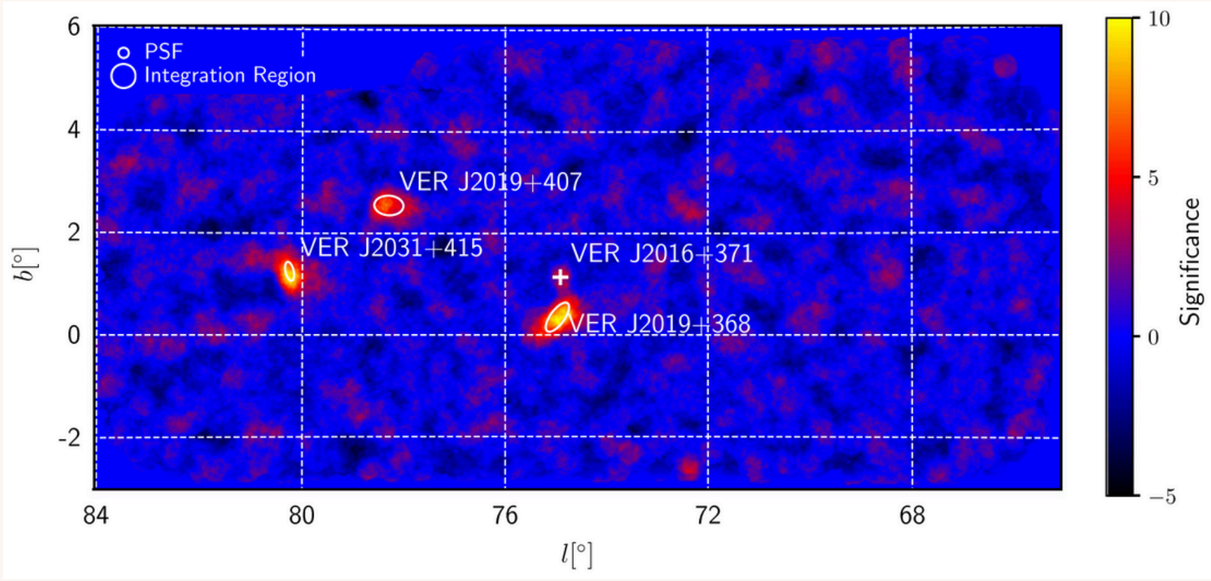
The Cygnus Region

- Cygnus is one of the richest Galactic γ-ray complexes
- Contains multiple PWNe, SNRs, OB associations, WR stars, μQs, etc.
- Some of the most prominent sources: VER J2019+368, VER J2016+371, γ Cygni, TeV J2032+4130

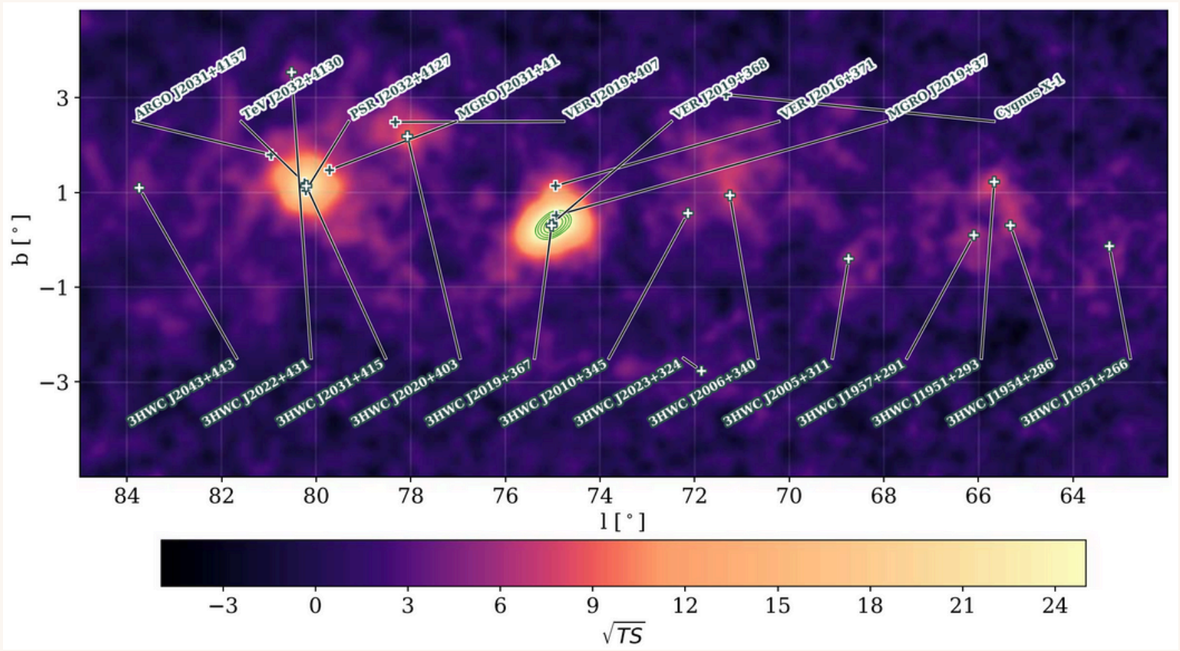
Potential sites for accelerating cosmic rays up to PeV energies



LHAASO Collaboration 2023



VERITAS Significance Map (Abeysekara et al. 2018)



HAWC Significance Map (Albert et al. 2020)

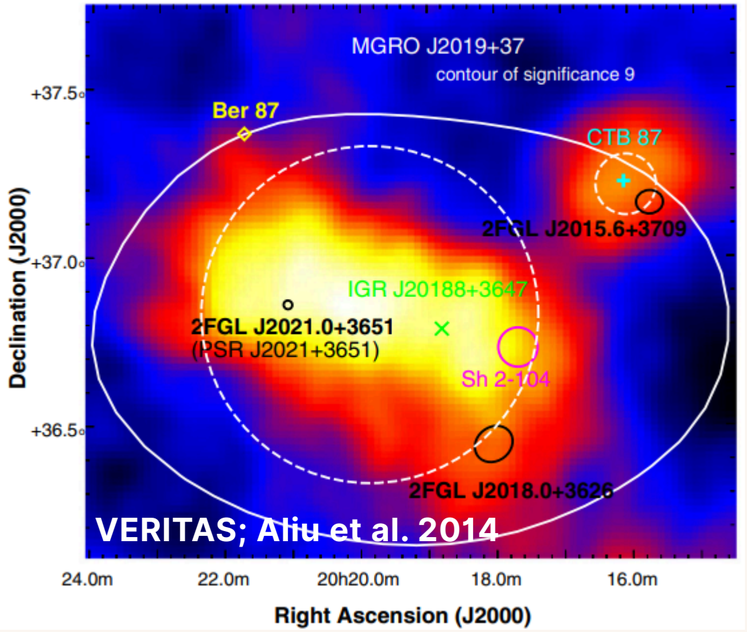
VER J2016+371 and VER J2019+368

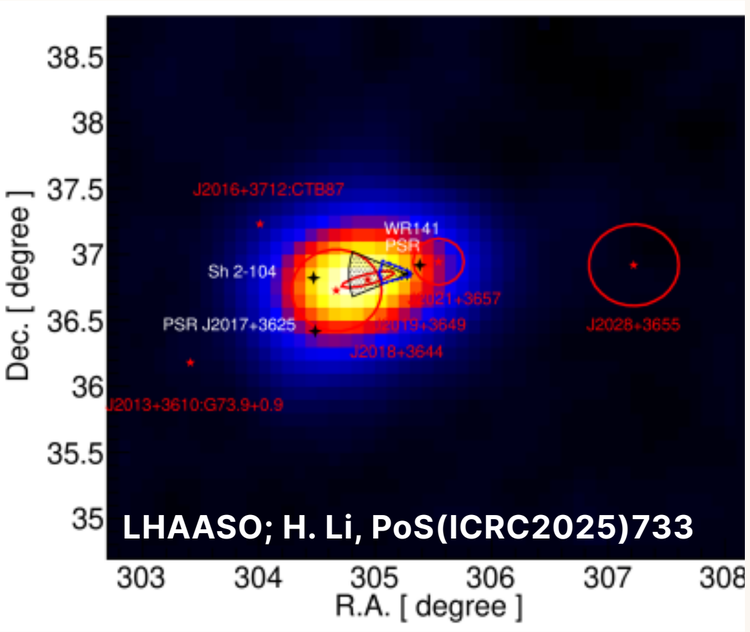
- Discovered by MILAGRO (MGRO J2019+37) (Abdo et al. 2007)

- Resolved in VER J2016+371 and VER J2019+368 by VERITAS (Aliu et al. 2014)

- VER J2016+371:
  - Point-like
  - Coincident with CTB 87
  - Complex system SNR + PWN
  - PSR J2016+3711 recently discovered (Qian-Cheng et al 2024)
  - LHAASO J2016+3712

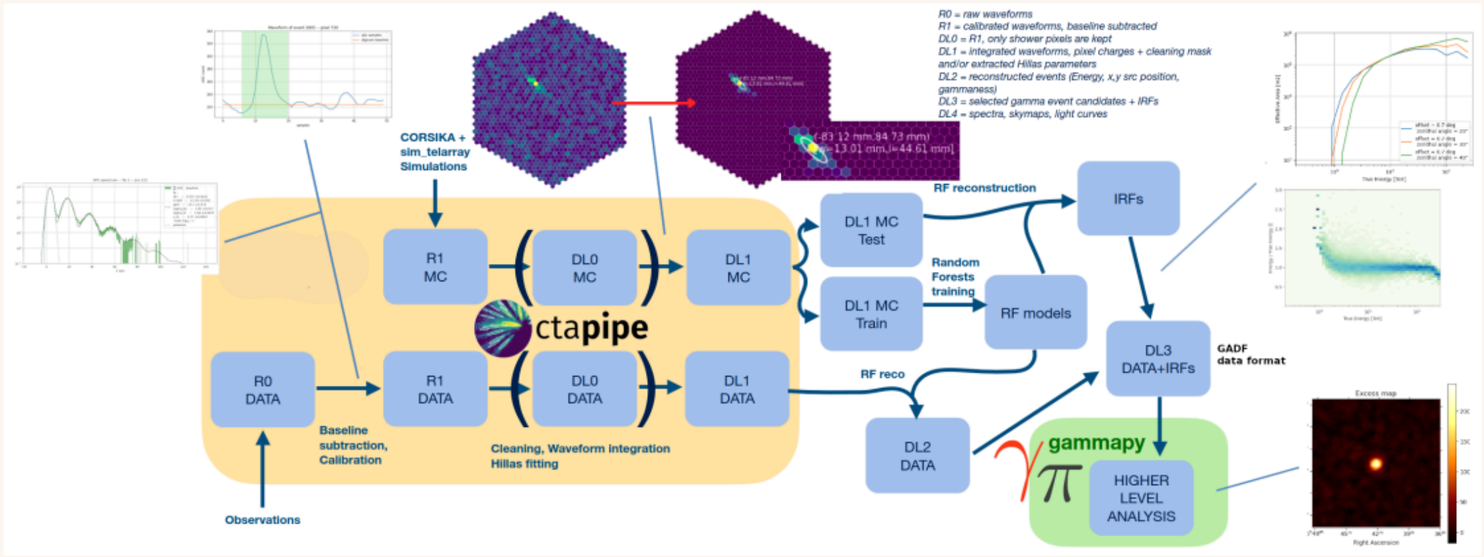
- VER J2019+368:
  - Extended
  - Many sources: PSR J2021+3651 + PWN (“Dragonfly”), Sh 2-104, WR 141, PSR J2017+3625, IGR J20188+3647 (X-ray transient from 2006)
  - Three LHAASO sources: LHAASO J2018+3644, LHAASO J2019+3649, LHAASO J2021+3657; the 1st with photons up to 0.27 PeV (H. Li, PoS(ICRC2025)733)





SST -1M Observations and Data Analysis

- Observational Campaign 2024–2025
- Quality Selection: zenith angles < 35°, NSB < 500 MHz, and reconstructed-to-expected intensity ratio 0.8–1.2
- ~85 h of good data after quality cuts
- Photon list + IRFs (10° MC zenith angle steps; closest IRF 20 min run) processed with sst1mpipe v0.8.1

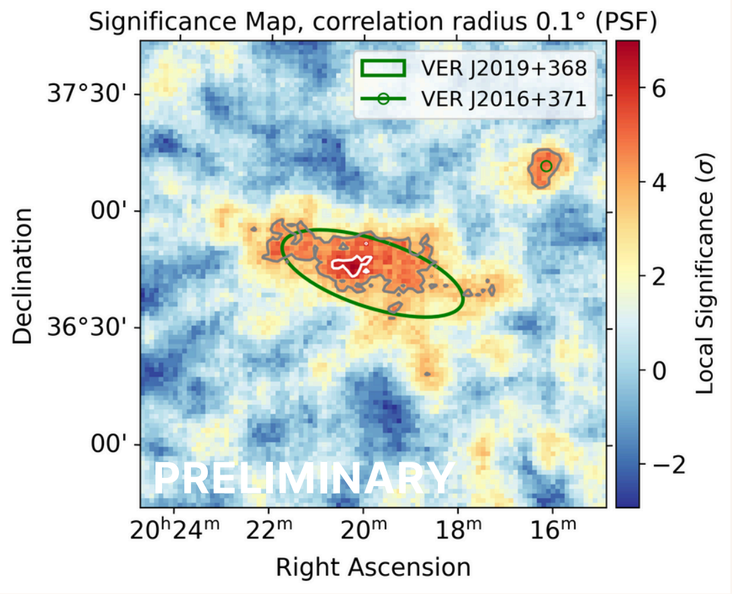


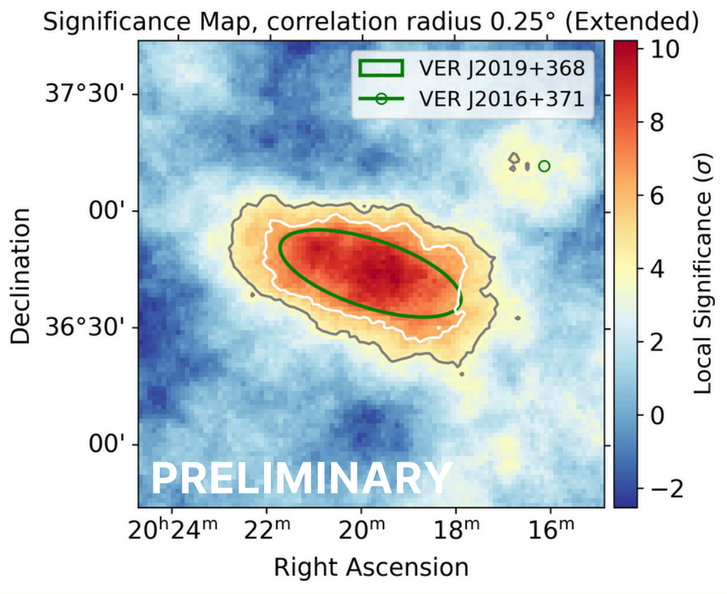
SST1-1M Pipeline Diagram: https://github.com/SST-1M-collaboration/sst1mpipe

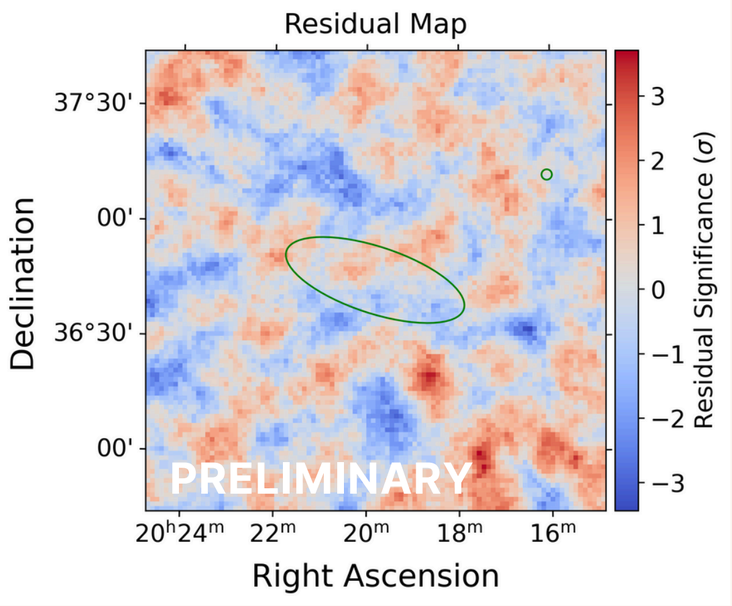
- Hillas intensities scaled using cosmic-ray rate ratio (events > 400 p.e.) → +8% / +5% systematics on flux / spectral index
- Gamma selection: energy-dependent gammaness cut (optimized on MC, 50% gamma retention per bin)

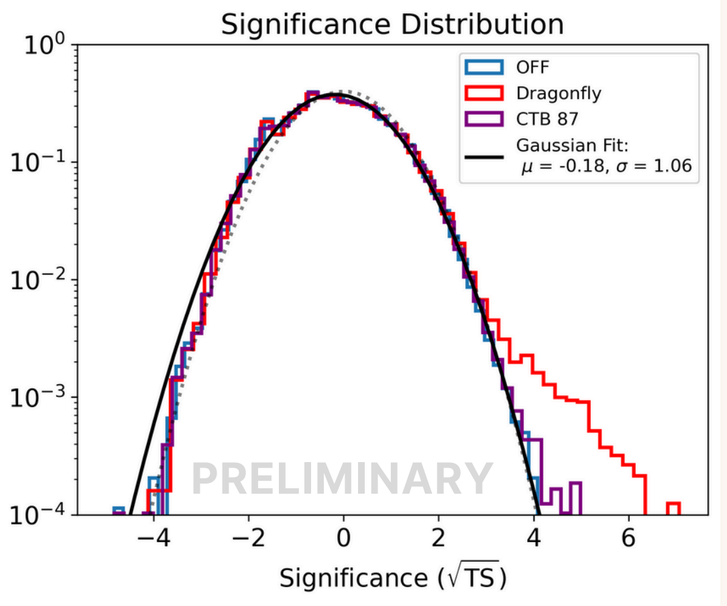
Significance Maps

- 1D analysis presented at ICRC 2025 (PoS(ICRC2025)703); here updated 3D analysis (spatial coordinates + energy) with FoV background performed with Gammapy 2.0.
- Energy range 1-300 TeV
- VER J2016+371 and VER J2019+368 regions clearly resolved
- VER J2016+371: Point-like, **best-fit** position (green circle) RA=304.02±0.02°, DEC=37.2±0.02°
- VER J2019+368: Extended, gaussian model **best-fit** (green ellipse) RA=304.94±0.06°, DEC=36.74±0.03°, σ=0.41°±0.05°, φ=71.42°±4.4° (northeast-southwest)

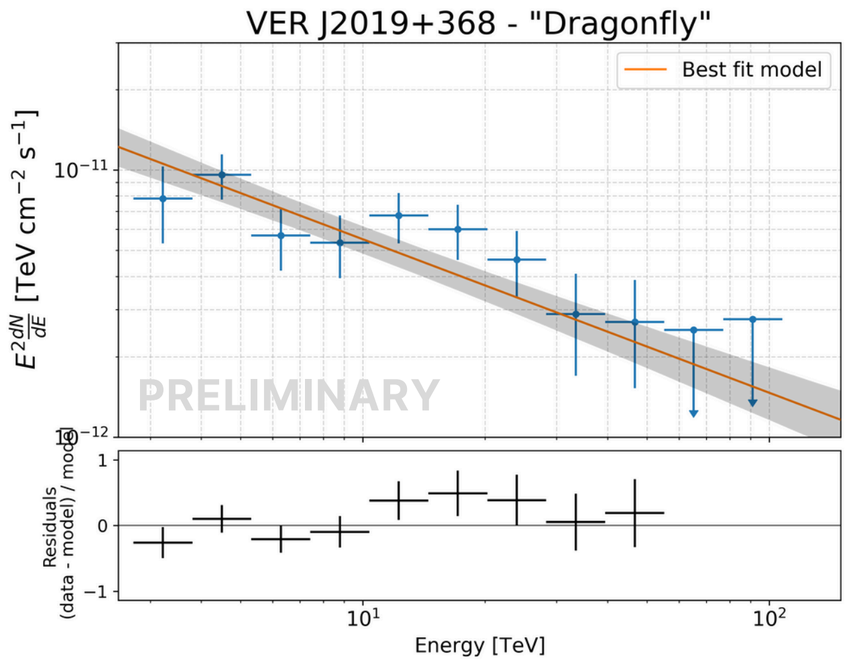








Spectral Energy Distributions

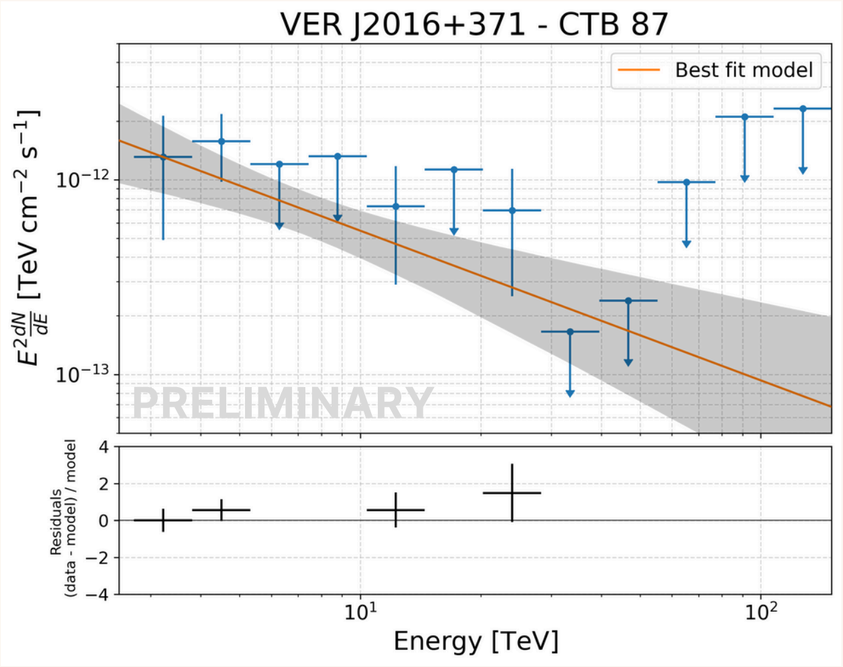


VER J2019+368

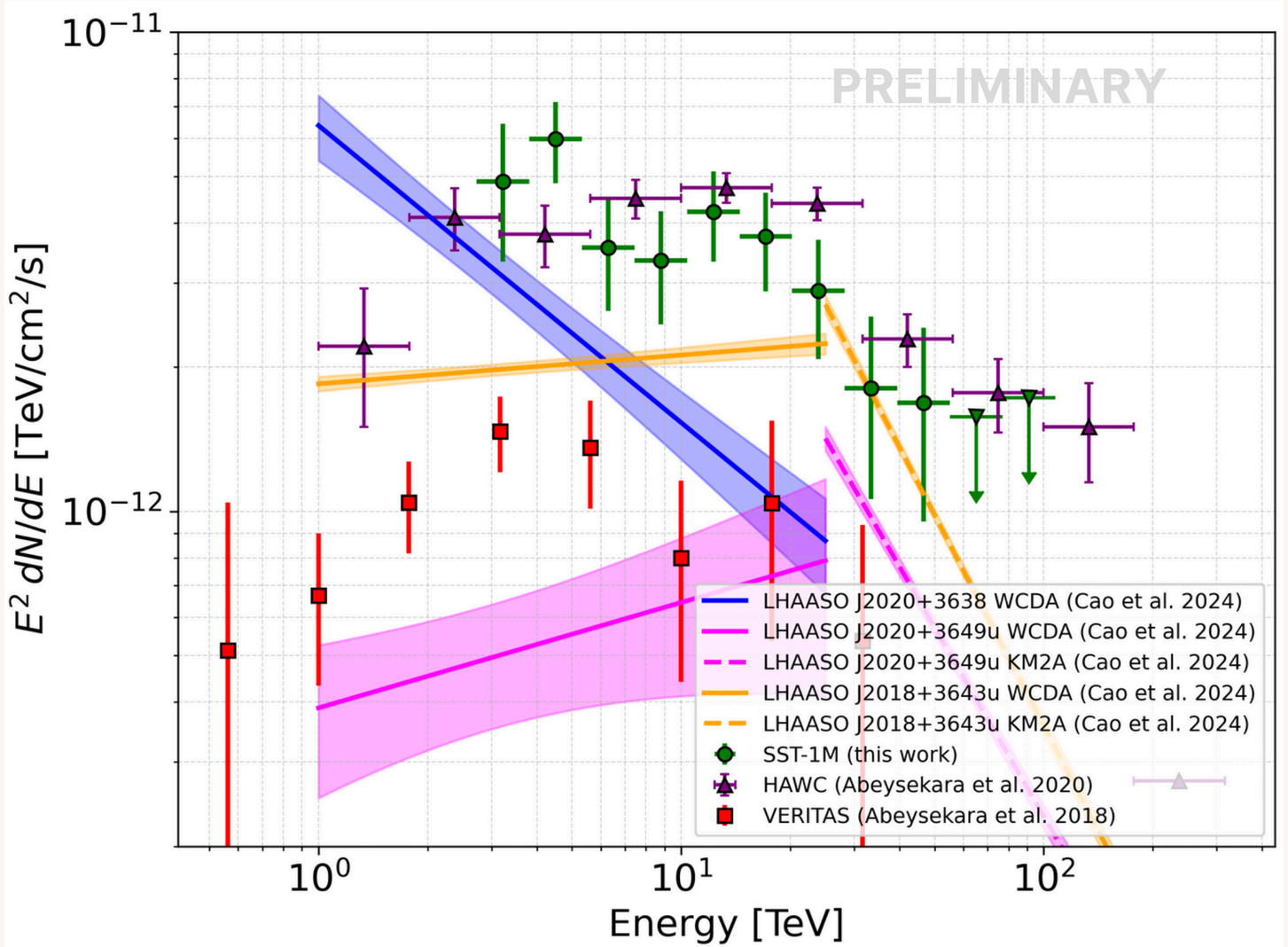
- Power Law (Log Parabola no statistically significant)
- Spectral Index: 2.57 ± 0.08
- Norm @ 10 TeV: (3.44±0.4)x10^{-14} TeV^{-1} s^{-1} cm^{-2}

VER J2016+371

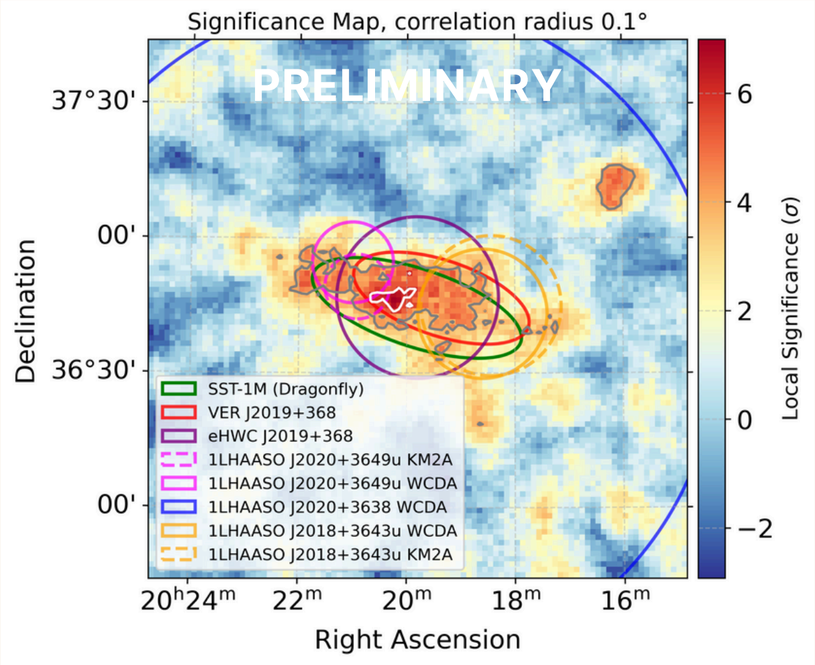
- Power Law
- Spectral Index: 2.77 ± 0.36
- Norm @ 10 TeV: (2.33±0.7)x10^{-14} TeV^{-1} s^{-1} cm^{-2}



VER J2019+368 Comparison with Previous Results



- Different best positions
- Different region sizes



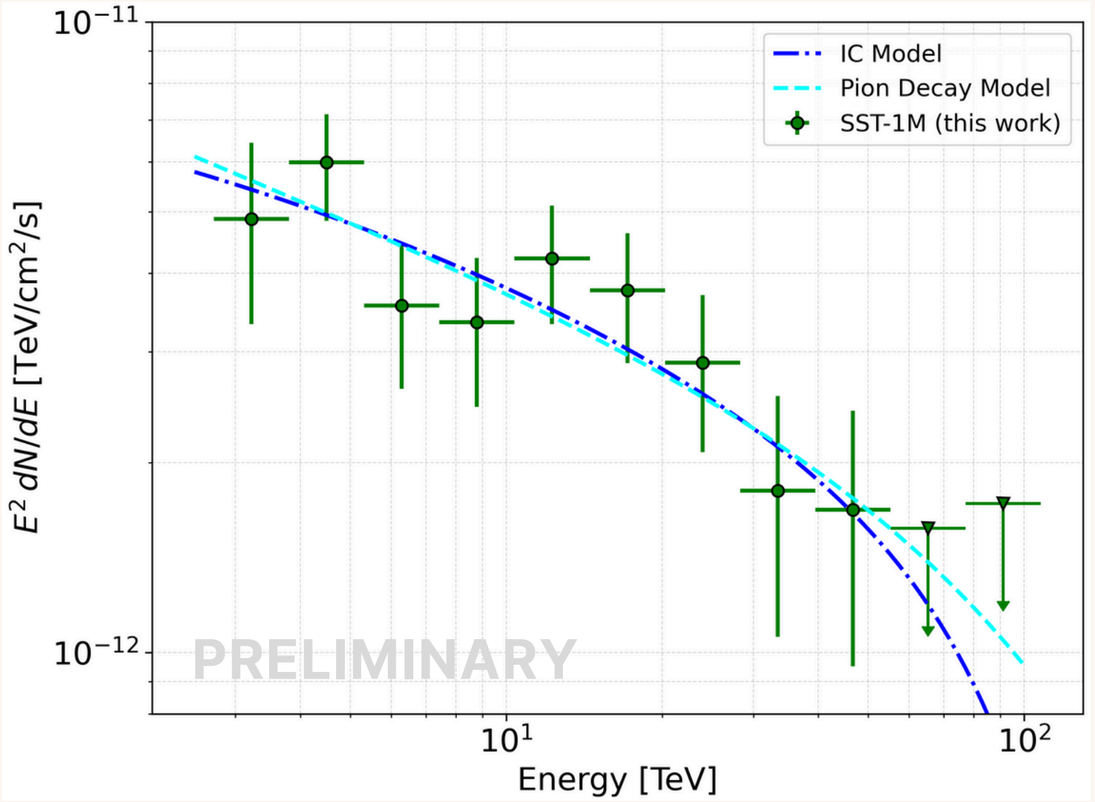
VER J2019+368 Preliminary Emission Modeling

Leptonic Scenario

- Inverse Compton with CMB and Galactic FIR (d=1.8kpc, T=30K, U=0.3 eV cm-3) (Mizuno et al. 2017)
- PL electrons with Γ = 3.03
- Maximum energy of 200 TeV
- Possible association with the Dragonfly PWN and PSR J2021+3651

Hadronic Scenario

- Pion Decay
- PL protons with Γ = 2.39
- Maximum energy of 1 PeV
- Target density of ISM (~ 1 cm^{-3})
- Accelerated during early stages of the SNR evolution?



Conclusions

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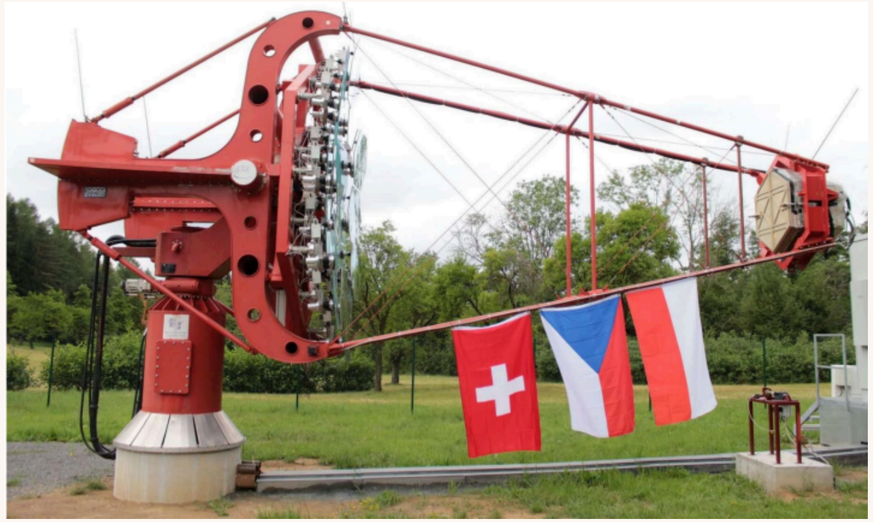
- Operations of two SST-1M telescopes continues in Ondřejov, Czech Republic
- Detection of VER J2019+368 (PL emission with Γ = 2.57 ± 0.08 up to 60 TeV) and VER J2016+371 (CTB 87)
- Good agreement with results from other observatories
- Preliminary modeling using leptonic and hadronic scenarios, both plausible
- Acceleration sites unknown (large discrepancies for PSR J2021+3651 distance in the literature), detailed modeling to be subject of a forthcoming study



Thank you!

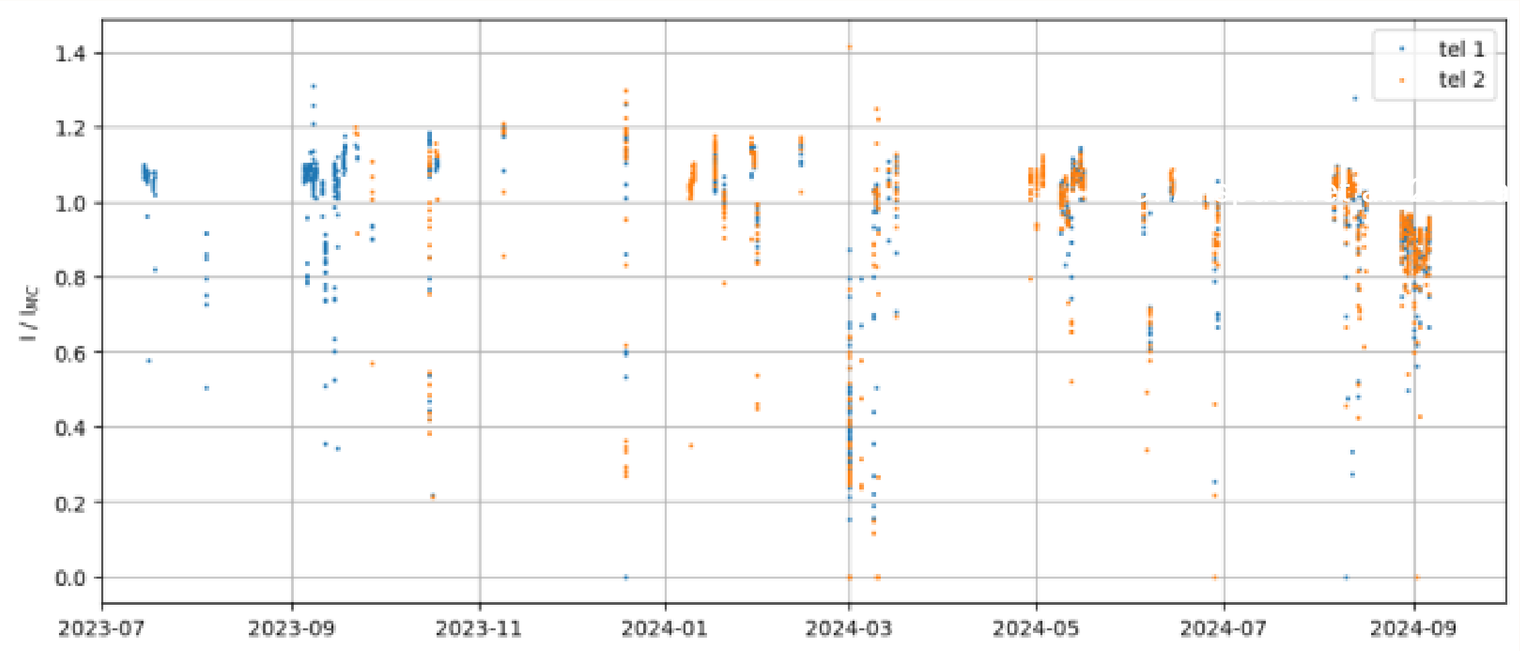
Back Up

Hillas intensity scaling

- Hillas intensities are rescaled using the cosmic-ray rate ratio (for events > 400 p.e.) to compensate for changes in mirror reflectivity, SiPM gain, and atmospheric transparency that affect the optical throughput.

- The cosmic-ray rate provides a stable reference for the telescope performance.

- After this correction, the remaining systematics are about +8 % on flux normalization and +5 % on the spectral index.



Off-axis performance

- MC solid lines
- Points data
- Gamma-ray acceptance
- Good agreement up to ~3° off-set from the center of the FoV