CTAO | LST COLLABORATION

東京大学 THE UNIVERSITY OF TOKYO

ICRR Institute for Cosmic Ray Research University of Tokyo

FoPM

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Galactic Center Observations with CTAO LST-1

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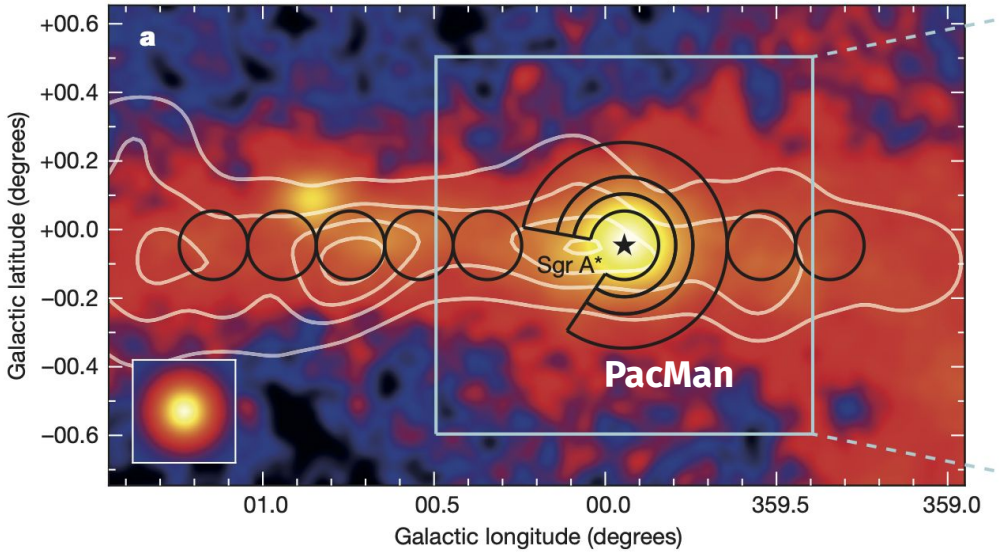
Introduction

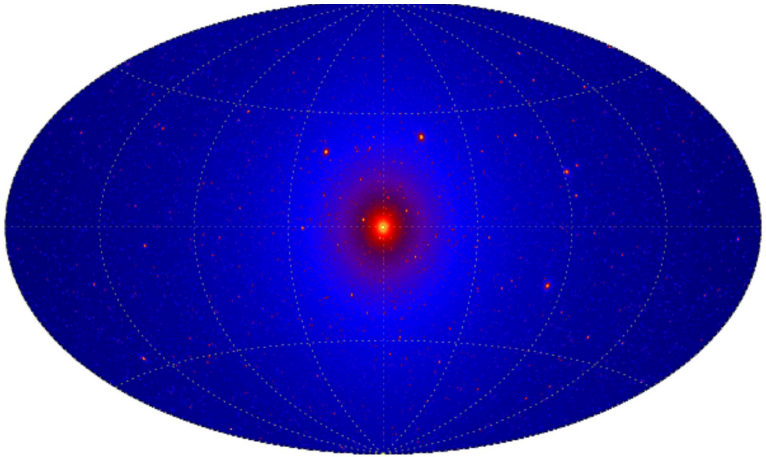
Galactic Center: a vital TeV gamma-ray target

Morphological/spectral studies of the Galactic Center play an essential role in understanding cosmic-ray acceleration and dark matter.

Sky map indicating sources and diffuse emissions
fig: HESS, Nature 531, 2016

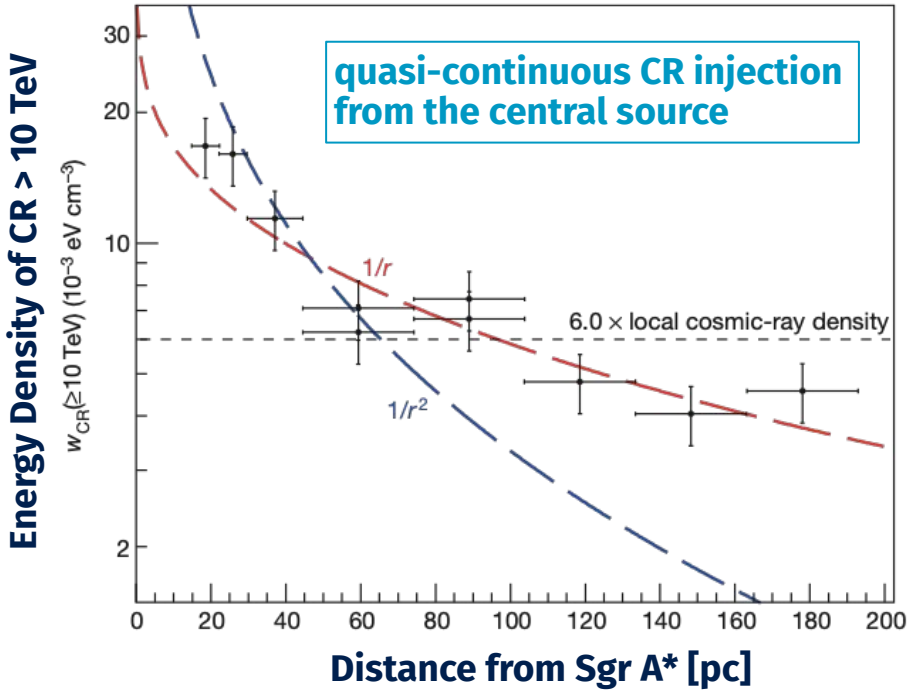


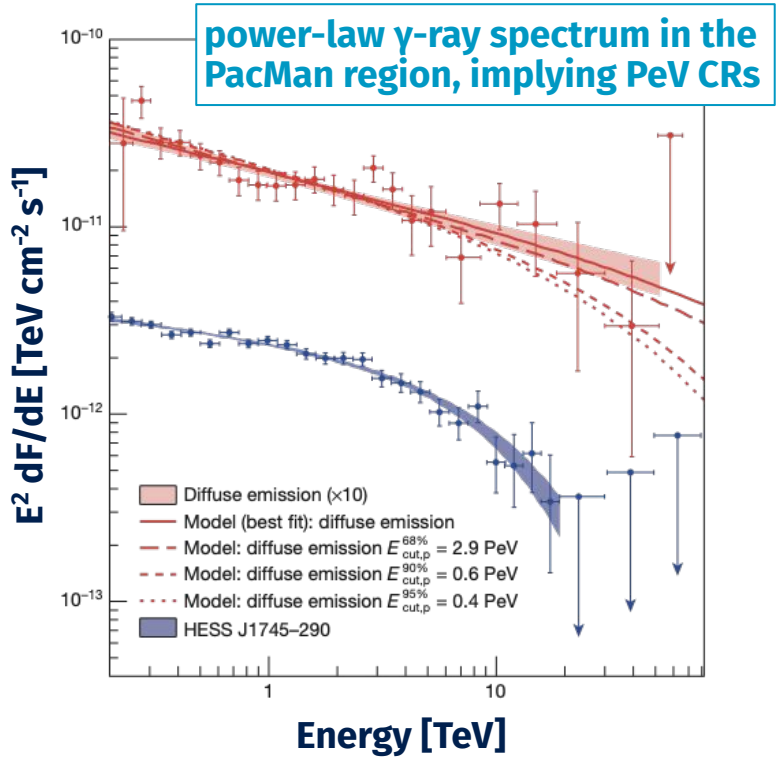
Expected high J-factor with dense DM density
fig: Pieri et al., PRD 83 023518, 2011



PeVatron Scenario

HESS 2016 (followed by HESS 2018 & VERITAS 2021) obtained a power-law spectrum and a 1/r CR profile, suggesting the presence of a PeVatron.

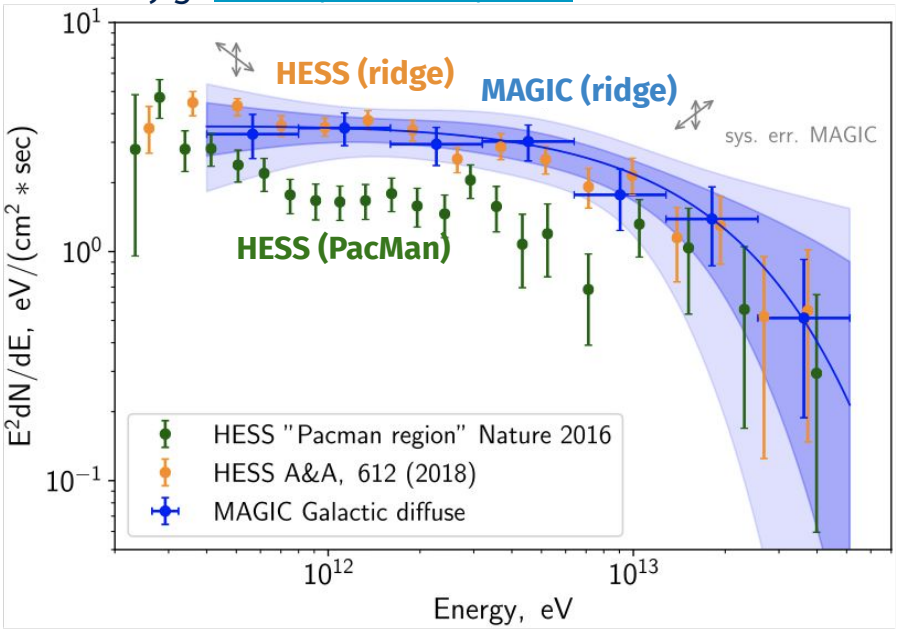




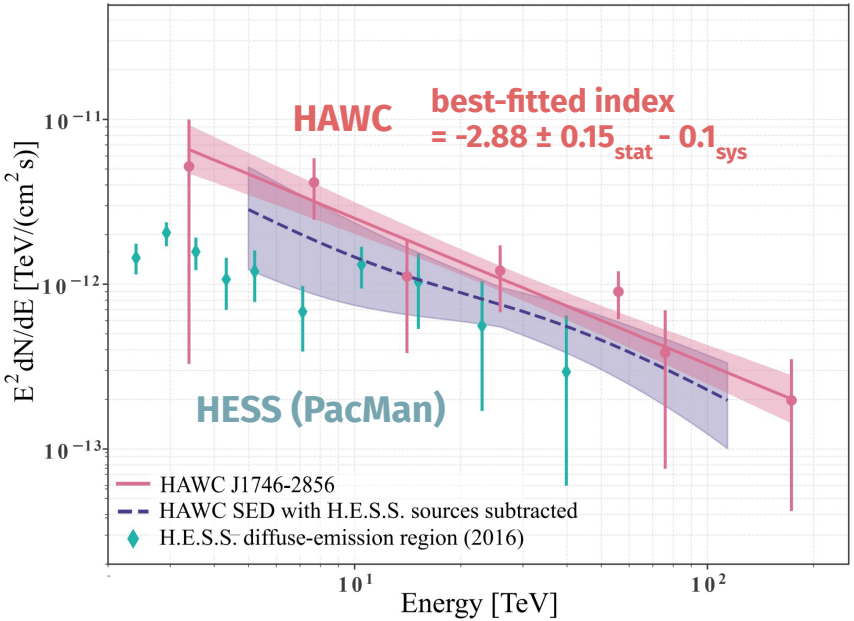
Disparities: Hints for the Spectral Curvature

However, MAGIC 2020 suggested a 2σ-hist for a spectral cut-off in the diffuse component; and HAWC 2024 reported a softer spectrum.

Exponential Cutoff around 20 TeV
fig: MAGIC, A&A 642, 2020



Softer Spectrum at higher energy
fig: HAWC, ApJL 973, 2024

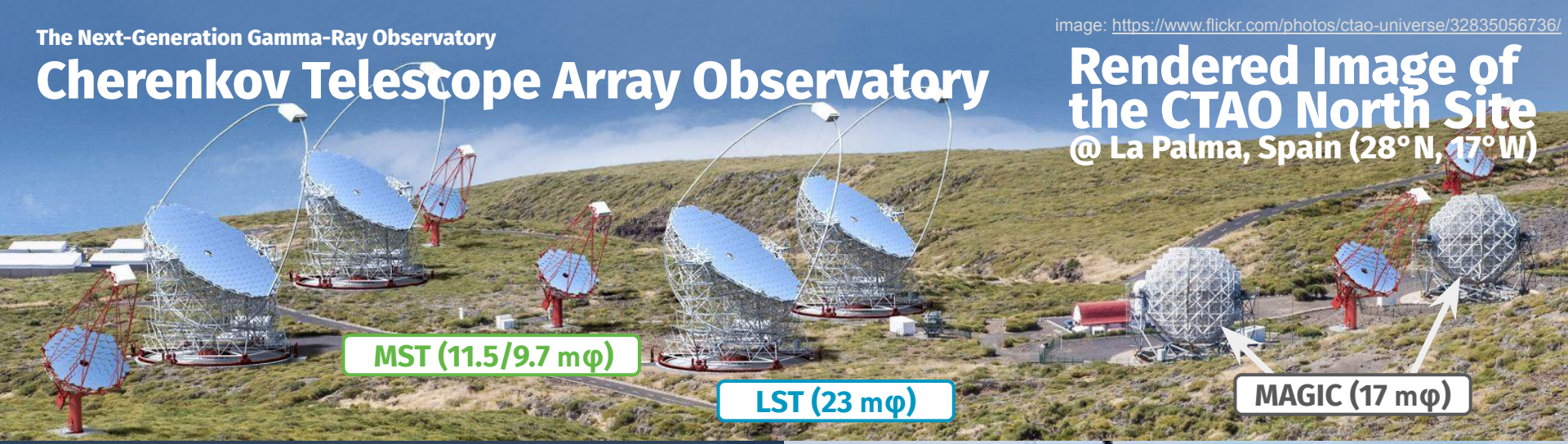


The Next-Generation Gamma-Ray Observatory

Cherenkov Telescope Array Observatory

image: https://www.flickr.com/photos/ctao-universe/32835056736/

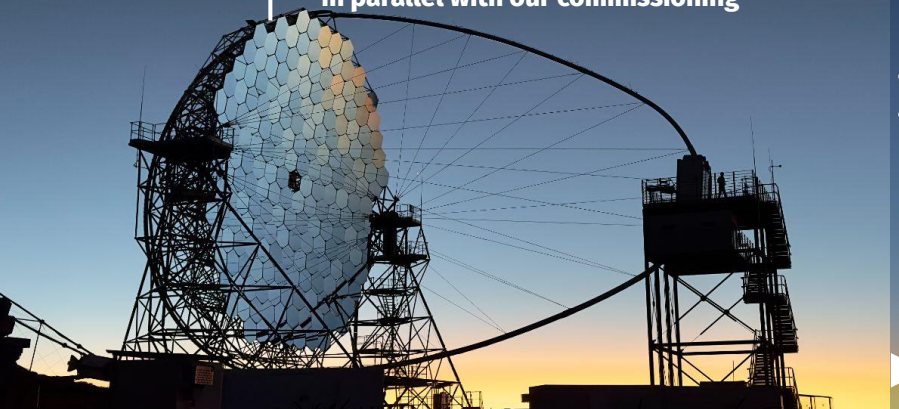
Rendered Image of the CTAO North Site @ La Palma, Spain (28° N, 17° W)



The First Large-Sized Telescope

LST-1

- inaugurated in 2018
- taking scientific data in parallel with our commissioning

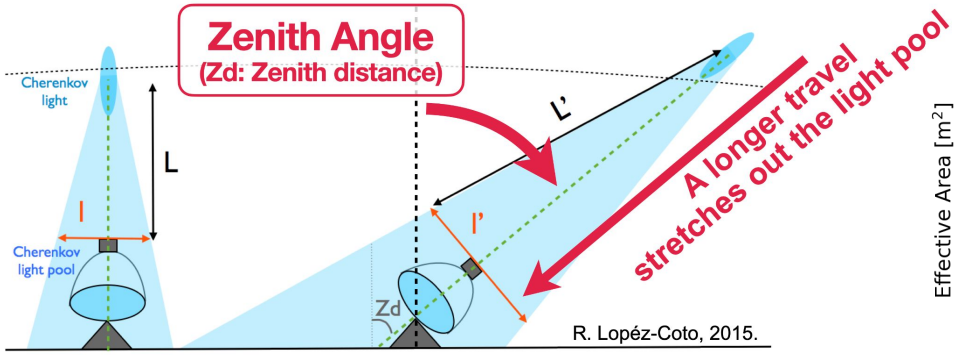


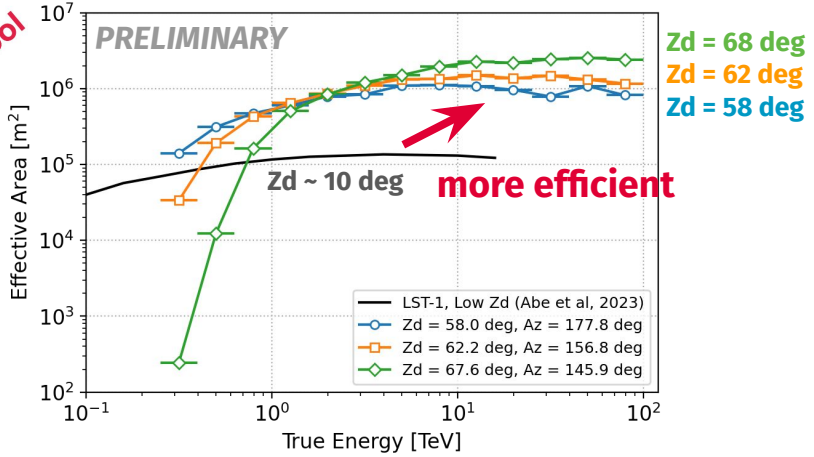
and we are building more!

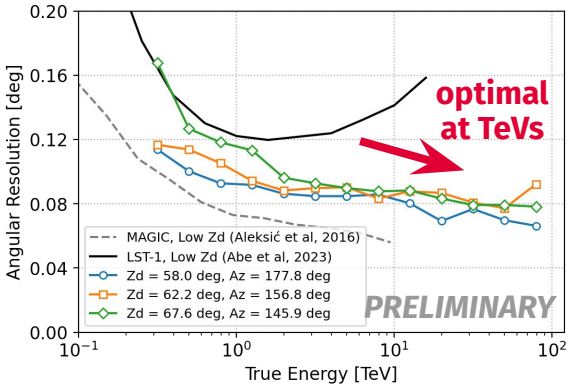
Video: LST-3 Dish Lifted (June 2024)

Large Zenith Angle Observation

LST-1 requires the large-zenith-angle technique to observe the Galactic Center, leading to the enhanced collection area in the TeV regime.







+) **increased collection area** by an order of magnitude

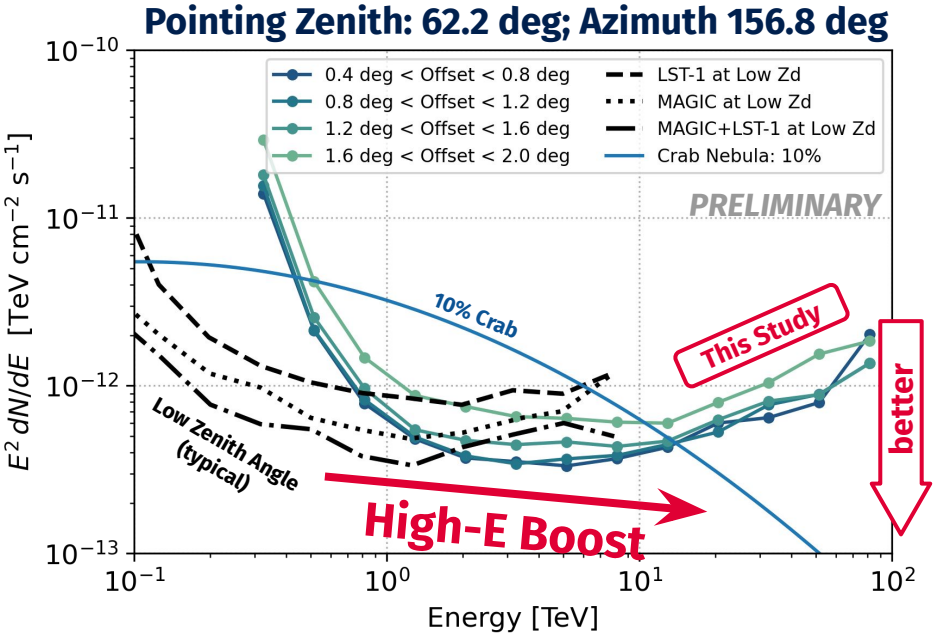
+) **decreased image leakage** (better reconstruction) at higher energy

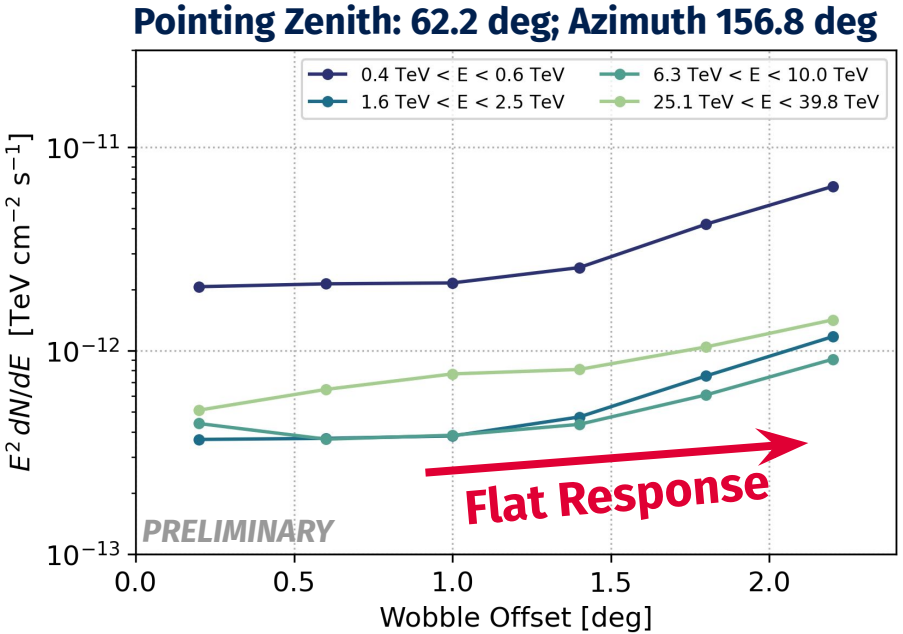
-) performance very sensitive to Zd even within the field of view

-) increased energy threshold from O(10) GeV to O(100) GeV or higher

LST-1: for TeV observations of extended sources

The large-zenith-angle observations enhance the sensitivity at TeVs.
The wide field of view is preferable to observe sources spanning >1 deg.





Current Status of the Ridge Diffuse Component

Findings that the current-generation telescopes reported are not completely consistent with each other.

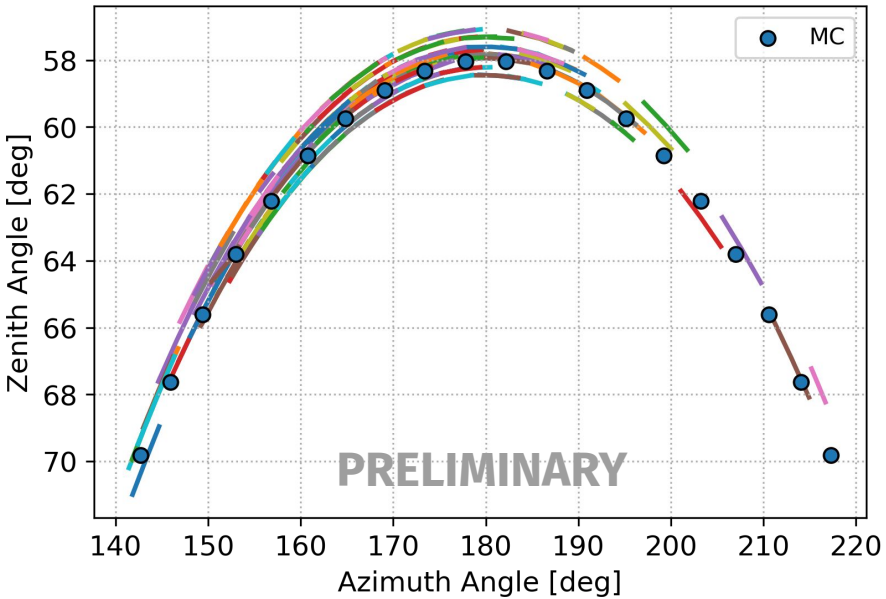
	HESS (2016, 2018)	MAGIC (2020)	VERITAS (2021)	LST-1 (This Study)
Pac Man	Power Law	Not Reported	Not Reported	
total ridge	Power Law	Cut-off at 20 TeV	Power Law	?
CR longitudinal profile	alpha = 1.10 ± 0.12 2D approach	0.9 < alpha < 1.4 3D approach	Not Reported	
Zenith Angle	Low Zd	Large Zd	Large Zd	Large Zd
Field of View	5.0 deg	3.5 deg	3.5 deg	4.5 deg

This study is trying to provide a new view towards this situation.

Galactic Center Studies with CTAO LST-1

Data & MCs

39 hours of good-quality data were collected with LST-1.
The MC simulations were performed along the Galactic Center trajectory.

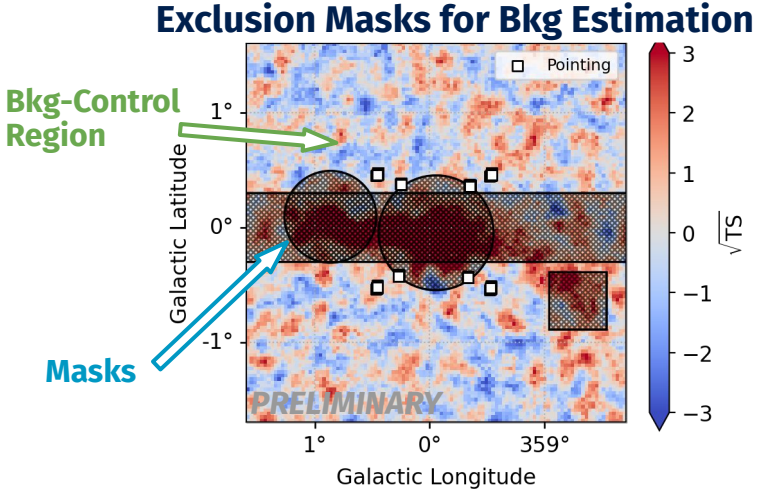


- Observation
  - **39-hour data** in 2021/2022 after selections
  - wobble offset: 0.5 deg or 0.7 deg
- MC
  - covers the field of view of LST-1 **across the Galactic Center trajectory**
- Reconstruction & Instrument Response Evaluation
  - evaluated telescope responses on a **run-by-run** / node-by-node basis

Background Estimation & 3D Analysis

Based on our development of pybkgmodel, a background-estimation tool, we performed a spatially-resolved spectral fit with gammapy.

- Background Modeling: the stacked exclusion-map method
  - modeled by events outside the masks below, similar to MAGIC (2020).
  - cf. HESS (2016, 2018) mainly used the reflected-region background.
- Signals: forward-folding with predefined spectral/spatial models

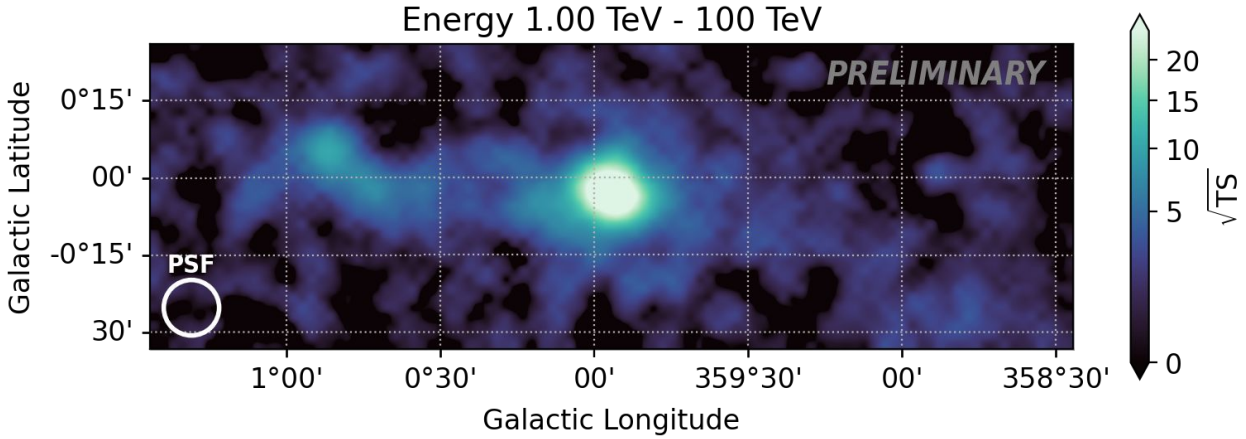


Source	Spatial	Spectral
Sgr A*	Point-like (Gaussian)	Power Law with Exp. Cutoff
G0.9+0.1	Point-like (Gaussian)	Power Law
Arc	Point-like (Gaussian)	Power Law
Ridge Diffuse	Template (see a slide below)	Power Law with Exp. Cutoff

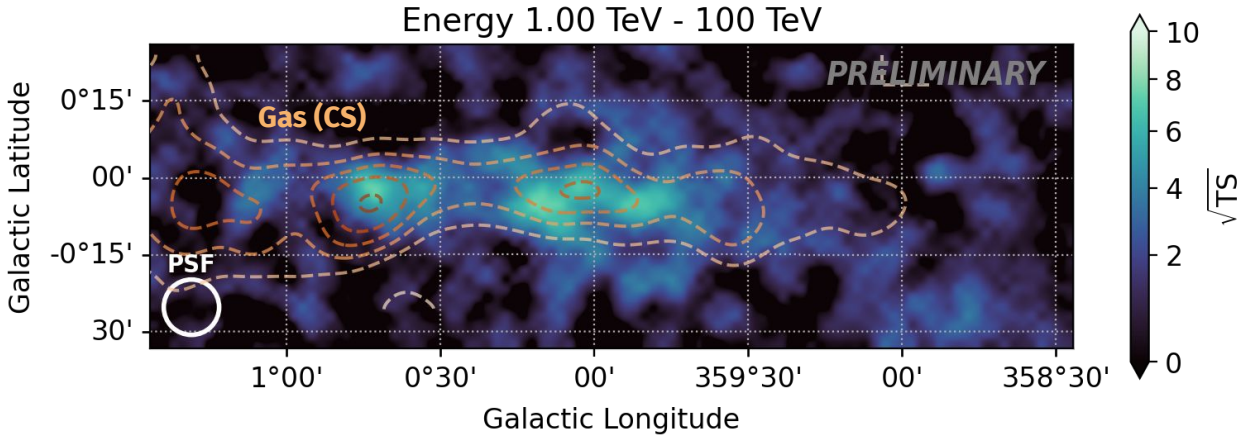
Result: Clear & Wide View of LST-1

*Contours: the integrated/smeared radio emission from CS molecules (Tsuboi+, 1999)

TS Map



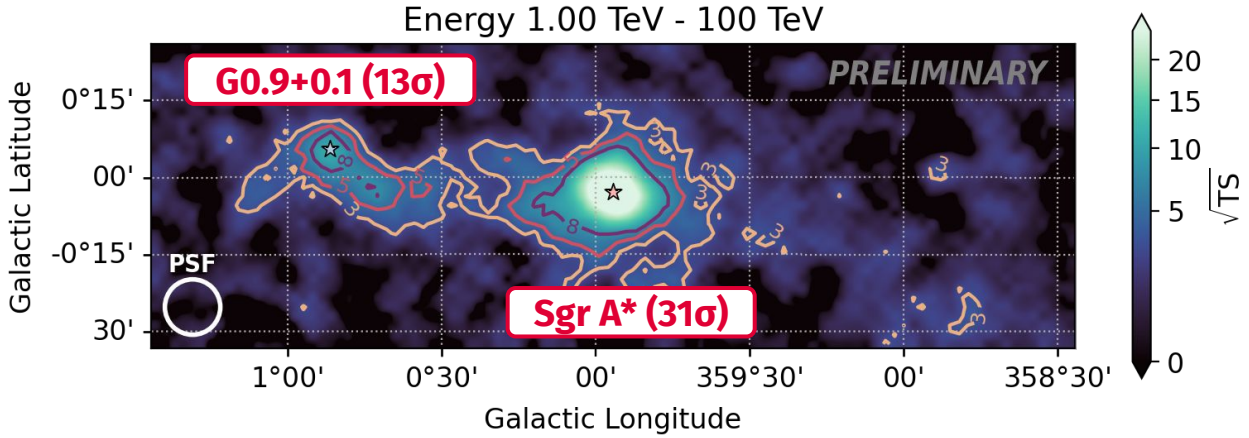
Sgr A* & G0.9+0.1 subtracted



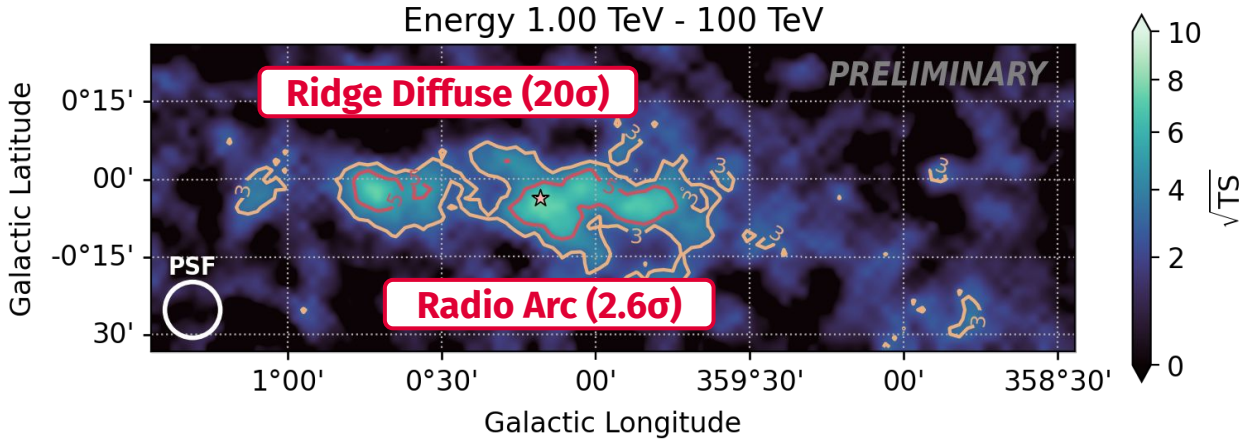
Result: Clear & Wide View of LST-1

*Significance in this study: >400 GeV
**cf. MAGIC 2020 (100hr, >1 TeV):
Sgr A*: 48σ, G0901: 11σ, Arc: 6.4σ, Diffuse: 17σ.

TS Map

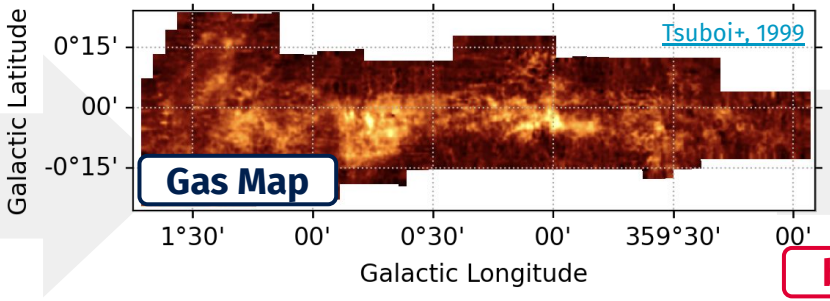


Sgr A* & G0.9+0.1 subtracted



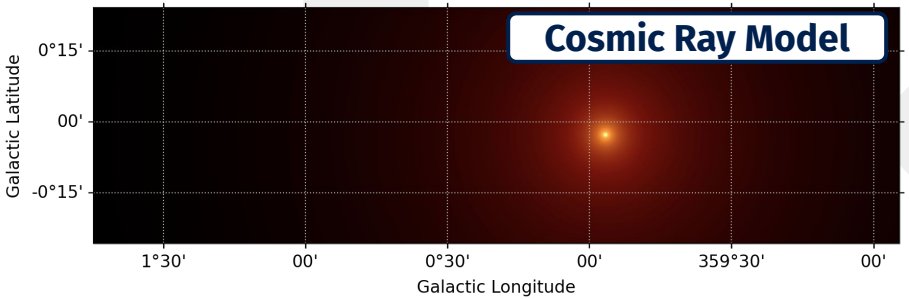
Method: the Ridge Diffuse Emission Morphology

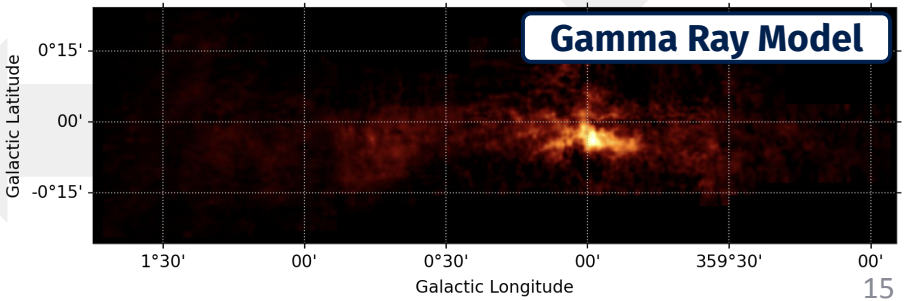
The diffuse γ-rays are modeled as resulting from inelastic *p-p* interaction between the dense gas and cosmic rays propagating from Sgr A*.



best-fitted CR index α ~ 1.1

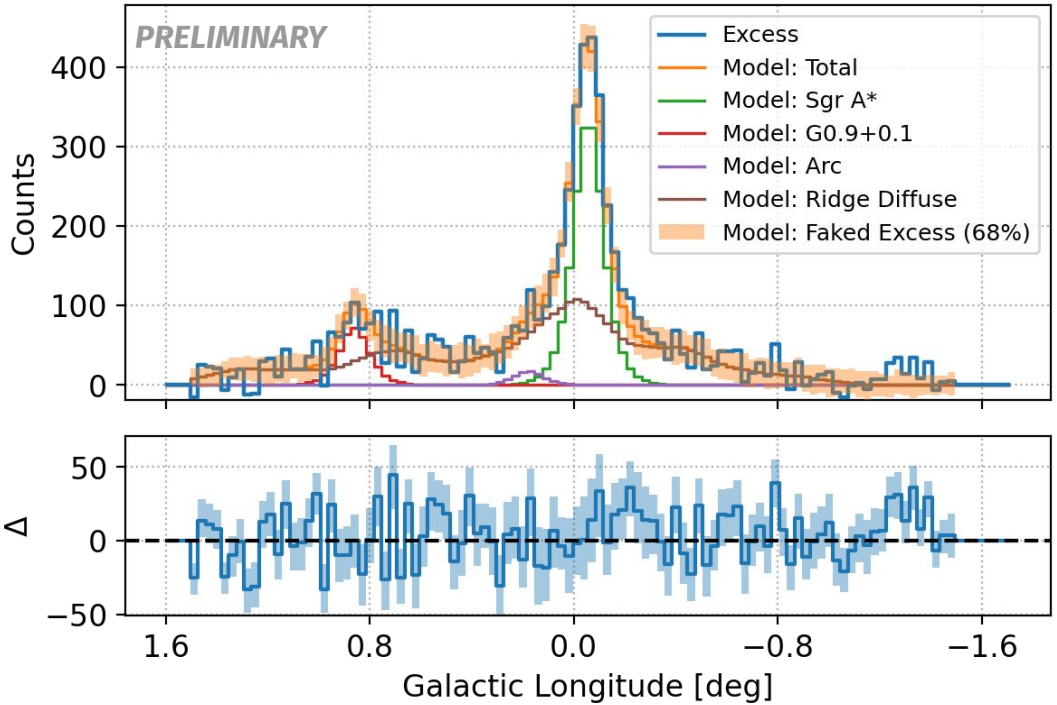
$$S(x,y) \propto \int \mathrm{d}z\, \rho_{\mathrm{gas}}(x,y,z) \cdot \rho_{\mathrm{CR}}(x,y,z) \sim \int \mathrm{d}z\, \rho_{\mathrm{gas}} \cdot \int \mathrm{d}z\, \rho_{\mathrm{CR}}; \quad \rho_{\mathrm{CR}}(r) = r^{-\alpha}$$





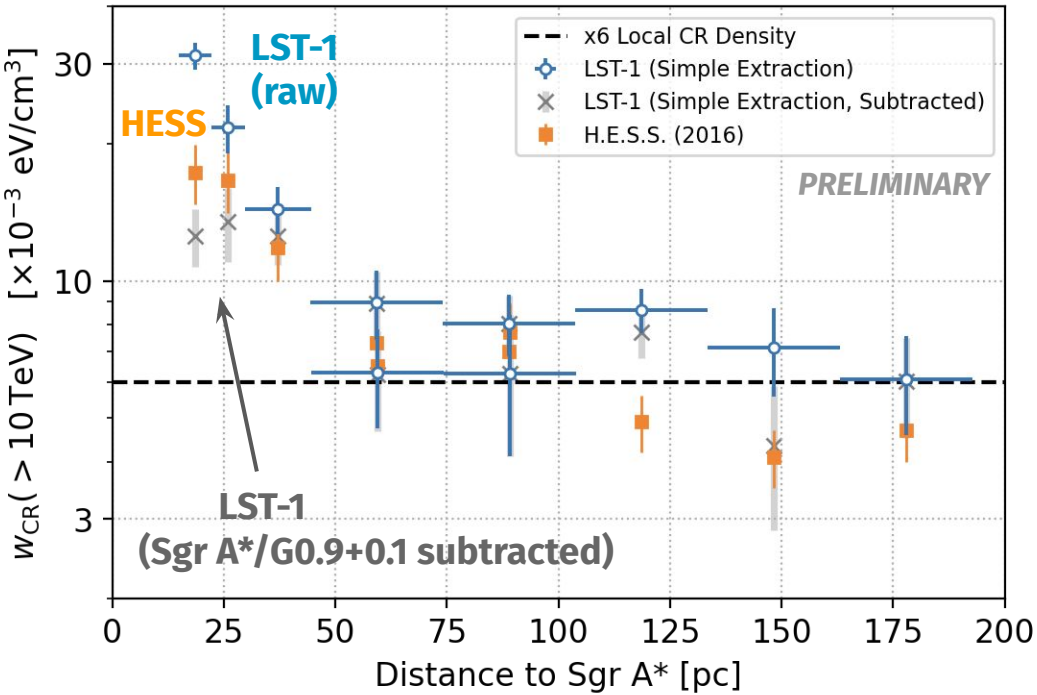
Result: Longitudinal Profile

The longitudinal profile obtained in -0.3° < b < 0.3° demonstrates the current set of models generally describes data well.



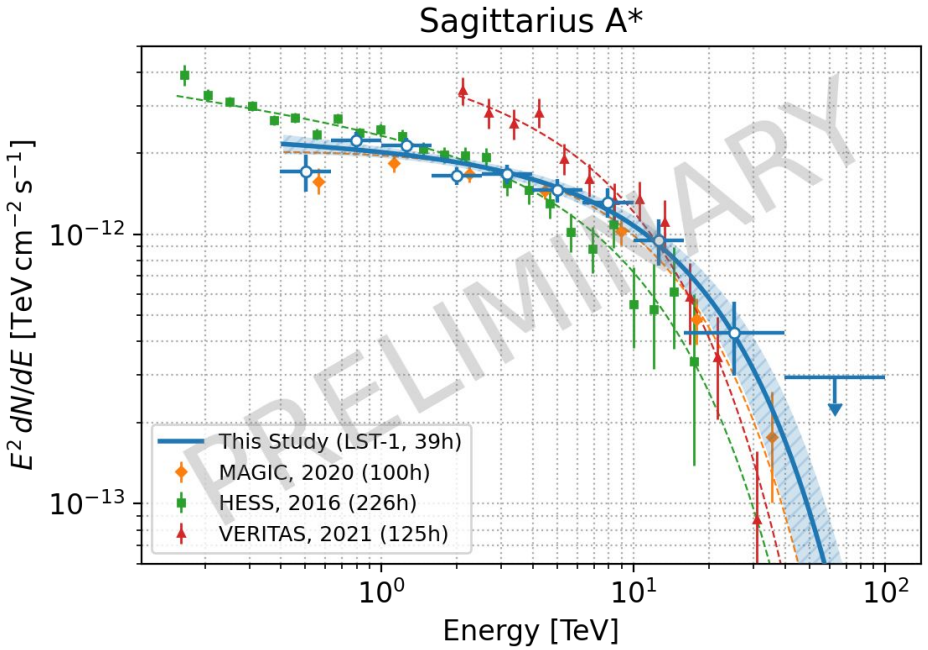
Result: CR Radial Profile

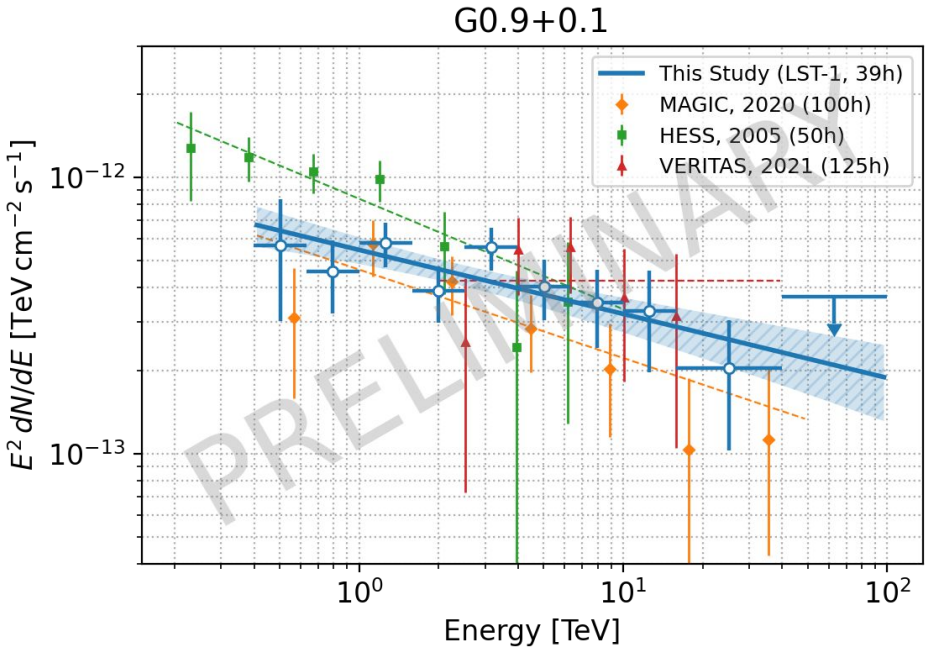
The cosmic-ray profile along the Galactic longitude has a peak structure, consistent with HESS 2016.



Result: SEDs of Point-like Sources

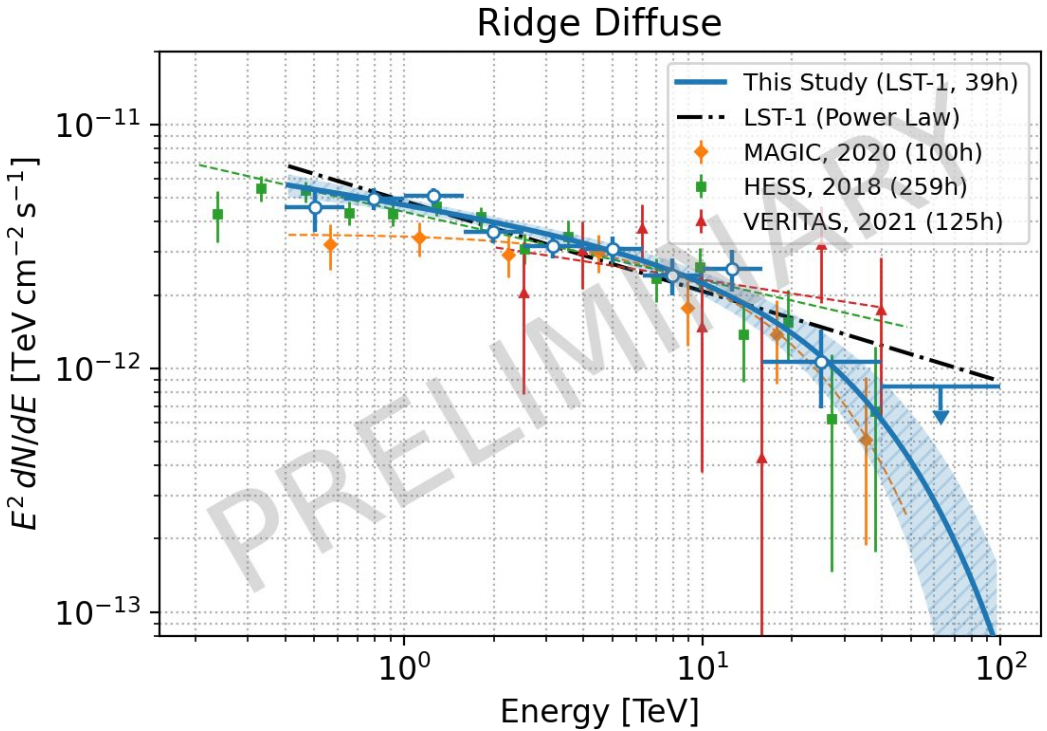
LST-1 results are generally consistent with the prior studies. A cutoff has not been seen in G0.9+0.1, despite the 4.8σ cutoff significance for Sgr A*.





Result: Ridge Diffuse Emission

The total diffuse emission favors the cut-off at 29 TeV with a significance of 2.8σ, consistent with [MAGIC 2020](#).



Conclusion & Summary

Summary

This study provides a new TeV view towards the Galactic Center region.

- **The LST prototype has proven to work well for TeV observations of the Galactic Center region**.
  - large-zenith-angle observations: Zd > 58 deg
  - wide field of view: the flat sensitivity up to 1.5 deg
- **3D Analysis was performed with 39-hr data**
  - higher significance of the ridge diffuse component & G0.9+0.1 than MAGIC 2020 with less than half the observation time
- **Spatial/Spectral distributions are generally aligned with previous studies**
  - the diffuse morphology aligns with the constant CR diffusion from Sgr A*
  - Ridge diffuse: cutoff around 30 TeV (2.8σ hint), consistent with MAGIC 2020

Back Up