CTA大口径望遠鏡初号機と MAGIC望遠鏡による研究成果

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2024.2.21　令和5年度共同利用研究成果発表会

Cherenkov Telescope Array (CTA)

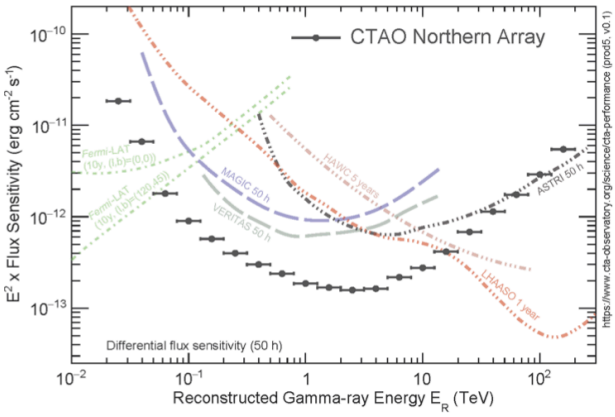
- New gamma-ray observatory under construction
- 4 LSTs will be set at northern site in La Palma, Spain, alongside 9 MSTs.
- Compared to current telescopes,

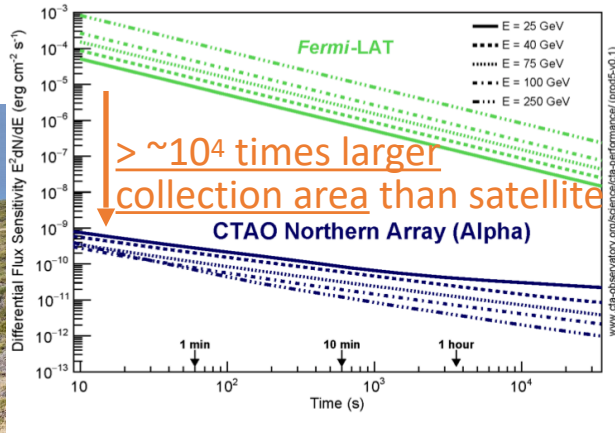
  - 10 times better sensitivity

  - 10 times wider energy range: 20 GeV – 300 TeV

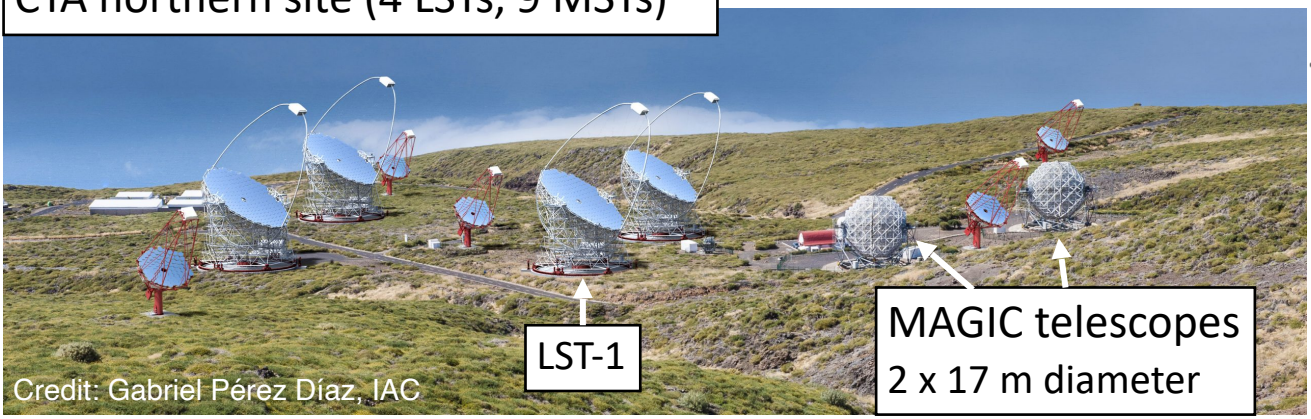
- We started LST-1 operation from 2018.

LST energy range



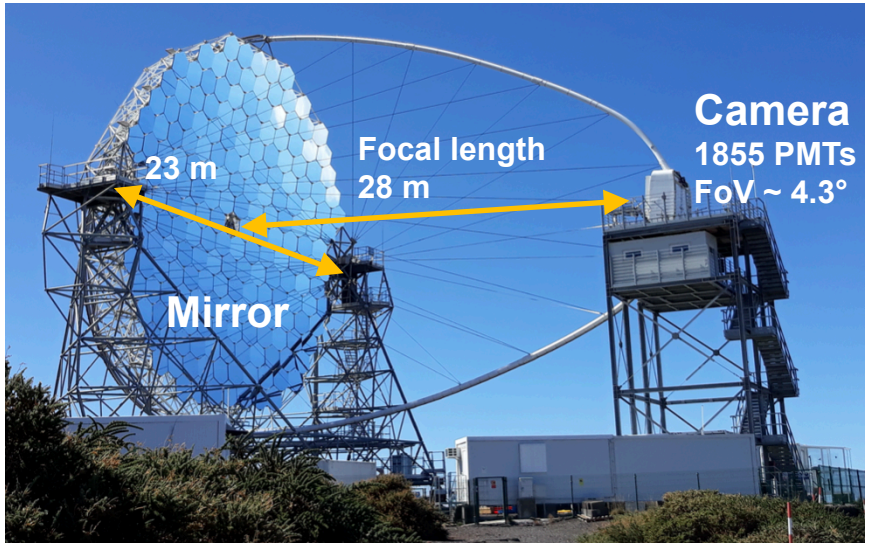


CTA northern site (4 LSTs, 9 MSTs)

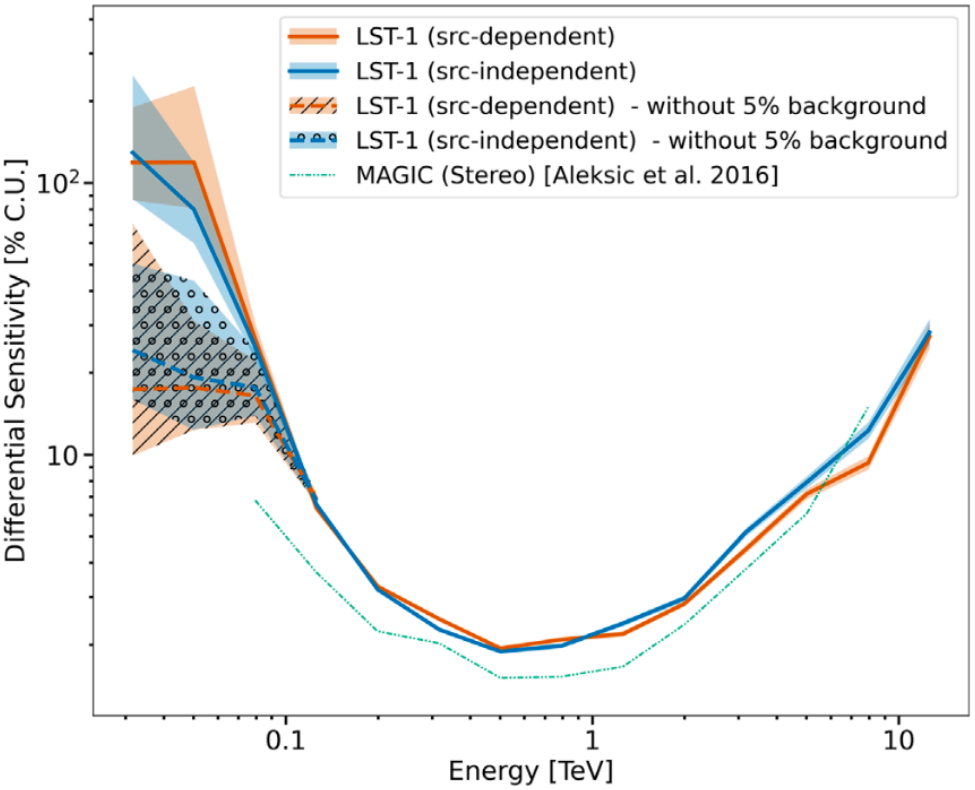


CTA large-sized telescope (LST)

- 23 m diameter: over 400 m^2 mirror area
- Targeting an energy threshold ~20 GeV
- Stereo observations at **lowest energy ever observed from ground**
- Ability to reposition to any point in the sky within 20 seconds
- Ideal for fast transients and soft sources



LST-1 performance



Flux Sensitivity
(zenith angle < 35 deg, 50 hours)

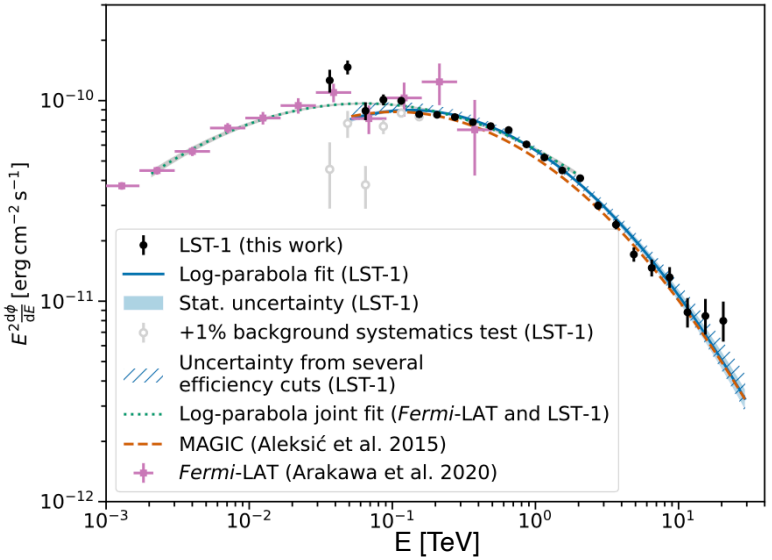
- Energy range widened to lower energy compared to MAGIC
- ~1.5 times less sensitive than MAGIC (stereo system)
  - consistent with single telescope performance vs stereoscopic system

- Astrophysical Journal **956**, 80 (2023)

Crab Nebula and Pulsar

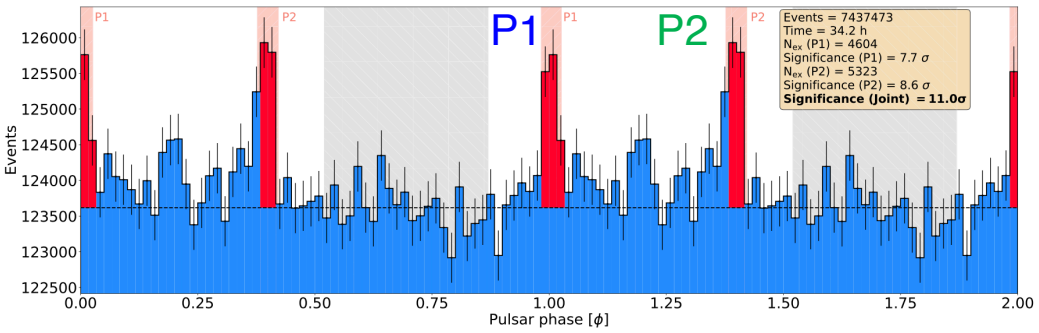
Crab Nebula spectrum

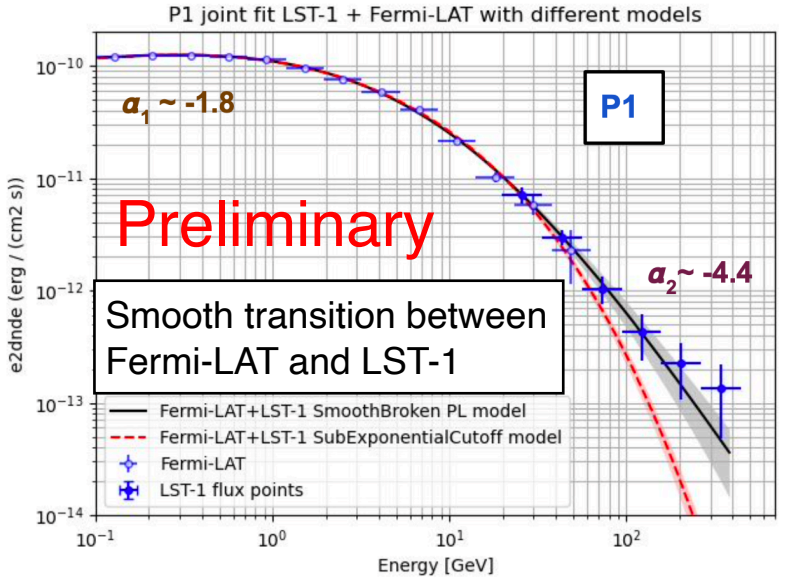
- 34.2 hours of data with zenith < 35°
- Systematic errors: gray points correspond to the effect of +1% background
- Compatible with MAGIC and *Fermi*-LAT



Crab pulsar

- Clear detection down to a few tens of GeV
- Confirms Power-law extension at VHE

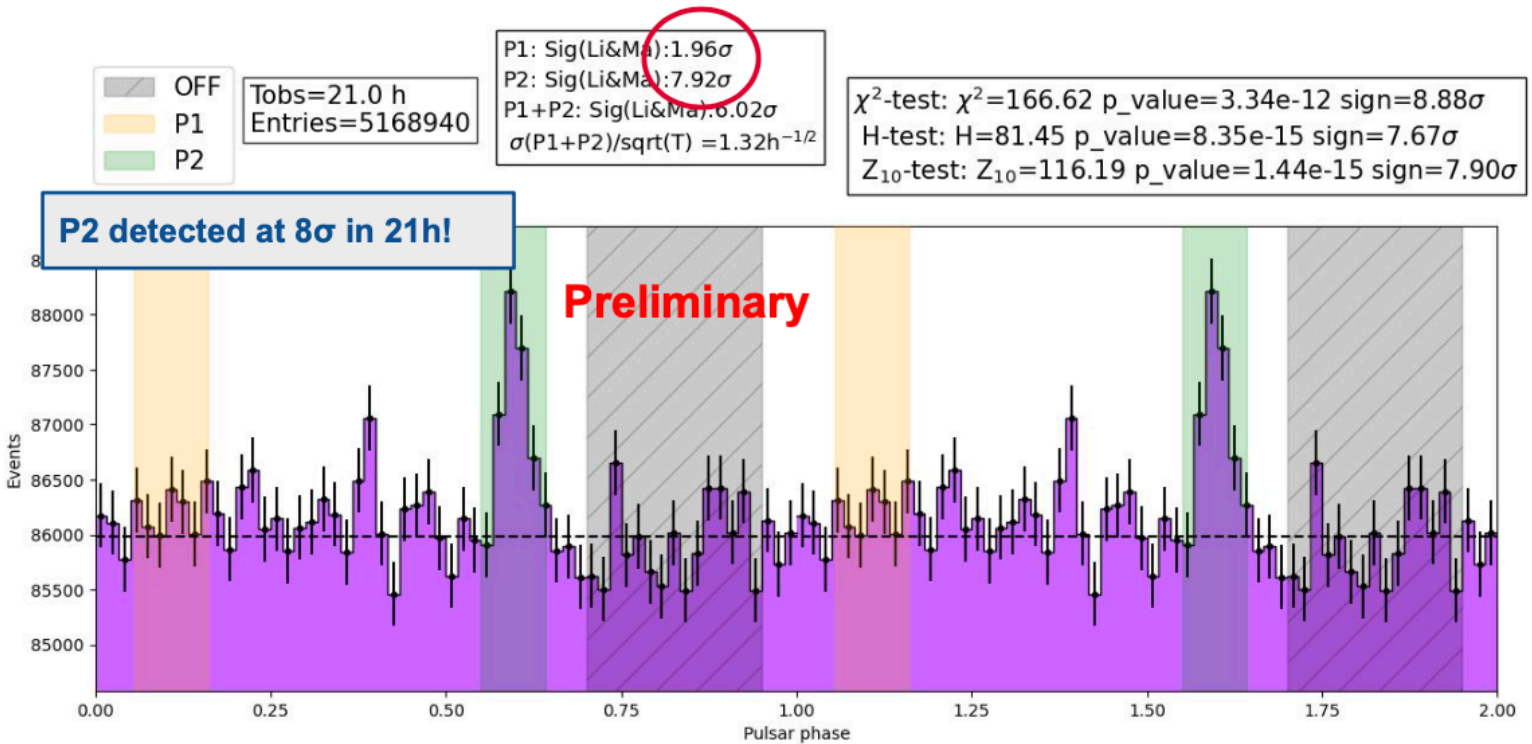




Geminga Pulsar

- One of the brightest pulsars detected by Fermi-LAT at few GeV
- 8σ detection for P2 in 21 hours of data

  MAGIC: 6.2σ sigma in ~80 hours
- This shows excellent performance of LST-1 at ~10 GeV.



Discovery of AGN OP 313 at VHE gamma-rays

- Flat Spectrum Radio Quasar (FSRQ), Redshift: z = 0.997
- Detected Dec. 2023 flare (ATel #16381)
- Most distant source with LST-1.
- This shows excellent performance of LST-1 for distant sources.
- Study of EBL is ongoing.

First detection of VHE gamma-ray emission from FSRQ OP 313 with LST-1

ATel #16381; *Juan Cortina (CIEMAT) for the CTAO LST collaboration*
*on **15 Dec 2023; 14:31 UT***
Credential Certification: Juan Cortina (Juan.Cortina@ciemat.es)

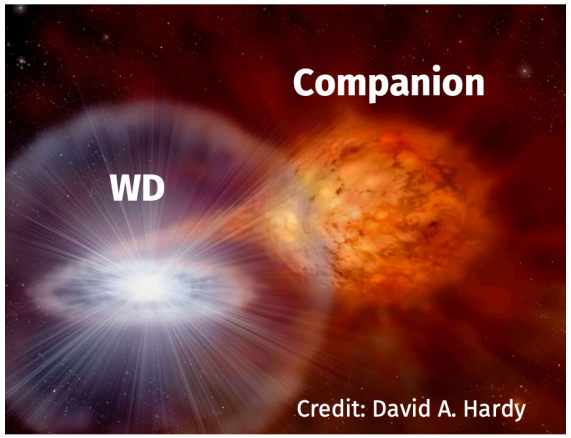
Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, AGN, Blazar, Quasar

𝕏 Post

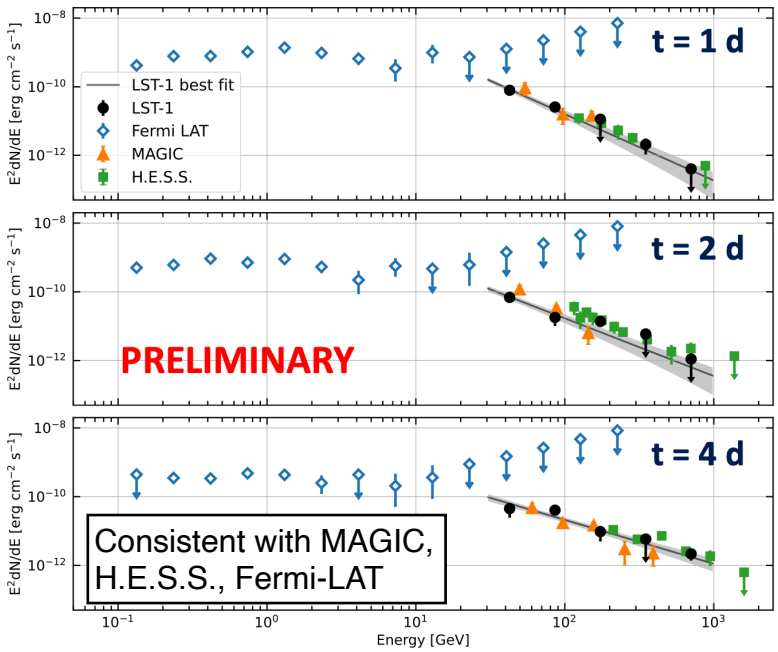
The Large-Sized Telescope (LST-1) on La Palma has been monitoring the very distant Flat Spectrum Radio Quasar (FSRQ) OP 313 (z=0.997, Schneider et al. 2010, AJ, 139, 2360) since November 2023. Following the announcement of enhanced gamma-ray emission by Fermi-LAT (ATel #16356) and several optical facilities (ATel #16360) in early December, the Fermi-LAT emission of OP 313 has been closely monitored using the FlaapLUC pipeline

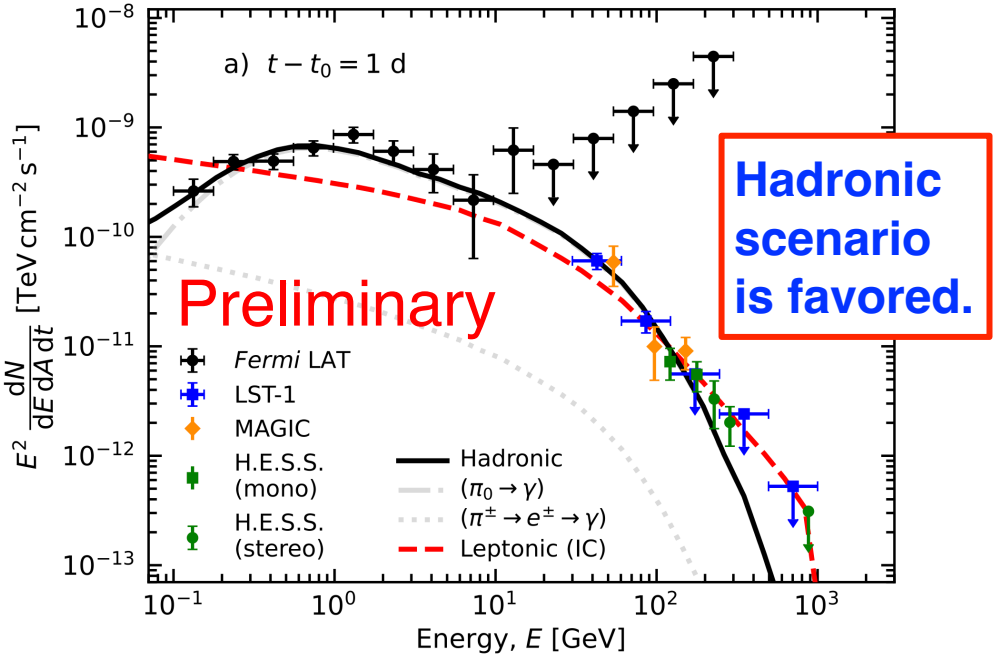
Detection of Nova RS Ophiuchi

- recurrent symbiotic nova, d~2.69 kpc
- First detected recurrent nova in VHE gamma rays by 2021 outburst (H.E.S.S. and MAGIC)
- LST-1 took part in the first VHE gamma-ray detection with >~6σ in each night



Novae established as new source class at VHE gamma rays



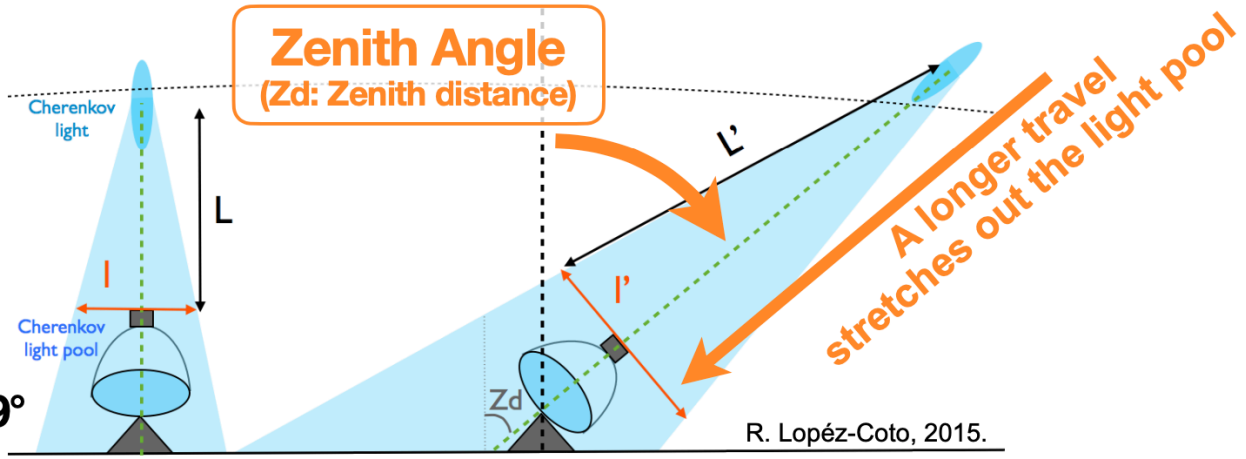


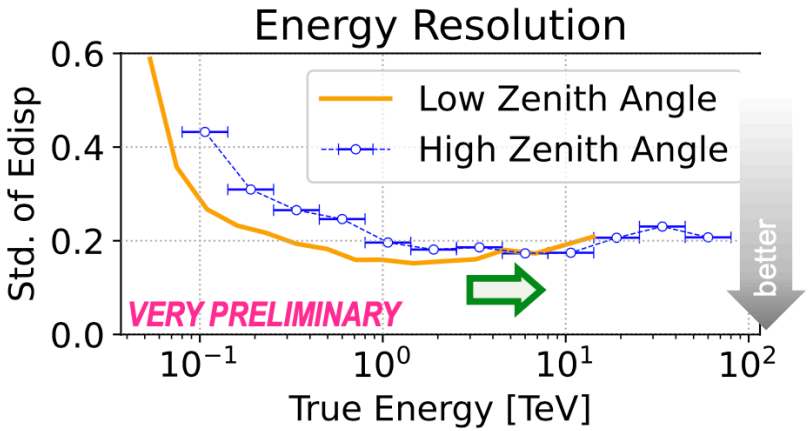
Hadronic scenario is favored.

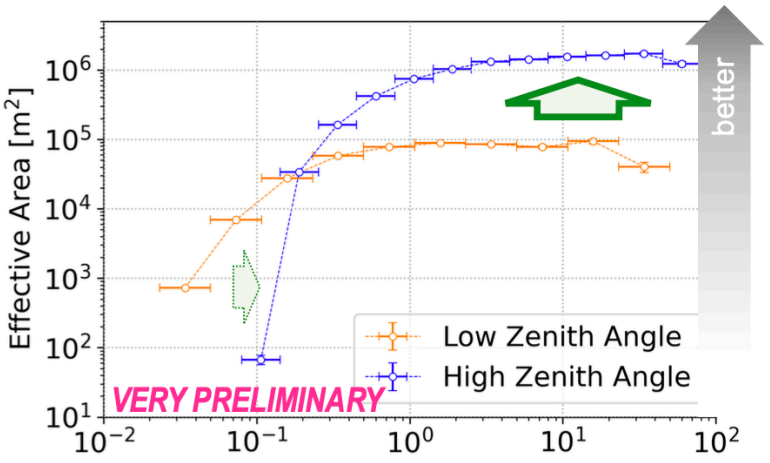
Large-zenith angle observation for Galactic Center

Large-zenith-angle observations (55-70 deg) enlarge the effective area at the high energies.

- **LST-1: 28°N**
- **Gal-Cent: Dec -29°**

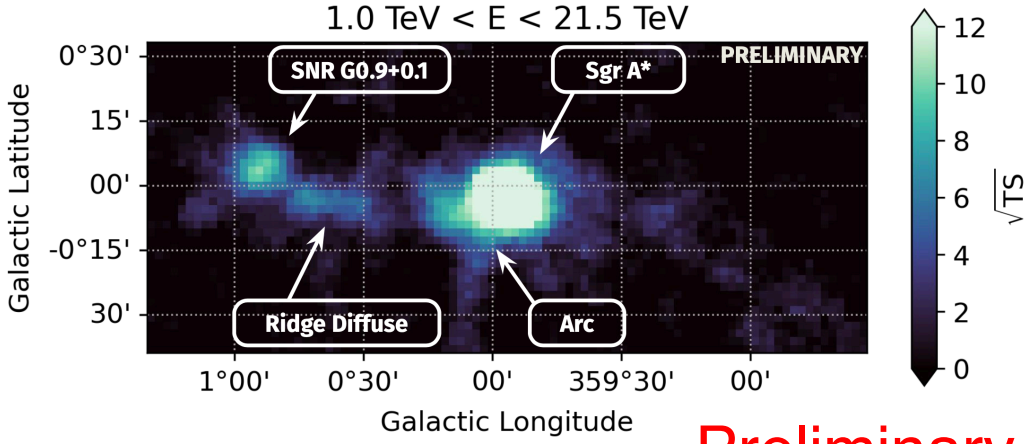




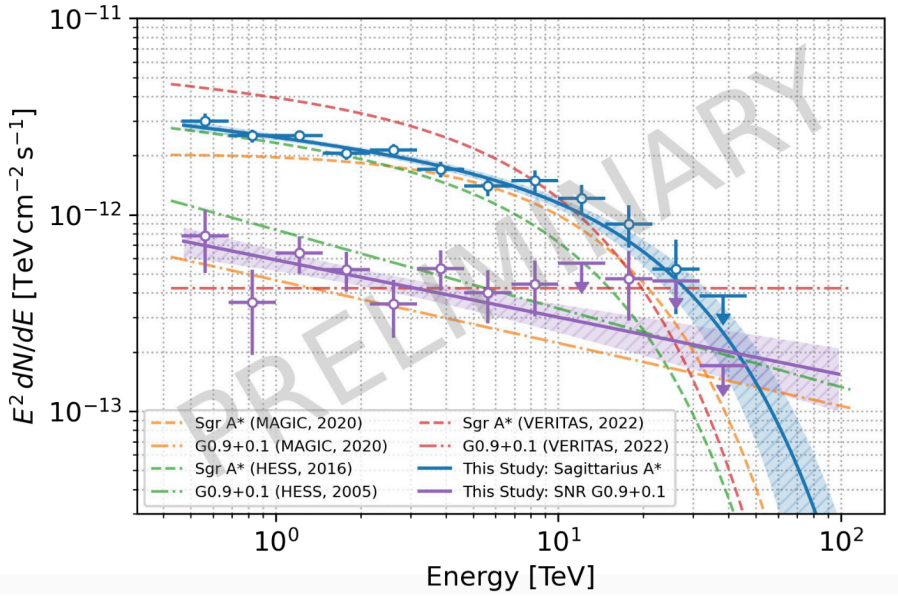


Galactic Center

- **39-hour data** in 2021/2022 after selection
- Analysis is carried out through a dedicated special background modeling.
- Sgr A* & SNR G0.9+0.1 SEDs are in line with results from other telescopes.
- Successful extended-source observations
- Observation is ongoing.

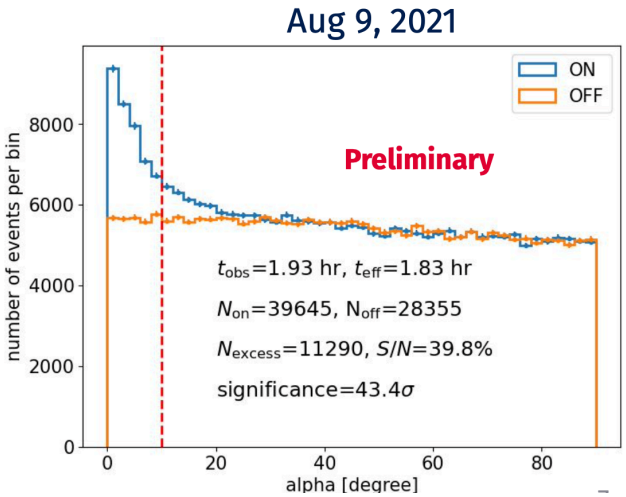


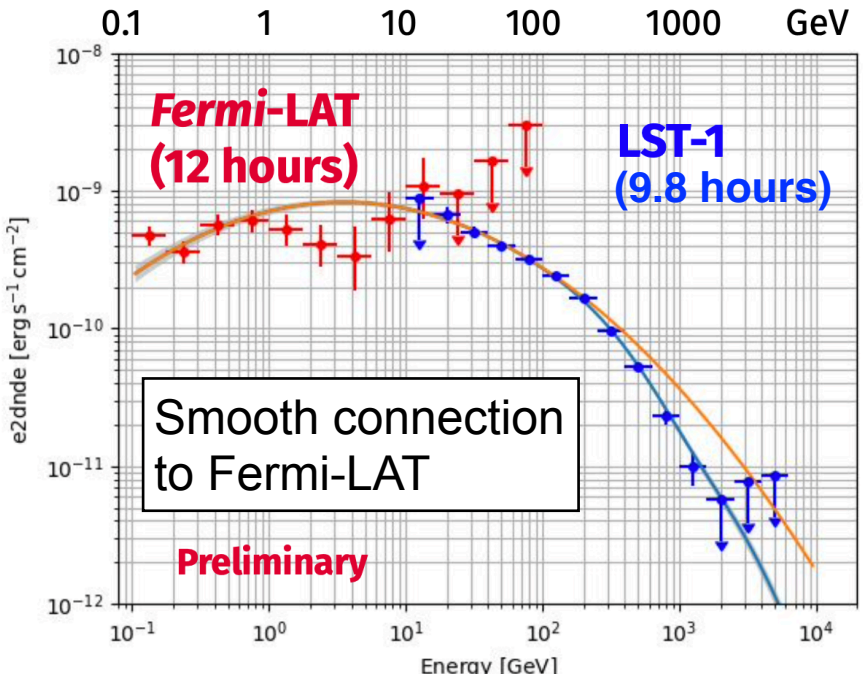
Preliminary

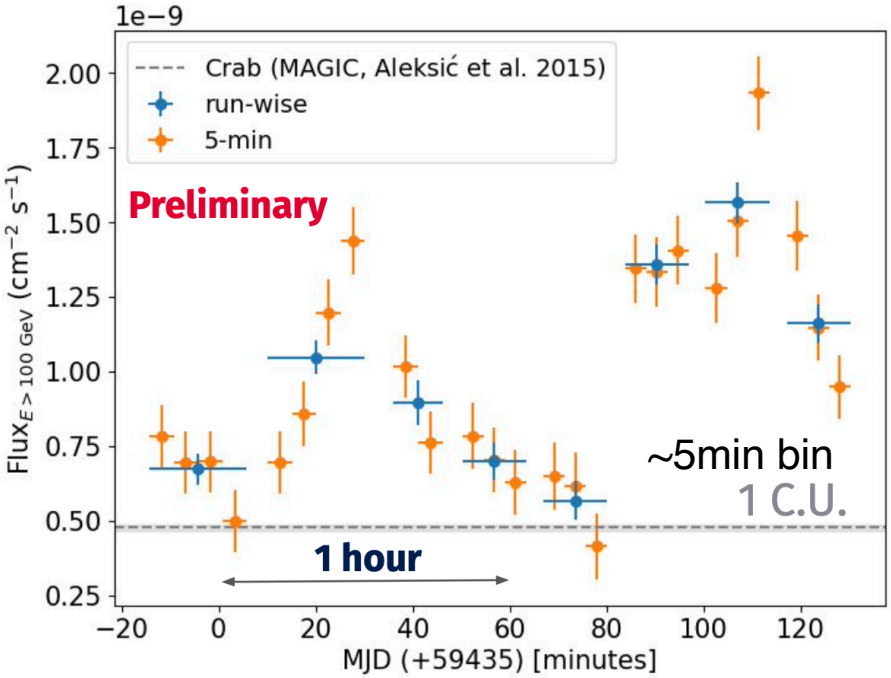


BL Lacertae

- Intermediate frequency peaked BL Lac at z = 0.069
- Flare in 2021 July and August was detected.
- Energy spectrum down to ~30 GeV
- Intra-night variability with sub-hour-scale was detected up to 3-4 Crab unit.
- MWL SED study is ongoing.
- QG and Relativity tests are ongoing.







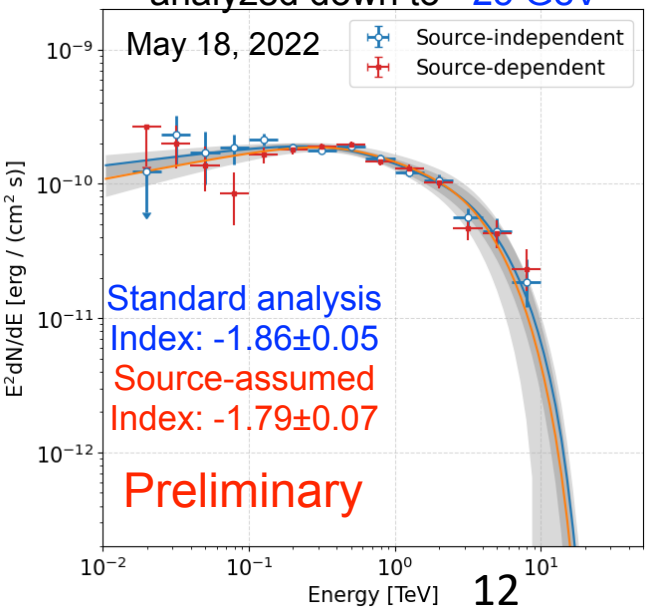
AGN zoo

- LST array aims to observe AGN up to z~2.
- More than one thousand hours of data taken with LST-1 from 2020:
  Near sources: Mrk 421, Mrk 501, 1ES 1959+650, …
  Distant sources: 1ES 0647+250, PG 1553+113, …
- All known TeV blazers, and detected (>5σ) up to a z~0.45

Observation summary

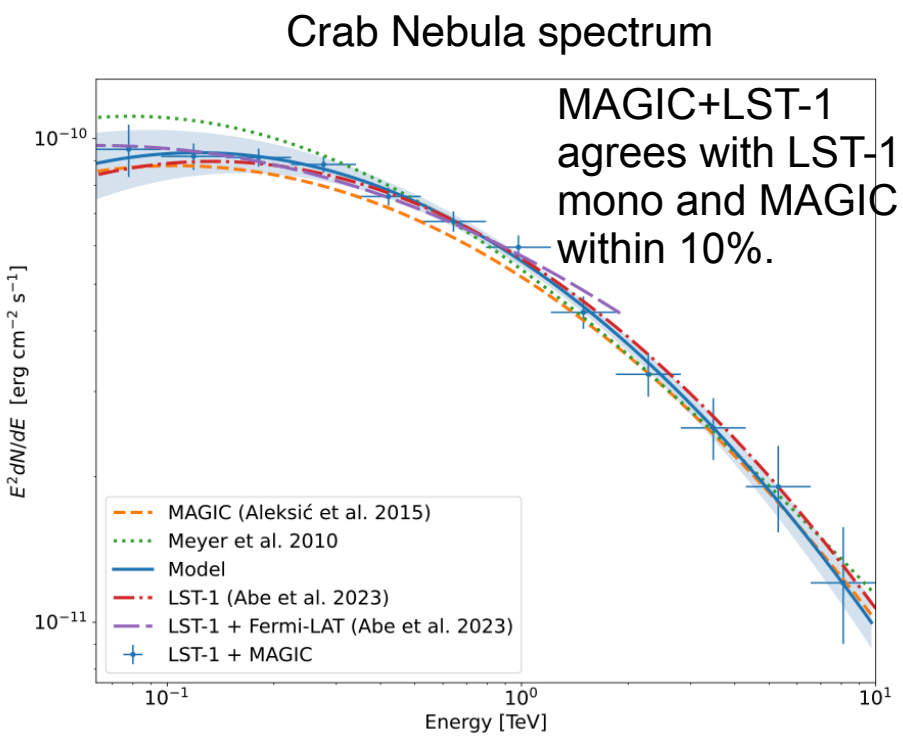
Source	Observation date	Redshift	Observation time before/after cut (h)	Detection significance (σ)
Mrk 421	2020 Dec. 12 - 2022 May 23	0.031	68.5 / 31.9	53
Mrk 501	2020 July 10 - 2022 May 22	0.034	67.2 / 39.7	21
1ES 1959+650	2020 July 11 - 2022 May 5	0.048	21.3 / 11.8	13
1ES 0647+250	2020 Dec. 16 - 2020 Dec. 21	0.45±0.05	8.8 / 8.2	7
PG 1553+113	2021 Apr. 8 - 2022 May 23	0.433	12.2 / 9.9	16

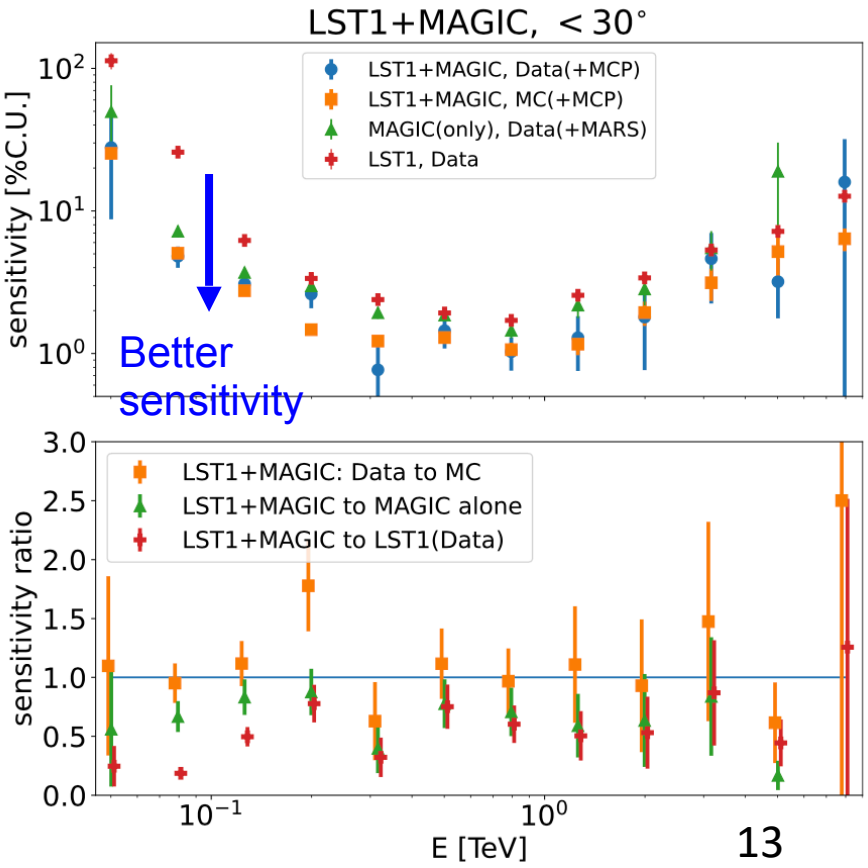
Mrk 421 flare SED
analyzed down to ~25 GeV



LST+MAGIC

- LST and MAGIC joint observation and analysis method
- Allow detection of 30% (40%) lower fluxes than MAGIC alone (LST-1 alone) (Current best sensitivity at tens of GeV in northern IACT)
- A&A **680**, A66 (2023)





MAGIC publication in refereed journals (2023)

8 papers:

First characterization of the emission behavior of Mrk421 from radio to VHE gamma rays with simultaneous X-ray polarization measurements
MAGIC collaboration, Abe *et al.*
Accepted in 2023 for publication in Astronomy & Astrophysics

MAGIC detection of GRB 201216C at z=1.1
MAGIC collaboration, Abe *et al.*
Monthly Notices of the Royal Astronomical Society **527** 5856–5867 (2024), accepted in 2023

A lower bound on intergalactic magnetic fields from time variability of 1ES 0229+200 from MAGIC and Fermi/LAT observations
MAGIC collaboration, Acciari *et al.*
Astron. & Astroph. **670** (2023) A145

Long-term multi-wavelength study of 1ES 0647+250
MAGIC collaboration, Acciari *et al.*
Astron. Astrophys. **670** (2023) A49

MAGIC observations provide compelling evidence of the hadronic multi-TeV emission from the putative PeVatron SNR G106.3+2.7
MAGIC collaboration, Abe *et al.*
Astron. & Astroph. **671** (2023) A12

Multimessenger Characterization of Markarian 501 during Historically Low X-Ray and gamma-Ray Activity
MAGIC collaboration, Abe *et al.*
Astroph.J. Suppl. **266** (2023)

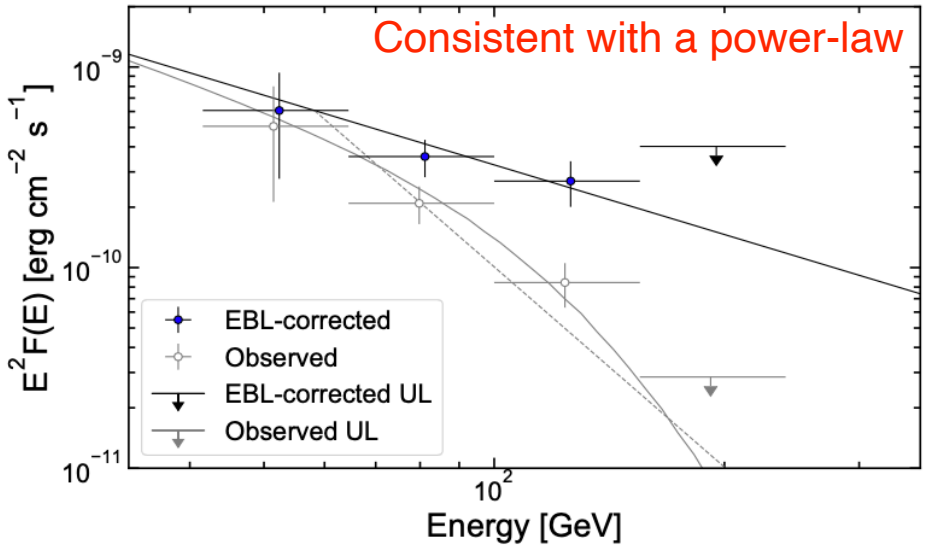
Search for Gamma-ray Spectral Lines from Dark Matter Annihilation up to 100 TeV towards the Galactic Center with MAGIC
MAGIC collaboration, Abe *et al.*
Phys. Rev. Lett. **130** (2023) 061002

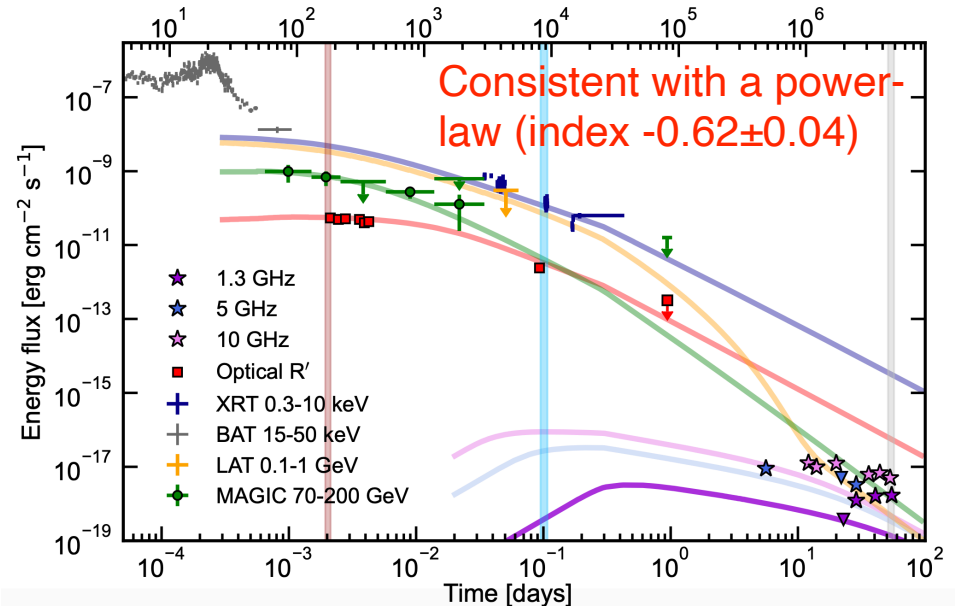
Study of the GeV to TeV morphology of the gamma-Cygni SNR (G78.2+2.1) with MAGIC and Fermi-LAT
MAGIC collaboration, Acciari *et al.*
Astron. & Astroph. **670** (2023) A8

MAGIC highlights

Detection of GRB 201216C

- Most distant GRB detected in VHE range, z = 1.1
- MAGIC observed from T_0 + 56 sec and detected between 70 and 200 GeV.
- From the light curves of the optical/sub-TeV fluxes, wind-like ambient medium density profile is suggested.
- MNRAS **527,** 5856–5867 (2024)





Summary

- LST-1 is continuing observation and performing scientific observation.
- Crab Nebula, pulsar: Significant detection down to few tens of GeV
- Geminga pulsar: significant detection of soft spectrum source
- Nova RS Ophiuchi: LST-1 took part in the first VHE gamma-ray detection with >~6σ in each night
- Blazar BL Lacertae: Flux variability with sub-hour-scale is observed.
- AGN zoo: detected (>5σ) up to a z~0.45
- Galactic center: successful extended-source observation
- MAGIC+LST method: 30-40% better sensitivity was achieved
- Observing FSRQ OP 313
- Observing GRB following burst alerts