FACULTY OF PHYSICS
AND APPLIED INFORMATICS
University of Lodz

Large-Sized Telescopes: progress in construction and first scientific results

J. Sitarek on behalf of the LST/CTAO Collaboration

2025.02.22, Particle Astrophysics in Poland, Warsaw

LST

- LST with mirror diameter of 23 m are the largest type of telescopes of CTAO
- Large mirror area = low energy threshold (~20 GeV) ideal instrument for soft sources (pulsars, distant AGNs and GRBs, …)
- Low energy threshold = more photons – possibility to study variability at shorter time scaless

LST Collaboration

- 480 Collaboration members
- 79 institutes
- 11 countries (Brazil, Bulgaria, Croatia, Czechia, France, Germany, Italy, Japan, **Poland**, Spain, Switzerland)

Poland in LST

- Part of collaboration since 2016
- Single group (University of Lodz): JS, W. Bednarek, G. Borkowski, P. Gliwny, J. Wójtowicz, N. Żywucka
- We work mainly on:
  - Development of analysis methods
  - Common operations with MAGIC
  - Low-level calibration
  - Observations, data analysis and interpretation.

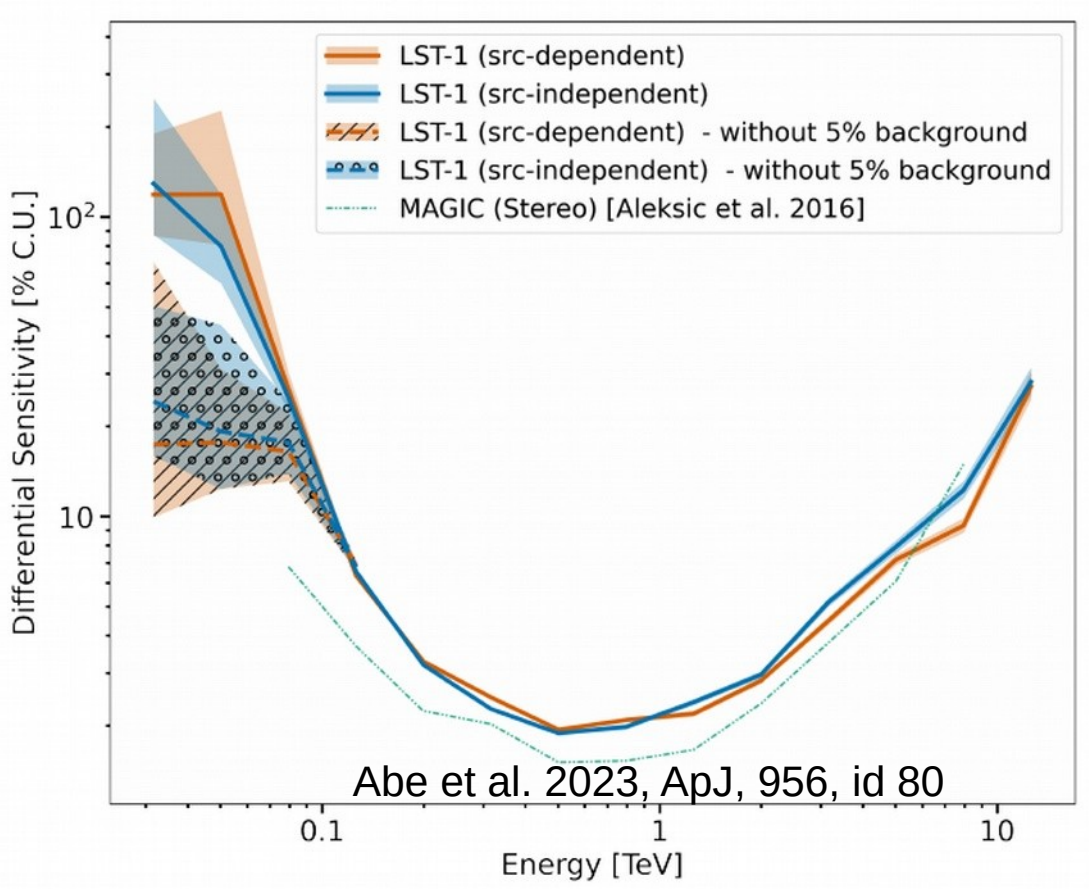
LST1

- Inaugurated in October 2018 followed by commissioning period
- Works ongoing on ensuring that the telescope fulfills the stringent CTAO standards
- In the meantime performing scientific observations
- So far:
  - Nearly 3000 hours of data collected
  - 6 published scientific and analysis methods papers,

more are coming...

LST-1 sensitivity

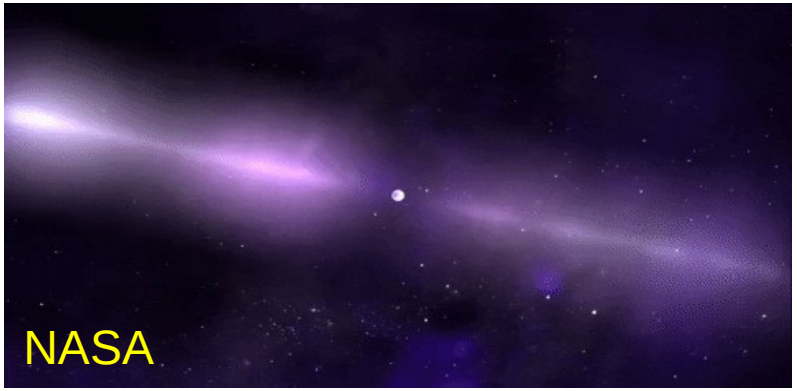
- The performance of the LST-1 telescope was evaluated with Crab Nebula observations and published
- As a single telescope, the sensitivity at the low energies is limited by low background suppression (irrelevant for pulsar observations)
- Despite being a single telescope, LST-1's sensitivity approaches the level of current-generation IACTs.



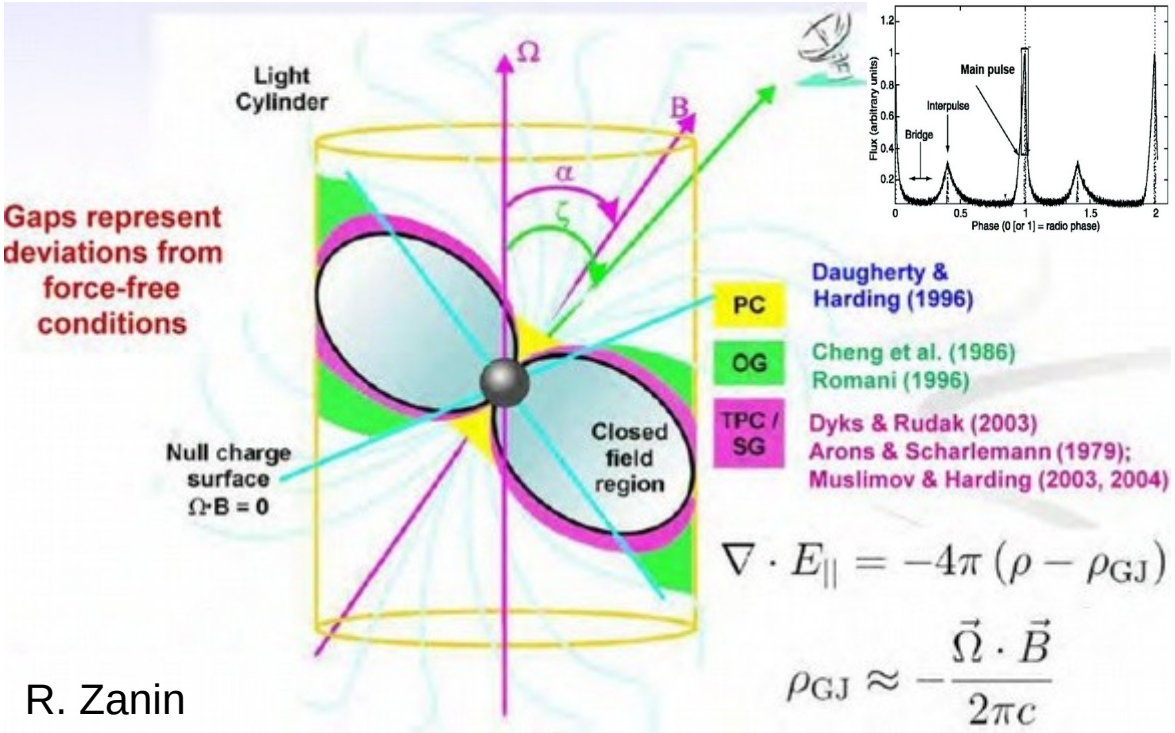
Science with LST-1

- Pulsars – exploiting low energy threshold
- Transients – energy threshold, fast repointing, being here and now
- Extended sources – due to larger trigger region than MAGIC it is easier to study

Pulsars

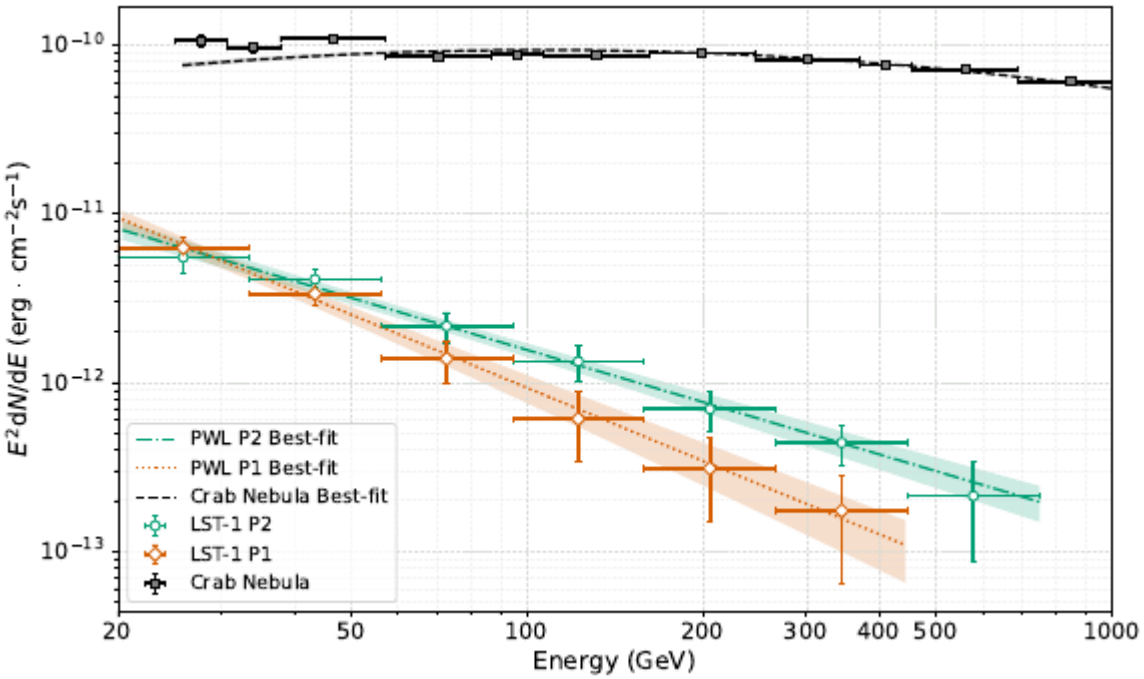


- Rapidly rotating neutron star with a beam of radiation sweeping over the observer
- Different regions where particles can be accelerated because the electric field is not counteracted by the charge pulled out from the surface of the neutron star

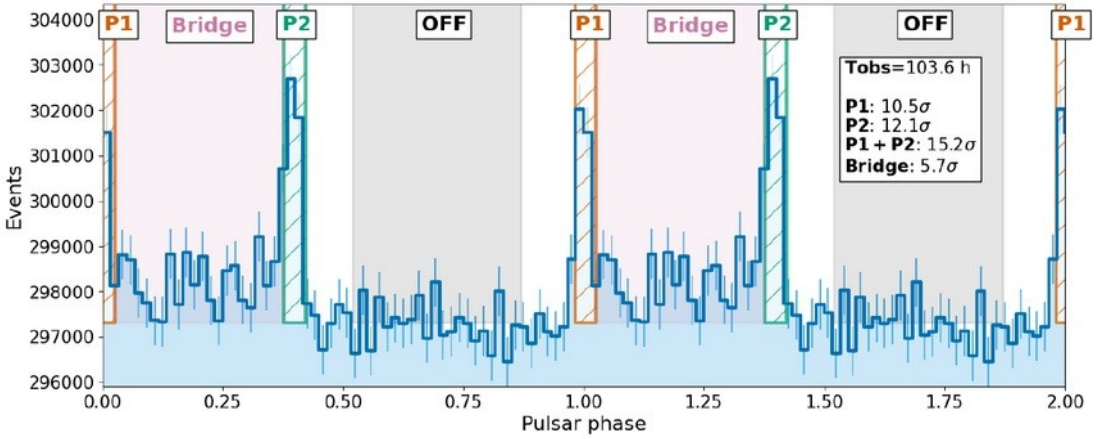


Crab pulsar

- The first detected VHE gamma-ray pulsar
- Detailed estimation of the SED for both peaks down to ~20 GeV

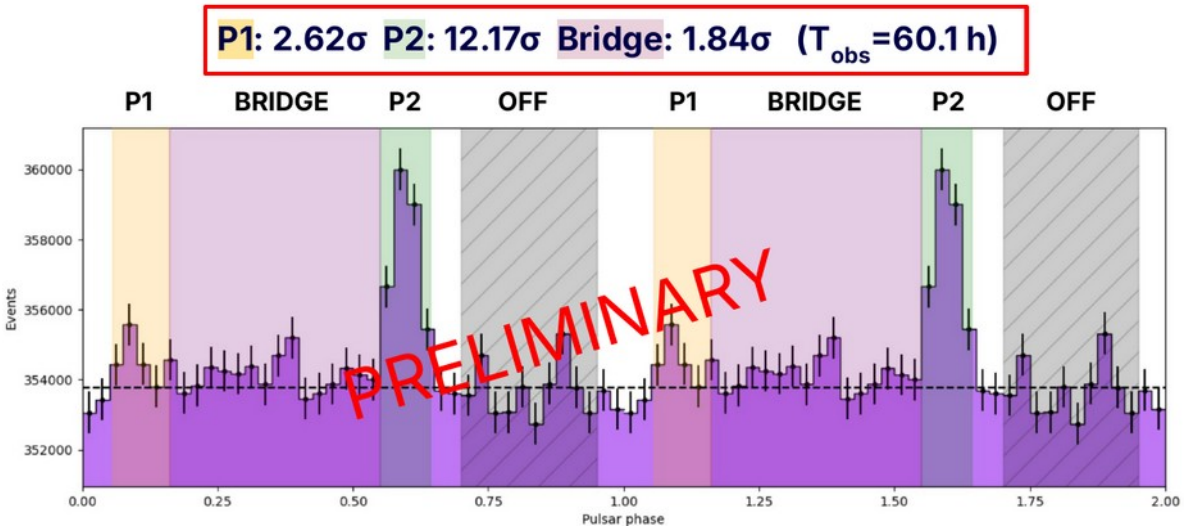


Abe at al. 2024, 690, A167



Geminga

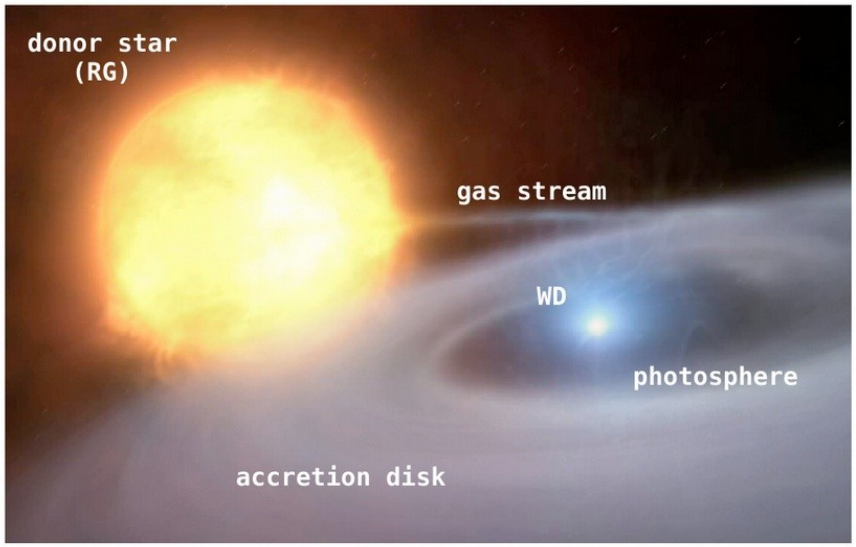
- Much older pulsar (340 kyr) than Crab (1 kyr)
- Observationally very soft source
- Highly significant signal in LST-1 observations



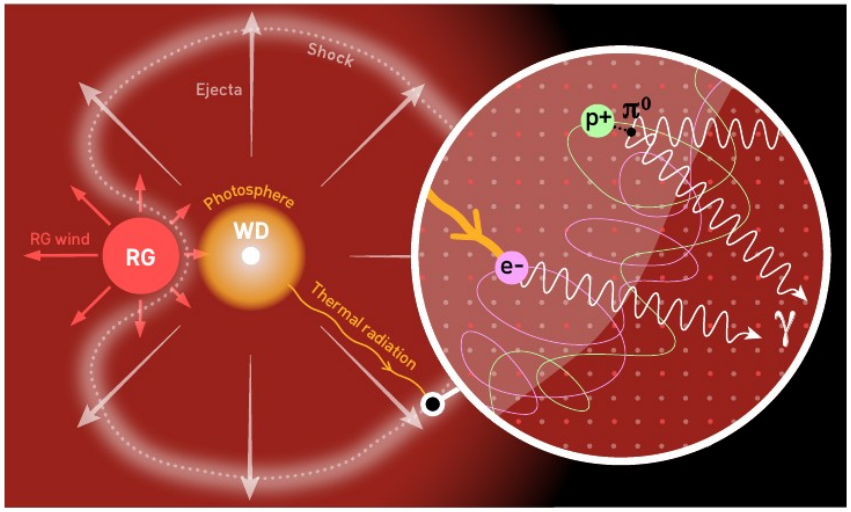
G. Brunelli, HONEST3 workshop, 2024

Novae

- Cataclysmic variable binary systems of a white dwarf (WD) and a donor star.
- Mass transfer from the donor star causes thermonuclear explosions of the hydrogen accumulated on the WD.
- If the donor star is a RG, the system is immersed in its wind, creating a **symbiotic binary**.
- Some novae have WD very close to the mass limit, causing repetition of outbursts in human lifespan (<100 years) – **recurrent novae**.
- Due to high optical brightness (lasting for weeks/months) they have been studied for centuries
- Since a decade also known GeV emitters but leptonic/hadronic origin was unknown



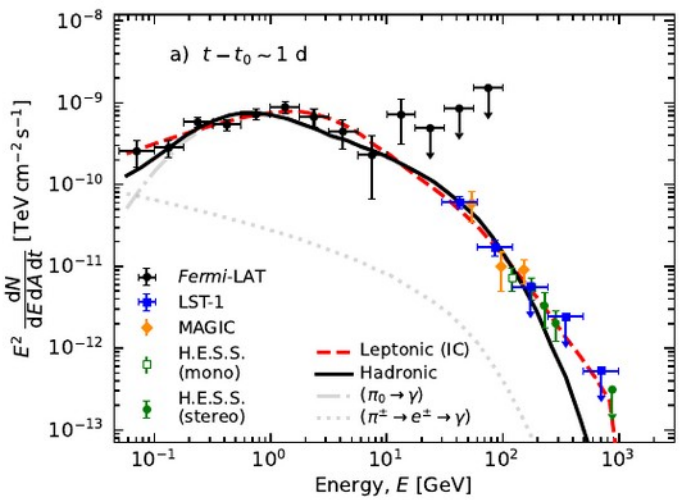
Credit: ESO / M. Kornmesser

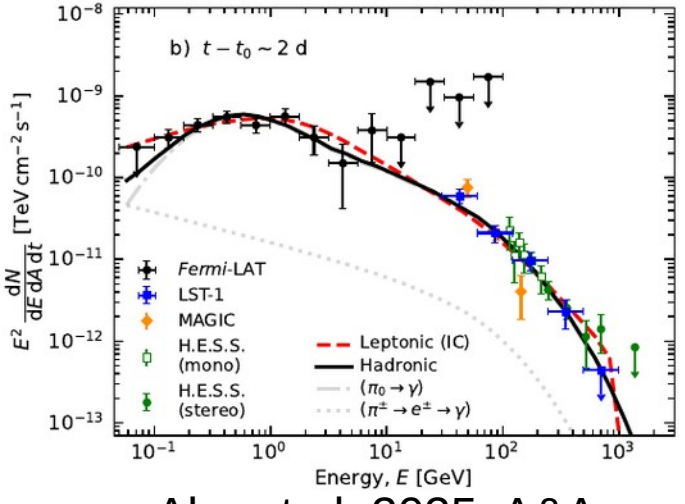


Acciari et al. 2022

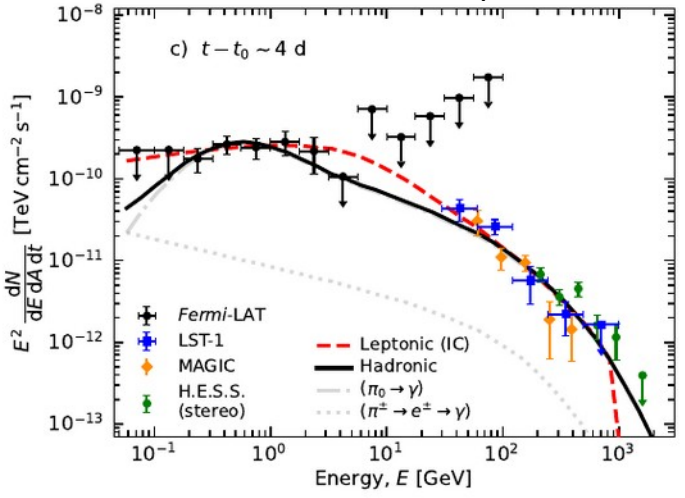
RS Ophiuchi

- Recurrent symbiotic novae with outbursts every ~15 years (latest on 2021.08.08)
- **The first nova detected in VHE gamma rays,** Independently followed and detected by H.E.S.S. (Aharonian et al. 2022) and MAGIC (Acciari et al. 2022) **and LST1**
- The LST1 spectrum is reconstructed daily, it is consistent with the MAGIC one but extends to lower energies



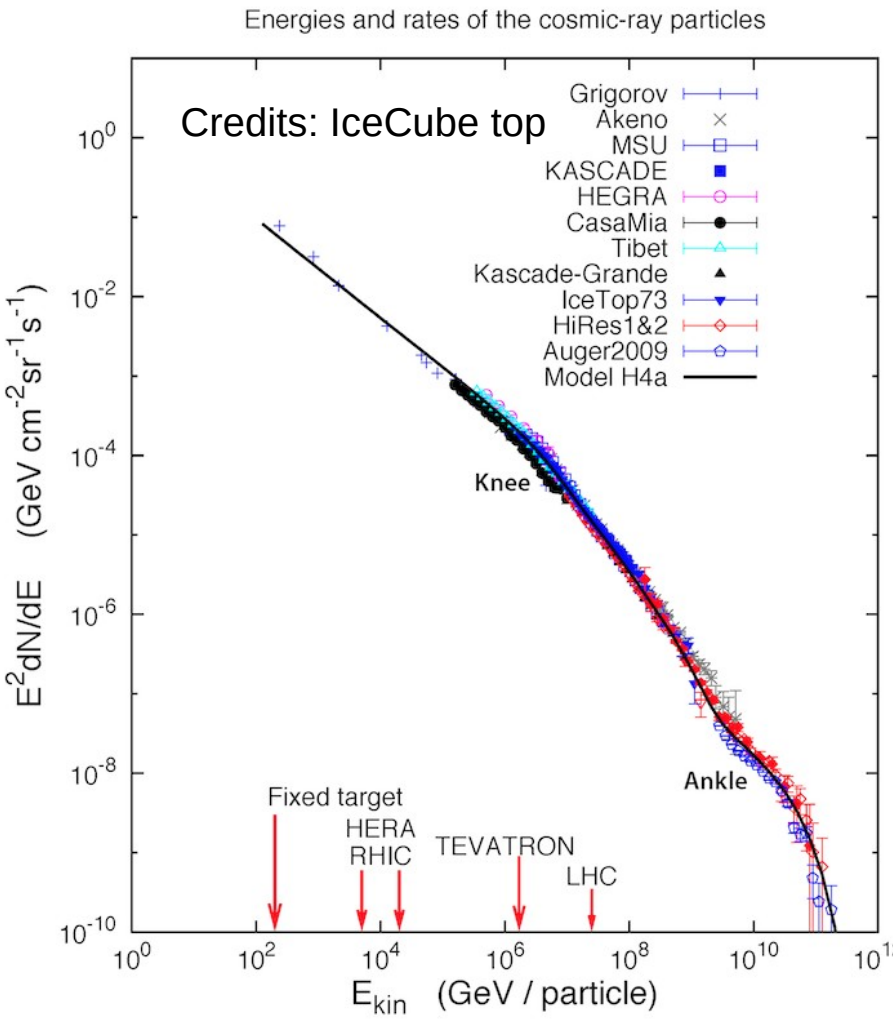


Abe at al. 2025, A&A

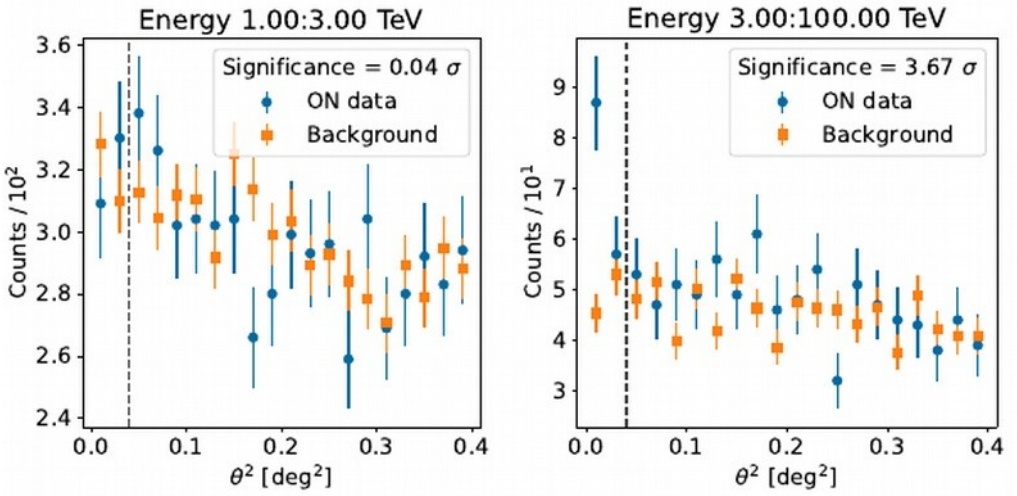


Galactic sources above 100 TeV ?

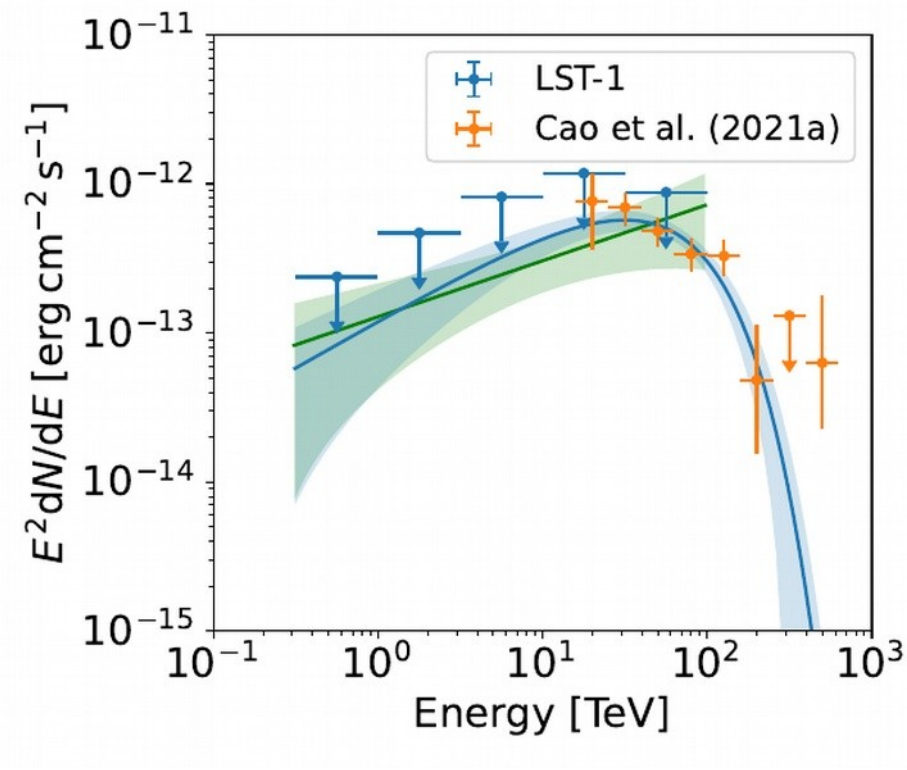
- To understand the knee in CRs we need to understand where the PeV protons are produced
- PeV protons will produce in hadronic interactions ~100 TeV gamma rays
- A lot of progress recently thanks to LHAASO
- ...but ~100 TeV photons can be also made in leptonic interactions
- Spectral and morphologic information of the O(100TeV) sources (+MWL information) needs to be studied to find true PeVatrons



LHAASO J2108+5157 in LST-1 eye



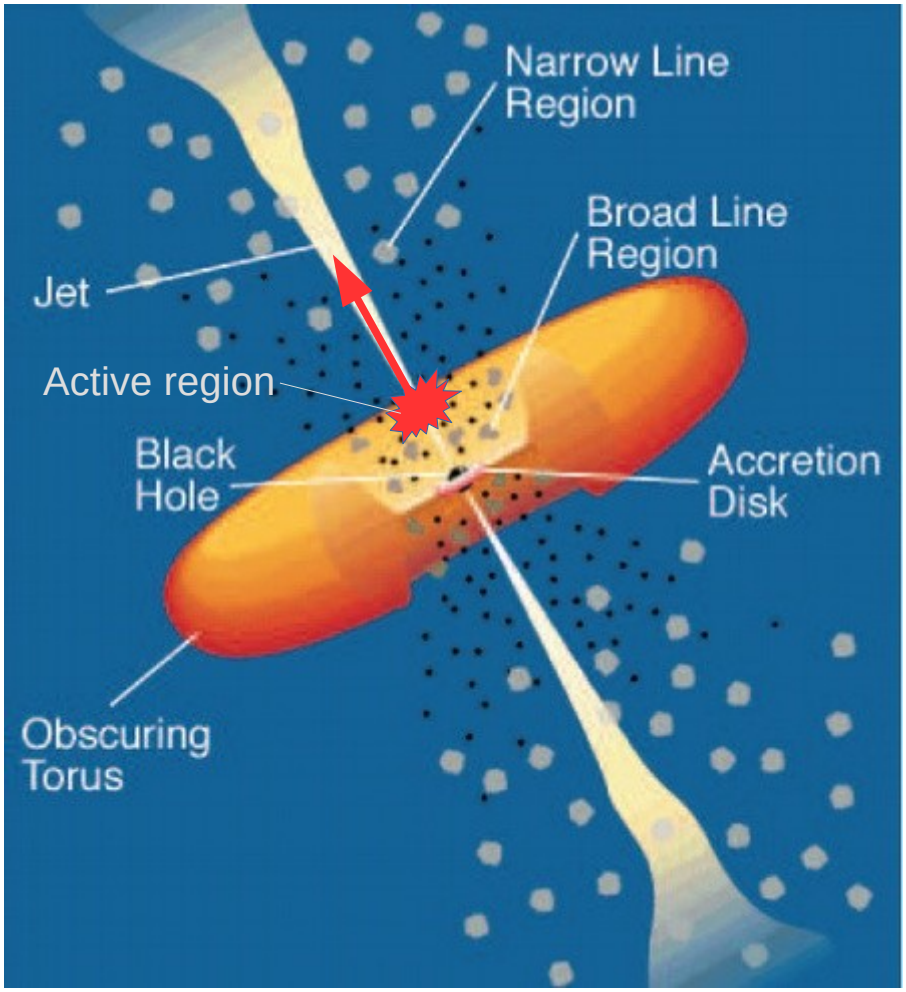
Abe et al 2023, 673, A75



- Deep exposure of a LHAASO-detected source
- Hint of emission at 3-10 TeV band
- (sub-)TeV emission strongly constrains the spectral shape
- The data however cannot distinguish between leptonic and hadronic origin of the emission

Active Galactic Nuclei

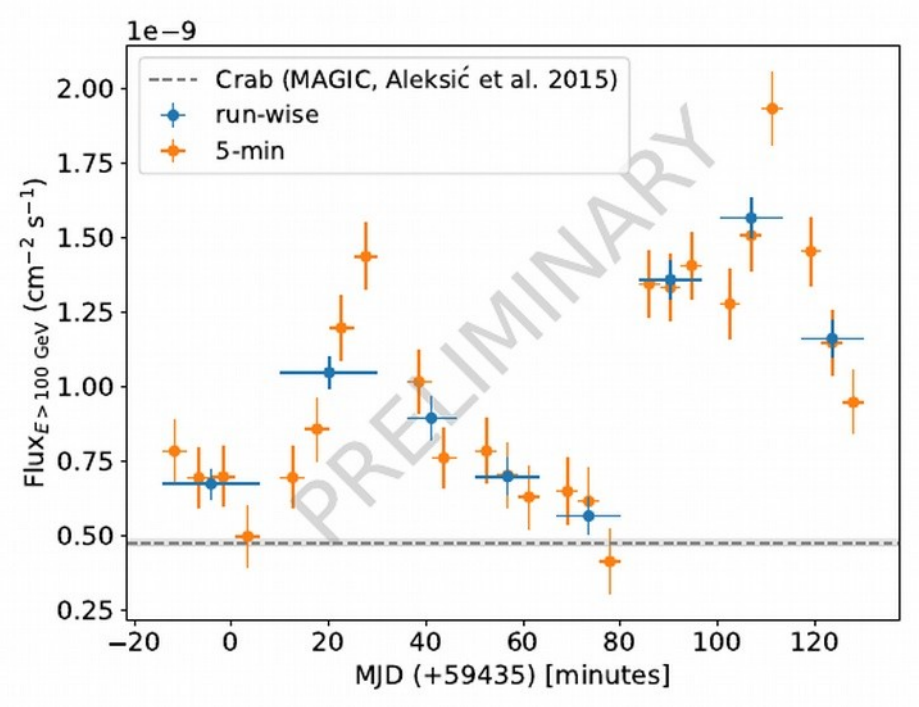
- AGNs are bright cores of some galaxies hosting supermassive black holes
- Gravitational collapse onto the black hole is powering ejection of relativistic jets
- Strongly variable non-thermal emission from radio up to TeV energies
- The most natural models assume that TeV (and MWL) emission comes from compact regions moving along the jet
- Many flares observed by the current generation of IACTs – often difficult to explain within simple models



Weekes 2003

BL Lac flare seen by LST-1

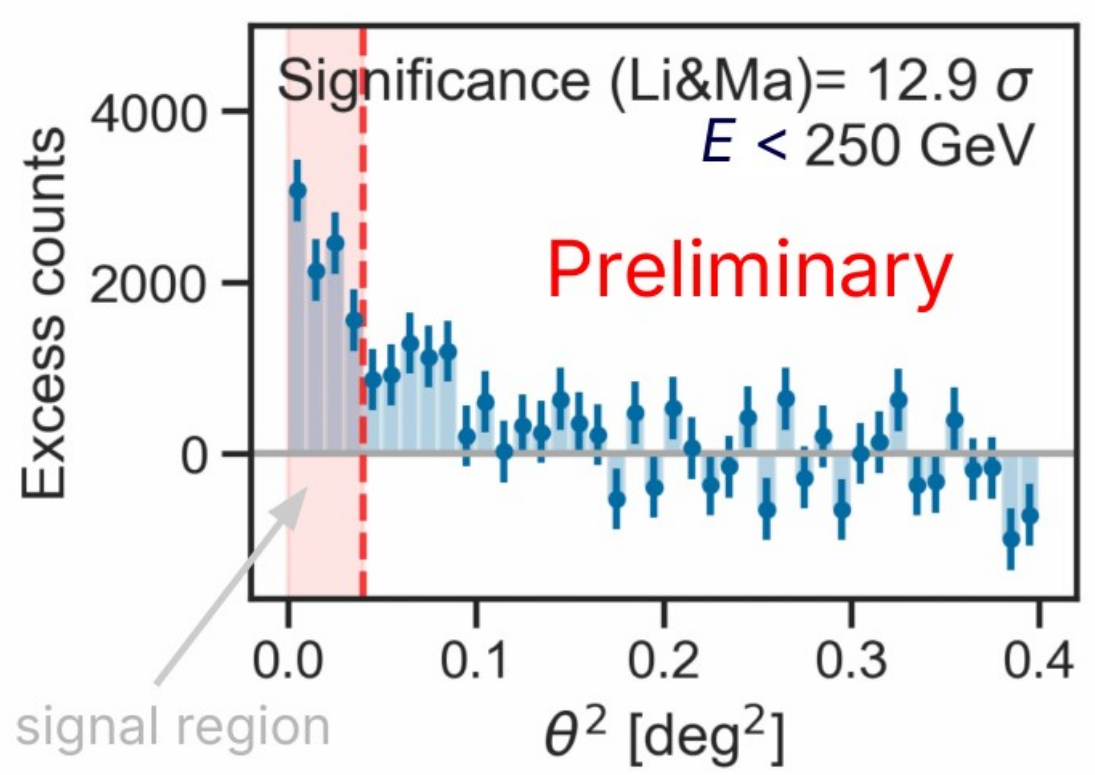
- Gamma ray spectra of blazars are (bend) power-law – the lower the energy threshold the larger event statistics
- Low energy threshold of LST allows studies at shorter time scales:
  - Possibility to probe acceleration and energy dissipation in the jet of an AGN
  - Bright flares provide data samples usable beyond the physics of individual sources: EBL, LIV, ALP, …



Nozaki et al. ICRC 2023

OP313

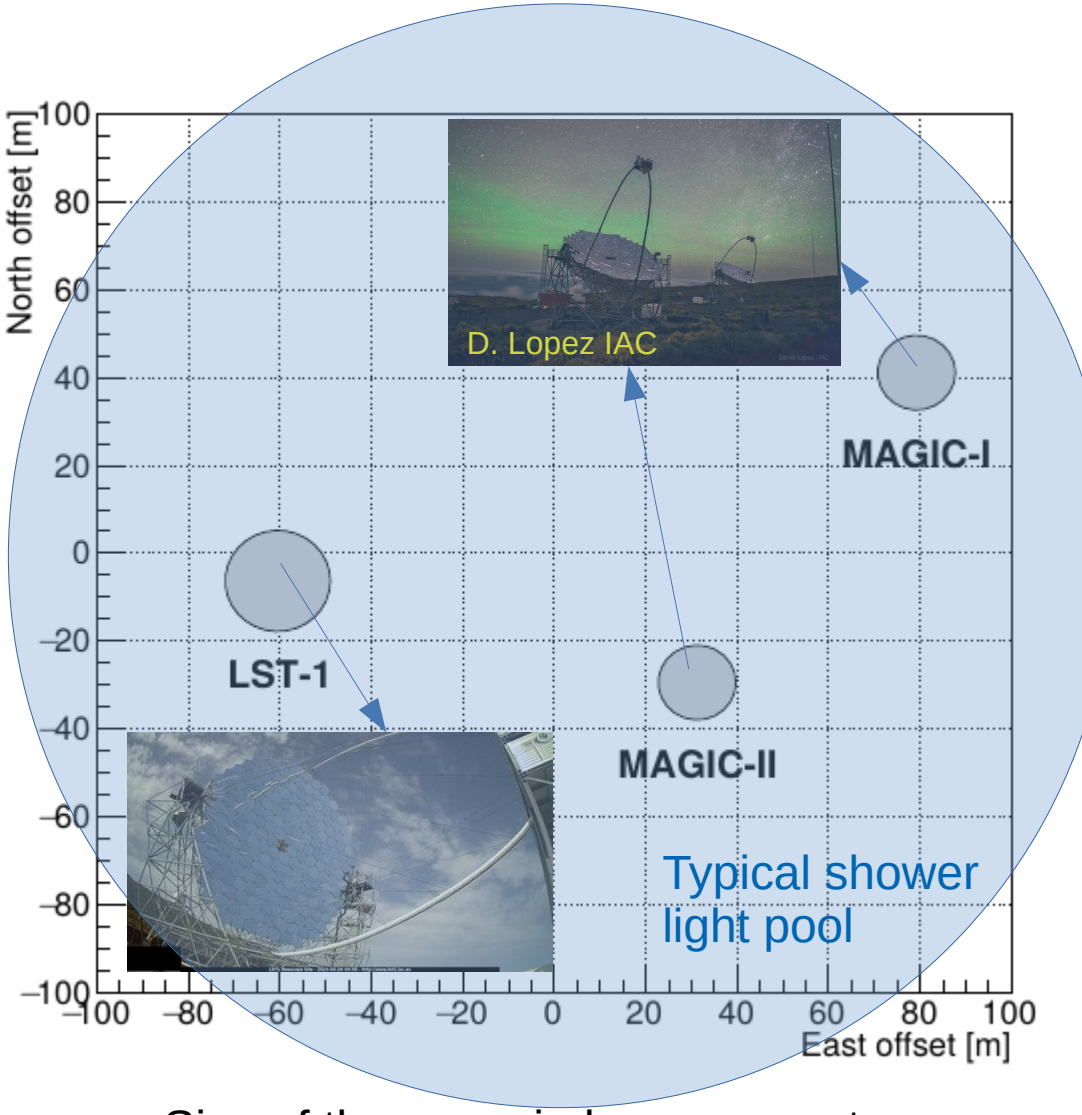
- FSRQ at z=0.9973
- The farthest source detected in VHE gamma-rays
- Potential not only for the studies of the physics of the source itself, but also fundamental physics
- The source keeps on flaring (ATels from LST, MAGIC and VERITAS in December and January)



J. Otero-Santos, Fermi Symposium 2024

MAGIC and LST-1

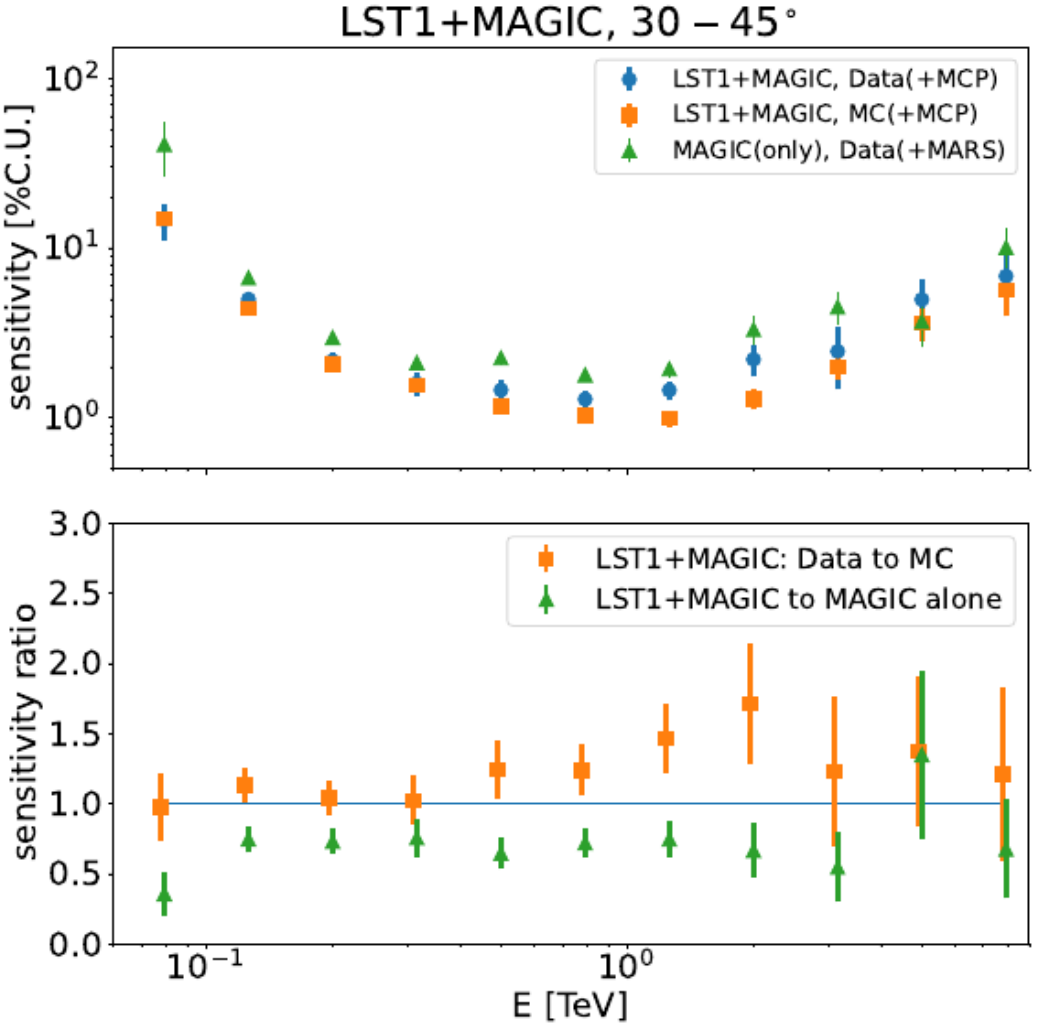
- Both MAGIC and LST-1 are located in the same site
- Proximity of both instruments allows common analysis of the same gamma-ray showers.
- For LST-1 this means going from mono to stereo ==> much better reconstruction and rejection of background
- For MAGIC this means a third telescope with larger light yield that catches nearly all showers seen by MAGIC-I and MAGIC-II



Size of the grey circles represent the mirror diameters

Joint observations

- Dedicated analysis chain for joint processing of MAGIC and LST-1 as a single instrument
- Joint observations allow detection of 30% (40%) lower flux than MAGIC-alone (LST-1-alone).
- This corresponds to the detection of the same flux in twice (nearly three times) shorter time.
- **MAGIC and LST-1 when combined have a better performance than working separately.**
- Both collaborations are working closely together on joint scheduling, the science topics (joint observation proposal call), follow up of fast transients, ...



Abe et al. 2023, A&A 680, A66

LSTs are going stereo !

- The constructions of the remaining LST telescopes are progressing rapidly
- LST2-4 will start their commissioning in short succession in 2025-2026
- The LST array once completed will have an unprecedented sensitivity in the sub-100 GeV range

LSTs are also going South!

- The original plan of CTAO for having LSTs also in the Southern array was abandoned in the alpha configuration due to limited funding
- Italian Collaborators managed to secure funding for two LSTs in the South.
- The different environmental conditions (need for earthquake resistance) means that the South LSTs will follow a modified design.
- First tenders assigned – but the plan is ambicious to have the South telescopes not far in time from North ones.

Summary

- The LST-1 is preparing for becoming part of CTAO and in the meantime is taking first scientific data
- Currently large focus on transients (both Galactic and extragalactic) as scientific targets
- Construction of LST2-4 are progressing fast, and in the meantime a stereoscopic system is being operated together with MAGIC telescopes.

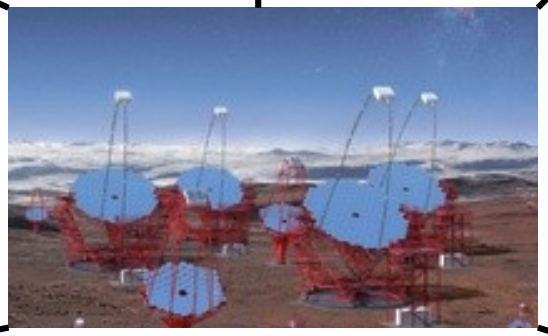
Backup

Physics with IACTs

Galactic Science:
SNRs, PWNe, Gal. Cent., Pulsars, novae ...

Extragalactic Science:
AGNs and beyond

Transients and Multi-Messanger:
Follow up of GRBs, GW, ν, ...

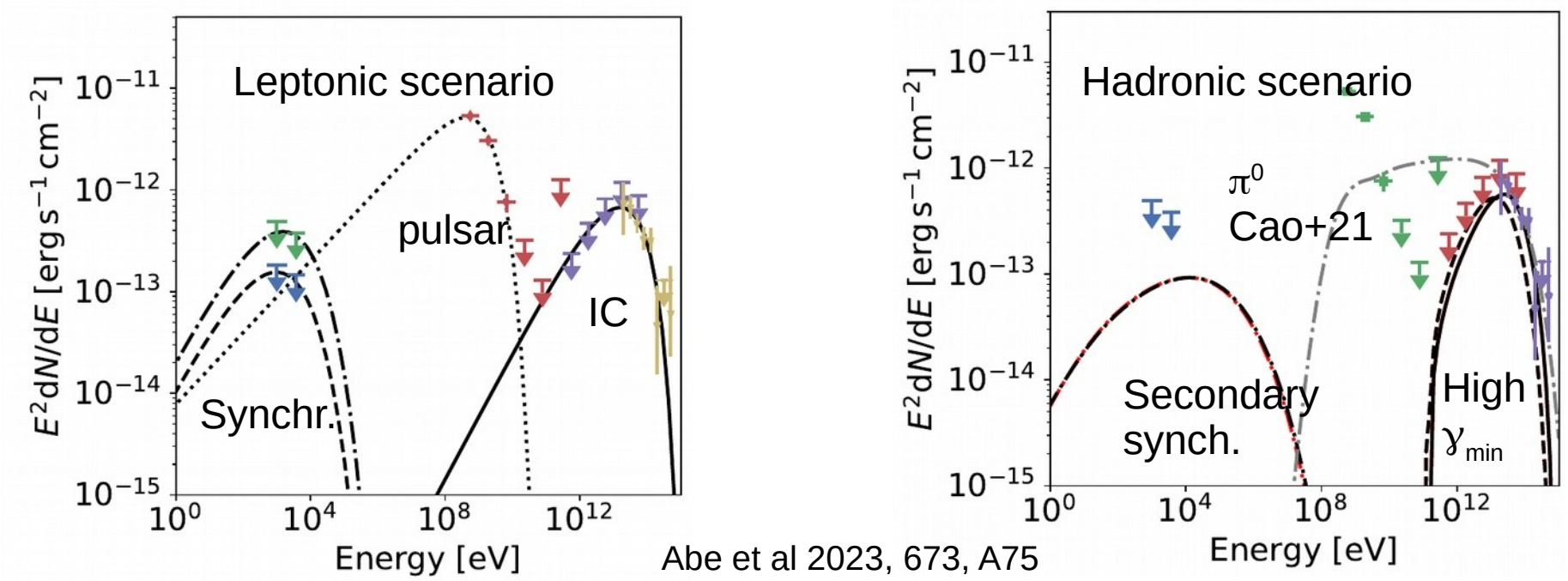


Fundamental Physics and Cosmology:
Probing Dark Matter, LIV, EBL, IGMF, ...

More than gamma rays:
Cosmic Rays, Intensity interferometry, optical measurements, ...

IACT are versatile instruments: many different scientific targets

Leptonic or hadronic?



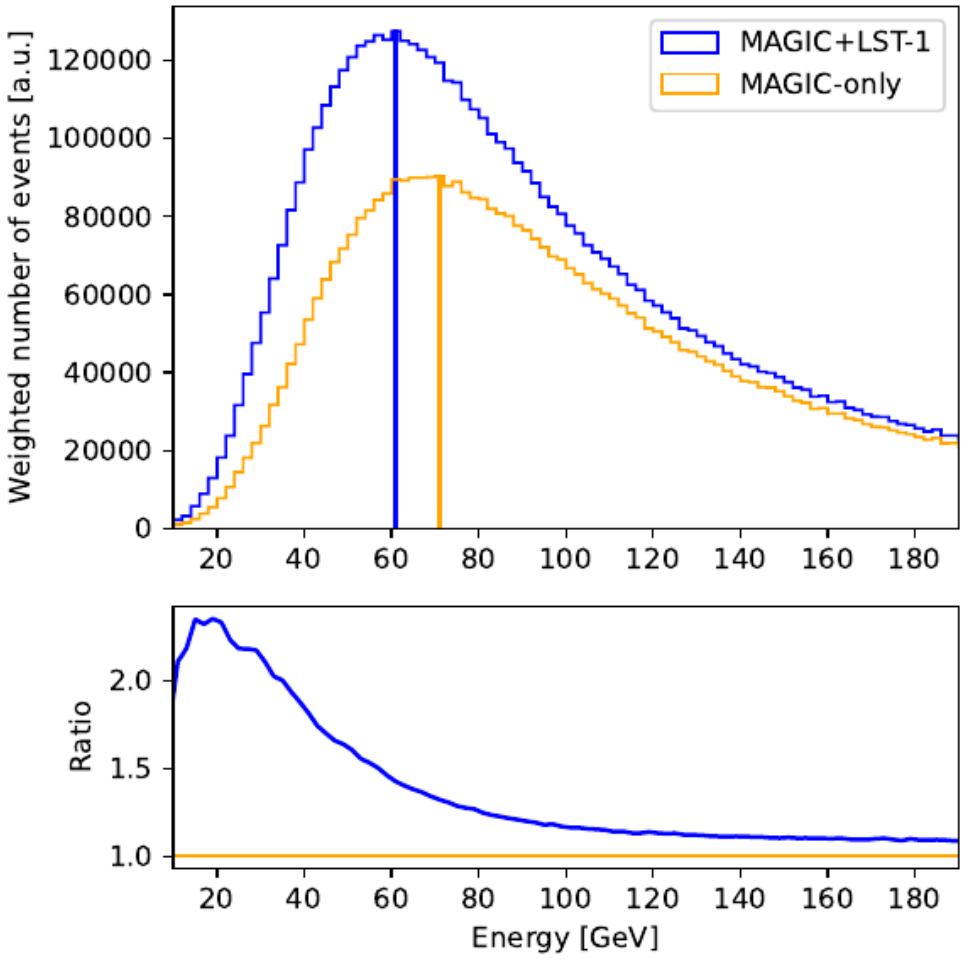
Abe et al 2023, 673, A75

- PWN or TeV halo
- But no pulsar detected to power the emission

- Pion production in molecular clouds
- No explanation for the GeV emission
- Injection of protons with high minimal Lorentz factor (1.6 x 10^5) is required

MAGIC and LST-1

- MAGIC and LST-1 events are matched by using a software trigger exploiting event time stamps
- Improved energy threshold and recovery of low energy events in which one of the MAGIC images does not survive the cleaning/quality cuts



Abe et al. 2023