CTAO
Cherenkov Telescope Array Observatory

UNIVERSITÀ DEGLI STUDI DI PADOVA

INFN
Istituto Nazionale di Fisica Nucleare

Search for VHE Short-Timescale Variability in PG 1553+113 with LST-1 of CTAO

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1 CTAO and LST-1

2 PG 1553+113

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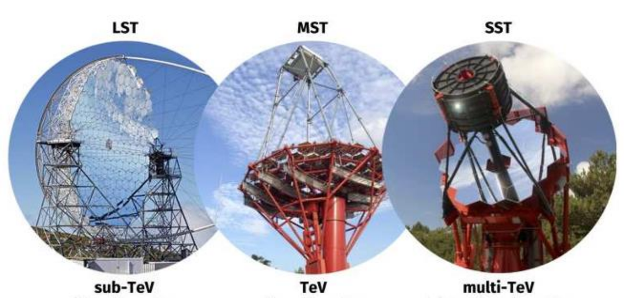
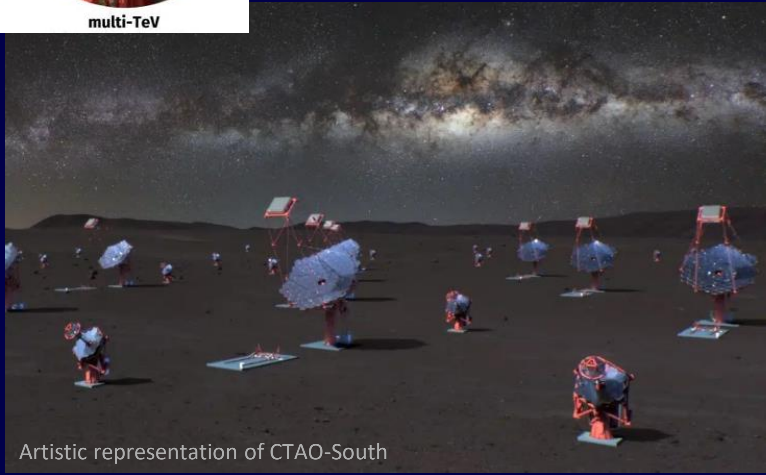
The CTAO

The Cherenkov Telescope Array Observatory (CTAO)

- Two sites: La Palma (Canary Islands) and Paranal (Chile)
- 3-size telescopes:
  - Large-Sized Telescope (LST)
  - Medium-Sized Telescope (MST)
  - Small-Sized Telescope (SST)



- Northern array: 13 telescopes (4 LSTs, 9 MSTs)
- Southern array: 51 telescopes (14 MST, 37 SSTs)
- Cover a wide energy range, from ~20 GeV to ~300 TeV
- Improved sensitivity, angular and energy resolution with respect to current γ-ray observatories



LST COLLABORATION

The LST-1 telescope

The first Large-Sized Telescope (LST-1) of the CTAO-North

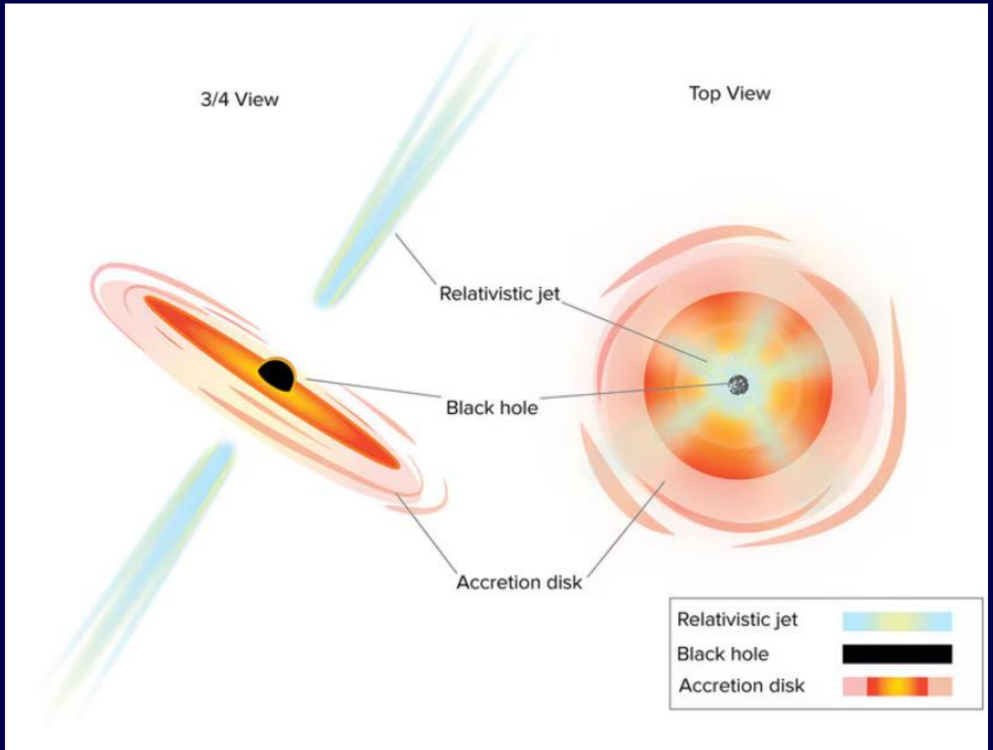
- Collecting data since 2019
- High sensitivity at low energies and low energy threshold - down to about 20 GeV
- Recently operating together with MAGIC telescopes
- Provides a unique opportunity to study short-timescale (sub-hour) variabilities

CTAO | LST COLLABORATION

The source: PG 1553+113

A high-frequency peaked BL Lac object

- BL Lac: blazar - class of Active Galactic Nuclei characterized by rapid spectral variability
- Non-thermal emission from the relativistic jet



Short-term variabilities

→ small spatial structures of the jet

→ provide constraints to the size of the photon-emitting regions

The source: PG 1553+113

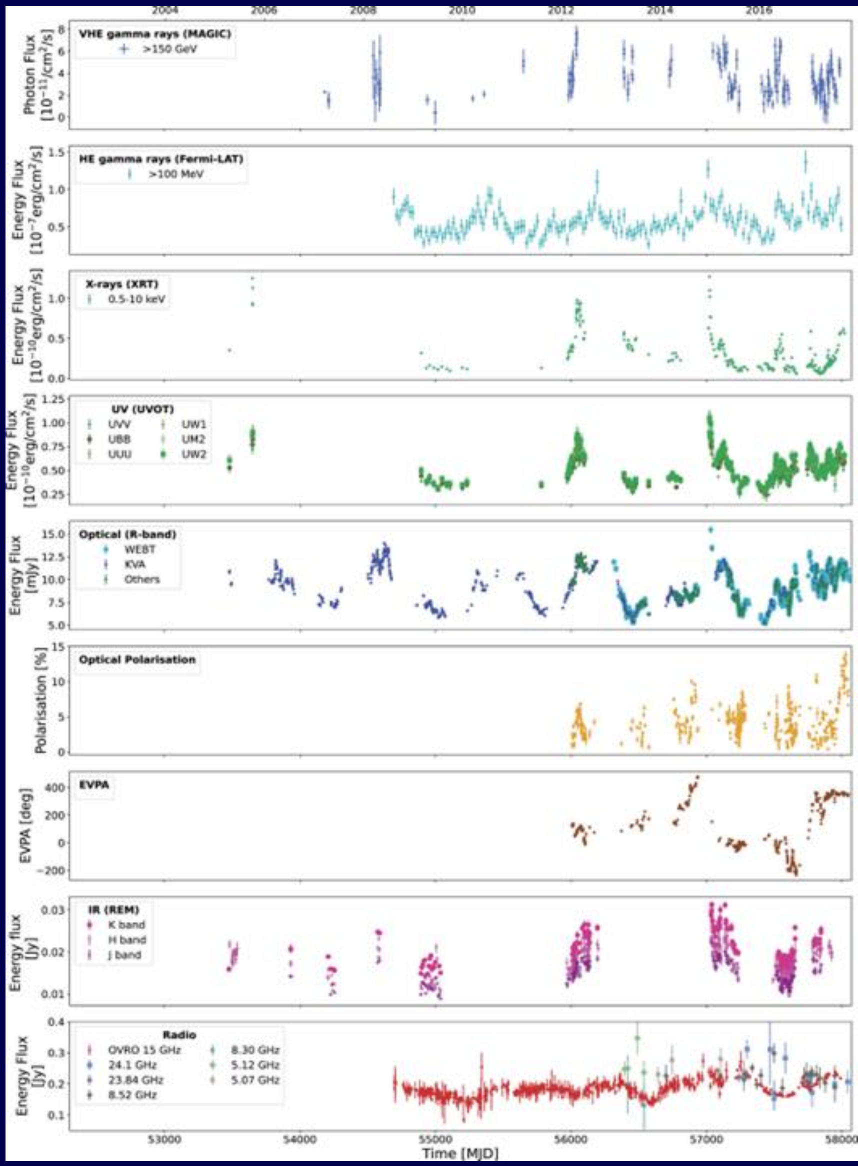
- Redshift: 0.433 (Dorigo-Jones et al., 2022)
- *Fermi-LAT*: periodic modulation 2.2 ± 0.1 yr at E > 100 MeV and E > 1 GeV (Ackermann et al. 2015, Peñil et al. 2023)

  - hint of periodicity in radio (delayed) and optical
- *XMM-Newton*: intra-day variability in the X-ray at 40 ± 12 min (Dhiman et al. 2021)
- Periodicity and variability not <u>yet</u> detected at VHE (E > 100 GeV)

  - intrinsic properties of the source?

  - short-term variability studies benefit from long exposure observations

  - available VHE light-curve sampling not as fine as achievable with LST-1

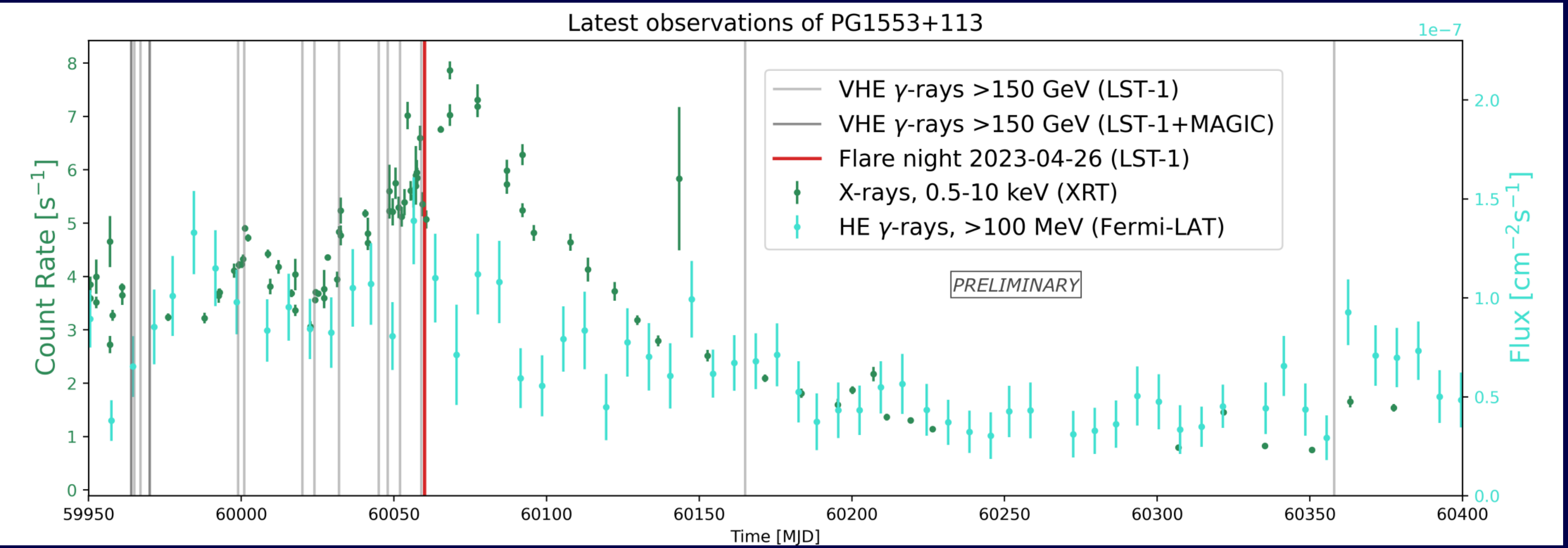


MAGIC Collab. MNRAS 529, 3894–3911 (2024)

LST COLLABORATION

PG 1553+113 observations

Source observation in 2023 – 2024



- Simultaneous MWL observations needed to study time correlations and locate emission regions
- X-ray observations not exactly overlapping LST-1 data of the flaring night

- X-ray count rates from Swift-XRT
- HE γ-ray flux from Fermi-LAT
- Dates of VHE γ-ray observations from LST-1 and LST-1+MAGIC, triggering on the high states

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LST-1 Observation

Long-exposure observation

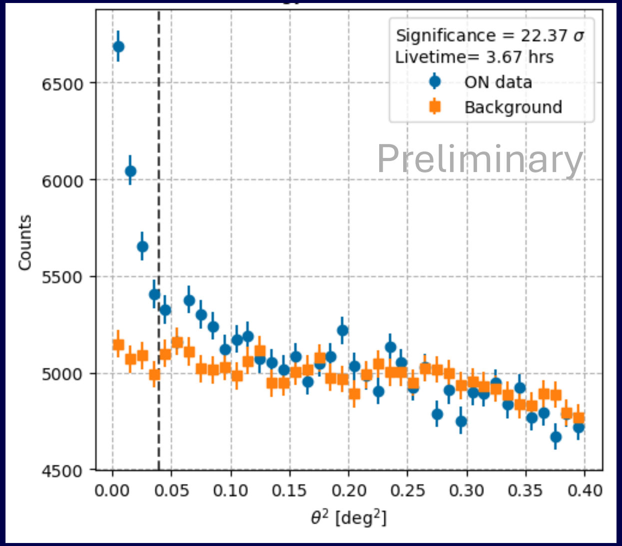
- LST-1 is observing PG 1553+113 since the beginning of 2021
- LST-1 triggered a target of opportunity (ToO) to perform a 4-hour observation on April 26th 2023

→ GOAL: investigate intra-night variability

- Triggered on the MAGIC monitoring data during the peak of the Fermi periodicity

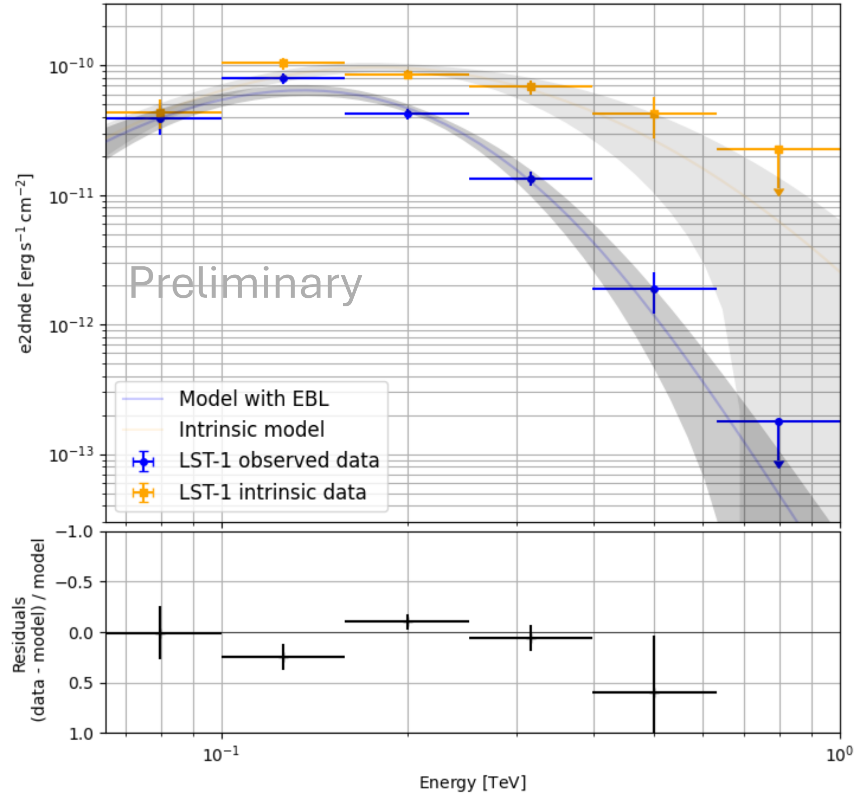
LST-1 Analysis

LST-1 data of PG 1553+113 flare observed on April 26th 2023



θ² plot

Significance = 22.37 σ



SED

- No energy cuts applied
- Spectral model: LogParabola

$$\Phi(E) = \Phi_0 (\frac{E}{E_0})^{-\alpha - \beta \log(\frac{E}{E_0})}$$

- Corrected for EBL absorption (Dominguez et al, 2011)
- Spectral parameters:
  - E_0 = 132 GeV
  - $\Phi_0 = 3 \times 10^{-9} \pm 3 \times 10^{-10}$ TeV^{-1} s^{-1} cm^{-2}
  - α = 1.2 ± 0.2
  - β = 1.2 ± 0.4

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LST-1 Analysis

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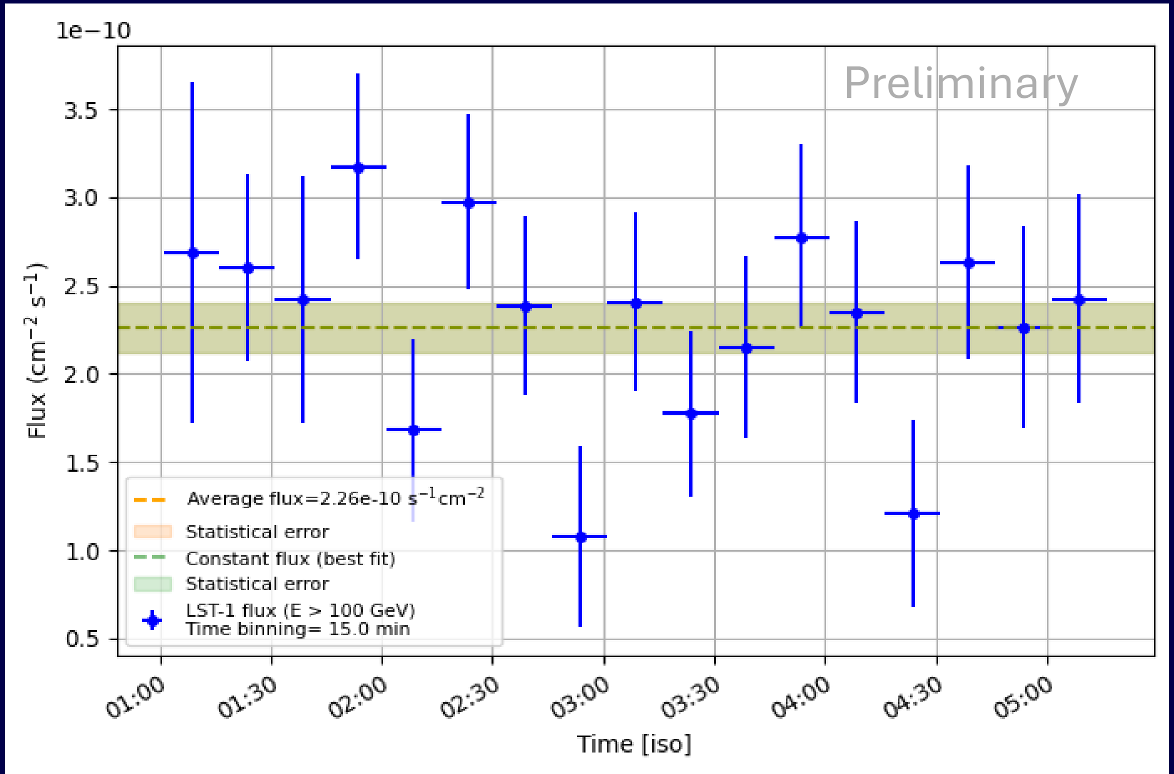

Light curve

- Time binning: **15 min**
- E > 100 GeV
- Average flux = 2.26×10^{-10} s^{-1} cm^{-2} (compatible with constant flux)
- Error bars with statistical error only
- Adding systematics – in progress

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Variability Analysis

Time variability significance estimators applied to the light curve

$\gamma\pi$ tools

- From the constant fit: $\chi^2 = 19.2$, $\chi^2_{red} = 1.2$, p-value = 0.26
- Fractional excess variance (F_{var})

$$F_{var} = \sqrt{\frac{S^2 - \langle \sigma_{err}^2 \rangle}{\langle x \rangle^2}}$$

where:

- S^2: sample variance
- σ^2: mean square error (MSE)
- <x>: mean flux

Results: F_{var} (%) ≤ 1.5 (< 2 σ)

- Point-to-point fractional variance (F_{pp})

$$F_{pp} = \frac{\sqrt{\left|\frac{1}{N-1}\sum_{i=1}^{N-1}(X_{i+1}-X_i)^2 - \sigma^2\right|}}{\bar{X}}$$

where:

- X_i: flux points
- X: flux mean

Results: F_{pp} (%) = 30 ± 7 (4.3 σ)

CTAO LST COLLABORATION

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overall amplitude of the intrinsic variability over the entire sample

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shortest-timescale variability, mean flux difference between consecutive points

$F_{pp}/F_{var} = 21.3$

CTAO | LST COLLABORATION

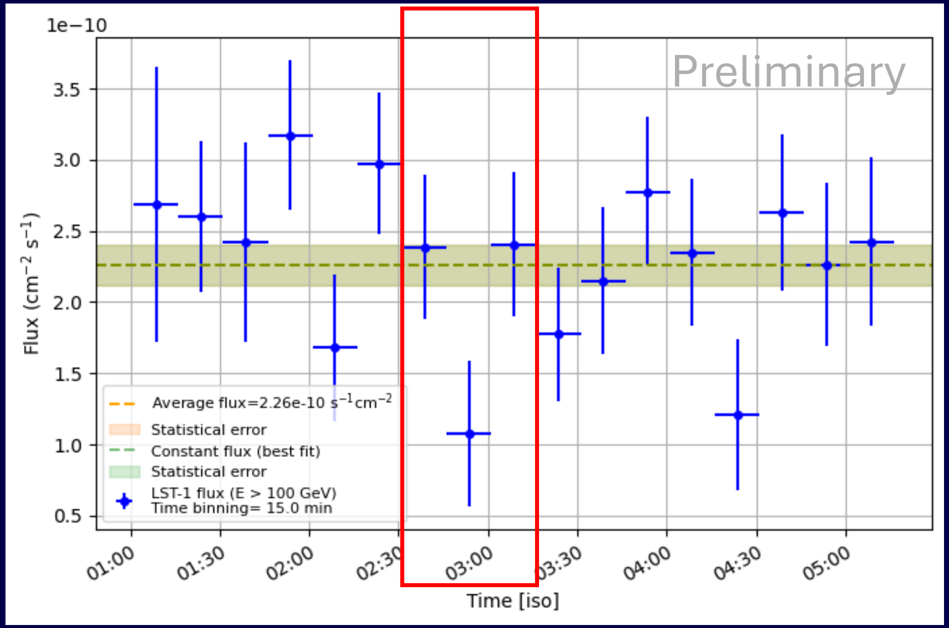
Variability Analysis

Time variability significance estimators applied to the light curve

$\gamma\pi$ tools

- Halving time: 13 ± 3.5 min (3.7 σ) at 02:38 UTC
- Doubling time: 12.9 ± 3.5 min (3.7 σ) at 02:53 UTC

$$F(t_1) = F(t_2)2^{(t_1 - t_2)/\tau}$$



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- Doubling time: 12.9 ± 3.5 min (3.7 σ) at 02:53 UTC

$$F(t_1) = F(t_2)2^{(t_1 - t_2)/\tau}$$

- Using shortest variability timescale, the upper limit on the radius of the emission region is:

$$R \leq \frac{c t_{var} \delta}{1+z}$$

where:

- c: speed of light in vacuum
- t_{var}: shortest variability timescale
- z: redshift
- δ: Doppler factor, ranges from 11 to 35 (Dhiman et al., 2021)

Results:

Maximum radius of the emitting region: 0.57×10^{15} cm

assuming δ = 35

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Conclusions

- Future observations will include multi-wavelength campaigns and monitoring during low-state periods (IXPE, XMM-Newton, Swift-XRT...)
- Significance values of variability estimators are not consistently high enough to claim intra-night variability
- In general, the point-to-point fractional variance being higher than the fractional excess variance is indicative of the presence of very short timescale variability
- Collecting additional data will increase statistics and allow better investigation of source behaviour on short timescales
- These results highlight the potential of next-generation IACTs for time-domain and variability studies

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Conclusions

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THANK YOU!

BACK-UP SLIDES

LST-1 Analysis

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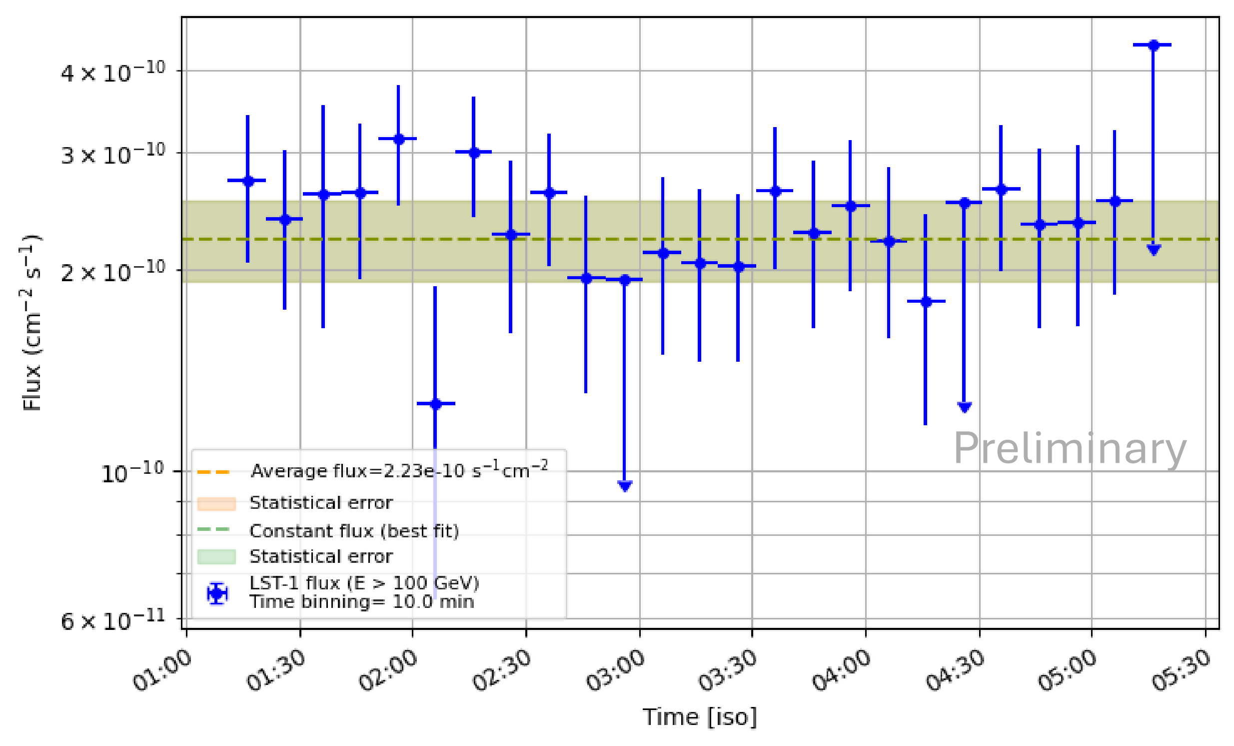


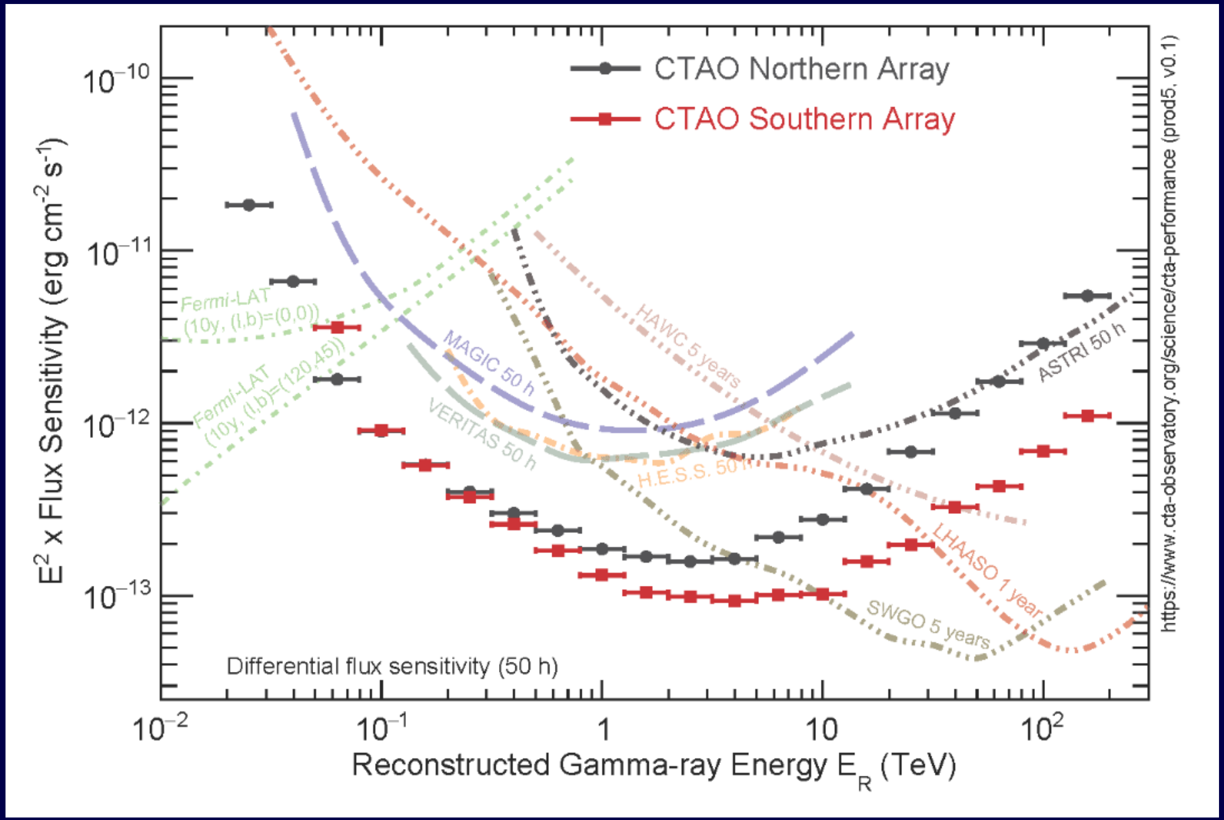
Light curve

- Time binning: **10 min**
- E > 100 GeV
- Constant flux = 2.23 x 10^{-10} s^{-1} cm^{-2}
- Error bars with statistical error only

CTAO LST COLLABORATION

CTAO sensitivity

CTAO sensitivity compared with other instruments

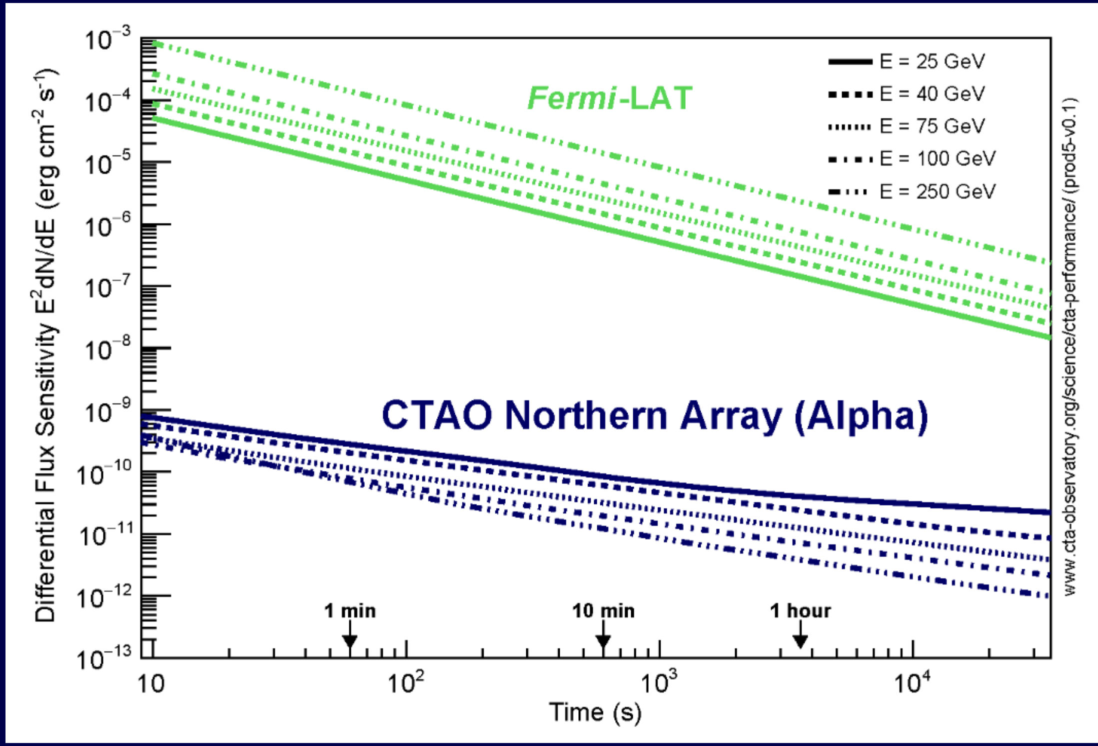


The differential sensitivity is defined as the minimum flux needed by the CTAO to obtain a 5-standard-deviation detection of a point-like source.

Credits: www.ctao.org

CTAO-North performance

CTAO-North temporal sensitivity compared with Fermi-LAT



CTAO-North, and in particular LSTs, offer **finer time sampling** and **higher flux sensitivity than Fermi-LAT**,

enabling detailed studies of **short-term variability** on sub-hour timescales.

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