CTAO
Cherenkov Telescope Array Observatory

Università degli Studi di Padova

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Sezione di Padova

Search for VHE Short-Timescale Variability in PG1553+113 with LST-1 of CTAO

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for the LST Collaboration of the CTAO Consortium[4]

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4 See *www.ctao.org*

Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

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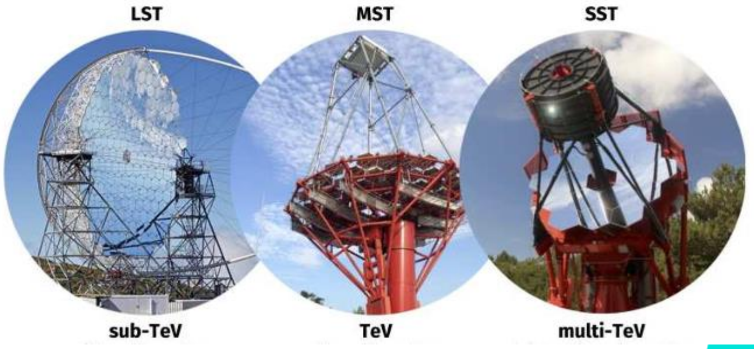
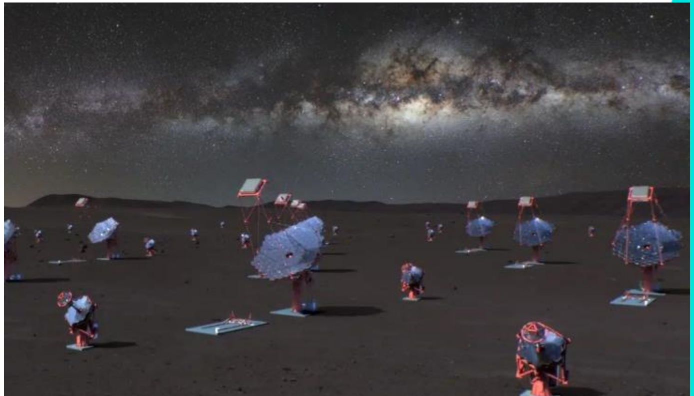
The CTAO

The **Cherenkov Telescope Array Observatory (CTAO)**

- **Two sites:** La Palma (Canary Islands) and Paranal (Chile)
- **3-size telescopes** - Large Size Telescope (LST)
  Medium Size Telescope (MST)
  Small Size Telescope (SST)
- **Southern array:** 51 telescopes (14 MST, 37 SSTs)
- **Northern array:** 13 telescopes (4 LSTs, 9 MSTs)
- Cover a wide energy range, from **~20 GeV to ~300 TeV**




Artistic representation of CTAO-South

https://www.ctao.org/

The LST-1 instrument

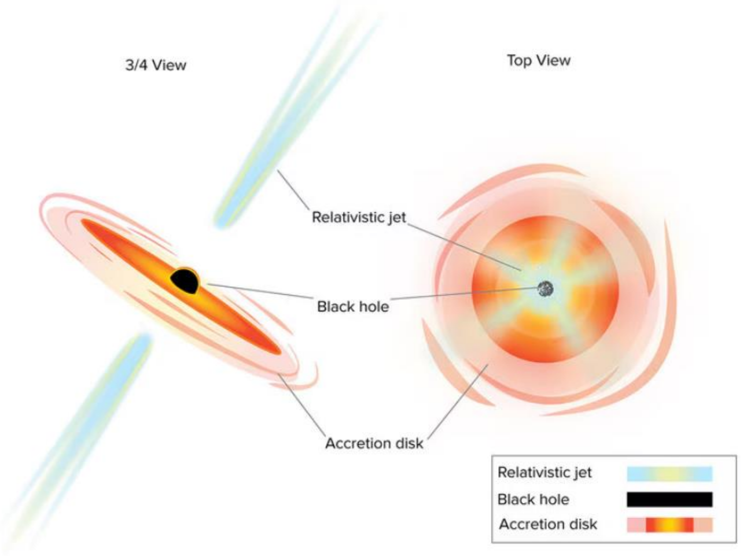
- The first Large-Sized Telescope (LST-1) of the CTAO-North
- Collecting data in commissioning mode since 2019
- **High sensitivity** at low energies and low energy threshold (down to about **20 GeV**)
- Provides a unique opportunity to study **short-timescale** (sub-hour) **variabilities**

The source: PG1553+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 important to constrain **the size** of the **photon-emitting region** in the jet



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The source: PG1553+113

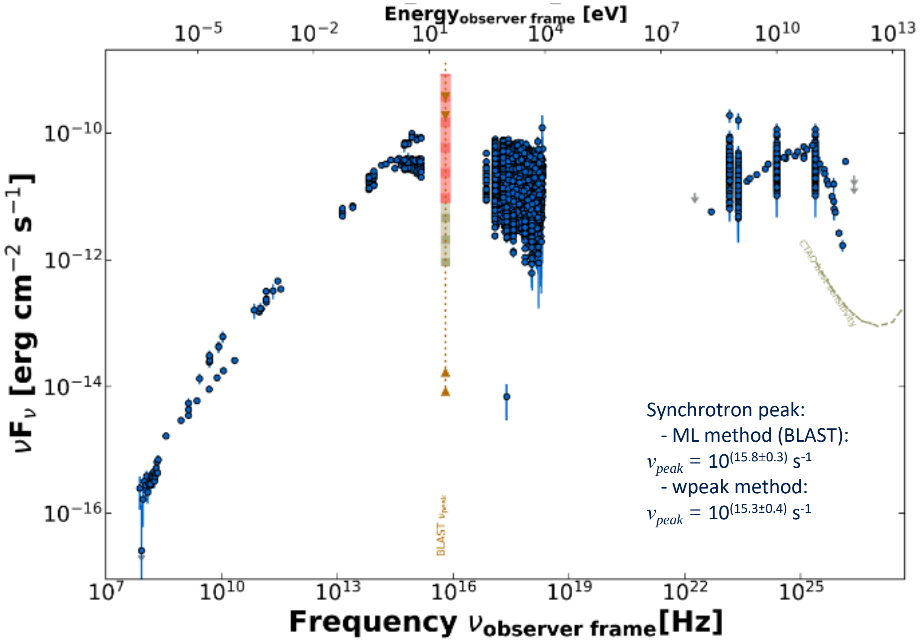
- Redshift: **0.433** (Dorigo-Jones et al., 2022)
- *Fermi*-LAT: **periodic modulation 2.18 ± 0.08 yr** at E > 100 MeV and E > 1 GeV (Ackermann et al., 2015)
  - Hint of periodicity in radio (delayed) and optical
- *XMM-Newton*: **intraday variability in the X-ray at 40.01 ± 11.67 min** (Dhiman et al. 2021)

not yet detected at TeV energies

- intrinsic property of the source?
- too short observation periods (1-2 hours)?

The source: PG1553+113

Spectral Energy Distribution (SED) of PG 1553+113



Correlation between:

- X-rays and VHE γ-rays
- optical/UV/IR and HE γ-rays

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

Interconnected emission processes e.g. a **multizone SSC emission scenario**

SED from:
https://firmamento.hosting.nyu.edu/

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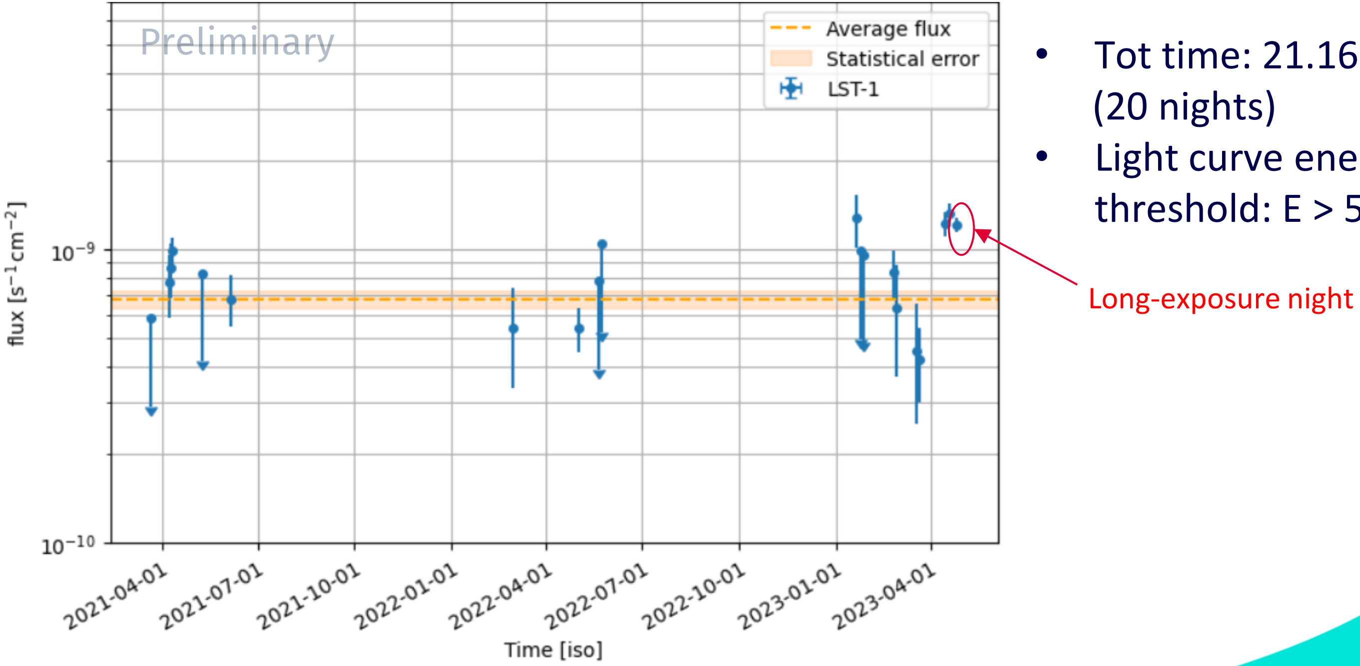
LST-1 Light curve

LST-1 data of PG 1553+113 from **03-2021** to **04-2023**

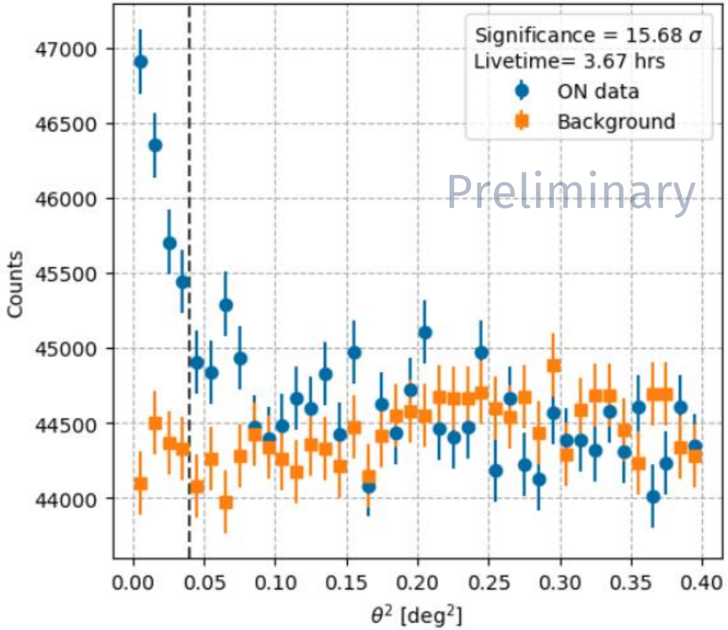


- Tot time: 21.16 hours (20 nights)
- Light curve energy threshold: E > 50 GeV

LST-1 observation of PG 1553+113 flare

Flare observed on **April 26th 2023**

θ² distribution of PG 1553+113 flare



→ **4-hours** observation during the night

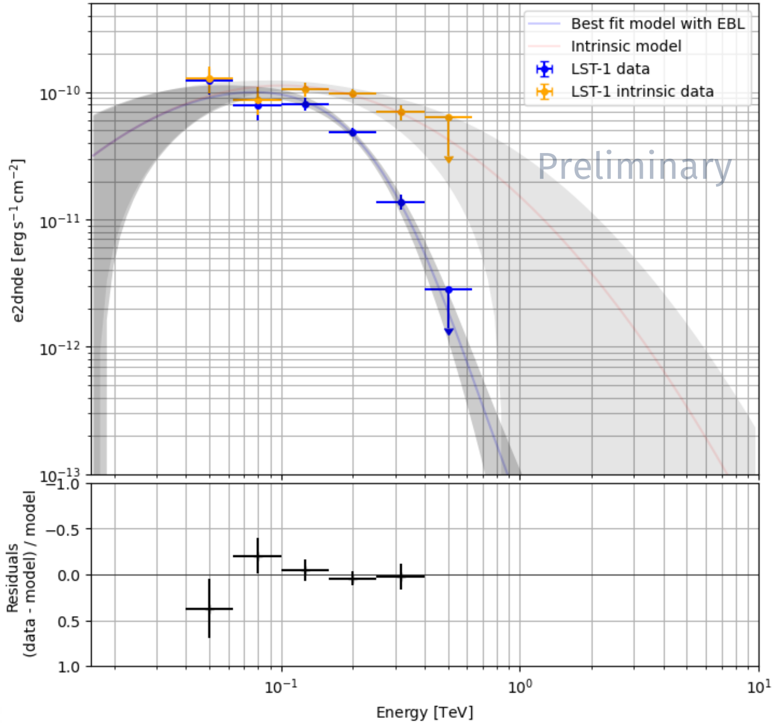
Significance (Li&Ma): **15.68σ**

Cut on θ^2: 0.04 deg^2

Goal: search for intra-night variability

LST-1 analysis of the flare

SED of PG 1553+113 flare



- Spectral model used: Log-Parabola

$$\phi(E) = \phi_0 \left(\frac{E}{E_0}\right)^{-\alpha-\beta\log\left(\frac{E}{E_0}\right)}$$

- Corrected for EBL absorption (Dominguez et al. 2011)
- Detection between 40 GeV and 400 GeV

Model parameters:

E_0= 120 GeV

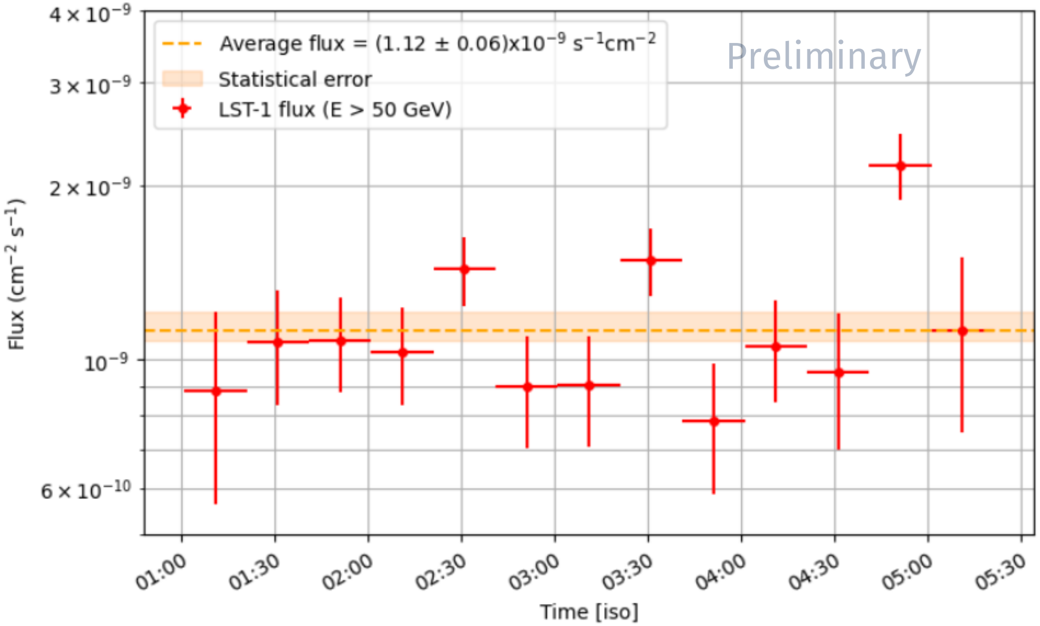
amplitude (Φ_0): 4.83 x10^{-9} ± 4.22 x10^{-10} TeV^{-1} s^{-1} cm^{-2}

alpha (α): 2.13 ± 1.54 x10^{-1}

beta (β): 3.81 x10^{-1} ± 2.48 x10^{-1}

LST-1 analysis of the flare

Light curve of PG 1553+113 flare



- Time binning: **20 min**
- E_{min}: 50 GeV
- Average flux (with statistical errors only): $(1.12 \pm 0.06) \times 10^{-9}\ s^{-1}cm^{-2}$
- Error bars with statistical errors only

Variability analysis

- Fractional RMS variability amplitude, F_{var}, defined as

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

where:

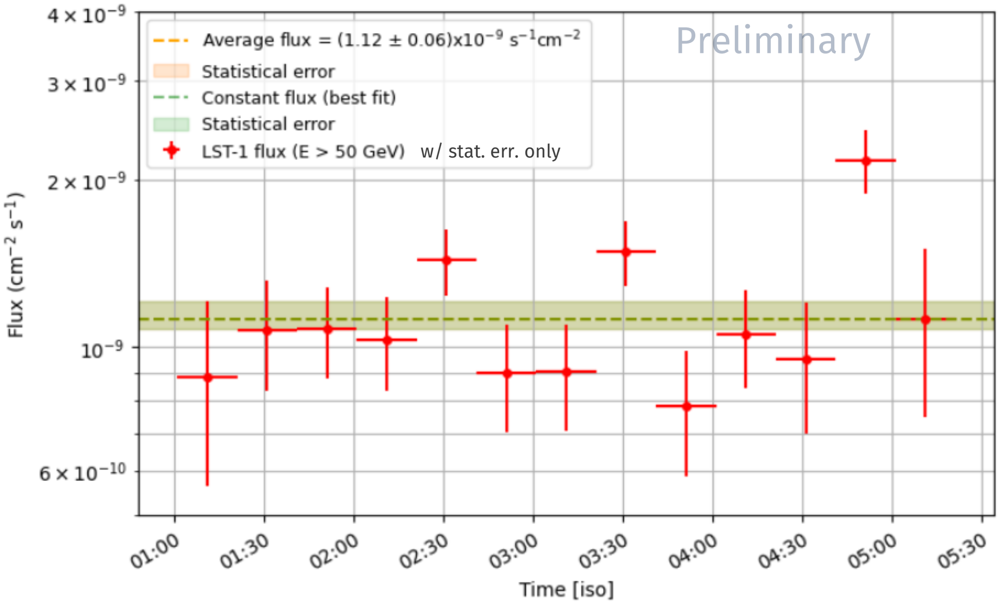
- S^2: sample variance
- σ^2: mean square error (MSE)
- <F>: mean flux

Results:

- **F_{var} (%) = 24.0 ± 6.9 (3.5σ)**

Constant flux (best fit, with statistical errors only):

$(1.12 \pm 0.06) \times 10^{-9}$ $s^{-1}cm^{-2}$, with **$\chi2_{red}$ = 2.2**



Variability analysis: shortest timescale

Flux halving/doubling

- Shortest variability timescale

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

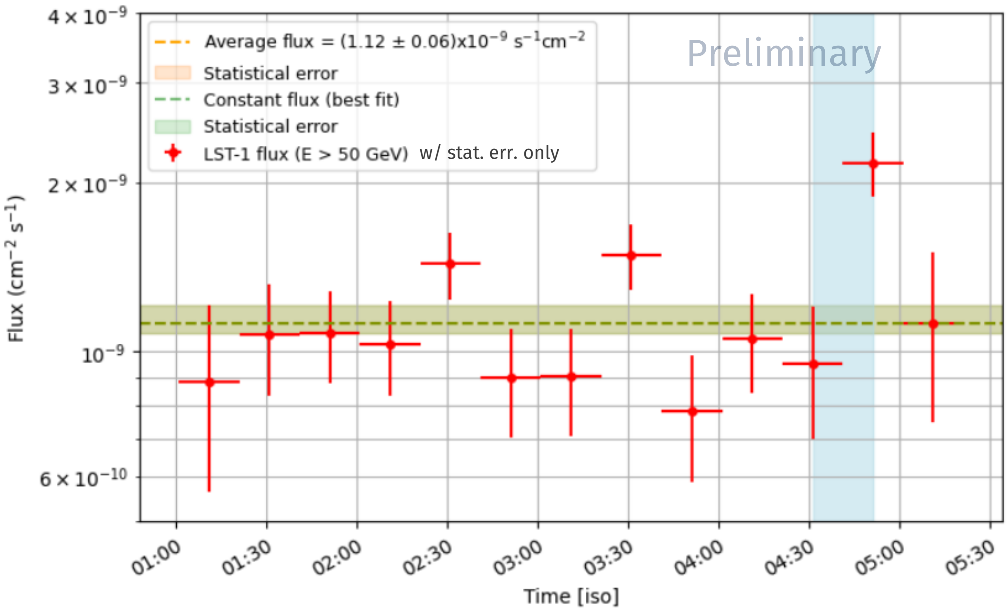
where:

- τ: characteristic halving/doubling time-scale
- $F(t_1)$ and $F(t_2)$ are the fluxes of the LC at times t_1 and t_2, resp.

Results:

- **doubling time of 16.5 ± 2.83 min**

at/after 04:31 UTC



New constraint on the emitting region

- Using shortest variability timescale, we computed an upper limit on the radius of the emission region

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

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: 0.73 × 10^{15} cm**

  assuming δ = 35

Future prospects

→ Further observations planned for next year (source in high-emission state)

→ Simultaneous MWL observations (e.g., XMM-Newton)

→ Finalise intra-night variability studies (ongoing)

→ SED modeling of the flare

(based on MAGIC results: two-zone model + variability timescale from this study)

→ Publication of flare analysis results (in preparation)

Future prospects

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THANK YOU!

Cherenkov Telescope Array Observatory

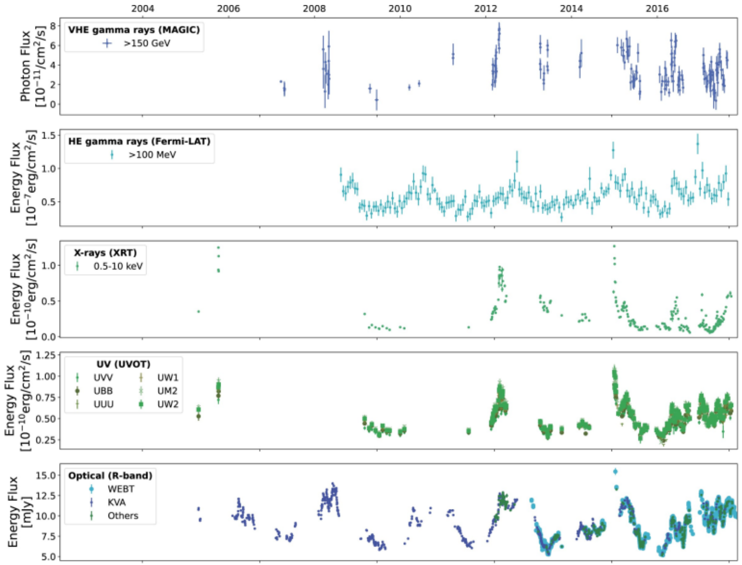
BACKUP SLIDES

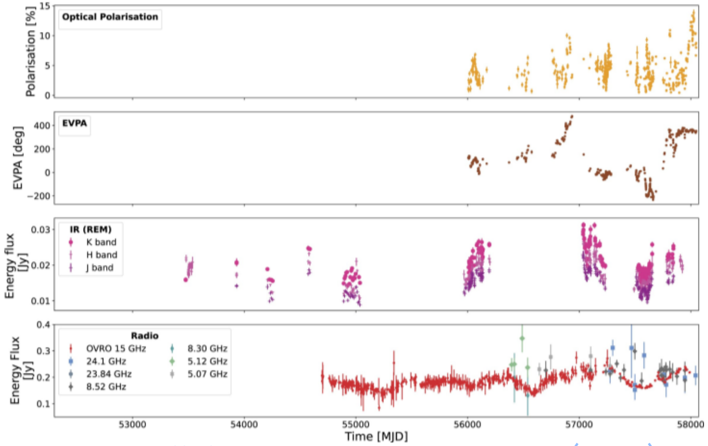
The source: PG1553+113

From the **multi-wavelength (MWL) long-term monitoring** of PG 1553+113 →

- **No periodicity** in X-rays and VHE γ-rays
- **Confirmed periodicity** in high-energy (HE) γ-rays
- **Correlation** between X-rays and VHE γ-rays, and between optical/UV/IR and HE γ-rays

MWL light curves





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

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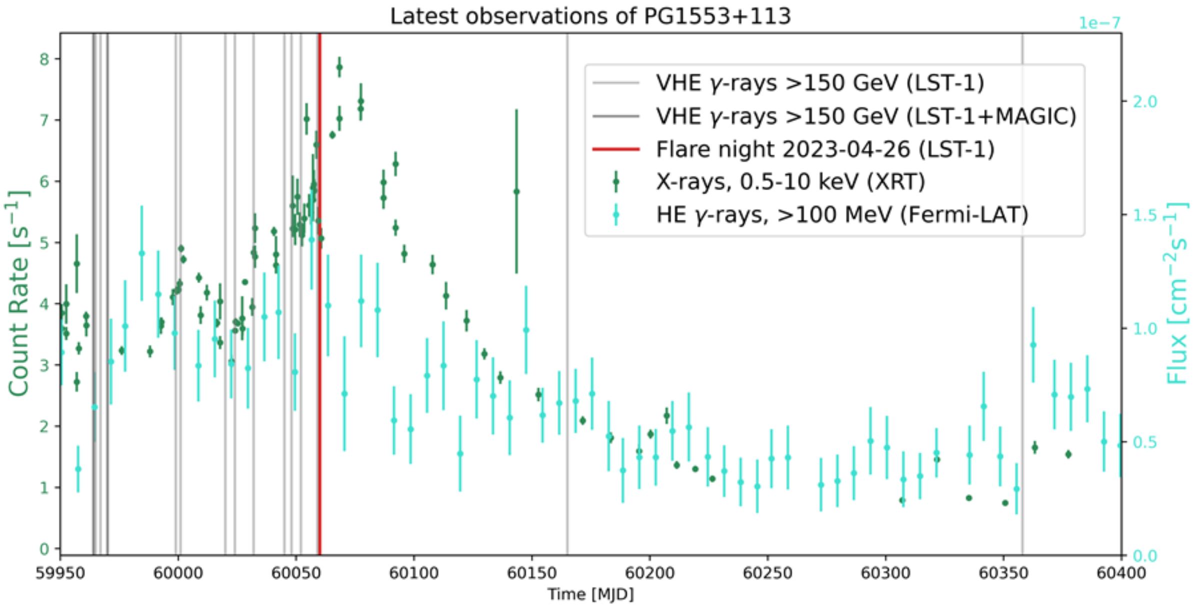
MWL Light curve

PG 1553+113 LC in X-rays (*Swift*-XRT), HE γ-rays (*Fermi*-LAT),
VHE γ-rays (LST-1, MAGIC) from 01-2023 to 03-2024



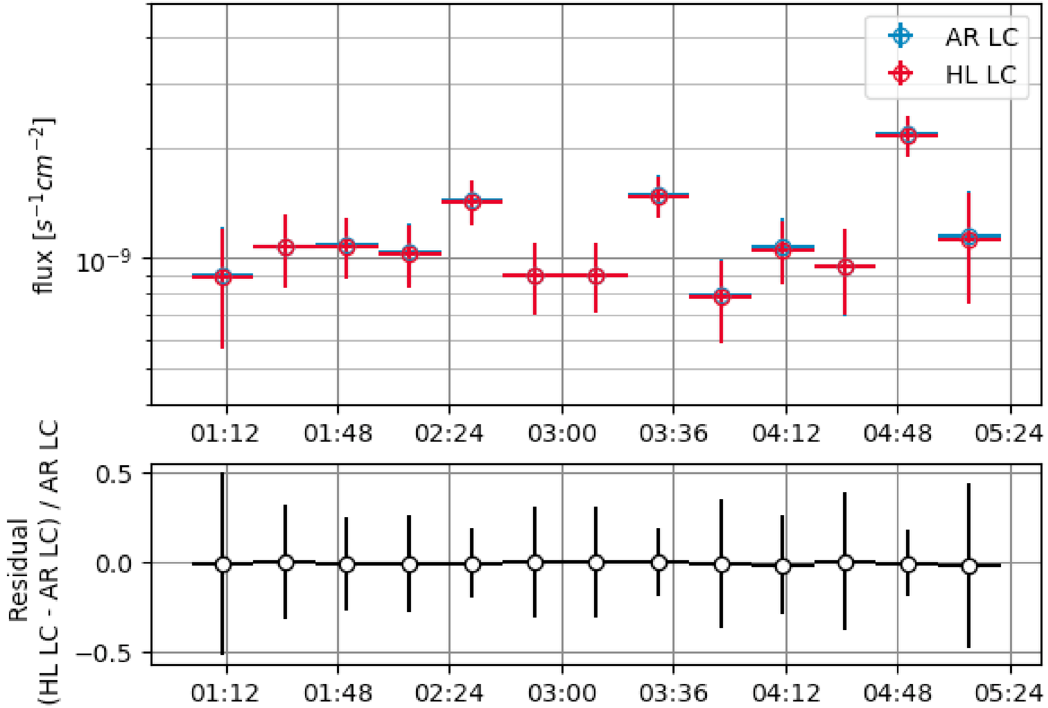
LST-1 Light curve comparison

Comparison of LCs

- Time binning: **20 min**
- E_{min}: 50 GeV

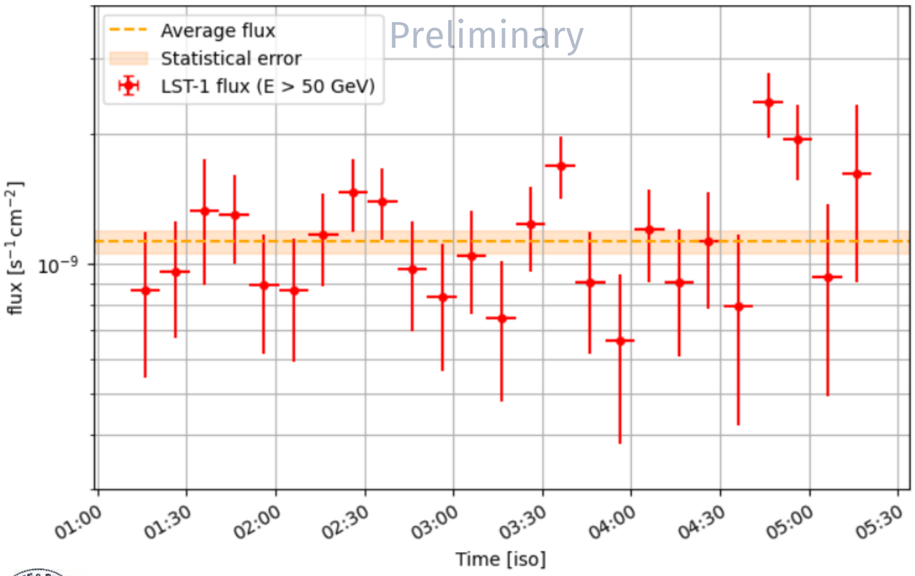
Cross-check with A. Ruina (INFN-PD)

MATCHING RESULTS!

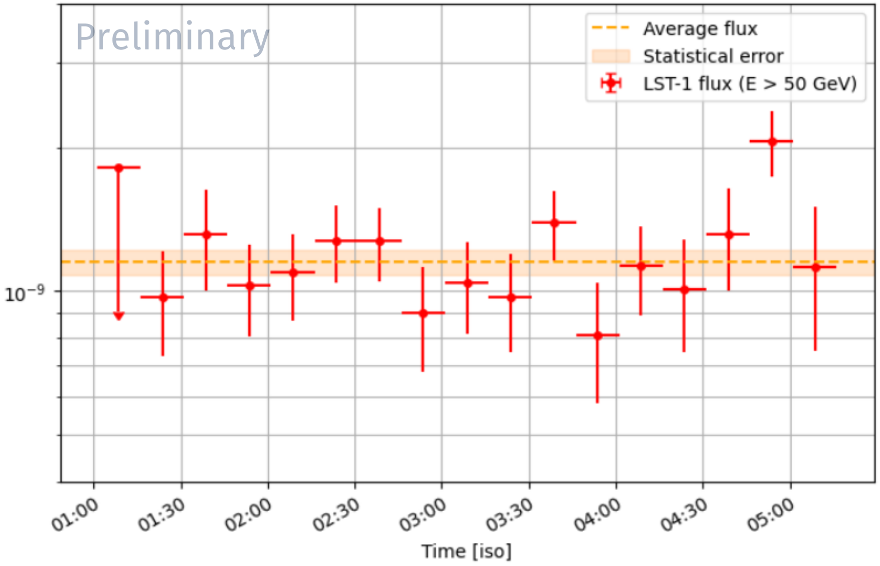


Flare LC

Time binning: 10 min, E_{min} = 50 GeV

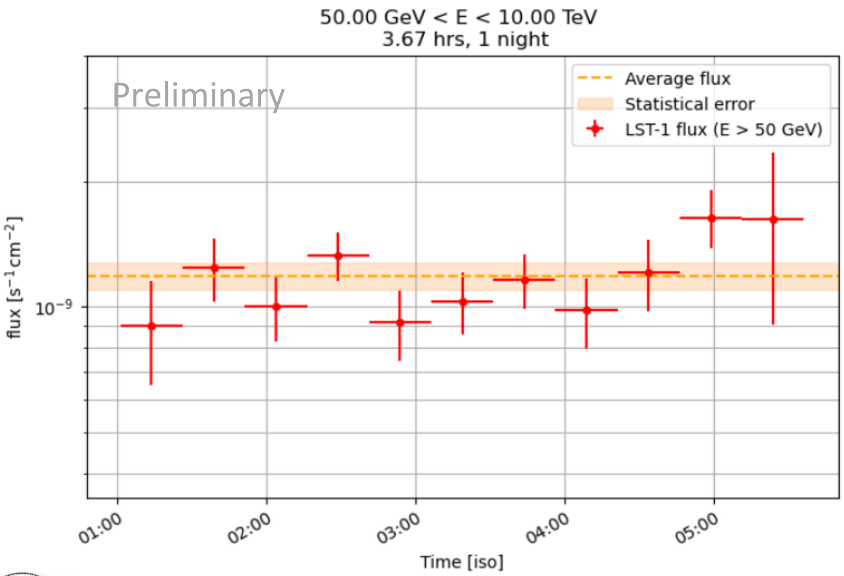


Time binning: 15 min, E_{min} = 50 GeV

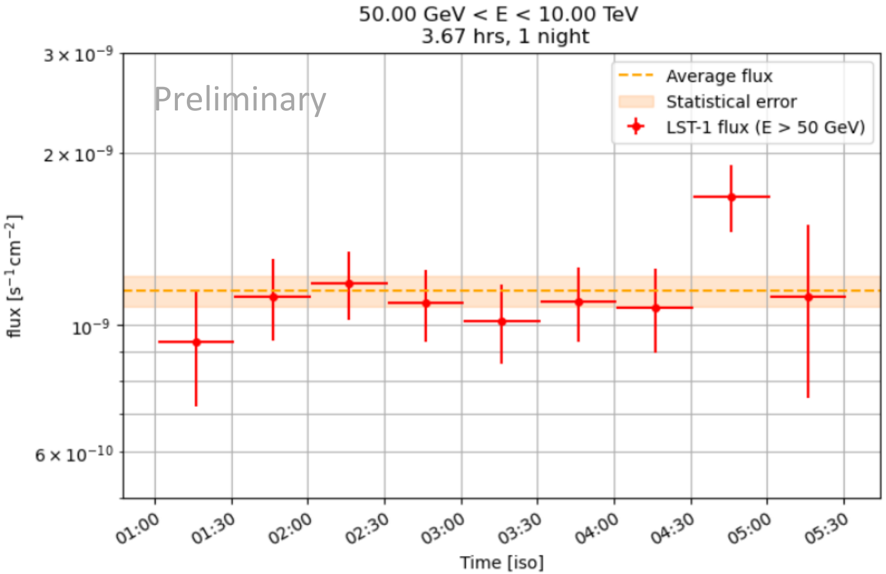


Flare LC

Time binning: 25 min, E_{min} = 50 GeV

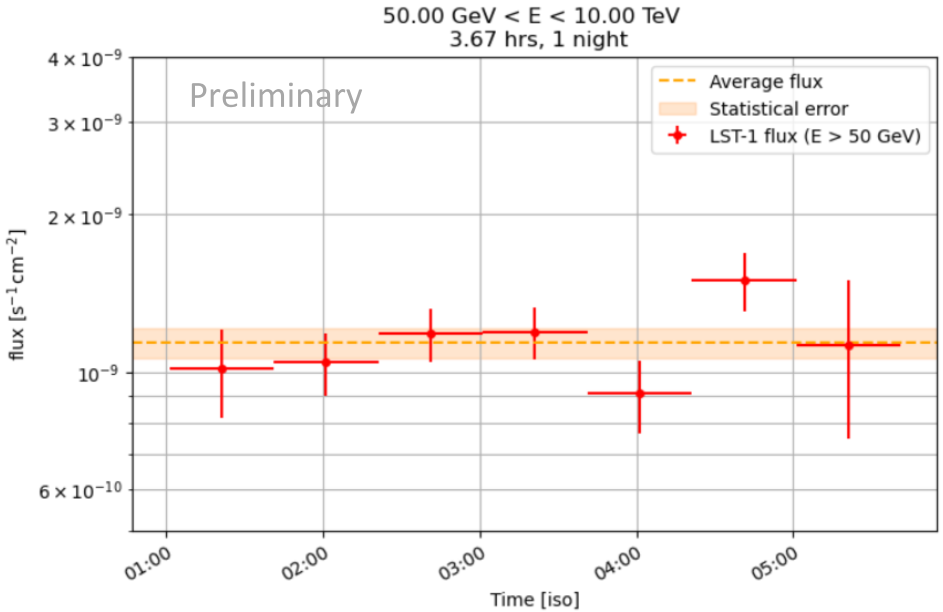


Time binning: 30min, E_{min} = 50 GeV



Flare LC

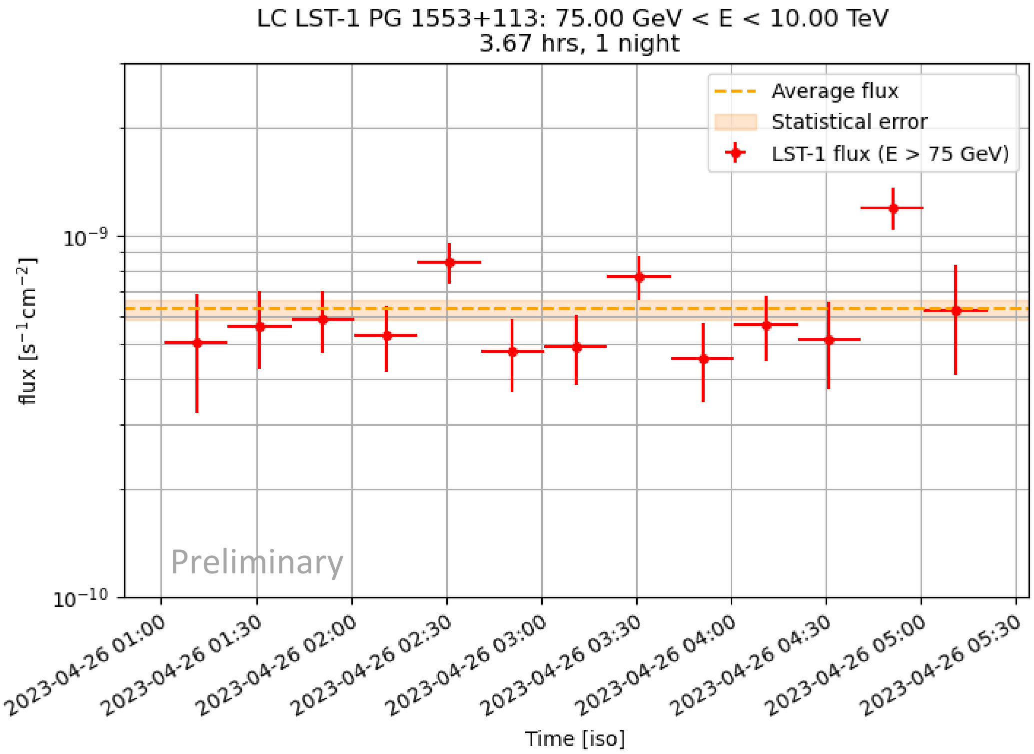
Time binning: 40 min, E_{min} = 50 GeV



Flare LC: Different threshold energy

Time binning: 25 min, E_{min} = 75 GeV

Average flux: 5.80×10^{-10} $s^{-1}cm^{-2}$



Flare LC: Different threshold energy

Time binning: 25 min, E_{min} = 100 GeV

Average flux: 2.90×10^{-10} $s^{-1}cm^{-2}$