CTAO

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

Arshia Ruina[1], Helena Luciani[2], Elisa Prandini[3]
for the LST Collaboration of the CTAO Consortium[4]

[1]National Institute of Nuclear Physics (INFN), Section of Padova, Italy (Email: arshia.ruina@pd.infn.it)
[2]Department of Physics, University of Trieste, Italy
[3]Department of Physics and Astronomy "Galileo Galilei", University of Padova, Italy
[4]See www.ctao.org

THE SOURCE OF INTEREST

- Source name: PG 1553+113
- Type: High-frequency peaked BL Lac object (HBL)
- Redshift, z: 0.433 (Jones et al., 2022)
- Detected with current generation of Imaging Air-shower Cherenkov Telescopes (IACTs) up to ~1 TeV (Aharonian et al., 2006; Albert et al., 2007)
- *Fermi-LAT*: periodic modulation 2.18 ± 0.08 yr at E > 100 MeV and E > 1 GeV (Ackermann et al., 2015); periodicity not yet detected at very high energies (VHE)
- *XMM-Newton*: intraday variability (IDV) in the X-ray at 2.4±0.7 ks i.e. the shortest observed doubling time for the X-ray flux (Dhiman et al. 2021); variability not yet detected at TeV energies
  - *intrinsic property of the source?*
  - *too short observation periods (1-2 hours)?*

MOTIVATION FOR THIS STUDY

- Short-term variabilities — key observable to probe the small spatial structures of the jet e.g. constraining the size of the photon-emitting region in the jet

THE LST-1 INSTRUMENT

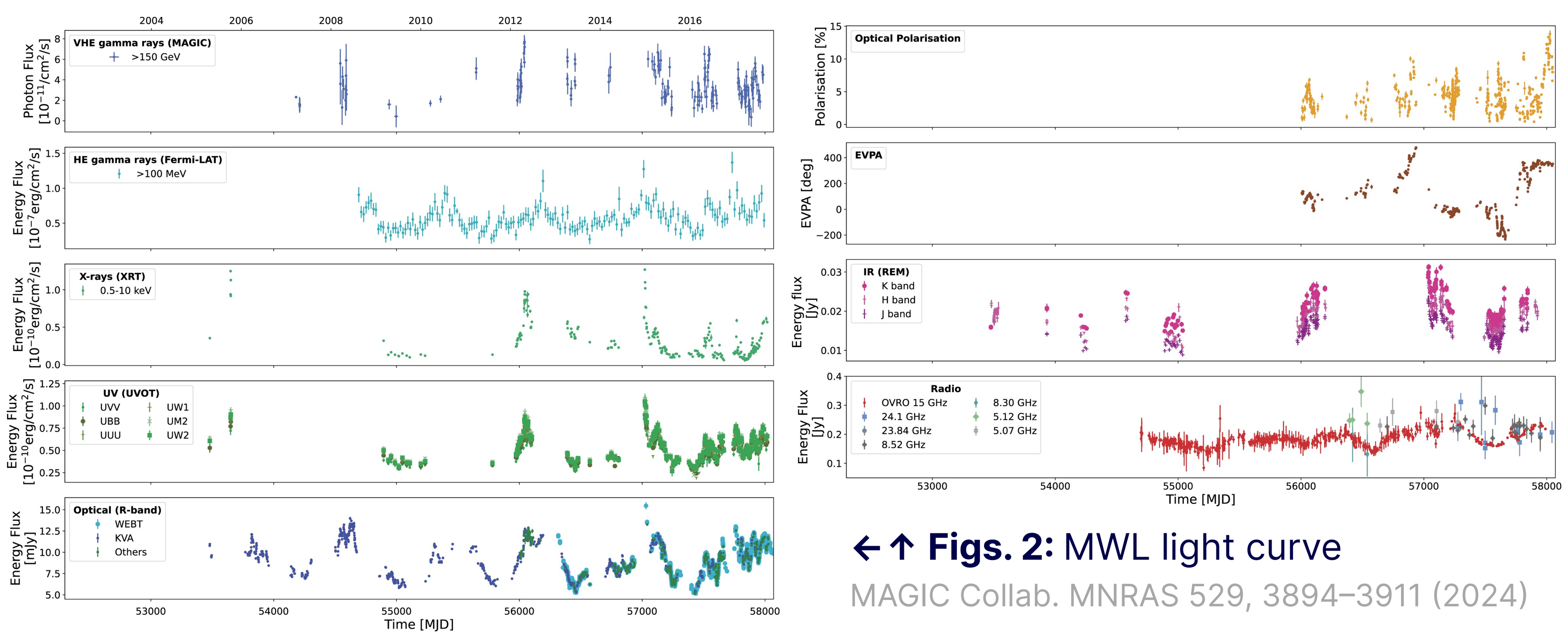
- LST-1 is the protoype of the Large-Sized Telescope of the Cherenkov Telescope Array Observatory's (CTAO) northern site
- Located on Roque de los Muchachos Observatory in La Palma, Spain
- LSTs have an optimised sensitivity for CTAO's low energy range i.e. 20-150 GeV, which gives us a unique opportunity to investigate blazar variabilities

Fig. 1: The LST-1 Telescope (image credit: Otger Ballester, IFAE)

MWL LONG-TERM MONITORING OF PG1553+113

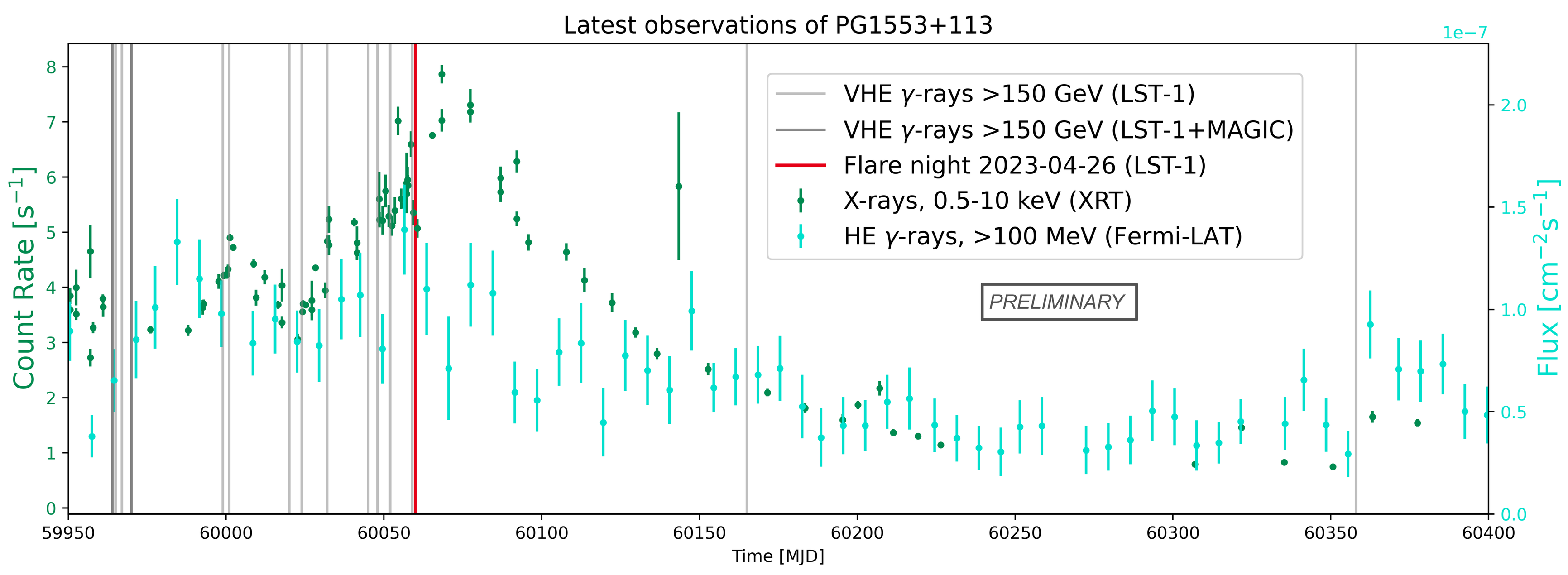
From recent multi-wavelength (MWL) studies:

- No periodicity in VHE γ-rays and X-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
  - *intertwined emission processes e.g. in a multizone, SSC emission scenario*

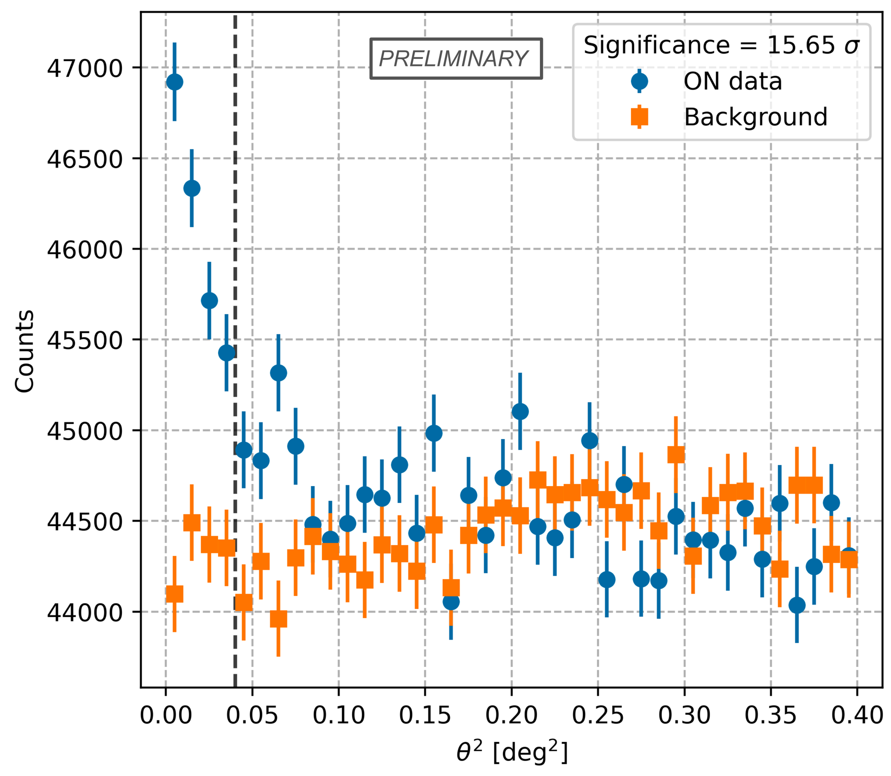


← ↑ Figs. 2: MWL light curve
MAGIC Collab. MNRAS 529, 3894–3911 (2024)

LST-1 OBSERVES A FLARE ON 2023-04-26

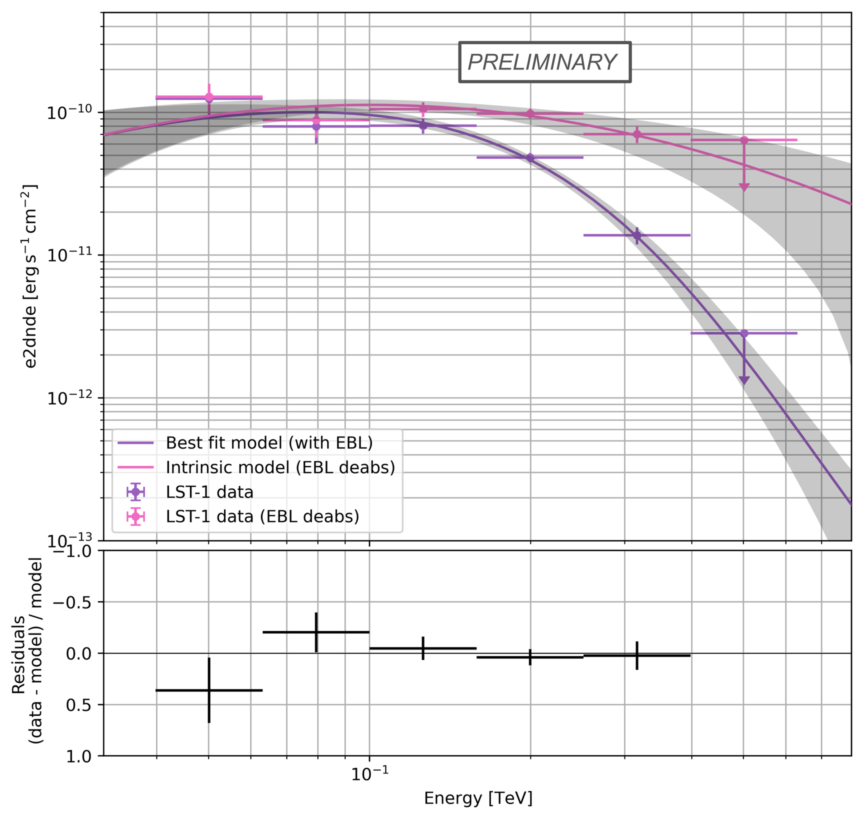


↑ Fig. 3: X-ray count rates from *Swift-XRT*, HE γ-ray flux from *Fermi-LAT* and dates of VHE γ-ray observations from LST-1 and LST-1 + MAGIC, triggering on the high states. LST-1 observation of the flare on 2023-04-26, indicated by the red line, was triggered on the MAGIC monitoring data during the peak of the *Fermi-LAT* periodicity.



↑ Fig. 4: θ² distribution

- Livetime: 3.67h
- 10 GeV < E_{reco} < 10 TeV
- Cut on θ²: 0.04 deg²
- Significance: 15.65σ

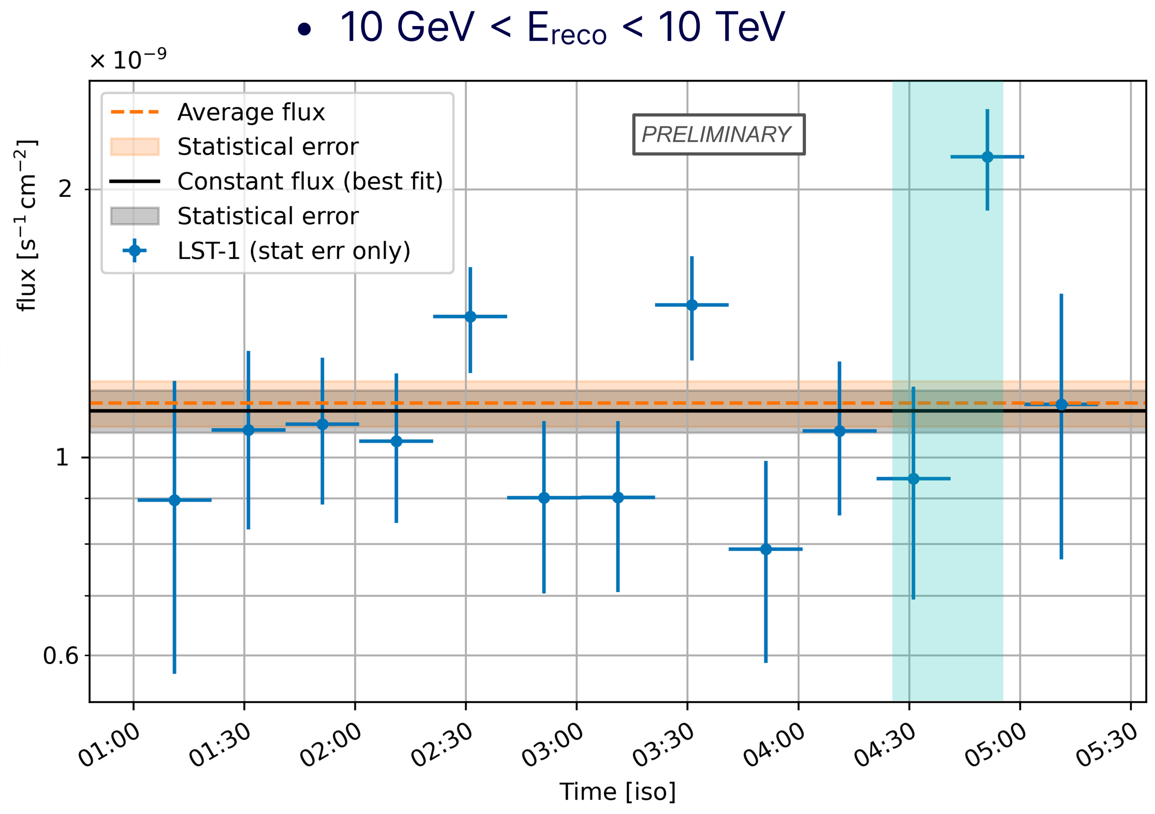


↑ Fig. 5: Spectral Energy Distribution (SED)

- Spectral model used: log-parabola * EBL absorption (Dominguez et al. 2011)
- 10 GeV < E_{reco} < 10 TeV

→ Fig. 6: Light curve

- Time binning: 20 min
- E_{min}: 50 GeV
- Average flux (with statistical errors only): (1.15 ± 0.07) x 10^{-9} $s^{-1}cm^{-2}$
- **Constant flux** (best fit, with statistical errors only): (1.12 ± 0.06) x 10^{-9} $s^{-1}cm^{-2}$ with **χ^2 = 26.2**



NEW CONSTRAINT ON THE EMITTING REGION

- We characterise the variations in the observed flux of PG1553+113 for 2023-04-26 by using the normalised RMS variability amplitude, F_{var}, defined as

$$F_{\rm var} = \sqrt{\frac{S^2 - \langle \sigma_{\rm err}^2 \rangle}{\langle F \rangle^2}} \quad \text{... (1)}$$

  where S^2 is the sample variance, σ^2 is the mean square error (MSE) and <F> is the mean flux, and obtain S^2 > MSE and F_{var} (%) = 24.0 ± 6.9 (3.5σ significance) which **hints towards the presence of IDV**
- We compute the shortest variability timescale using the flux halving/doubling timescales as follows

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

  where τ is a characteristic halving/doubling time-scale and $F(t_1)$ and $F(t_2)$ are the fluxes of the LC at times t_1 and t_2, respectively, obtaining a **doubling time of 0.99 ± 0.17 ks** at/after 2023-04-26 04:31:09.184 UTC (as indicated in Fig. 6)
- Using this shortest variability timescale, we compute an upper limit on the radius of the emission region using the formula

$$R \leq \frac{c t_{\rm var} \delta}{1 + z} \quad \text{... (3)}$$

  where the Doppler factor, δ, ranges from 11 to 35 (Dhiman et al. 2021) and constrain the maximum radius of the emitting region to the range **(0.23-0.73) × 10^{15} cm**

FUTURE PROSPECTS

- Collect more data with LST-1 in 2025 during the high state of the source, exploiting its ~2-year periodicity (in HE γ-rays), to probe better the short timescales
- Plan to make simultaneous MWL observations with XMM-Newton
- Higher sensitivities of the upcoming CTAO and other next-generation arrays will make it possible to observe the source also in its low state

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