Detection of TeV variability from the Peculiar Gamma-Ray Loud Active Galactic Nucleus IC 310 by LHAASO

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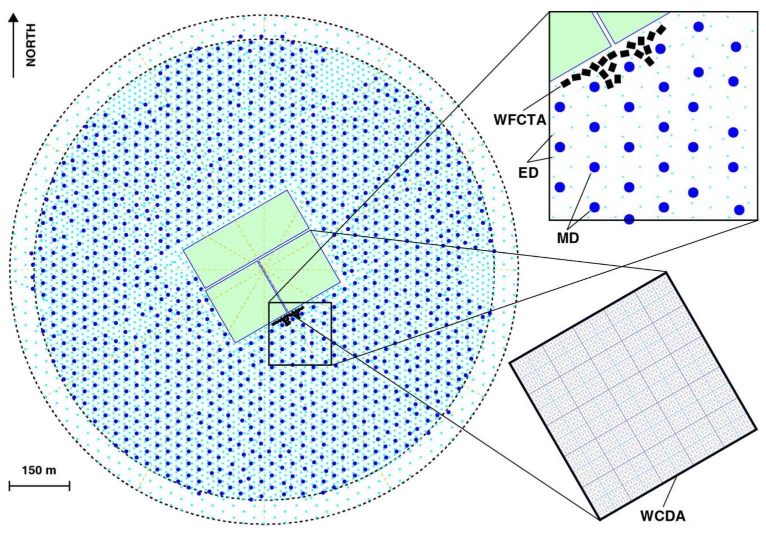
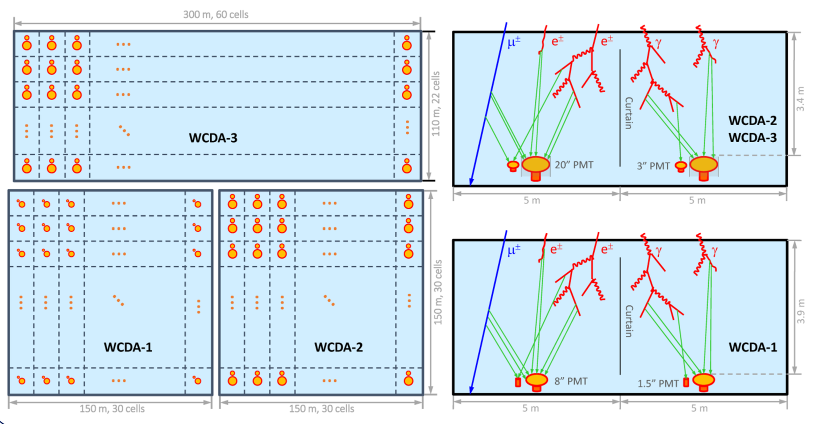
FACTS OF IC 310

- Type: Active Galactic Nucleus (AGN); Subtype: Radio galaxy / transitional between BL Lac object and FR I radio galaxy.
- Host: Lenticular galaxy in the Perseus cluster.
- Distance: ~78 Megaparsecs ($z = \sim 0.0189$).
- Radio: Observed by VLBI, EVN, and VLA – showing a compact, one-sided jet structure. A misaligned blazar, possibly bridging BL Lac and radio galaxy.
- Optical/Infrared: Host galaxy well-studied; low-luminosity AGN features.
- X-ray: Detected by XMM-Newton, Chandra – shows variable emission correlated with jet activity.
- Gamma-ray: Observed by Fermi-LAT (GeV) and MAGIC (TeV, in 2009). Notable fast TeV variability: sub-minute variability timescale observed in 2012, challenging classical jet emission models.

LHAASO & LHAASO-WCDA

Layout of LHAASO
- Four types of detectors formed into 3 arrays: WCDA, KM2A, WFCTA
- New instruments are under construction: LACT, ENDA





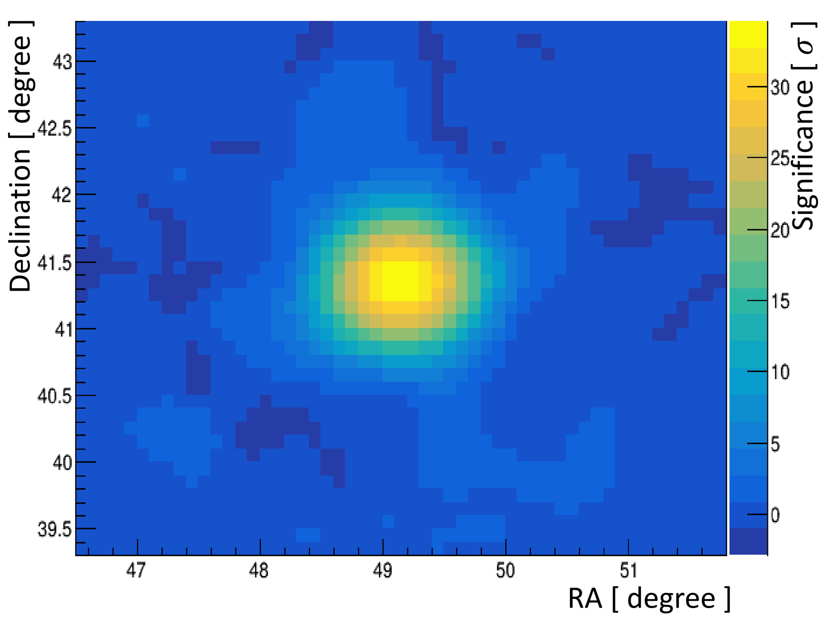
LHAASO-WCDA
- 3120 cells in 3 pools
- Area: 78,000 m^2

DATA & DATA ANALYSIS PIPELINE

- Data period: March 8, 2021 – July 31, 2024.
- Joint 3D likelihood fitting using data from WCDA and KM2A.
- Bayesian block method applied to identify flares during the active phase (p-value threshold: 0.05).
- Spectral Energy Distribution (SED) Modeling:
  - Intrinsic spectrum: single power-law.
  - Observed spectrum: power-law with exponential cutoff.
  - EBL absorption model: Saldana-Lopez 2021 (optical depth evaluated at redshift z = 0.0189).

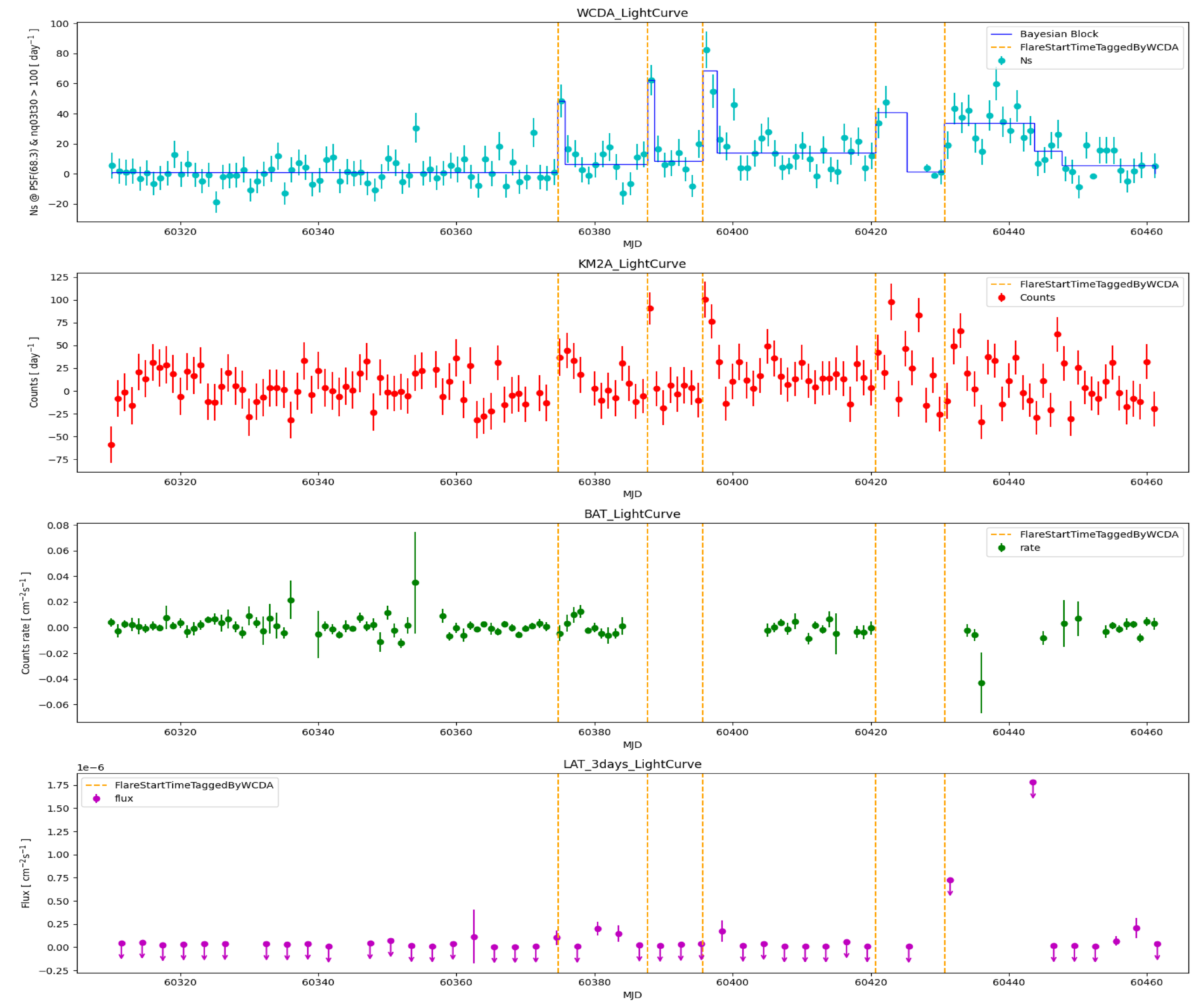
IC 310 ACTIVITY & ITS DETECTION

- IC 310 became suddenly active in early 2024.
- Five major outbursts were identified:
  - i. March 6
  - ii. March 19
  - iii. March 27 – 28
  - iv. April 21 – 22
  - v. May 1 – 13
- The combined significance of these outbursts is 34.5 σ.



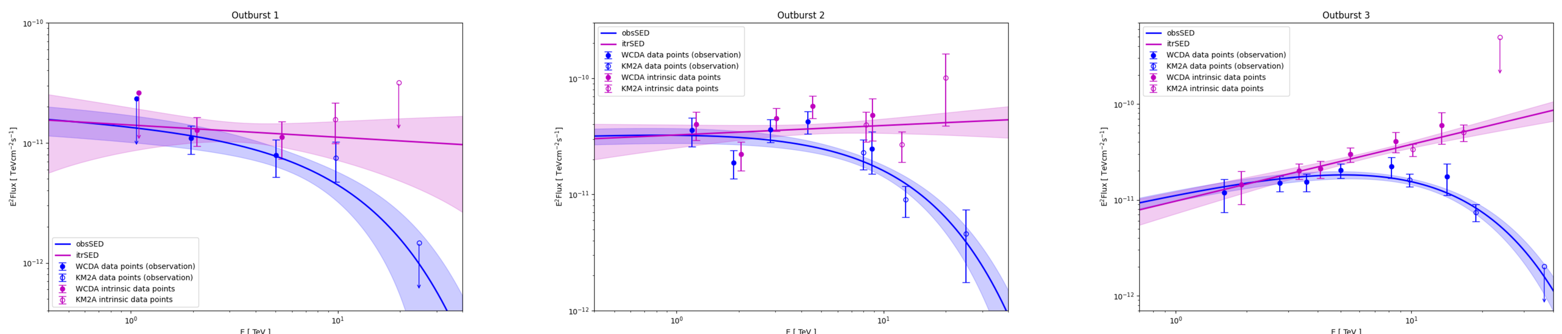
Overall excess of 5 bursts detected by LHAASO-WCDA.

LIGHT CURVES

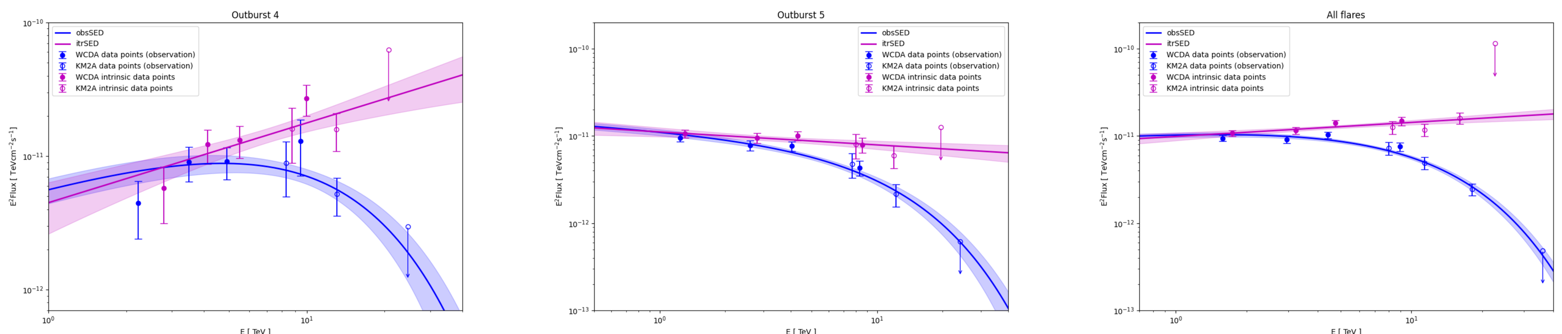


Light curves of IC 310 from LHAASO-WCDA, LHAASO-KM2A, SWIFT-BAT, and Fermi-LAT (from top to bottom). The flare periods highlighted in the plots are identified based on LHAASO-WCDA data.

FLUXES OF THE FIVE OUTBURSTS



Outburst (i) Outburst (ii) Outburst (iii)



Outburst (iv) Outburst (v) Outburst (sum)

SED fits for the five outbursts and their combined spectra. Purple data points and curves represent the intrinsic spectra, while blue indicates the observed ones.

SED parameters obtained by the fits.

Outburst number	F_0 [10^{-12} TeV^{-1}cm^{-2}s^{-1}]	α	Outburst number	F_0 [10^{-12} TeV^{-1}cm^{-2}s^{-1}]	α	E_{cut} [TeV]
1 (PL)	2.05±0.42	2.10±0.28	1 (PEC)	2.16±0.61	2.10	10.4±4.6
2 (PL)	5.60±0.71	1.92±0.13	2 (PEC)	6.14±0.99	1.92	10.1±1.9
3 (PL)	2.67±0.40	1.41±0.13	3 (PEC)	3.42±0.46	1.41	8.74±0. 95
4 (PL)	1.24±0.30	1.40±0.20	4 (PEC)	1.76±0.41	1.40	7.88±1.45
5 (PL)	1.56±0.10	2.15±0.08	5 (PEC)	1.71±0.16	2.15	9.54±1.39
Sum (PL)	1.83±0.10	1.84±0.06	Sum (PEC)	2.12±0.14	1.84	9.34±0.66

INTERPRETATION & MODELLING

- The following scenarios are currently being considered and modeled:
  - Leptonic: two-zone scenarios
  - Hadronic: proton–proton (p–p) interactions
  - Hadronic: proton synchrotron processes
  - Hadronic: proton–photon (p–γ) interactions
- Theoretical investigations are still ongoing, and no final results are available at this stage.

SUMMARY

- Multiple outbursts were detected during the active phase of IC 310 in 2024.
- An outburst with unprecedented spectral hardness α=1.40±0.20 ➔ challenges the conventional one-zone SSC model.
- The median energy in the highest-energy bin surpasses all previous records.