Variability studies of active galactic nuclei from the long-term monitoring program with the Cherenkov Telescope Array

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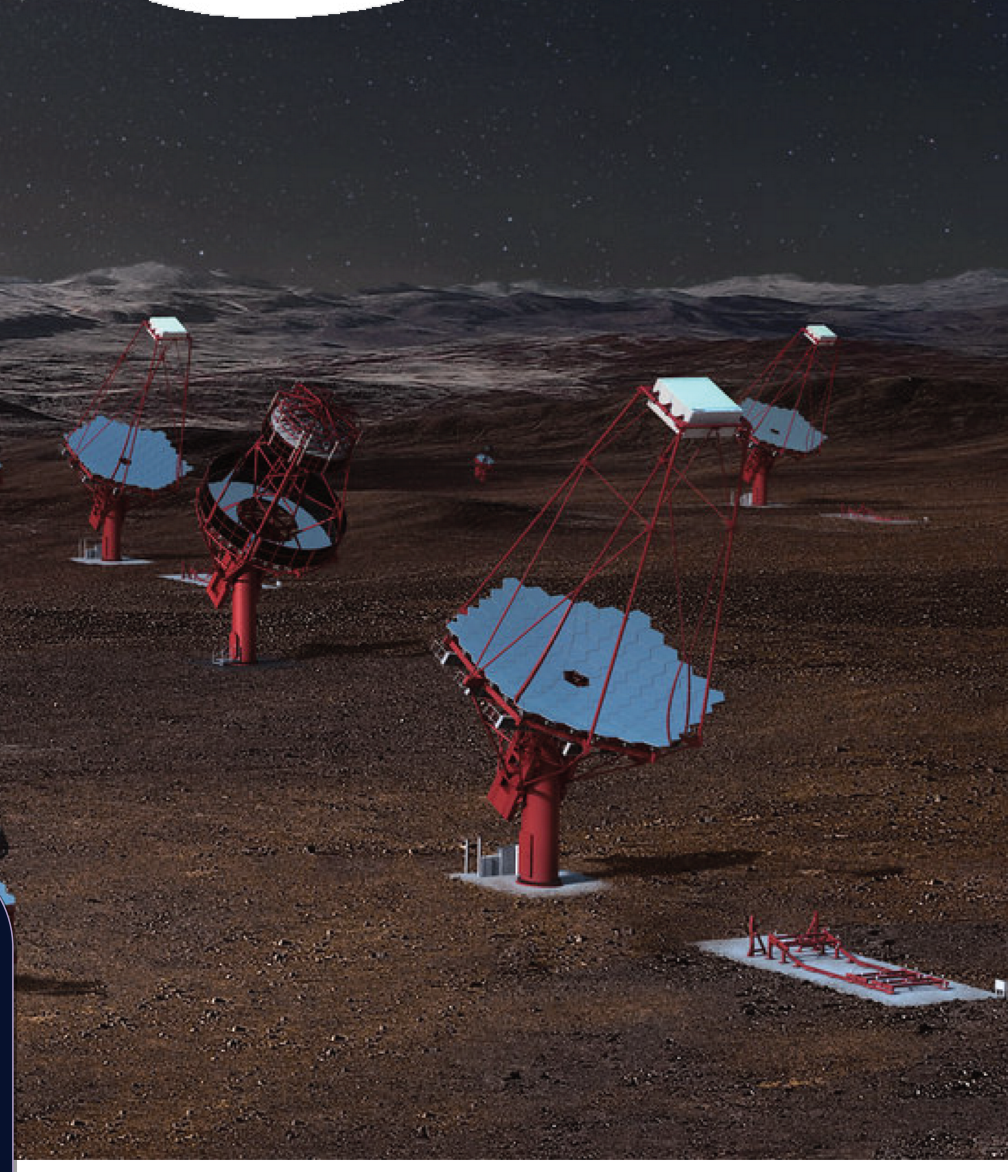
cherenkov telescope array



ABSTRACT

Blazars are active galactic nuclei (AGN) with a relativistic jet oriented toward the observer. This jet is composed of accelerated particles which can display emission over the entire electromagnetic spectrum. Spectral variability has been observed on short- and long-time scales in AGN, with a power spectral density (PSD) that can show a break at frequencies below the well-known red-noise process. This break frequency in the PSD has been observed in X-rays to scale with the accretion regime and the mass of the central black hole. It is expected that a break could also be seen in very-high-energy gamma rays, but constraining the shape of the PSD in these wavelengths has not been possible with the current instruments. The Cherenkov Telescope Array (CTA) will be more sensitive by a factor of five to ten depending on energy than the current generation of imaging atmospheric Cherenkov telescopes, therefore it will be possible with CTA to reconstruct the PSD with a high accuracy, bringing new information about AGN variability. In this work, we focus on the AGN long-term monitoring program planned with CTA. The program is proposed to begin with early-start observing campaigns with CTA precursors. This would allow us to probe longer time scales on the AGN PSD.

Introduction

The Cherenkov Telescope Array (CTA) will be the next generation of ground-based imaging atmospheric Cherenkov telescopes (IACT) array. It will improve the sensitivity to gamma rays above 20 GeV by a factor of five to ten depending on energy compared to current IACT. Therefore, CTA will bring a new outlook on the Universe, in particular on its non-thermal emission.

Active Galactic Nuclei (AGN) are astrophysical sources that emit radiation across the entire electromagnetic spectrum, generated by both thermal and non-thermal processes. Relativistic jets, near the central black hole of an AGN, are significant sources of non-thermal emission and can accelerate particles to the relativistic regime. Blazars are those AGN with the jet oriented towards the observer with variable flux and spectral properties. Very high energy (VHE) gamma-ray AGN variability occurs on different timescales, from short AGN flares (minutes to hours) to long-term variations (years) [1]. AGN behavior on short time scales can be described by leptonic or hadronic emission, as discussed in poster 34 [2]. Measurement of long-term behavior of AGN allows to reconstruct the power spectral density (PSD) that might show a break from pink noise at low frequencies to red noise at high frequencies [3]. Such a break has been observed in X-rays [4] to scale with the black hole mass and the accretion rate [5,6]. The characterization of the PSD break at very high energies, even for brightest AGN, is challenging with current IACT but CTA holds promise for several sources.

This poster focuses on the AGN long-term monitoring program of CTA, part of the AGN CTA Key Science Project (KSP) [7], where it is proposed to monitor 15 selected AGN over 10 years at least once a week during their visibility period.

Creation of AGN models from time series generator

AGN modelling is performed through the following procedure [8] :

$$F_{var} = \int_{\frac{1}{T}}^{\frac{1}{\delta t}} PSD(\nu)d\nu \qquad T = 10 \text{ years},\ \delta t = 30 \text{ min},\ F_{var} = 2$$

- → PSD : a pink- to red-noise
- → flux distribution : log-normal [9]
- → Spectral index : harder when brighter behavior [13,14]
- → Flux and spectral variability : injected to median spectrum through the fractional variability + extrapolation to the very high energy (VHE) domain.

Spectral model → log-parabola with exponential cut-offs :

$$\Phi_z(E,t) = \Phi(t)\left(\frac{E}{E_0}\right)^{-\Gamma(t)-\beta ln\frac{E}{E_0}} e^{-\frac{E}{E_{\text{cut}}}} e^{-\tau_{\gamma\gamma}(E,z)} \qquad (1)$$

Photon index; Differential flux at the reference energy; Reference energy; Log-parabola curvature; Cutoff energy; Absorption of VHE photons in the extragalactic background light [11]

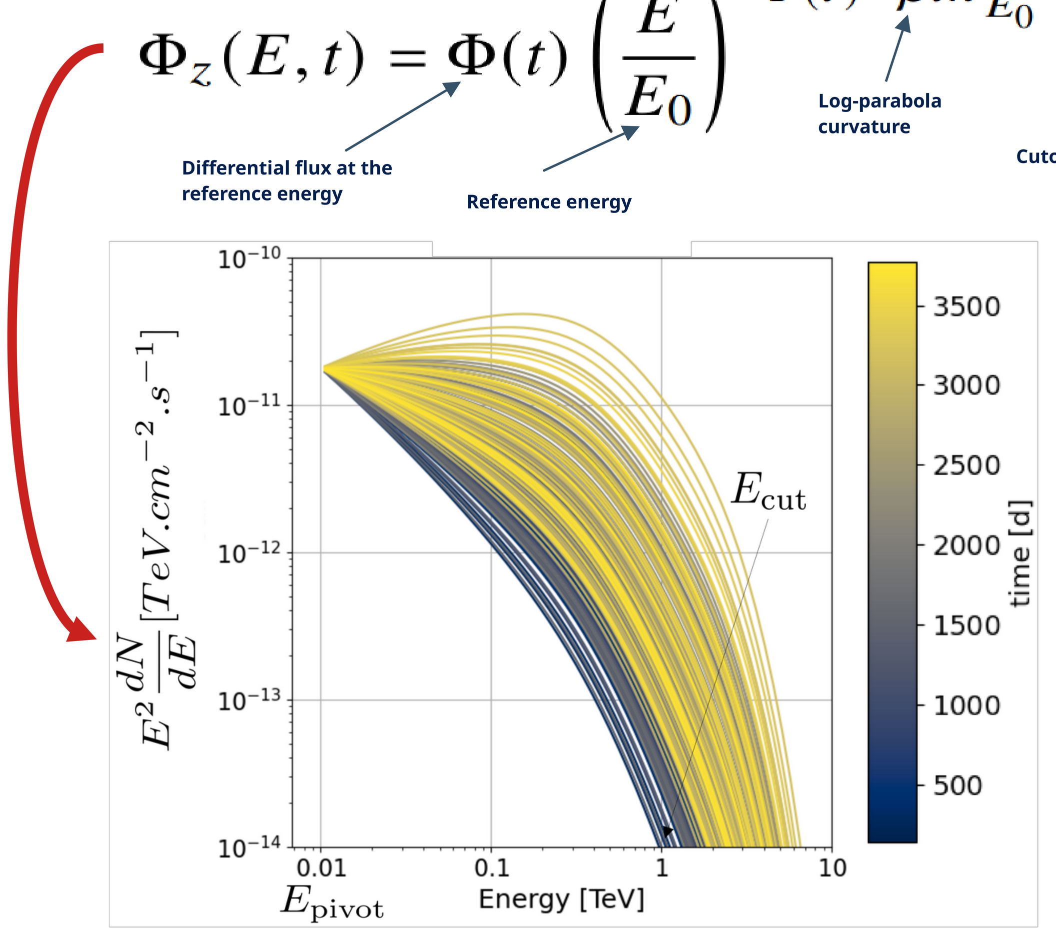


Fig. 1:
Spectra generated for BL Lac.
Color code = 10 years time evolution from blue to red.

→ The spectral variability :
- constant flux at a pivot energy = 10 GeV [15].
- amplitude of the variability :
  - described by fractional variability
  - injected at the cutoff energy.

Simulation of CTA observations and light curve reconstruction

To simulate CTA observations we are using the CtaAgnVar pipeline :
- → designed to simulate and analyze VHE AGN observations with CTA
- → based on Gammapy, the high-level analysis pipeline for CTA [16].

Observation sequence created with :
- → AGN time-dependent spectral model
- → visibility of the source throughout the night considered
- → zenith angle followed → dynamically select the instrument response functions(CTA IRFs – prod5 v0.1)

Long-term monitoring program : → weekly cadence with 30 min of integration time.

Focus on three bright sources:
- Mrk 501 (much bright in North, BL Lac type)
- BL Lac (fainter than Mrk 501, but the first new candidate for CTA North)
- PKS 1510-089 (more distant + observed from South, flat spectrum radio quasar)

→ significance distributions are shown in Figure 2.

CTA sensitivity improvement →

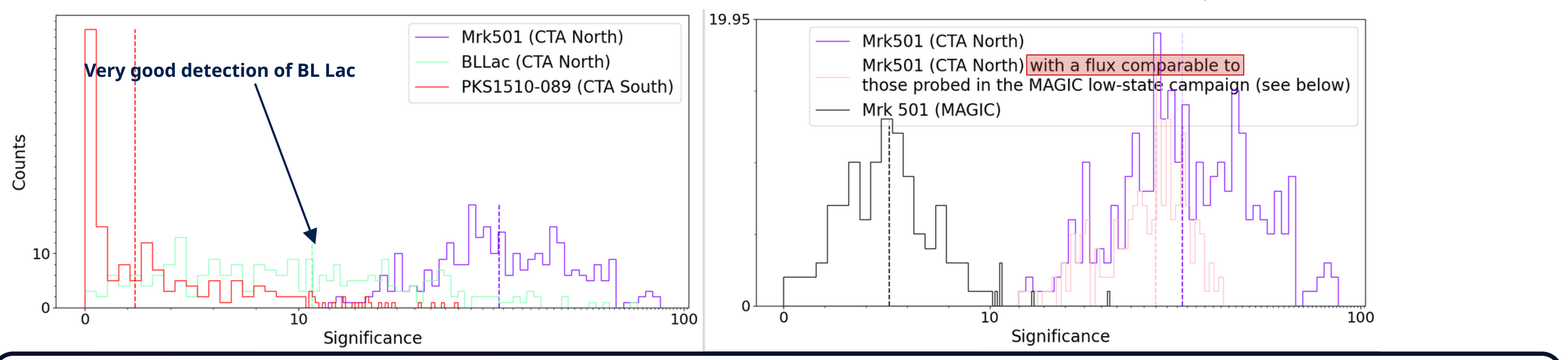
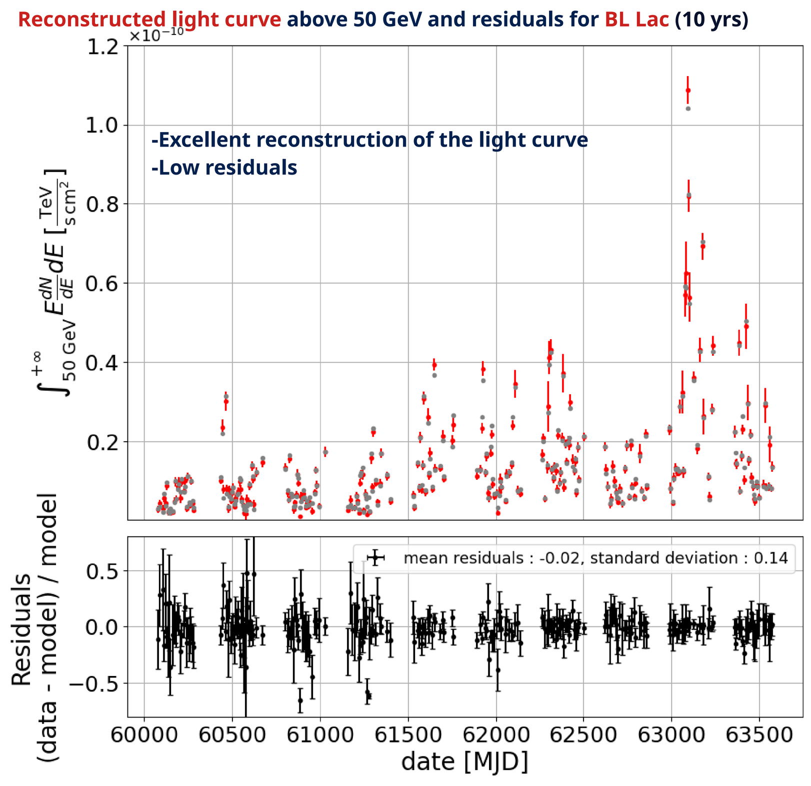


Fig. 2:
Detection significance in 30 min, σ , for the selected bright sources. The vertical dotted line is the median value associated to each source. These distributions are compared with the one of Mrk 501 observed by MAGIC [17].

Reconstructed light curve above 50 GeV and residuals for BL Lac (10 yrs)



Reconstructed median spectrum for BL Lac (10 yrs)

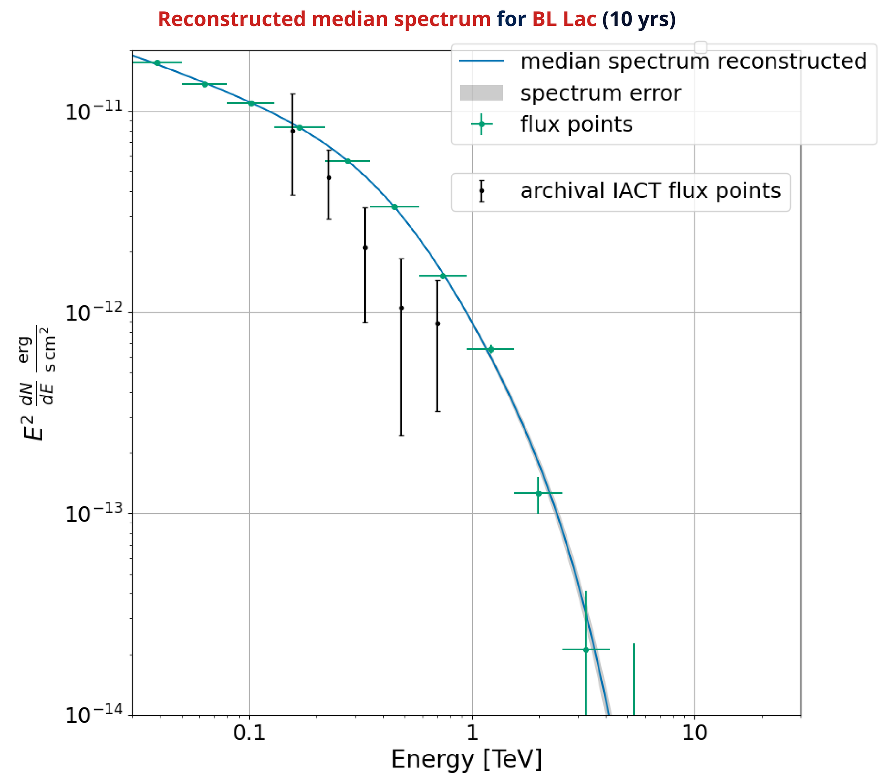


Fig. 3 :
Gray points : injected values
Blue points : reconstructed ones

Fig. 4:
Black points : flux points reconstructed with current IACT extracted from STeVECat [10].

PSD reconstruction

PSD estimated following [8,15] for each source in the CTA AGN KSP [7]

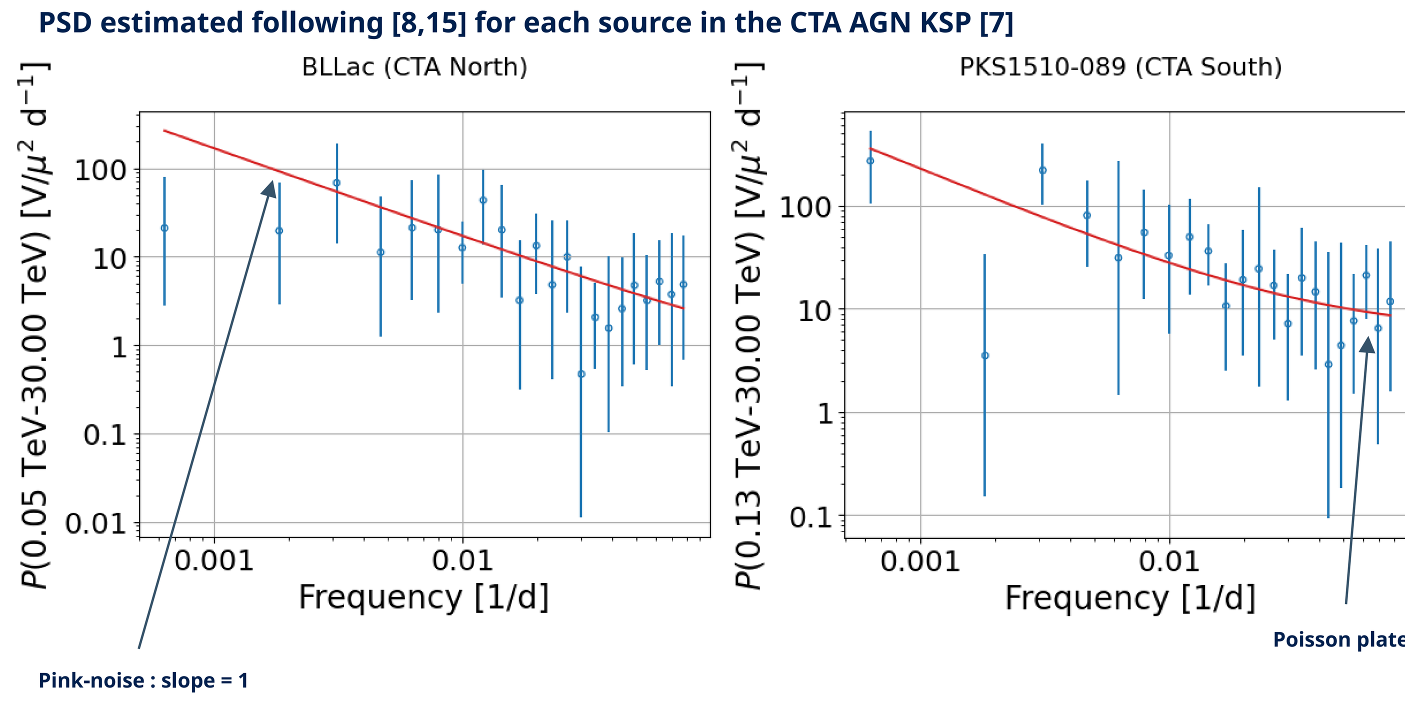


Fig. 5:
Periodograms (blue points) of the simulated data for BL Lac (left) and PKS 1510-089 (right).
The red line = injected PSD

→ source PSDs can be established with the CTA observation scheme.

CTA perspective for long-term VHE AGN studies

In this contribution :
- → Studied the capabilities of CTA for the long-term VHE AGN monitoring program.
- → BL Lac or PKS 1510-089 :
  - CTA reaches the same precision level as the current IACT with Mrk501.
  - Can estimate the PSD
- → Here : simple pink-noise input spectrum here (will be refined in a forthcoming publication)
- → Observing campaigns with CTA precursors (MAGIC and LST-1)

The results presented here are encouraging and show that CTA will be able to probe deeply the VHE AGN long-term behavior.

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www.cta-observatory.org/consortium_acknowledgments

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