# Feasibility studies on search for the Lorentz invariance violation signatures from flaring blazars with the Cherenkov Telescope Array

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## MOTIVATION AND SUMMARY

**The current paradigm in General Relativity (GR), Quantum Mechanics (QM), and Quantum Field Theory (QFT) is that the physical laws must be invariant under Lorentz transformations. However, some theories aiming at unifying GR and QM (such as Quantum Gravity (QG) and string theory) allow Lorentz Invariance Violation (LIV) at the Planck scale (~$10^{19}$GeV), leading to observable consequences, due to a modified energy-momentum dispersion relation for photons. Particularly, LIV can be tested by searching for time delays in the TeV gamma-ray photons coming from distant and highly variable astrophysical sources, such as relativistic flows from pulsars, Gamma-ray Bursts (GRBs) and Active Galactic Nuclei (AGN). Specially, blazar jets possess the desired characteristics to search for LIV effects. Using the AGN Evolution Simulator Code (AGNES), the broadband spectra of a blazar can be modeled with the time-dependent one-zone Synchrotron-Self-Compton (SSC) code during a flaring state, and the presupposed LIV delays can be introduced alongside the intrinsic time-lags from the source. In this work, we aim to analyze the capacity of the Cherenkov Telescope Array (CTA) to detect global time delays and to discriminate between the contribution of intrinsic phenomena in the jet and possible LIV effects, as well as constrain the flaring process and jet parameters. The methodology and preliminary results from the simulations performed for the feasibility studies with CTA are presented.**

## INTRODUCTION

A searching strategy proposed to identify LIV signatures from Very High Energy (VHE) remote cosmic sources, such as blazars, is to look for energy-dependent time delays on the arrival-time of photons at different energies [1]. Particularly, flaring episodes from blazars have been analysed to check for LIV signatures in the VHE gamma-ray data from the current generation of Imaging Atmospheric Cherenkov Telescopes (IACT) [2,3].

### AGN Modeling: AGNES [4]

- Hypothetical flare of Mrk 501
- One-zone SSC model parameterization
- ~5.5hrs evolution of the flare
- Output: SED snapshots with and without injected LIV delay

Input: AGN time-dependent spectral model

### CTA-AGN-VAR Pipeline [5]

The tool to simulate AGN observations with CTA in a realistic manner:

- Produces a photon list of gamma-like events
- Light curve reconstruction from input model
- Dynamical selection of CTA Instrument Response Functions (IRFs)
- Takes into account observational constraints

### Preliminary Results

- Light curve comparison with and without LIV induced time delay, in different energy bands
- Can CTA detect intrinsic time delays?
- Is there an observable LIV signature?
- Outlook and future improvements

**Fig. 1.** Flowchart of the project. The main steps of the methodology and preliminary results are outlined in the different sections of the poster.

## BLAZAR TIME-DEPENDENT MODELING

Homogeneous one-zone SSC model [6]: spherical bulk of dense leptonic plasma inside the jet of a blazar.

- Generic acceleration mechanism: shock and stochastic processes and/or magnetic reconnection
- Radiative cooling: synchrotron + SSC

Intrinsic time delays in two main regimes (cooling-driven or acceleration-driven) arise from this minimalistic scenario [7].

Using the AGN Evolution Simulator (AGNES) software [4], we modeled the temporal evolution of a "typical" flare for Mrk501 (Fig. 2).

- Electron distribution: Cut-Off Power-Law.
- Cooling-driven regime (fast acceleration).
- Decreasing time delays at TeV energies.

LIV injection:

- Time delay: 400 s/TeV (subluminal case).
- Linear correction to the energy– momentum dispersion relation [1].
- Light curves shift depending on their energy.

### Intrinsic + LIV delays model for Mrk501 "typical" flare

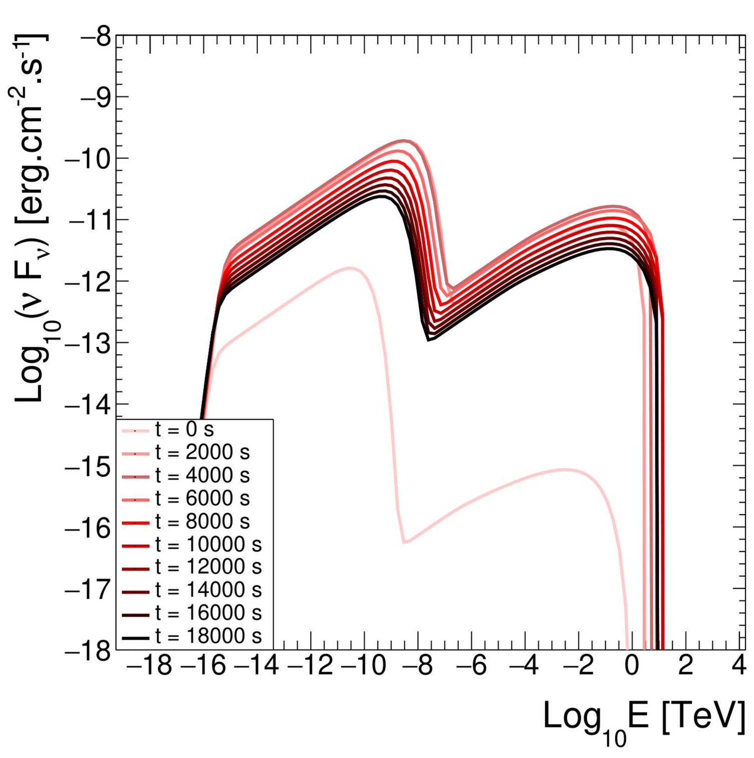


**Fig. 2.** Temporal evolution of Mrk501 Spectral Energy Distribution (SED) computed with AGNES.

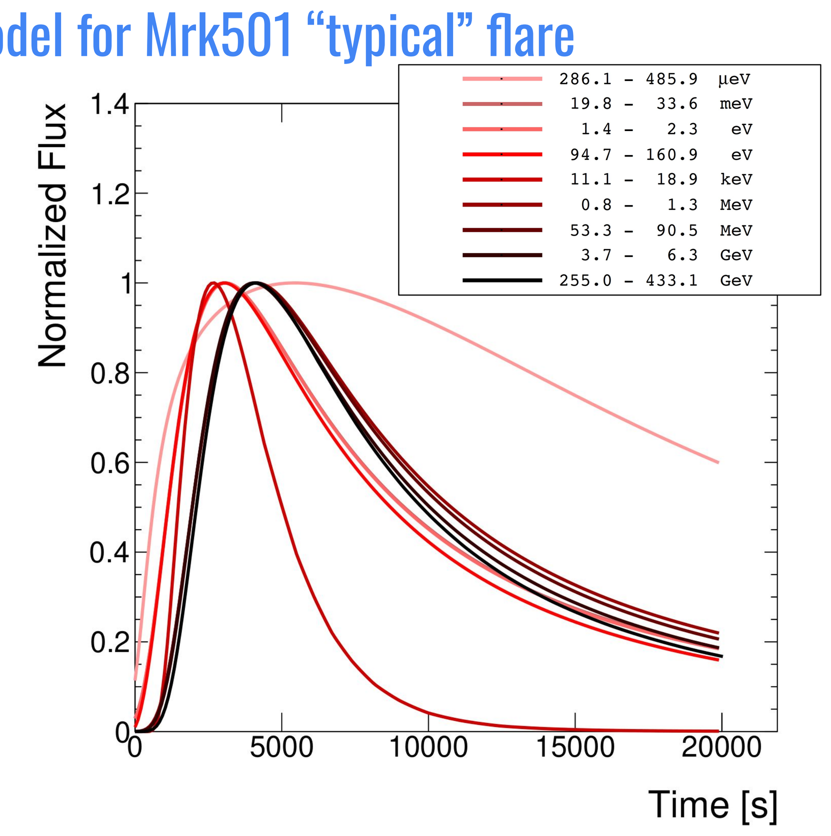


**Fig. 3.** Theoretical light curves in different energy bands produced by AGNES for Mrk501 "typical" flare.

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## CTA SIMULATIONS: AGN-VAR PIPELINE

CTA will improve at least by an order of magnitude the sensitivity, as well as energy and angular resolution, in comparison to the current generation of IACTs. As part of its scientific program, CTA will explore problems in fundamental physics, including LIV search and setting constraints on this possible effect in astrophysical sources.

### CTA-AGN-VAR

Is the high-level analysis pipeline developed fo CTA based on Gammapy [7]

- CTA configuration: Alpha Array
  CTA-N: 4 LSTs and 9 MSTs
  CTA-S: 14 MSTs and 37 SSTs
- Prod5 IRFs [8].
- Realistic follow-up of the source.
- Fit an analytical spectral model: Power Law + Exp Cut-Off
- Extragalactic Background Light (EBL) attenuation effect.
- Input: Temporal evolution of Mrk501 SED during a typical flare with and without an injected LIV delay.
- Output: Reconstructed light curves from simulations on different energy bands (see Figs. 4 and 5).

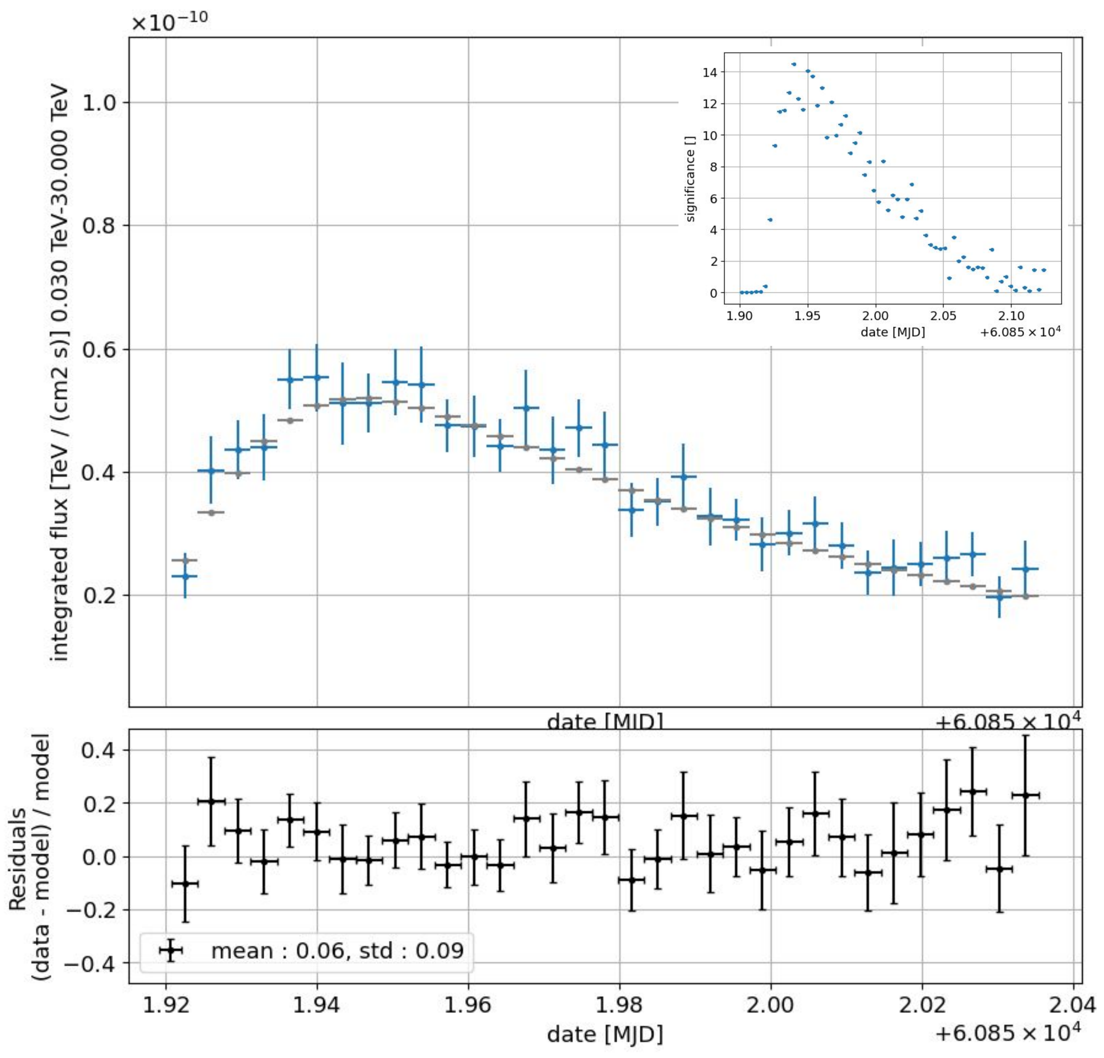


**Fig. 4.** Simulated lightcurve as possibly observed by CTA-N using 5 min time bins and the injected model shown in Fig. 2. The results of simulations are presented as blue points and the injected model (computed with AGNES) is shown in grey. Only time bins with significant flux detection (>5σ) are shown.

## PRELIMINARY RESULTS

Using the reconstructed 5 min time bin light curves:

- Comparison of the intrinsic and LIV effects in different energy bands.
- Light curves are fitted using an asymmetric Gaussian function [9].
- Peak determination is estimated from the best-fit parameterization.

From preliminary results:

- CTA-N Alpha array appears to be sensitive enough to register the intrinsic time delays in our simulations.
- The results from purely intrinsic scenario are consistent with the injected model, with a smaller delay at high energies (> 300 GeV).
- There is a clue for detection at the highest energies of a delay between the purely intrinsic case and the case with the injected LIV effect. However, the significance of this delay is rather poor at this stage.
- MWL ligth curves with injected LIV effects are more difficult to interpret. No significant delay was found between the different energy bands tested, which deserves further analysis with a refined methodology and other LIV signature tests (work in progress).

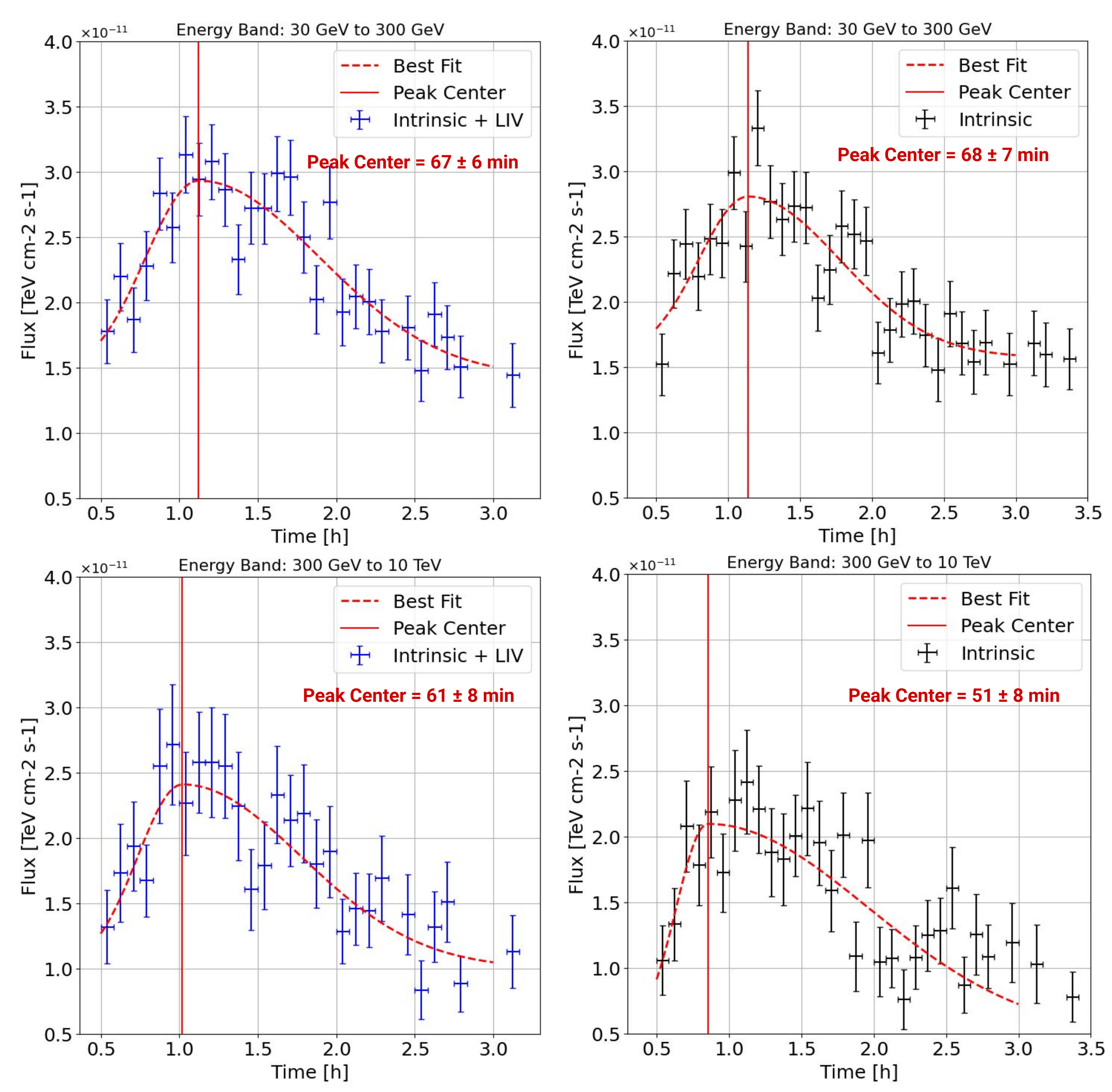


**Fig. 5.** Reconstructed light curves in low (30 GeV to 300 GeV) and high (300 GeV to 10 TeV) energy bands. The best-fit curve and peak center are shown in red. **Left:** Intrinsic + LIV delay model (blue points). **Right:** Intrinsic model (black points).

## CONCLUSION AND OUTLOOK

This first analysis suggests that CTA-N Alpha configuration should be able to detect intrinsic delays in "typical" blazar flares, but detecting the LIV effects with such kind of flare seems challenging.

Improvements for the project in the near future:

- Test exceptional blazar flares (up to 2 orders of magnitude higher SED) with the CTA-AGN-VAR pipeline.
- Check the Southern Array (CTA-S) and CTA Omega configuration.
- Test different scenarios: subluminal/superluminal LIV injected delays with cooling/acceleration-driven regimes.
- Perform a larger number of simulations to obtain the calibrated statistical error.
- Apply the likelihood fitting method [10] to the light curves in order to improve the estimation of time delays.

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