Study of active galactic nuclei variability and Lorentz invariance violation with MAGIC and LST-1 telescopes

One of the key open questions in theoretical physics is the unification of general relativity and quantum field theory into a single framework of quantum gravity (QG). One possible manifestation of such a theory is the violation of Lorentz invariance (LIV), a fundamental symmetry of spacetime. QG effects are expected to emerge near the Planck scale $\sim 10^{19}$ GeV, well beyond the reach of current experiments. While any resulting signatures are predicted to be minuscule, they may accumulate over cosmological distances. As a result, very-high-energy gamma rays could serve as valuable probes for studying QG.

This thesis investigates LIV through time-of-flight (ToF) analyses of rapidly variable active galactic nuclei (AGN), using observational data from two major imaging atmospheric Cherenkov telescopes: the Major Atmospheric Gamma Imaging Cherenkov (MAGIC) telescopes and the Large-Sized Telescope prototype (LST-1). Before exploring LIV ToF searches, the thesis introduces BASiL (Bayesian Analysis including Single-event Likelihoods), a novel statistical method that improves signal estimation in ON/OFF measurements by incorporating event-level likelihoods. For the LIV ToF analysis, we first apply a new binned maximum likelihood method to the 2014 flare of Markarian 421 observed by the MAGIC telescopes. The thesis then presents a combined LIV analysis of two AGN flares using the gLike software framework. This includes MAGIC observations of the September 2020 BL Lacertae flare, modelled here with a one-zone synchrotron self-Compton scenario, and LST-1 data from another flare of BL Lacertae that was detected in August 2021. These analyses yield updated lower bounds on the quantum gravity energy scale, placing the 95% CL limits at $7.2 * 10^{19}$ GeV for the superluminal case and $7.0 * 10^{19}$ GeV GeV for the subluminal case.

Keywords: Lorentz invariance violation, very-high-energy gamma rays, imaging atmospheric Cherenkov telescopes, active galactic nuclei, BL Lacertae, Markarian 421, time-of-flight analysis, maximum likelihood, Bayesian statistics