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Axion-like Particles in the Very-High-Energy Sky: From MAGIC to CTAO

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Axion-like particles (ALPs) are promising candidates for new physics beyond the Standard Model, motivated by their potential to resolve one of the greatest mysteries of the Universe: Dark Matter (DM). Their ability to oscillate into photons in the presence of an external magnetic field, leads to expected signatures imposed on the observed photon spectra of astrophysical sources. In gamma-ray astronomy, photon-ALP oscillations can lead to observable effects across a broad energy range, from GeV to TeV. These effects may help explain irregularities in photon spectra and the apparently anomalous transparency of the Universe to very-high-energy (VHE) gamma rays.
For ALP masses in the neV range and magnetic field strengths of O(μG), photon-ALP oscillations are most prominent in the GeV regime. This energy range lies at the lower end of the sensitivity for the future Cherenkov Telescope Array Observatory (CTAO), driven by the Large-Sized Telescopes (LSTs) subarray. It is also covered by the MAGIC telescopes, making them both particularly well-suited to probe ALP effects in the VHE gamma-ray domain.
A recent study conducted by the MAGIC collaboration using the data of the radio galaxy NGC1275 collected via observations of the Perseus cluster has set the strongest constraints to date on the ALPs masses from 40-80 neV. A currently underway project aimed at analyzing blazar data taken by the first Large-Sized Telescope (LST-1) of CTAO will be the first one to derive combined constraints on the ALPs parameter space from VHE observations of multiple sources.
Looking ahead, preliminary studies performed with the CTAO support its potential to explore previously inaccessible regions of the parameter space thanks to its unprecedented sensitivity, energy coverage, and improved resolution. With its dual-site configuration, CTAO will enable high-statistics, multi-source studies across the entire VHE sky, and allowing us to further advance our understanding of photon-ALP mixing in the high-energy Universe.

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