CTAO sensitivity to axion-like particles

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Abstract. Axion-like particles (ALPs) are a common feature in several extensions of the Standard Model, arising, for example, as a solution to the strong CP problem in quantum chromodynamics, or as a prediction of string theories. A significant property for the experimental detection of ALPs is their coupling to photons, which enables ALP-photon conversions in ambient magnetic fields.
In particular, gamma rays could convert into ALPs in the magnetic fields of distant objects and then reconvert in the Milky Way's magnetic field. By eluding absorption by the extragalactic background light (EBL), such a mechanism could produce a hardening in the gamma-ray spectra of these sources. We investigate the capability of the Cherenkov Telescope Array Observatory (CTAO) to detect signatures of ALP-photon conversions in the very-high-energy spectra of known blazars at energies above 10 TeV, comparing different magnetic field scenarios.

1 Axion-like particles in high-energy astrophysics

Distant astrophysical sources ($z \lesssim 1$) are difficult to observe in the very high energy (VHE) gamma rays due to scattering on the extragalactic background light (EBL). Axion-like particles (ALPs) could reduce this opacity by ALP-photon oscillations in external magnetic fields, with effects depending on the ALP mass m_a and ALP-photon coupling $g_{a\gamma}$ (see e.g. [1]).

In the magnetic fields at the source, VHE photons could convert into ALPs, which would then traverse the EBL and reconvert to photons in the Milky Way's magnetic field. In this case, the resulting VHE spectra of distant sources would be harder than expected in the EBL-only case, providing a signature for ALP-photon interaction. The observed spectrum of a source with intrinsic spectrum ϕ_{int} would be given by

$$\phi_{\text{obs}} = P_{\gamma\gamma}\phi_{\text{int}}\,, \tag{1}$$

where $P_{\gamma\gamma}$ is the photon survival probability.

2 Dataset simulation and results

Following ref. [2], we considered two blazars, PG 1553+113 ($z \geq 0.4$) with a a turbulent intra-cluster magnetic field ($B \sim \mu$G) and PKS 1424+240 ($z \geq 0.6$) with a coherent jet magnetic field ($B \sim 10^{-2}$ G). Using GammaALPs v0.3.0[1] we computed $P_{\gamma\gamma}$ for each choice of m_a,

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[1]https://github.com/me-manu/gammaALPs

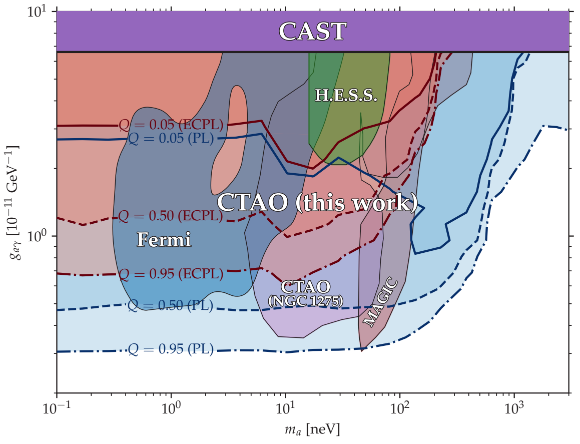

Figure 1. The CTAO sensitivity in the ALP parameter space obtained in this work. Exclusion regions obtained by Fermi, H.E.S.S. and MAGIC (collected at https://github.com/cajohare/AxionLimits) are shown for comparison, as well as the CTAO projections for NGC 1275 reported in ref. [4].

$g_{a\gamma}$ and magnetic field realization, and calculated intrinsic spectra from the observed fluxes by H.E.S.S. (2005) and VERITAS (2009)[2]. We then simulated 50 h of observations between 0.1 – 100 TeV for each source, using Gammapy v1.0.1[3] and the CTAO Southern Array prod5 version v0.1 instrument response functions (IRFs), assuming both a simple power law (PL) and a power law with exponential cutoff (ECPL) with cutoff energy 1 TeV as intrinsic spectral shapes. The EBL model from ref. [3] was used.

For each simulated dataset and ALP model, we obtained a test statistic (TS) and compared it to the expected distribution in the null hypothesis in order to obtain detection significance levels for each point in the ALP parameter space. In Figure 1 we compare the 3σ sensitivity over the ALP parameter space, combining results from both considered blazars, with known excluded regions by other gamma-ray observatories and with the CTAO projections reported in [4]. Owing to the turbulent magnetic fields considered for PG 1553+113, the TS for a certain $(m_a, g_{a\gamma})$ point depends on the specific field realization, and the choice of different quantiles Q of the TS distribution thus reflects different degrees of optimism in detection significance. Work is currently in progress to improve these results using data simulated within the CTAO collaboration.

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References

[1] I. Batković et al., Universe **7** (2021). 10.3390/universe7060185
[2] M. Meyer, J. Conrad, JCAP **2014**, 016 (2014). 10.1088/1475-7516/2014/12/016
[3] A. Domínguez et al., MNRAS **410**, 2556 (2011). 10.1111/j.1365-2966.2010.17631.x
[4] H. Abdalla et al., JCAP **2021**, 048 (2021). 10.1088/1475-7516/2021/02/048

[2]Available in text format from the collaboration websites, at https://www.mpi-hd.mpg.de/HESS/pages/publications/auxiliary/AA477_481.html and https://veritas.sao.arizona.edu/documents/PKS1424+240_VERITAS_2011_2014ApJ...785L..16A.txt respectively.
[3]https://doi.org/10.5281/zenodo.7734804