Extreme BL Lacs at multi-TeV energies with the CTA

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cherenkov telescope array

ABSTRACT

Extreme BL Lacs (EHBL) are a subclass of blazars with unique properties, such as synchrotron peaks in the hard X-ray band and extremely hard TeV spectra peaking above 10 TeV. Their exceptional properties make them interesting sources for current Cherenkov telescopes and a major topic for the upcoming Cherenkov Telescope Array (CTA), the next-generation ground-based γ-ray observatory. In particular, quite interesting is the possibility that, despite the strong γ-γ absorption, EHBL will be detected above 10 TeV. We explore the possibility that photon–axion-like particle oscillations give rise to an effective decrease of the opacity.

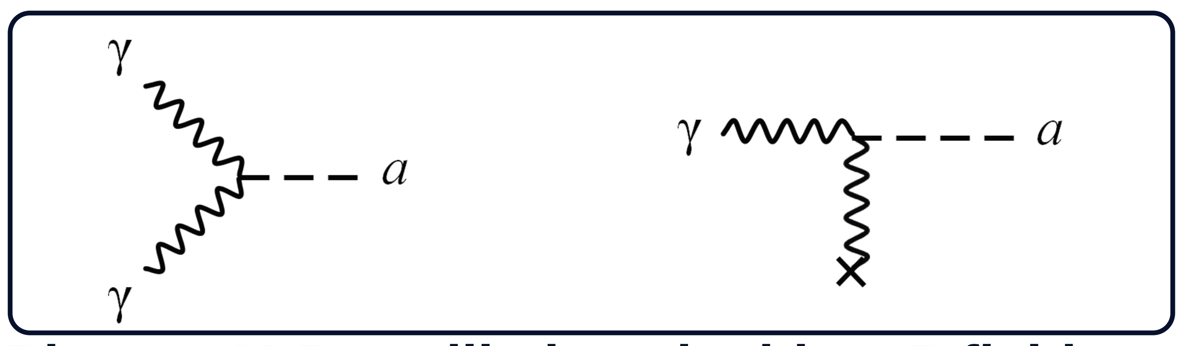
Supported by:

I. Axion-like particles (ALPs)

Properties:

- Predicted by String Theory
- Very light particles ($m_a < 10^{-8}$ eV)
- Spin 0
- Interaction with two photons (coupling $g_{a\gamma\gamma} = 1/M$)
- Interactions with other particles discarded

ALP interactions:

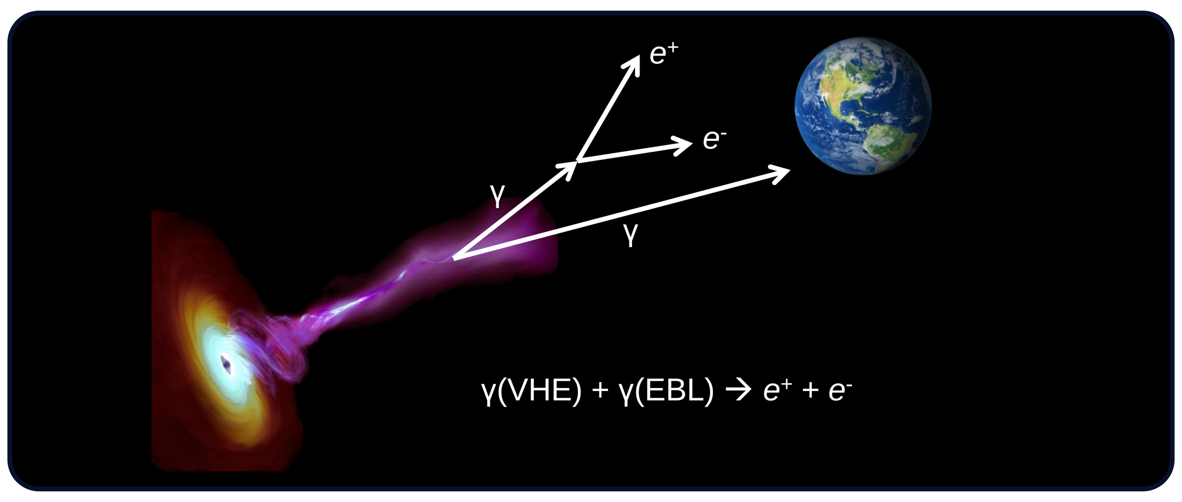


Photon-ALP oscillations inside a *B* field:

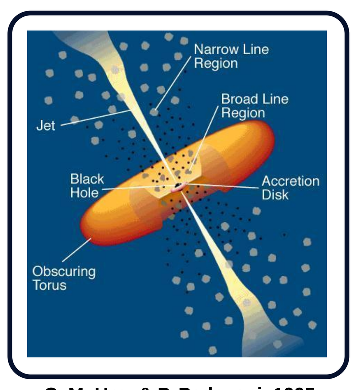
II. ALPs in astrophysical context

Extragalactic background light (EBL)

- EBL absorbs VHE photons
- ALPs are not absorbed
- Photons are not absorbed when are converted to ALPs
- Photon-ALP oscillations reduce the optical depth
- More photons detectable by Earth observatories at TeV energy



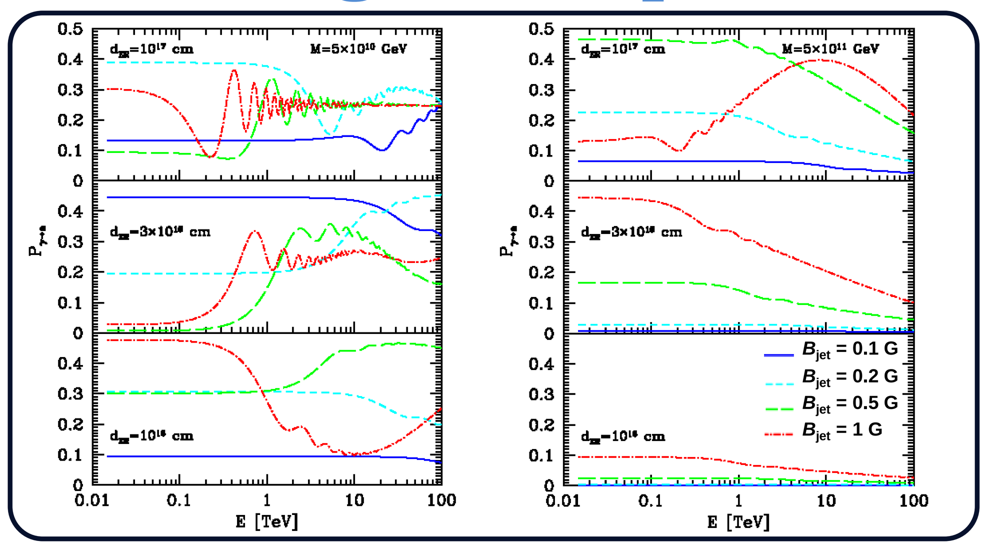
Blazars



C. M. Urry & P. Padovani, 1995

- Active galactic nuclei (AGN) divided into flat spectrum radio quasars (FSRQs) and BL Lacs
- Photons produced at the jet base
- VHE photons absorbed by the broad line region (BLR) present in FSRQs
- Photon-ALP oscillations modify blazar emission
- In FSRQs they reduce BLR optical depth (like EBL)
- They explain FSRQ emission above 20 GeV [1]

III. Extragalactic photon-ALP oscillations

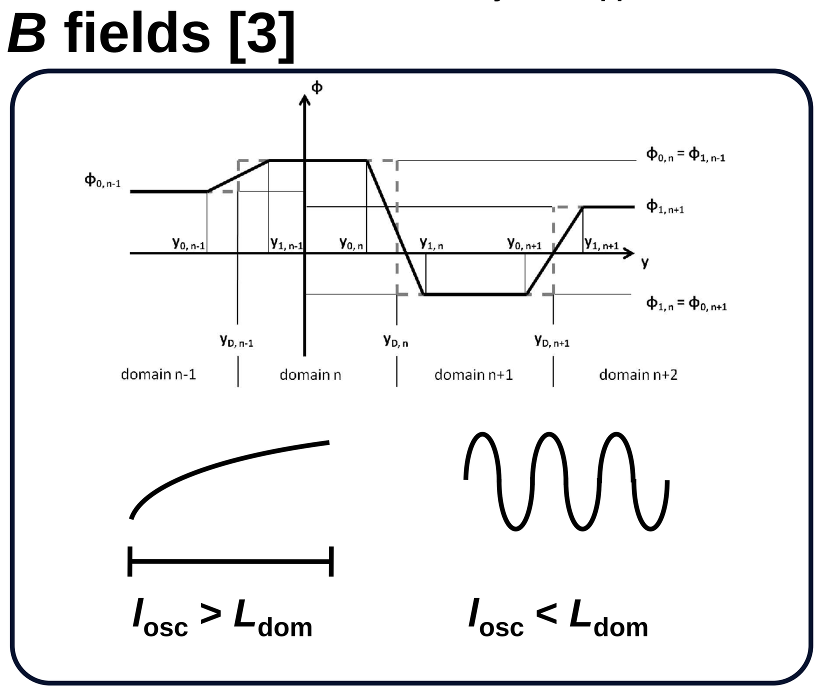


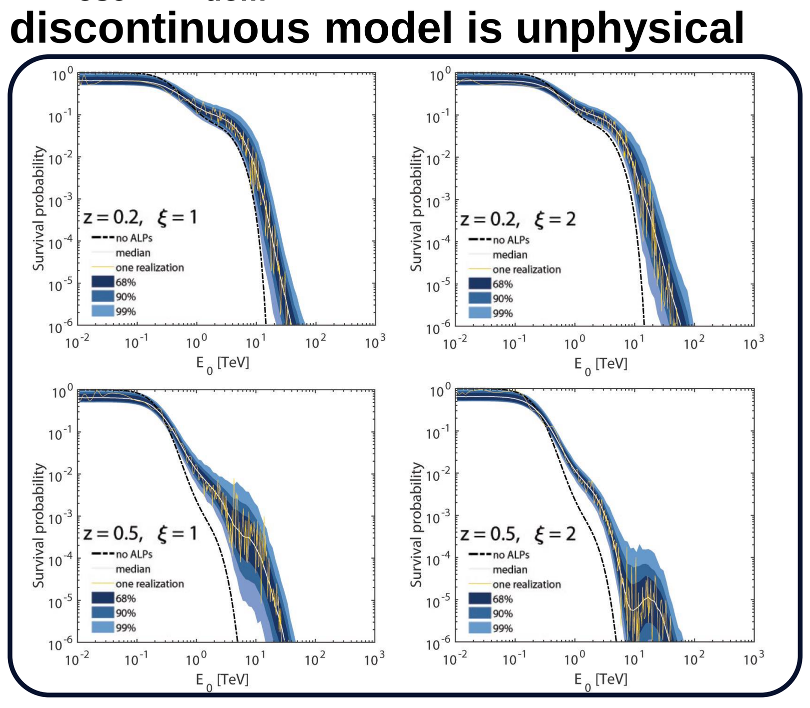
Propagation in the BL Lac jet [2]

- Photons produced at $d_{VHE} = 10^{16}$ cm from the centre
- $B_{jet} = 0.1 – 1$ G and scales as 1/distance
- Electron density $n_e = 5 \cdot 10^4$ cm^{-3} and scales as 1/distance^2
- Lorentz factor $\Gamma = 15$
- Photon-ALP conversion inside B_{jet}
- Amount of photons/ALPs produced strongly depends on the values of d_{VHE}, B_{jet}, $g_{a\gamma\gamma}$

New model for propagation inside domain-like *B* fields [3]

- New model for astrophysical magnetic fields *B*
- Useful for: extragalactic space, spiral and elliptical galaxies, radio lobes
- Domain-like model but now with continuous components of *B* (old model → discontinuities)
- Magnetic domain lengths L_{dom} are random variables with some distribution (power law)
- l_{osc}: photon/ALP oscillation length
- If $l_{osc} > L_{dom}$ photon/ALP beam insensitive to *B* structure – old discontinuous model can be used
- If $l_{osc} < L_{dom}$ photon/ALP beam sees the *B* structure – old discontinuous model is unphysical





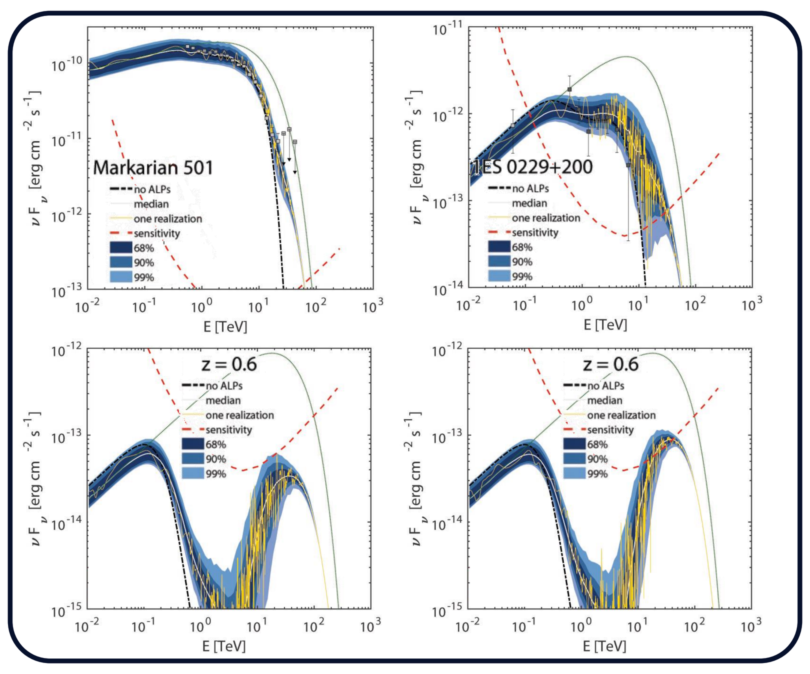
Propagation in the extragalactic space [4]

- Extragalactic magnetic field B_{ext}
- L_{dom} with distribution $L_{dom}^{-1.2}$
- For $E > 40$ TeV CMB photon dispersion makes $l_{osc} < L_{dom}$
- Photon/ALP beam becomes sensible to the B_{ext} shape
- For $E > 40$ TeV only the new continuous B_{ext} model gives physical results about the photon survival probability
- Last data on EBL
- $\xi = (B_{T,ext}/\text{nG}) \cdot (g_{a\gamma\gamma} \cdot 10^{11}\ \text{GeV}) = 0.5 – 5$
- Redshift $z = 0.02 – 2$

Propagation in the Milky Way & total effect [5]

- Important only the regular component of the Milky Way magnetic field B_{MW}
- $B_{MW} = 5$ μG, coherence length $l_{coh} = 10$ kpc
- But detailed sky maps of B_{MW} exist

- Combination of photon propagation in B_{jet}, B_{ext}, B_{MW}
- Exponentially truncated spectra
- $B_{jet} = 0.1$ G, $B_{ext} = 0.5$ nG
- $g_{a\gamma\gamma} = 2 \cdot 10^{-11}$ GeV, $m_a = 10^{-10}$ eV
- $d_{VHE} = 3 \cdot 10^{16}$ cm, $n_e = 5 \cdot 10^4$ cm^{-3}
- $\Gamma = 15$



IV. For the future

- It is challenging for conventional physics to explain the highest energy point in the spectra of Markarian 501 and of 1ES 0229+200
- photon/ALP oscillations are instead successful
- As the energy increases photon/ALP oscillations differ more and more from conventional physics
- photon/ALP oscillations generate an observable oscillatory behavior in observed blazar spectra
- These features can in principle be detected by the planned new observatories like the Cherenkov Telescope Array (CTA)
- Dedicated simulations for CTA about blazar spectra – Stay tuned!

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