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CTA prospects for probing cosmology and fundamental physics with gamma rays

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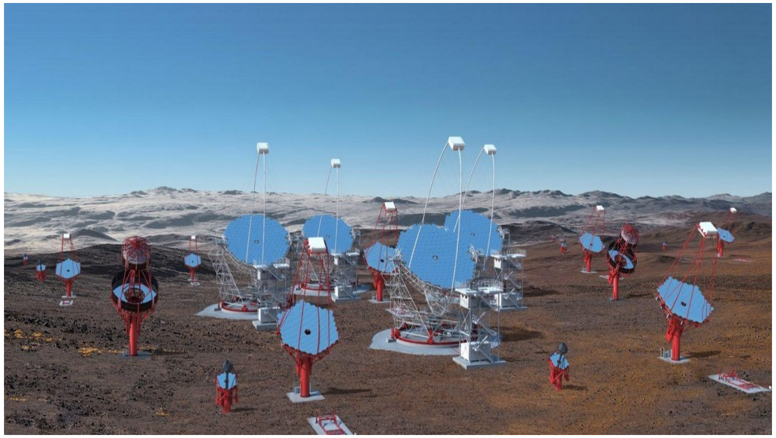
Cherenkov Telescope Array project

The largest Cherenkov observatory every built

~1500 scientists and engineers
~200 institutes
31 countries

→ Large international effort

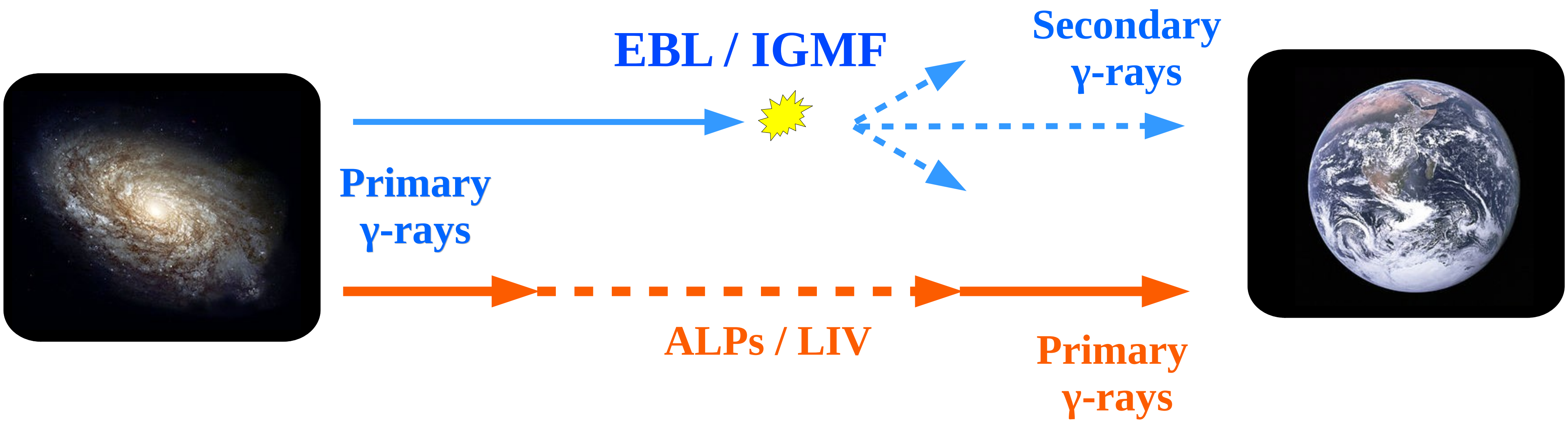
Southern site (Chile)



Northern site (Canary Islands)

Extremely rich scientific outcome is expected

Propagation of VHE γ-ray emission



Gamma rays interact on their way with several entities:

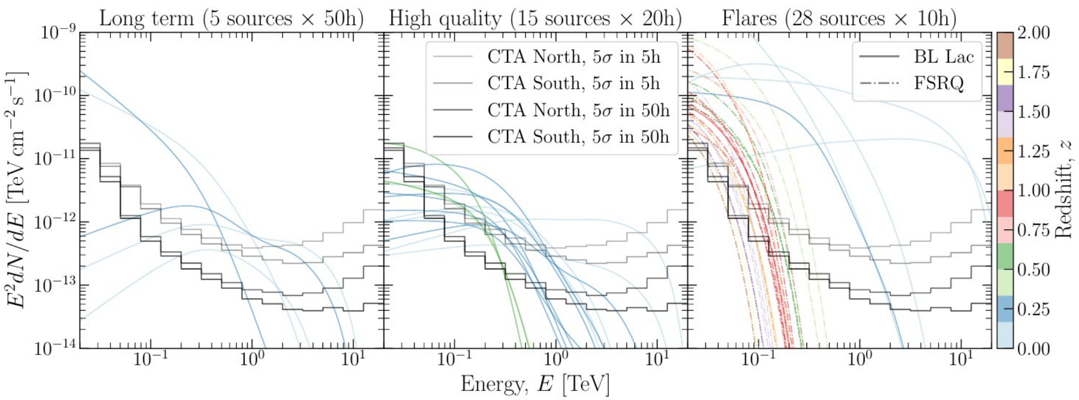
- **EBL** absorption and e^+e^- pairs generation;
- **IGMF** dilution of the secondary flux;
- **LIV** change of the absorption threshold;
- **ALPs** spectral features and optical depth decrease

Can be studied with a wide energy range gamma-ray telescope like CTA

CTA measurement of EBL intensity

Considered CTA AGN programs:

- **<u>long-term monitoring</u>** of selected AGNs that will be observed regularly with short snapshots
- **<u>high-quality spectra</u>** program with deep observations of AGNs of different classes and at different distances
- **<u>blazar flares follow-up</u>** program target VHE flares from AGNs, triggered either by external facilities or internally by the monitoring program performed with CTA. Crucial to probe highest redshifts.



Select AGNs with known redshift:

- detected with >5 sigma above E(τ=1);
- present in 3FHL;
- detected on daily scales with Fermi/LAT

→ 48 sources in total in redshift range [0.05; 2]

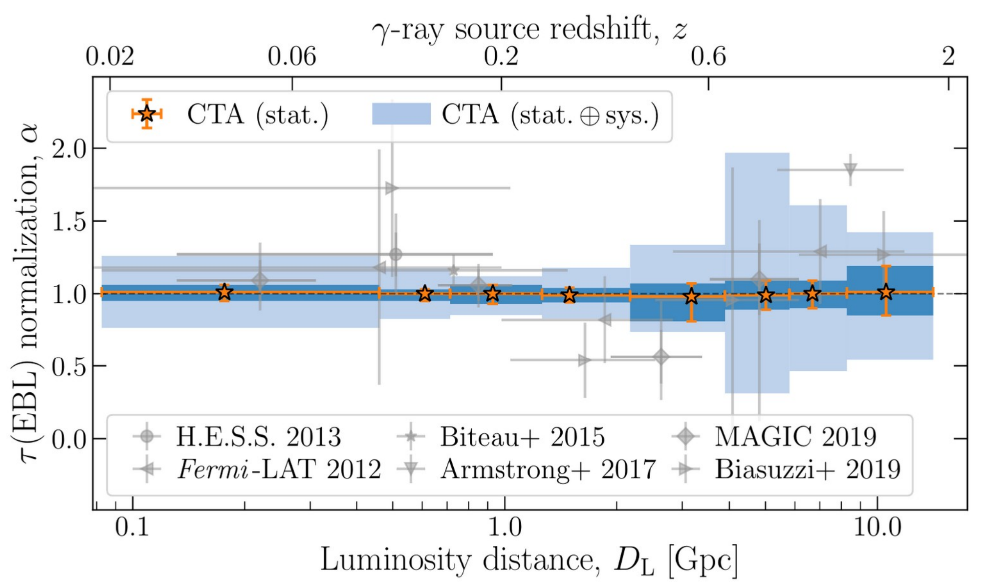
CTA measurement of EBL intensity

EBL parametrization:

$$\tau'(E_\gamma) = \alpha \times \tau(E_\gamma)$$

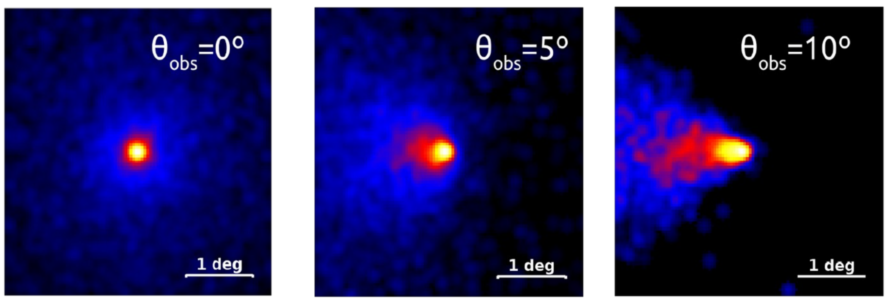
What we may expect:

- probe EBL over 4 decades (0.1-100 μm)
- may probe star formation up to z ~ 1.5 – 2
- learn about contributions from UV sources z ~ 2 (integral nature of EBL)
- complementary constraints on cosmological parameters (e.g. H_0 and Ω_M)



→ First illustration of what CTA is expected to deliver

CTA sensitivity to IGMF



"Smoking gun": extended halo

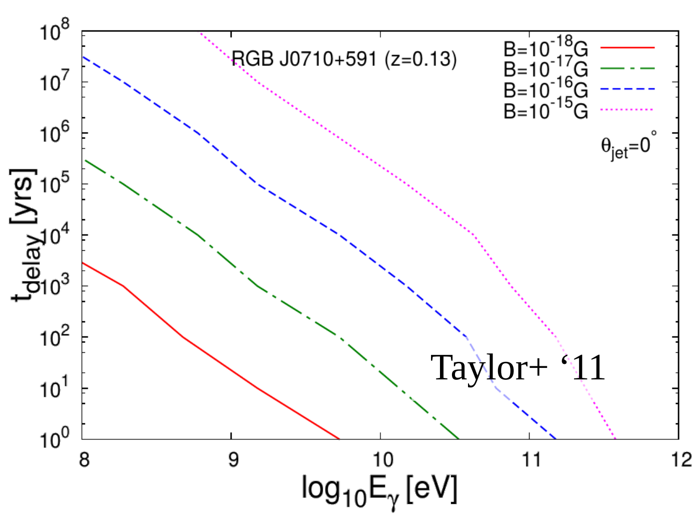
Size and shape depend on IGMF strength **and** source parameters (jet opening and orientation).

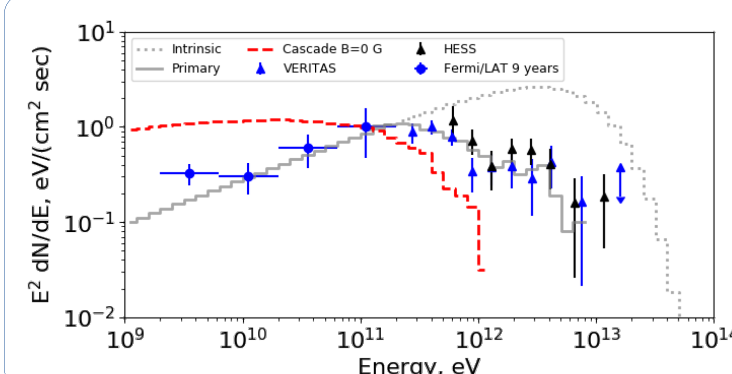
Delayed emission

The delay is set by IGMF, but light curve shape may also depend on the jet parameters.

New spectral components

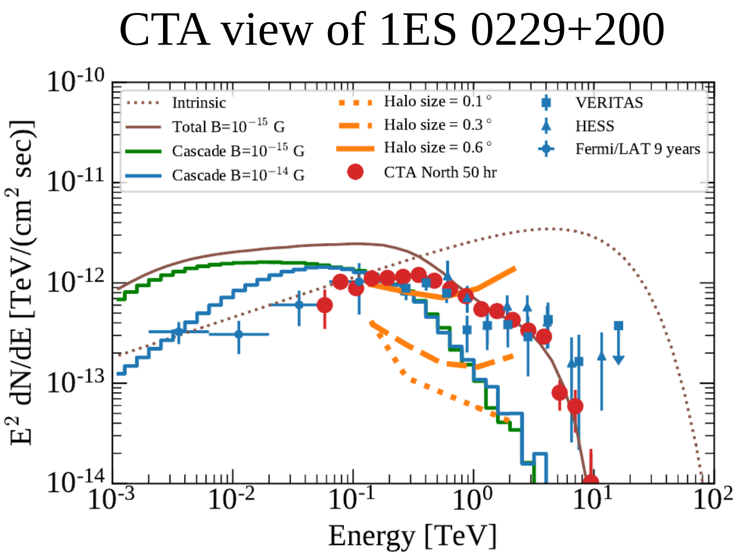
Depend on IGMF, source spectrum, jet orientation.

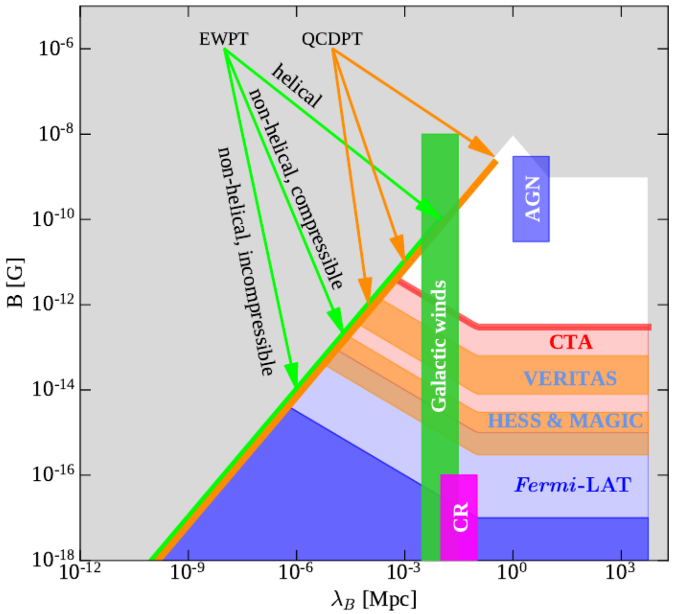




CTA observations promise to address these all at once

CTA sensitivity to IGMF





What we may expect:

- High accuracy measurements of the “IGMF reference” source up in 50 GeV – 10 TeV range
- Self-consistent joint spectro-morphological fit using 3D MC simulations of cascade
- CTA may reach ~3x10^{-13} G IGMF, closing the gap with existing constraints from γ rays.
- Incorporation of time delay information will be possible with dedicated (decade-long) observational campaigns.

CTA sensitivity to ALP signatures

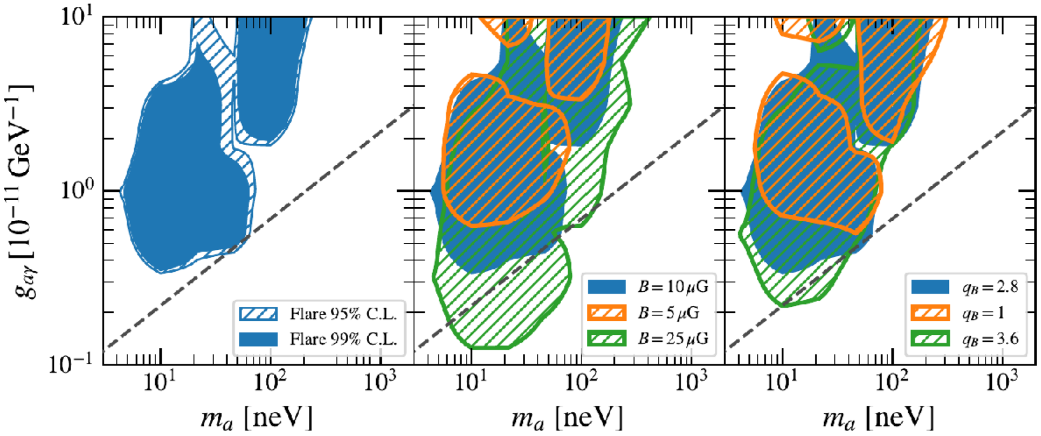
cta

Test case of NGC 1275:

- **known source** in the center of the nearby Perseus cluster
- **two flux states** simulated with different exposure
- **ALP parameters grid** scan
- **Asimov data set and TS calibration** to reliably calculate confidence ranges
- **assume no ALPs** and calculate limits

Impact of different ingredients:

Magnetic field turbulence

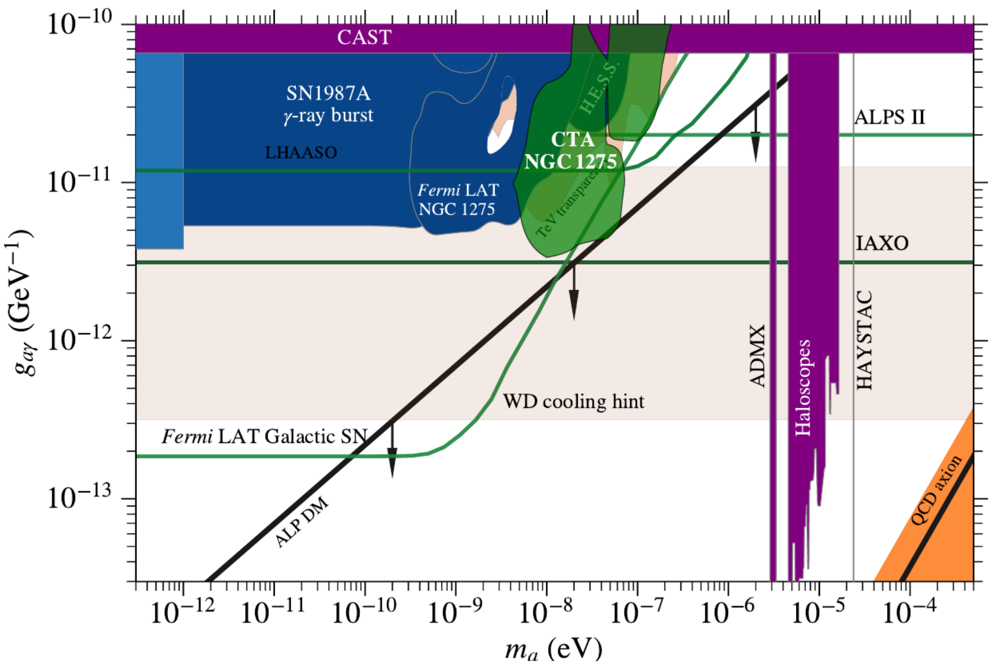


Central magnetic field

CTA sensitivity to ALP signatures

What we may expect from CTA:

- will probe 10x larger ALP masses compared to Fermi-LAT
- 10x improvement over state-of-the art H.E.S.S. limits
- start exploring the ALP DM parameter space in 20-130 neV range
- promise to be more sensitive than LHAASO, comparable to future IAXO and ALPS II experiments



Data on several γ-ray sources can be combined to further improve the CTA sensitivity (e.g. IC 310 from the same Perseus cluster).

CTA sensitivity to LIV signatures

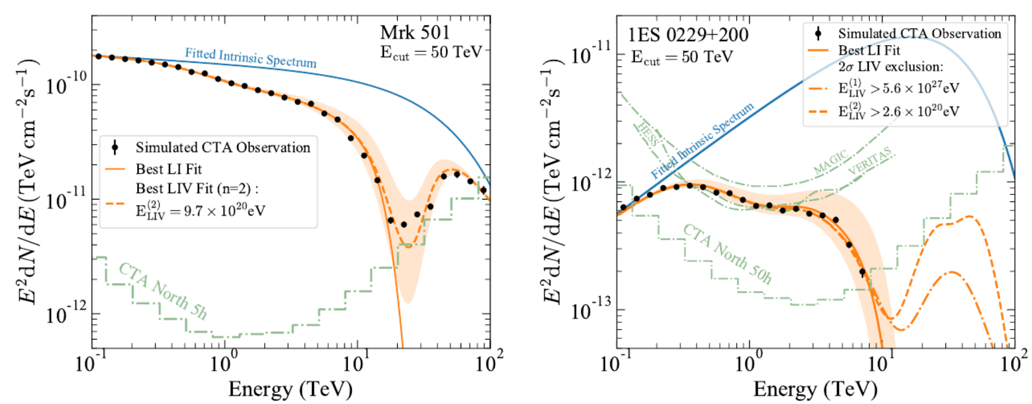
Pair-production threshold with LIV:

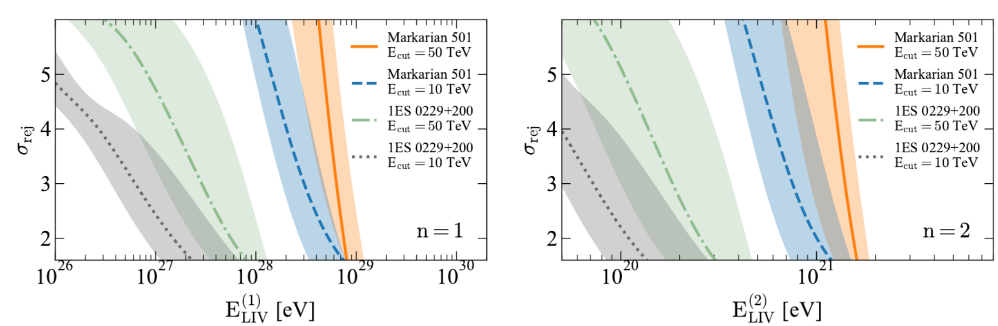
$$\epsilon'_{th} = \frac{m_e^2}{E'_\gamma} + \frac{E'^{n+1}_\gamma}{4\left(E^{(n)}_{\mathrm{LIV}}\right)^n}$$

Our simulations:

- **two sources:** flaring Mrk 501 and stationary 1ES 0229+200
- **low/high E_{cut}** simulations
- **Scan LIV leading orders** n=1,2
- **EBL model uncertainties** accounted for

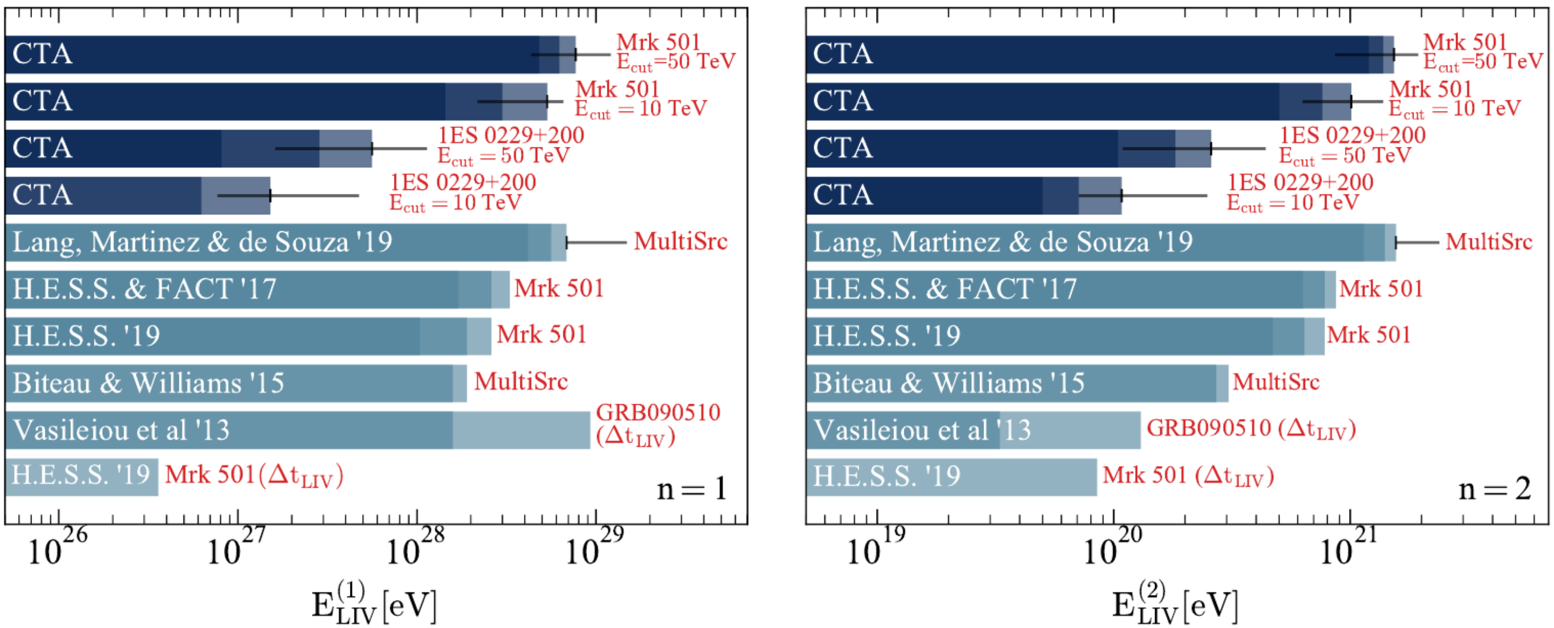
Examples of simulated LIV signatures





LIV rejection scan

CTA sensitivity to LIV signatures



What we may expect from CTA:

- order of magnitude improvement over existing limits
- 2-3x better limits for single source observations
- may still be complemented with time delay constraints and multi-source analysis

→ CTA is a promising explorer of fundamental symmetries at extreme energies

Perspectives for CTA γ-ray propagation constraints

- EBL measurements may be further boosted with additional observations of other extragalactic transients and γ-ray bursts at high redshifts (other KSPs)
- IGMF, ALPs and LIV sensitivities were computed for 1-2 prototypical AGNs and should be seen as the minimum CTA capabilities. Also would further improve from joint observations with Fermi-LAT.
- Intrinsic source spectral model may be further improved via multi-wavelength observations and theoretical modeling

CTA alone will provide unprecedented sensitivity for probing cosmology and fundamental physics!

- EBL constraints may be complemented by IR observations with JWST and future mid- to far-infrared satellites.
- IGMF constraints may be complemented by future searches of the intergalactic rotation measure with SKA.
- ALP signals may be tested with ALPS II and IAXO experiments
- LIV studies may be combined with results of upgraded Pierre Auger and Telescope Array observatories

These are just some of the synergies between CTA and upcoming multi-wavelength/-messenger facilities...