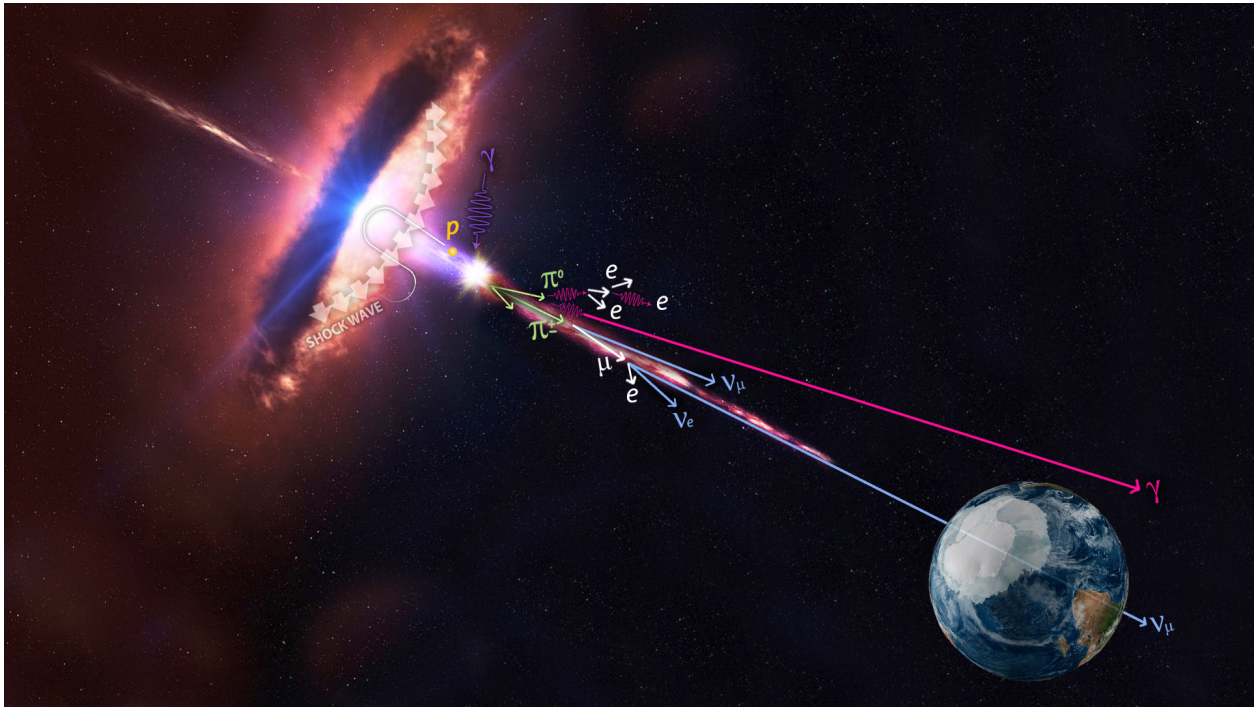
2020 Meeting of the Cosmic Ray Division
of the Mexican Physical Society
23-26 November, 2020

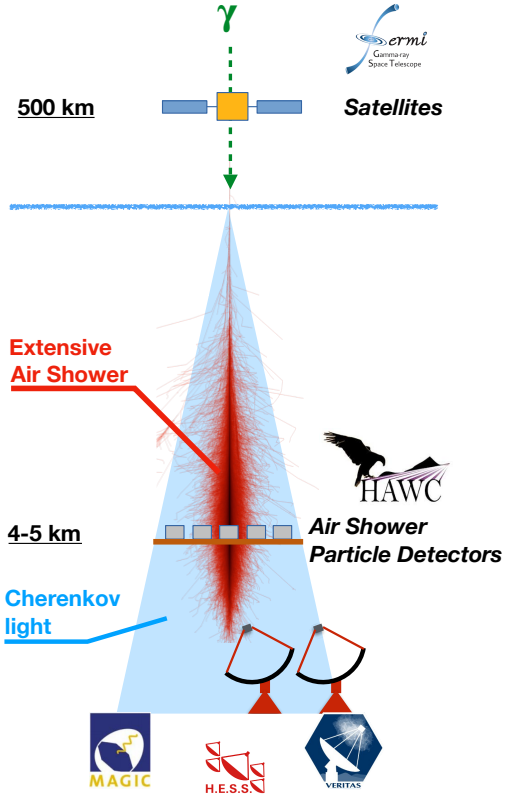
Prospects for LIV test with CTA

The CTA Consortium [1]
Represented by Humberto Martínez-Huerta [2]

[1] See https://www.cta-observatory.org/consortium_authors/authors_2020_10.html
[2] IFSC-USP / FCFM-UNACH

Astroparticle Physics

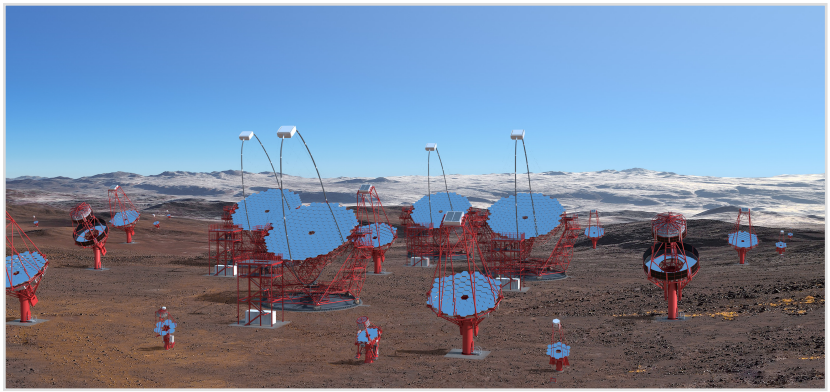




The Array Locations

19 Telescopes
- 4 LSTs
- 15 MSTs

99 Telescopes
- 4 LSTs
- 25 MSTs
- 70 SSTs



CTA Consortium

August 2019

31 Countries
~200 Institutes
~1500 members

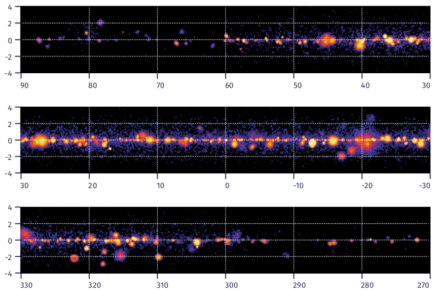
Three major study themes

CTA science program: https://arxiv.org/abs/1709.07997

Understanding

The origin and role of relativistic cosmic particles

- Accelerate
- Propagate
- …



Probing

Extreme environments

- Neutron Stars
- Black Holes
- Relativistic Jets
- …

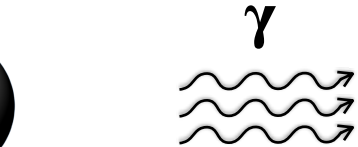
Exploring

Frontiers in Physics

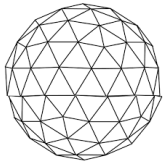
- **Fundamental physics**
  - **Lorentz Invariance Violation**
- Dark Matter
- Axions
- …

Lorentz Invariance Violation (LIV)

Theory ⟶ Phenomenology ⟶ Experiment

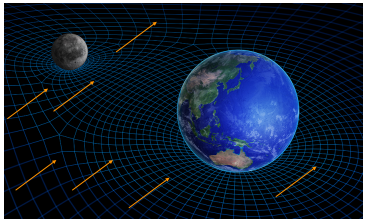


$c = 3 \times 10^8$ m/s



$c \neq 3 \times 10^8$ m/s

$c' = (1 \pm \delta)c$



Fundamental Energy Scale $E_{QG} : E_{Pl} : E_{LIV}$

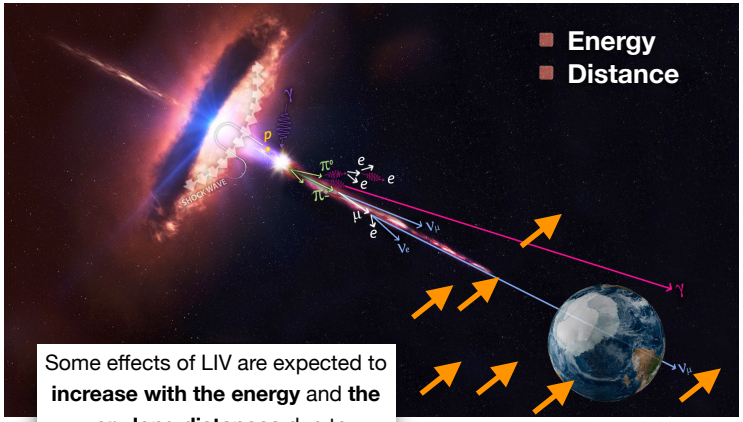
$$c' = \left[1 \pm f\left(\frac{E_\gamma}{E_{\mathrm{LIV}}}\right) \pm \ldots\right] c$$

$$E_\gamma^2 - p_\gamma^2 = \delta_{\gamma,n}\, p_\gamma^2 \approx \frac{E_\gamma^{n+2}}{\left(E_{\mathrm{LIV}}^{(n)}\right)^n}$$

n = 0, 1, 2, …

Family of LIV- modified dispersion relations that may lead to similar phenomenology!

it is not necessarily bound to a particular LIV-model, which allows to generalize to some point the search of LIV-signatures.



Some effects of LIV are expected to **increase with the energy** and **the very long distances** due to cumulative processes

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LIV Threshold shifts

- Corrections to known processes
  -Pair production

$$\gamma\gamma_b \rightarrow e^+e^-$$

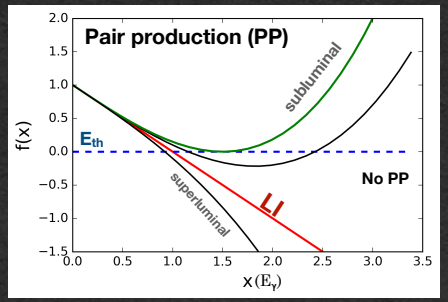
γ_{LIV}

γ

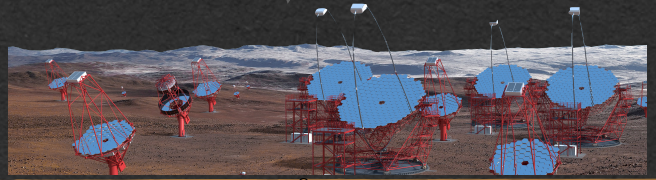
e^+e^-

quantify the phenomenon!!

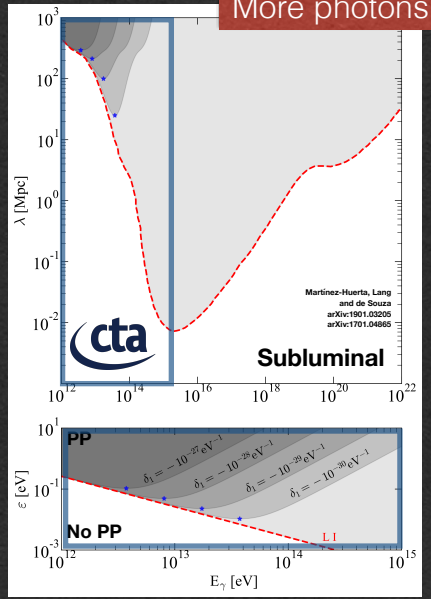
$$\tau_\gamma(E_\gamma, z, \eta, n, E^{(n)}_{LIV})$$



$$\epsilon^{\mathrm{LIV}}_{th} = \frac{m_e^2}{4E_\gamma K(1-K)} - \frac{\delta_{\gamma,n}E_\gamma^{n+1}}{4}$$



More photons!!



- ✓ Superluminal
- ✓ CMB region
- ✓ Several EBL Models

Work cases

Two possible scenarios

- **Finding LIV signal**

  Input LIV simulations and find CTA detection.

- **Excluding LIV signal**

  Input LI simulations and find CTA LIV rejection.

Work cases

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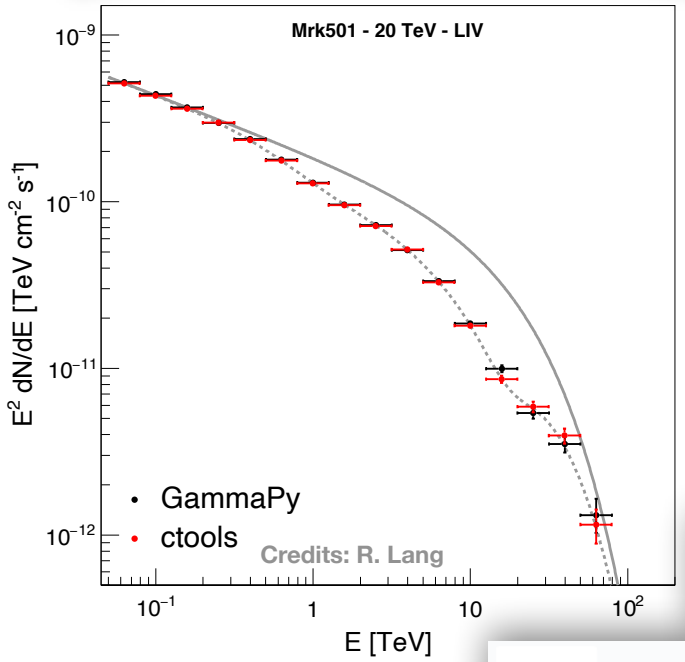
Finding LIV signal

1. LIV- Simulation
2. Find the best $\mathbf{Fit}_{\text{-LIV}}$
3. Find the best $\mathbf{Fit}_{\text{-LI}}$
4. LIV signal significance

Simulation cross-check



ctools
cherenkov telescope array

gammapy
Gamma-ray astronomy Python tools

Finding LIV signal

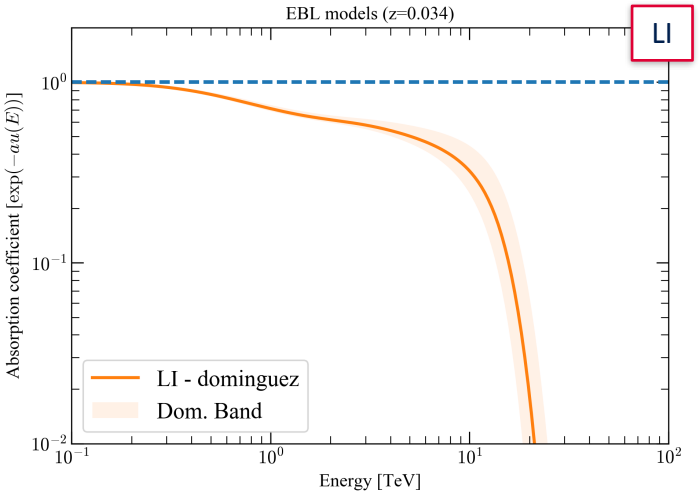
1. LIV- Simulation
2. Find the best **Fit$_{\text{-LI}}$**
3. Find the best **Fit$_{\text{-LIV}}$**
4. LIV signal significance

Free parameters

N_0 [TeV^{-1} cm^2 s^{-1}]

Index

Ec [TeV]



Finding LIV signal

1. LIV- Simulation
2. Find the best **Fit$_{\text{-LI}}$**
3. Find the best **Fit$_{\text{-LIV}}$**
4. LIV signal significance

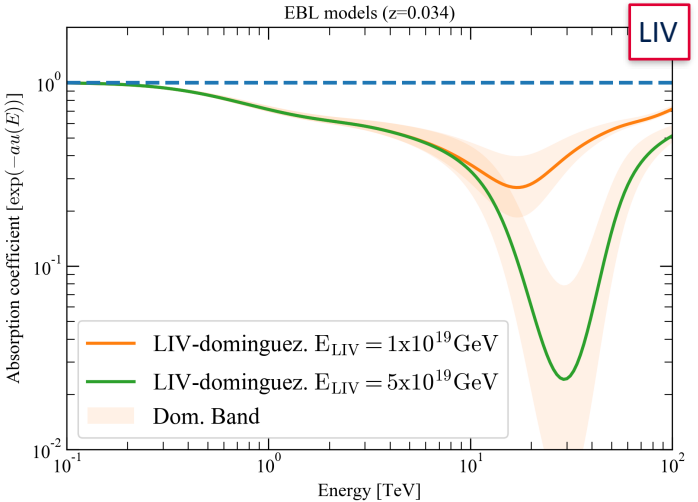
Free parameters

E_{LIV} [GeV]

N_0 [TeV^{-1} cm^2 s^{-1}]

Index

Ec [TeV]



Finding LIV signal

1. LIV- Simulation
2. Find the best **Fit$_{\text{-LI}}$**
3. Find the best **Fit$_{\text{-LIV}}$**
4. LIV signal significance

×

Src - cases

- **Mrk501**
  - 50 TeV EcPL: Case 1
  - 10 TeV EcPL: Case 2
- **1ES 0229+200**
  - 50 TeV EcPL: Case 3
  - 10 TeV EcPL: Case 4

×

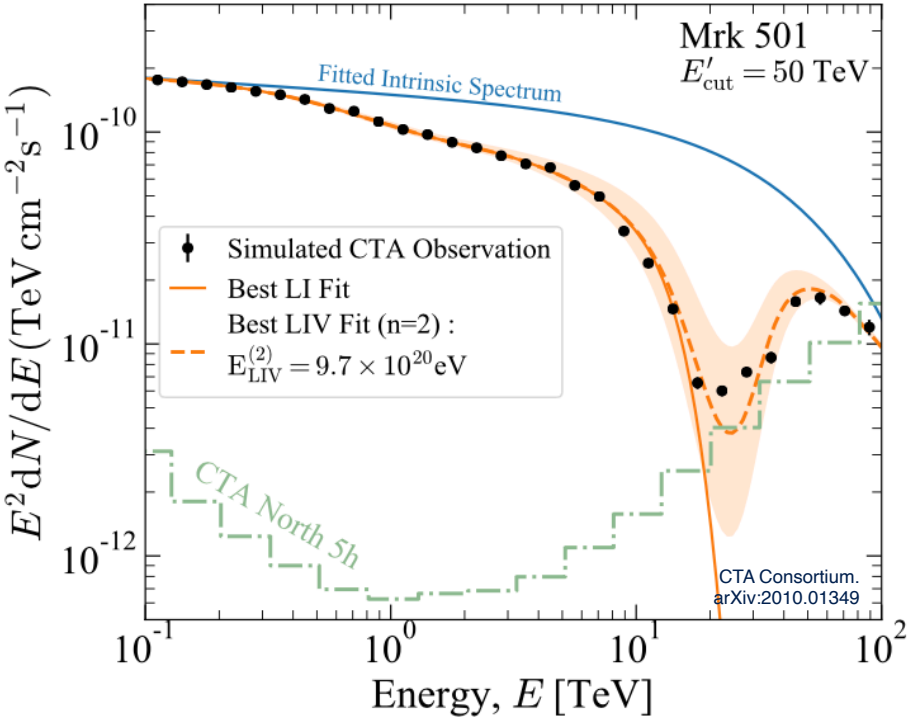
n=1

n=2

gammapy

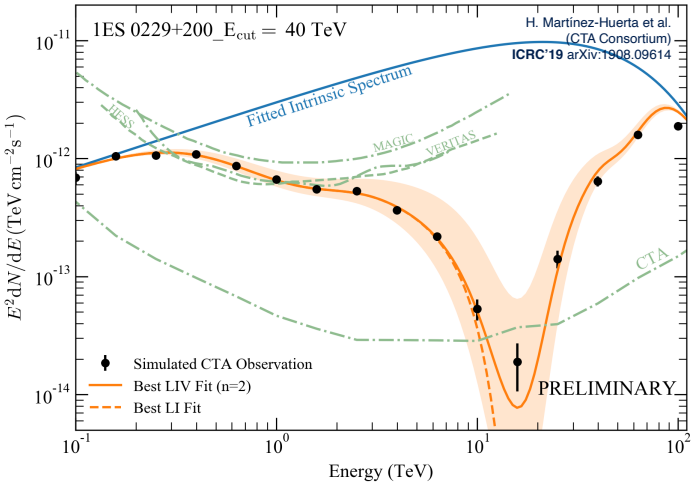
Gamma-ray astronomy Python tools

Finding LIV signal



Simulation of Mrk501 with E_{cut} = 50TeV assuming LIV with $E^{(2)}_{LIV} = 10^{21}$ eV

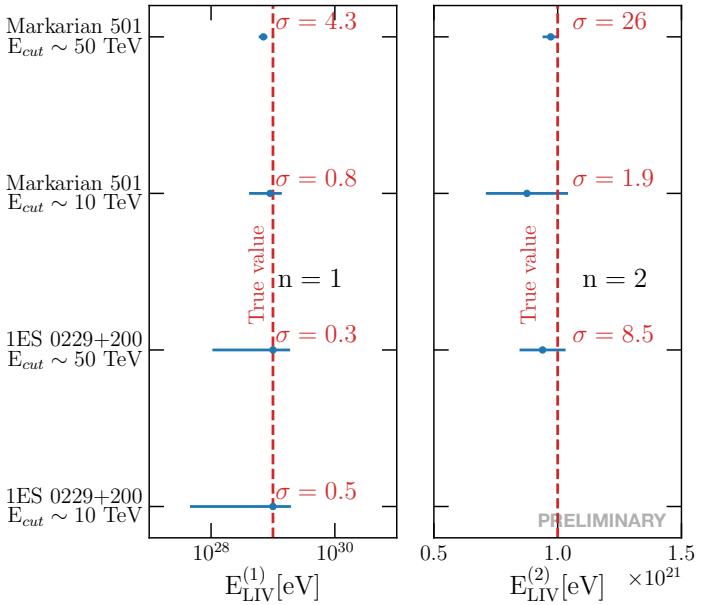
Simulation of 1ES 0229+200 with E_{cut} = 40 TeV assuming LIV with $E^{(2)}_{LIV} = 10^{21}$ eV



Finding LIV signal

1. LIV- Simulation
2. Find the best **Fit**$_{\text{-LI}}$
3. Find the best **Fit**$_{\text{-LIV}}$
4. LIV signal significance

Agreement between best-fit parameters and the simulated true values.



Work cases

Two possible scenarios

- **Finding LIV signal**

  Input LIV simulations and find CTA detection.

- **Excluding LIV signal**

  Input LI simulations and find CTA LIV rejection.

Excluding LIV signal

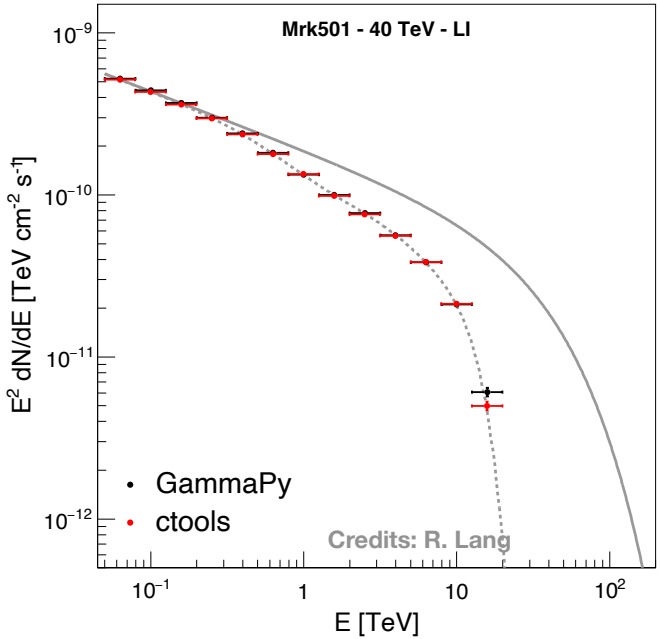
1. LI- Simulation ← Different step from the previous scenario
2. Find the best **Fit**$_{\text{-LI}}$
3. Find the best **Fit**$_{\text{-LIV}}$
4. Exclusion significance
   - **5 σ**
   - **3 σ**
   - **2 σ**

← Different step from the previous scenario

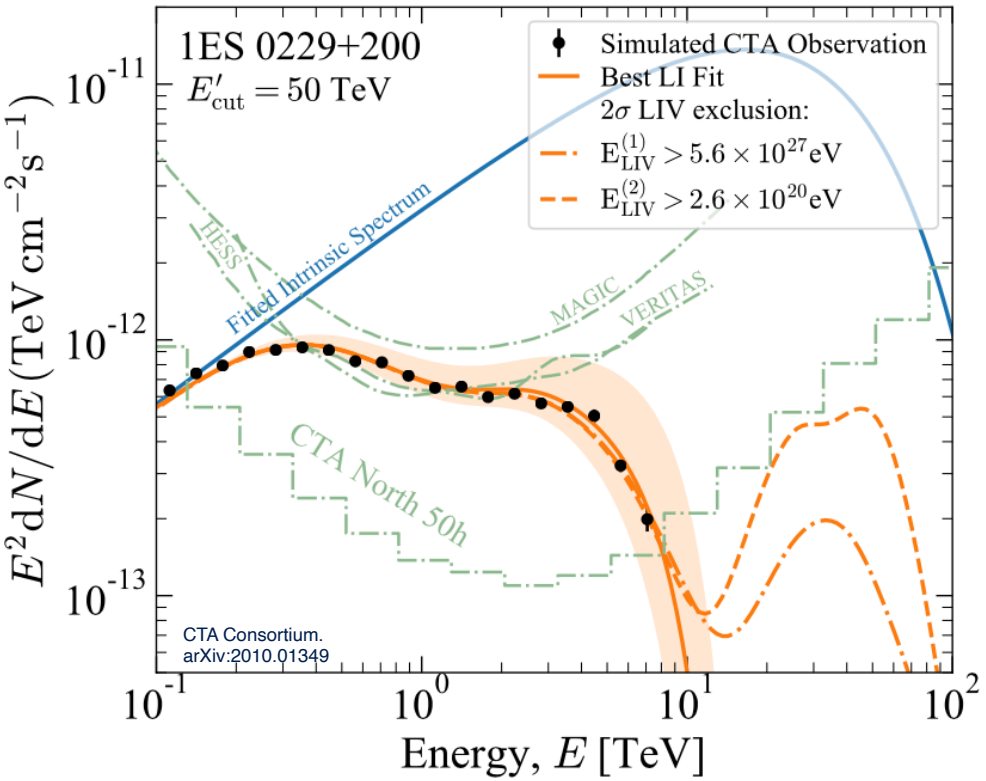
Excluding LIV signal

1. LIV- Simulation
2. Find the best **Fit$_{\text{-LI}}$**
3. Find the best **Fit$_{\text{-LIV}}$**
4. Exclusion significance

Simulation cross-check



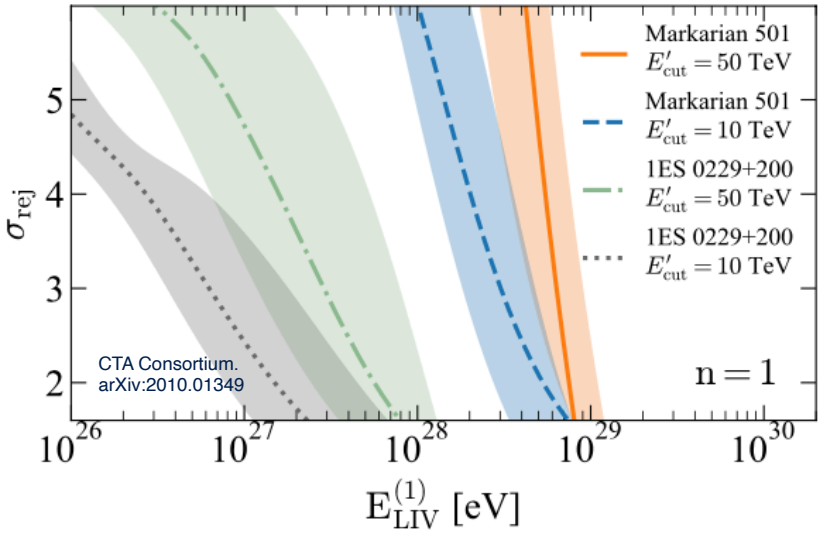
Excluding LIV signal

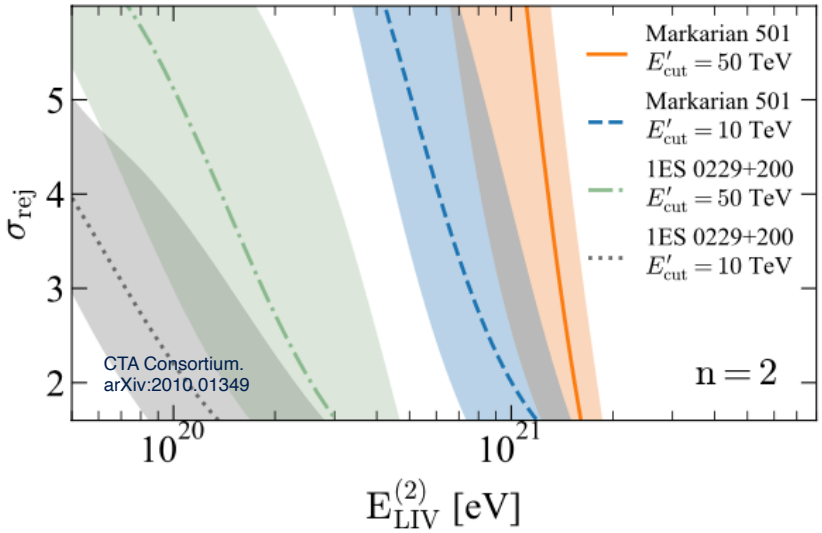


Simulation of 1ES0229+200 with E_{cut} = 50TeV and LI propagation.

The LIV models excluded at 2 σ for n = 1 and 2 are also shown for comparison

Excluding LIV signal

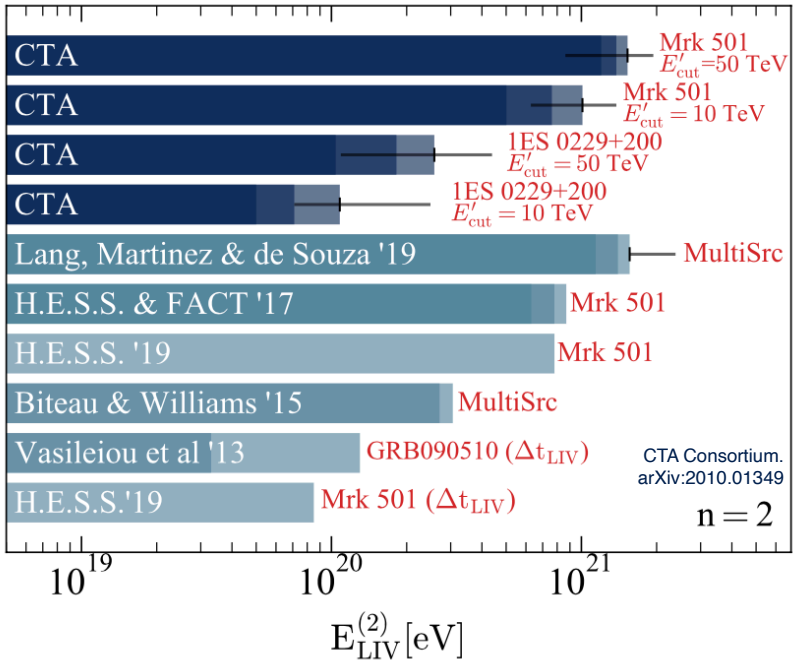




Confidence level for the rejection of LIV energy scales for n=1 and n=2,

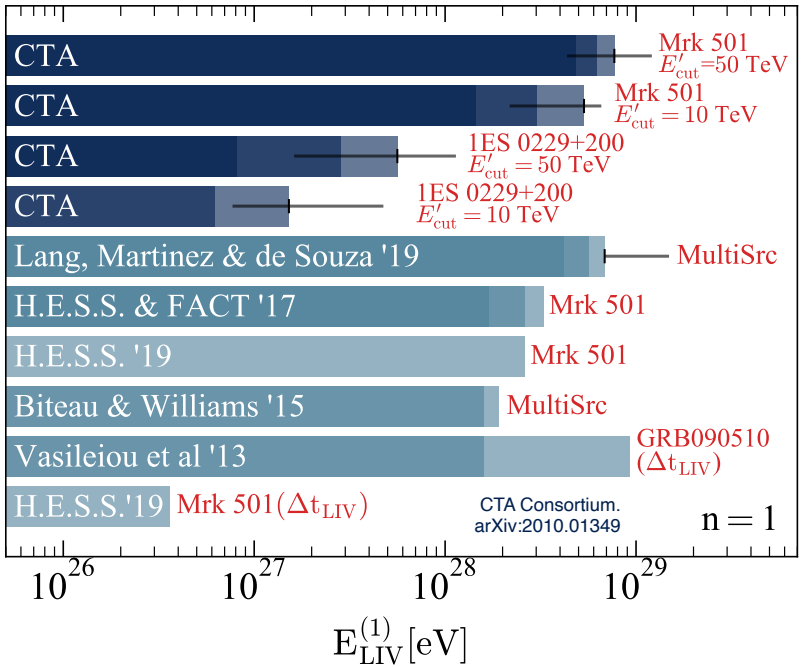
including the **EBL systematic error**

Excluding LIV signal



- CTA shows competitive sensitivity limits **using a single source analysis.**
- Better confidence levels are marked with darker colors.
- Systematic errors are shown in black for the 2σ limit.

Excluding LIV signal



- CTA shows competitive sensitivity limits **using a single source analysis.**
- Better confidence levels are marked with darker colors.
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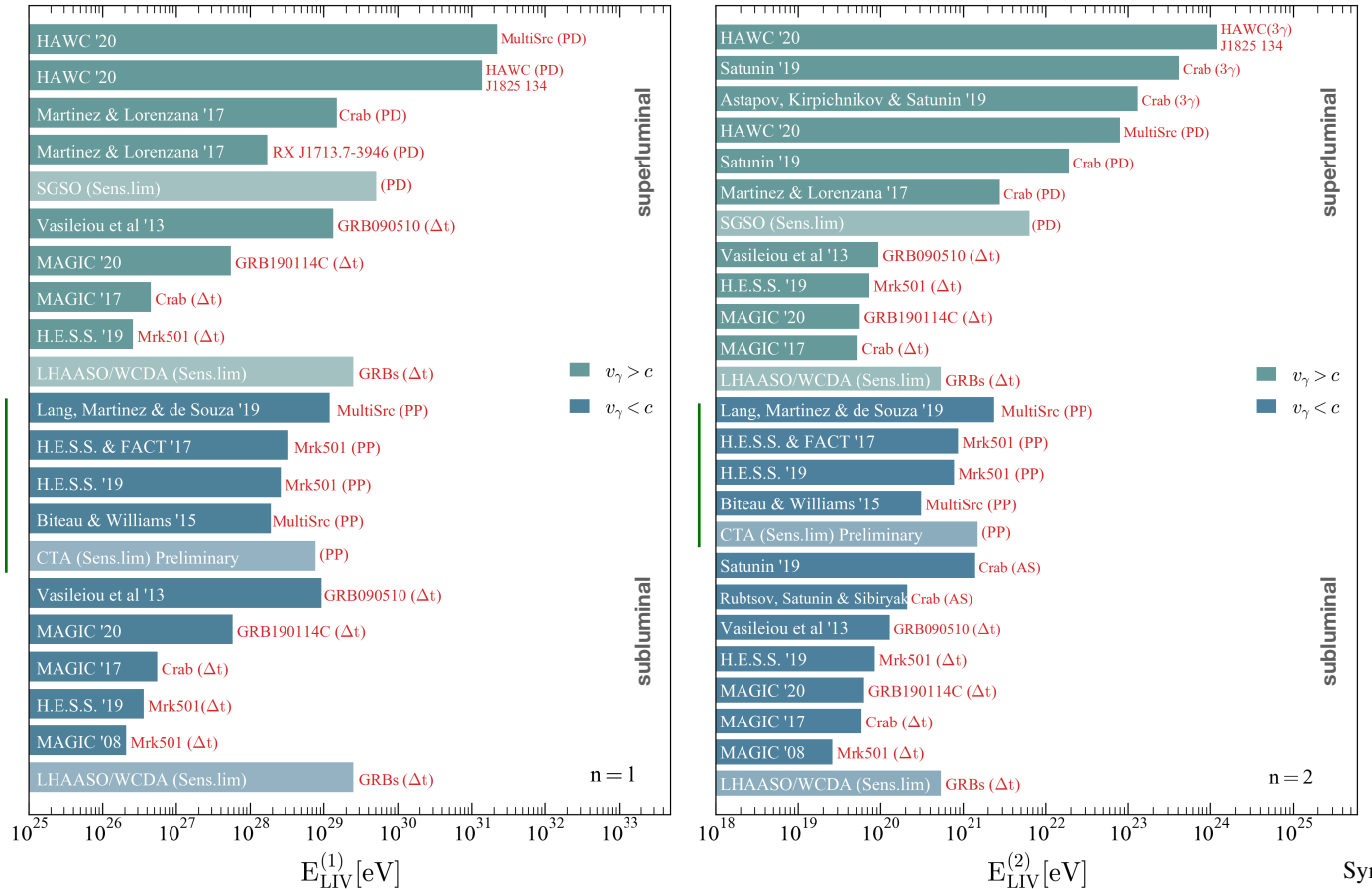
Strong LIV Exclusion limits in the photon sector by astroparticle tests

Pair production threshold shifts (PP)

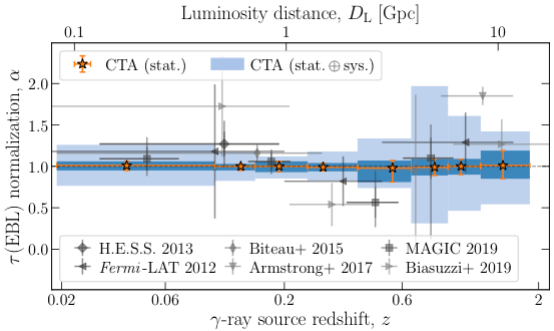


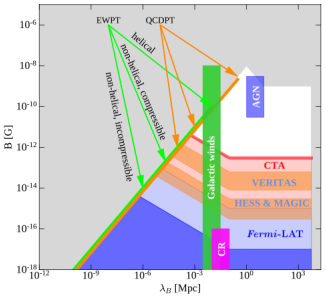
Plot based on:
Symmetry 2020, 12, 1232.

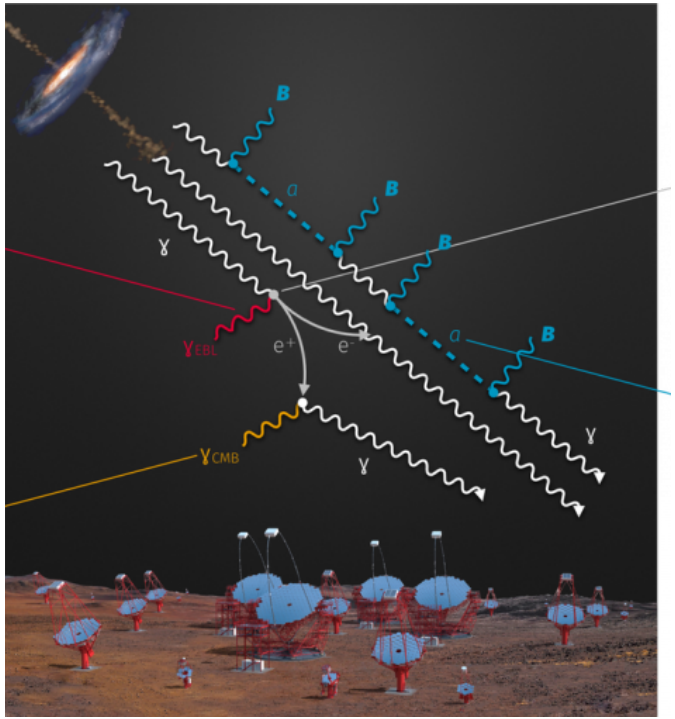
Testing the frontiers of physics with CTA

Sensitivity of the Cherenkov Telescope Array for probing cosmology and fundamental physics with gamma-ray propagation
CTA Consortium. **(arXiv:2010.01349)**

Gamma rays produce electron-positron pairs when interacting with EBL photons

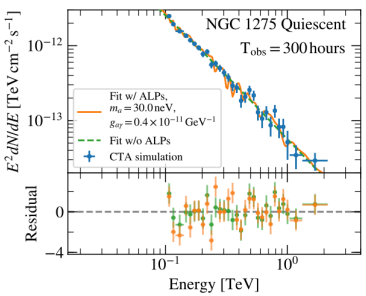


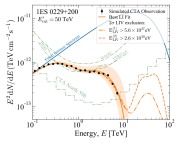


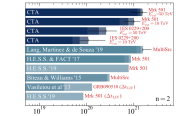


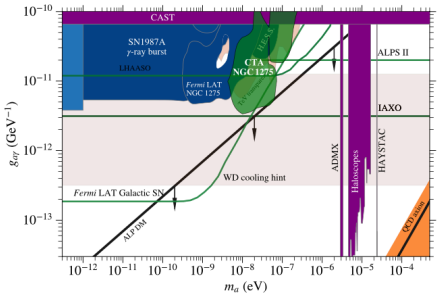
https://www.cta-observatory.org/what-propogation-of-energetic-light-can-tell-us/

Exotic processes such as LIV or coupling to axion-like particles could modify the absorption, resulting in characteristic spectral features.









Remarks

- We have used the **optical depth with a generic LIV** deformation of the free particle dispersion relation **to study CTA's potential to find** LIV phenomena **and place limits on the LIV energy scale.**

- In this analysis, we found that
  - CTA has the potential to discriminate LIV signal from LI
  - If there is not LIV, **stringent limits to the LIV energy scale** can be established due to CTA capability, even using a single source analysis, that are **a factor of two to three more restrictive** than those obtained by current instruments using the same search channel.


LIVE
Recording
View Options
CTA Consortium Meeting, October 2020
Mute
Start Video
Invite
459
Participants
Polling
Share
Chat
Pause/Stop Recording
Breakout Rooms
More
End Meeting

Thanks!