cherenkov telescope array

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Testing cosmology and fundamental physics with the Cherenkov Telescope Array

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H. Martinez-Huerta, S. Pita, I. Vovk
for the CTA Consortium

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CTA Symposium

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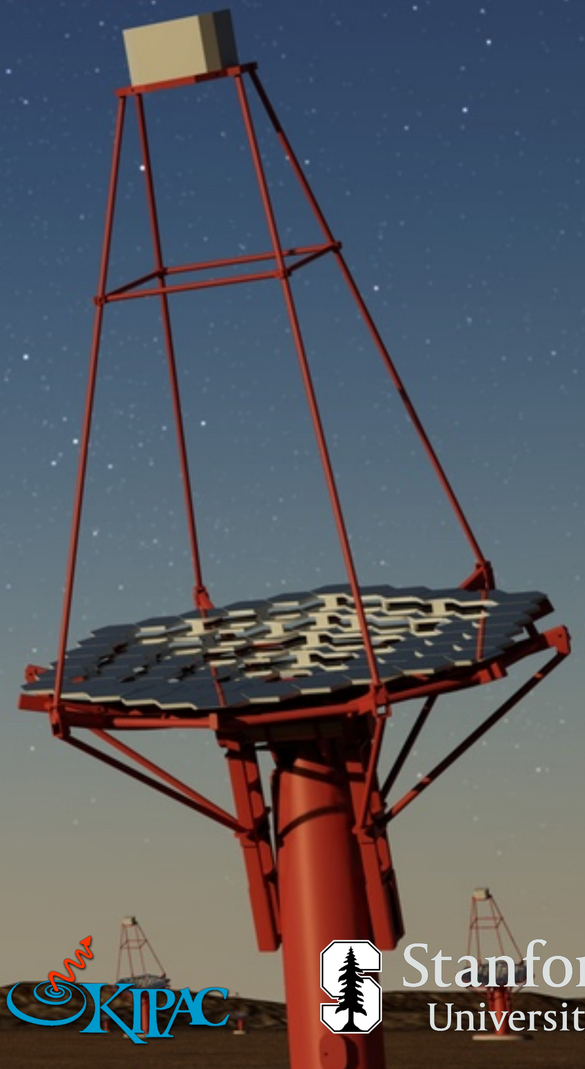
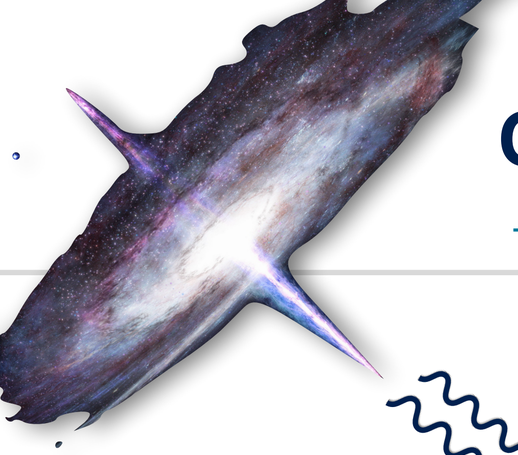
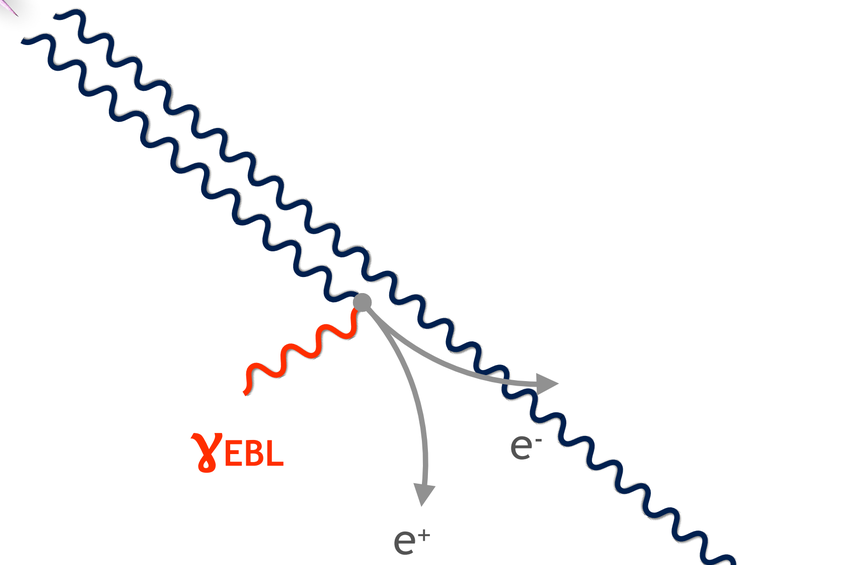


SLAC KIPAC Stanford University

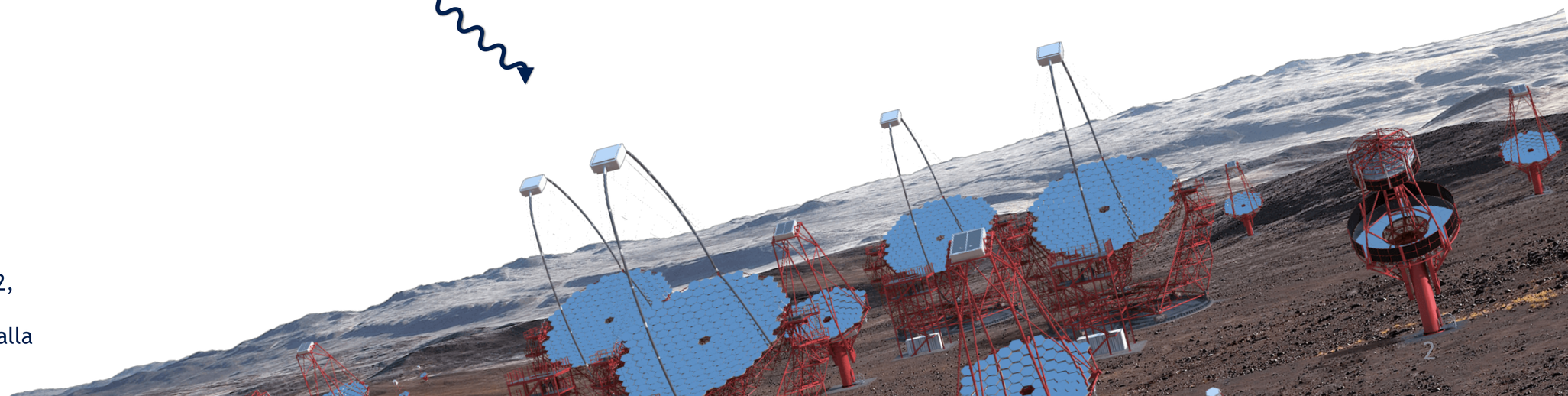
Constraining the extragalactic background light

→ See talk by Marco Ajello





[e.g. Hauser & Dwek 2001; Dwek & Krennrich 2013; Ackermann et al. 2012, Abramowski et al. 2013, Biteau & Williams 2015; Ahnen et al. 2016; Abdalla et al. 2017; Abdollahi et al. 2018]



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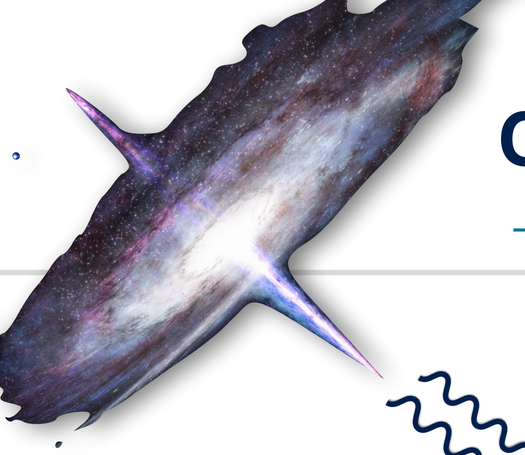
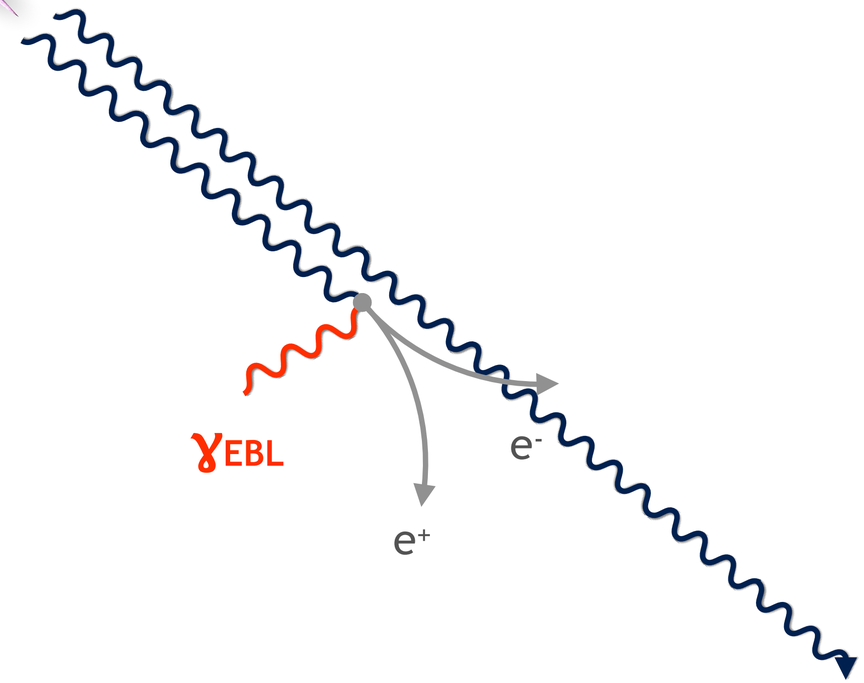
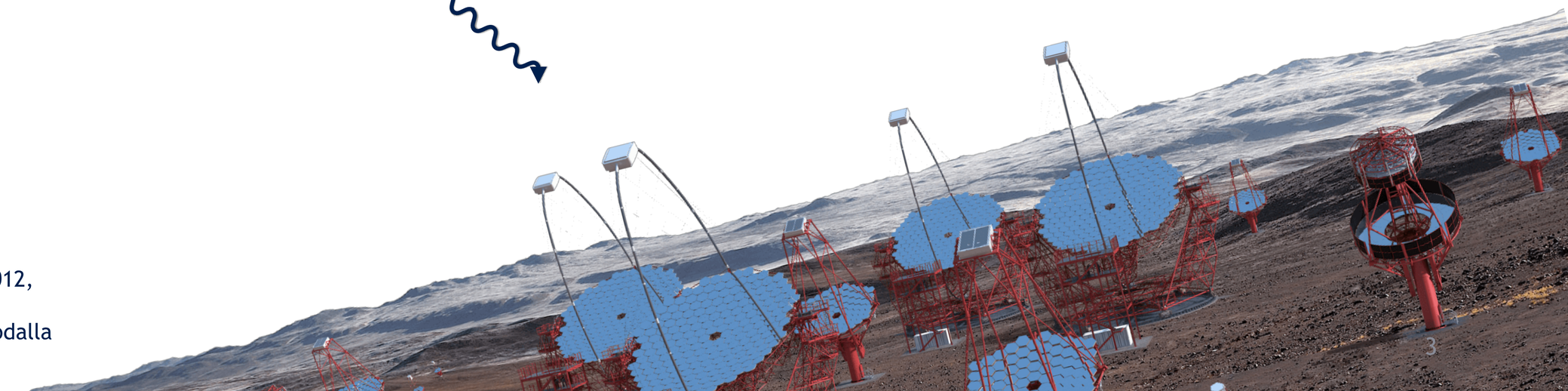




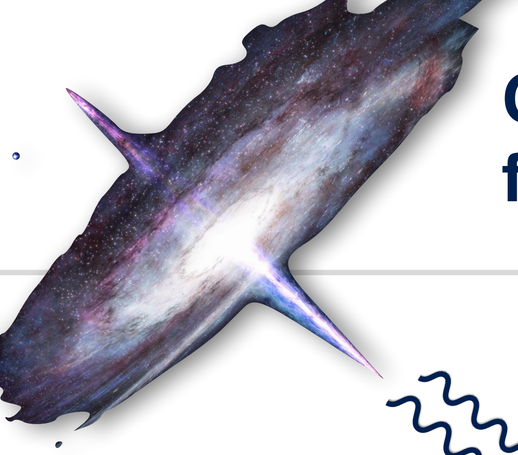
$$E_\gamma \gtrsim 210\,\mathrm{GeV}\left(\frac{\lambda}{1\,\mu\mathrm{m}}\right)$$

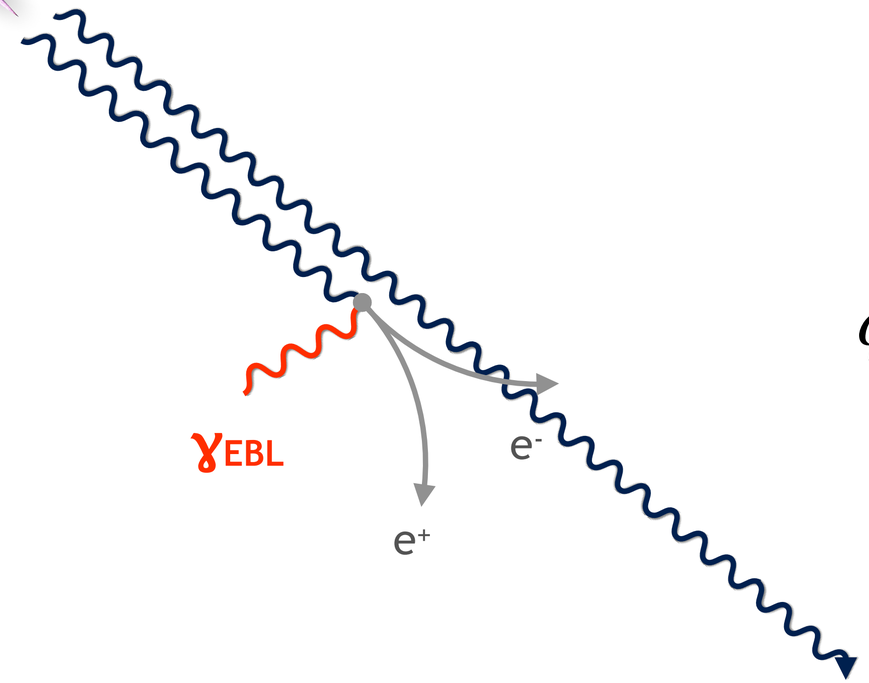
[e.g. Hauser & Dwek 2001; Dwek & Krennrich 2013; Ackermann et al. 2012, Abramowski et al. 2013, Biteau & Williams 2015; Ahnen et al. 2016; Abdalla et al. 2017; Abdollahi et al. 2018]



Constraining / detecting the intergalactic magnetic field

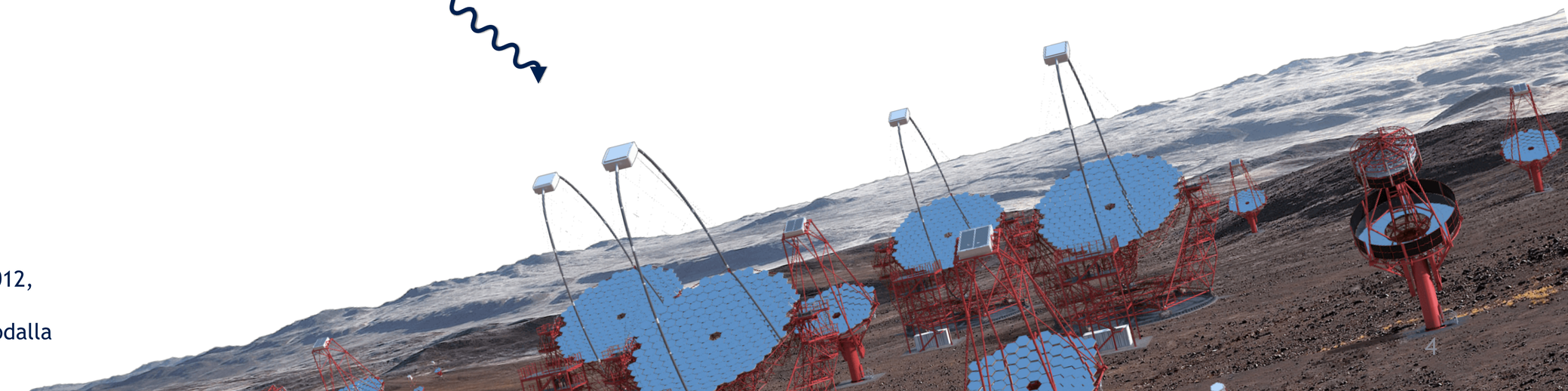
→ See talk by Rafael Alves Batista





$$E_\gamma \gtrsim 210\,\mathrm{GeV}\left(\frac{\lambda}{1\,\mu\mathrm{m}}\right)$$

$$\phi_{\mathrm{obs}} = \phi_{\mathrm{emitted}}\,\exp\left(-\alpha\,\tau(E_0, z_0)\right)$$



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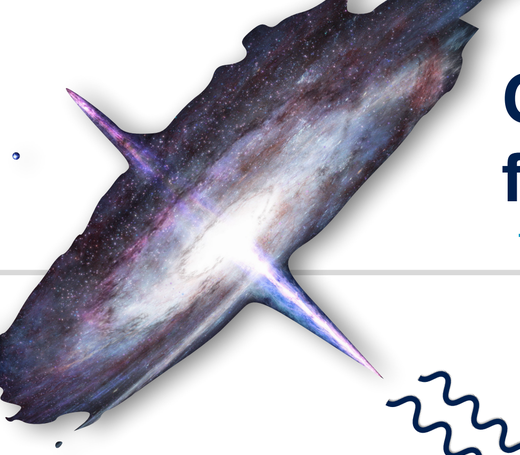

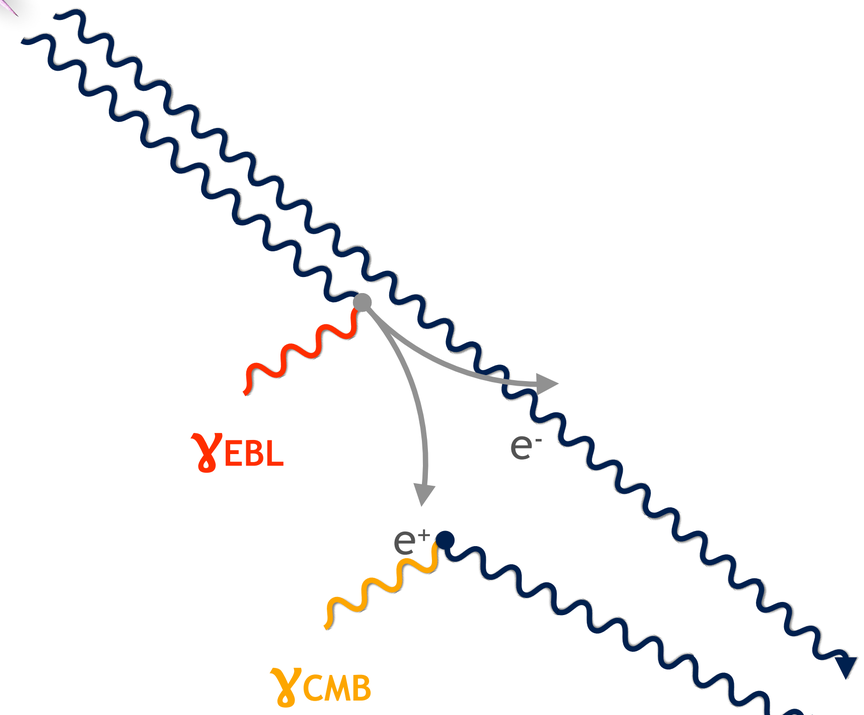

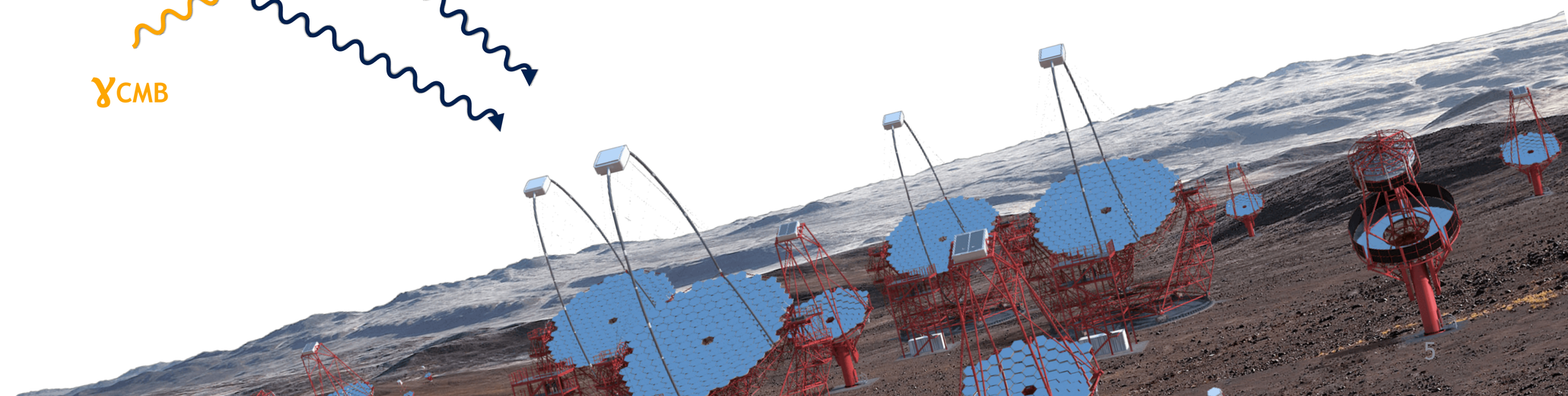

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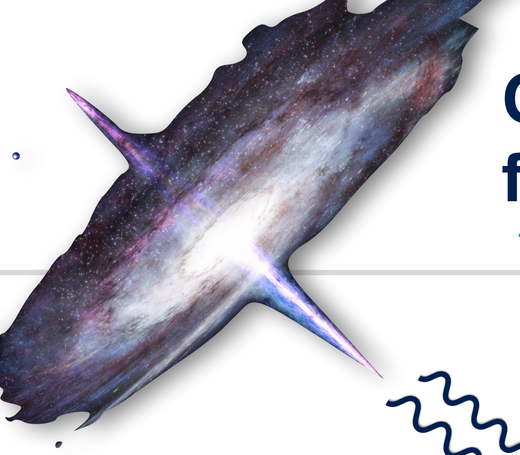
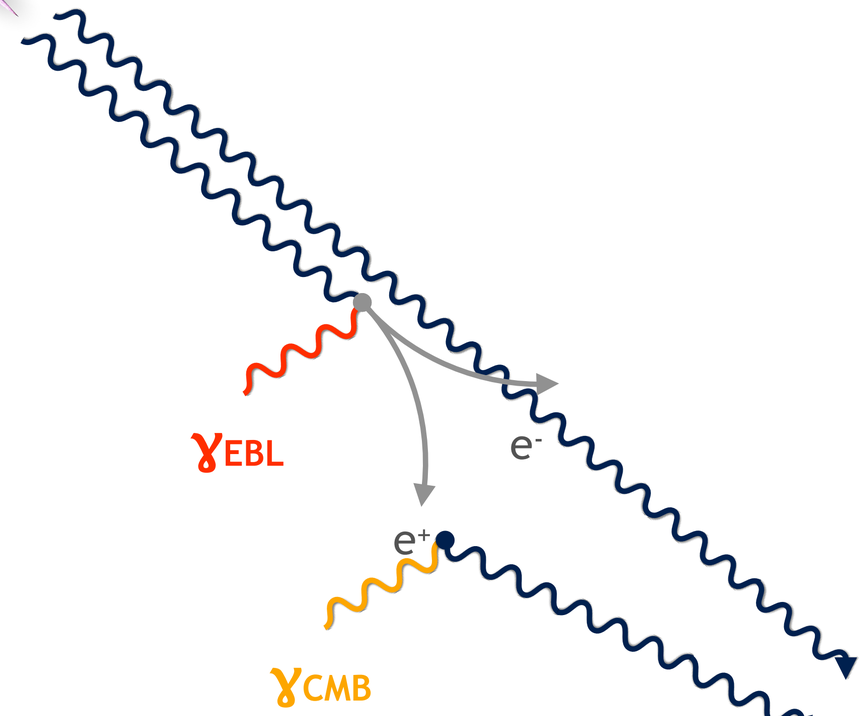
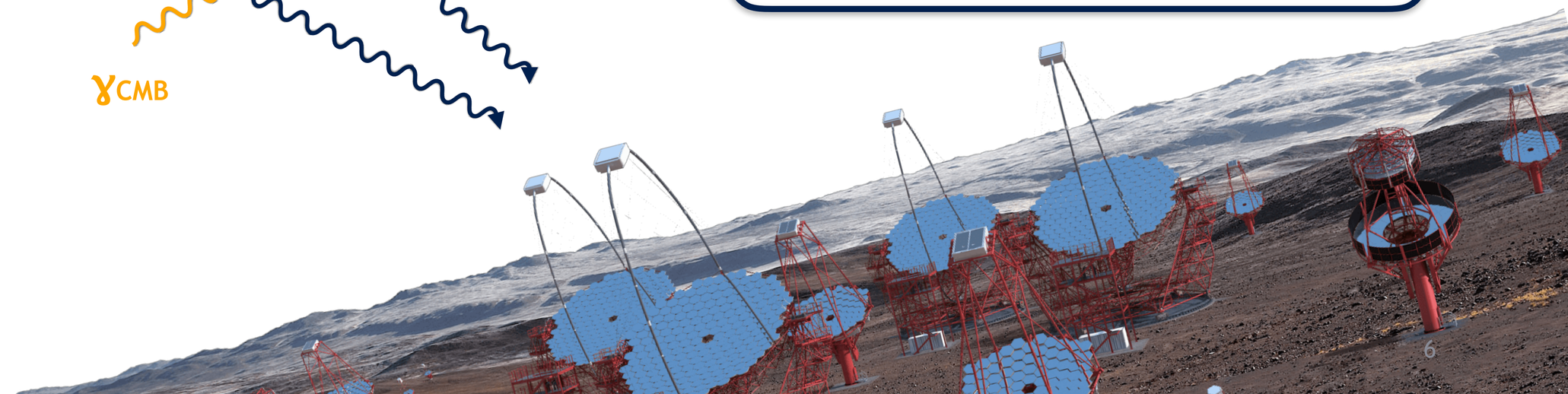




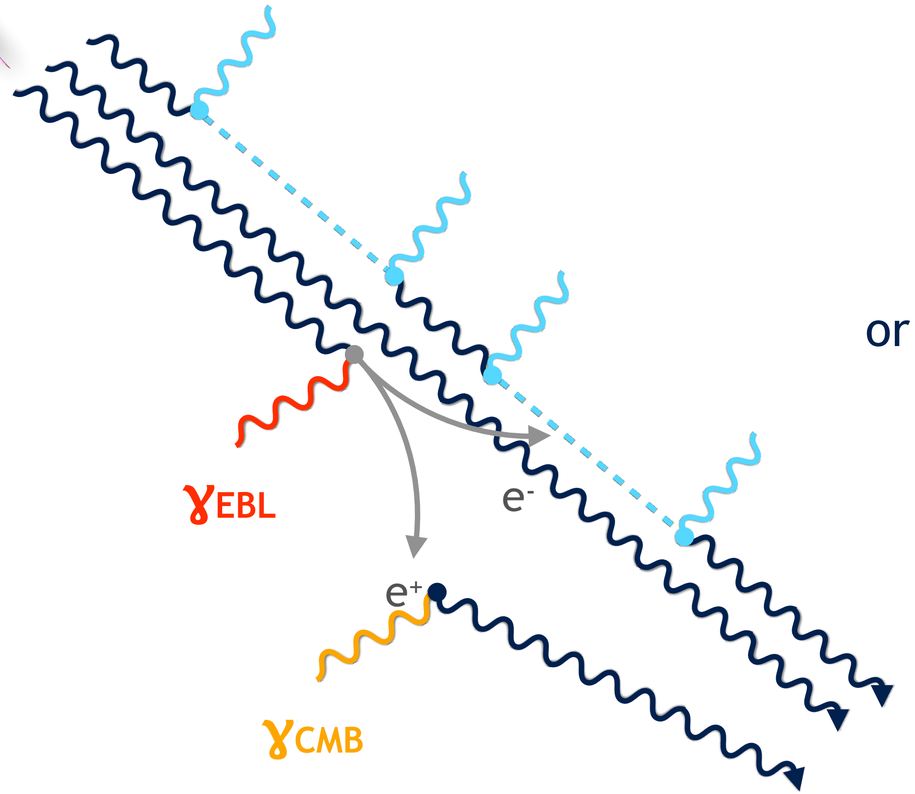
IGMF dependent observables:

- **Excess ɣ rays at lower energies [e.g. Neronov & Semikoz 2008]**
- **Extended ɣ-ray halos [Aharonian et al. 1994]**
- **Time delayed ɣ-ray emission [Plaga 1995]**



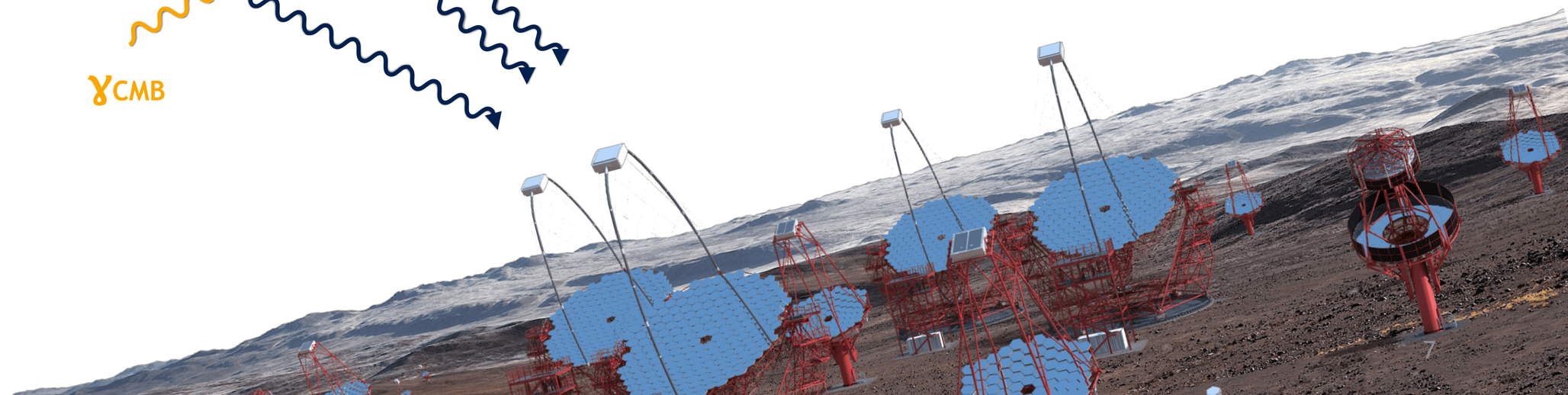
Searching for oscillations between gamma rays and axion-like particles

→ See also talk by Subir Sakar & Francesco Miniati



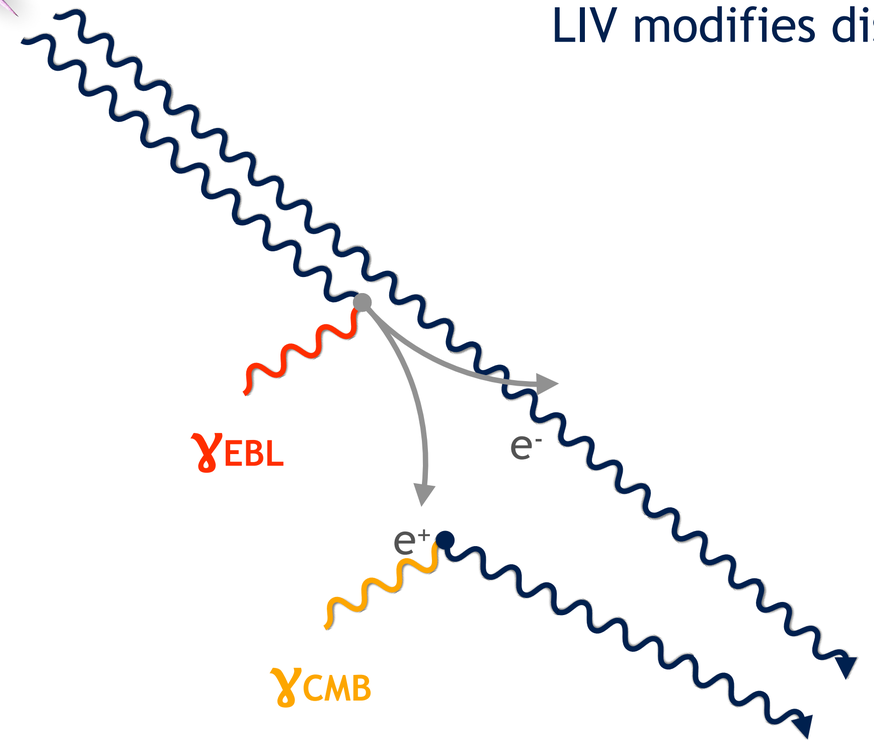
Photon-ALP oscillations could lead to a
reduced gamma-ray opacity
or oscillation features in gamma-ray spectra

[Csaki et al. 2003;
Östman & Mörtsell 2005;
Hooper & Serpico 2007;
Mirizzi et al 2007;
Hochmuth & Sigl 2007;
De Angelis et al. 2008;
Wouters & Brun 2012,2013;
Abramowski et al. 2013;
Ajello et al. 2016;
Montanino et al. 2017;
Liang et al. 2018;
Malyshev et al. 2018;
Majumdar et al. 2018;
Xia et al. 2018;
Zhang et al. 2018]



Searching for signatures of Lorentz invariance violation

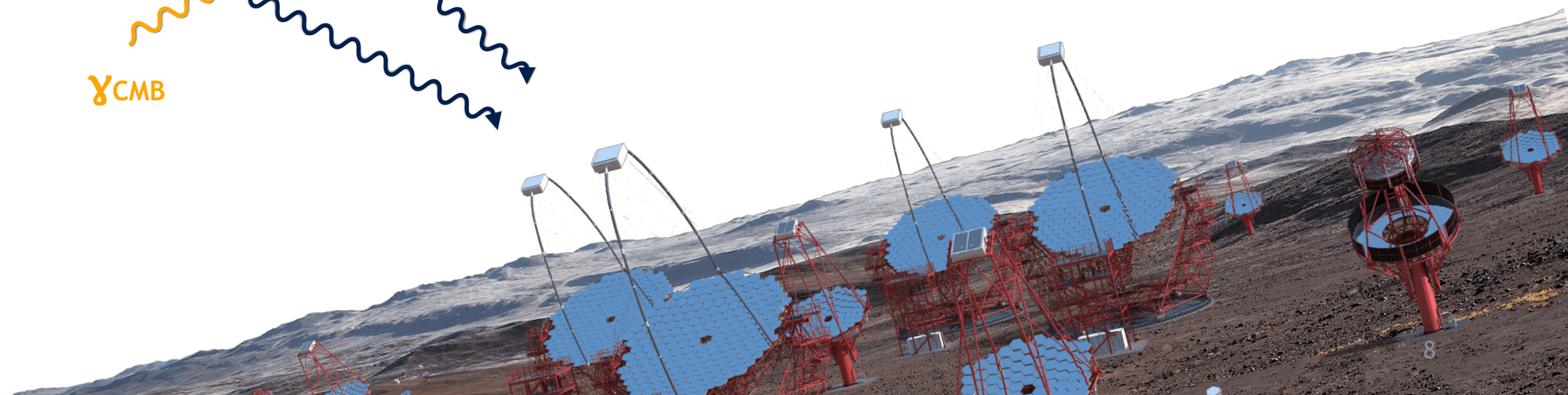
→ See talk by John Ellis, Subir Sakar



LIV modifies dispersion relation of photon (subluminal case):

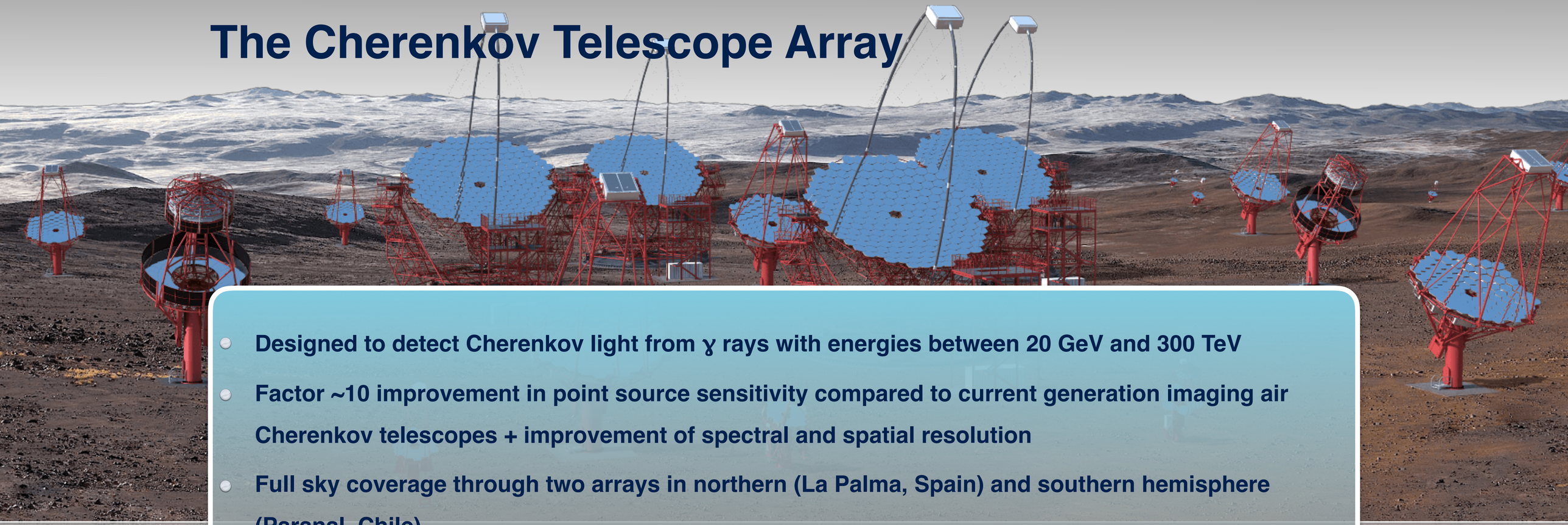
$$E_\gamma^2 - p_\gamma^2 = -\frac{E_\gamma^{n+1}}{E_{\mathrm{LIV}}^n}$$

Which modifies the energy threshold for pair production



[e.g. Kifune 1999;
Jacob & Piran 2008; Abdalla & Böttcher 2018;
Lorentz & Brun (H.E.S.S.) 2016]

The Cherenkov Telescope Array

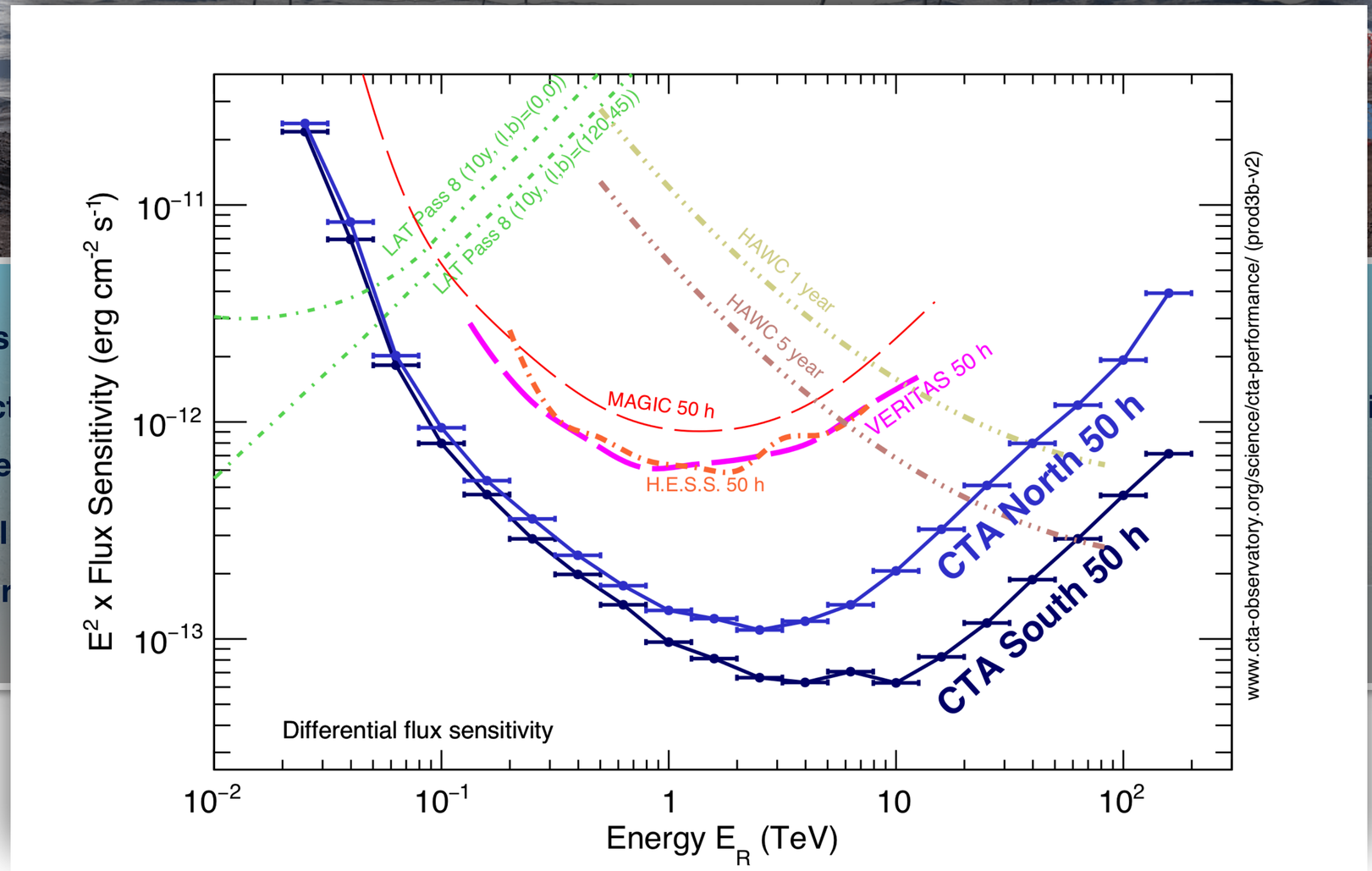


- Designed to detect Cherenkov light from ɣ rays with energies between 20 GeV and 300 TeV
- Factor ~10 improvement in point source sensitivity compared to current generation imaging air Cherenkov telescopes + improvement of spectral and spatial resolution
- Full sky coverage through two arrays in northern (La Palma, Spain) and southern hemisphere (Paranal, Chile)

	No. North	No. South	Energy Range (TeV)
Large Sized Telescopes	4	4	0.02-0.2
Mid Sized Telescopes	15	25	0.1-10
Small Sized Telescopes	–	70	5-300

https://www.cta-observatory.org/

The Cherenkov Telescope Array



Mid Sized Telescopes	15	25	0.1-10
Small Sized Telescopes	—	70	5-300

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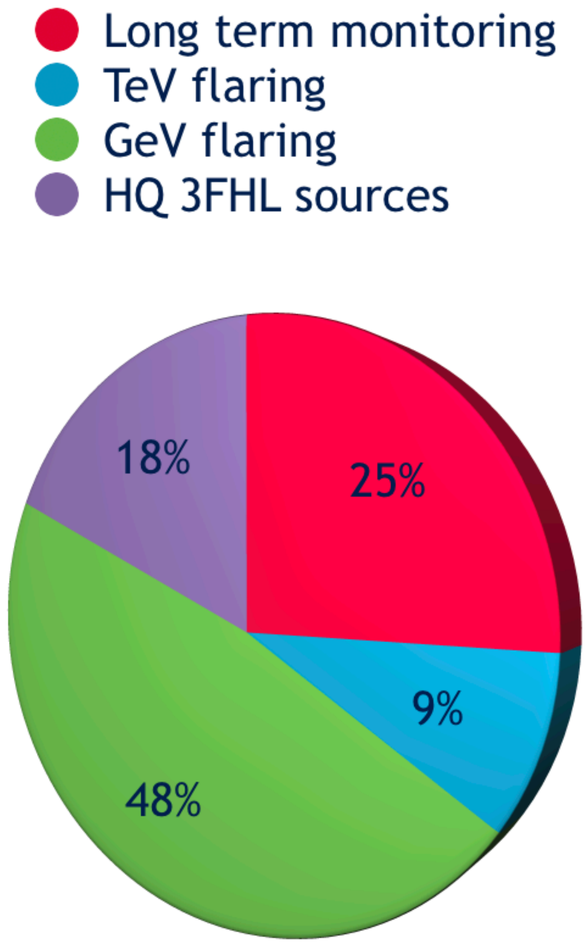
Probing the effects: simulations and method

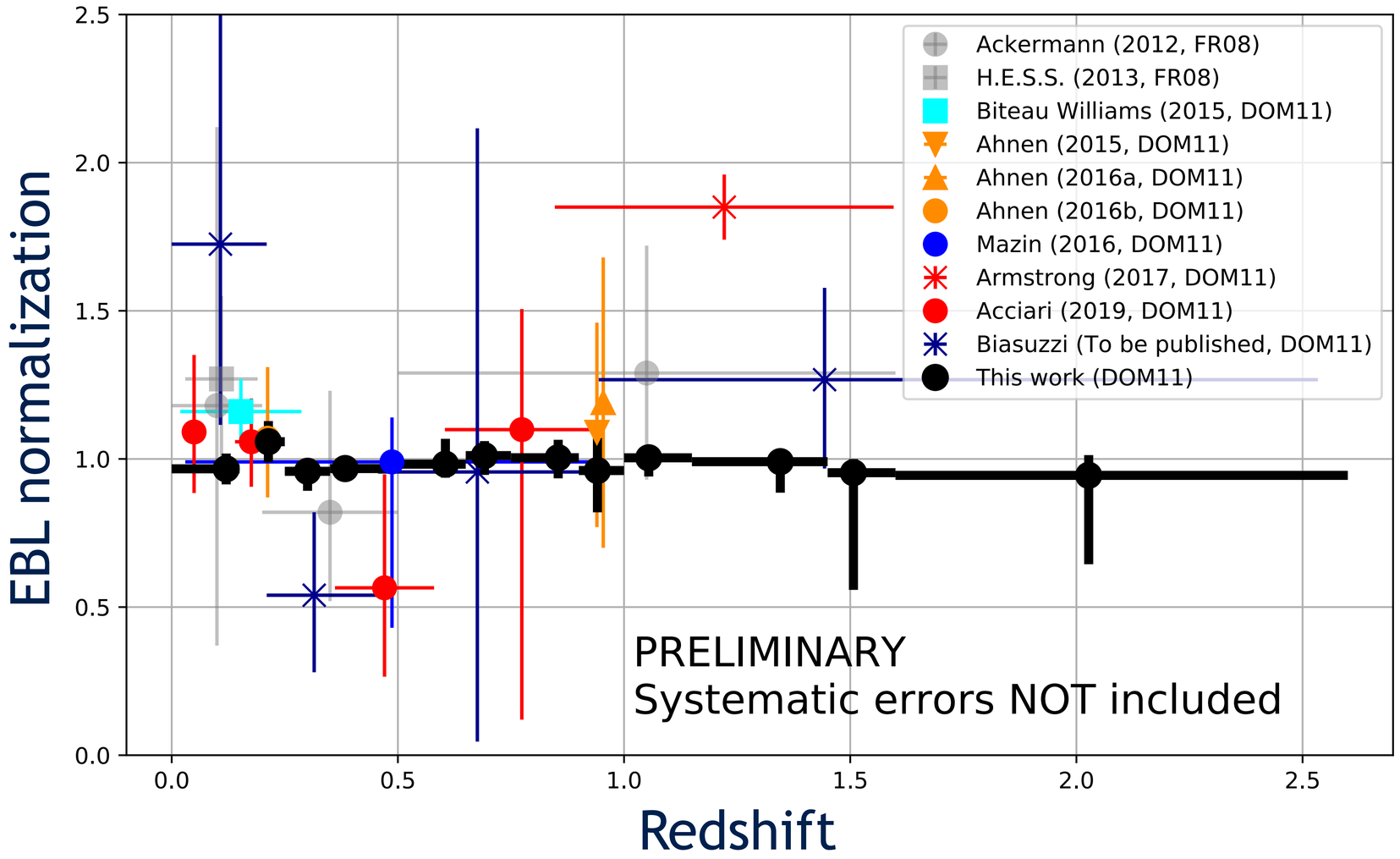
- CTA simulations carried out with `ctools` and `gammapy`
- Maximum likelihood estimation used to determine source spectral parameters and parameter in question
- Likelihoods combined if multiple sources considered (e.g. for EBL)

EBL: Source selection and simulations

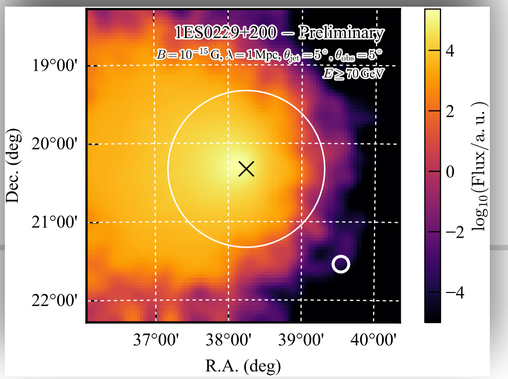
- 80 sources used, $0.019 < z < 2.55$
- 1110 hours of total observation time over 10 years
- Assumed intrinsic spectra:
  - Fits to published spectral data points (long term & TeV flaring)
  - Dedicated Fermi analysis (GeV flaring)
  - 3FHL extrapolation
  - Exponential cut-off at 1 / (1 + z) TeV
- Only sources with firm redshift determination used



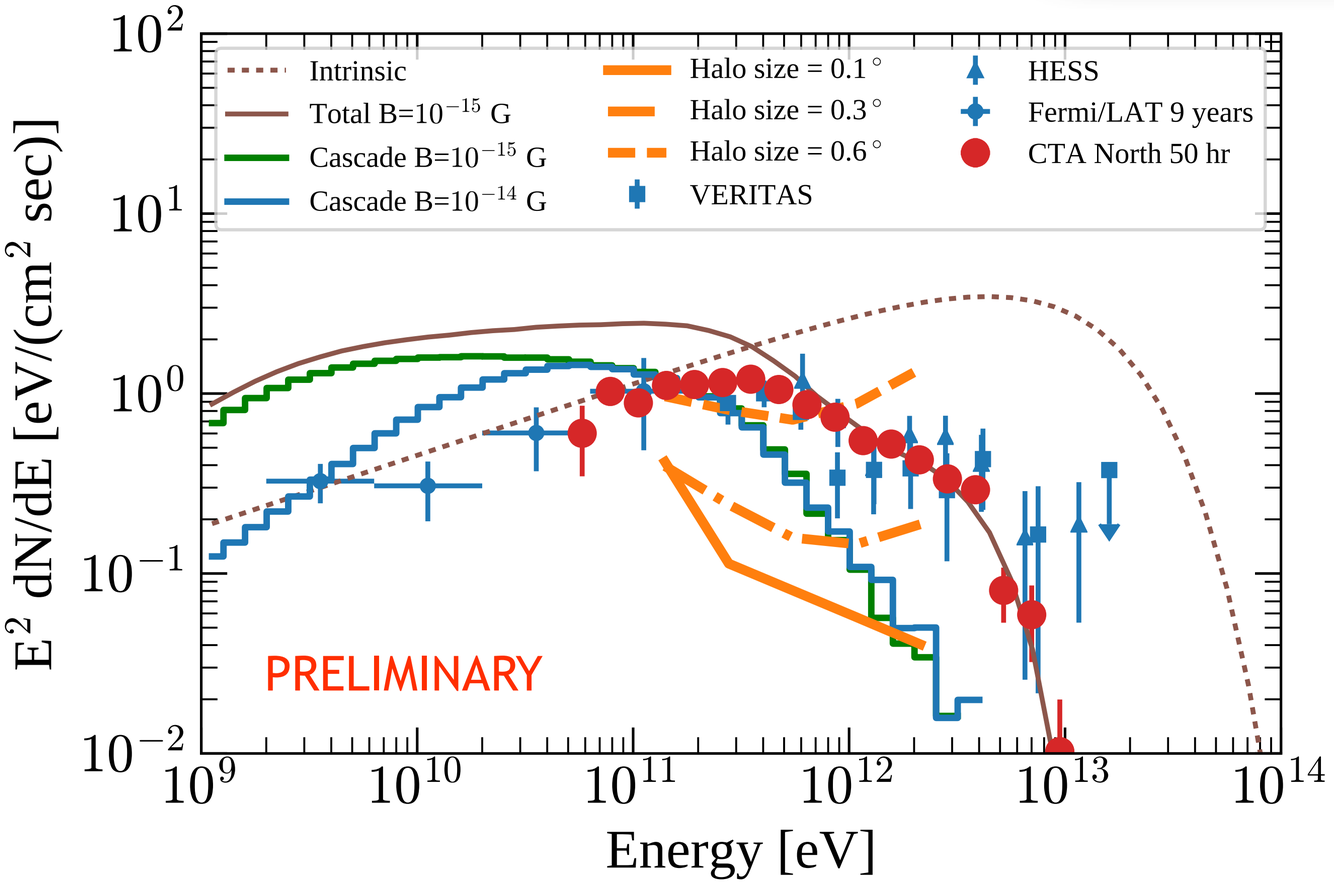
EBL: Results


EBL normalization
Redshift
0.0
0.5
1.0
1.5
2.0
2.5
Ackermann (2012, FR08)
H.E.S.S. (2013, FR08)
Biteau Williams (2015, DOM11)
Ahnen (2015, DOM11)
Ahnen (2016a, DOM11)
Ahnen (2016b, DOM11)
Mazin (2016, DOM11)
Armstrong (2017, DOM11)
Acciari (2019, DOM11)
Biasuzzi (To be published, DOM11)
This work (DOM11)
PRELIMINARY
Systematic errors NOT included

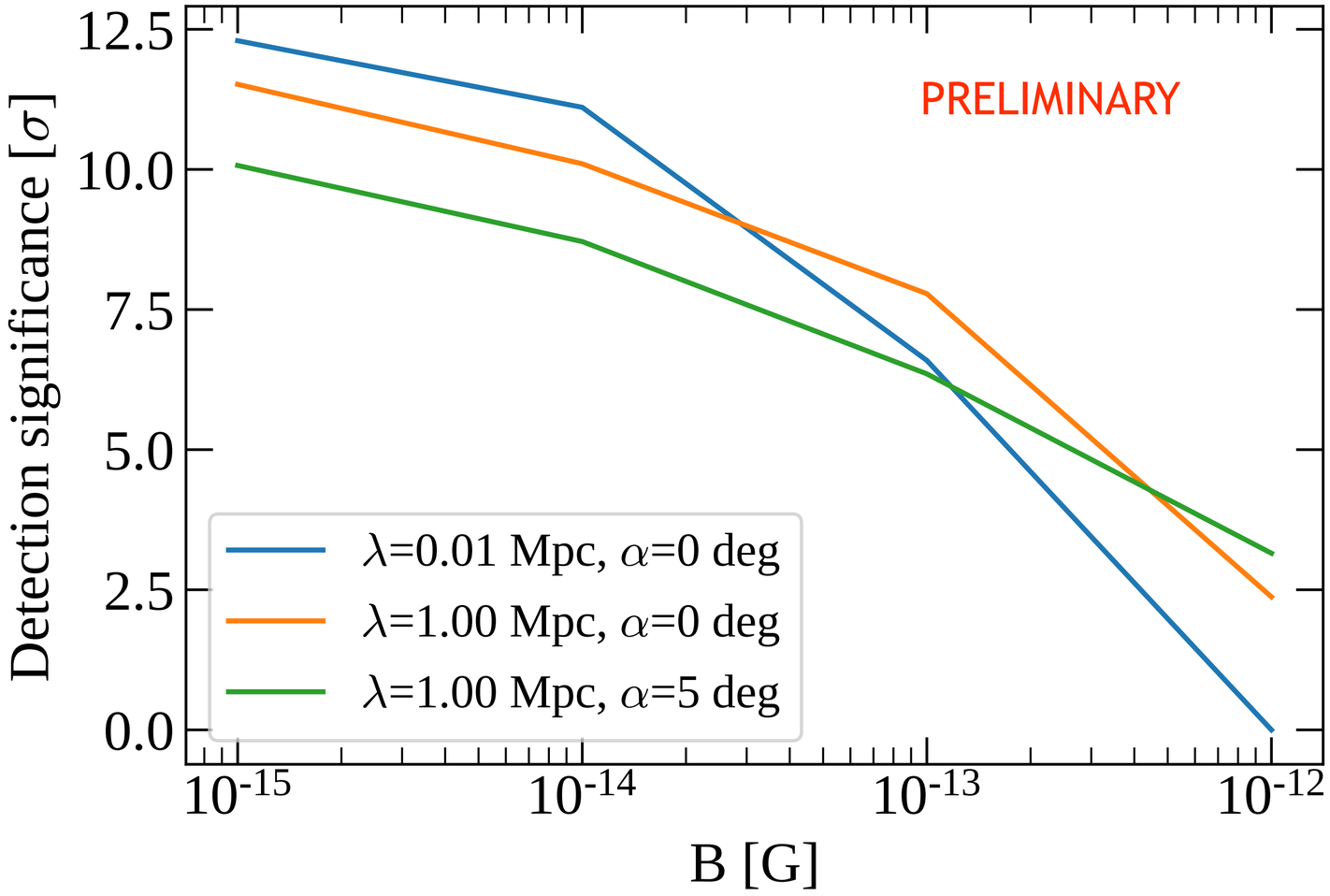
Simulating and searching for the cascade



- Assumed observations: 50 hours of 1ES0229+200
- Cascade simulated with `CRPROPA` code [Alves Batista et al. 2016]
- Include point-source and extended halo component in the fit

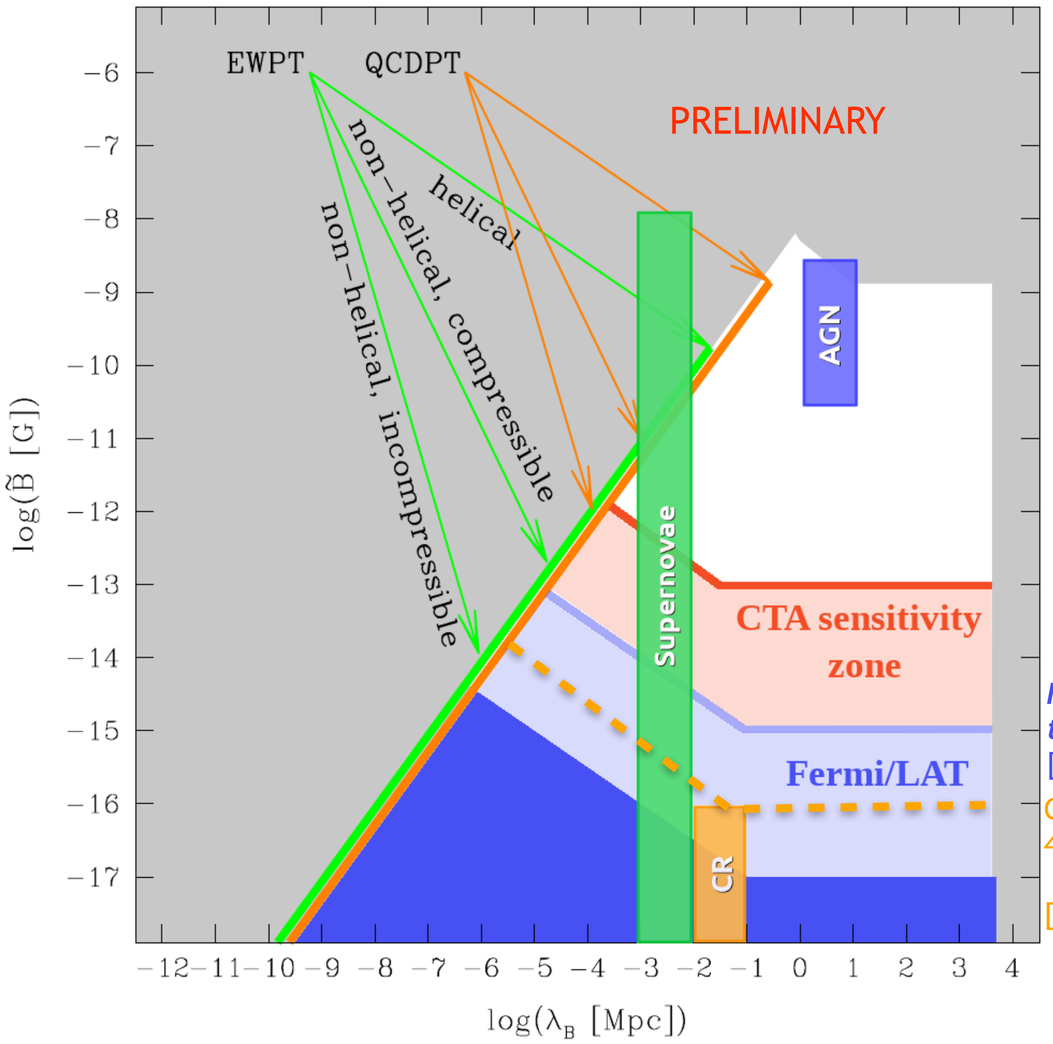


Possible detection significance of the halo



IGMF parameter space that will be probed with CTA observations

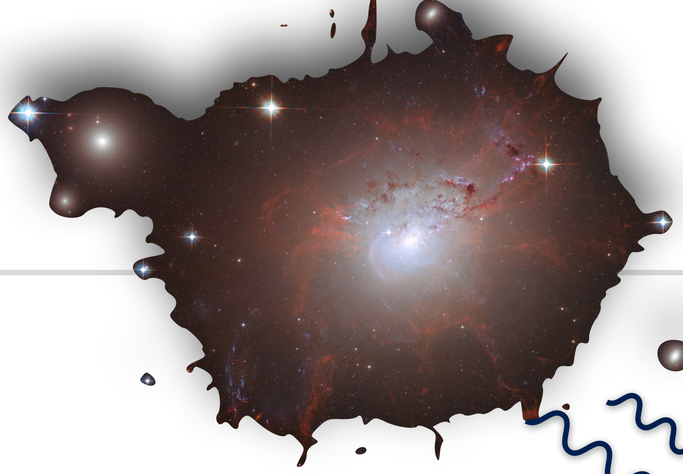
Adapted from Durrer and Neronov (2013)

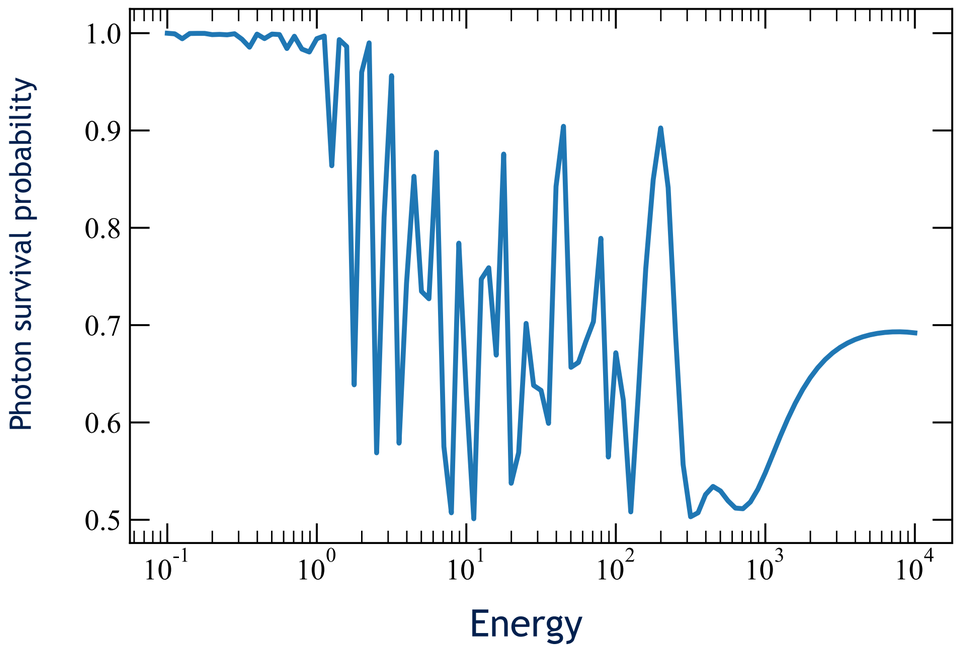


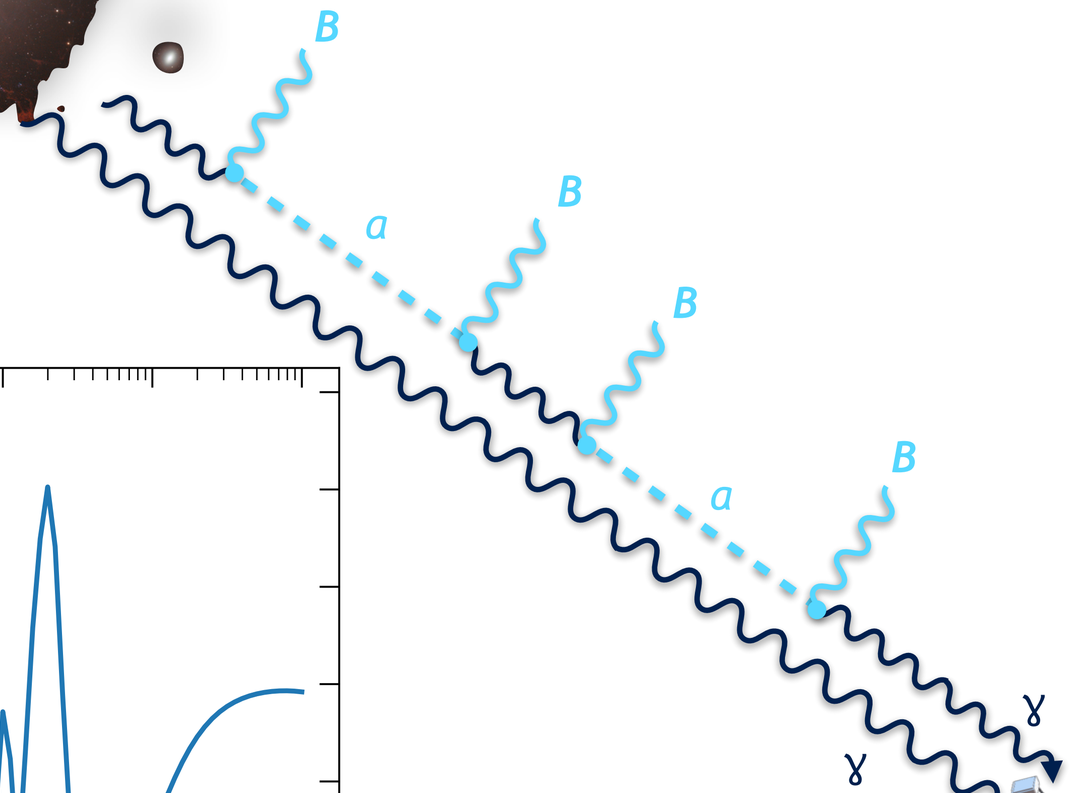
***Fermi*-LAT limits,**
t_{max} = 10 yr,
[Ackermann et al. 2018]

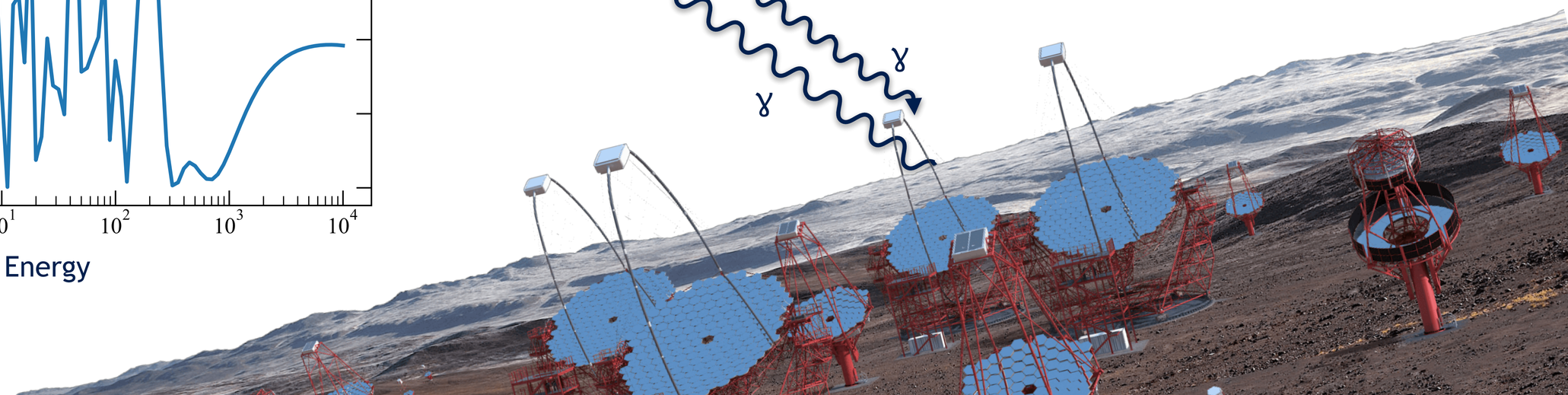
CTA spectrum only,
4 blazars, T_{obs} = 120 hours,
t_{max} = 10 yrs,
[MM et al. 2016]

Searching for spectral irregularities with NGC 1275









[Ajello et al. 2016]

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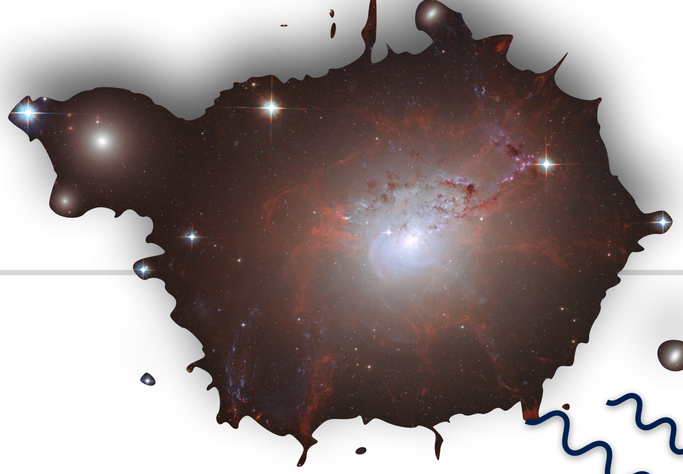

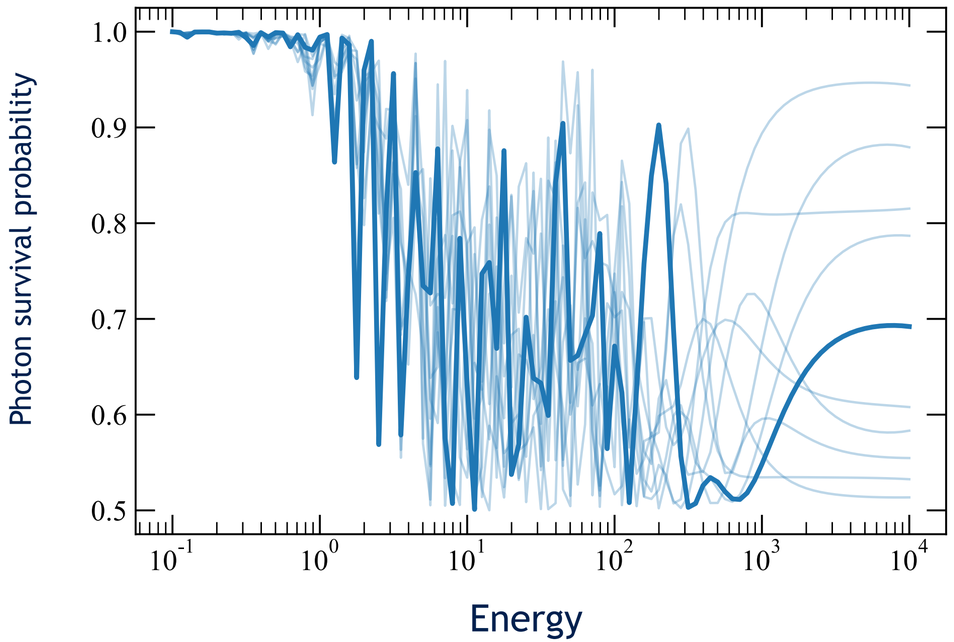

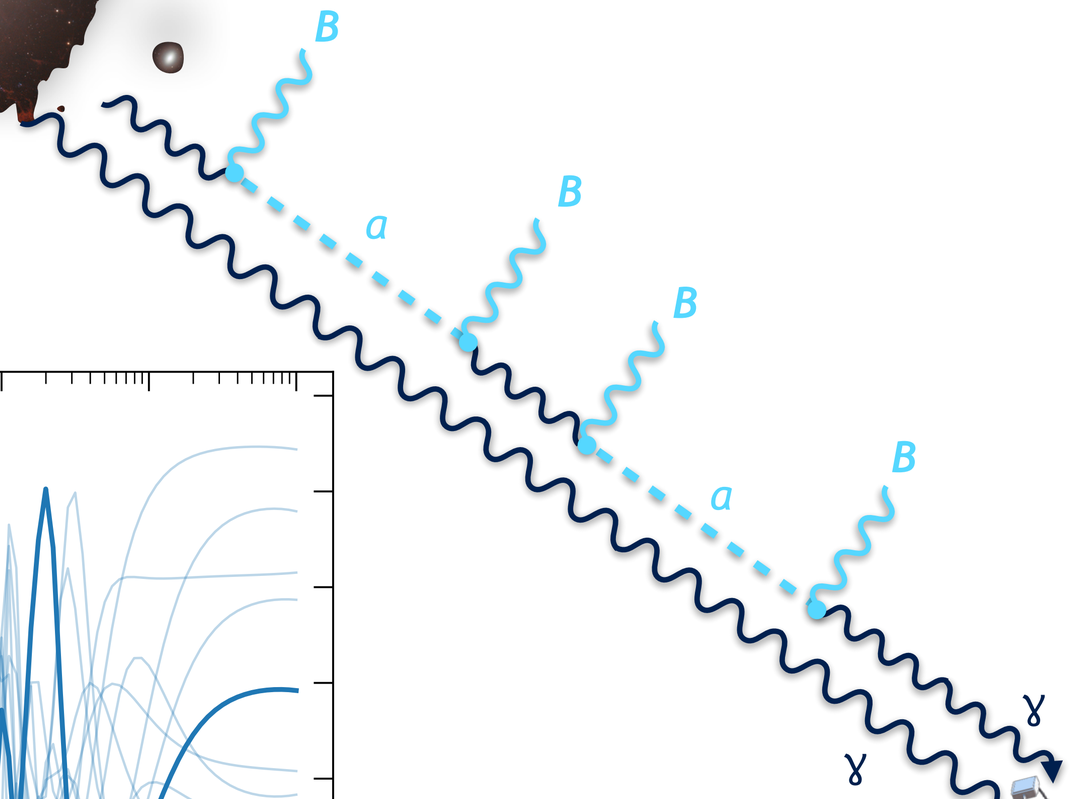

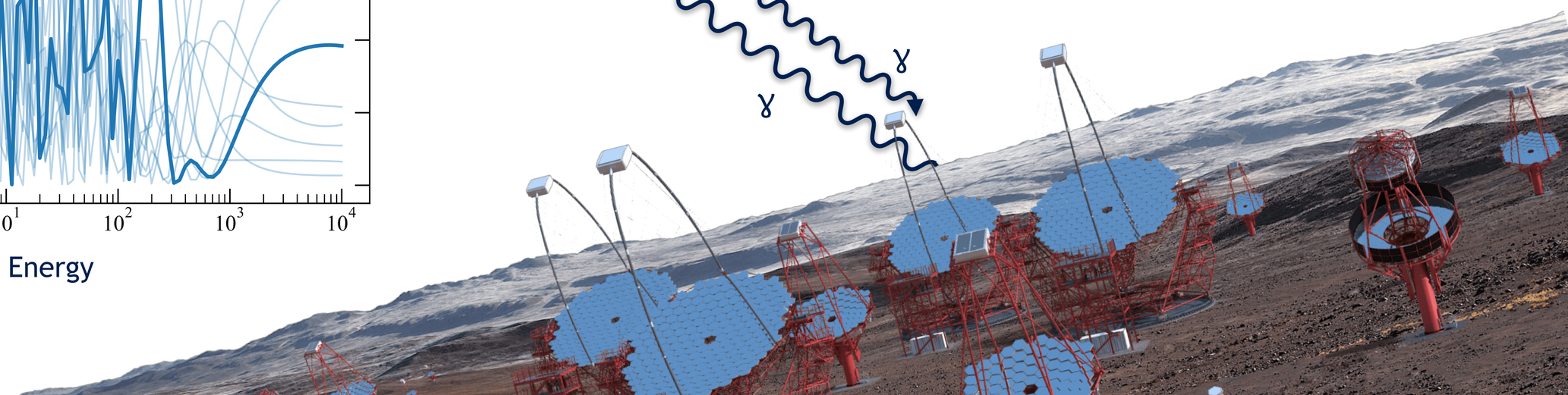

[Ajello et al. 2016]

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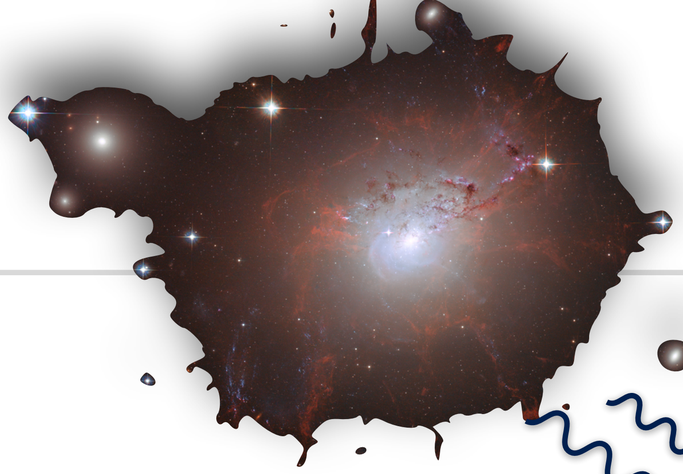
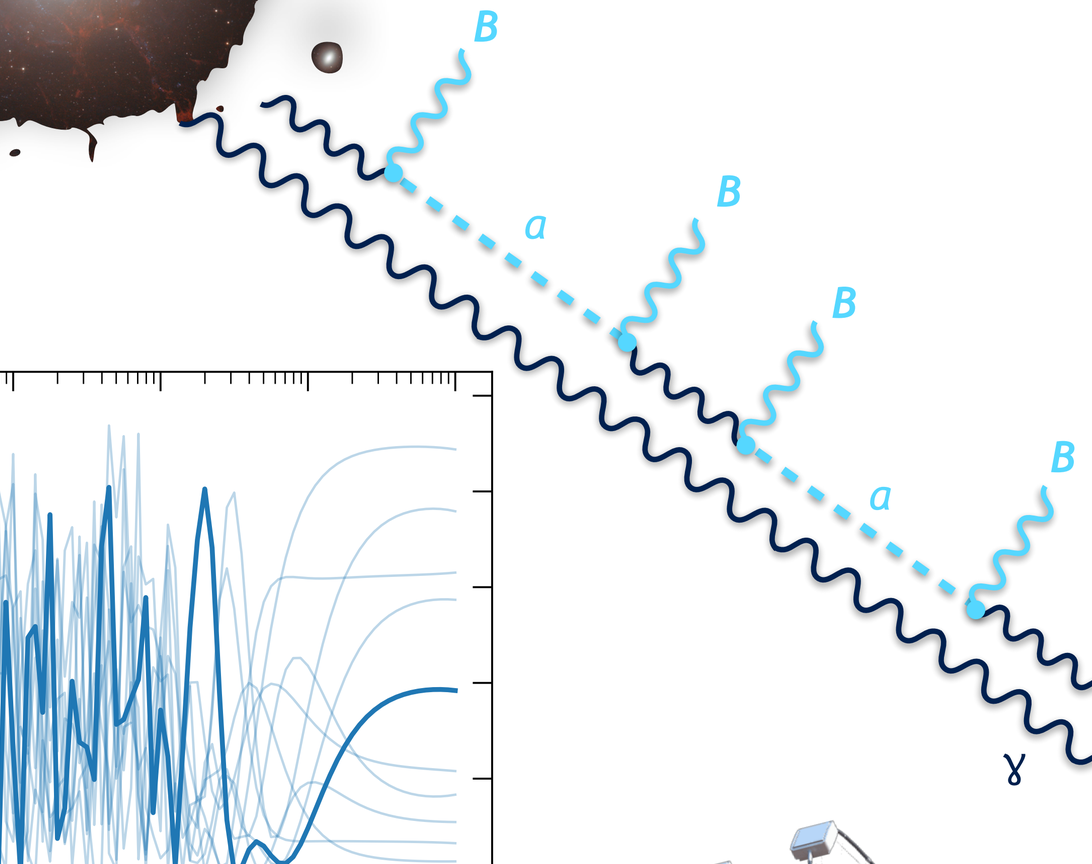
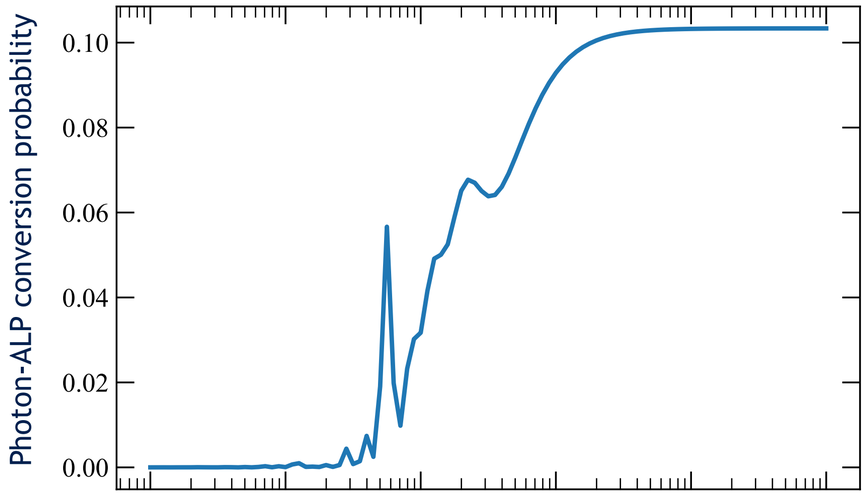
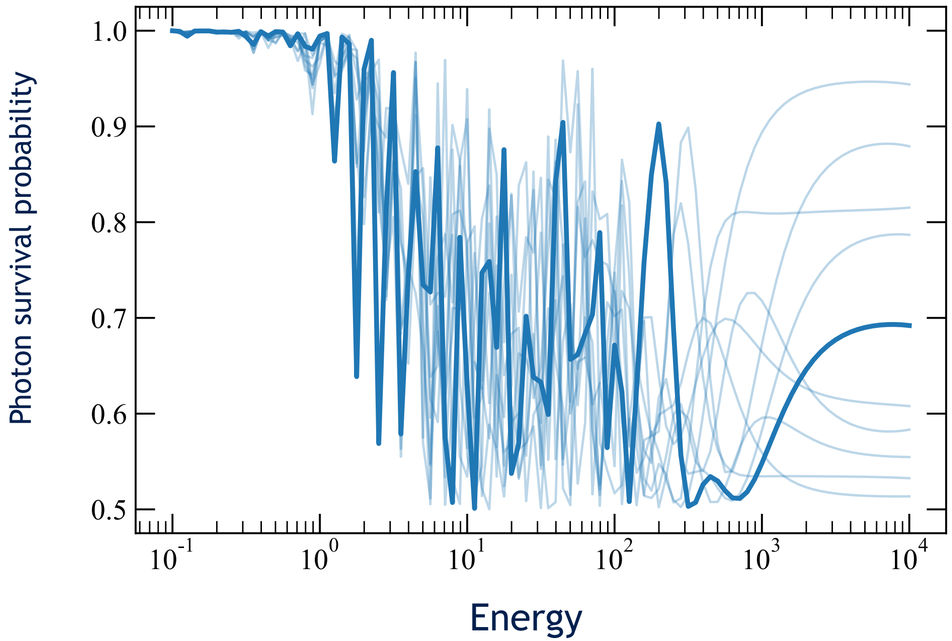
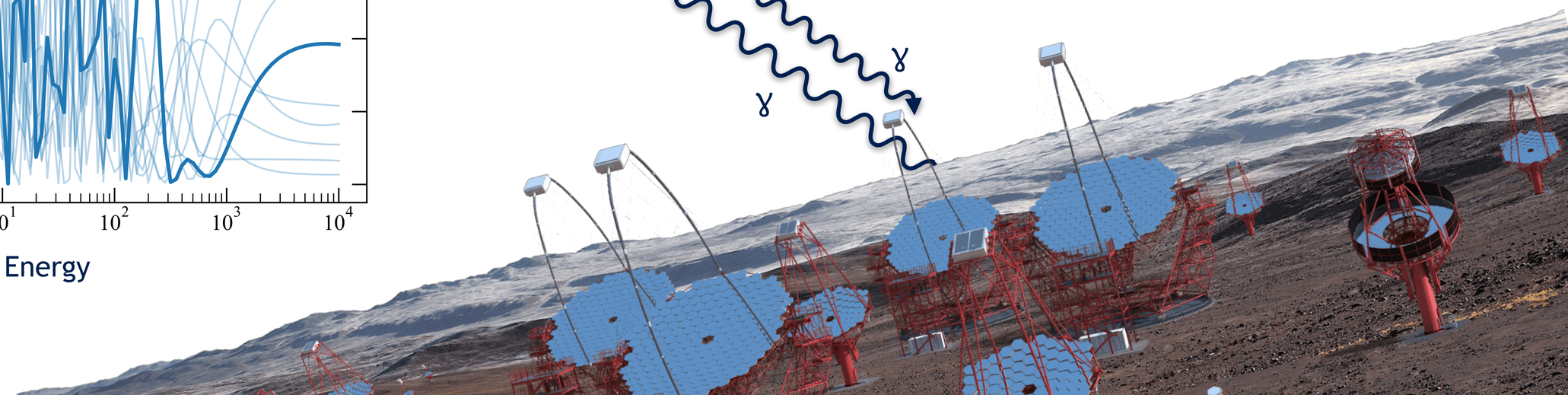






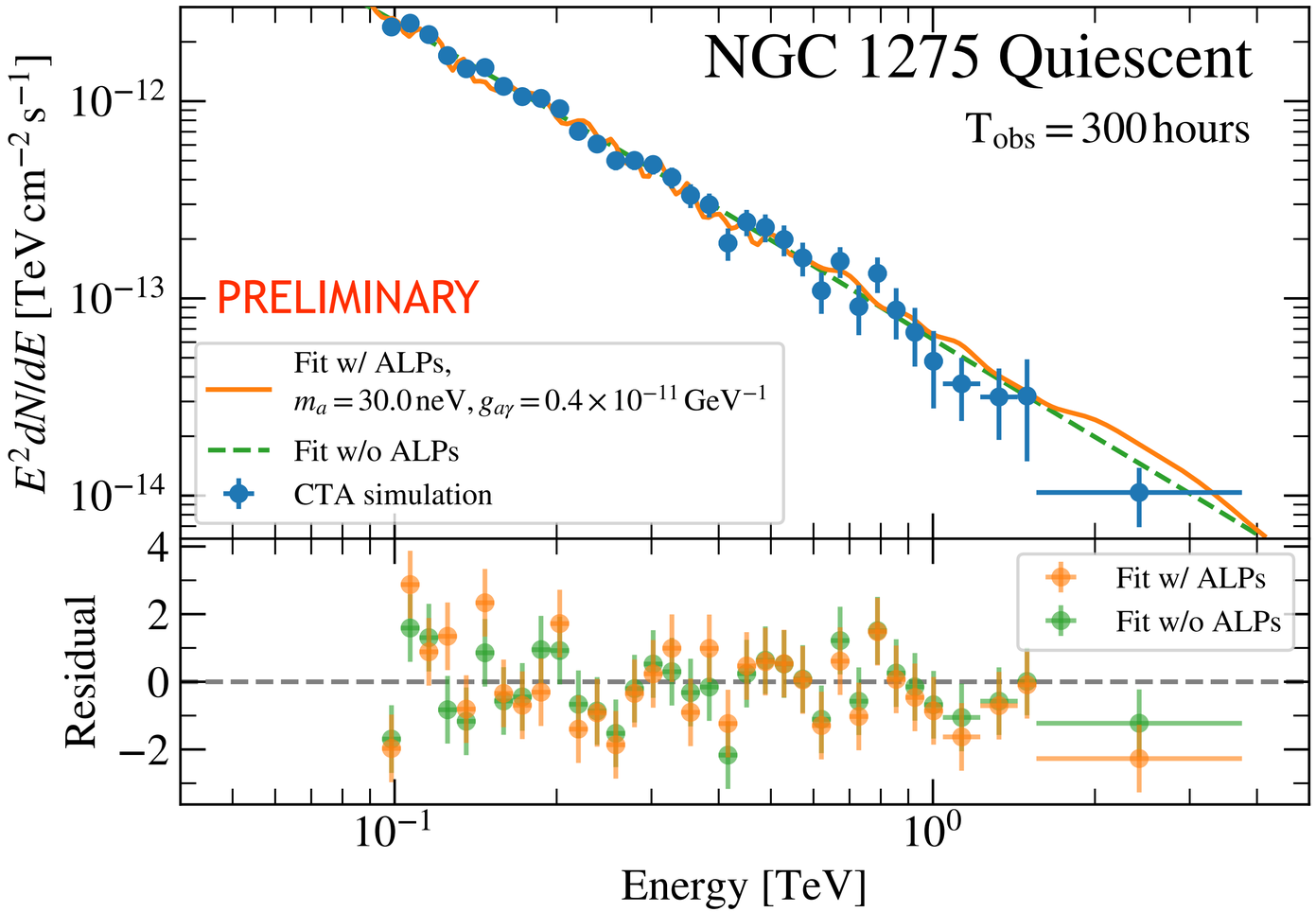




[Ajello et al. 2016]

Simulated spectrum of NGC 1275

NGC 1253 will be observed through galaxy cluster key science program



Simulated spectrum of NGC 1275

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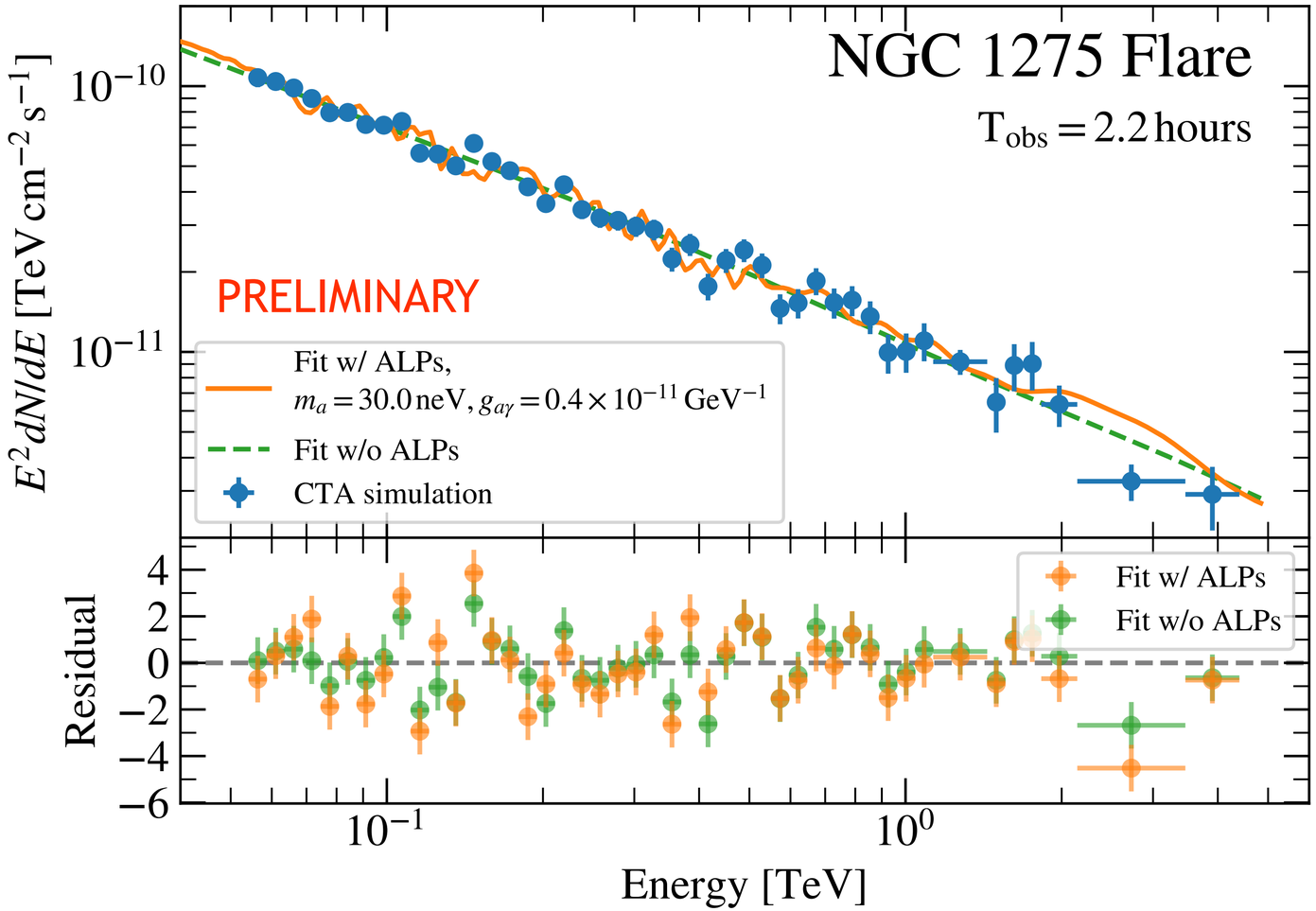
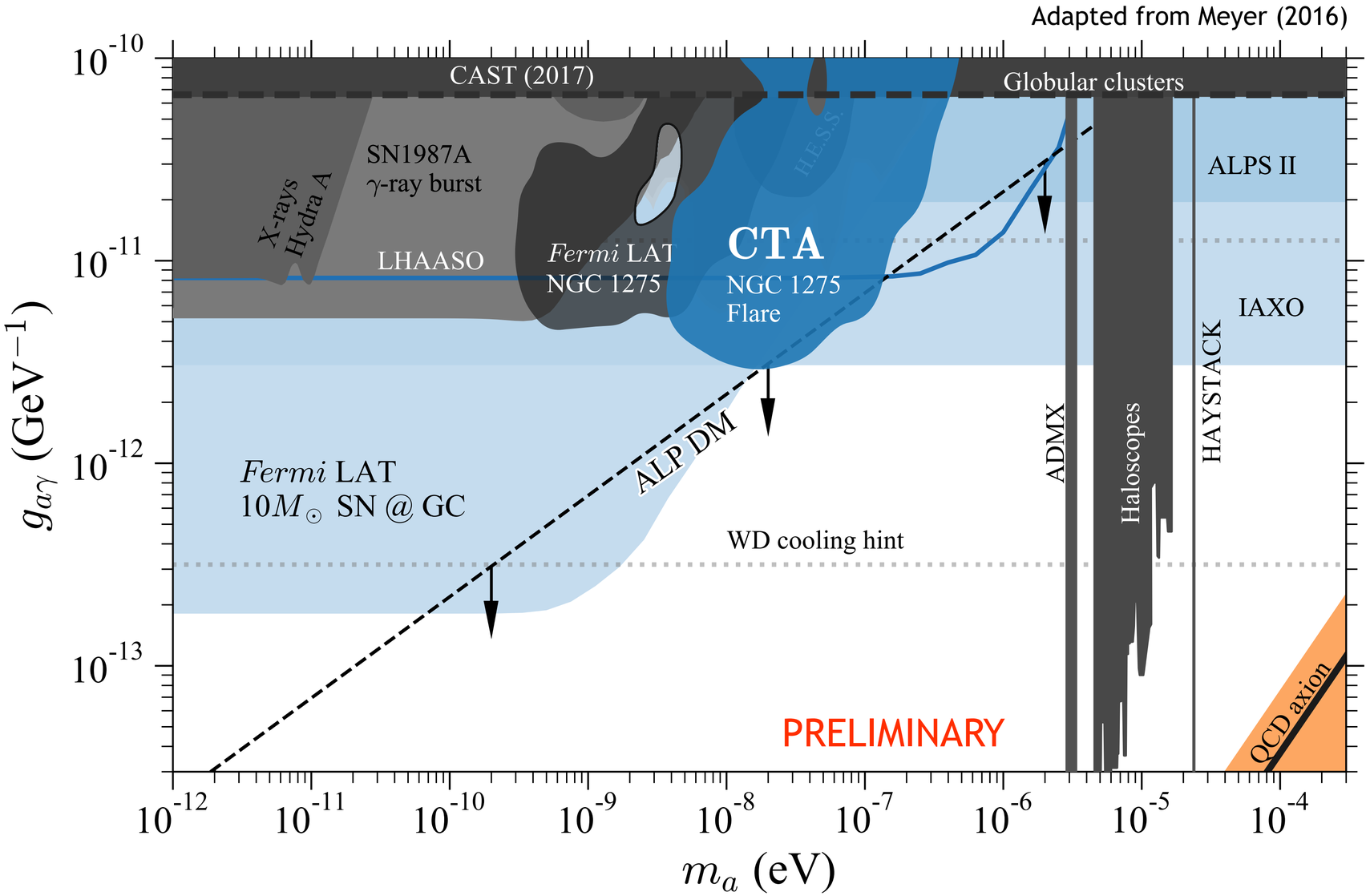
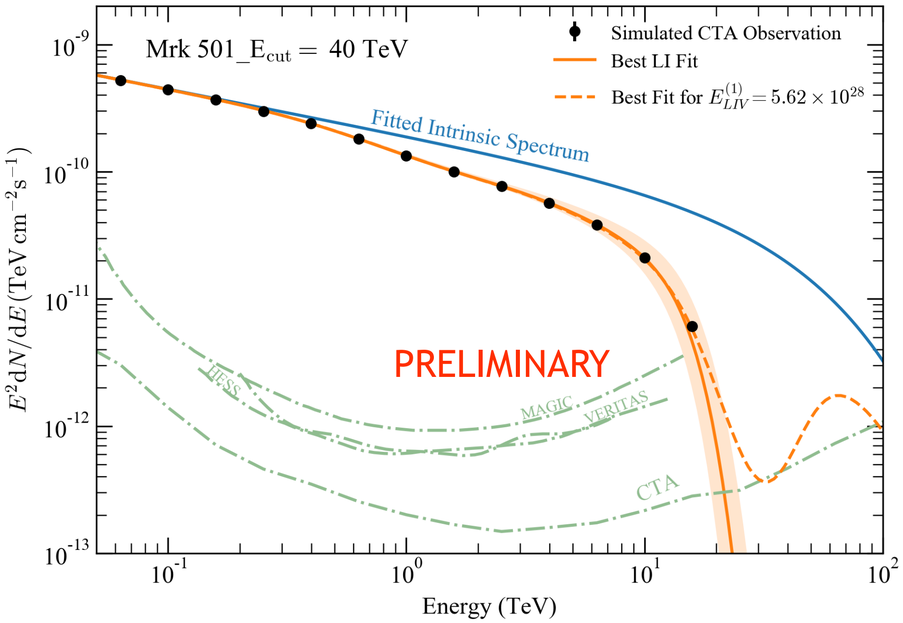


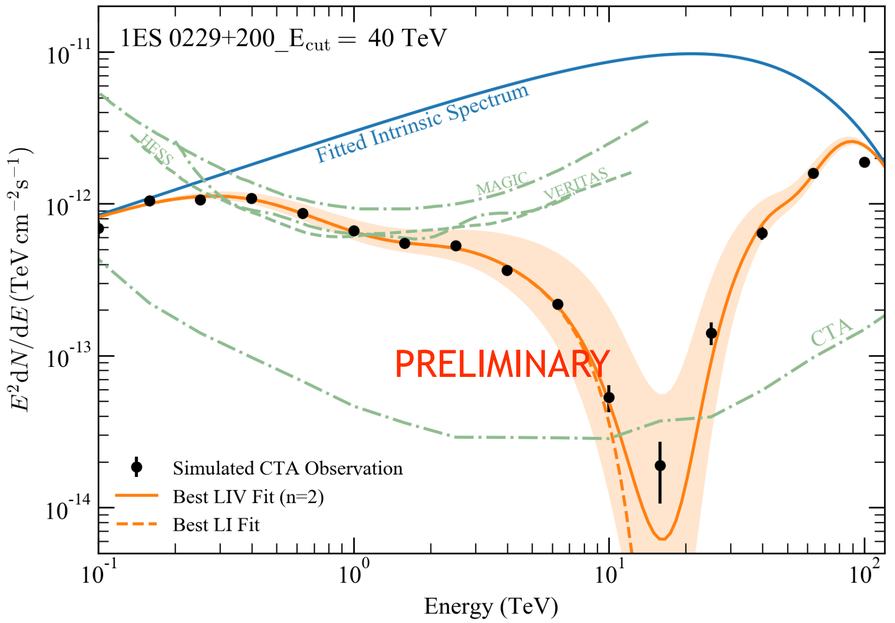
ALP parameter space that will be probed with CTA



Searching for LIV signatures

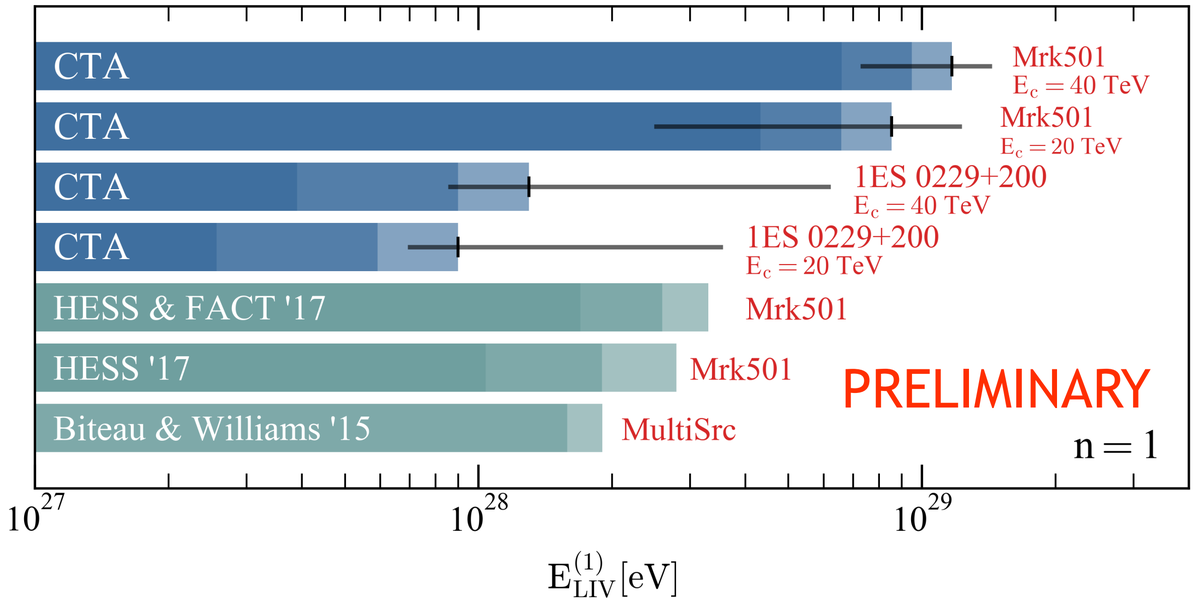


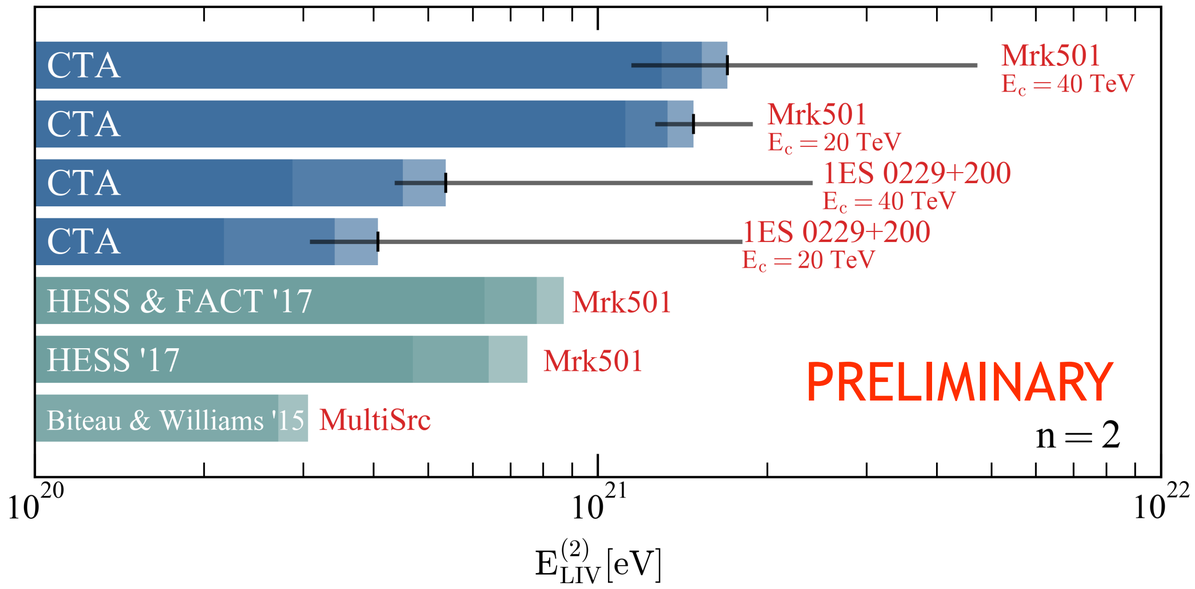
Mkn 501 flare
LIV absent



1ES0229+200
LIV n=2 present

Possible constraints on LIV





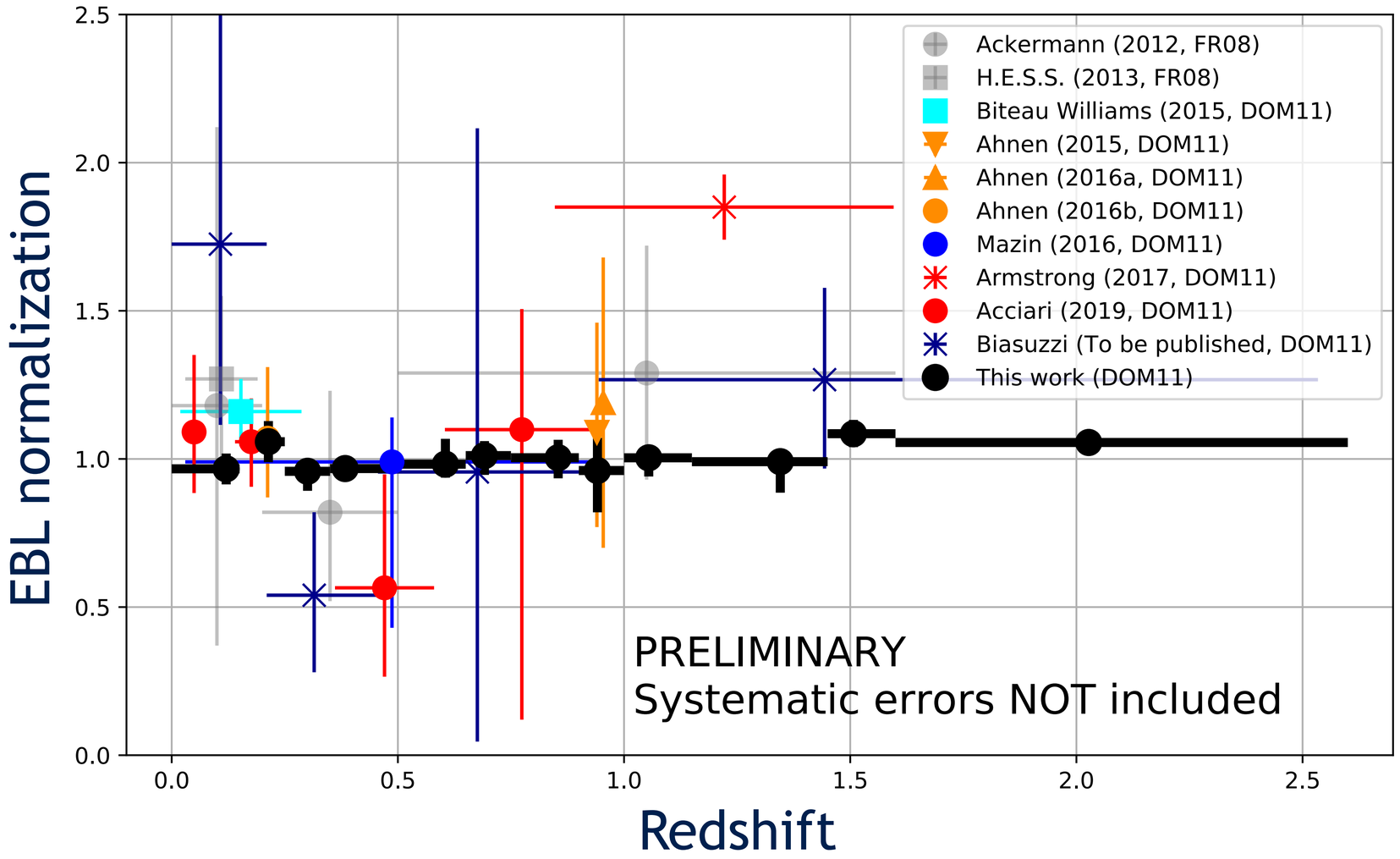
Conclusions

- We have conducted a comprehensive sensitivity study to assess CTA capabilities to search for processes that affect gamma-ray propagation
- Developed tools are ready to be used when first CTA data is taken
- Dedicated sensitivity studies and detailed tool development will be continued in the future
- **CTA will have unprecedented sensitivity to detect (constrain) the EBL, IGMF, ALPs, and LIV**

Back up

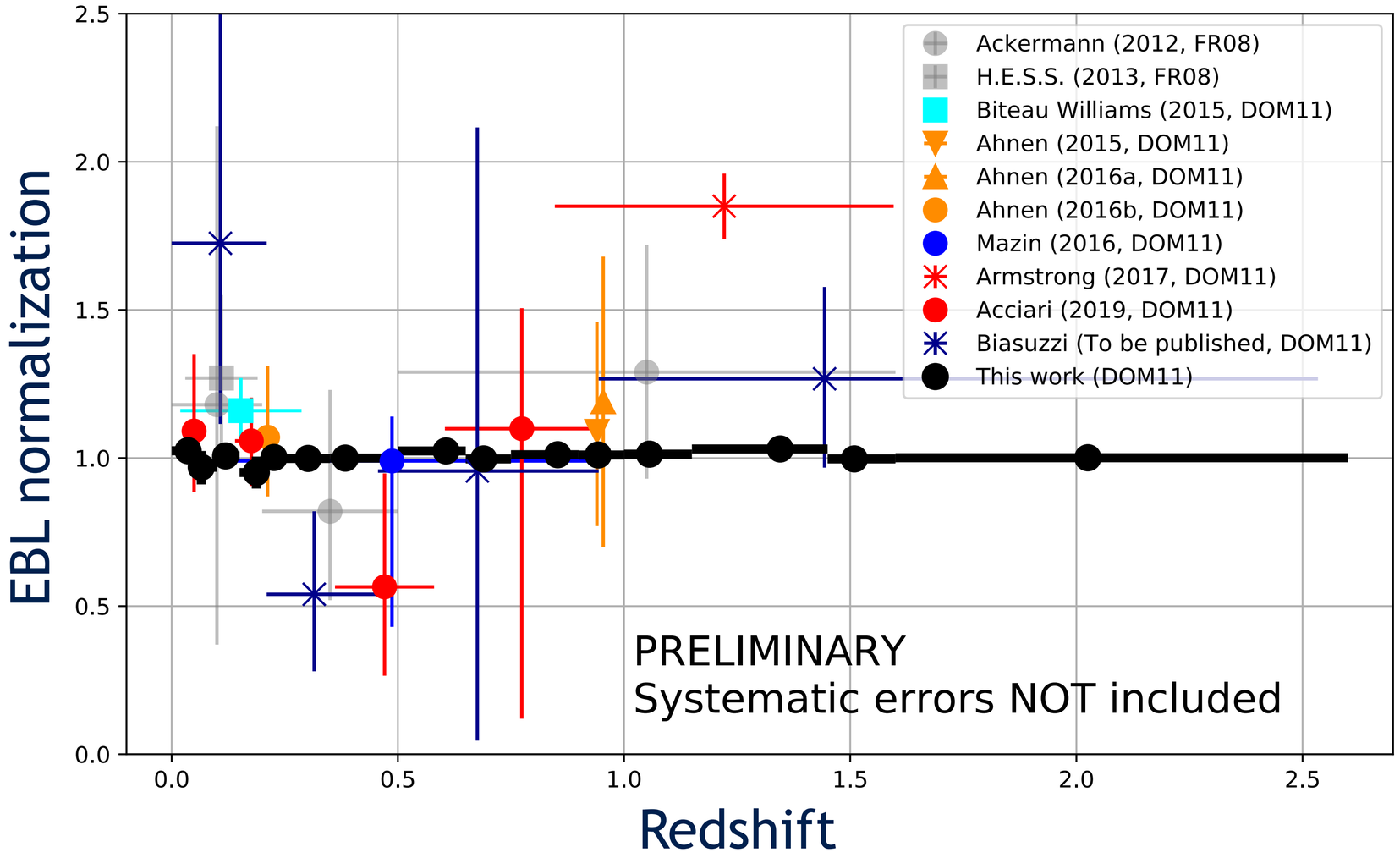
EBL: Results

No exponential cutoff fitted in last two redshift bins

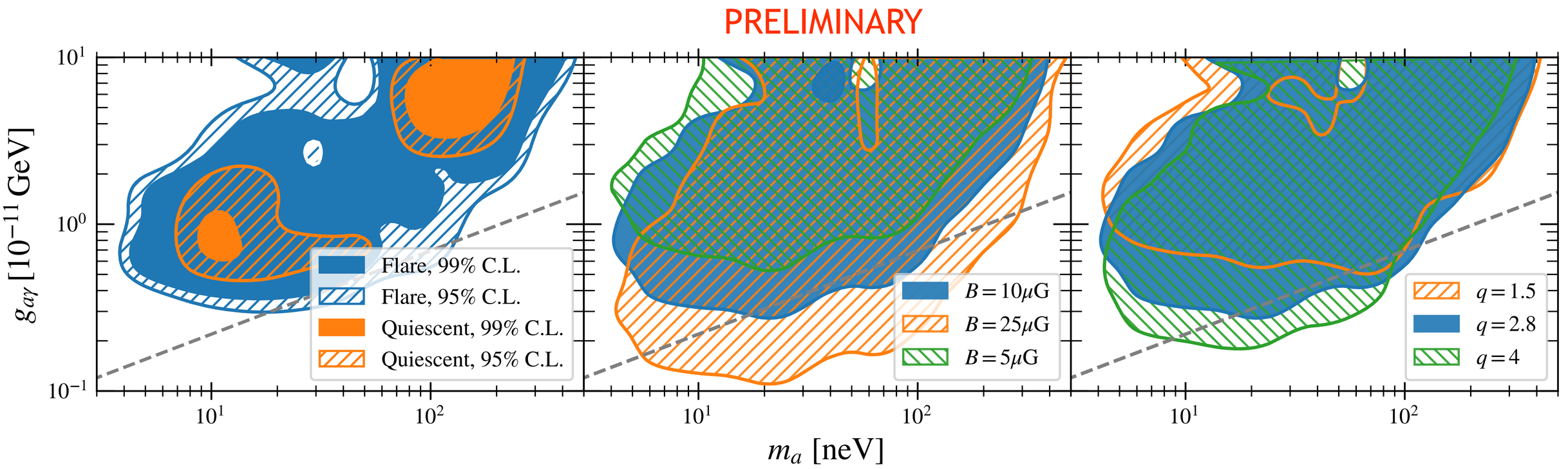


EBL: Results

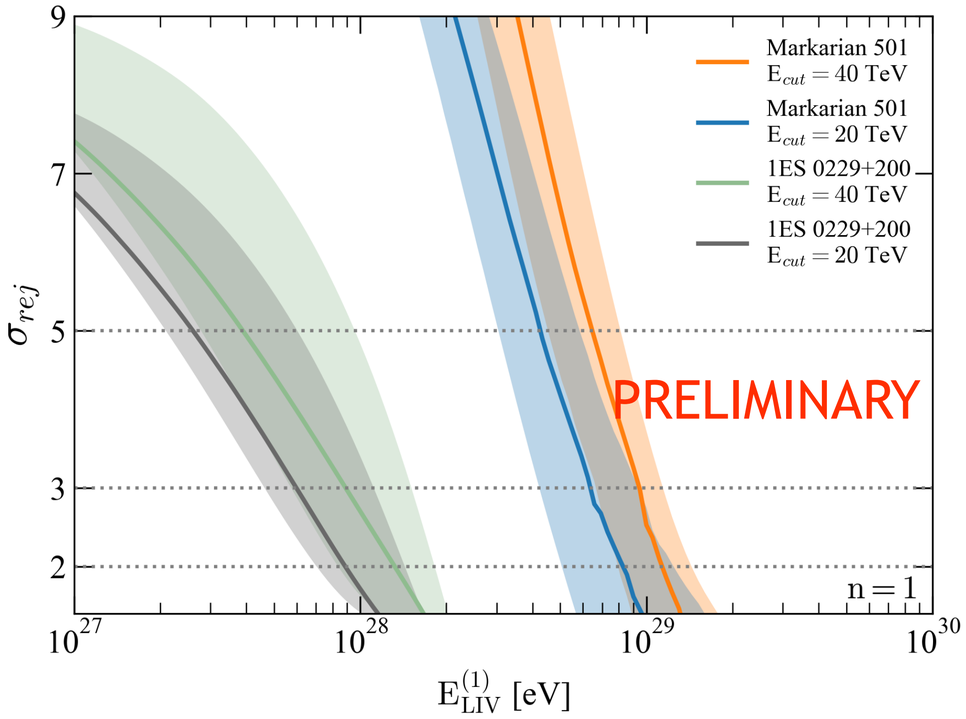
Exponential cutoff simulated at 10 TeV / (1+z) and no exponential cutoff fitted beyond z=0.5



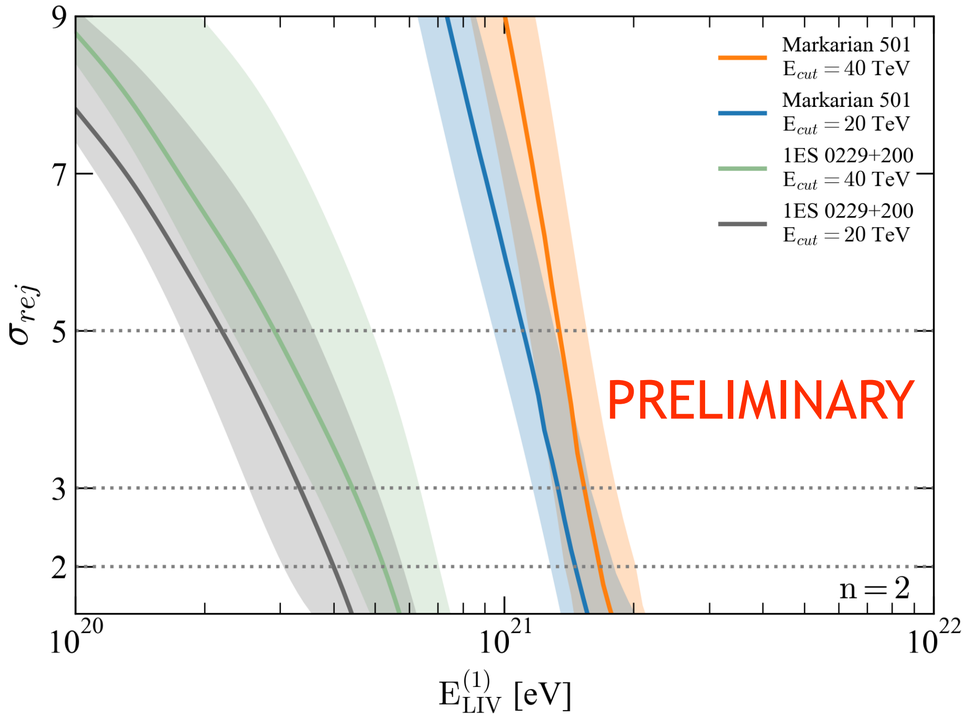
Systematic effects on ALP constraints



LIV detection rejection significances



n=1



n=2