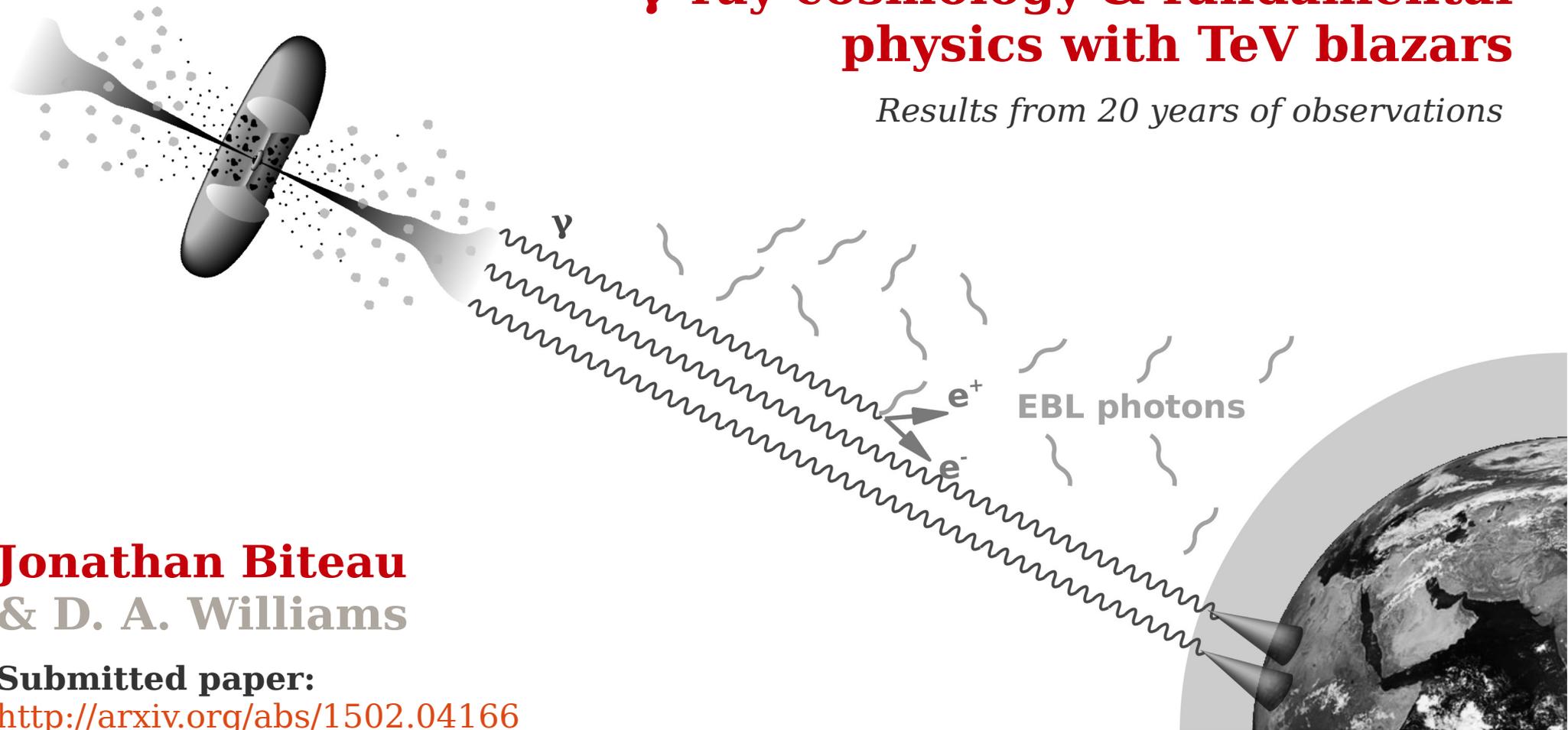


# **$\gamma$ -ray cosmology & fundamental physics with TeV blazars**

*Results from 20 years of observations*



**Jonathan Biteau**  
& D. A. Williams

**Submitted paper:**

<http://arxiv.org/abs/1502.04166>

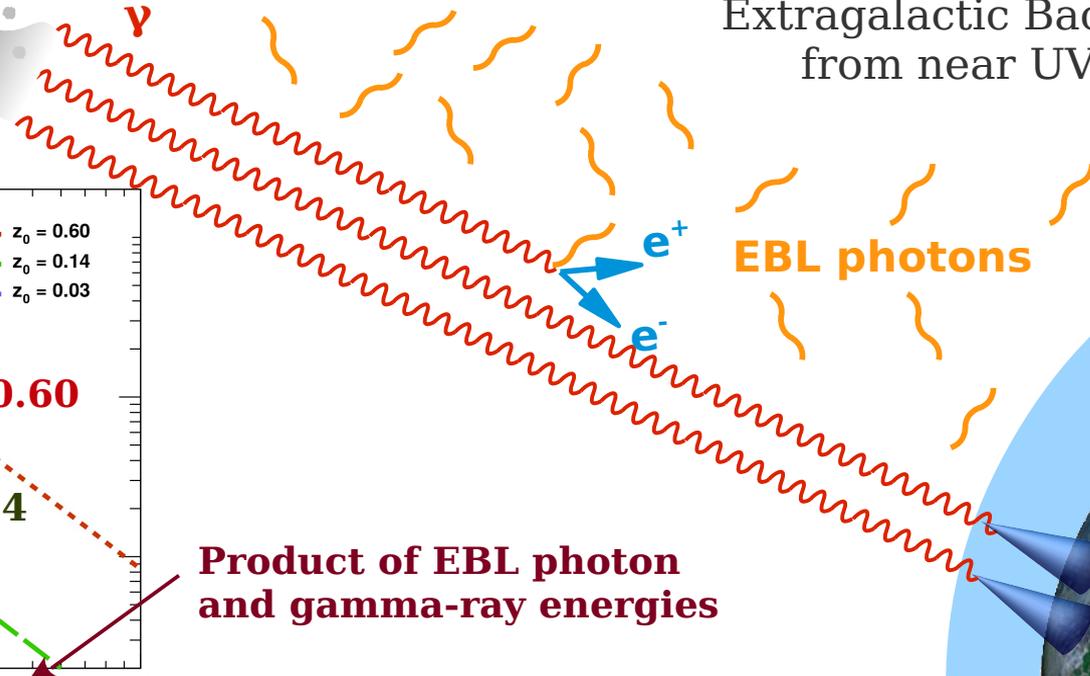
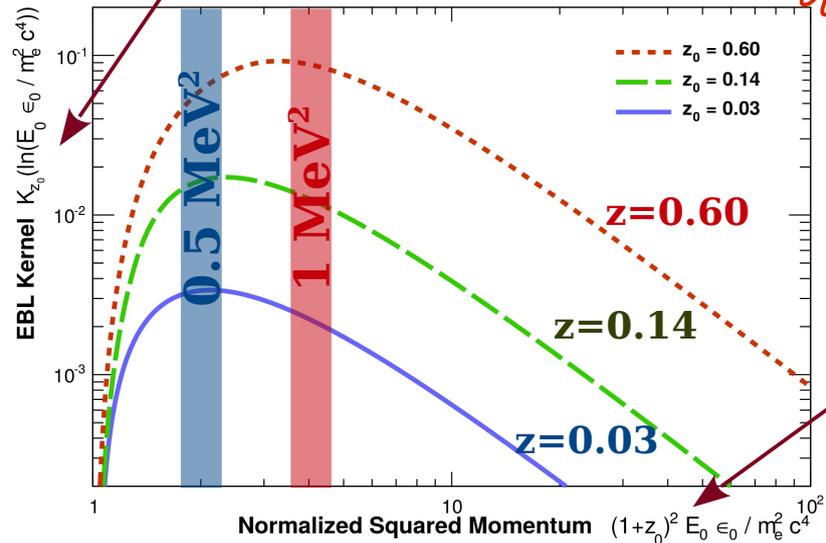
# Gamma-ray Absorption

## Pair creation along the line of sight

Most likely when gamma-ray energy times diffuse photon field energy equals 0.5–1 MeV<sup>2</sup>

→ TeV gamma-rays interact with eV photons i.e. with the Extragalactic Background Light from near UV to far infrared

## Probability of interaction



Product of EBL photon and gamma-ray energies

# Dataset and Hypotheses

## Dataset

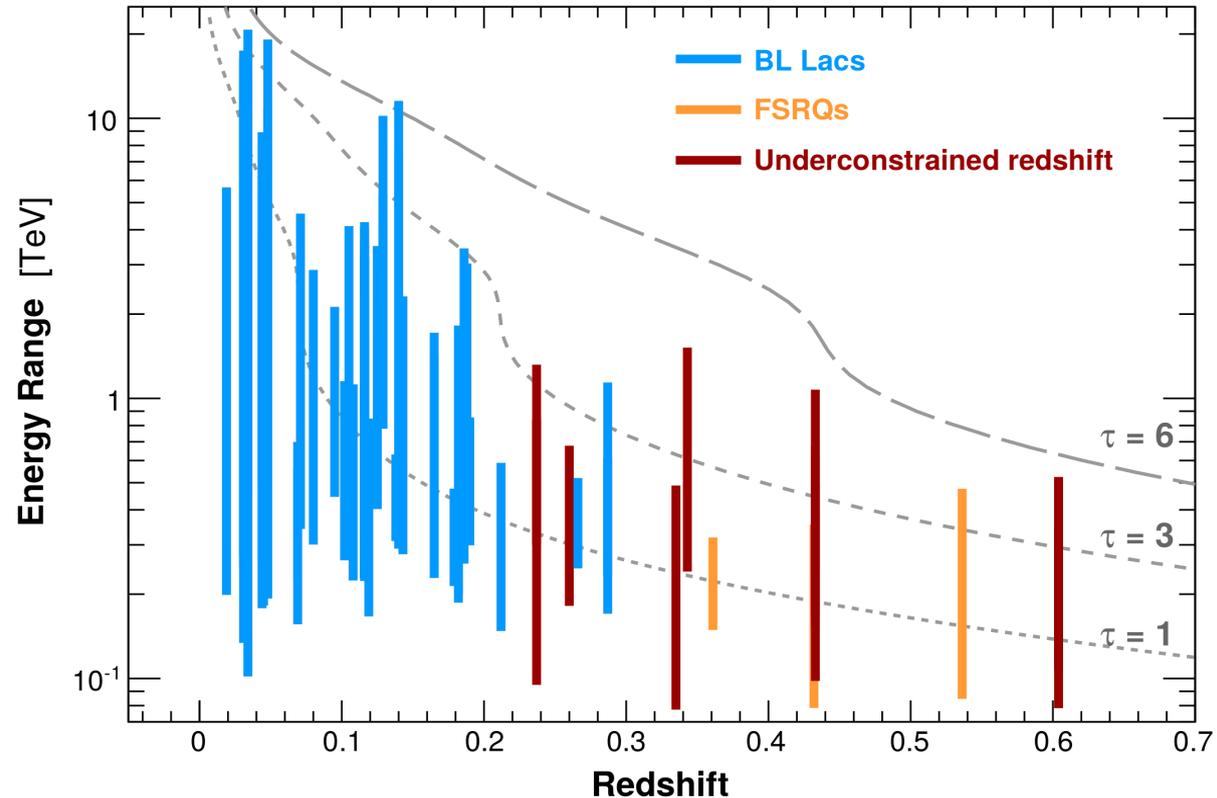
- . 106 TeV spectra from 38 sources, i.e.  $\sim 80\%$  of published data
- . GeV spectra when contemp. GeV-TeV observations

## Going public

- . Interest from MWL community  
→ TeVCat, ASDC SED builder

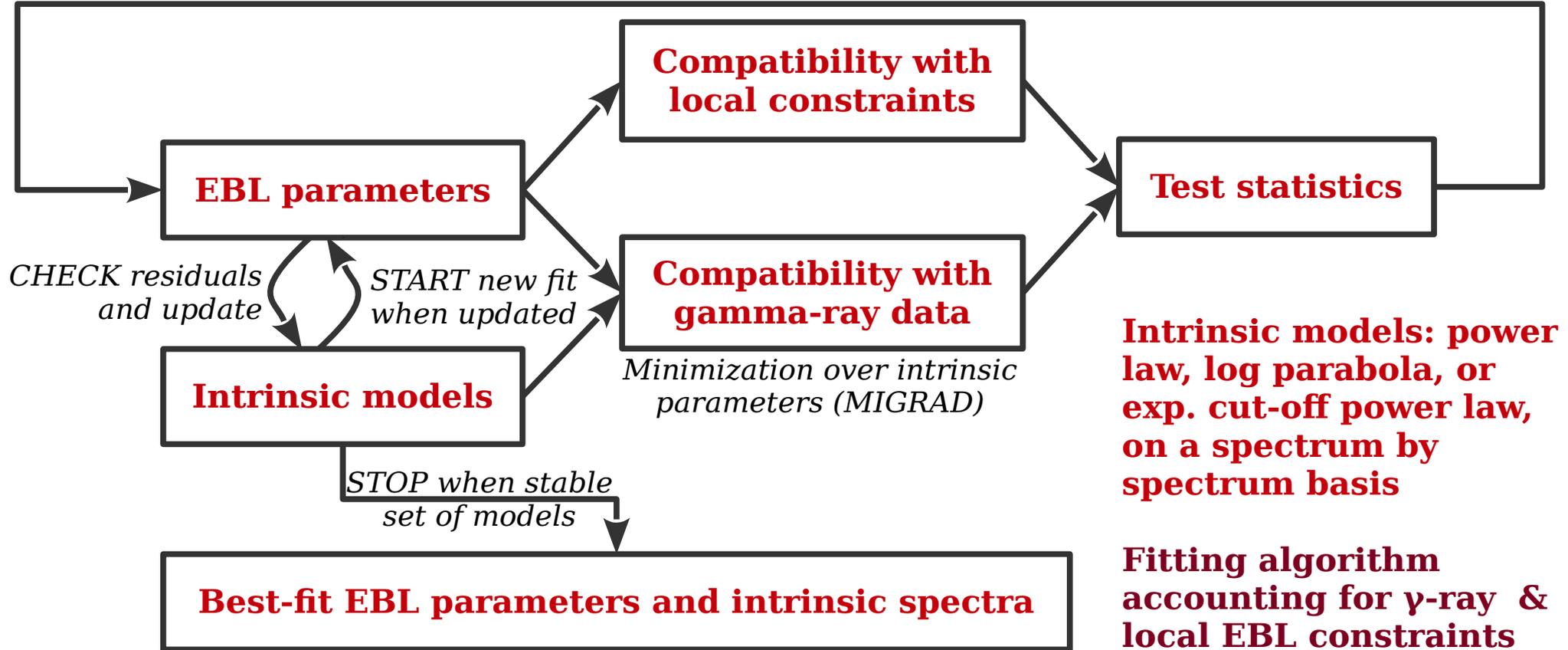
## Hypotheses

- . TeV emission at the source = smooth concave spectrum
- . TeV softer than GeV



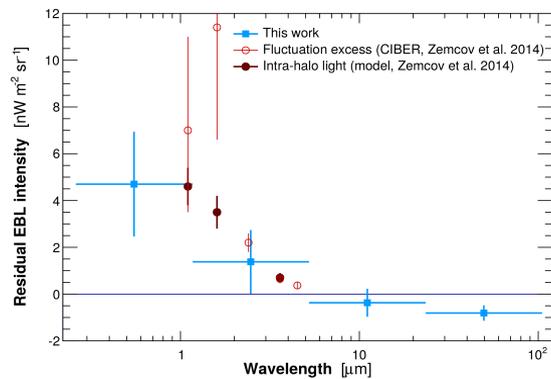
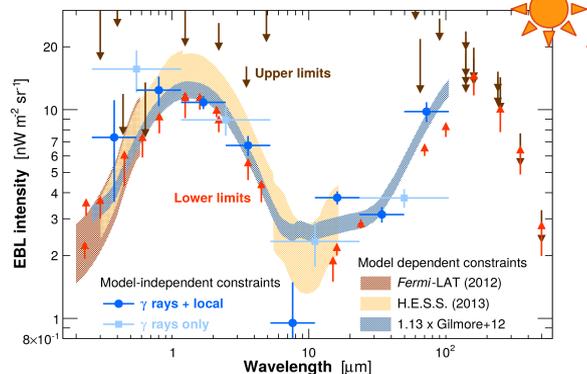
# Fitting algorithm

Minimization over EBL parameters (SIMPLEX, MIGRAD, HESSE) ~ 10-20 sec



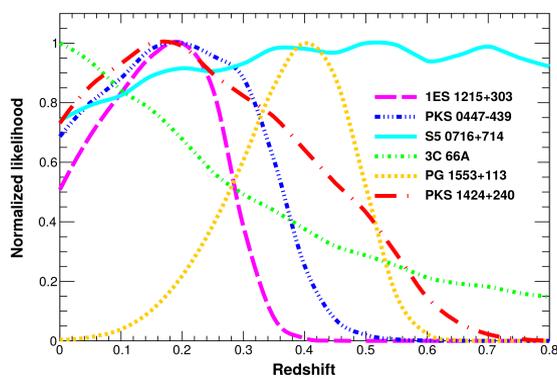
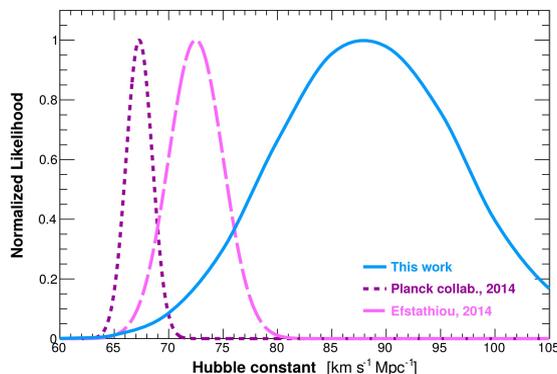
# Scientific Topics Studied

## EBL Spectrum



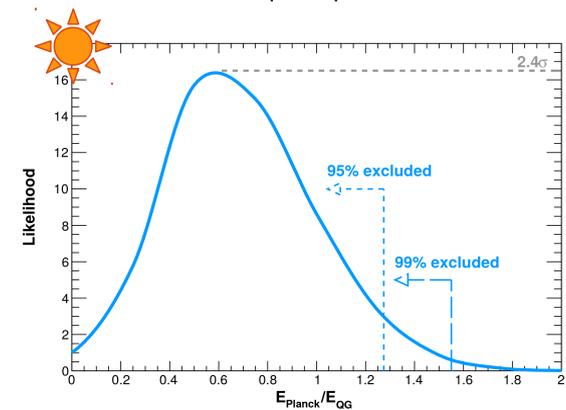
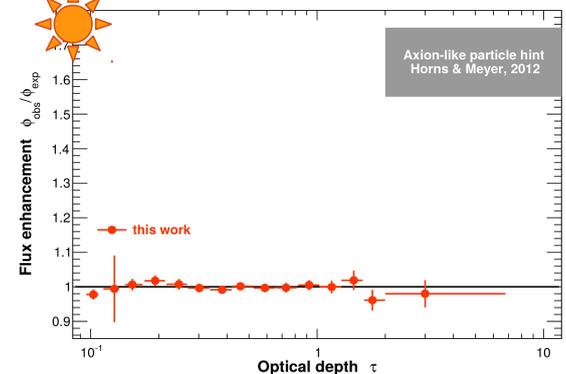
## Unresolved Sources & Reionization...

## Hubble Constant



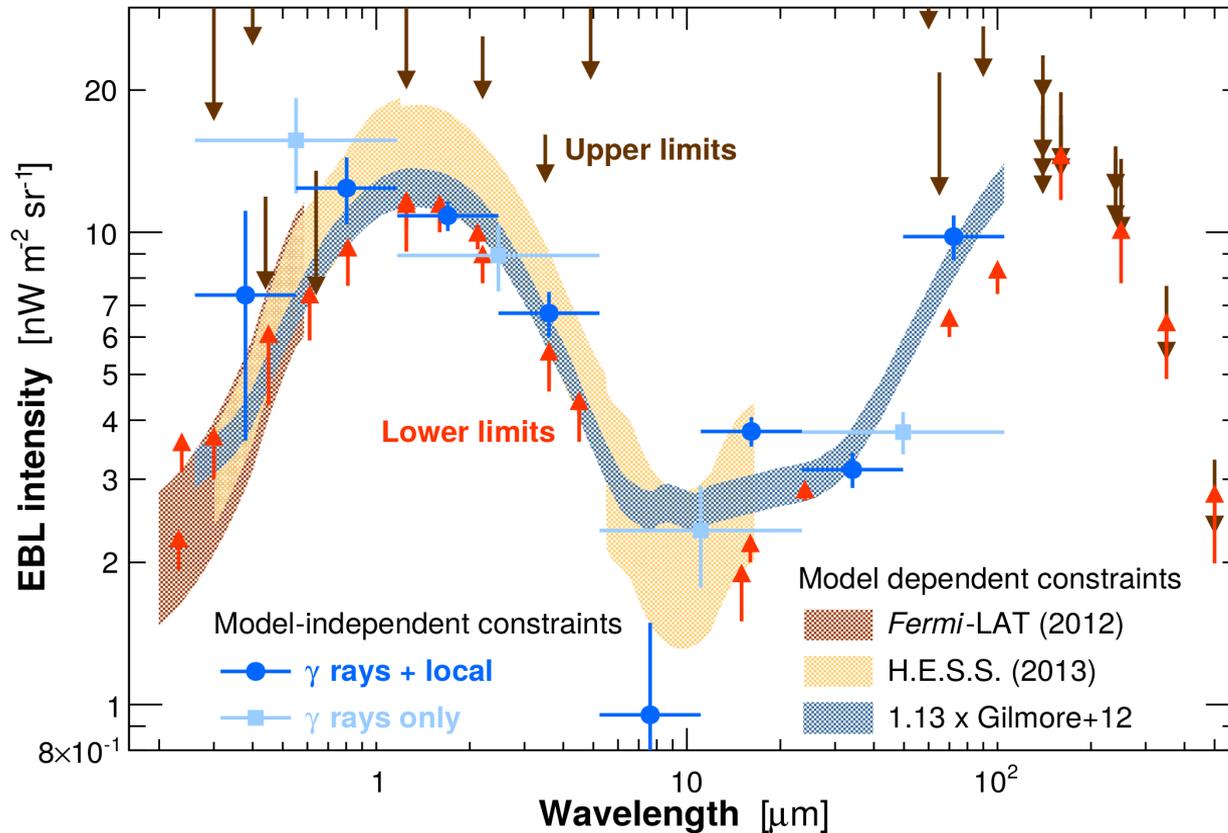
## Source distances

## Axion-Like Particles



## Lorentz Invariance

# The Extragalactic Background Light



- .  $11\sigma$  wrt to zero EBL both for model-dependent & independent methods
- . Good agreement with Gilmore+12, Dominguez+11, Franceschini+08 models. 4 others ruled out.
- . EBL (0.1 - 1000  $\mu\text{m}$ ):  
 $62 \pm 12 \text{ nW m}^{-2} \text{sr}^{-1}$   
 $6.5 \pm 1.2\%$  of the CMB
- . No significant tension with galaxy counts

**Gamma-ray inferred EBL is NOT too low with respect to expectations from UV-IR observations!**

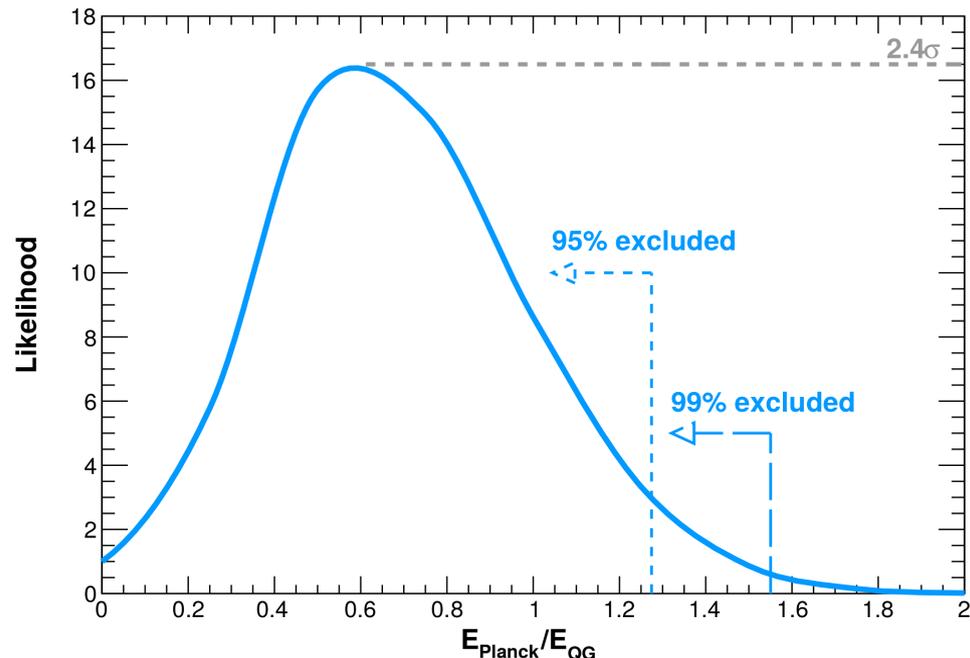
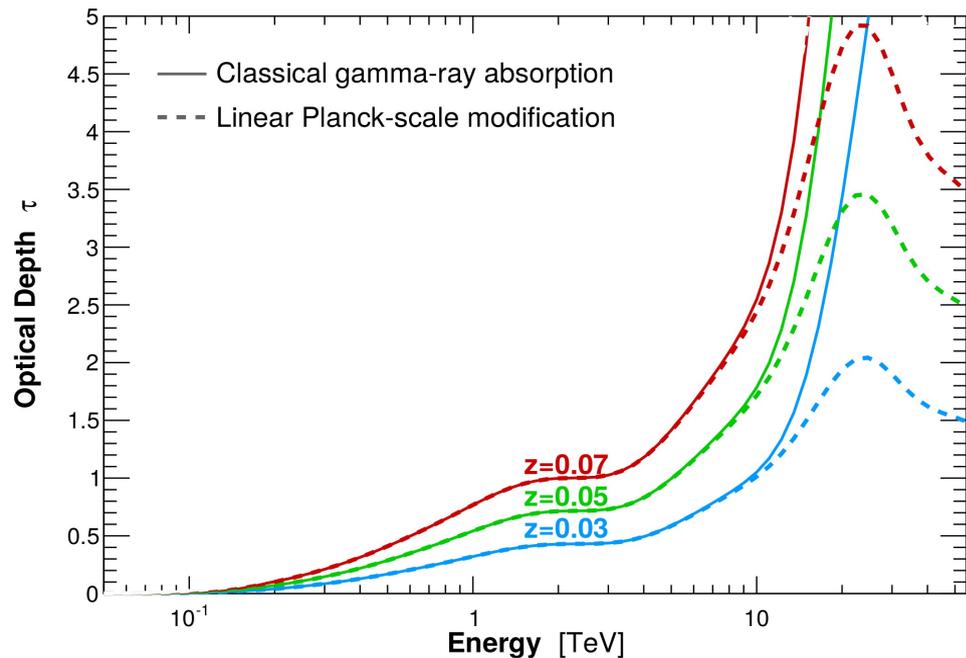
# Lorentz Invariance

## Principle

. Modified dispersion relation:  $E^2 \times (1 + E/E_{\text{QG}}) = p^2 + m^2$  with  $E_{\text{QG}} \sim E_{\text{Planck}} \sim 10^{28}$  eV

## Results

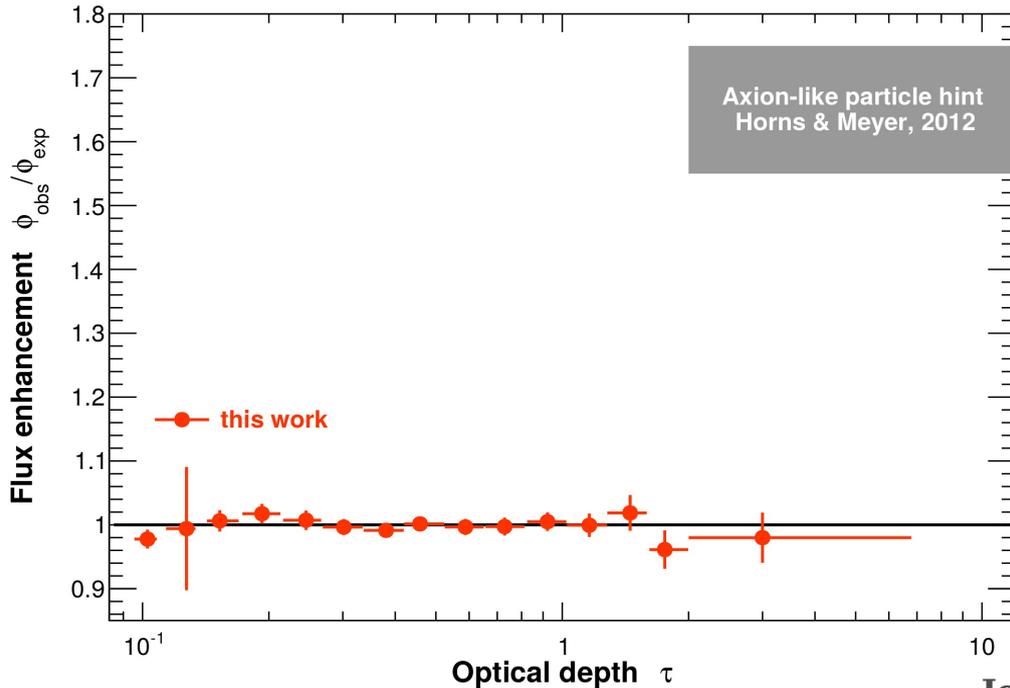
.  $2.4\sigma$  preference for  $E_{\text{QG}} \sim 1.5 \times E_{\text{Planck}}$ , **99% conf. level lower limit:  $E_{\text{QG}} > 0.6 \times E_{\text{Planck}}$**



# Axion-Like Particles

## Method: Study flux residuals as a function of optical depth

- . Horns & Meyer 12, Meyer+13 found a 3-4 $\sigma$  flux enhancement above  $\tau=2$ , interpreted as a coupling of gamma rays with hypothetical ALPs
- . Flux enhancement computation in  $\tau$ -bins, accounting for flux uncertainties



## Results

- . All spectra are well fit by classical EBL absorption
- . Flux enhancement above  $\tau=2$ :  **$-2 \pm 4\%$**  vs  $\sim 70\%$  inferred from Horns & Meyer 12

**No anomaly correlating with optical depth (or energy) detected!**

**Undermines the science case for ALPs or UHECR line-of-sight reprocessing!**

# Summary

## Computing the gamma-ray optical depth to the EBL gets simpler!

- . 3D integral (distance, energy, angle) → 2D integral (distance, energy) analytically
- . 2D integral → convolution product, based on a simplified evolution (valid up to  $z \sim 0.8$ )

## First spectral fit of the EBL spectrum in a model-independent way

- . Largest sample of gamma-ray spectra ever used in a gamma-ray cosmology study
- . Best-fit EBL preferred at  $11\sigma$  with respect to zero EBL
- . Gilmore+12, Dominguez+11, Franceschini+08 do an equally good job as the model-independent method. Other recent models are ruled out.
- . Gamma-ray based results in good agreement with expectations from local estimates

## First quantitative search for Lorentz Invariance Violation based on pair-creation

- . Interesting (but insignificant)  $2.4\sigma$  excess around  $E_{\text{Planck}}$  → need more  $>20$  TeV data!
- . Limit  $E_{\text{QG}} > 0.6 \times E_{\text{Planck}}$  (99%) better than and independent of AGN-variability-based approaches, e.g.  $E_{\text{QG}} > 0.2 \times E_{\text{Planck}}$  at 95% from H.E.S.S. observation of PKS 2155-304.

## No indication of ALPs or UHECR signatures

- . Gamma-ray spectra of blazars are well fit with classical absorption!