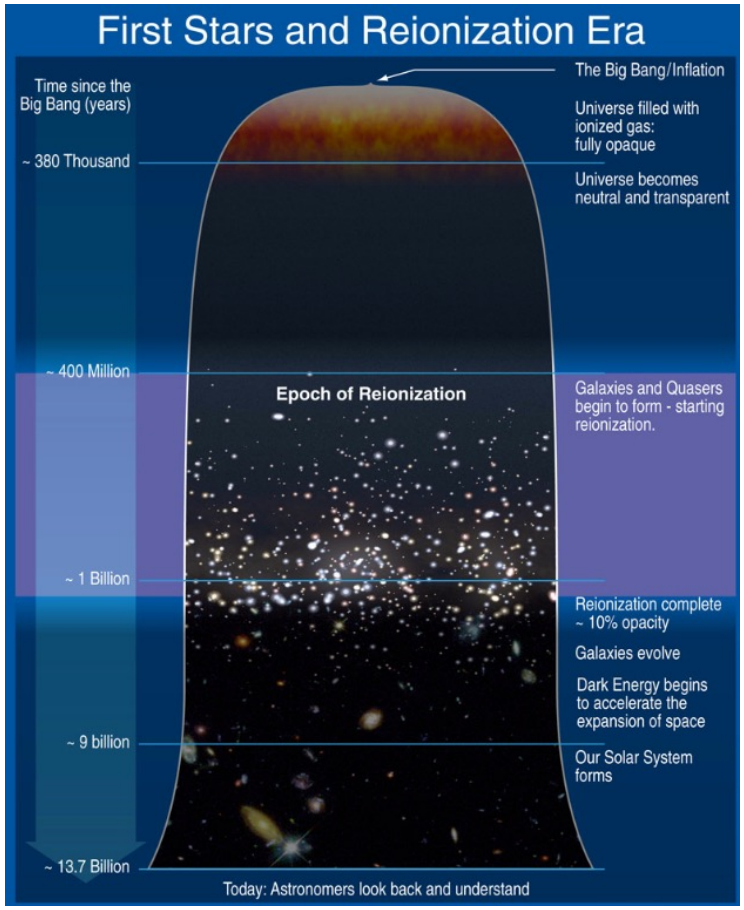
EBL constraints from gamma-ray opacity measurements

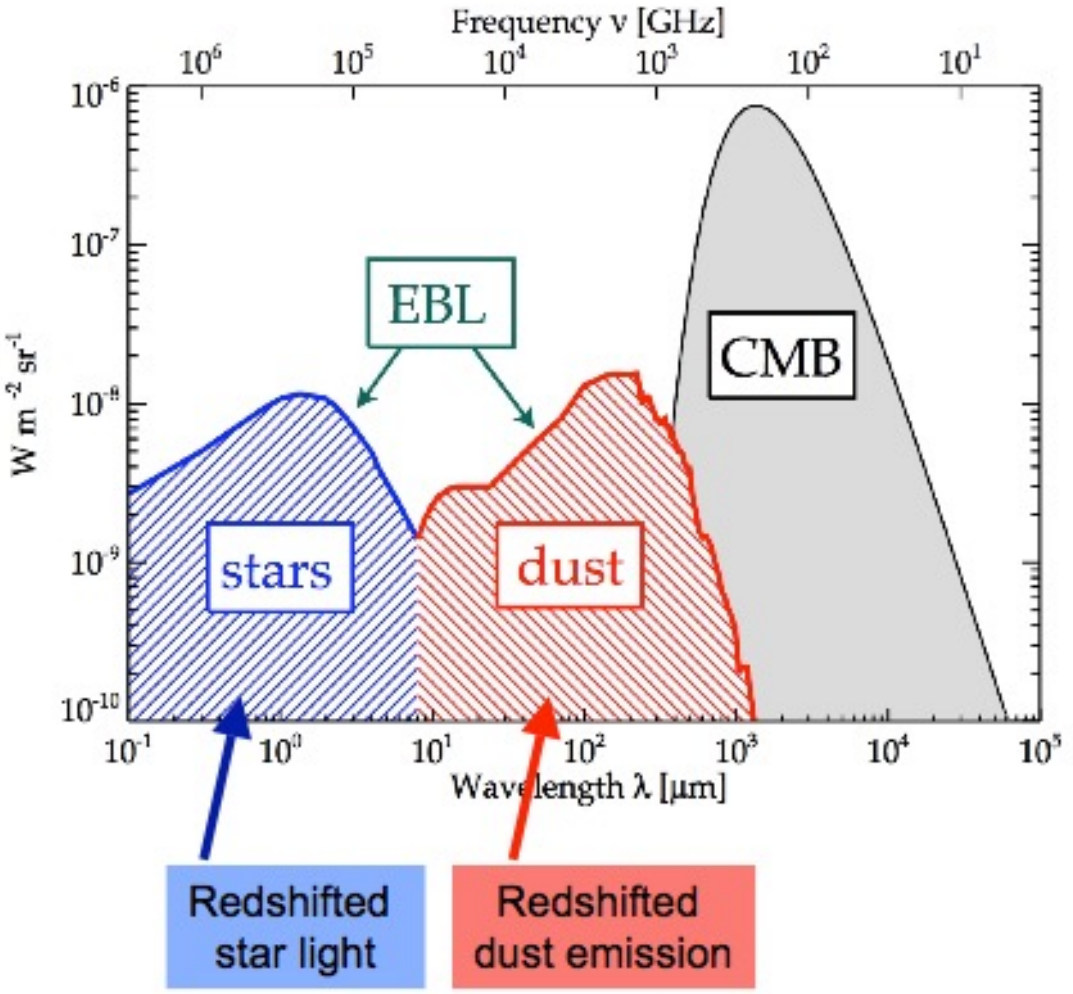
In collaboration with Justin Finke, Vaidehi Paliya, Alberto Domínguez, Abhishek Desai, Dieter Hartmann, Kari Helgason

Fermi-LAT collab. 2018, *Science, 362, 1031*
Desai+2019, ApJL, 874,7
Domínguez+19, ApJ, 885, 137

Marco Ajello
[Clemson University]

The Extragalactic Background Light

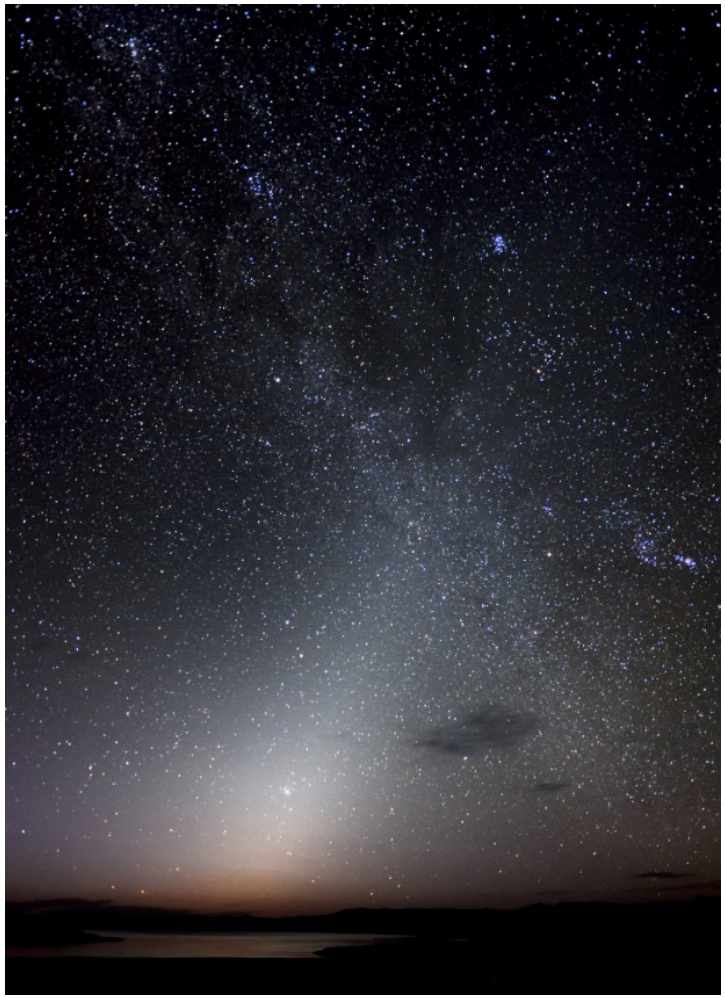


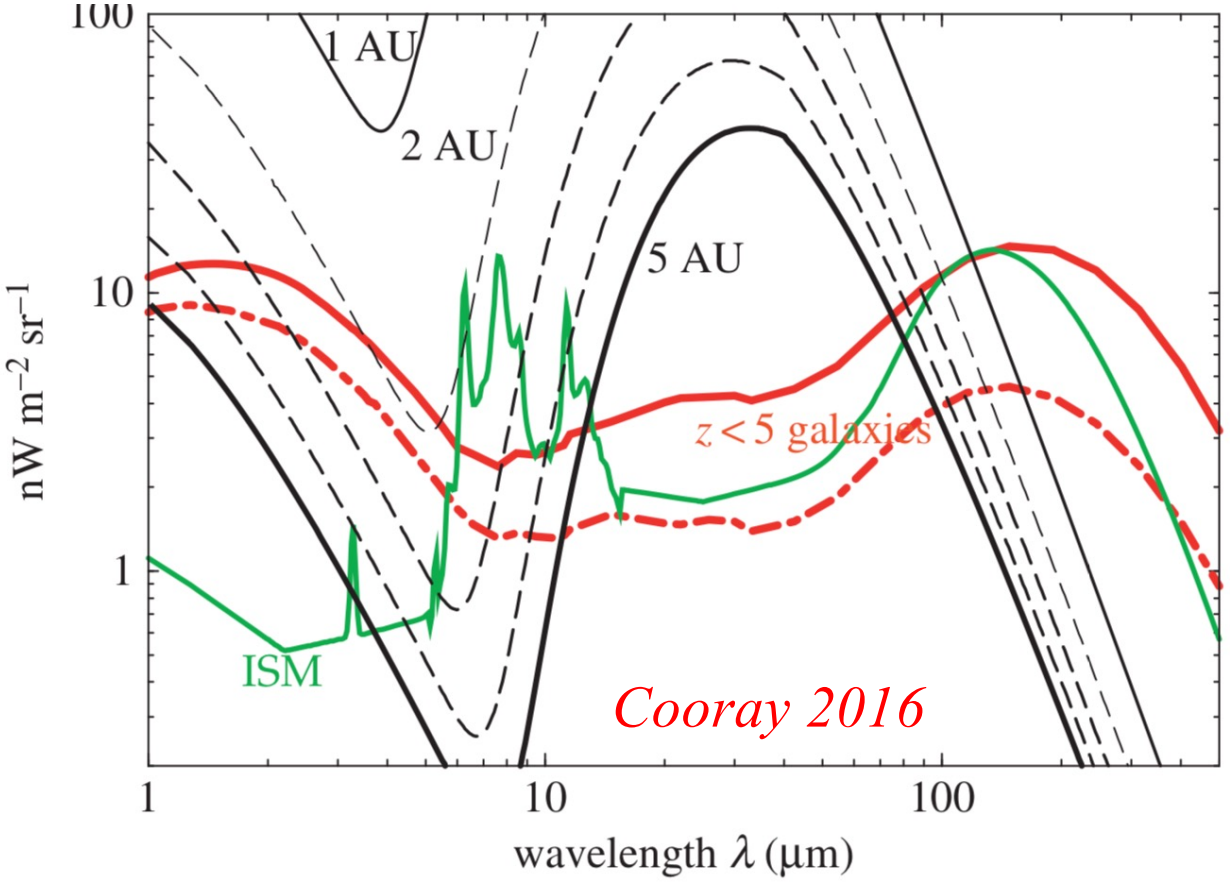


- ->constraints on galaxy evolution, star formation activity, dust extinction processes
- ->understanding cosmic structure formation and evolution

Bright foregrounds

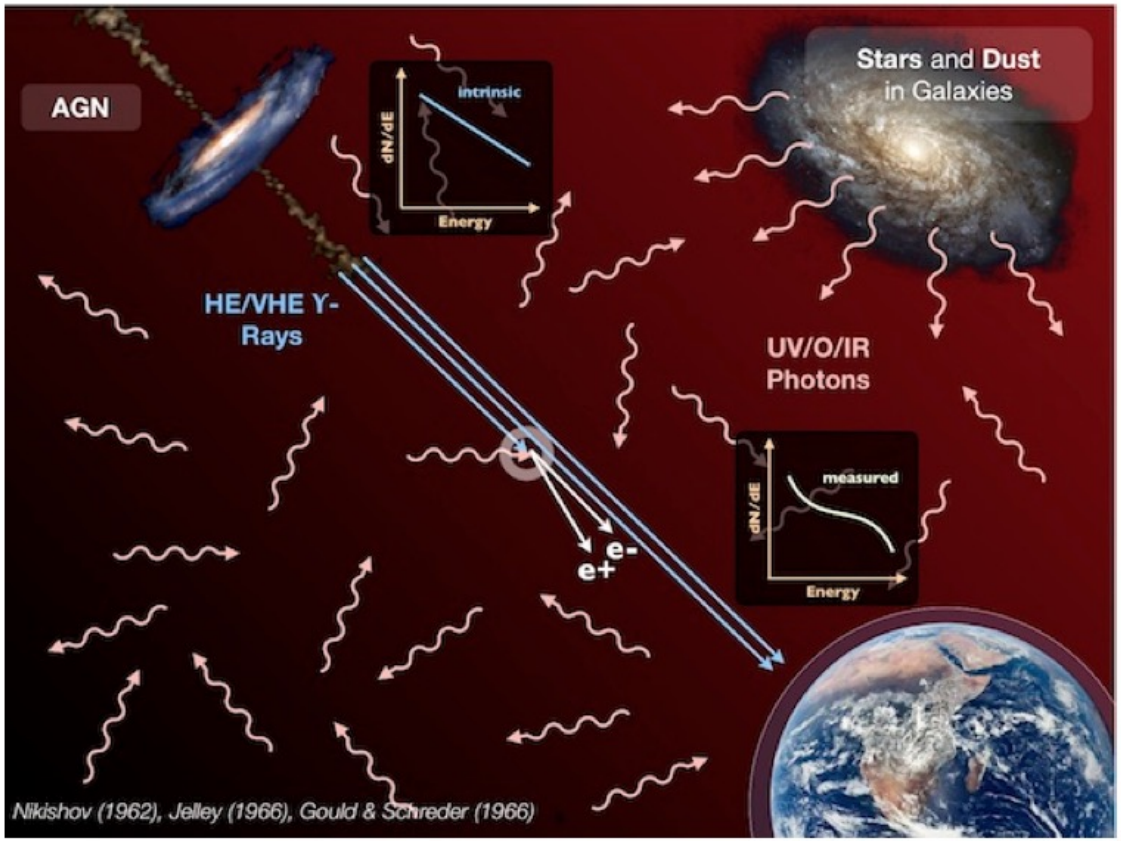
- Zodiacal light and our Galaxy are a hindrance for EBL direct measurement





Indirect EBL Measurement

- 2 Photons convert into an electron-positron pair if :
  - $E\gamma \times E_{EBL} \geq 2(m_e c^2)^2$



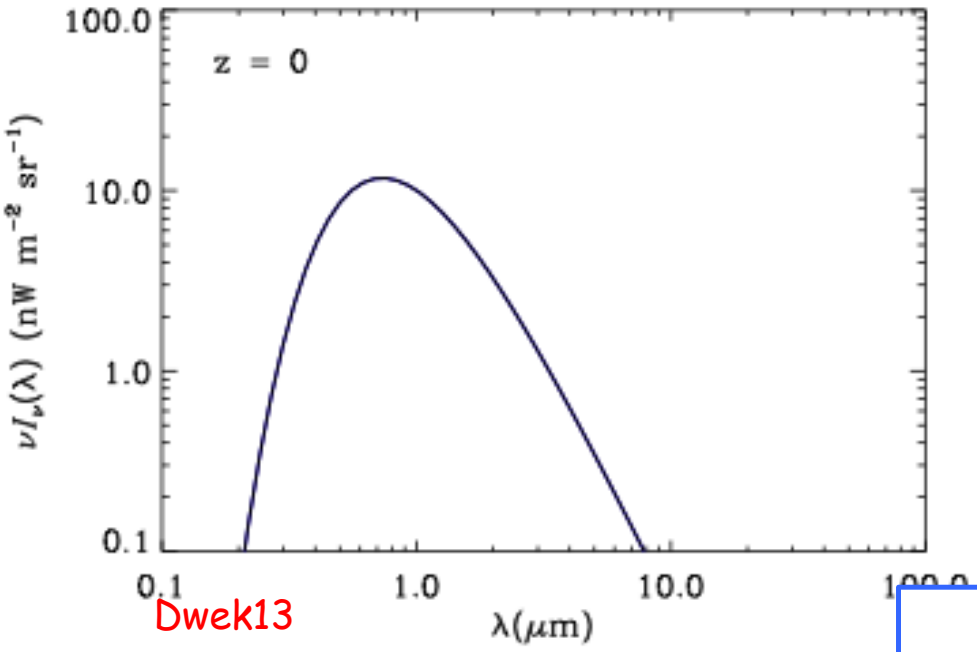
Intrinsic spectrum is attenuated

$$\frac{dN_{obs}}{dE} = \frac{dN_{int}}{dE} \times e^{-\tau_\gamma(E,z)}$$

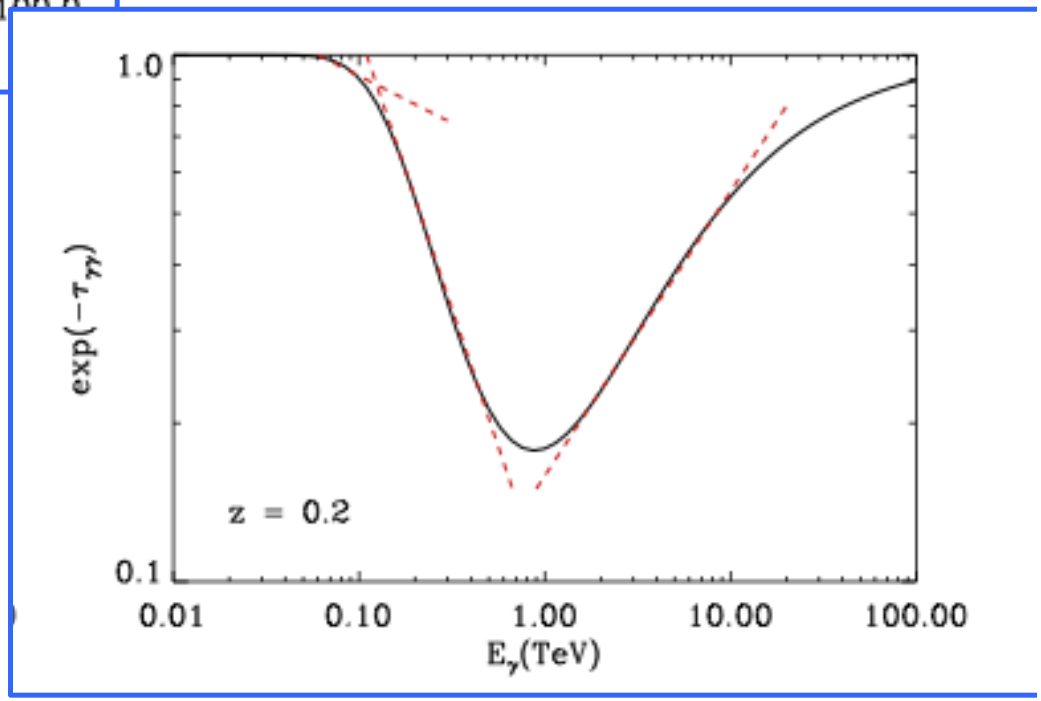
Optical Depth

$$\tau_\gamma = \int_0^z d\ell(z) \int_{-1}^{+1} d\mu \frac{1-\mu}{2} \int_{\epsilon'_{thr}}^{\infty} d\epsilon' \frac{dn_{bkg}}{d\epsilon} \sigma_{\gamma\gamma}(E', \epsilon', \mu)$$

What kind of absorption ?



Dwek13



"Spectroscopy" of the EBL

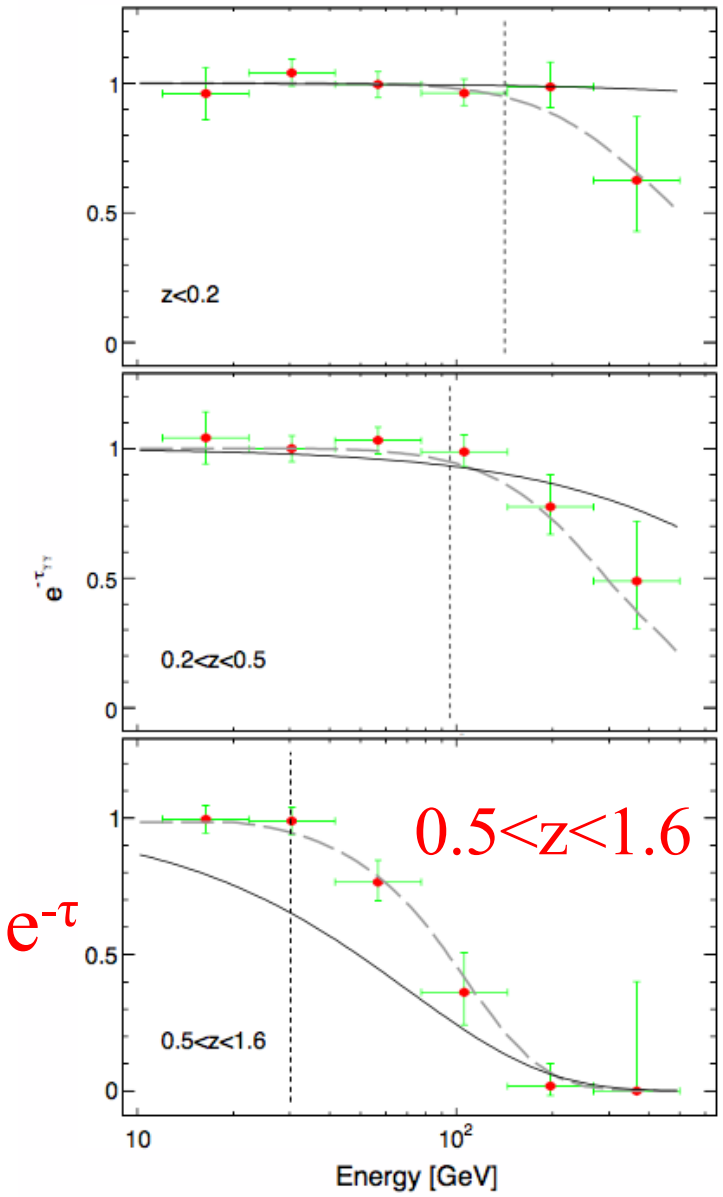
- 2 Photons convert into an electron-positron pair if :
  - $E\gamma \times E_{EBL} \geq 2(m_e c^2)^2$

γ-ray (z=0)	E=10 GeV	E=100 GeV	E=1TeV
EBL photon	26 eV	2.6 eV	0.26 eV

γ-ray (z=1)	E=10 GeV	E=100 GeV	E=1TeV
EBL photon	52 eV	5.2 eV	0.52 eV

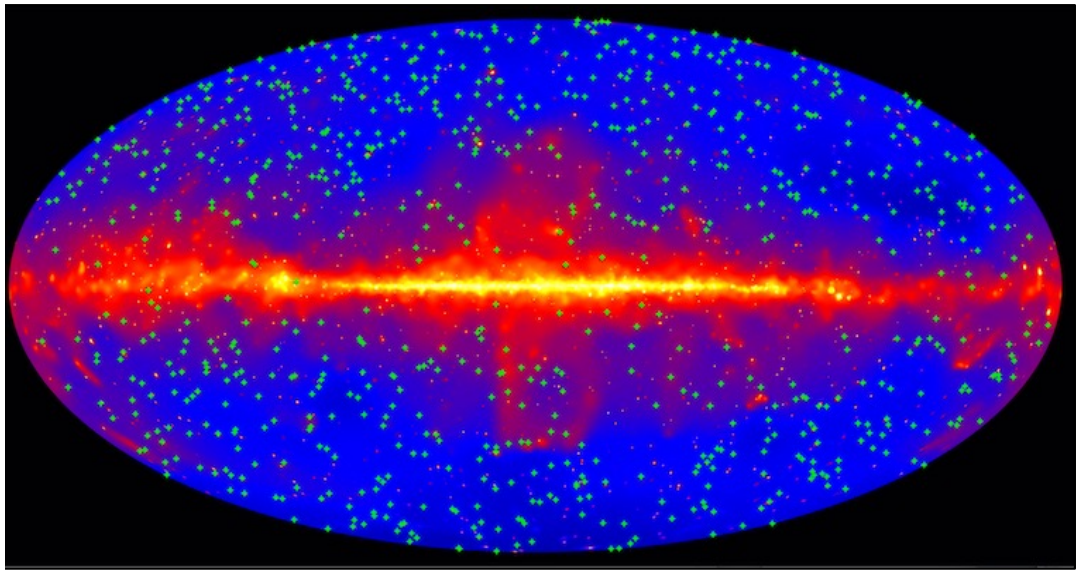
Detection of the EBL attenuation

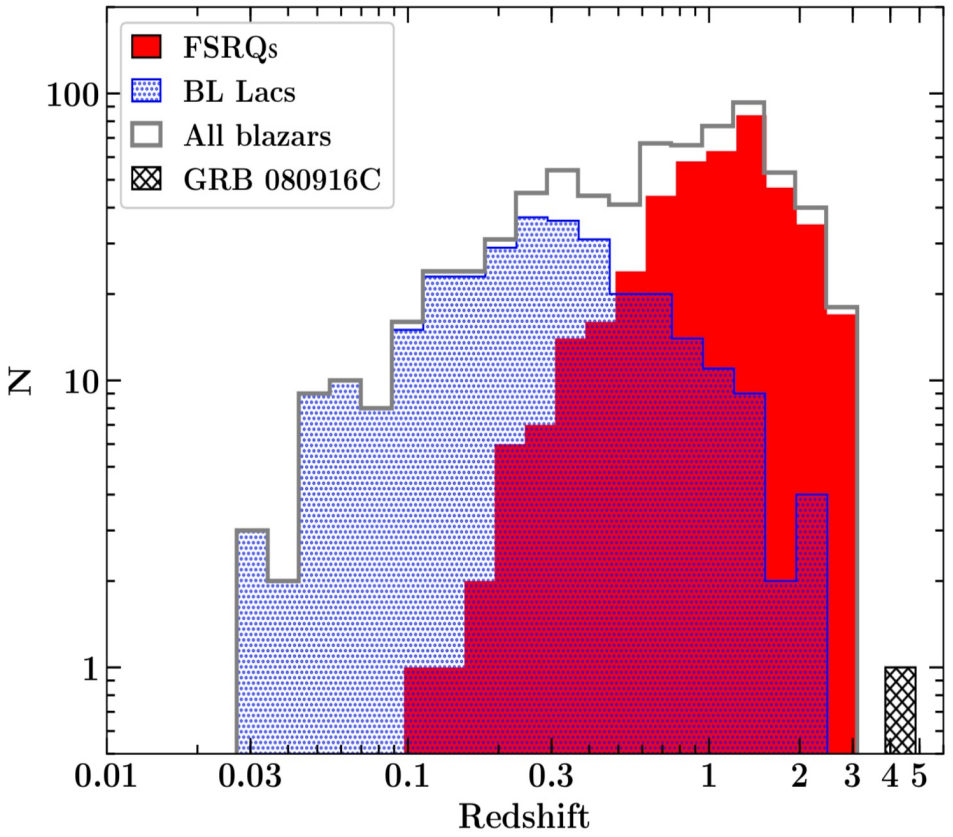
Ackermann et al. 2012



Average over 4 billion years !

Improved Dataset (2018)



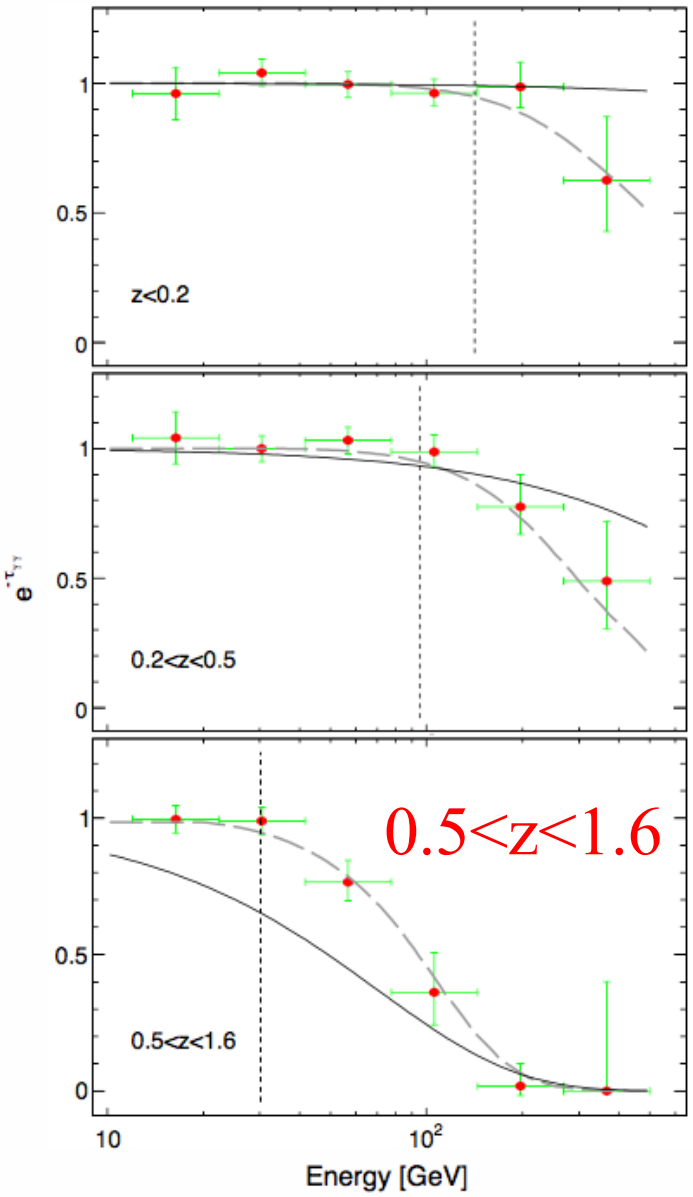


- Use 9 years of P8 LAT data
- 739 blazars + 1 GRB
- Perform a time-resolved analysis
- Analysis optimized on simulations

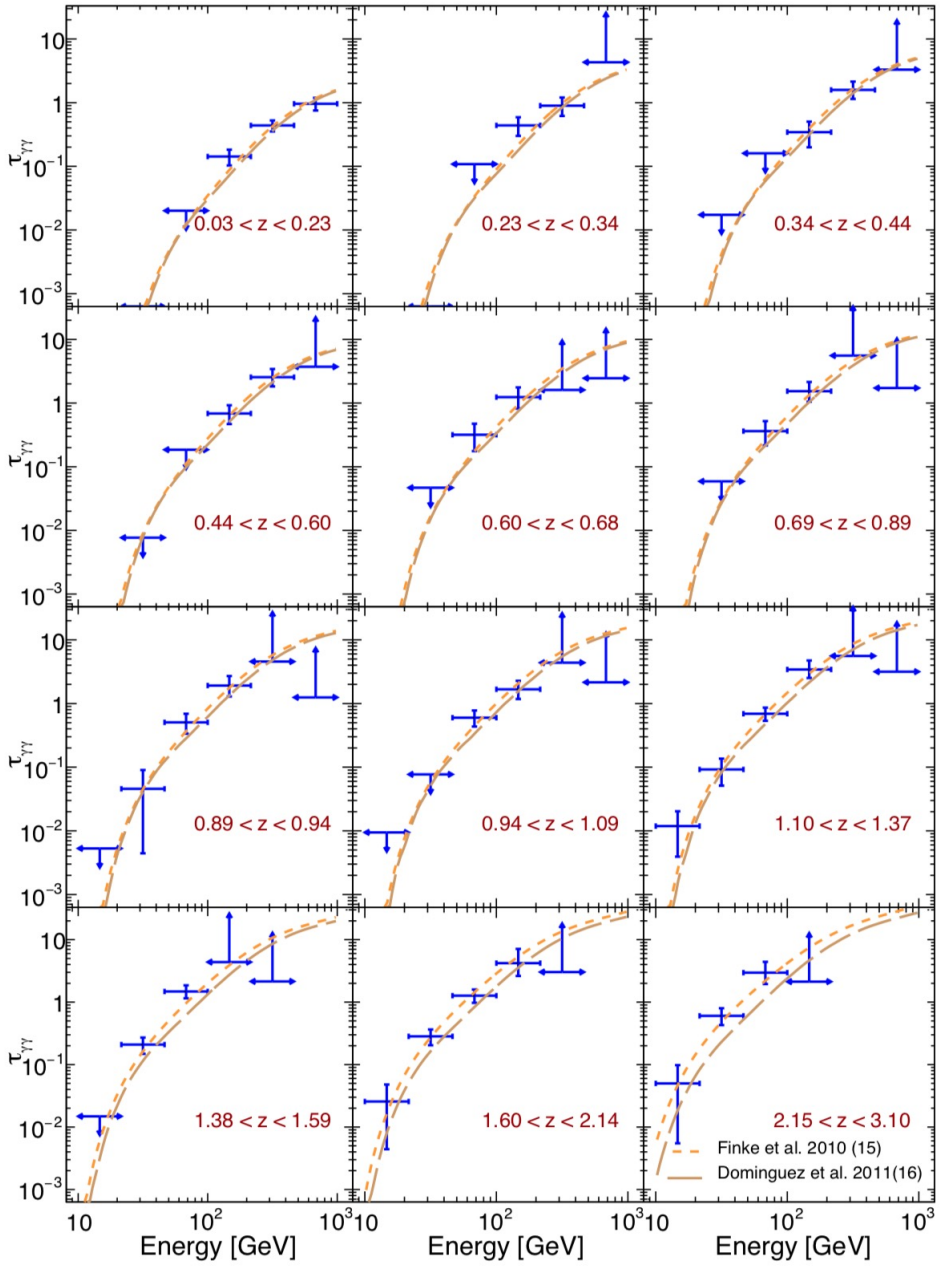
Analysis improved over the Ackermann+12 results

From Detection to Characterization

Ackermann et al. 2012

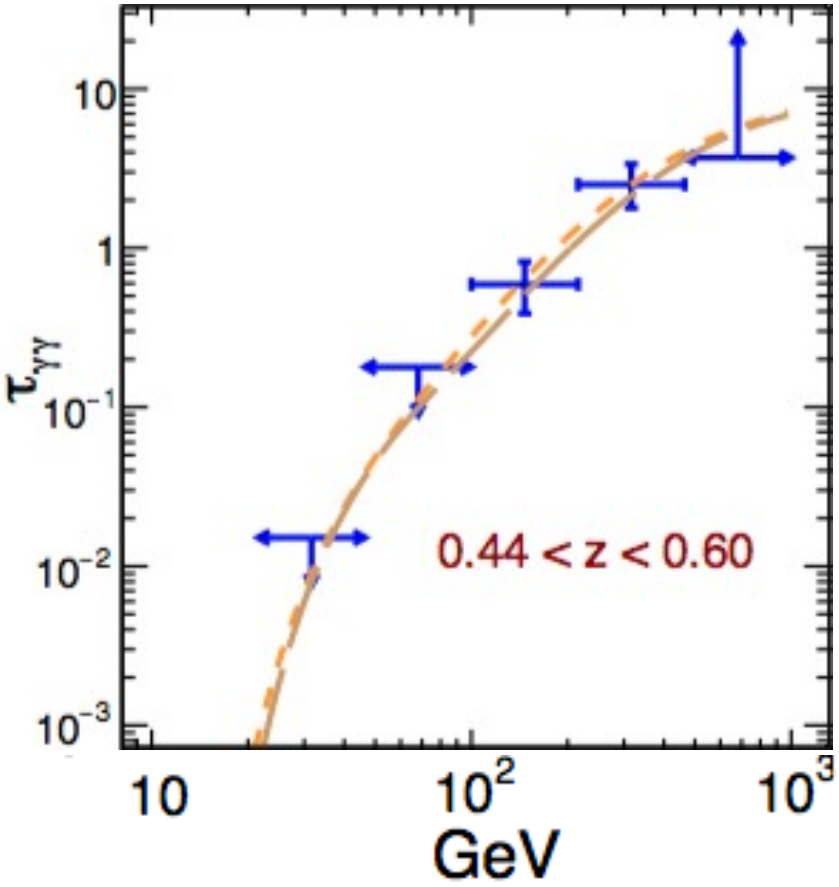


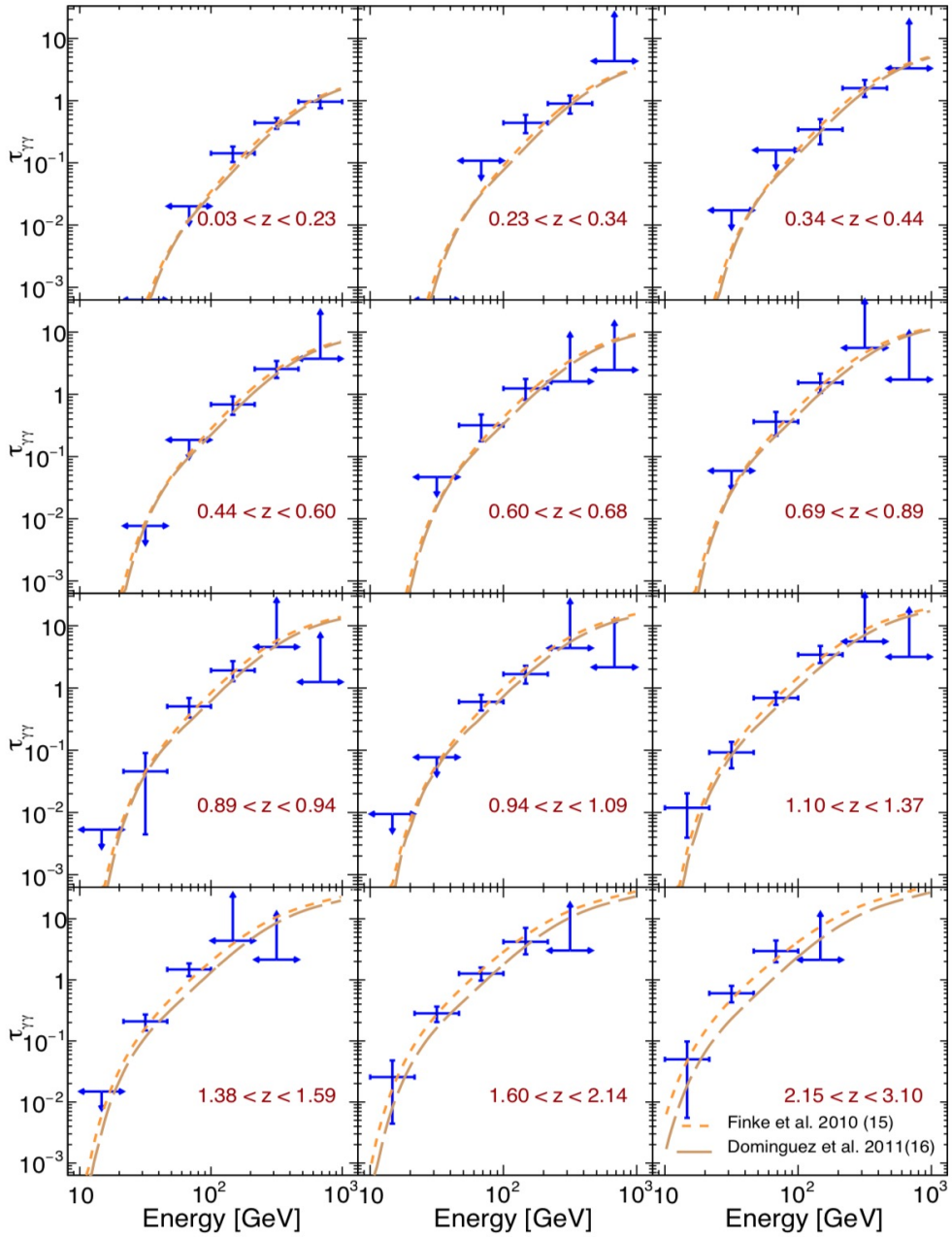
Abdollahi et al. 2018



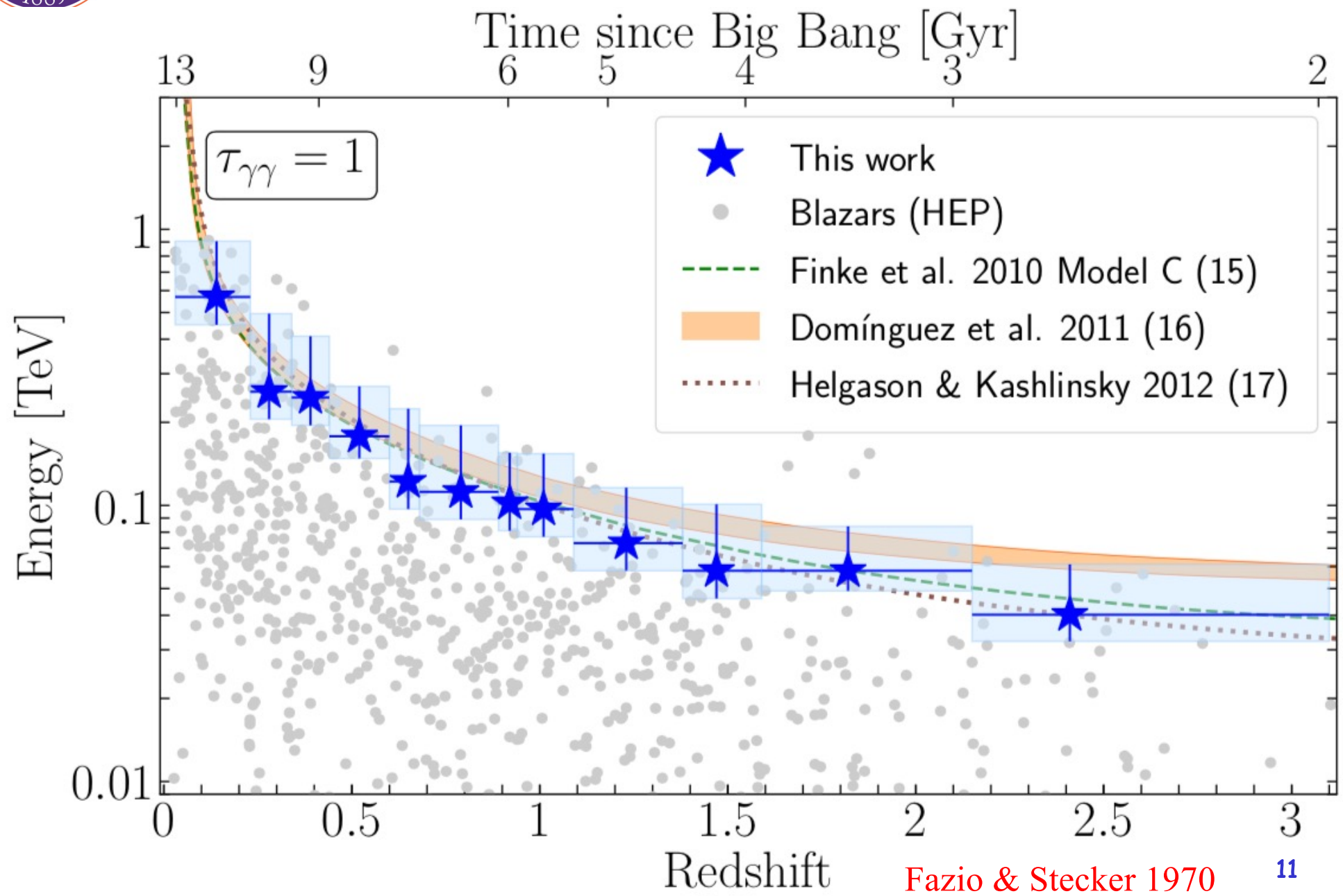
EBL measurements over 11 billion years

The fun part: Evolution with *z*
from z=0.03 to 3.1



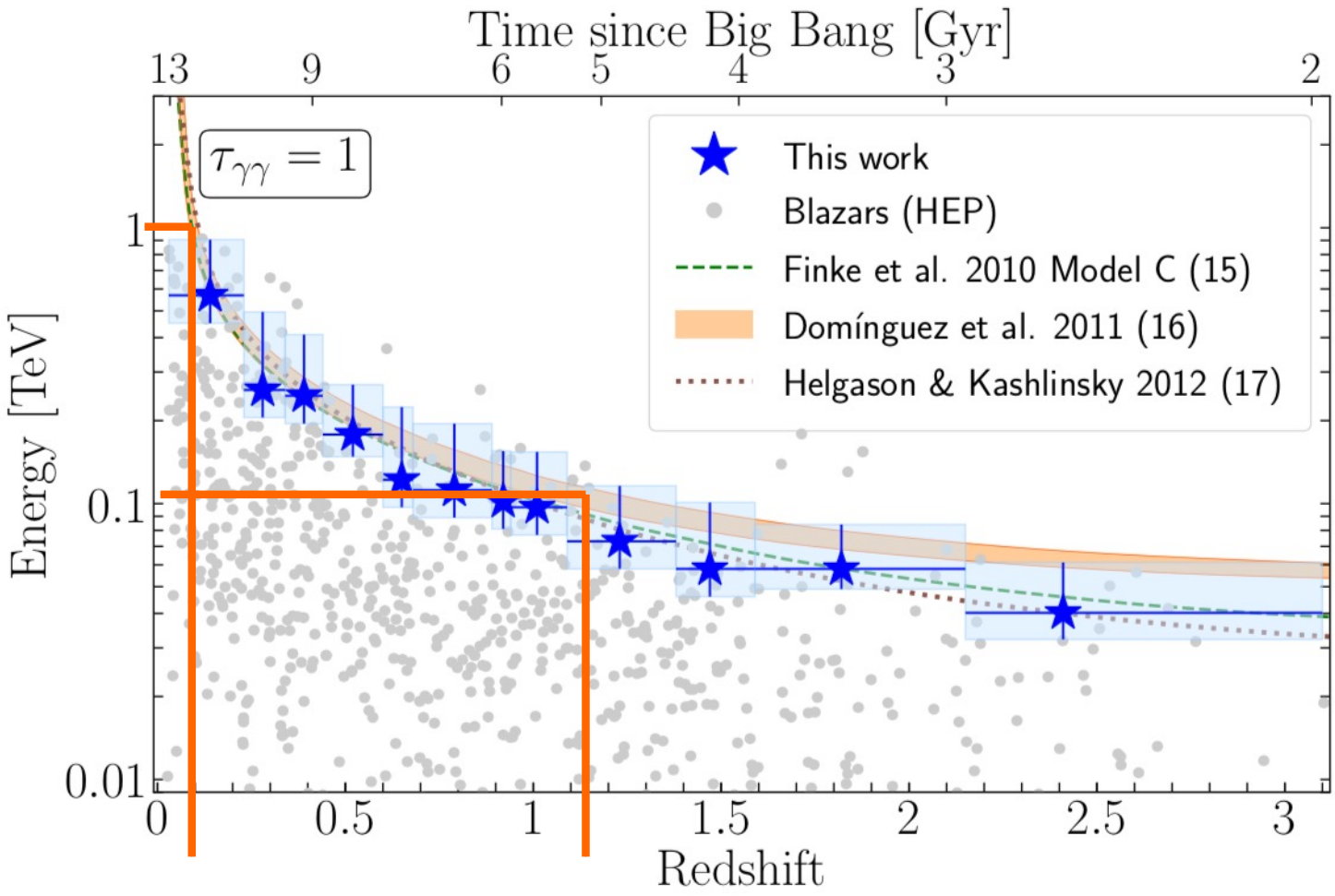


The Cosmic Gamma-ray Horizon



Fazio & Stecker 1970

The Cosmic Gamma-ray Horizon



"*The measurement of the EBL using GeV gamma rays is only sensitive to the average EBL*"

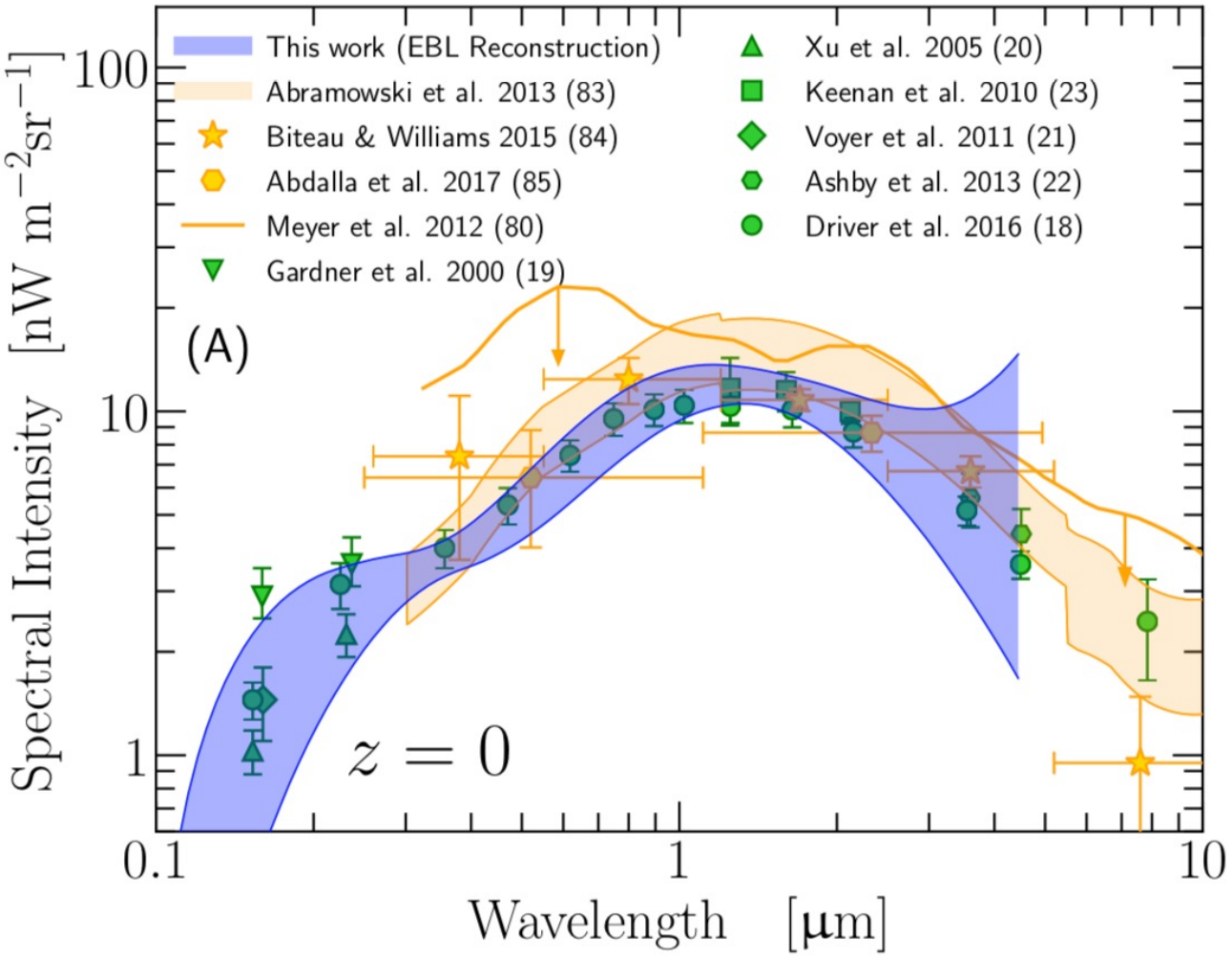
Indirect EBL measurement

$$\tau_{\gamma\gamma}(E_\gamma, z_s) = c \int_0^{z_s} \left|\frac{dt}{dz}\right| dz \int_{-1}^{1} (1-\mu)\frac{d\mu}{2} \int_{2m_e^2c^4/\epsilon_\gamma(1-\mu)}^{\infty} \sigma(\epsilon_{\rm EBL}, \epsilon_\gamma, \mu) n_{\rm EBL}(\epsilon, z) d\epsilon_{\rm EBL}$$

$$n_{\rm EBL}(\epsilon, z) = (1+z)^3 \int_z^{\infty} \frac{j(\epsilon, z)}{\epsilon} \left|\frac{dt}{dz'}\right| dz'$$

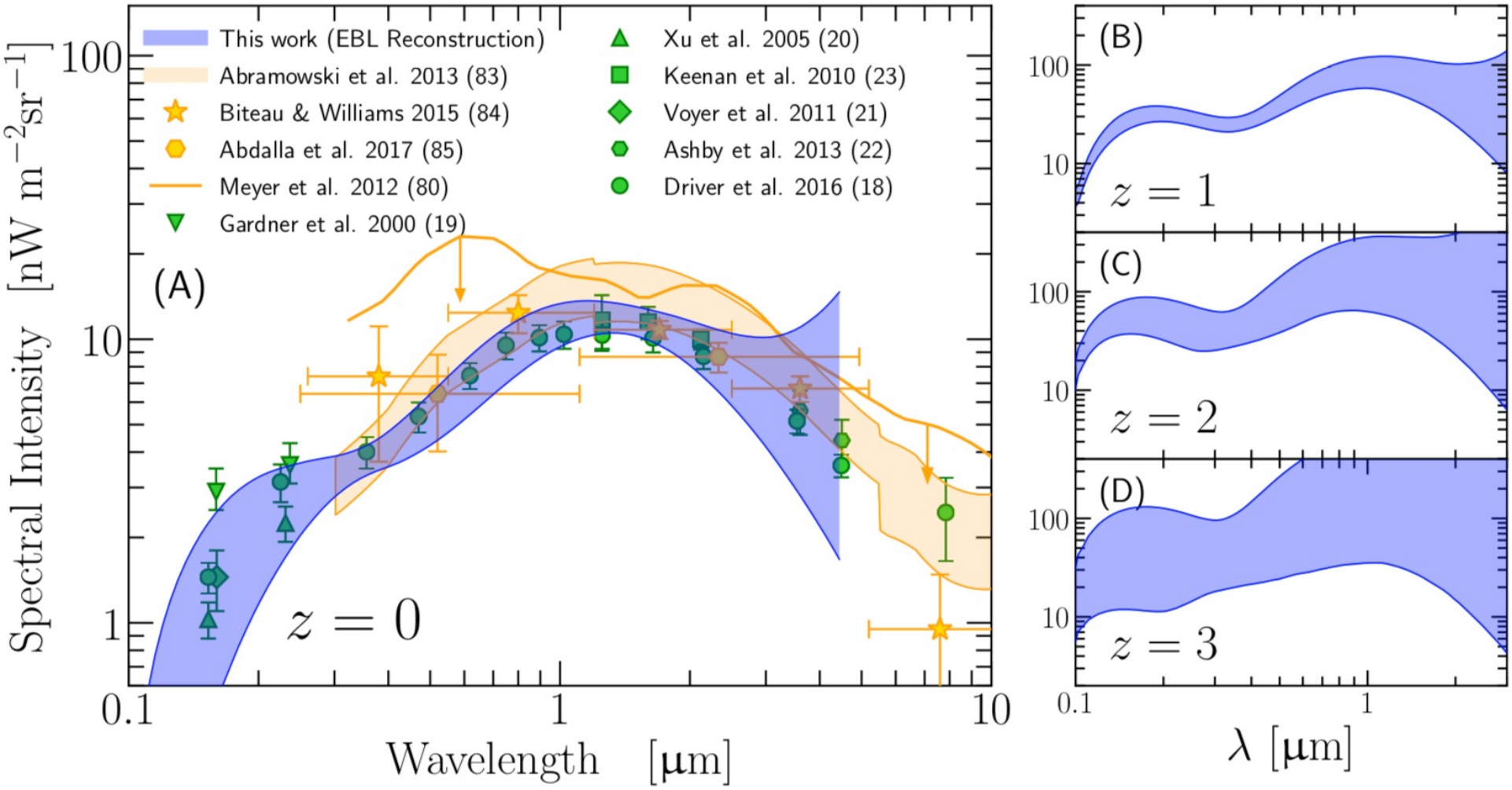
- We cannot invert 3-4 integrals, so we need to find another way
- Two methods, both fitted via MCMC to LAT τ data
- Method 1-empirical: model j(e,z) has sum of log-normal distributions that can evolve independently (Helgason et al.)
- Method 2-theoretical: use stellar population models (Finke et al. 2010) and optimize the parameters of the Cosmic Star Formation History

The EBL with Redshift



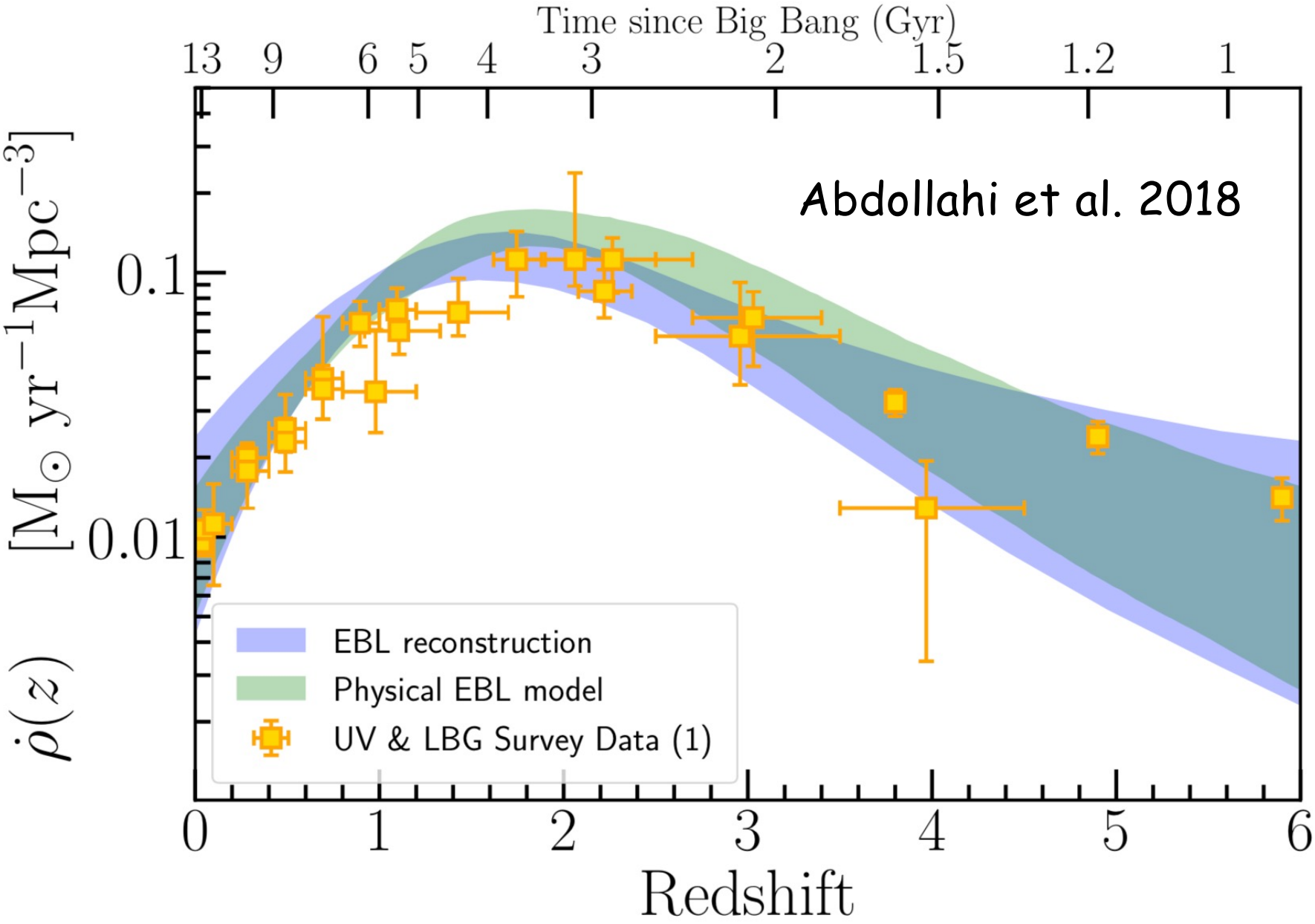
UV background in agreement with quasar proximity measurements by e.g. Kulkarni & Fall 1993, Scott+00 etc

The EBL with Redshift



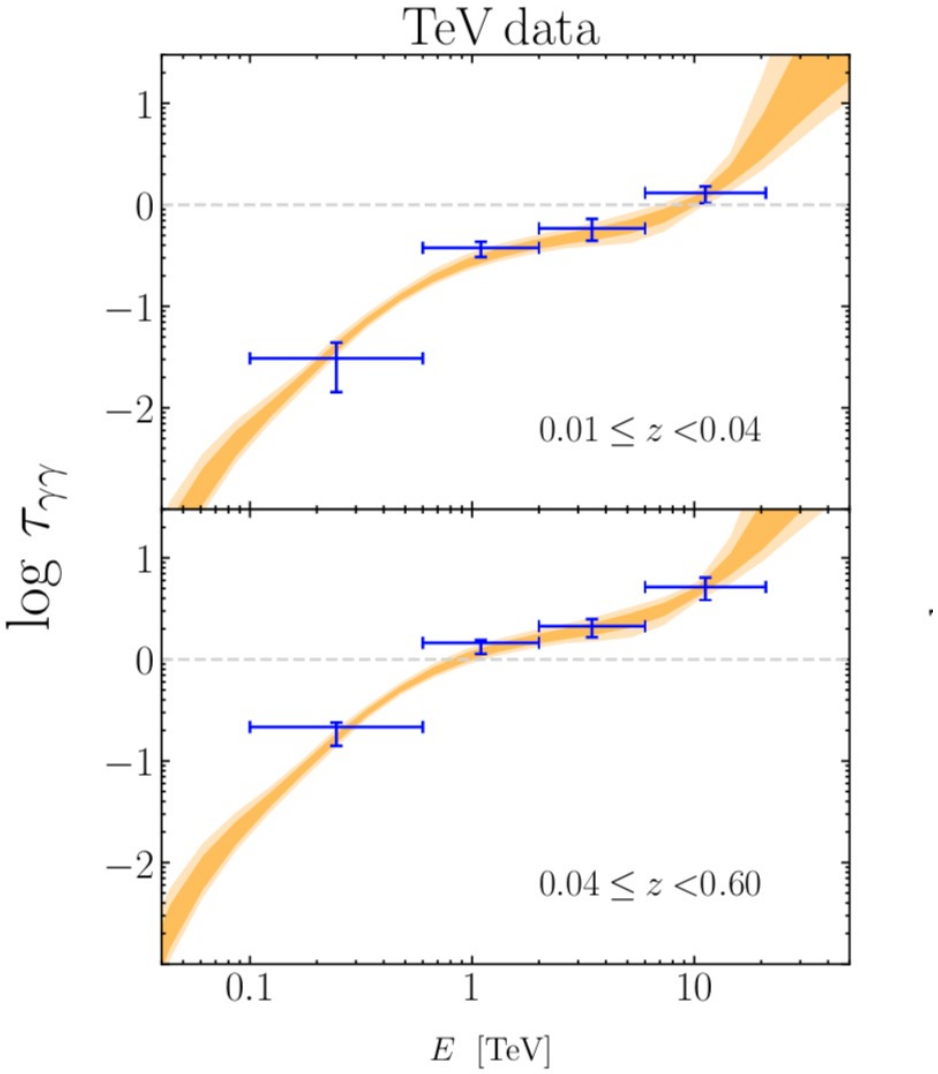
UV background in agreement with quasar proximity measurements by e.g. Kulkarni & Fall 1993, Scott+00 etc

Star Formation History



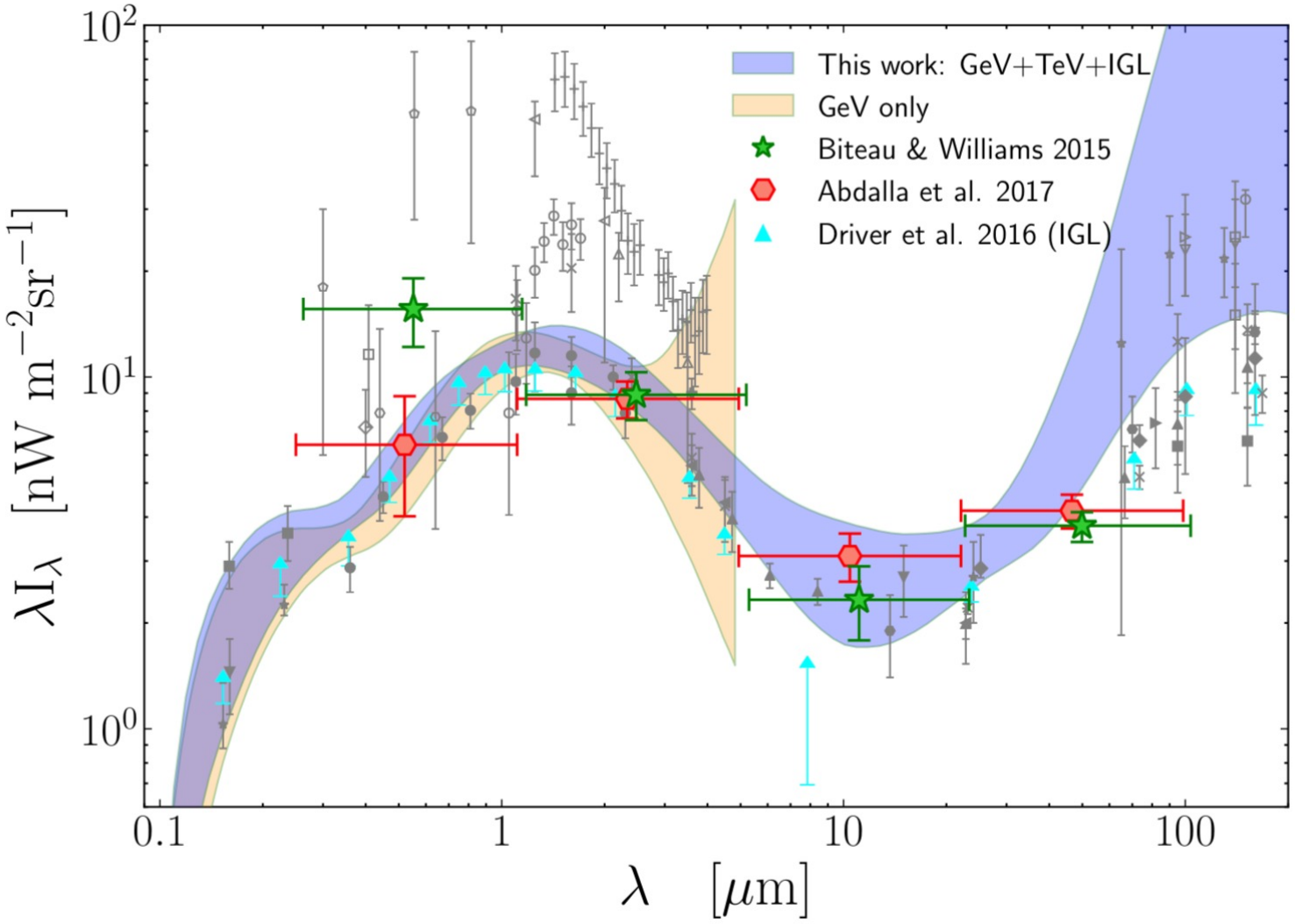
EBL with GeV-TeV data

- Analysis of 38 detected TeV blazars reported in Biteau & Williams 2015 (Desai, et al., ApJL, 2019)



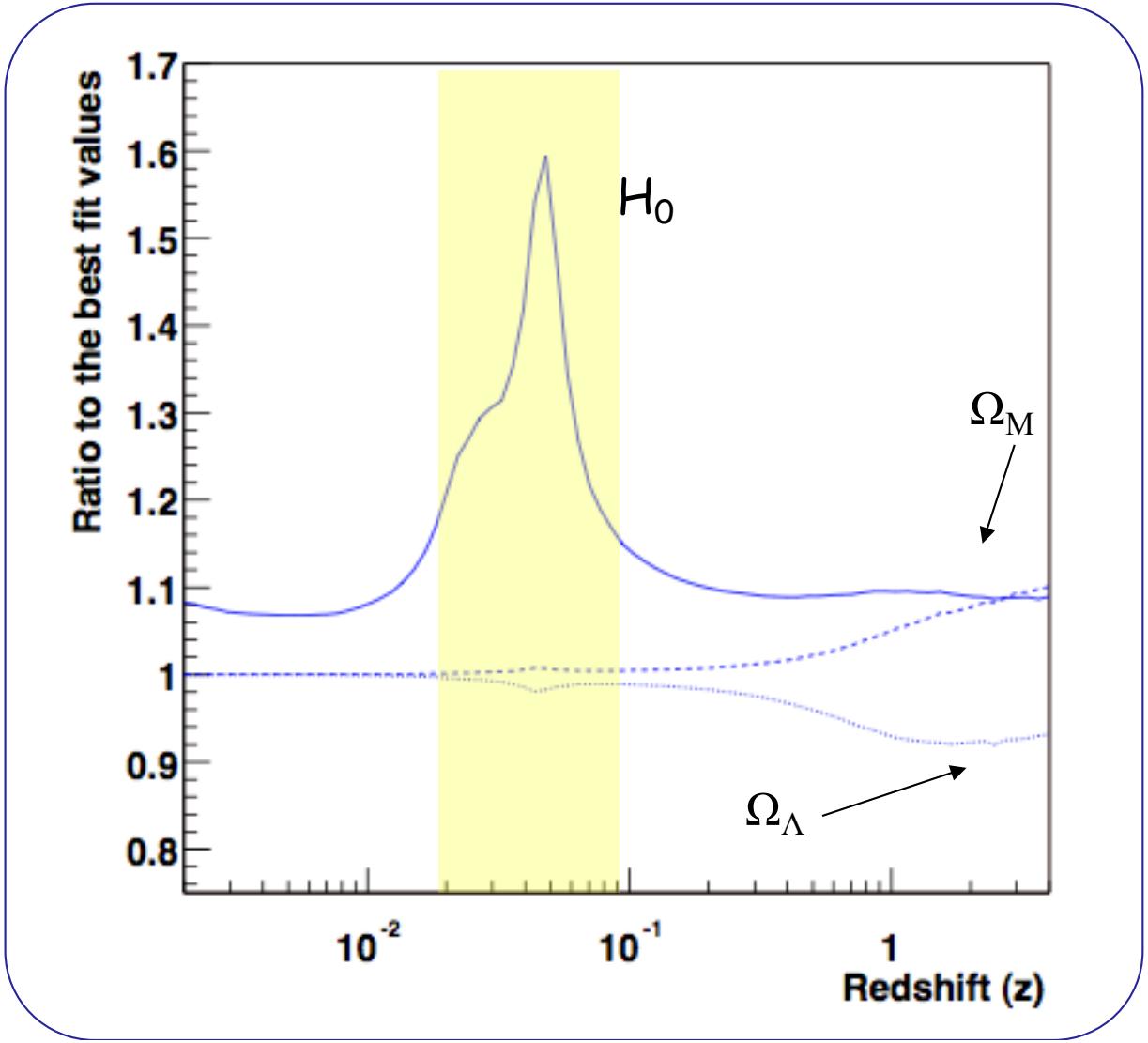
The newest EBL measurement

- Analysis of 38 detected TeV blazars (Desai, et al., ApJL, 2019)
- It allows us to characterize the EBL up to the mid-IR

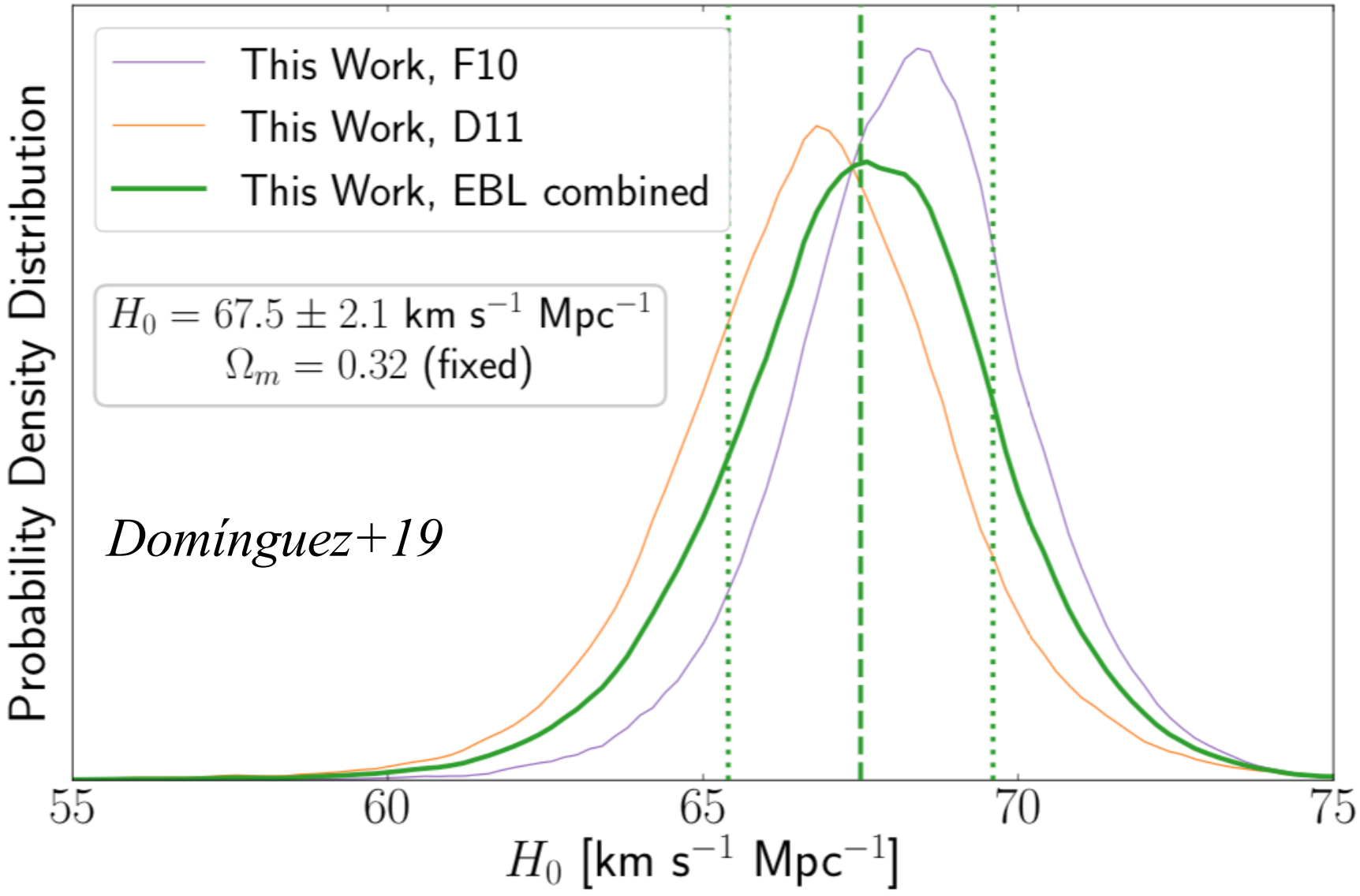


Hubble Constant with the EBL

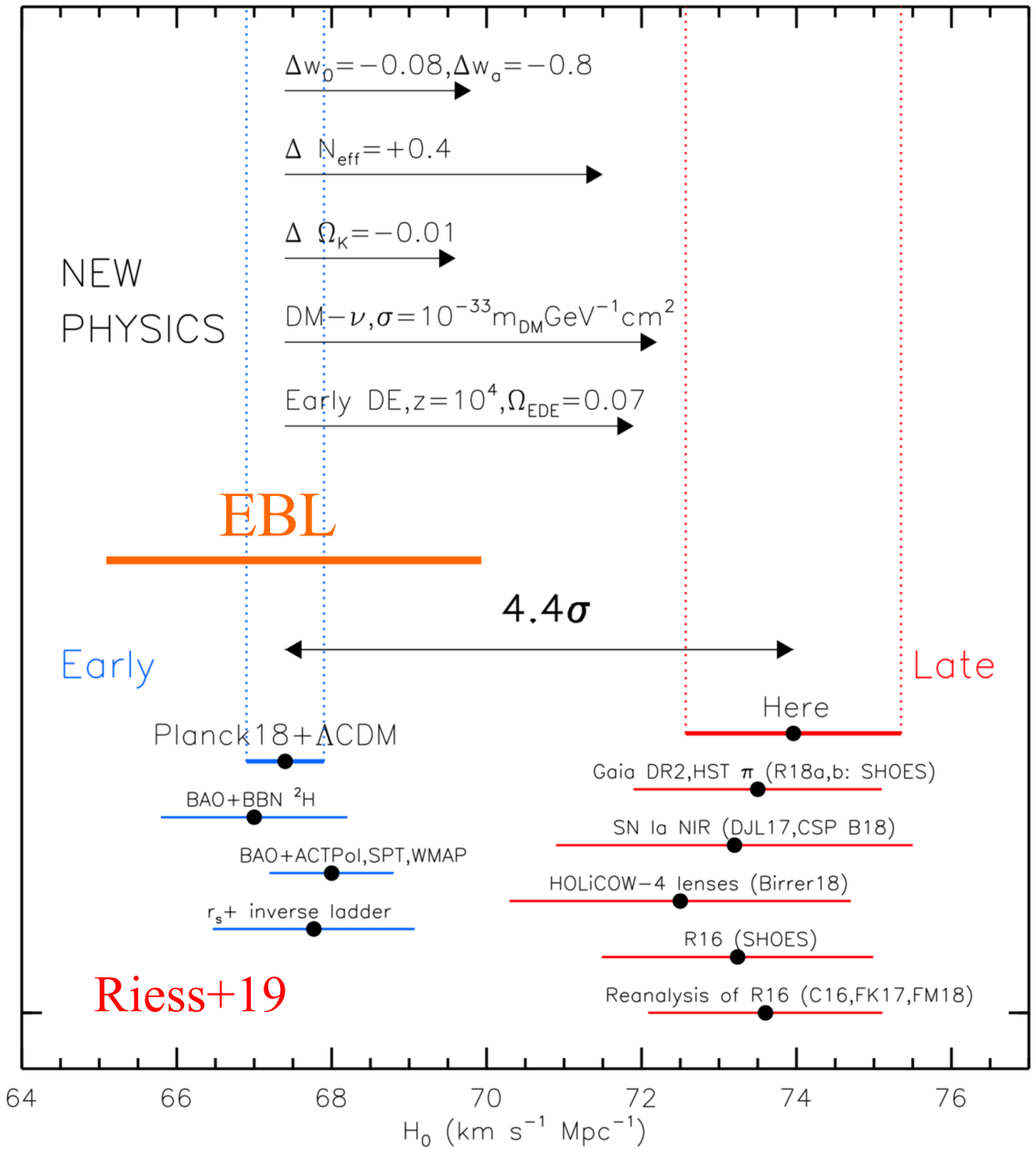
$$\tau_\gamma = \int_0^z \mathrm{d}\ell(z) \int_{-1}^{+1} \mathrm{d}\mu \frac{1-\mu}{2} \int_{\epsilon'_{\mathrm{thr}}}^{\infty} \mathrm{d}\epsilon' \frac{\mathrm{d}n_{\mathrm{bkg}}}{\mathrm{d}\epsilon} \sigma_{\gamma\gamma}(E', \epsilon', \mu)$$



Hubble Constant from the EBL



Hubble Constant (2019)

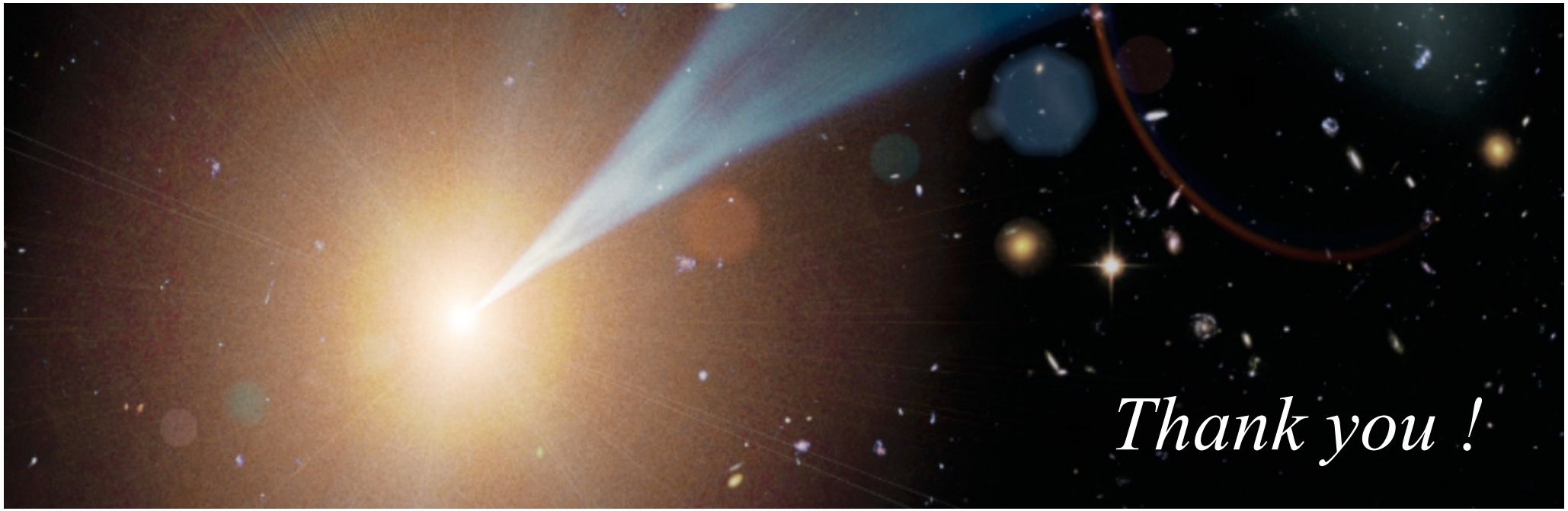


Outlook

- At GeV energies:
  - There are ~6-7 more years and ~3000 blazars. TS_{EBL} increases linearly with time, so expect 70-80% improvement. Probably it will go from 12 to ~20 epochs at which we can measure τ

- At TeV energies:
  - Desai et al. used 106 individual TeV spectra
  - Baxter et al. will use 400 individual TeV spectra

- CTA should be able to revolutionize the field



- EBL is a powerful tool for galaxy evolution, star formation and cosmology

V. Paliya A. Desai K. Helgason J. Finke A. Domínguez D. Hartmann