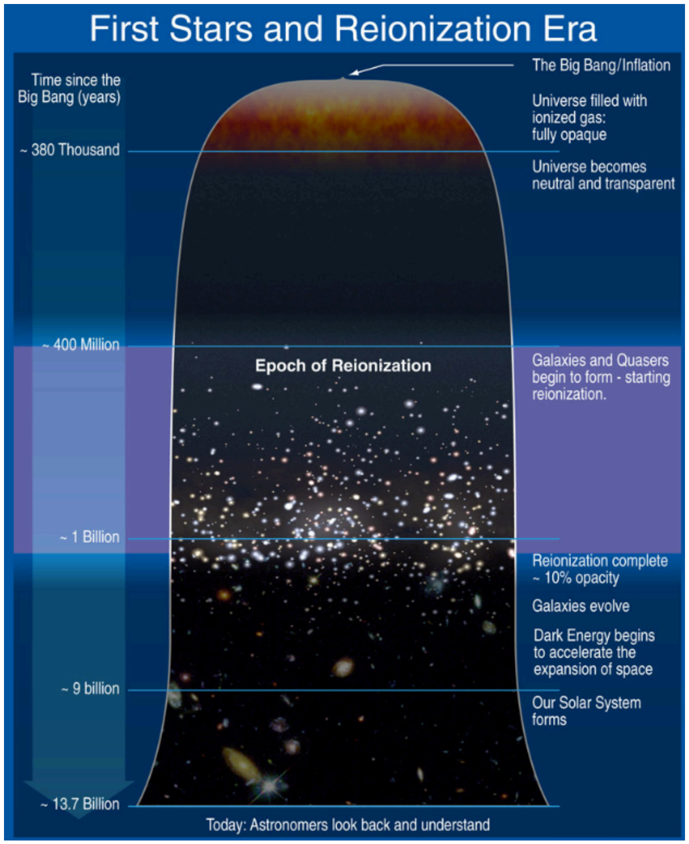
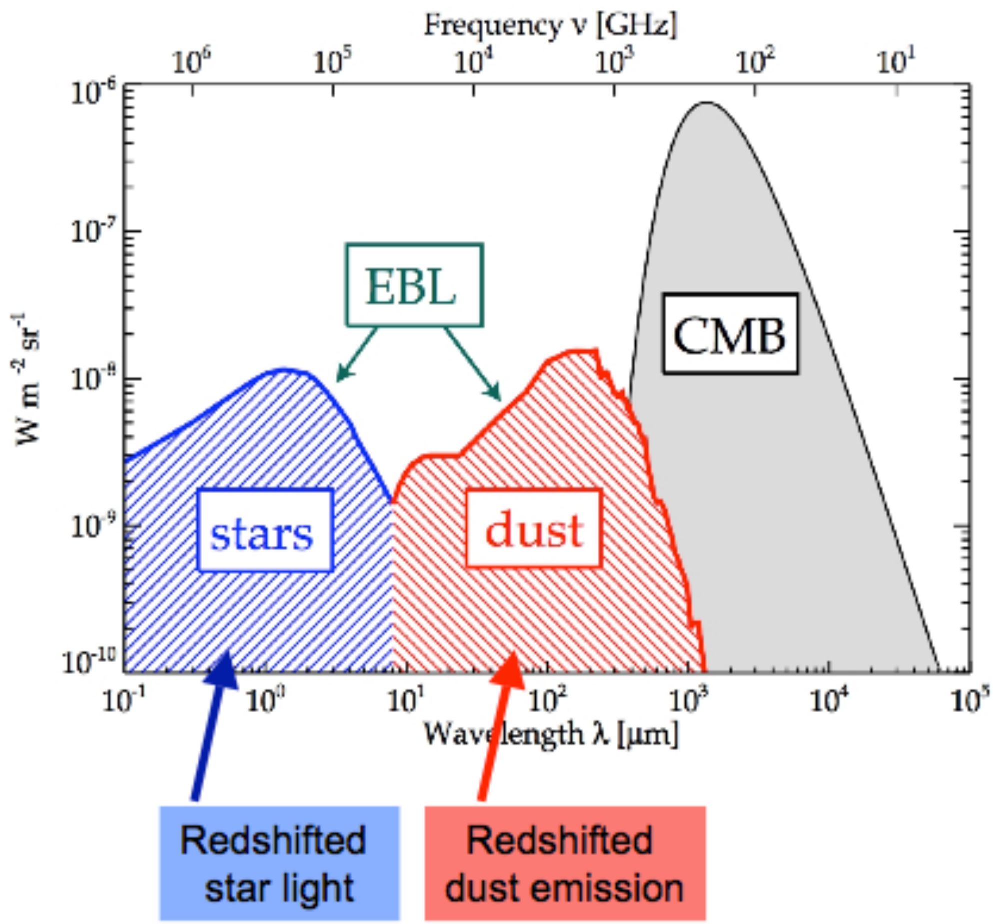
The Extragalactic Background Light

Marco Ajello [Clemson University]

1st CTA Science Symposium

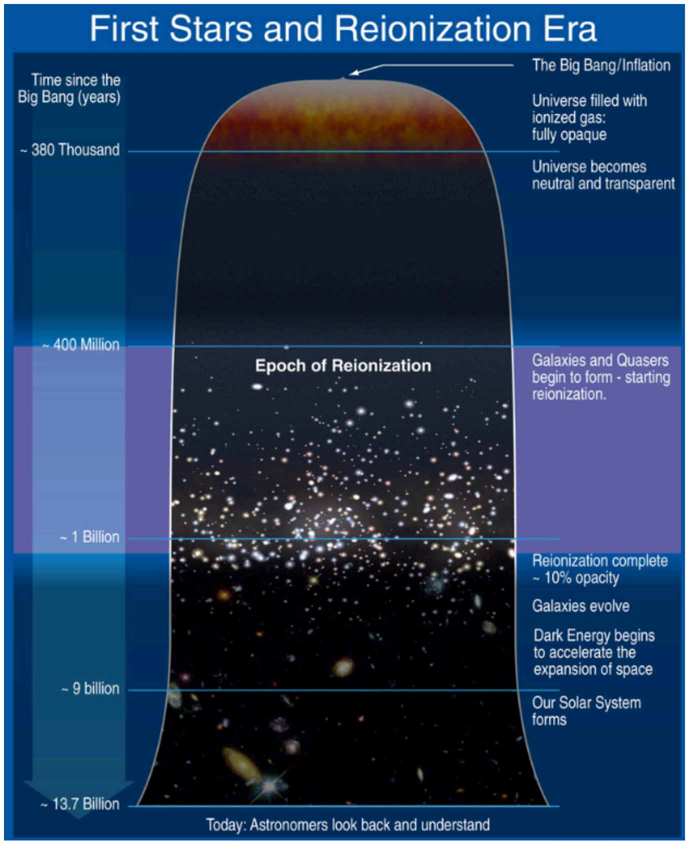
The Extragalactic Background Light

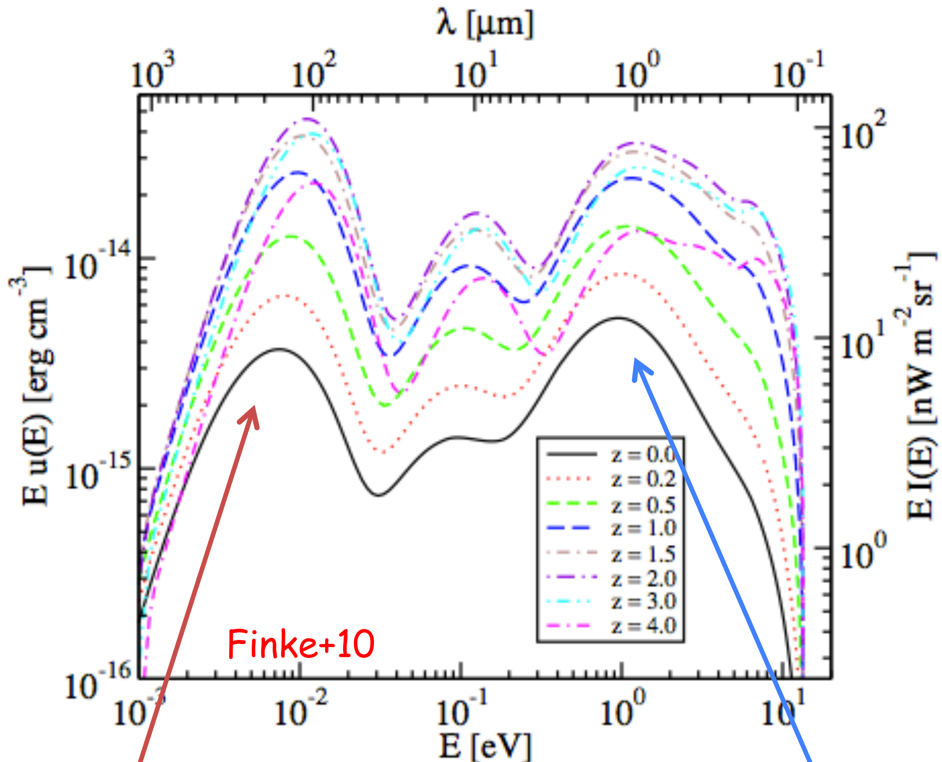




- ->constraints on galaxy evolution, star formation activity, dust extinction processes
- ->understanding cosmic structure formation and evolution

The Extragalactic Background Light





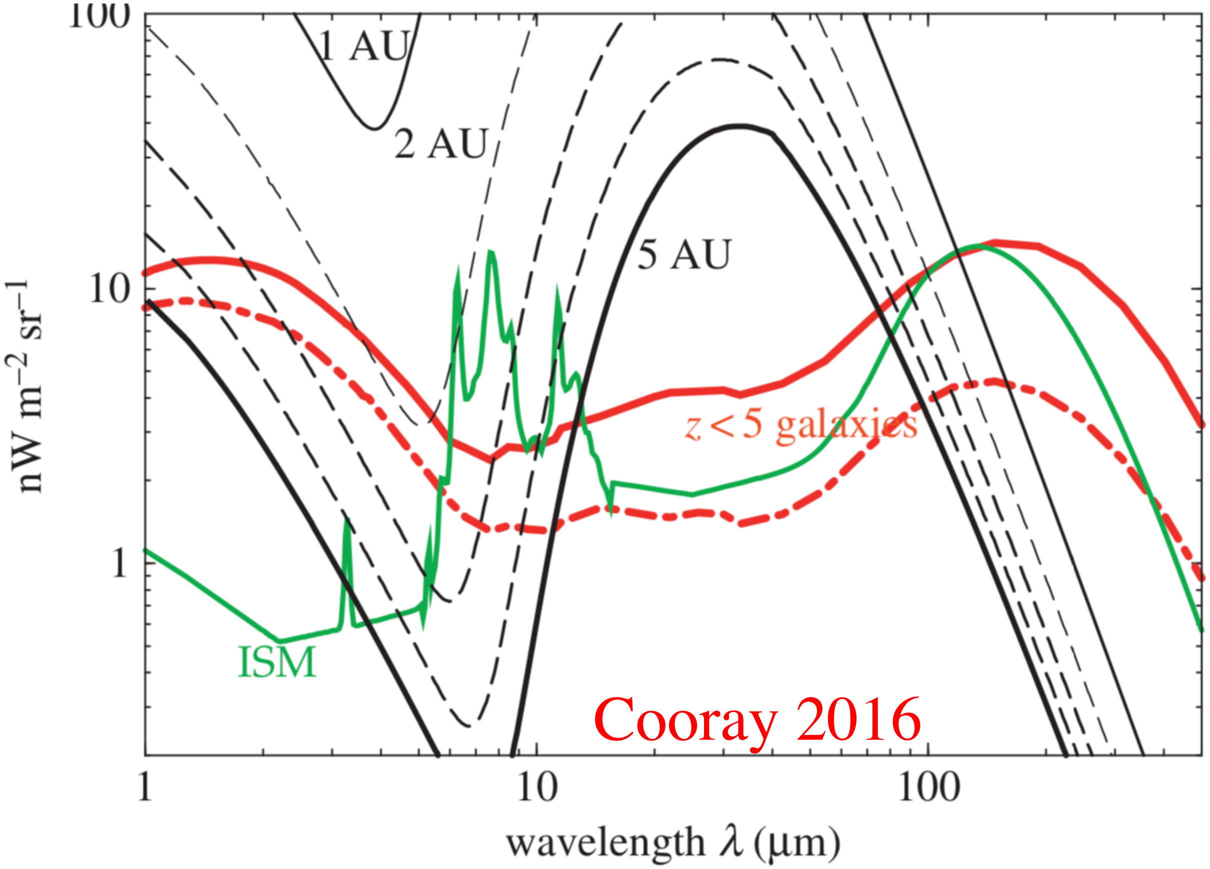
AGN/star light reprocessed by dust

Light emitted by stars and AGN

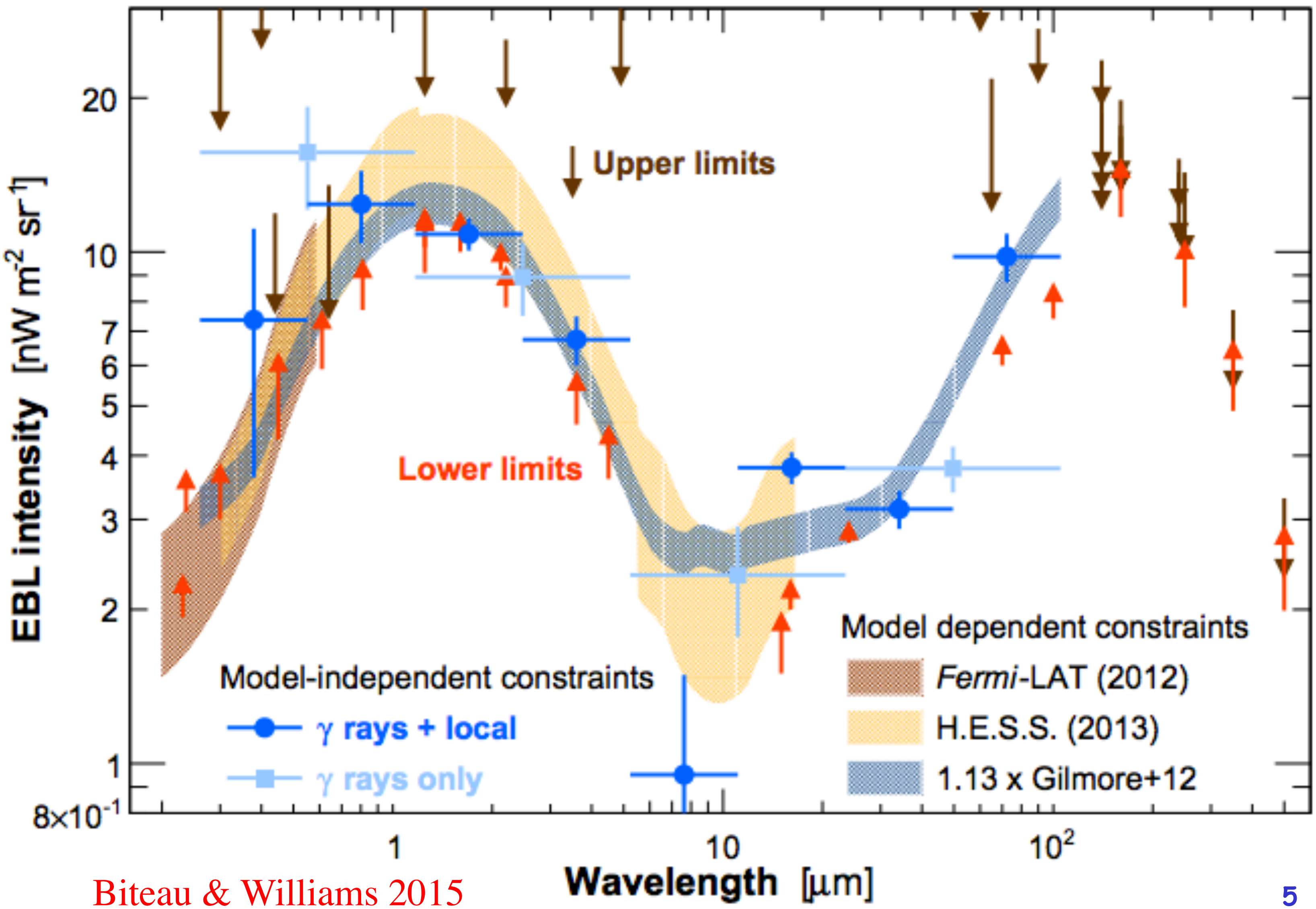
- ->constraints on galaxy evolution, star formation activity, dust extinction processes
- ->understanding cosmic structure formation and evolution

Bright foregrounds

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

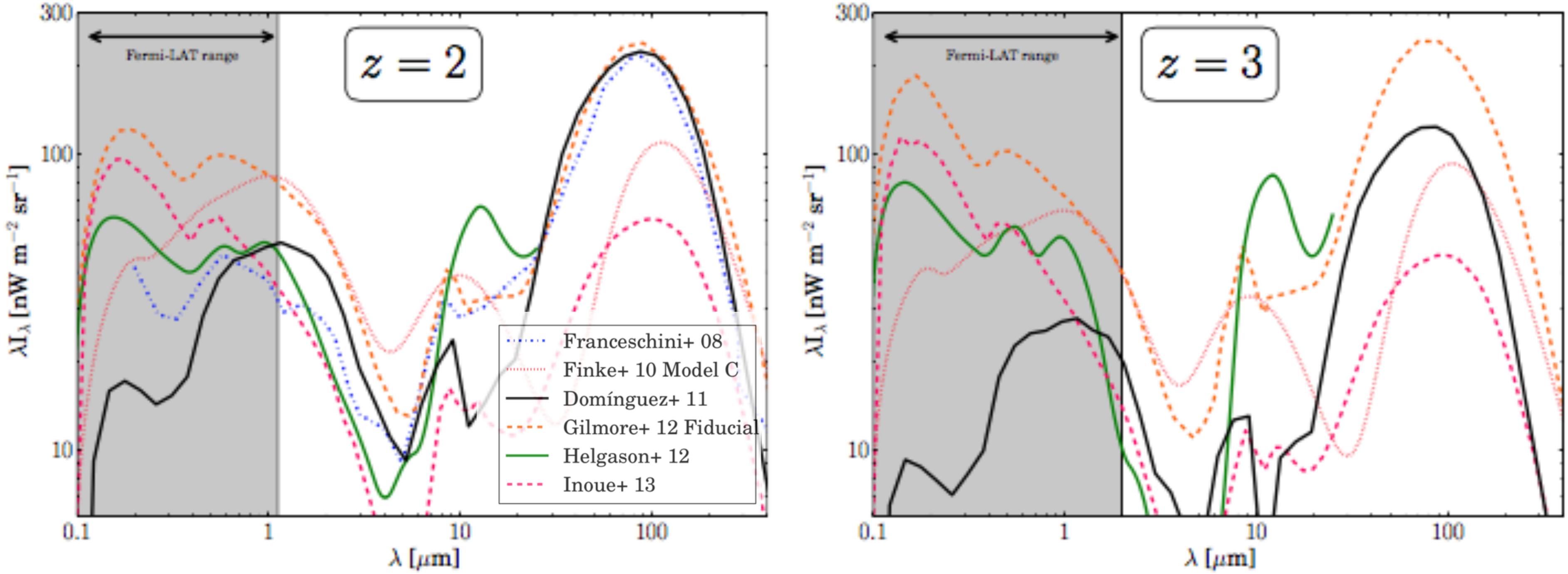


EBL Measurements



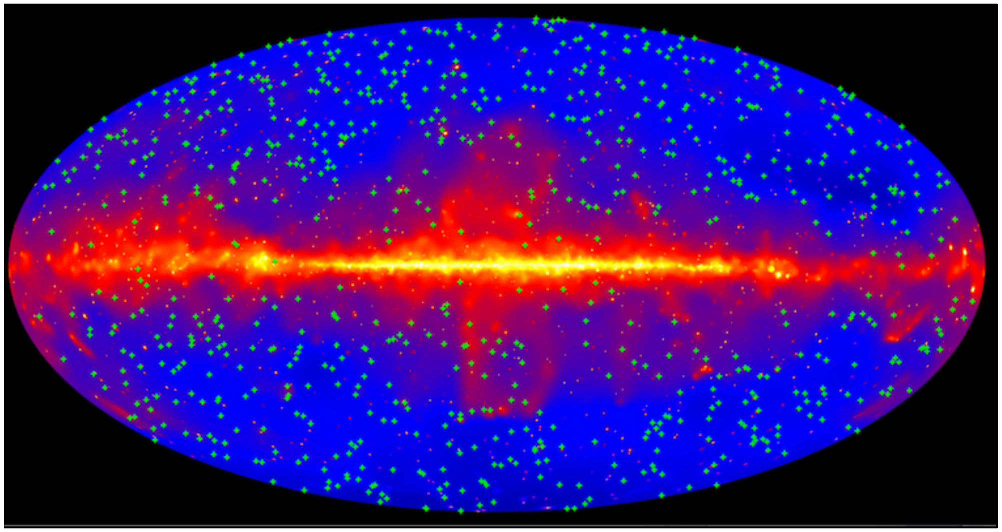
Biteau & Williams 2015

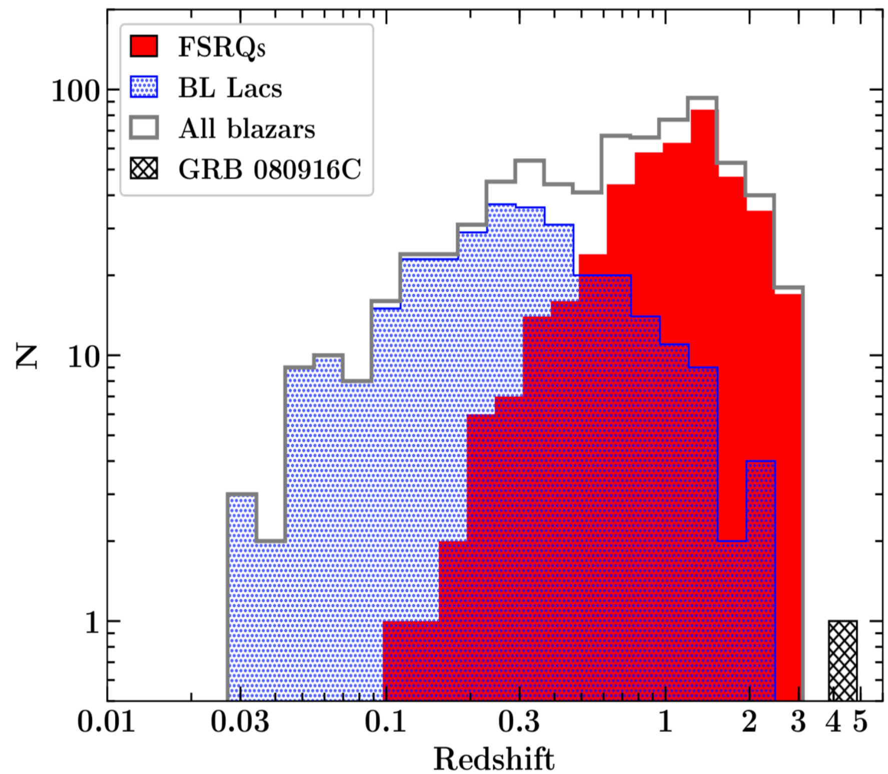
Reality Check



1. *Build up of the EBL largely undetermined*
2. *Build up fundamental to determine galaxy/stellar evolution processes*

This work



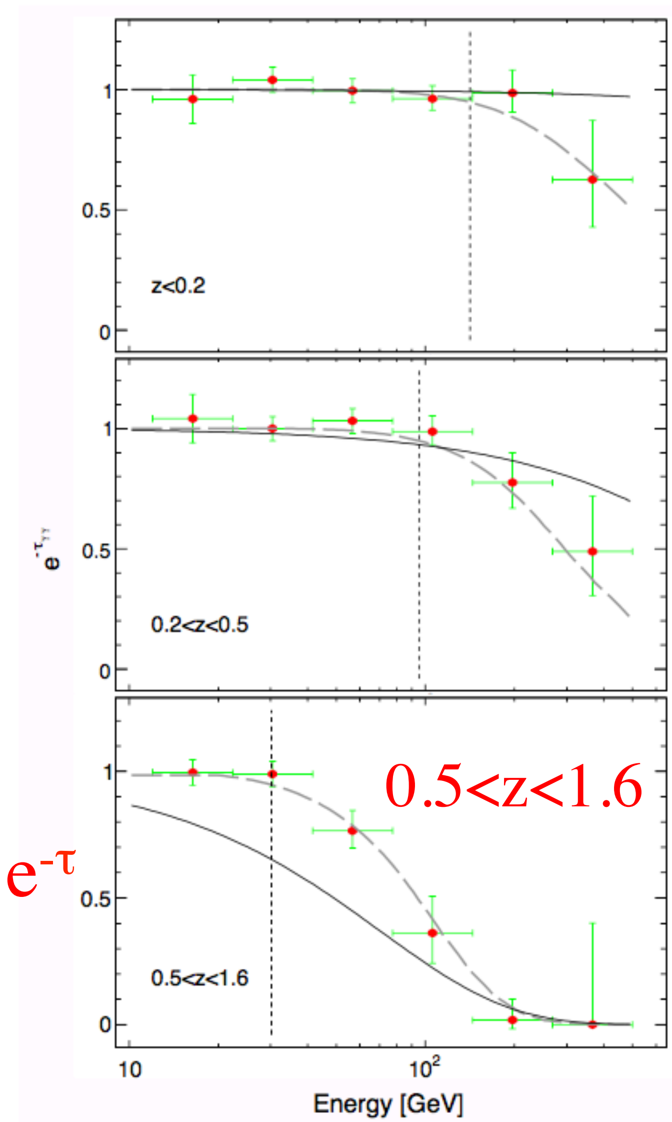


- Use 9 years of P8 LAT data
- 739 blazars + 1 GRB
- Perform a time-resolved analysis,
- Analysis optimized on simulations

Analysis improved over the Ackermann+12 results

First ‘Detection’ of the EBL attenuation

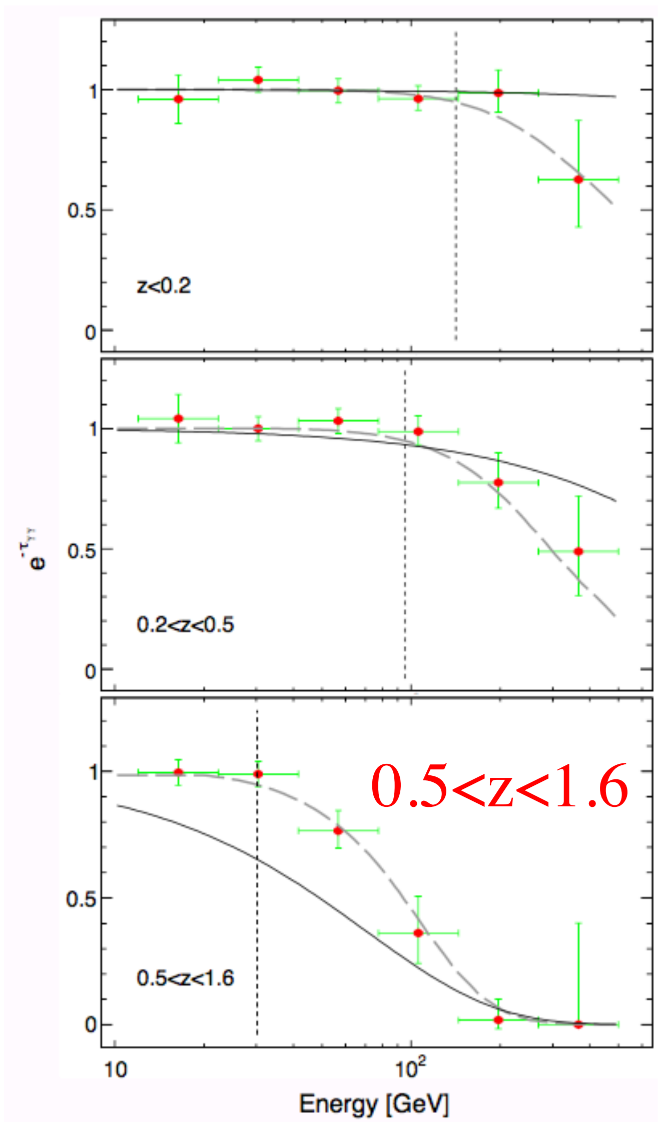
Ackermann et al. 2012



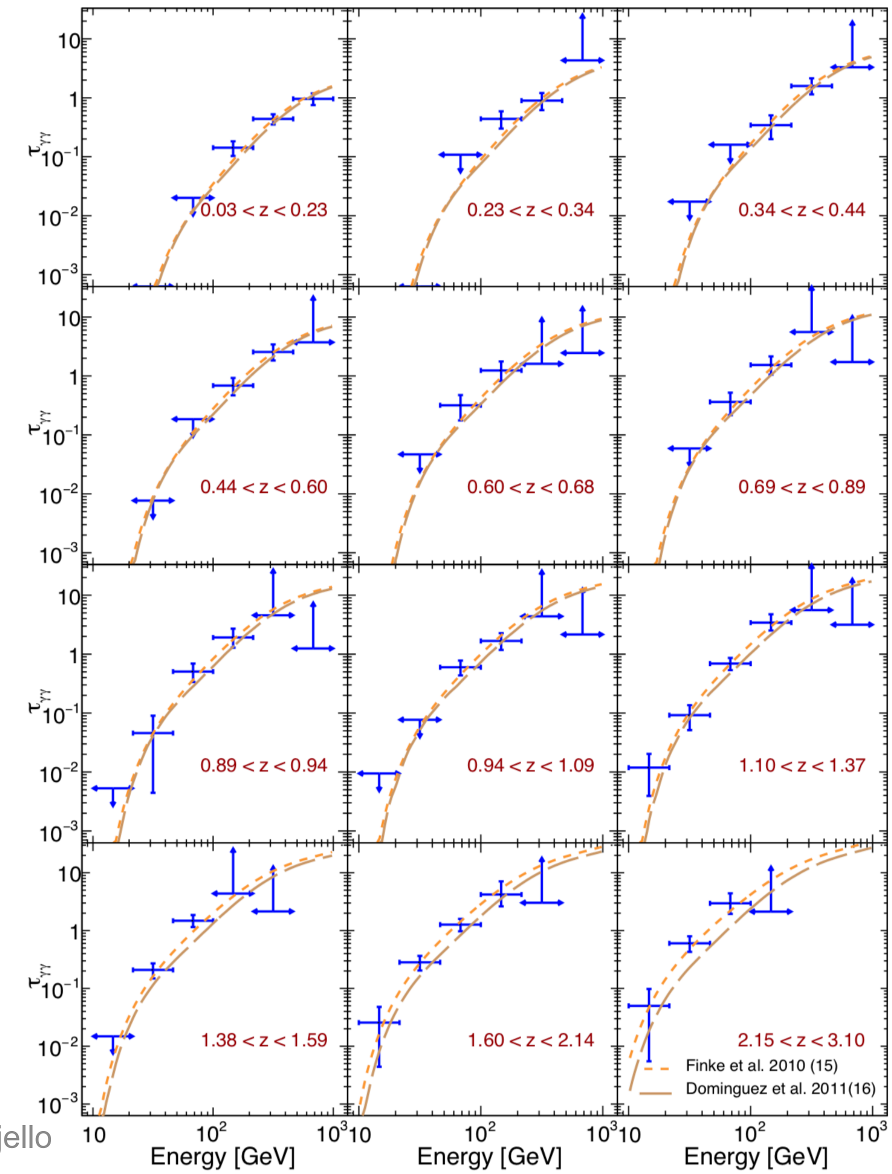
Average over 4 billion years !

From ‘Detection’ to ‘Characterization’

Ackermann et al. 2012



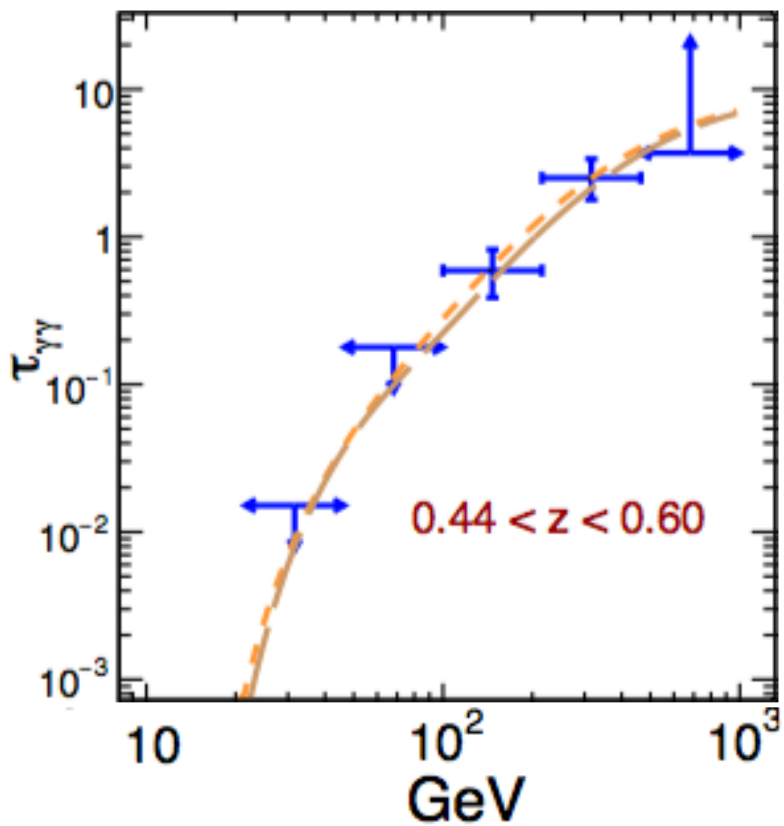
Abdollahi et al. 2018

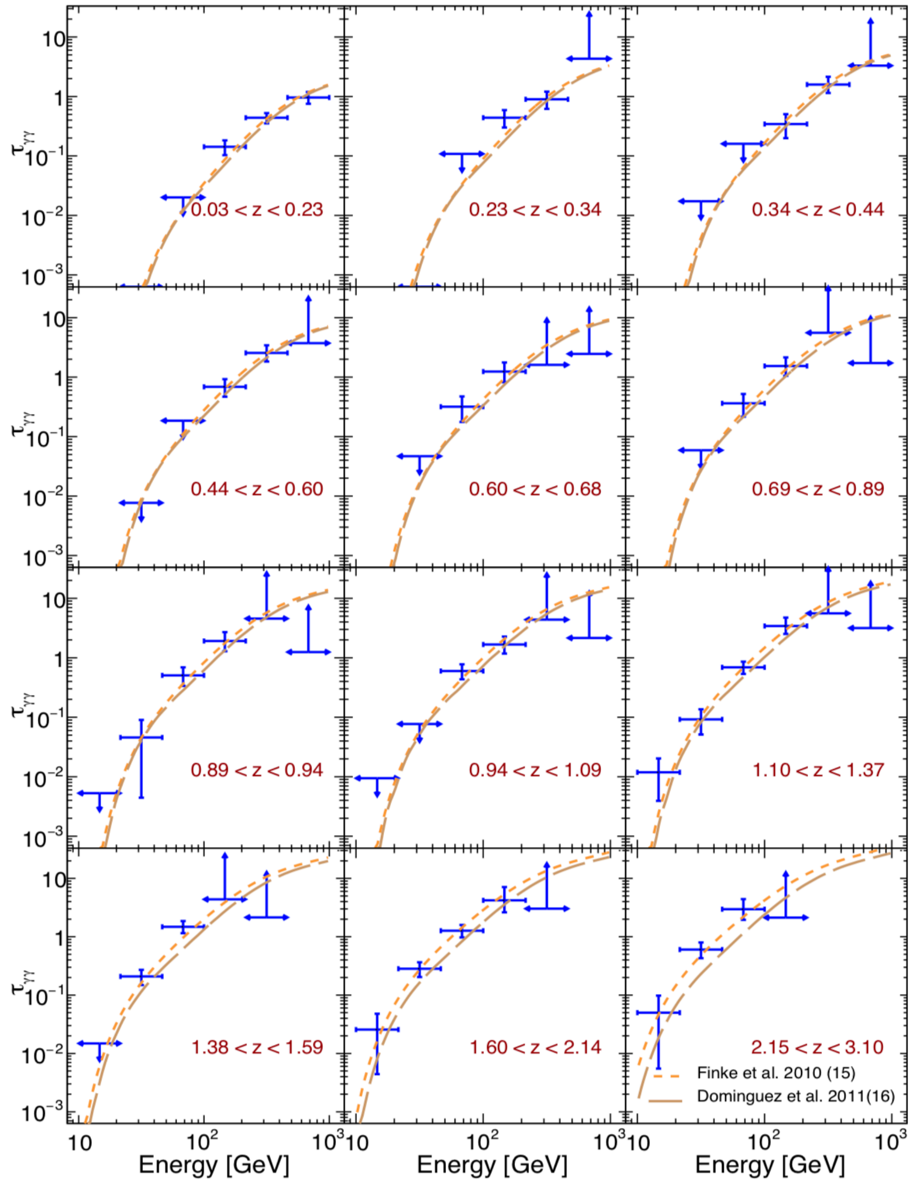


Marco Ajello

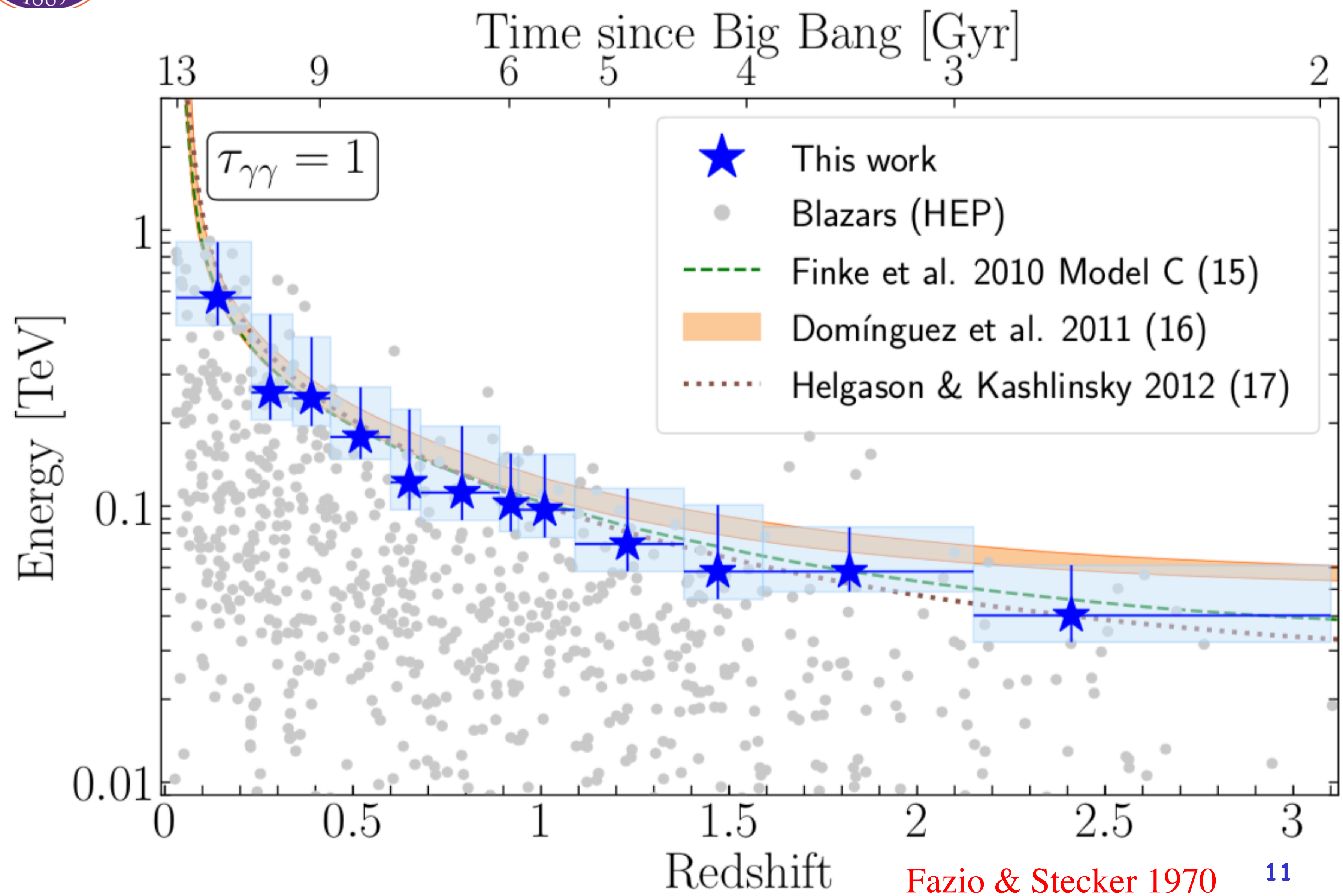
EBL measurements over 11 billlion years

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



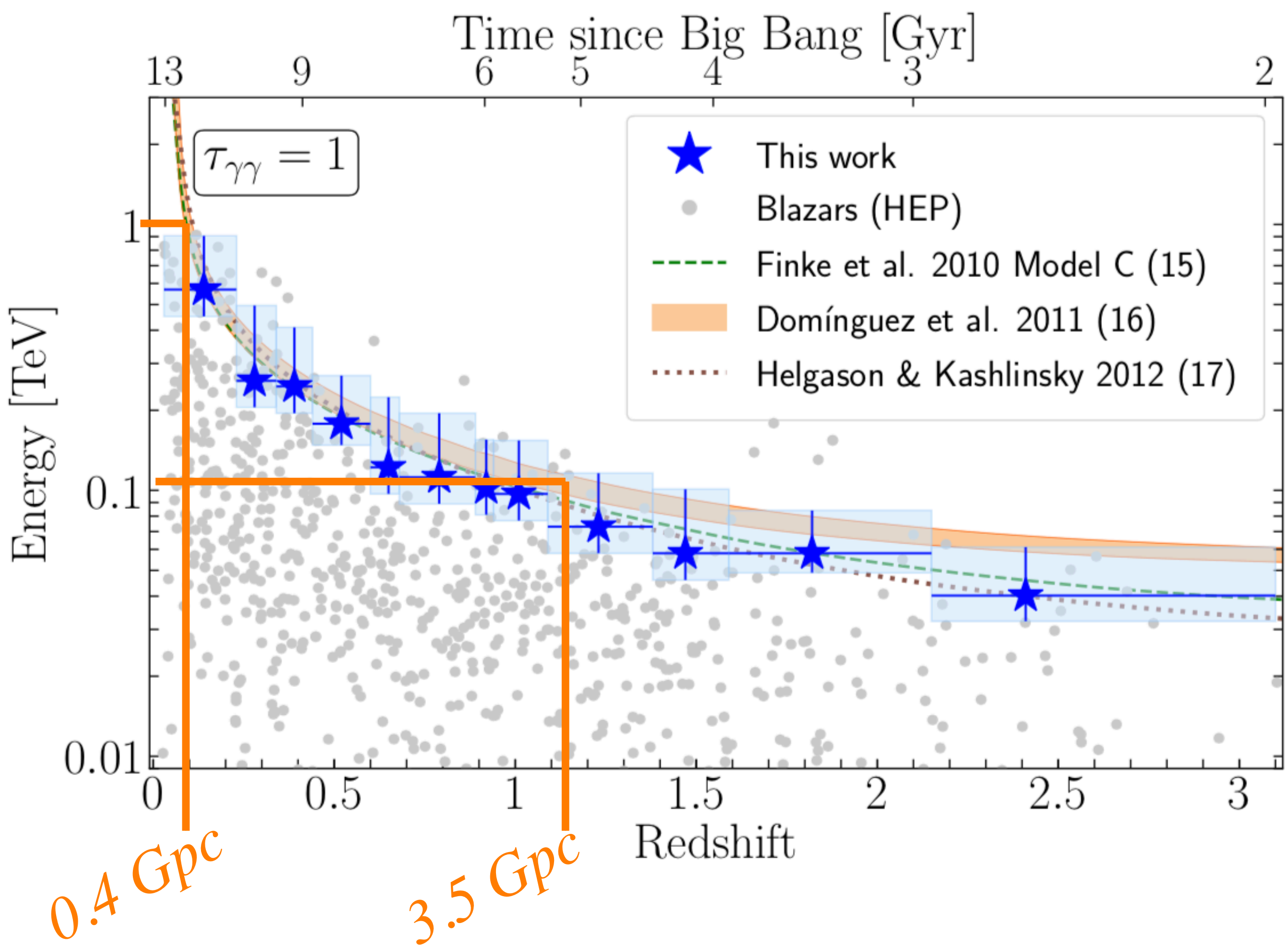


The Cosmic Gamma-ray Horizon



Fazio & Stecker 1970

The Cosmic Gamma-ray Horizon



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

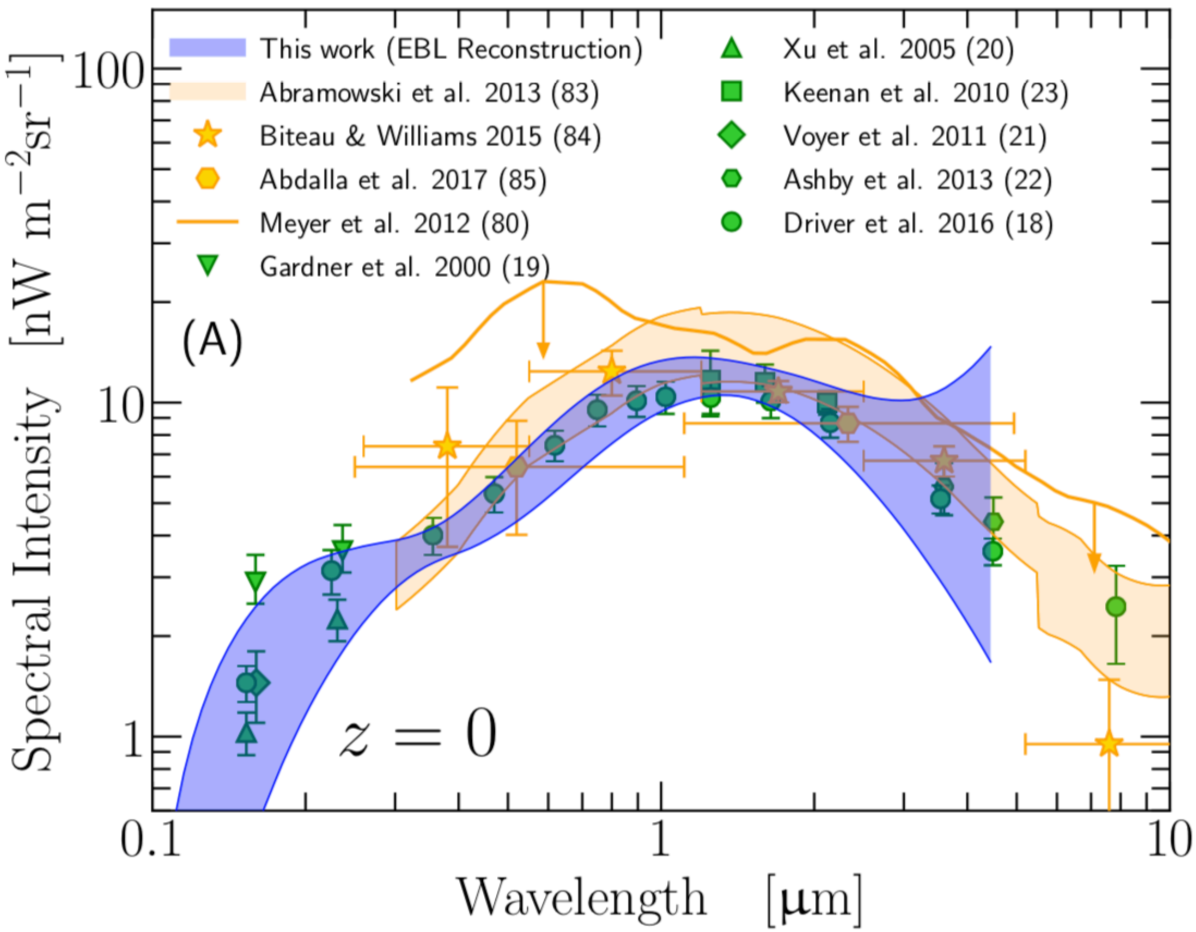
Indirect EBL measurement

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

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

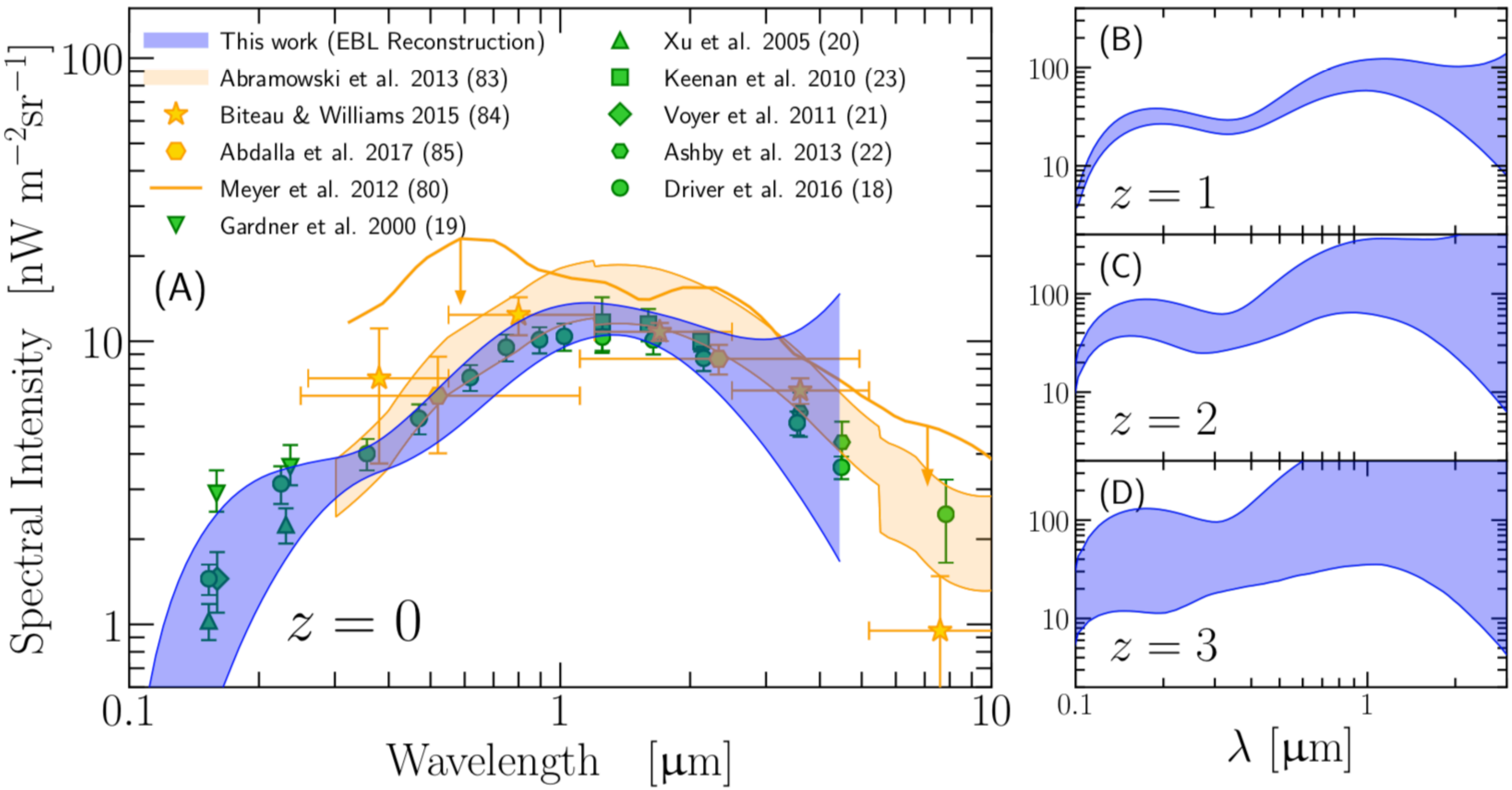
- We cannot invert 3-4 integrals, so we need to find another way
- Two methods, both fitted via MCMC to LAT τ data
- Method 1-empirical: model j(e,z) has sum of log-normal distributions that can evolve independently
- Method 2-theoretical: use stellar population models (Finke et al. 2010) and optimize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

The EBL with Redshift



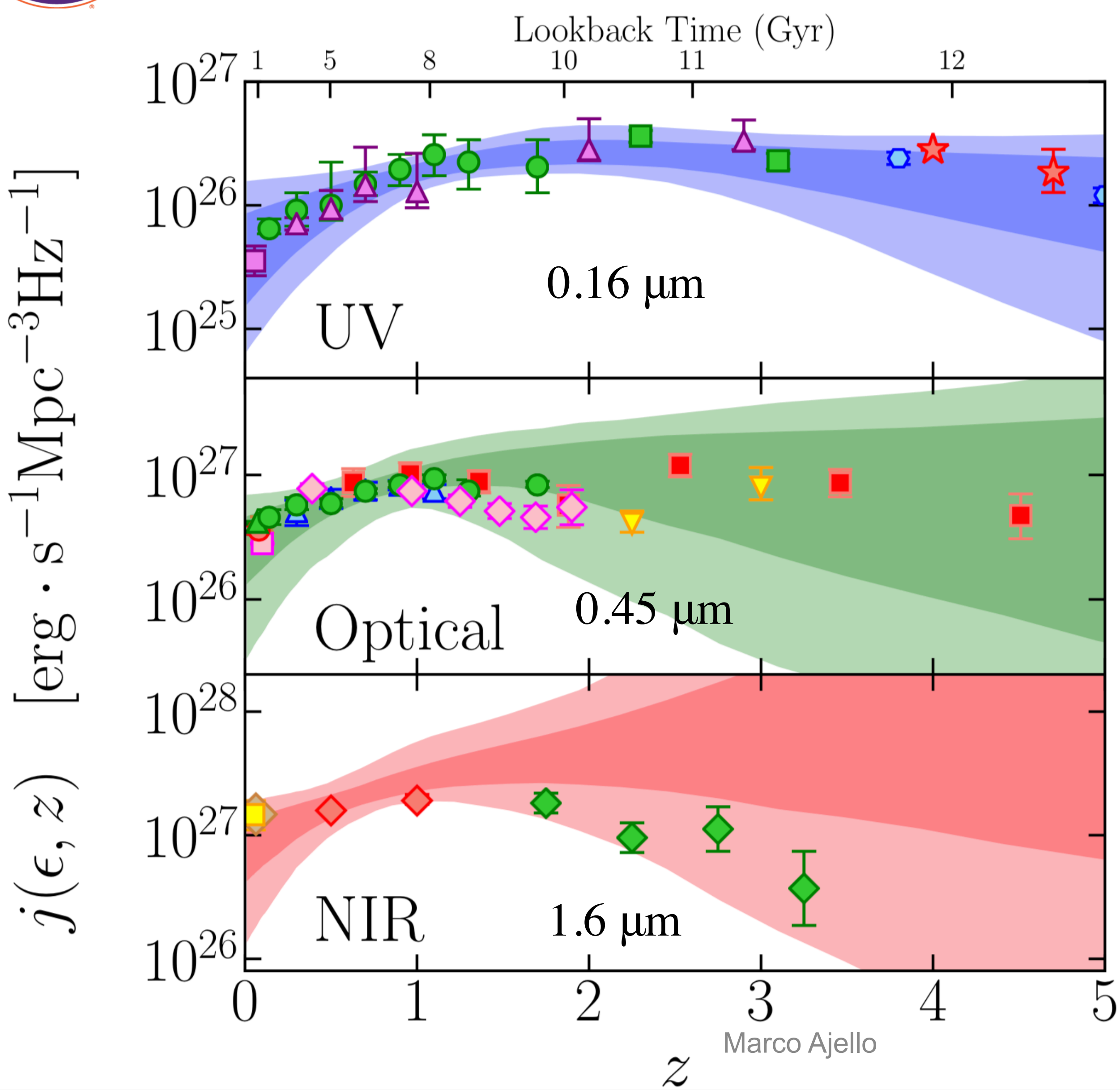
UV background in agreement with quasar proximity measurements by e.g. Kulkarni & Fall 1993, Scott+00 etc

The EBL with Redshift

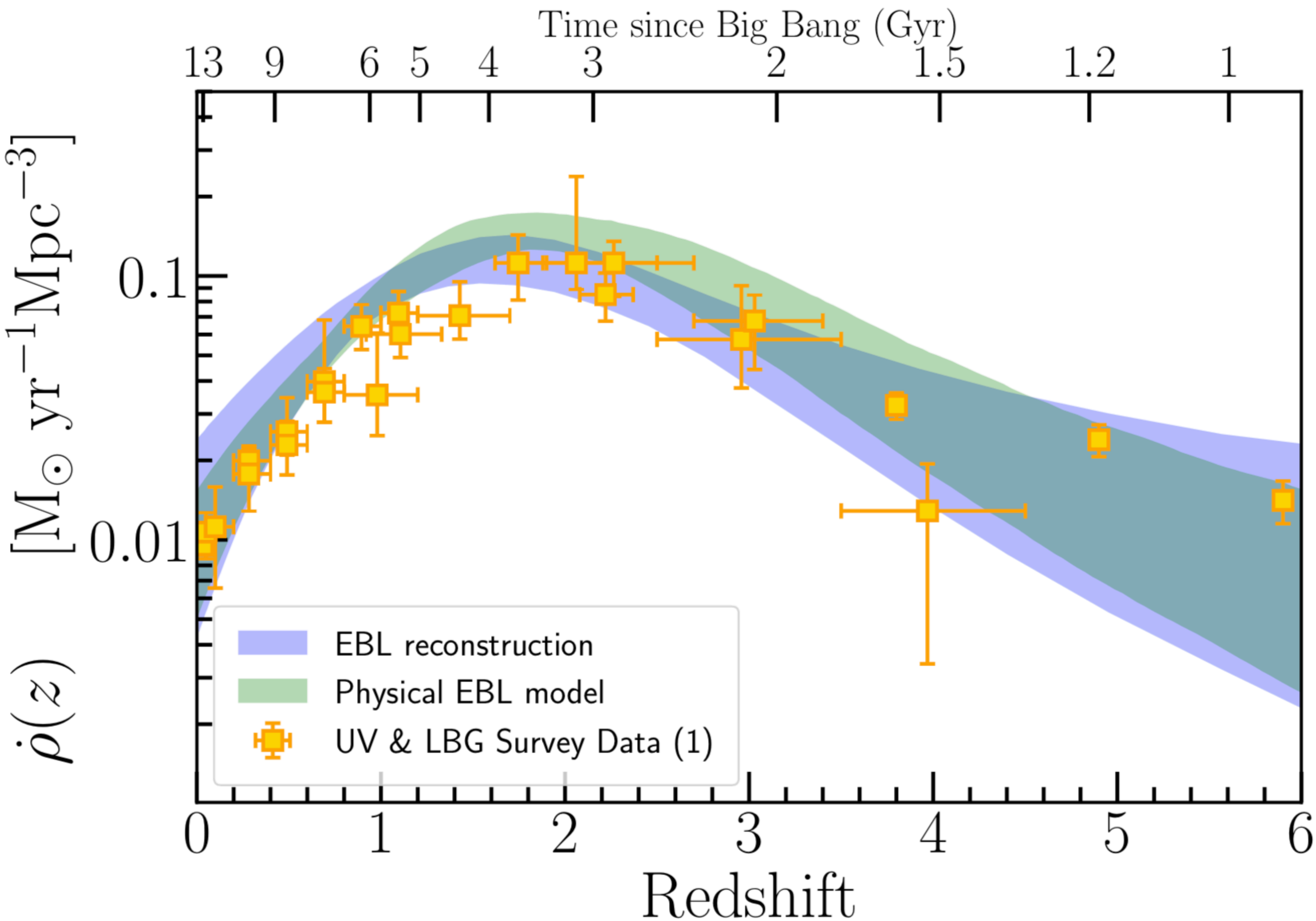


UV background in agreement with quasar proximity measurements by e.g. Kulkarni & Fall 1993, Scott+00 etc

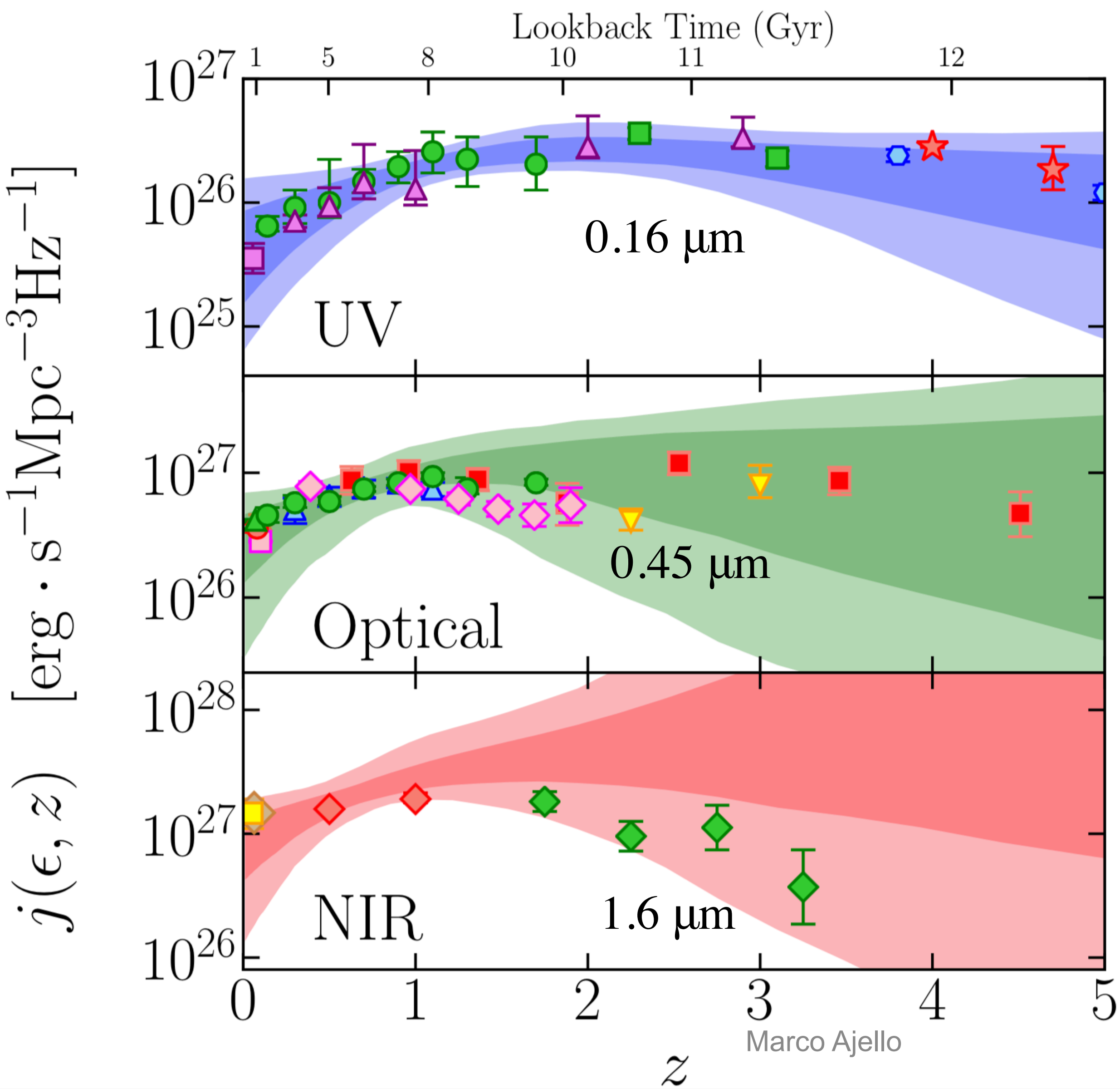
Cosmic Luminosity Density



Star Formation History



Cosmic Luminosity Density

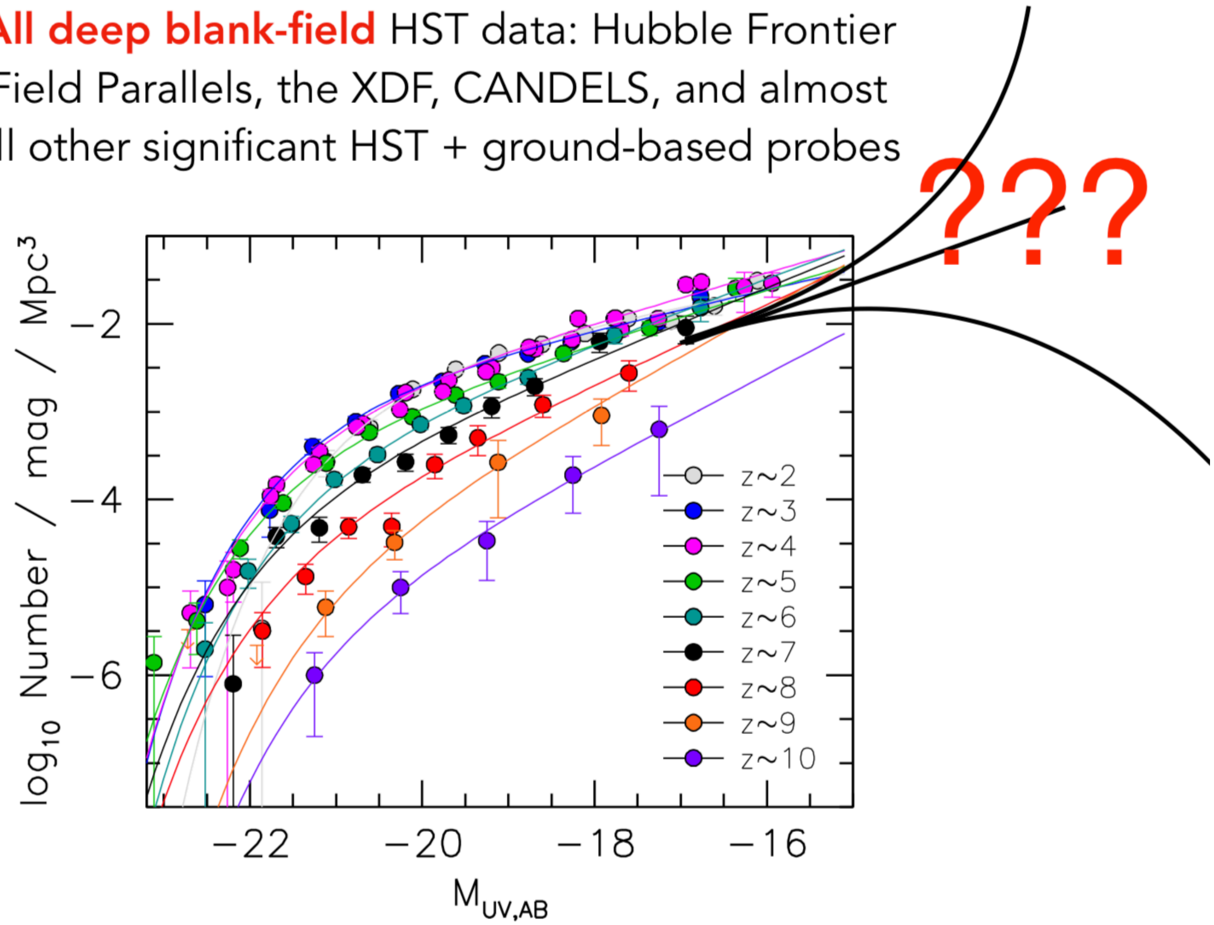


← GRB 080916C
at z=4.35

Re-ionization

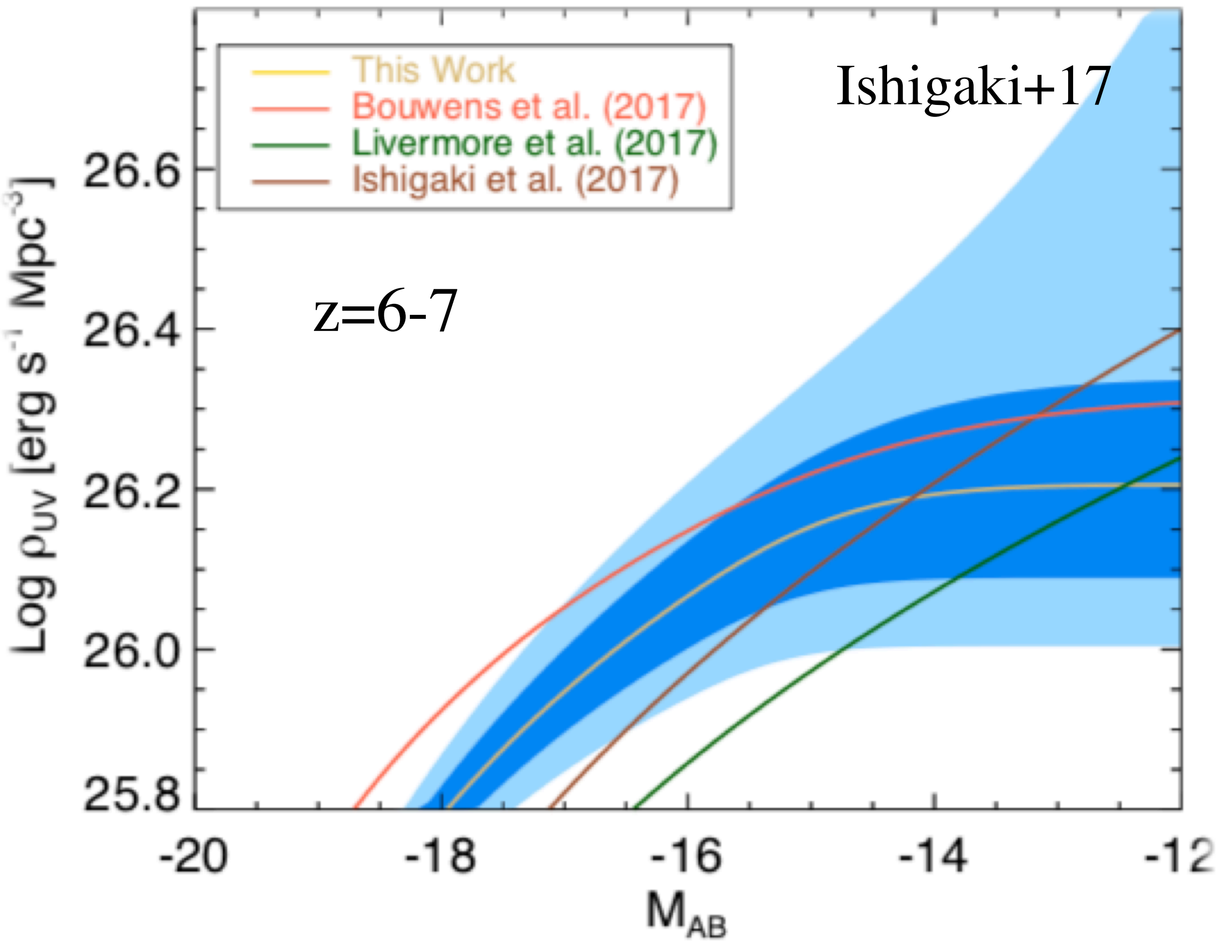
Hubble Frontier Fields

All deep blank-field HST data: Hubble Frontier Field Parallels, the XDF, CANDELS, and almost all other significant HST + ground-based probes



Bouwens+2018 (in prep); Oesch+2017

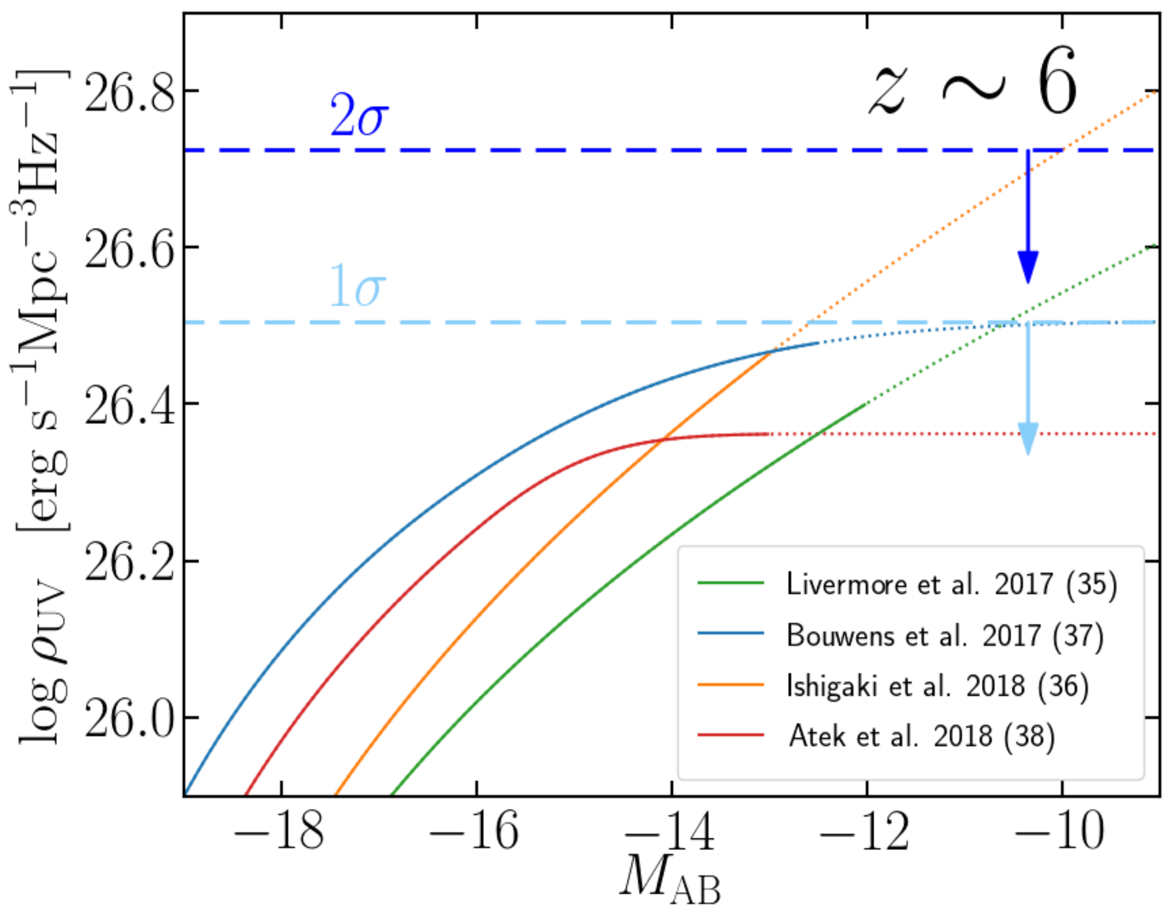
Hubble Frontier Fields



- Inconsistencies between the analyses attributed to details of the mass modeling of the lens (Atek+18, Bouwens+17, Livermore+17, Ishigaki+17)

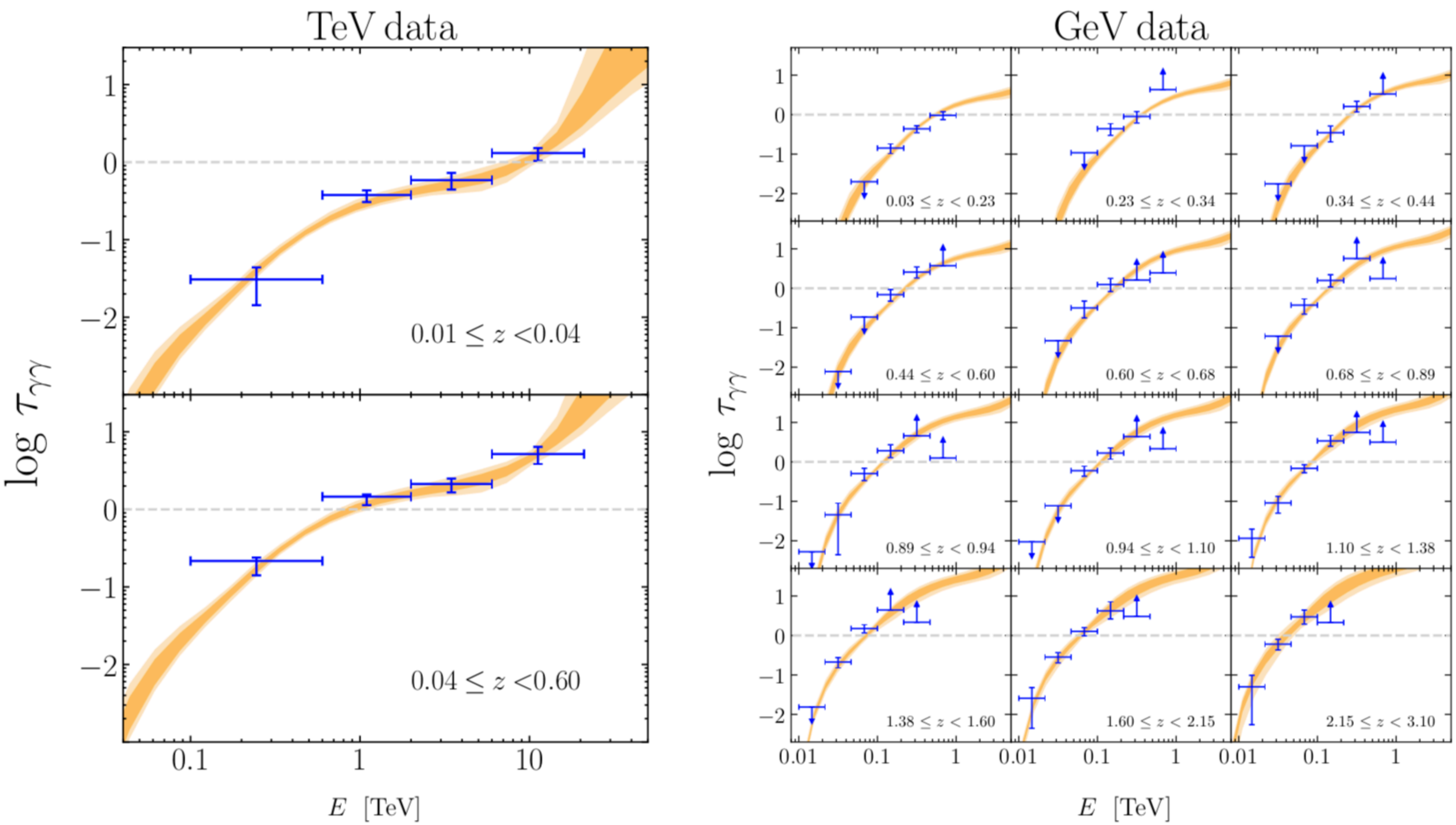
End of re-ionization

Hubble Frontier Fields



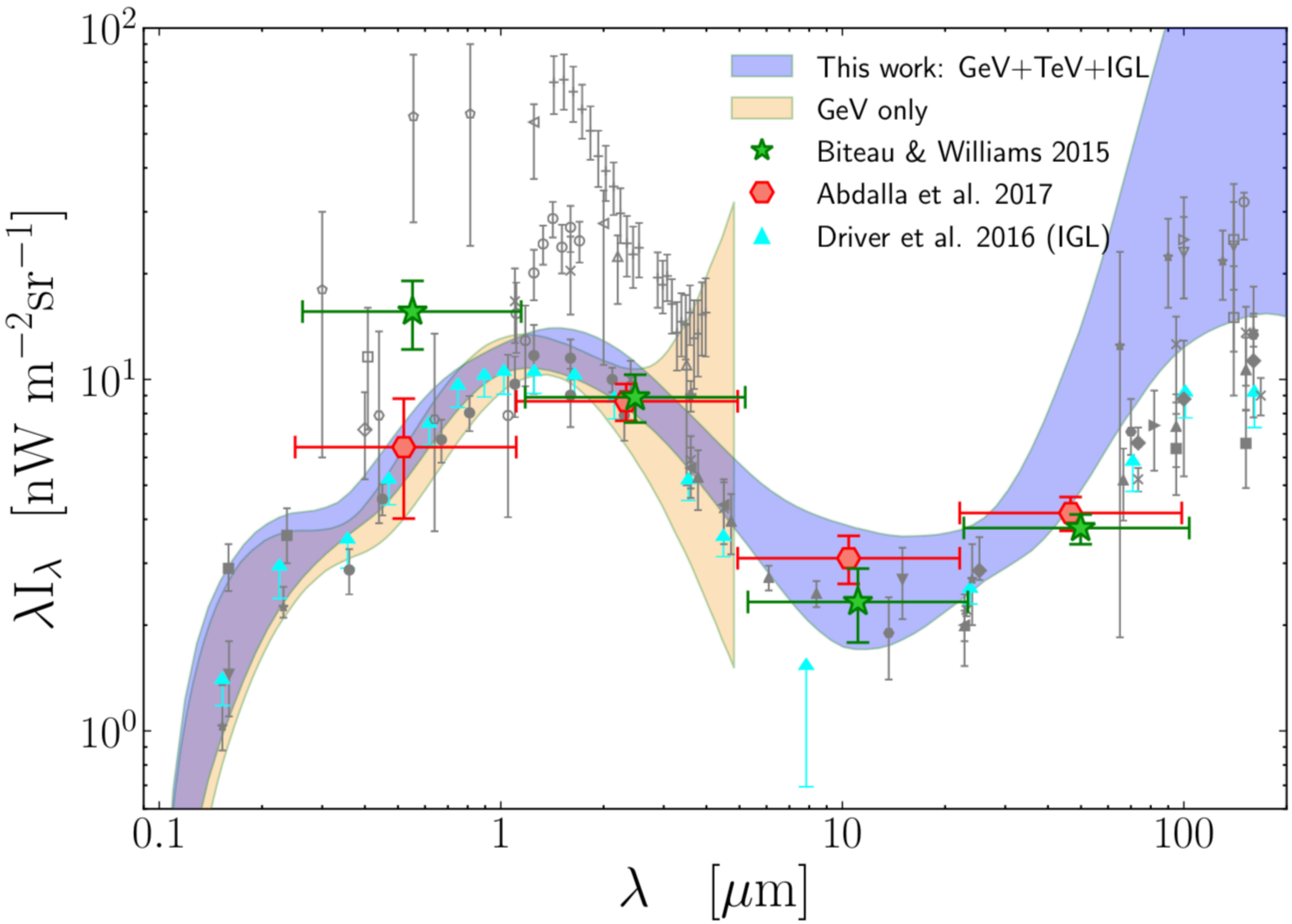
EBL with GeV-TeV data

- Analysis of 38 detected TeV blazars reported in Biteau & Williams 2015 (Desai, Helgason, Ajello, ApJL, 2019)



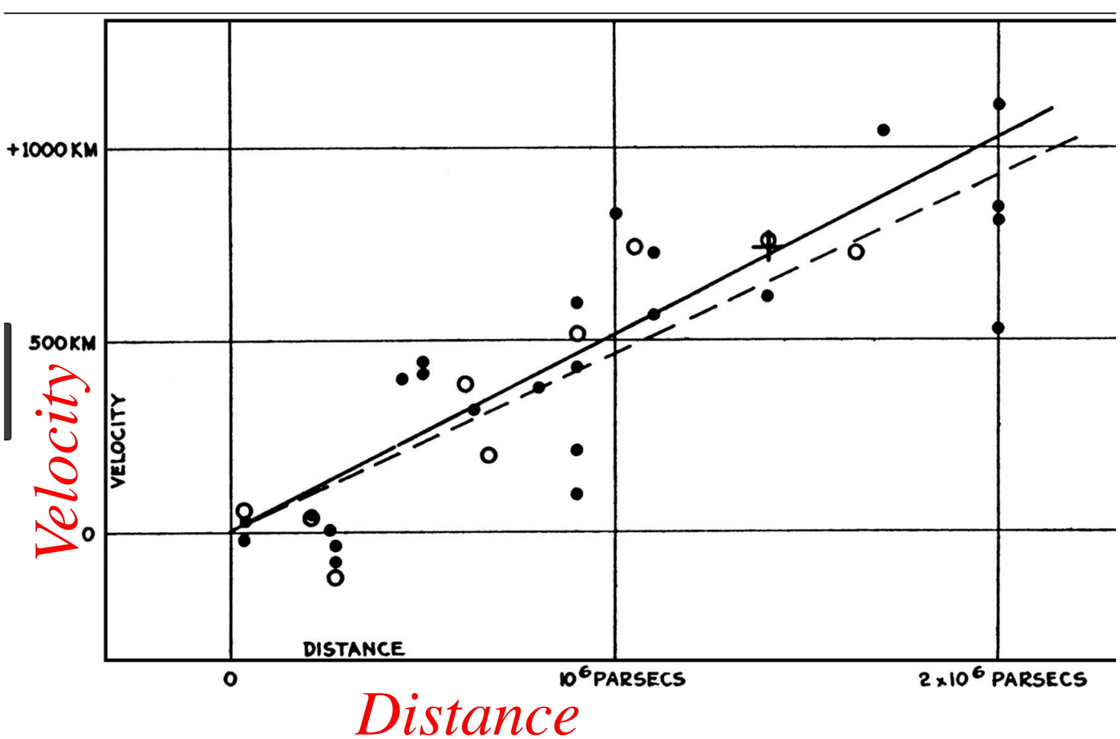
The newest EBL measurement

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

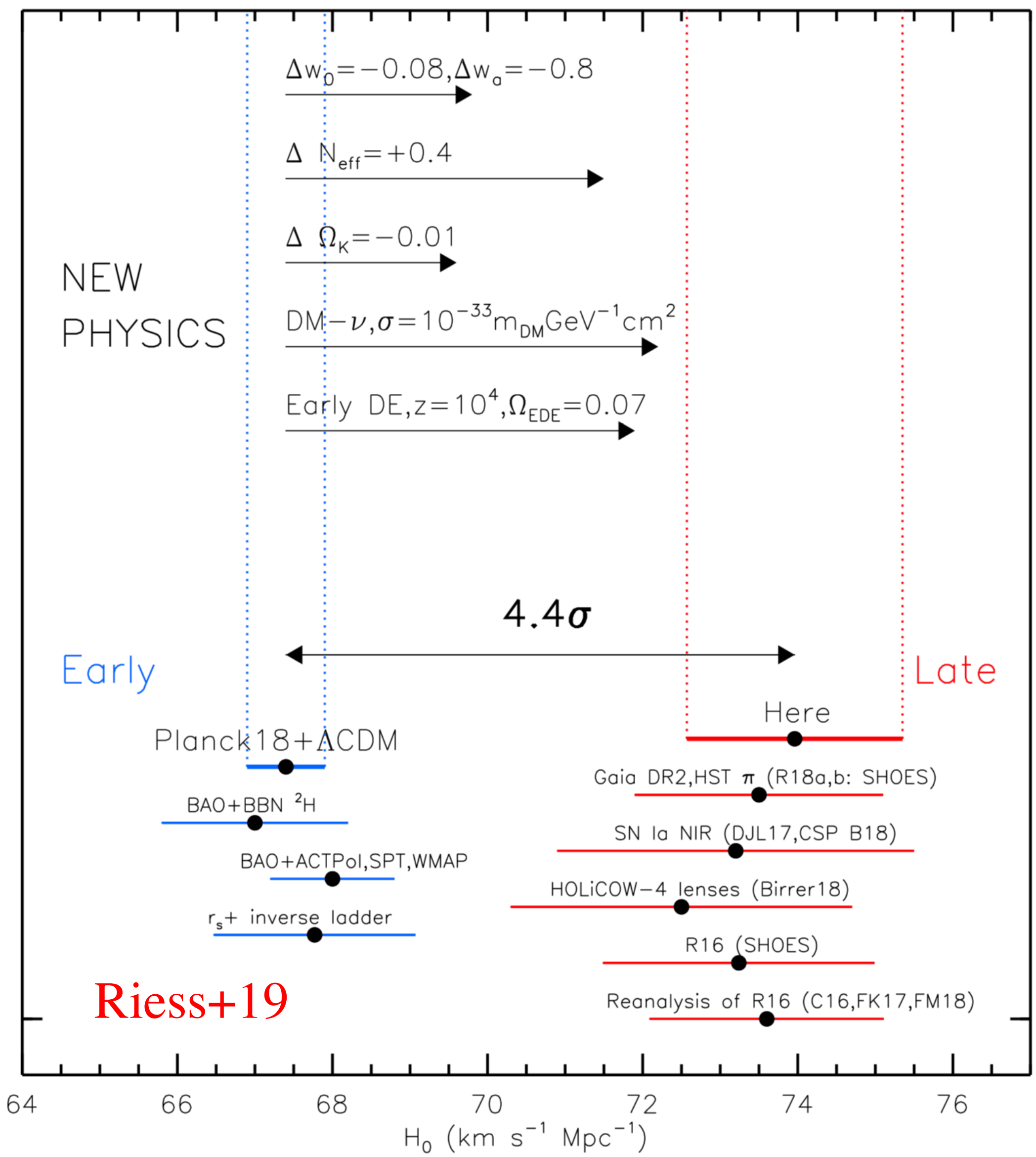


Hubble-Lemaître Law

- Hubble and Lemaitre first to show the Universe is expanding
- Hubble constant (1941): H_0=500 km/s/Mpc

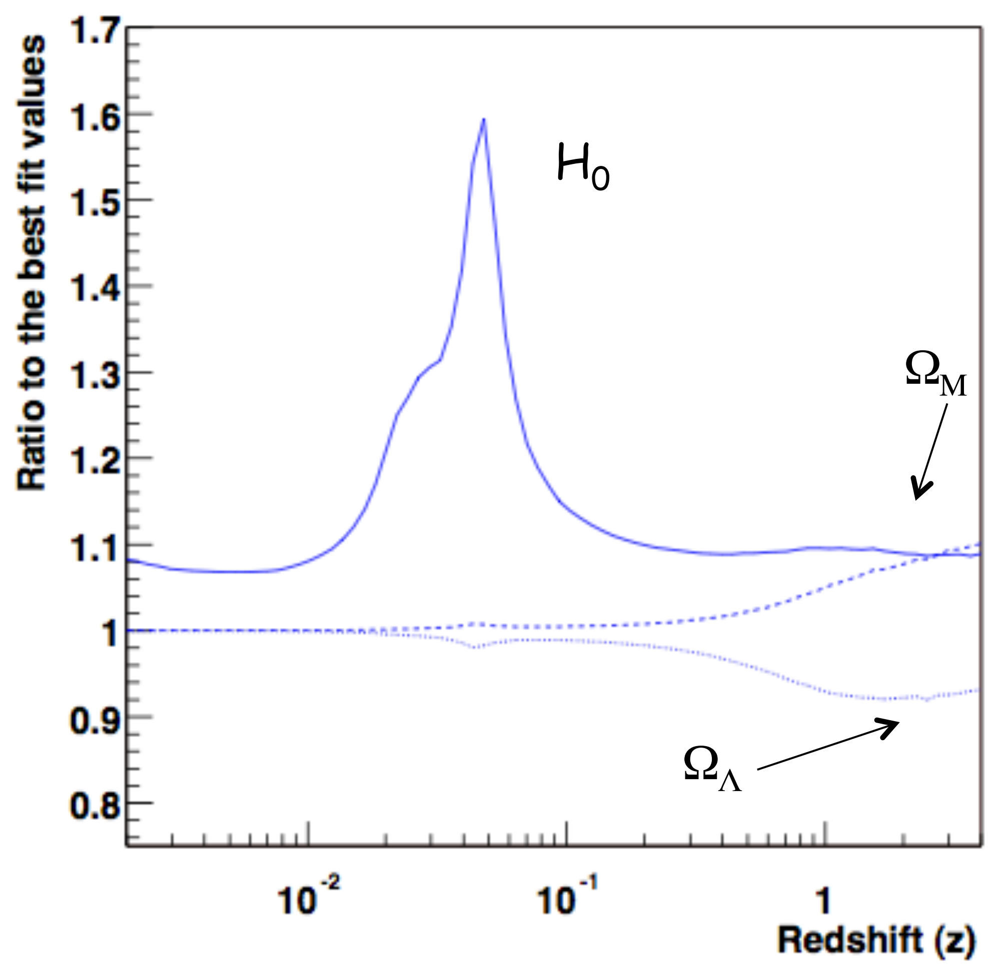


Hubble Constant (2019)

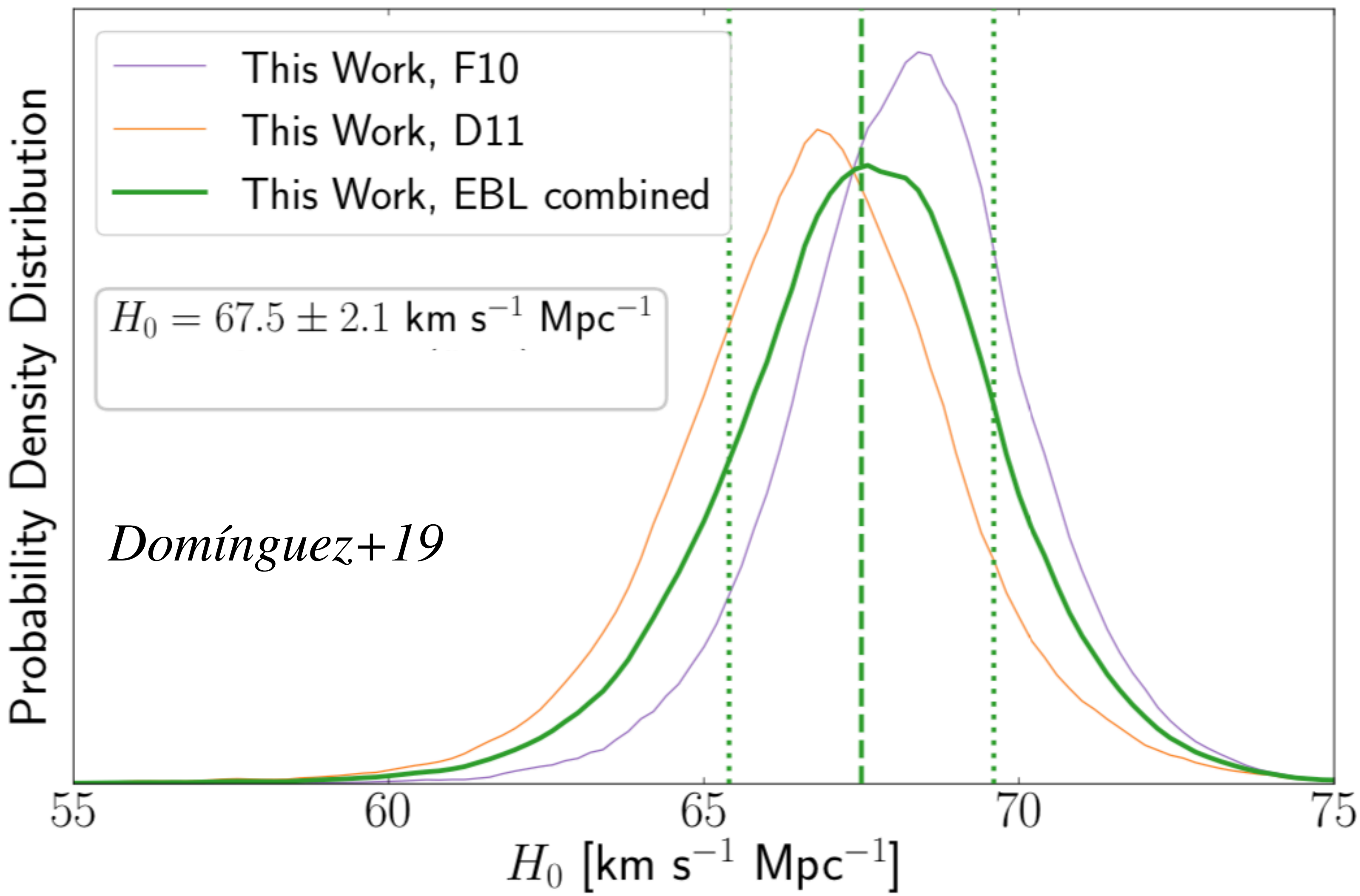


Hubble Constant with the EBL

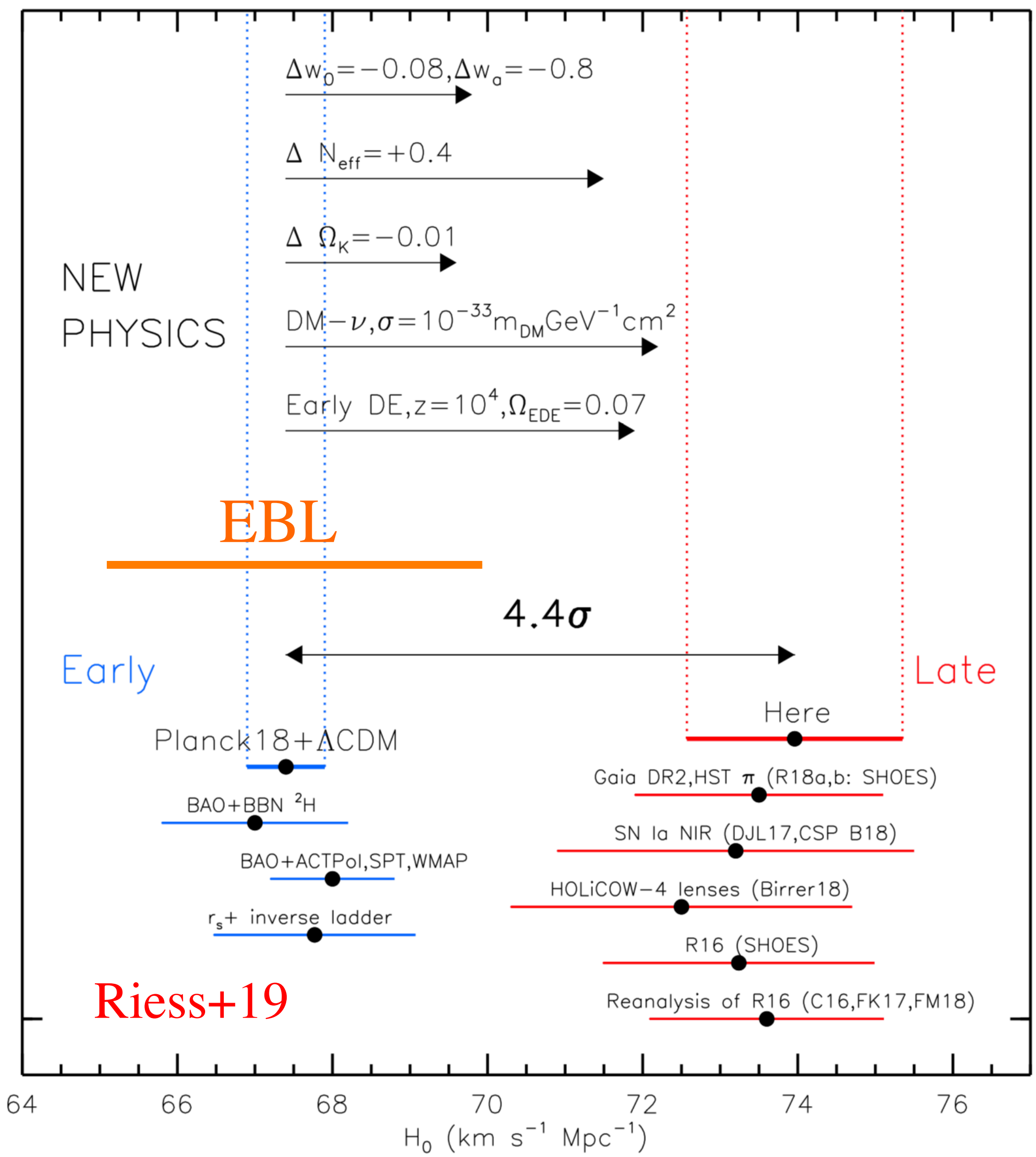
$$\tau_\gamma = \int_0^z d\ell(z) \int_{-1}^{+1} d\mu \frac{1-\mu}{2} \int_{\epsilon'_{\rm thr}}^{\infty} d\epsilon' \frac{dn_{\rm bkg}}{d\epsilon} \sigma_{\gamma\gamma}(E', \epsilon', \mu)$$



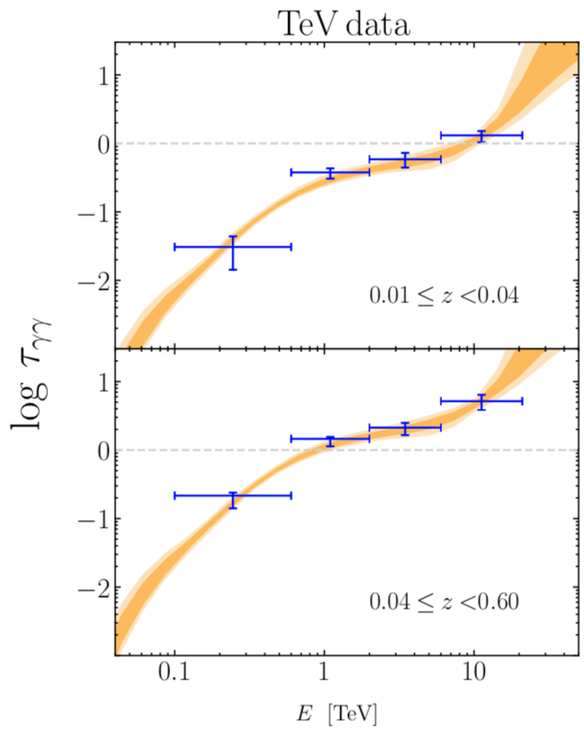
Hubble Constant from EBL

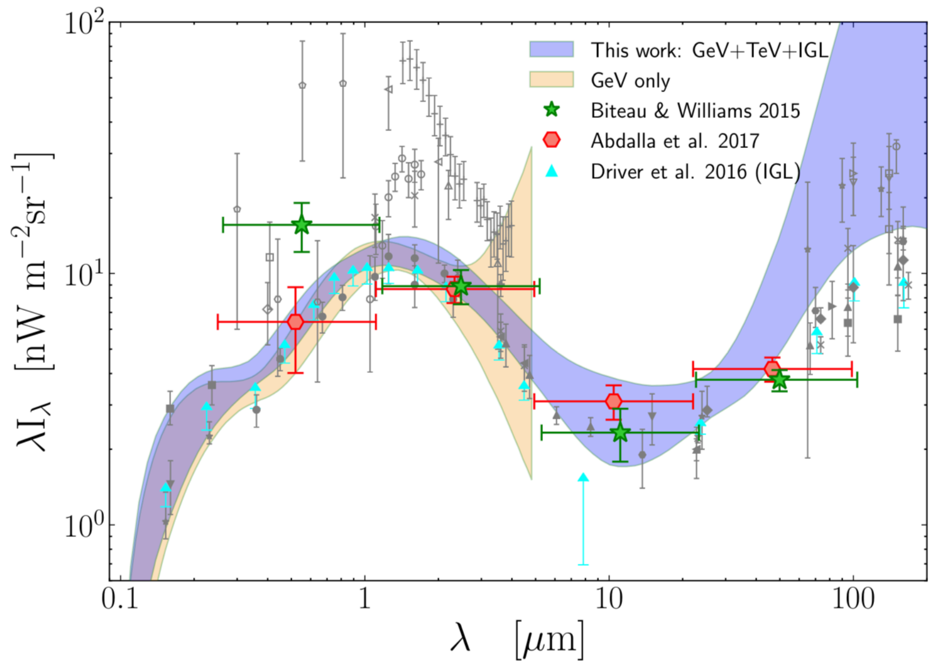


Hubble Constant (2019)



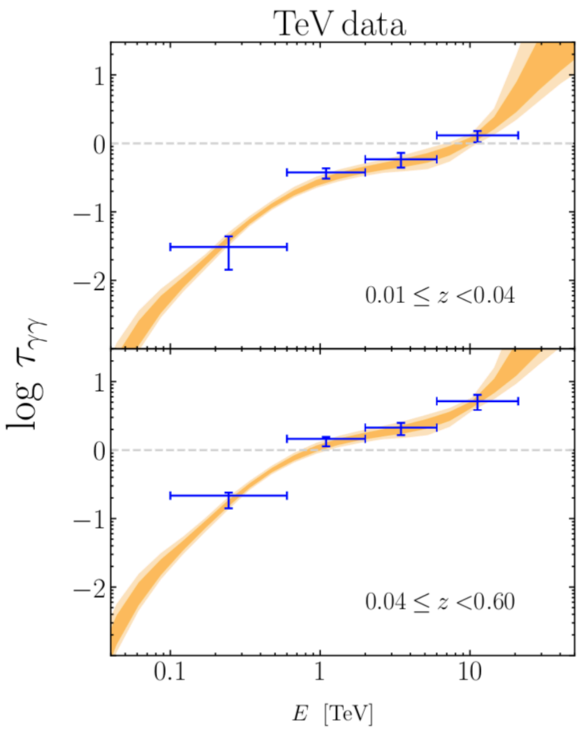
What will CTA do for the EBL ?

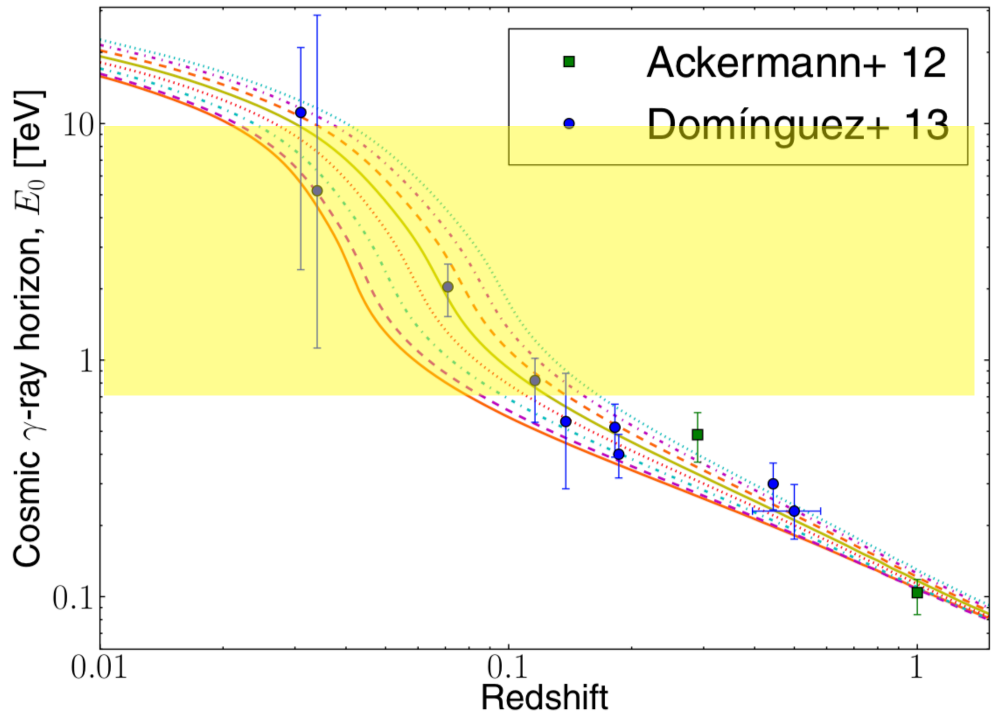




- Fantastic determination of the optical depth up to at least z=1.6
- Extend the EBL measurements to the far-IR peak

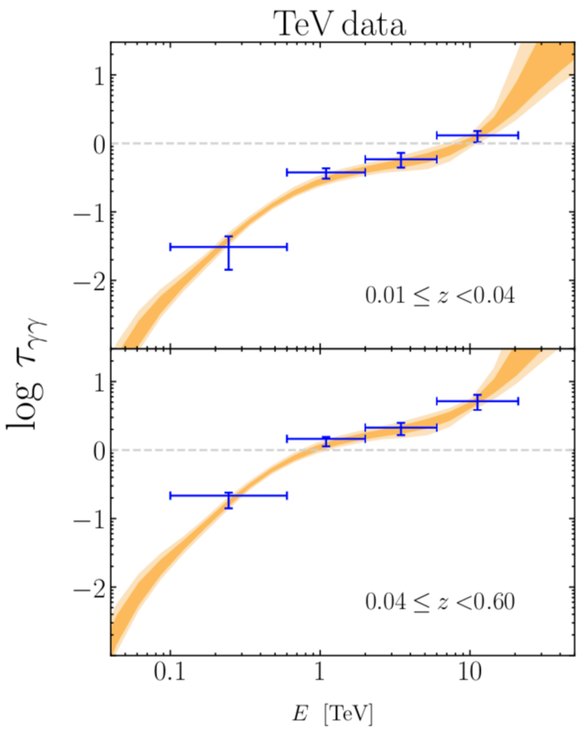
What will CTA do for the EBL ?

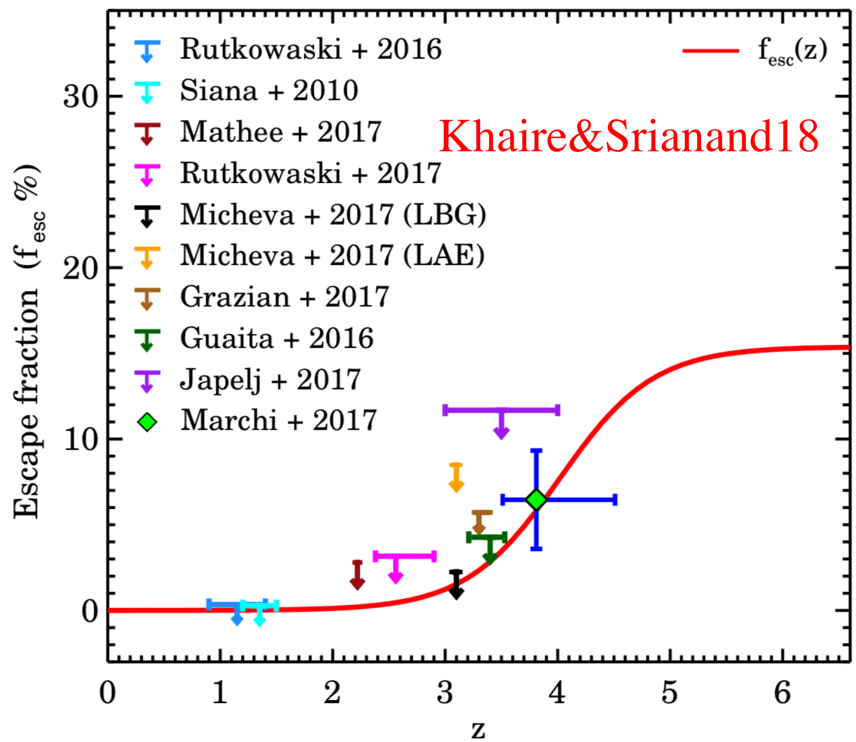




- Fantastic determination of the optical depth up to at least z=1.6
- Measure the far-IR EBL (dust) and its evolution
- Measure the Hubble constant with negligible statistical error

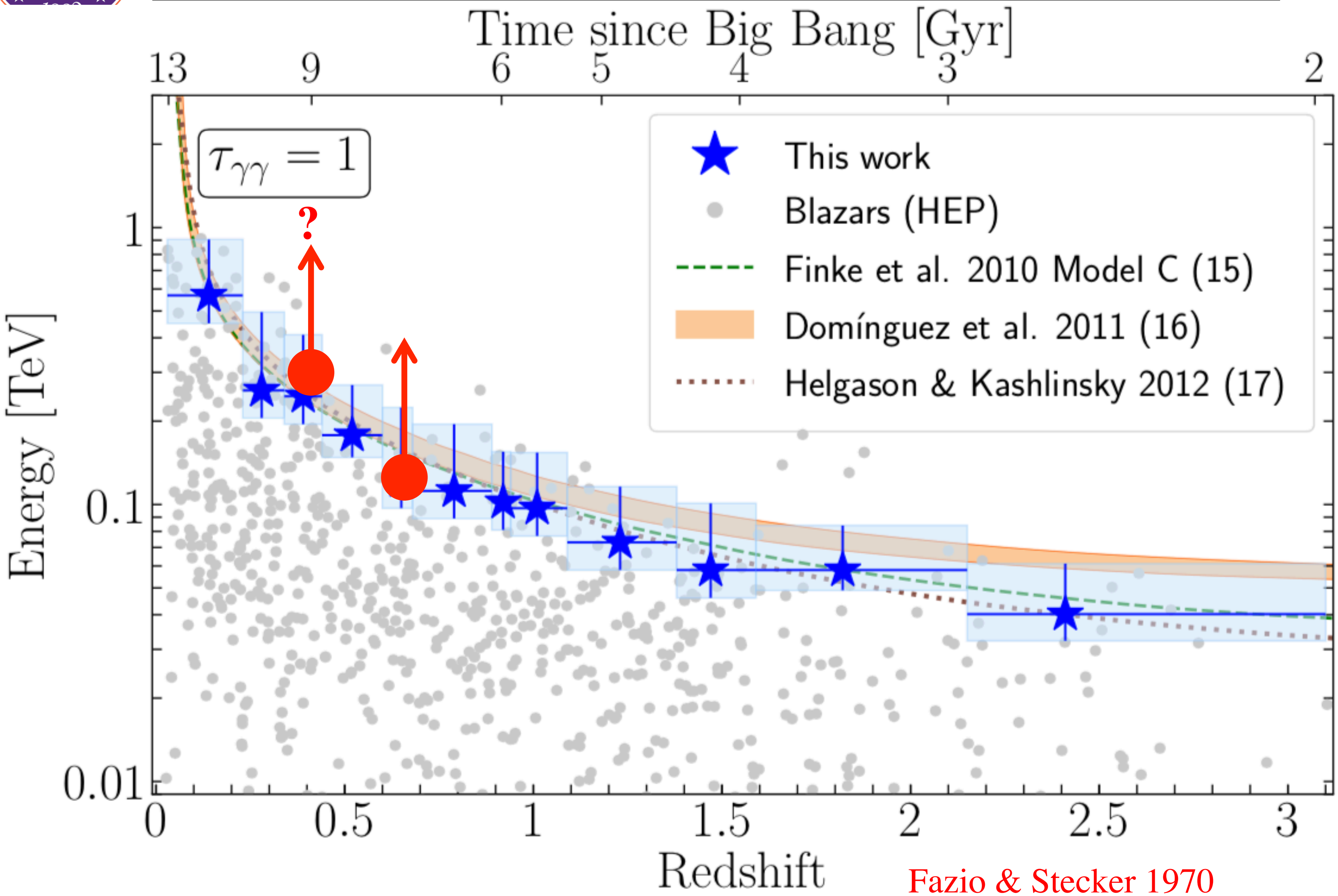
What will CTA do for the EBL ?





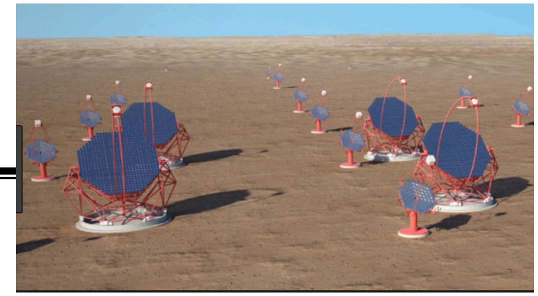
- Fantastic determination of the optical depth up to at least z=1.6
- Measure the far-IR EBL (dust) and its evolution
- Measure the Hubble constant with negligible statistical error
- Constrain interesting galaxy-related parameters

GRB190114c and GRB180720B



Fazio & Stecker 1970

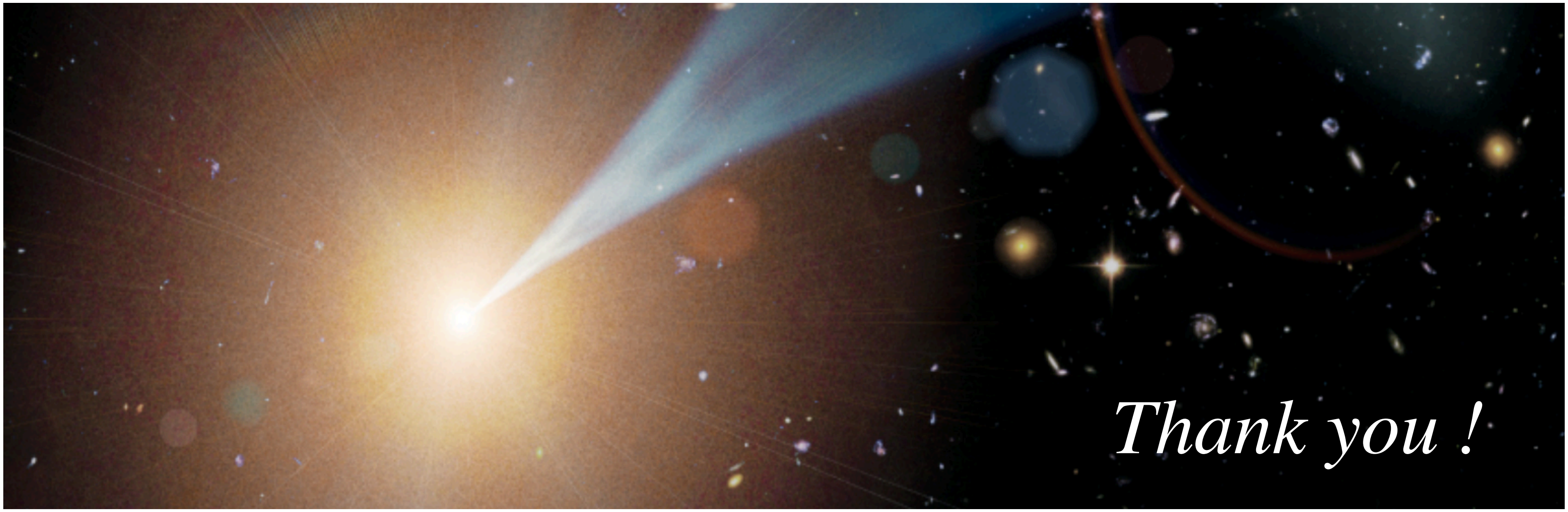
Outlook



- *Fermi*-LAT has already detected more than 3000 blazars (!)
  - Assuming we can obtain redshifts for many of those and that the LAT will take data for ~20 years:
  - We expect that the S/N of the current EBL measurement will double
  - This will provide the best constraints on the evolving EBL and the UV background

- The Cherenkov Telescope Array will
  - improve our knowledge of <u>the IR EBL and its evolution</u>
  - <u>provide stronger constraints on H_0</u>

- Some of the most interesting EBL advancements may come from GRBs



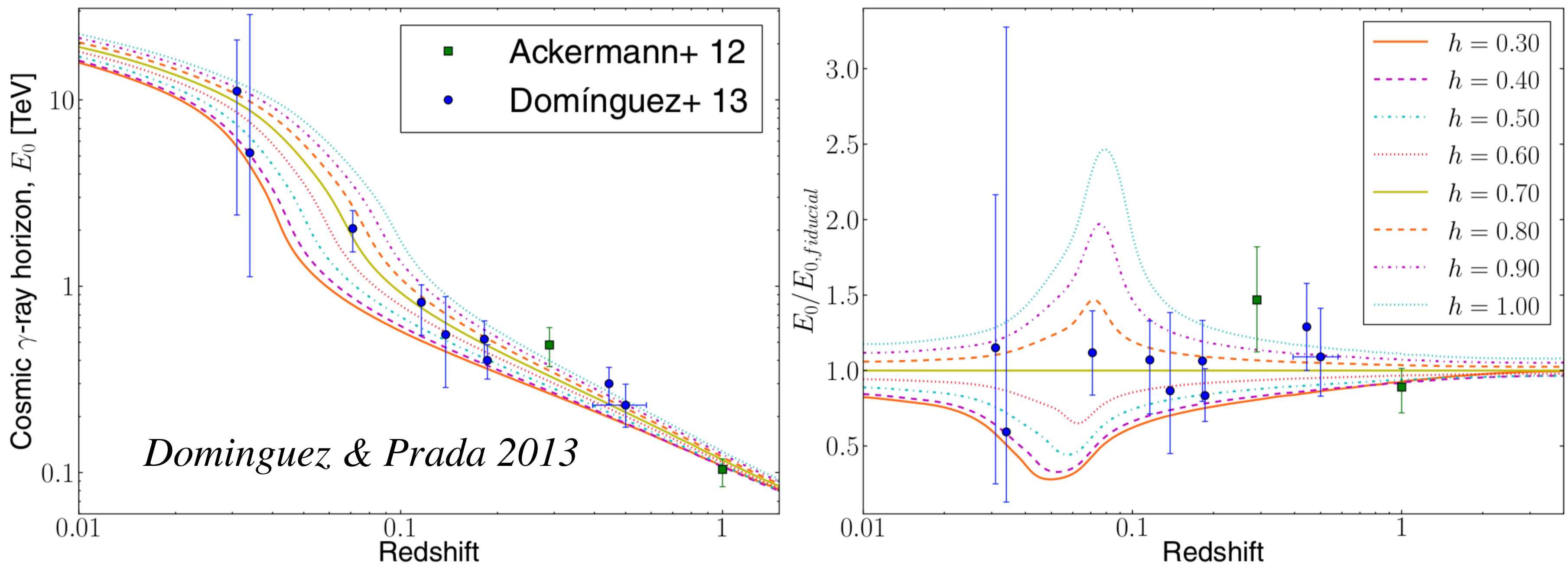
- EBL is a powerful tool for galaxy evolution, star formation and cosmology

V. Paliya A. Desai K. Helgason A. Dominguez J. Finke





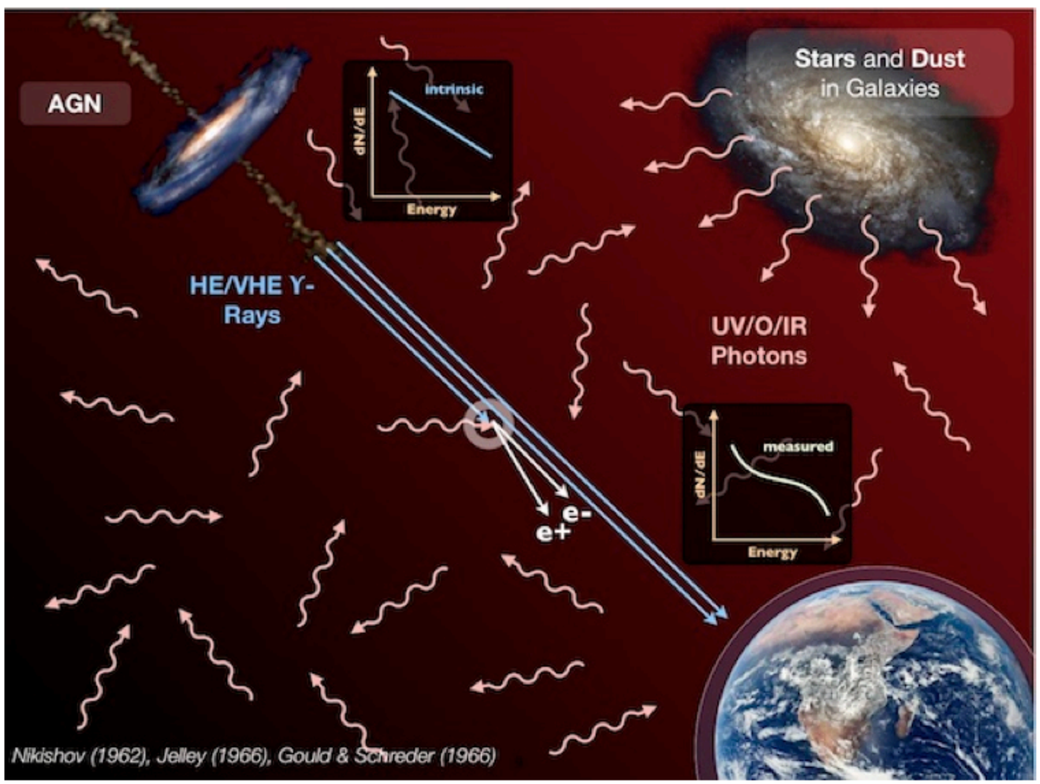
Hubble constant



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

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

“Spectroscopy” of the EBL

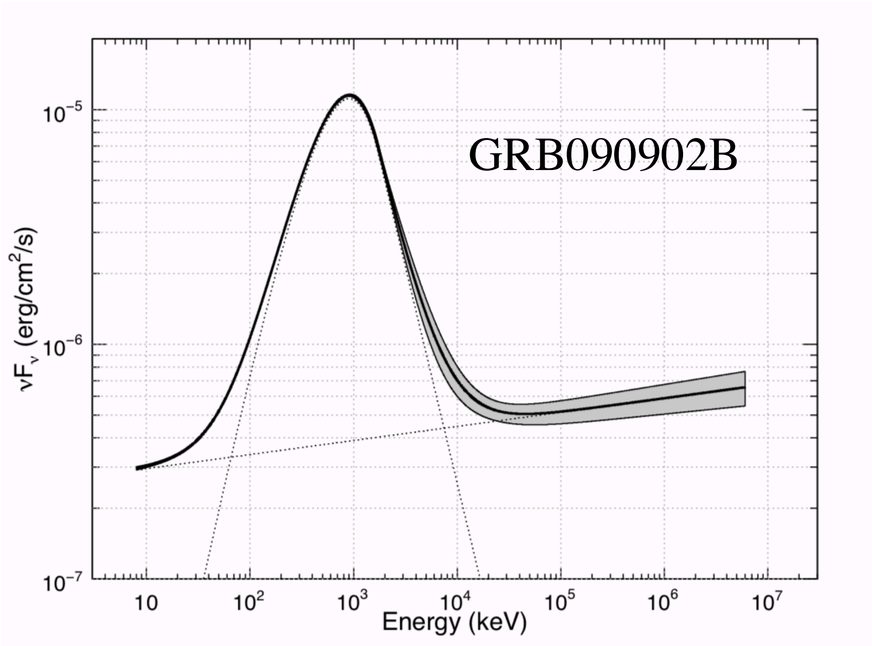
- 2 Photons convert into an electron-positron pair if :
  - $E\gamma \times E_{EBL} \geq 2(m_e c^2)^2$

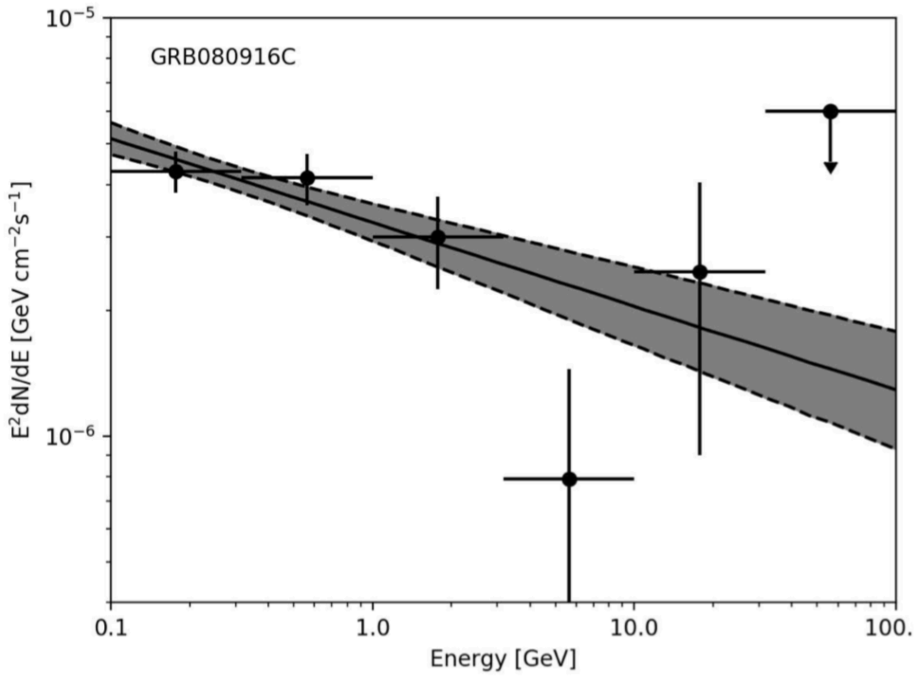
γ-ray (z=0)	E=10 GeV	E=100 GeV	E=1TeV
EBL photon	26 eV	2.6 eV	0.26 eV

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

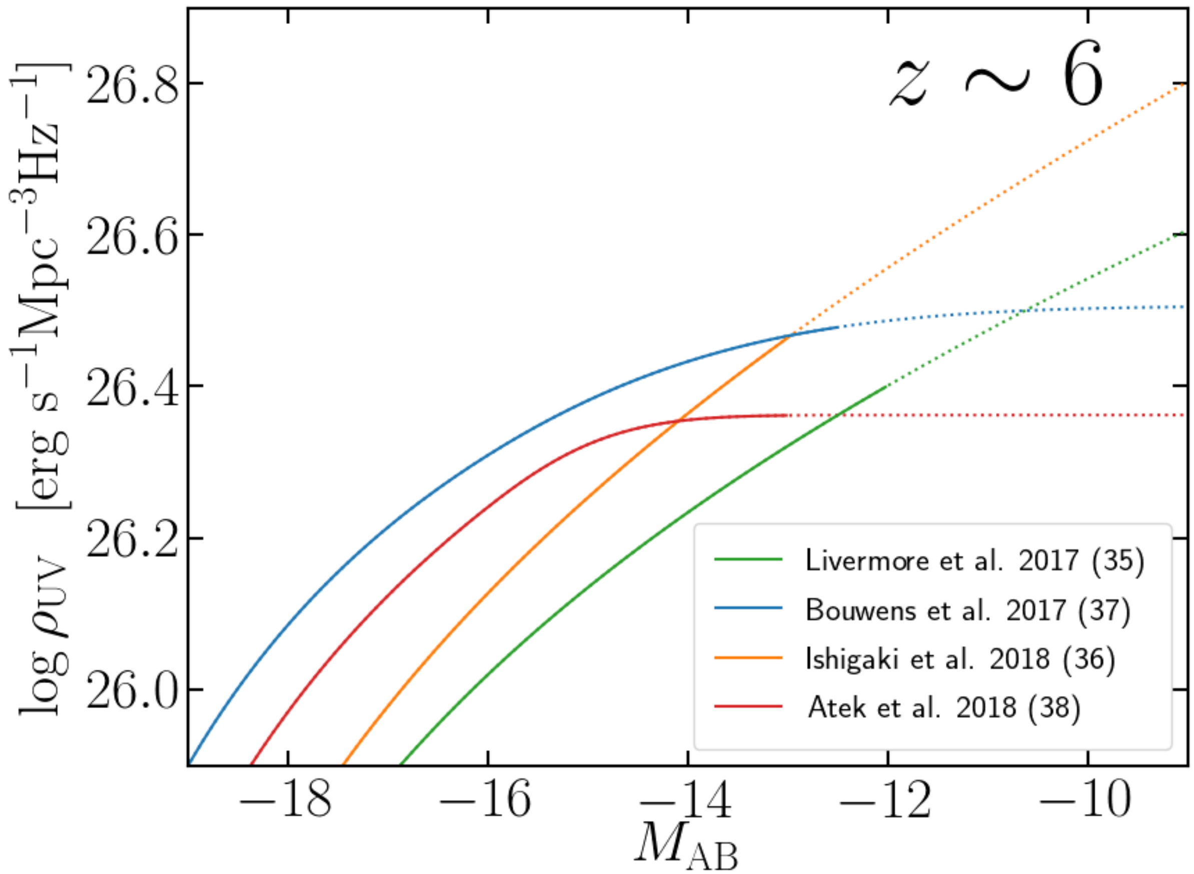
GRB 080916C

- A high fluence, highest redshift GRB detected by the LAT



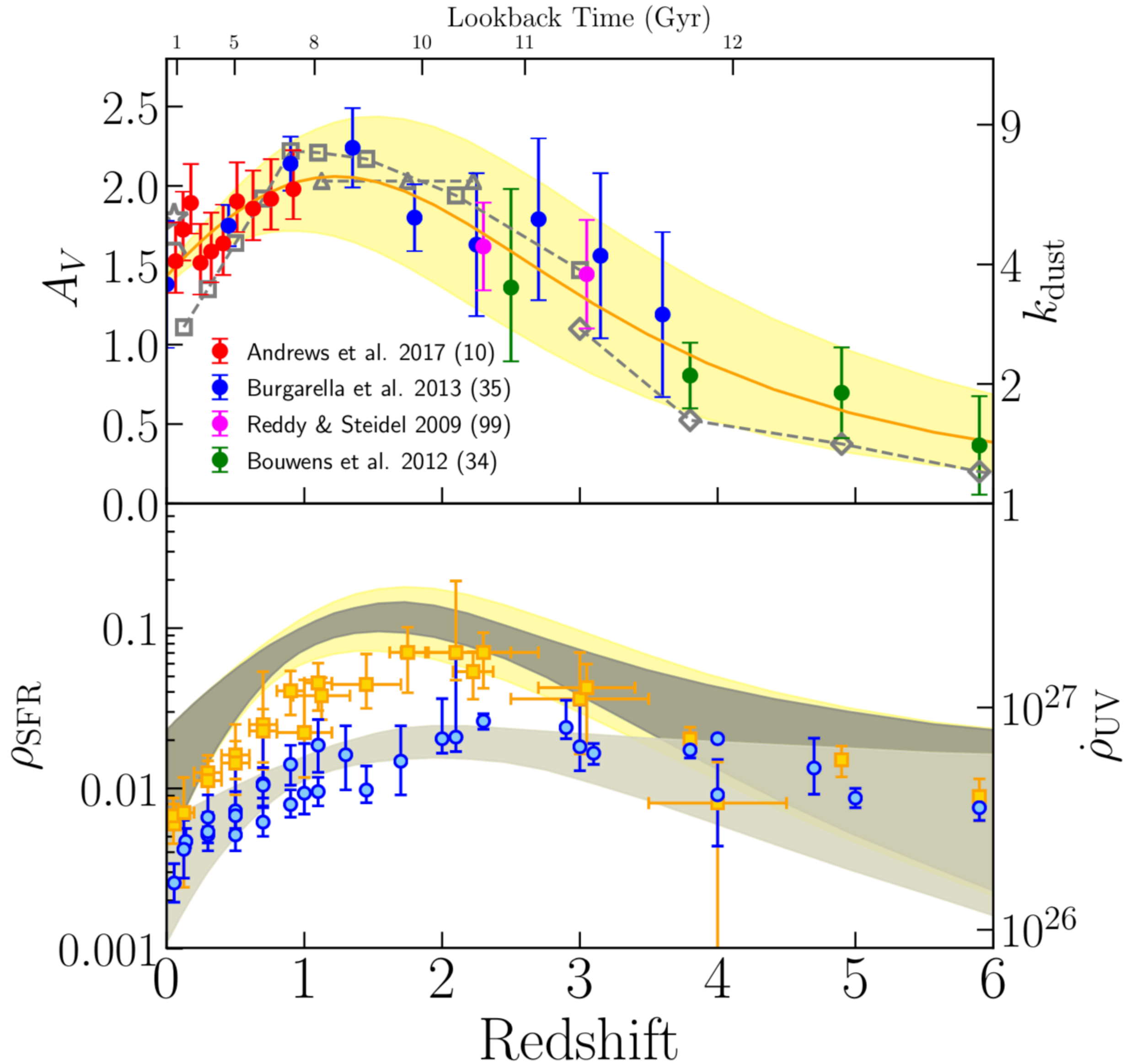


Re-ionization

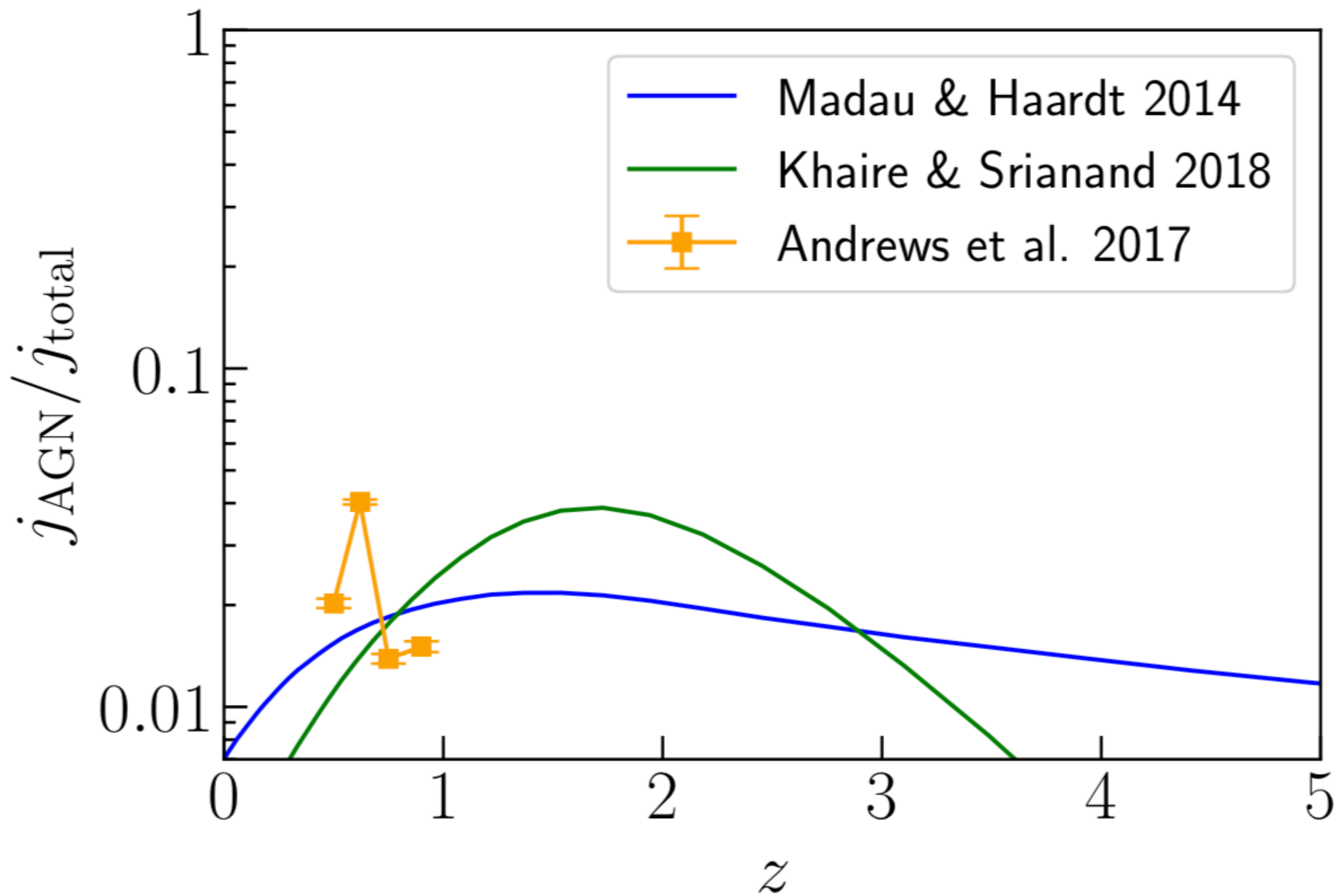


Hubble Frontier Fields

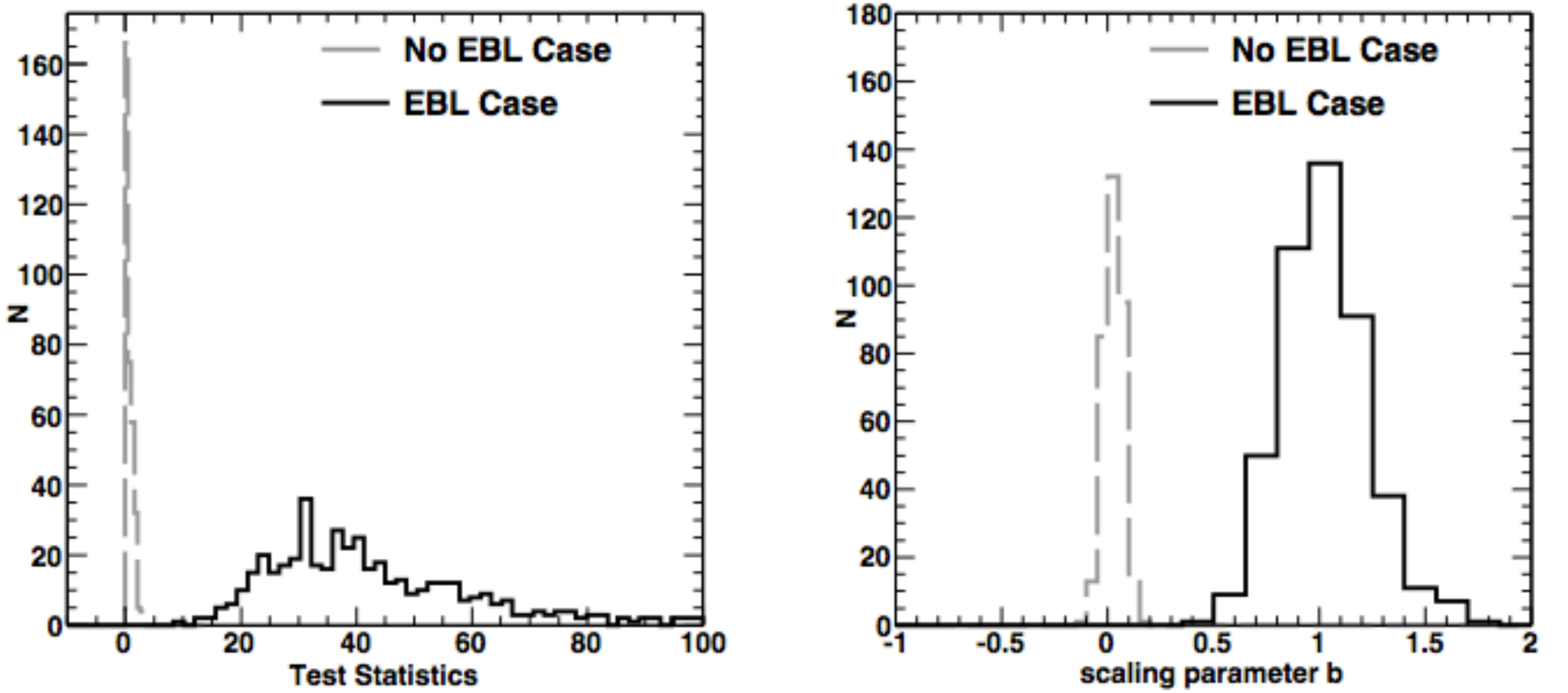
Dust attenuation



AGN Contribution



Monte Carlo Simulations



Ackermann et al. 2012, *Science*, 338, 1190

A new measurement of the EBL

2012

- 46 months of P7 data
- 1-500 GeV
- 150 BL Lacs
- z~0 to z=1.6

2018

- 108 months of P8 data
- 1-1000 GeV
- 739 blazars + 1 GRB
- z~0 to z~3.1/4.35