Extragalactic Background Light and Gamma-Ray Attenuation

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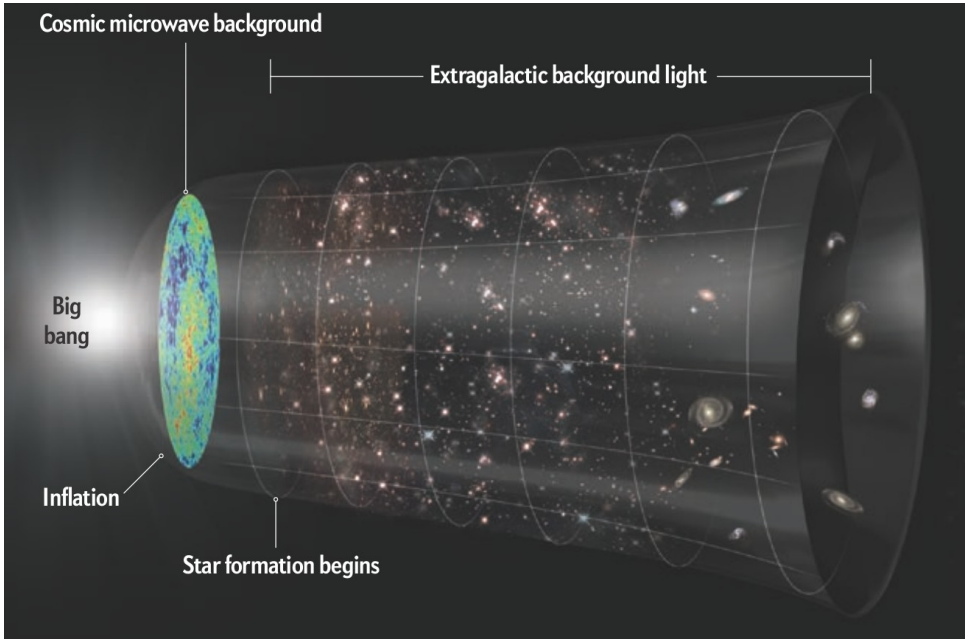
Galaxy Evolution and Cosmology

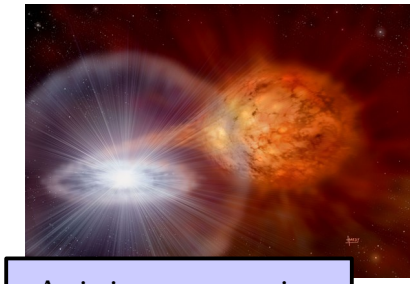


Scientific American, June 2015

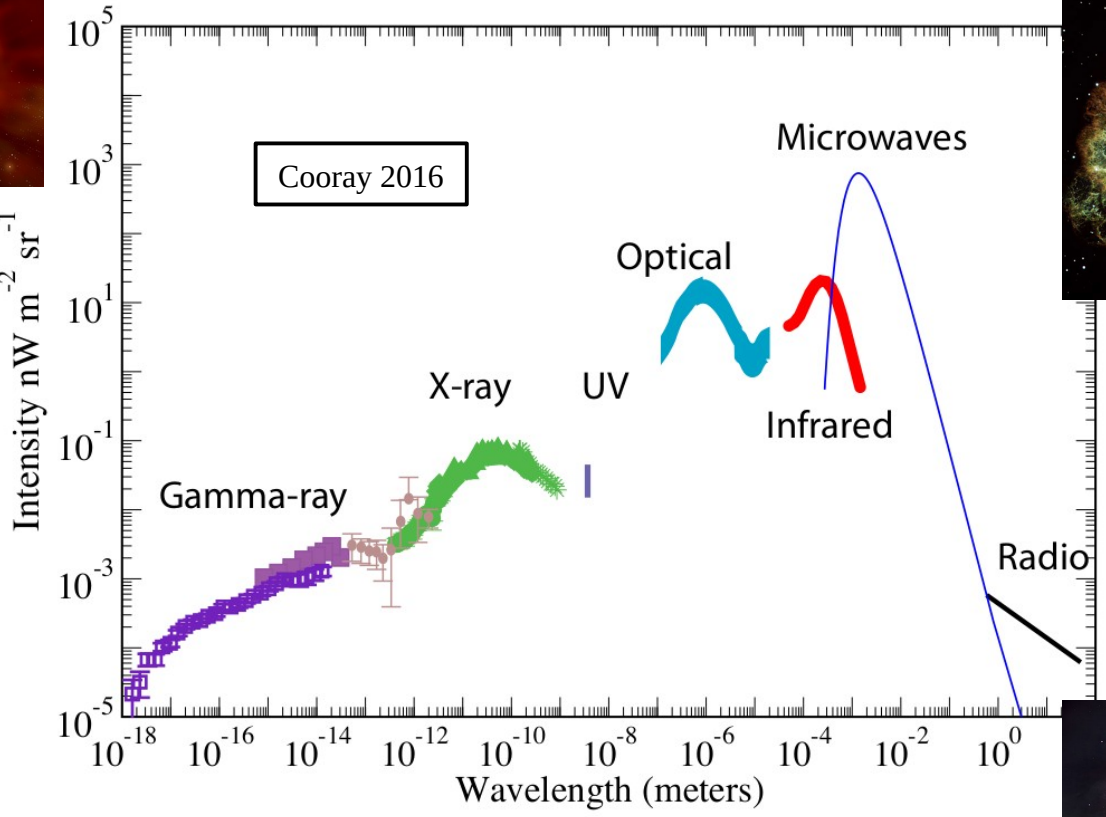
$$\Omega_m = \Omega_b + \Omega_D$$

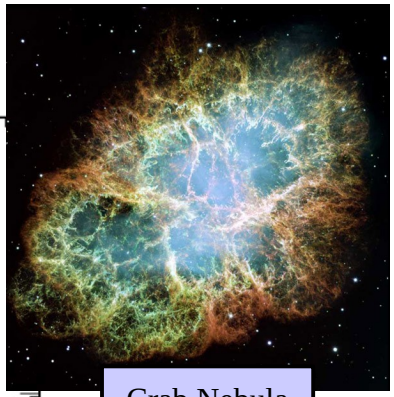
$$\Omega_m + \Omega_\Lambda = 1$$

Cosmic Diffuse Extragalactic Backgrounds

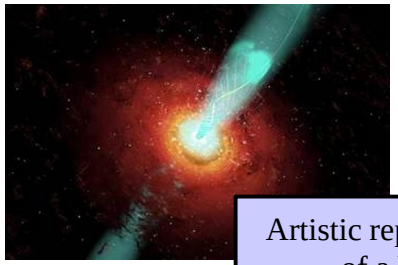


Artistic representation of a binary system





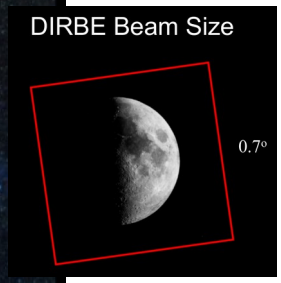
Crab Nebula

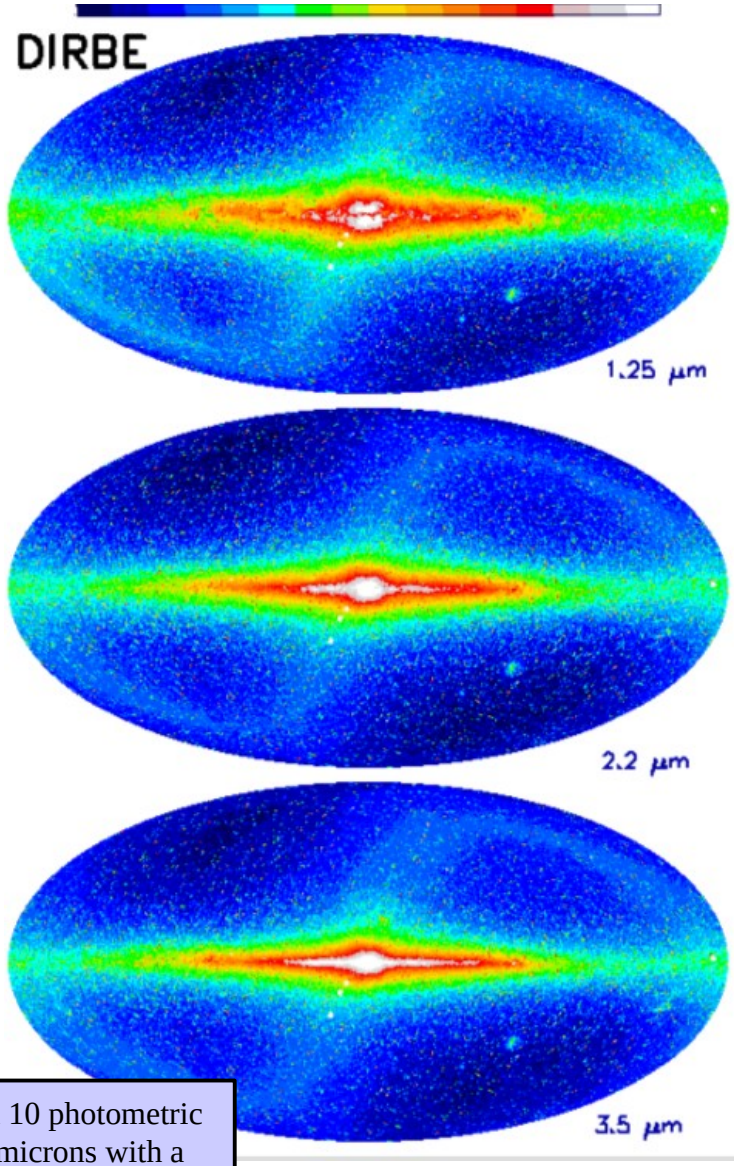


Artistic representation of a blazar

Orion Nebula (birth place of stars)

Measuring the Extragalactic Background Light





DIRBE imaged the sky in 10 photometric bands from 1.25 to 240 microns with a beam size of 0.7x0.7 sq. degrees

Measuring the Extragalactic Background Light

Zodiacal light, visible under the right conditions: typically after the sunset in Spring and right before sunrise in Autumn

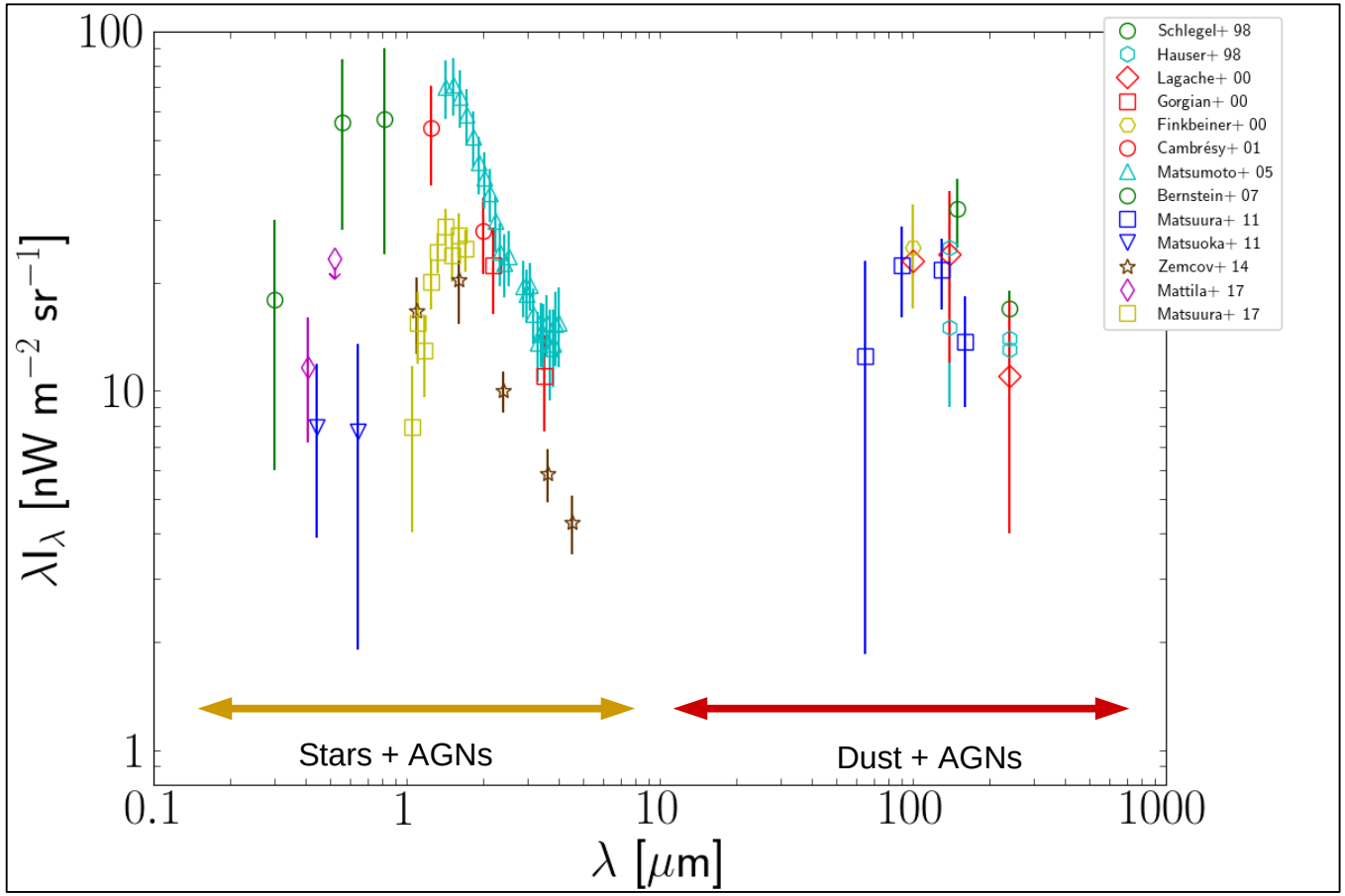
TABLE 2

DECOMPOSITION OF THE DIRBE INTENSITY

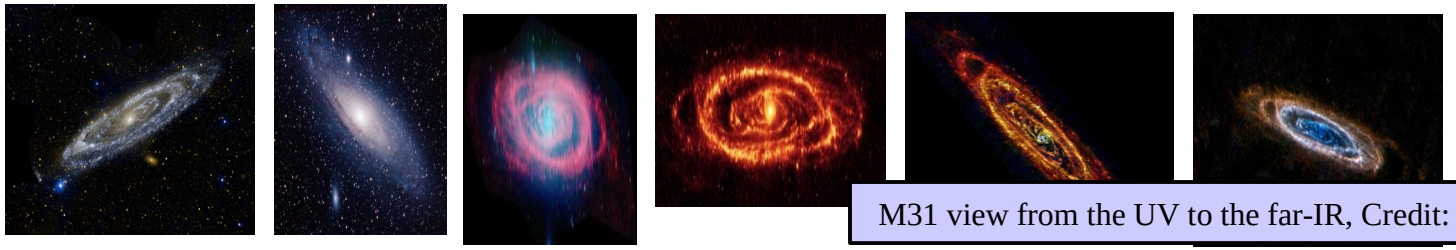
Component	2.2 μm (kJy sr^{-1})	3.5 μm (kJy sr^{-1})
Total	137.5 $\pm$ 0.3	105.3 $\pm$ 0.3
Zodi	101.8 $\pm$ 3.8	80.4 $\pm$ 3.3
ISM	...	1.1 $\pm$ 0.2
Stars, $m < 9$ mag.....	7.4 $\pm$ 2.2	5.3 $\pm$ 1.8
Stars, $m > 9$ mag.....	11.9 $\pm$ 0.6	5.7 $\pm$ 0.3
EBL	16.4 $\pm$ 4.4	12.8 $\pm$ 3.8

EBL is an order of magnitude lower than foregrounds and subject to large systematic uncertainties, e.g. Gorjian+ 00

Measuring the Extragalactic Background Light

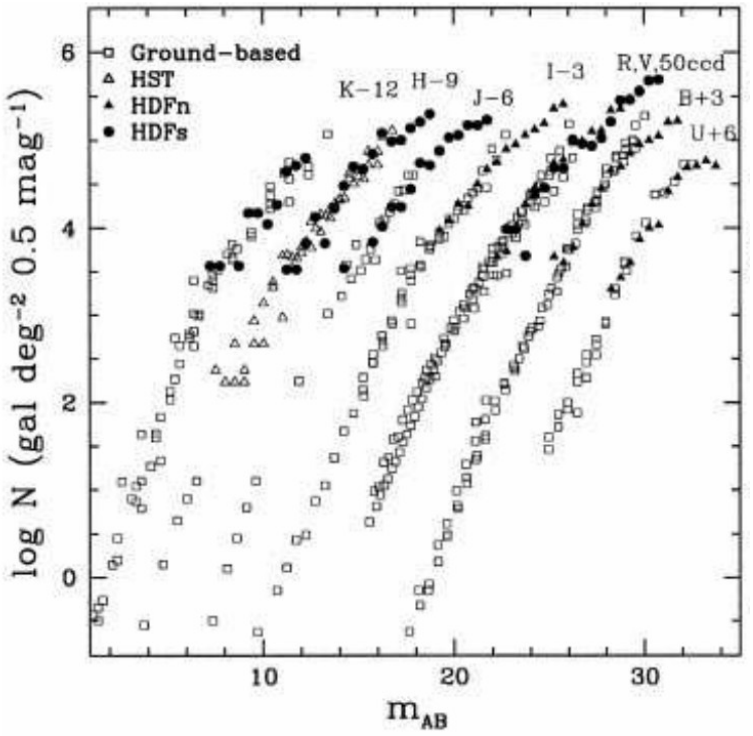


UV | optical | near-IR | mid-IR | far-IR



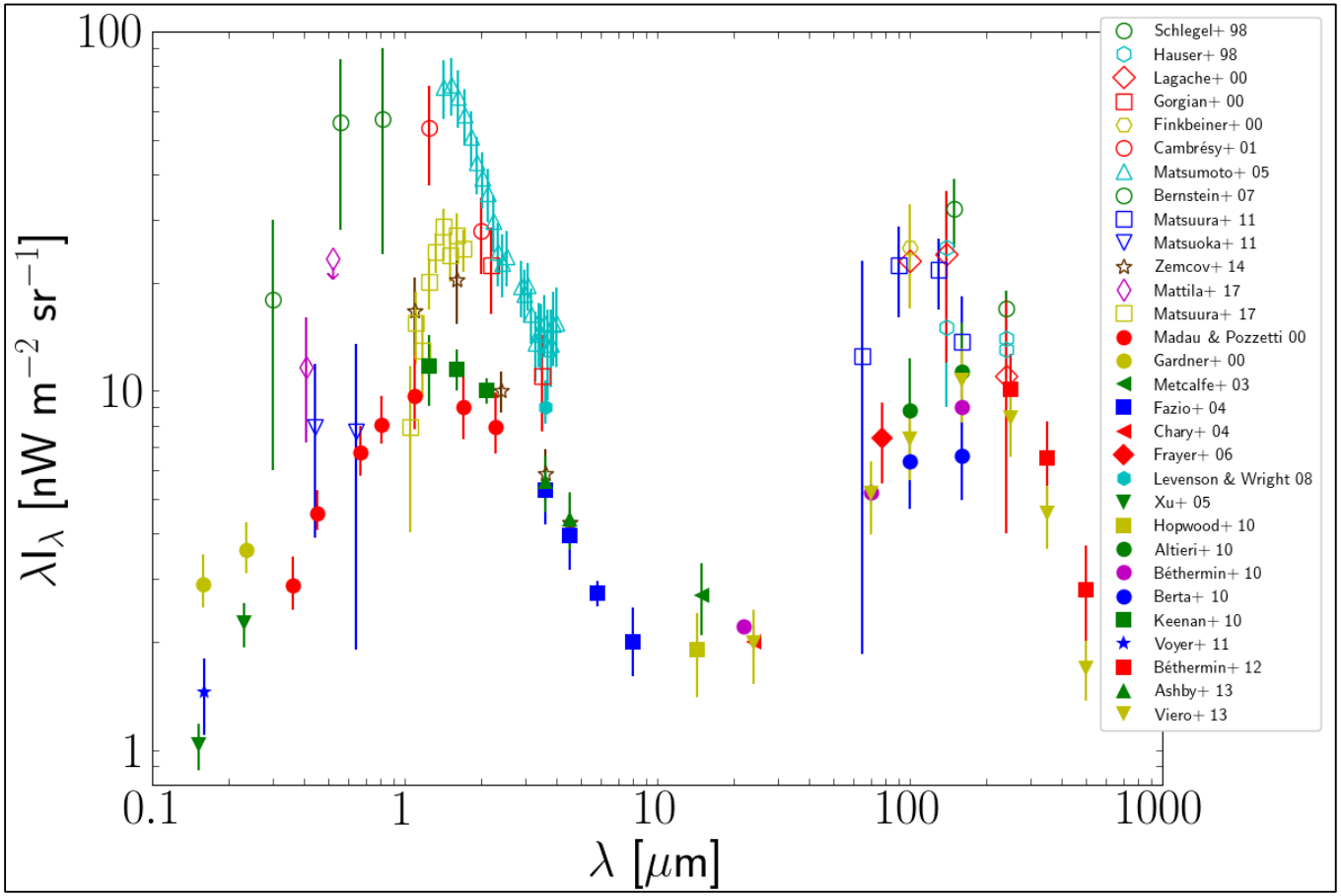
M31 view from the UV to the far-IR, Credit: NASA & ESA

Measuring the Extragalactic Background Light



Galaxy number counts in the Hubble Deep Field, e.g. Madau & Pozzetti, 2000

Measuring the Extragalactic Background Light



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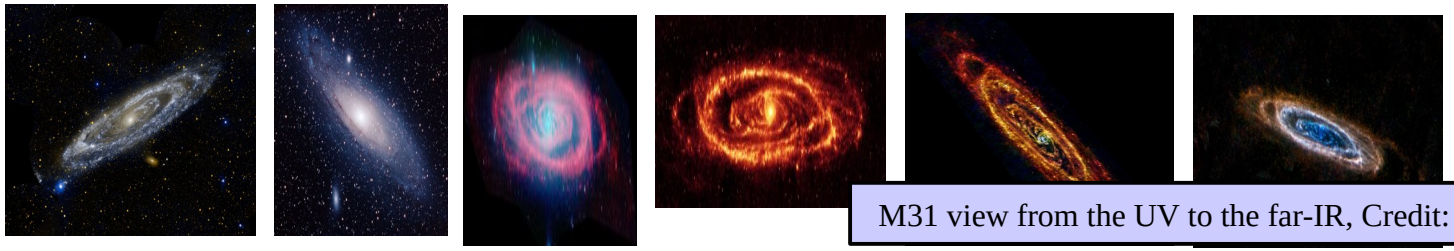

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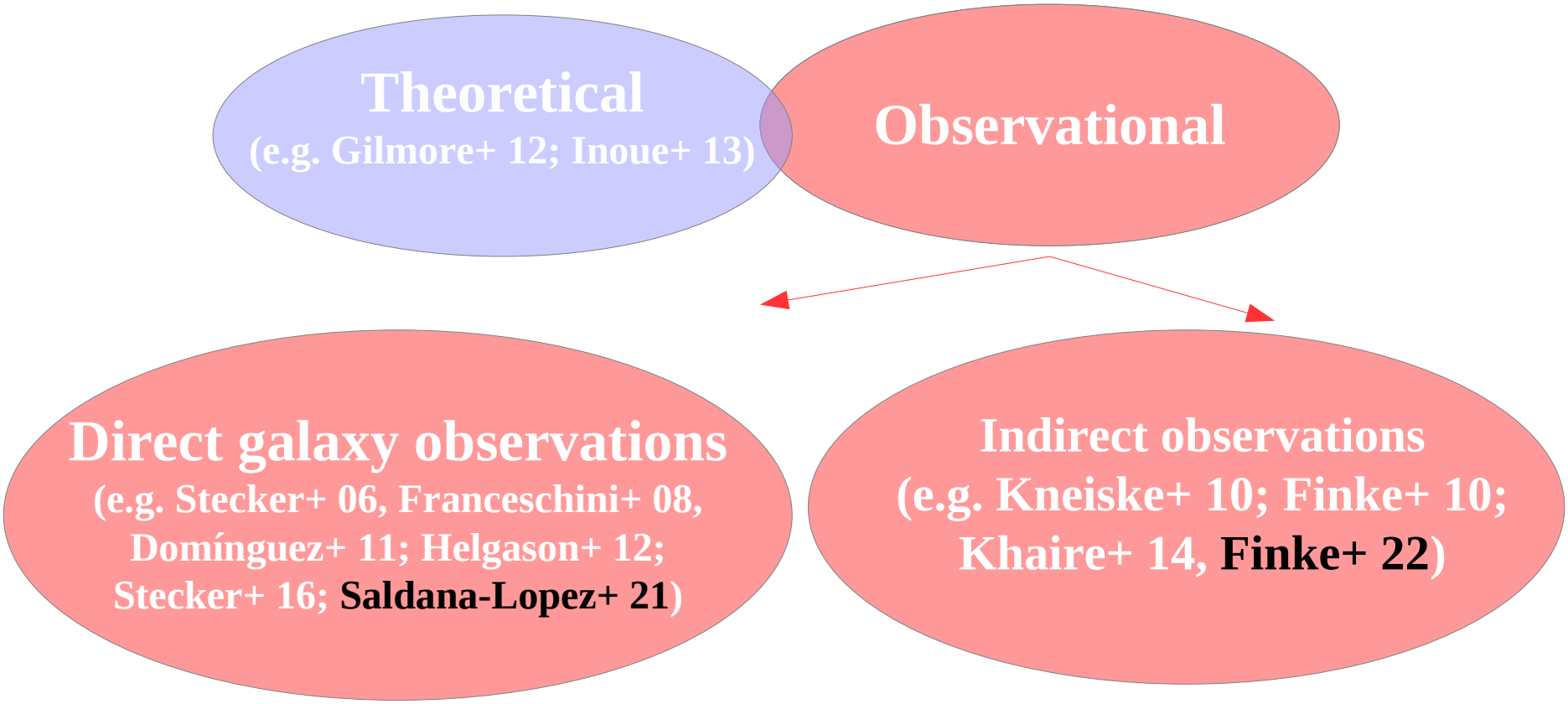
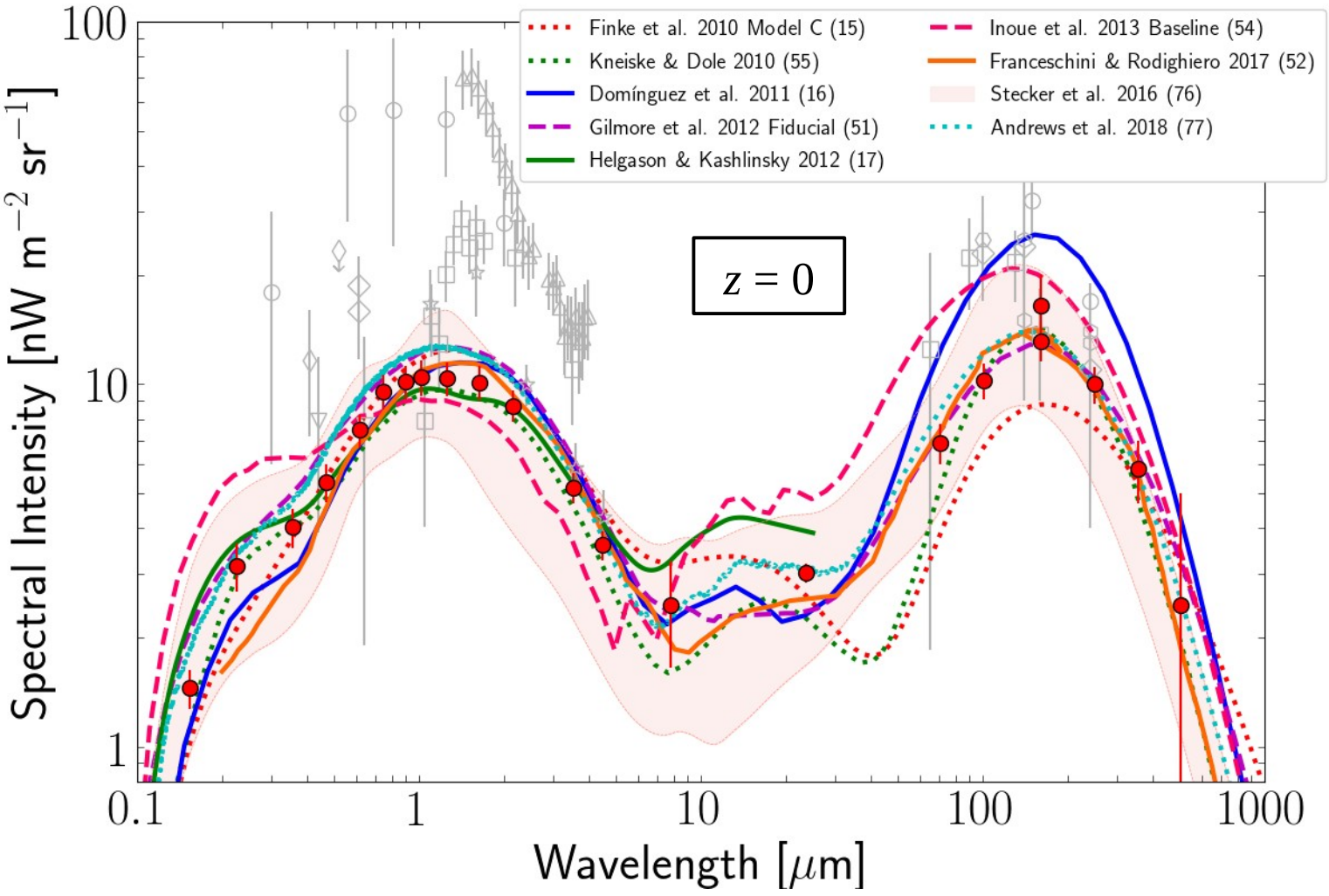
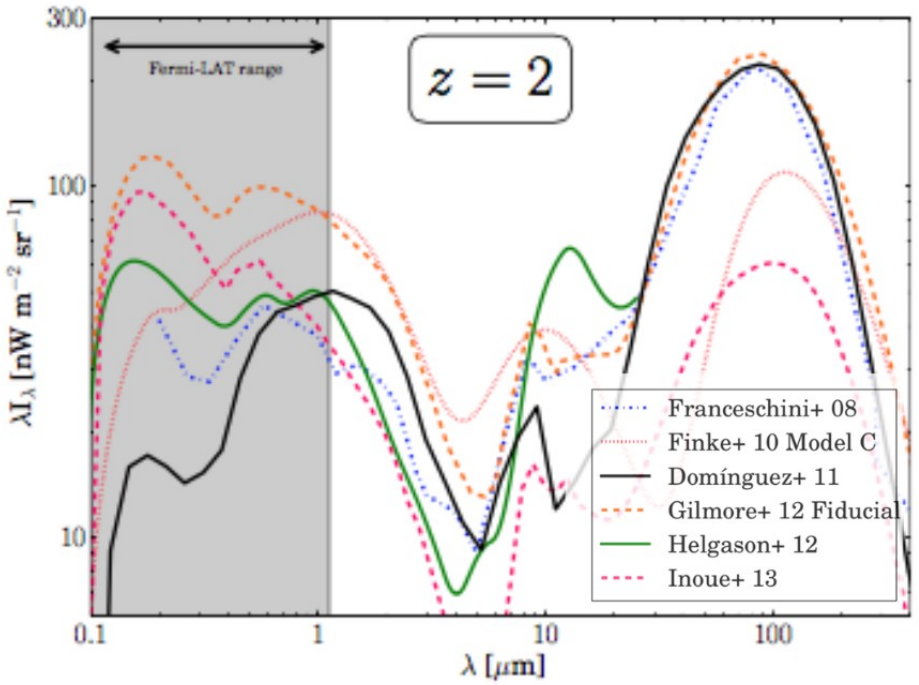
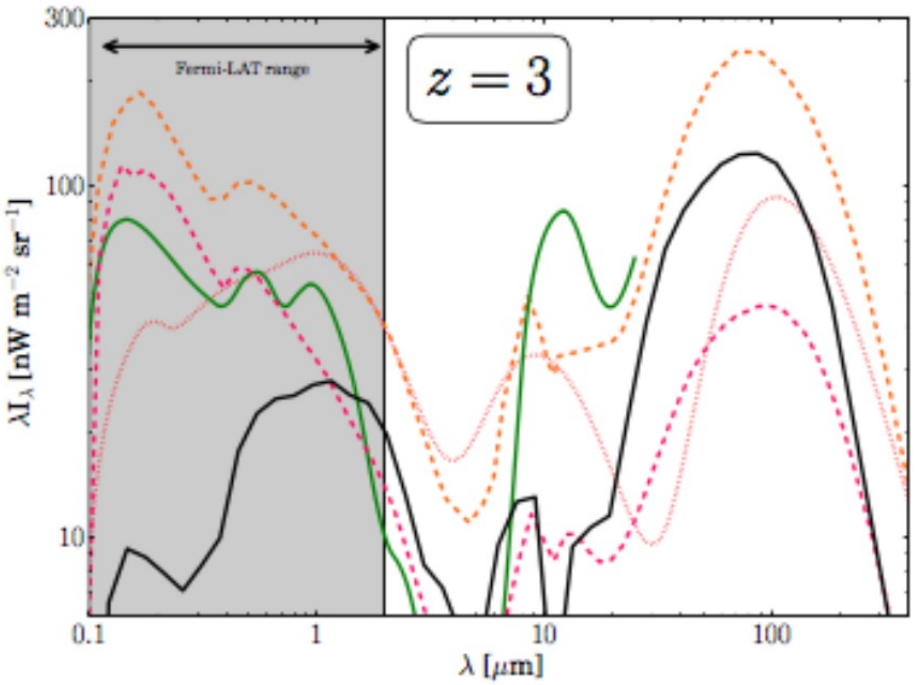


Extragalactic Background Light (Local)



Extragalactic Background Light (Evolution)

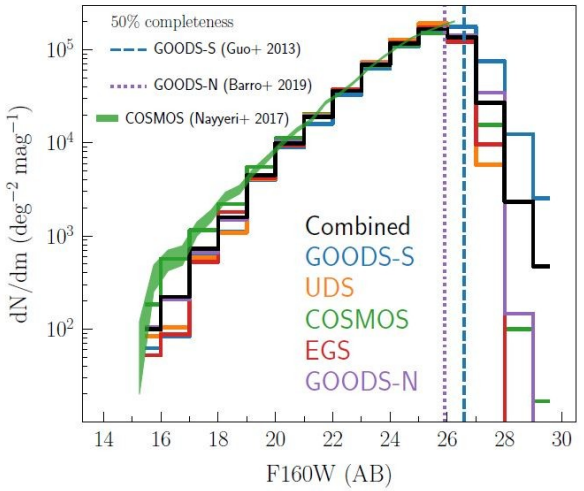


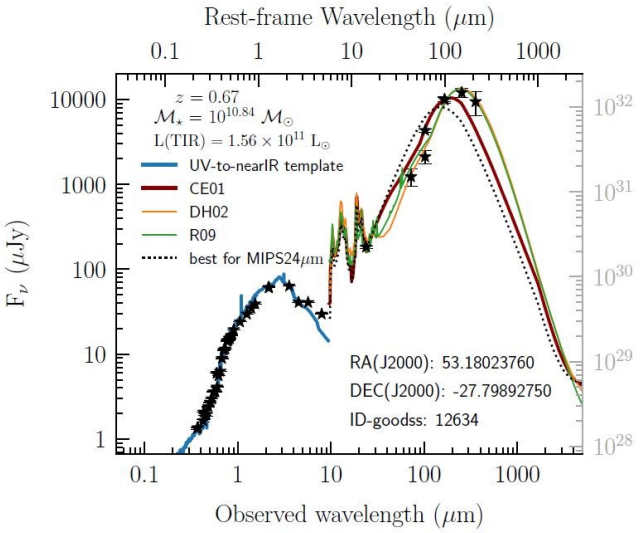


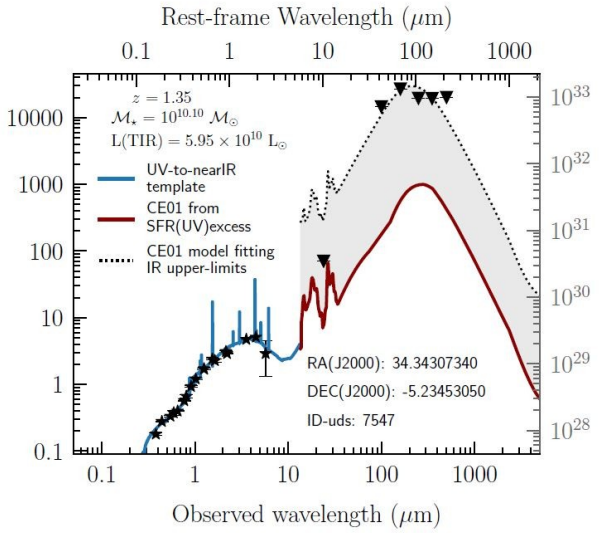
Strong divergence

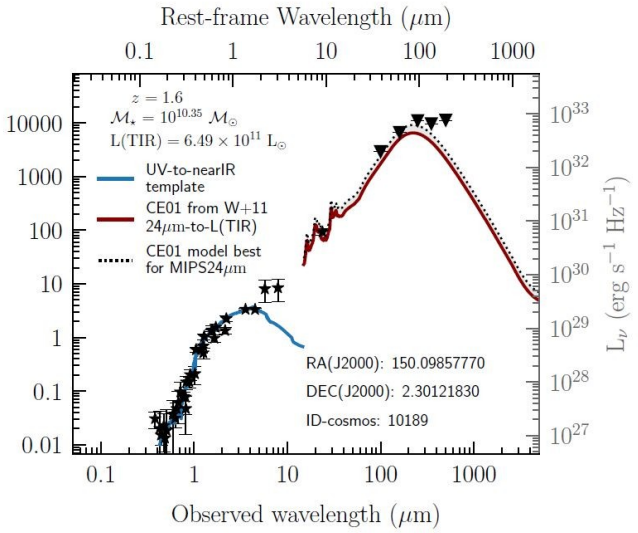
New EBL Model Saldana-Lopez+ 21

- 150,000 galaxies
- 0 < z < 6
- 5 CANDELS fields, reducing cosmic variance



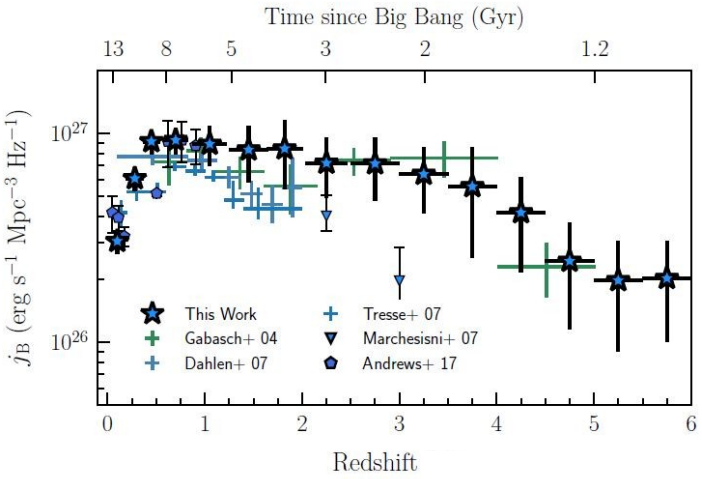


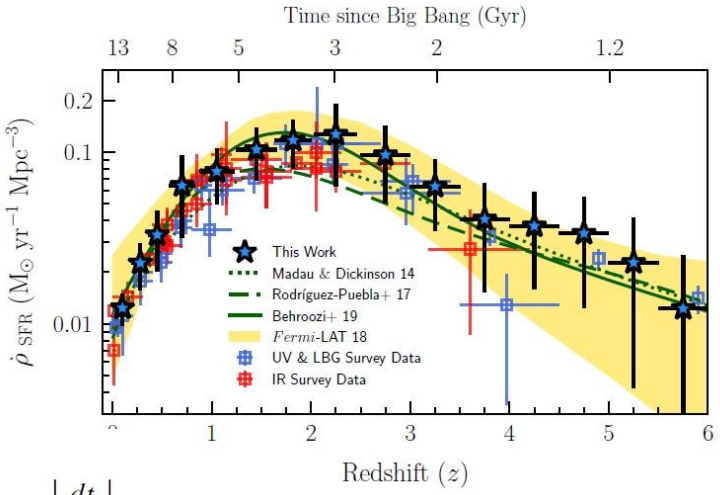




Saldana-Lopez et al. (2022)

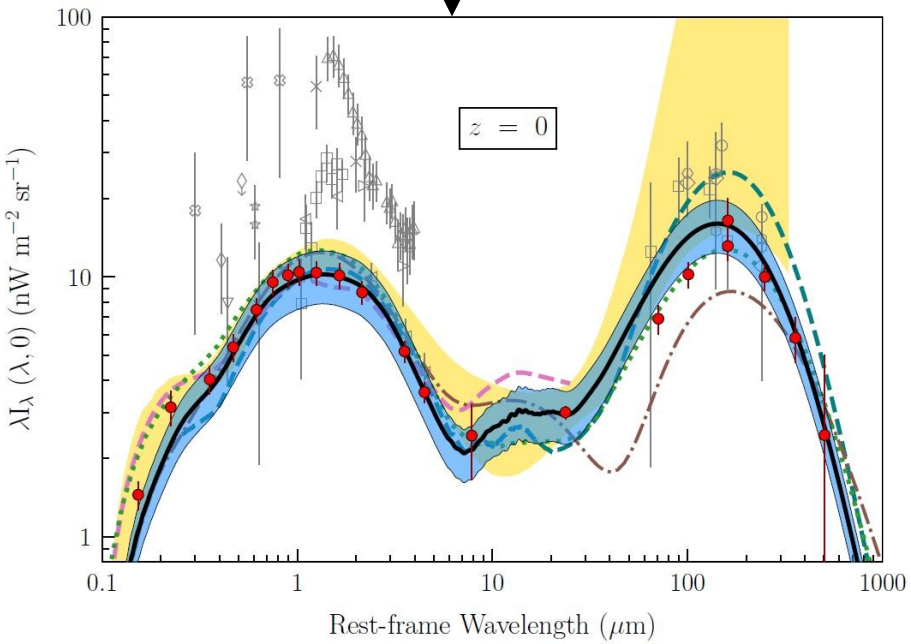
New EBL Model Saldana-Lopez+ 21

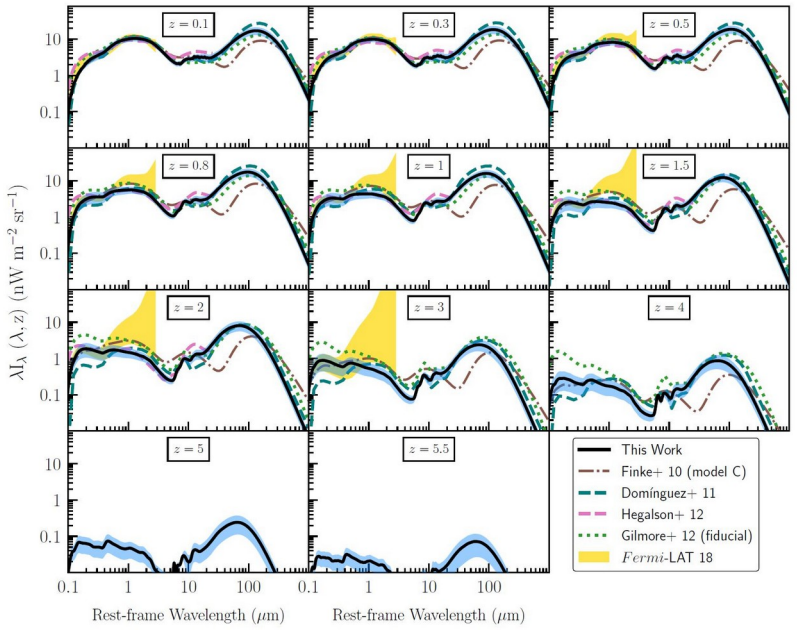




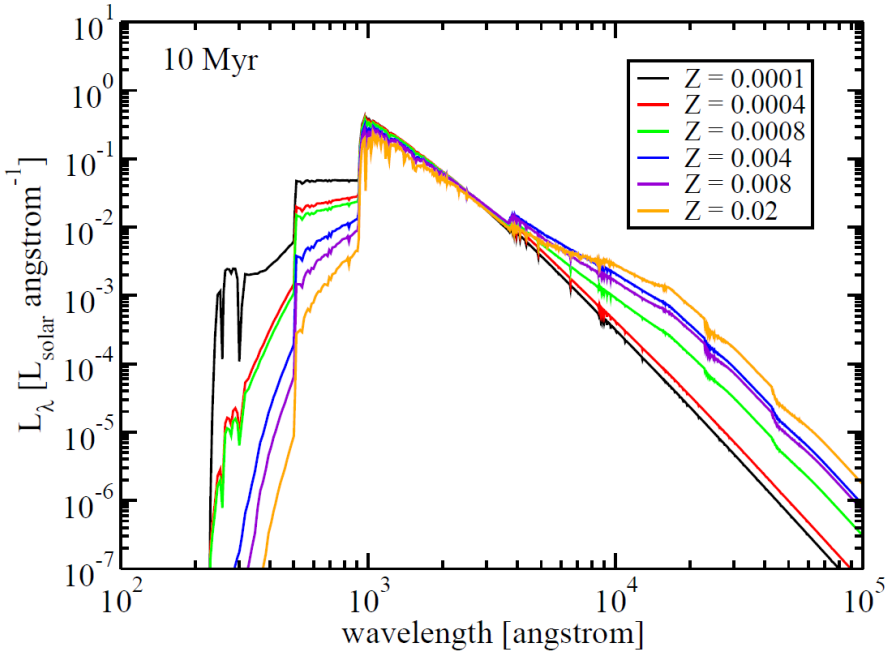
$$\lambda I_\lambda(\lambda, z_i) = \frac{c^2}{4\pi\lambda} \int_{z_i}^{z_{max}} j\left(\lambda(1+z_i)/(1+z'), z'\right) \left|\frac{dt}{dz'}\right| dz'$$

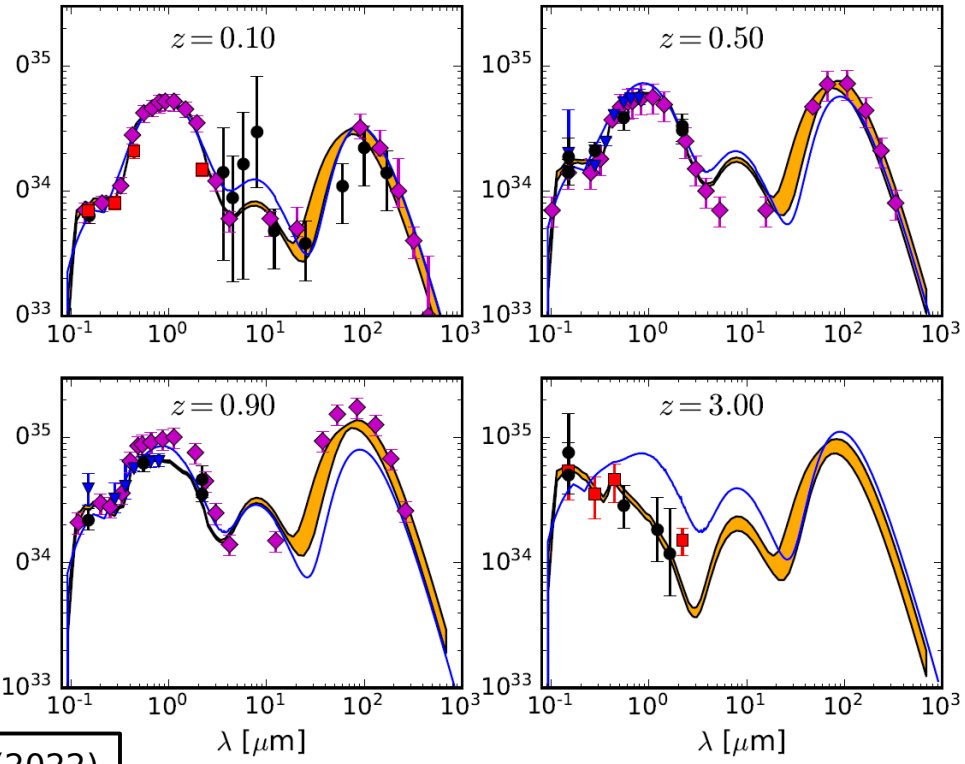
Saldana-Lopez et al. (2022)

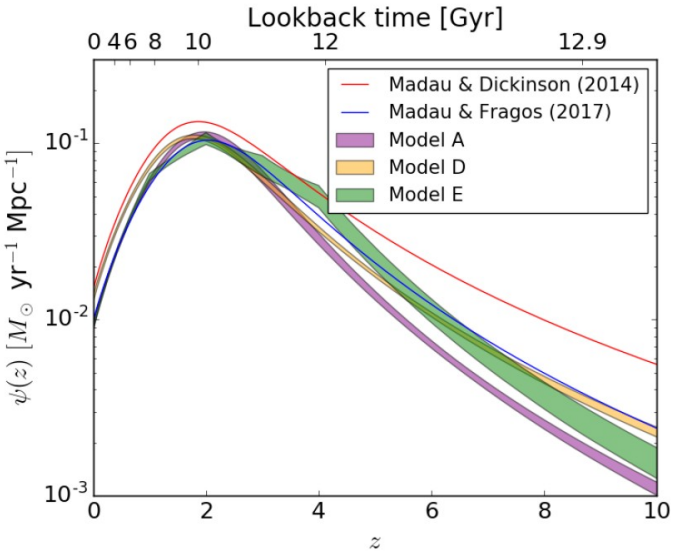




New EBL Model Finke+ 22

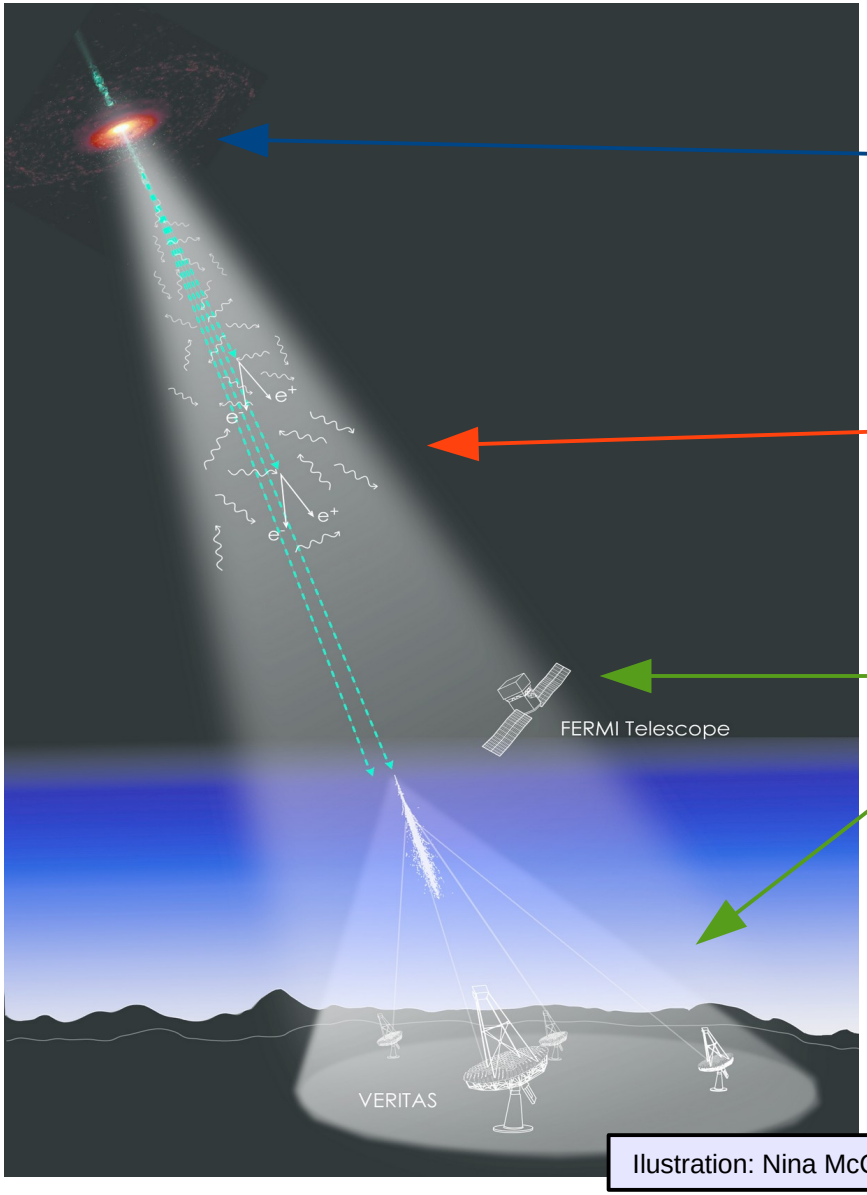






Finke et al. (2022)

Gamma-ray Attenuation



Ilustration: Nina McCurdy & Joel Primack

Extragalactic source:
e.g. Blazar

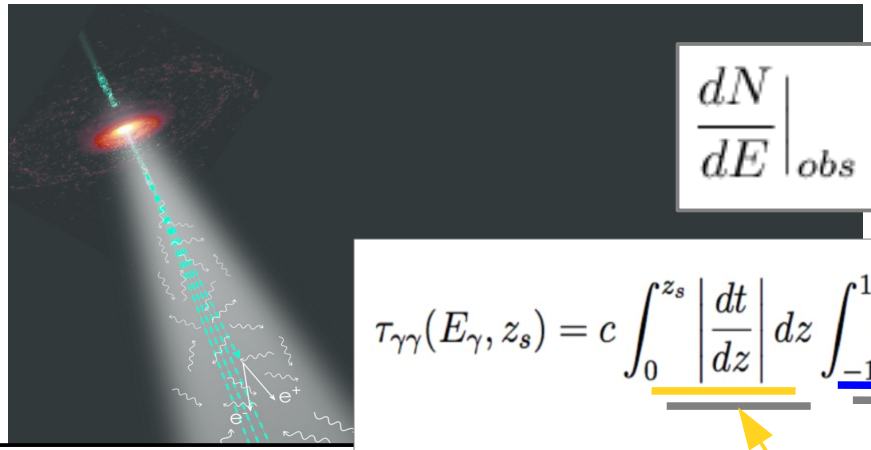
Blazars: AGNs emitting at all wavelength with energetic jets pointing towards us.

Pair-production interaction

Reverse of most known electron-positron annhilation process

Telescopes: Fermi-LAT and Imaging Atmospheric Cherenkov Telescopes (IACTs)

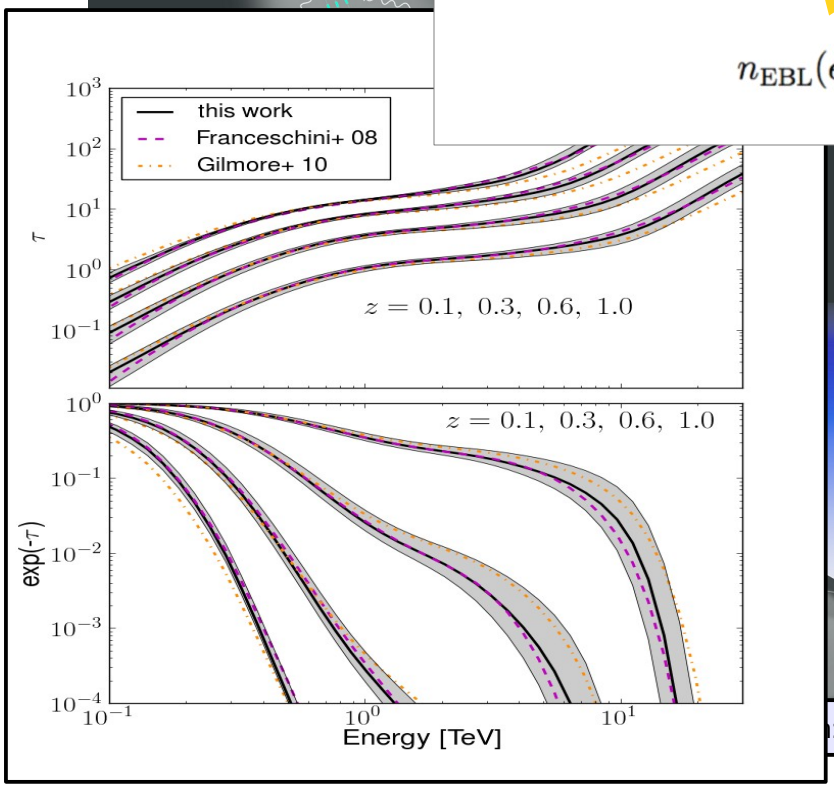
Gamma-ray Attenuation



$$\left.\frac{dN}{dE}\right|_{obs} = \left.\frac{dN}{dE}\right|_{int} \exp\left[-\tau(E,z)\right]$$

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

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



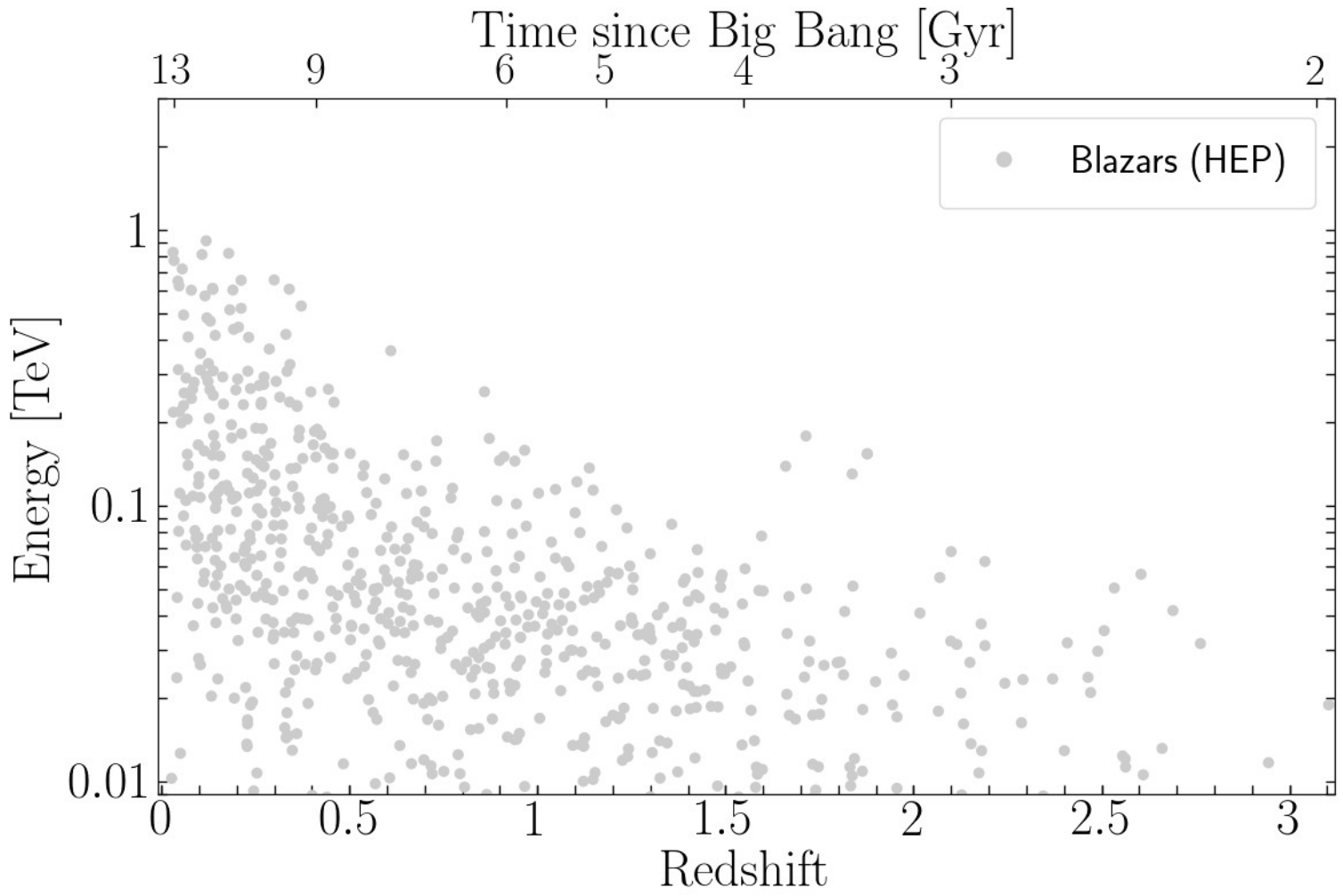
distance

cross section

EBL photon density evolution

: Nina McCurdy & Joel Primack

Cosmic Gamma-Ray Horizon



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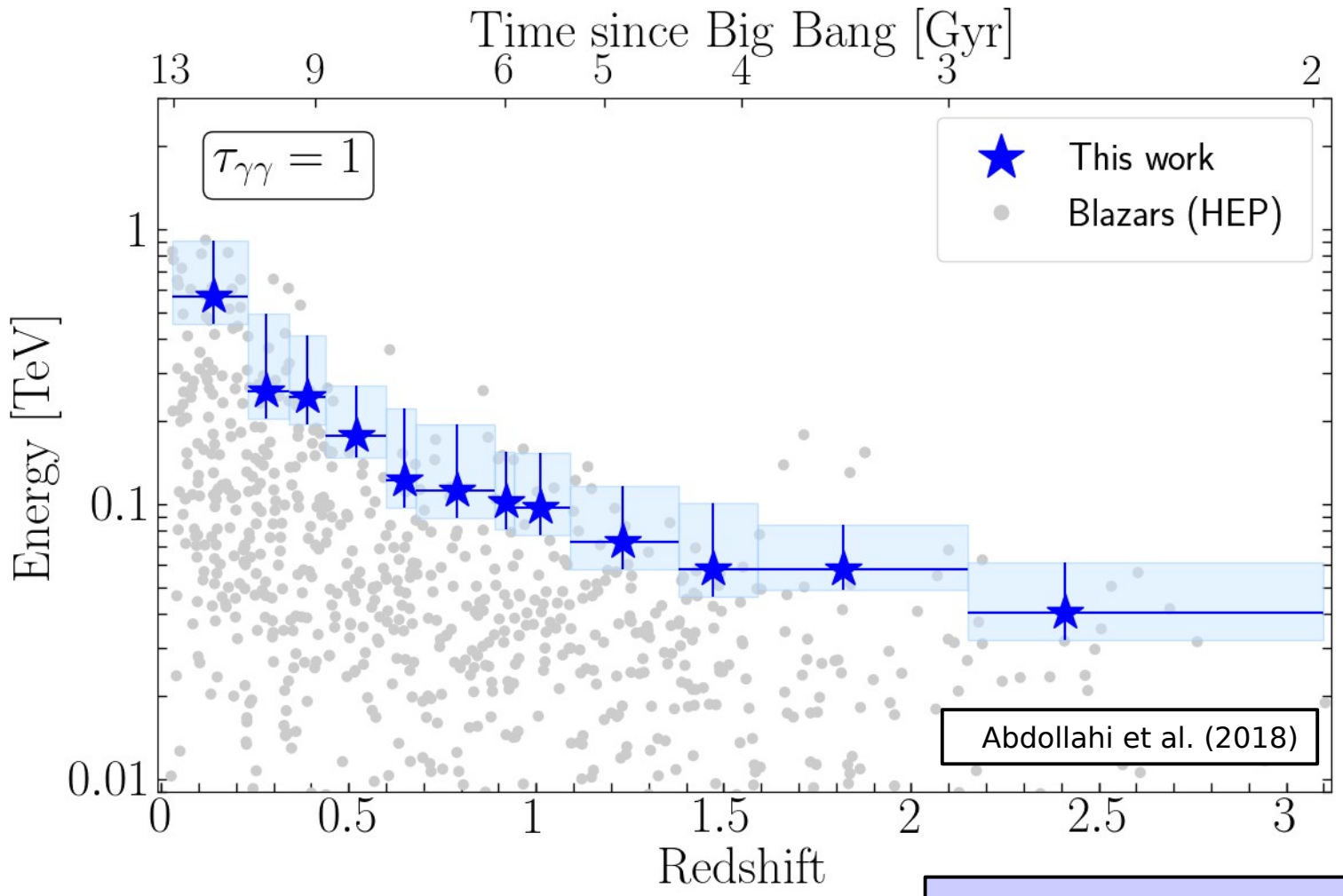
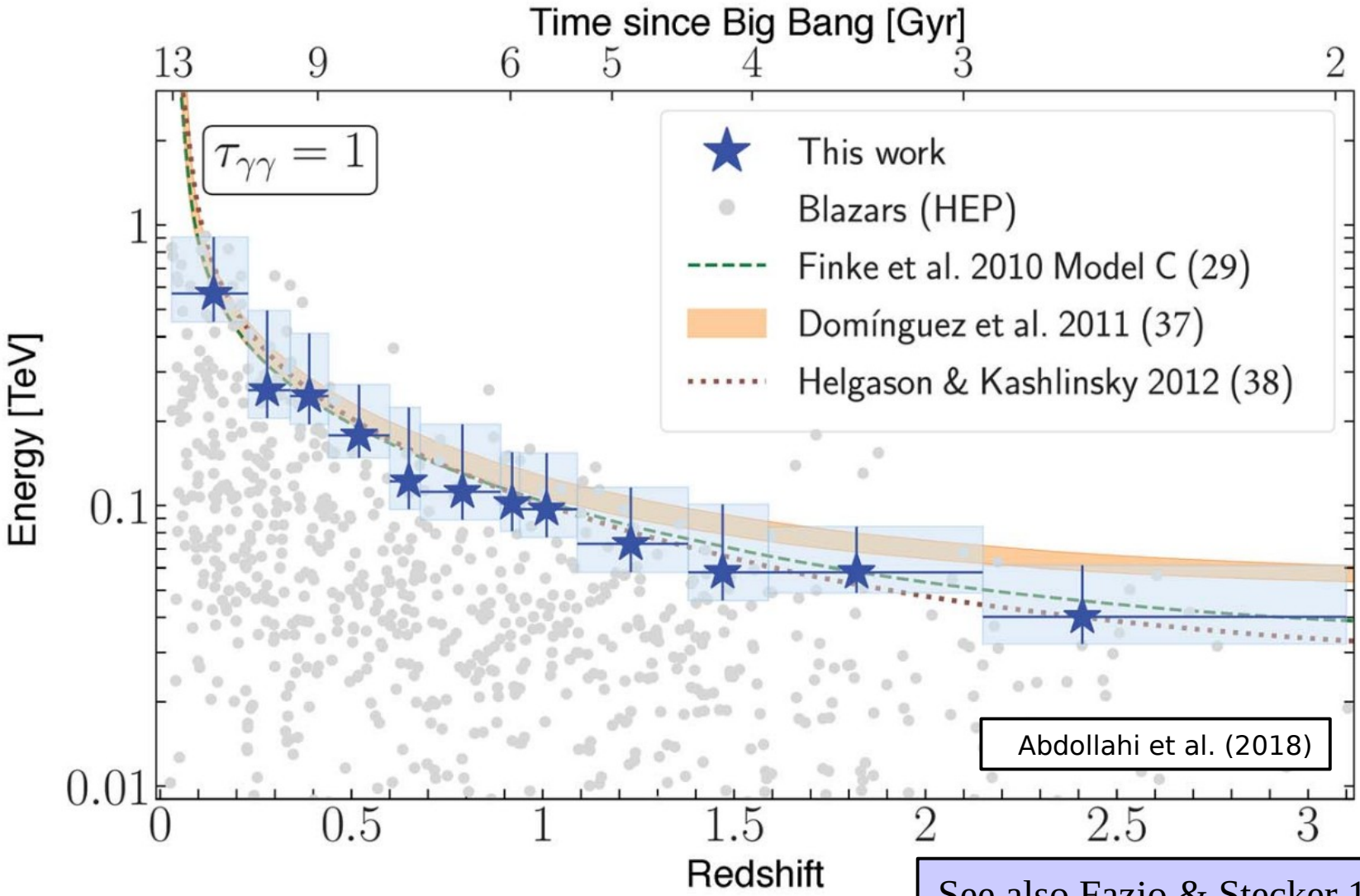


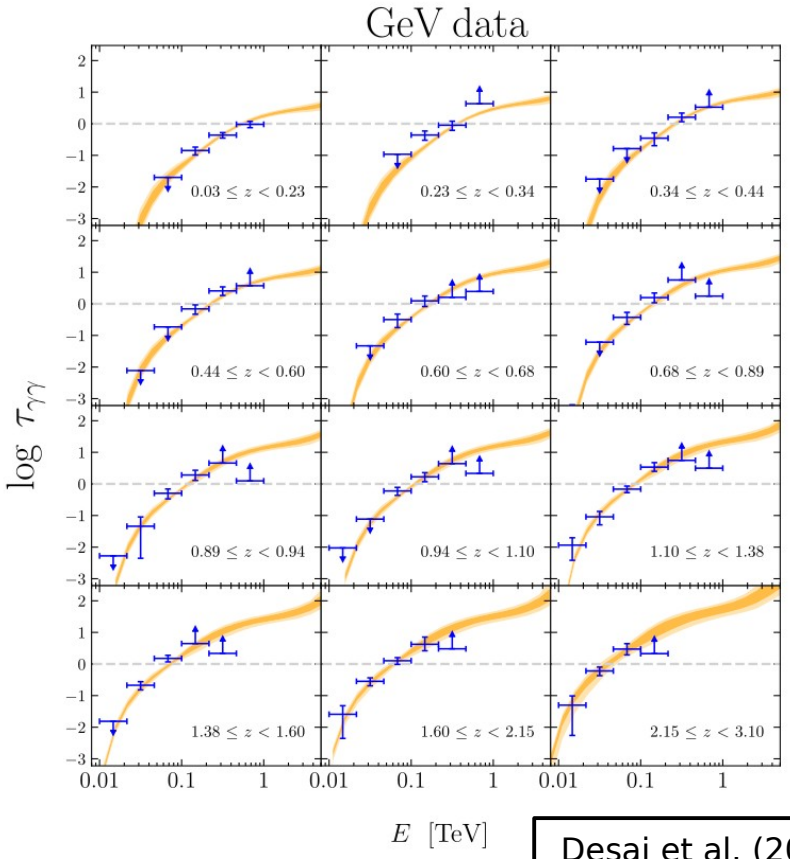
See also Fazio & Stecker 1970, Domínguez et al. 2013

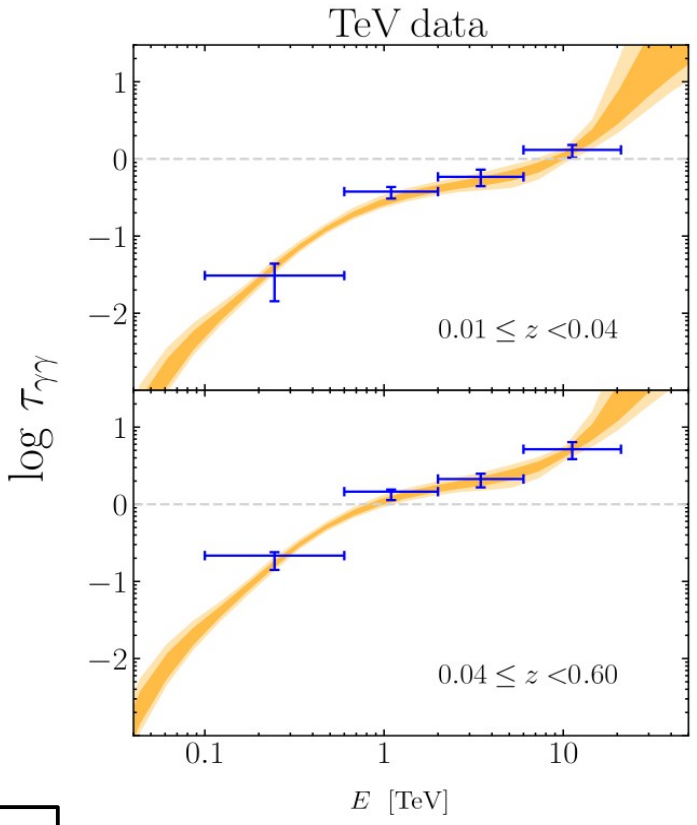
Cosmic Gamma-Ray Horizon



See also Fazio & Stecker 1970, Domínguez et al. 2013

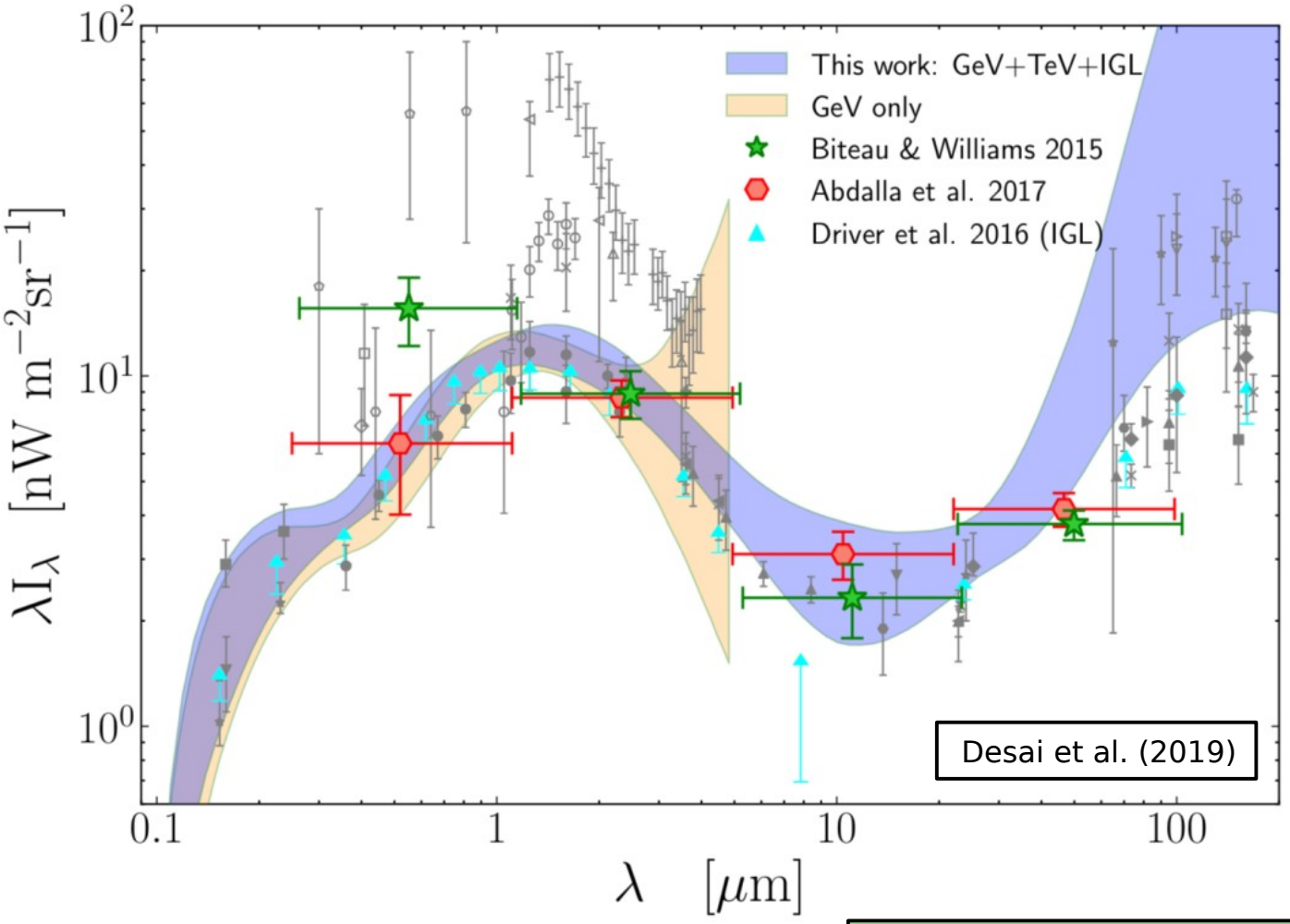
Optical Depths from Gamma-ray Data





Desai et al. (2019)

Extragalactic Background Light from Gamma Rays



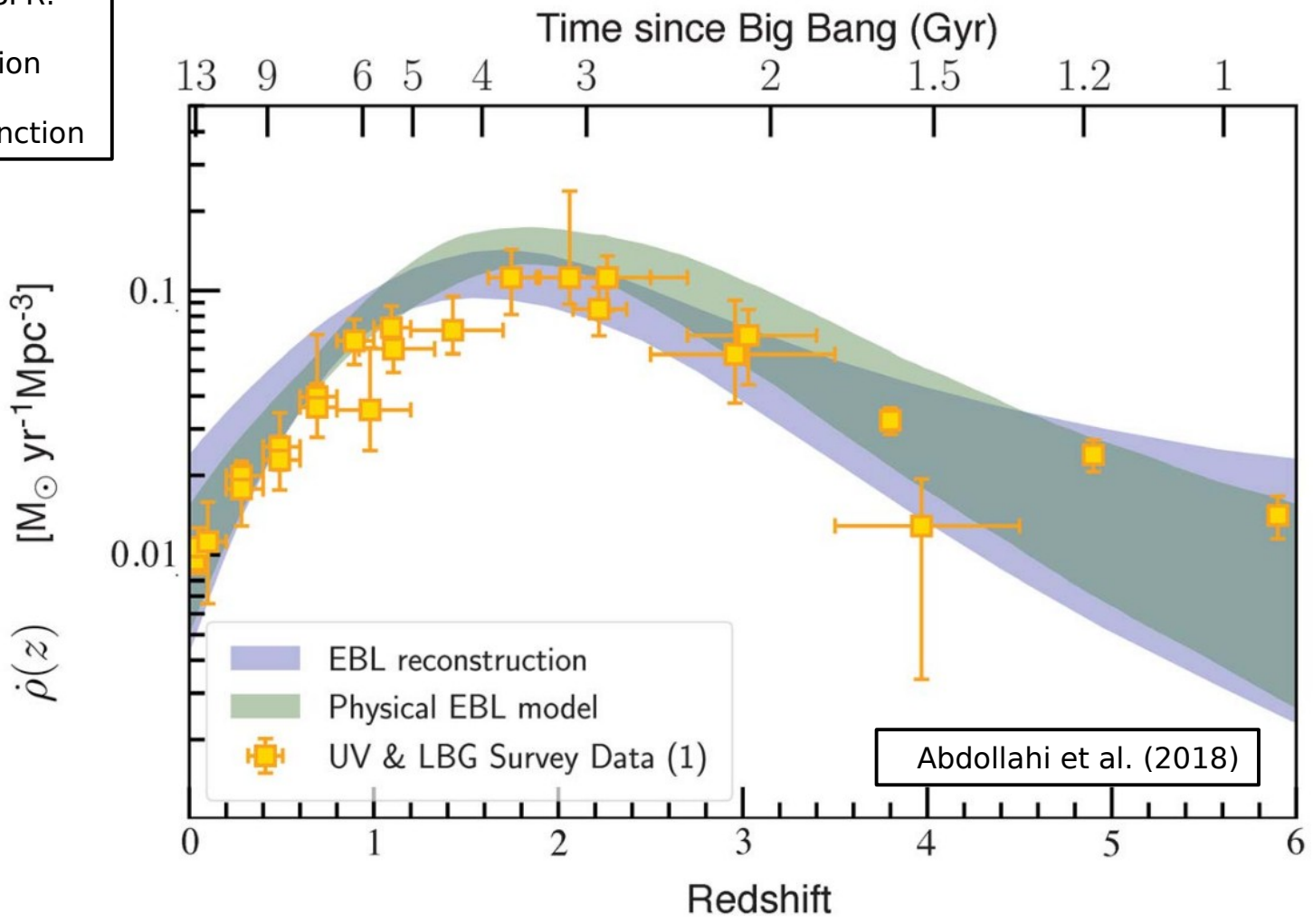
Local Extragalactic Background Light
(also see works by the MAGIC, VERITAS, and H.E.S.S. Collaborations)

Cosmic Star Formation Rate

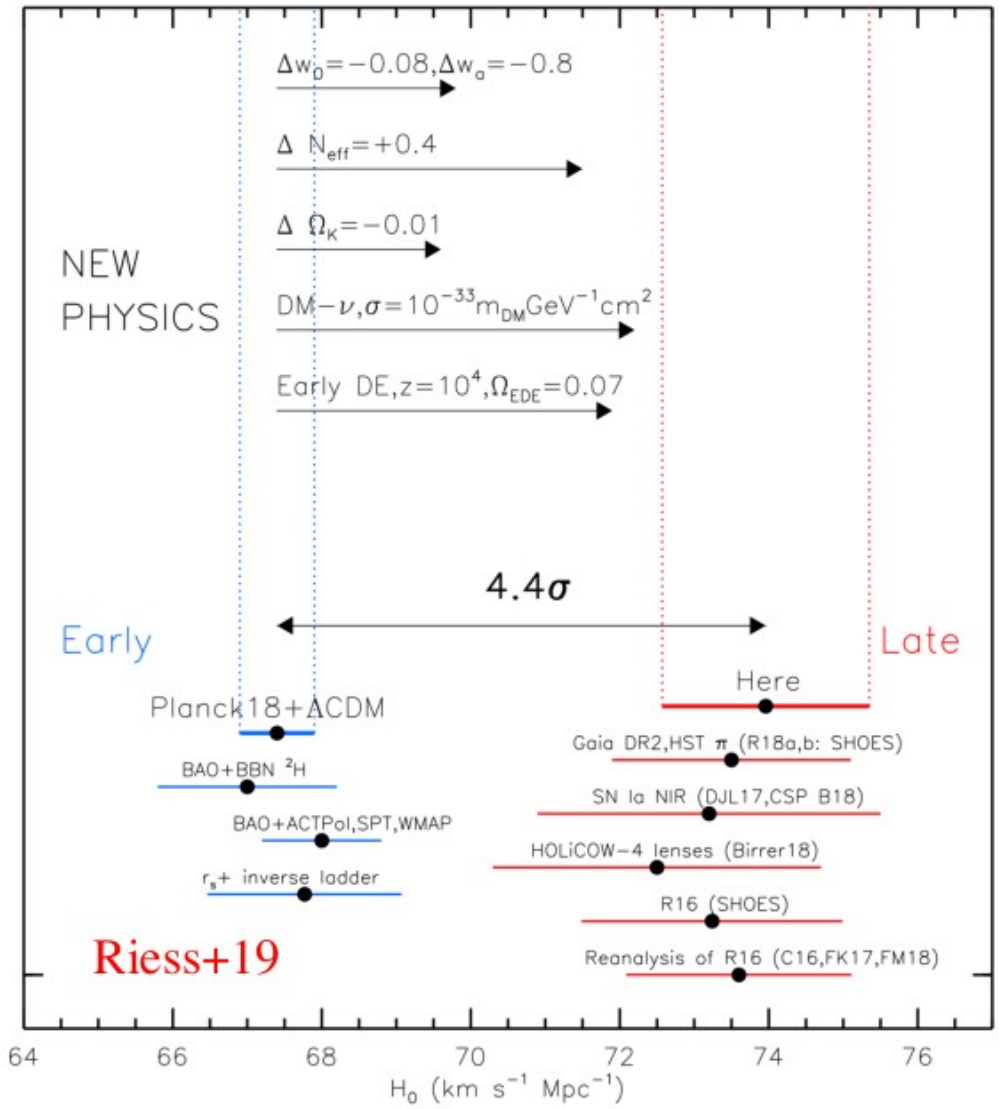
UV (0.16 microns) to SFR:

(1) Initial Mass Function

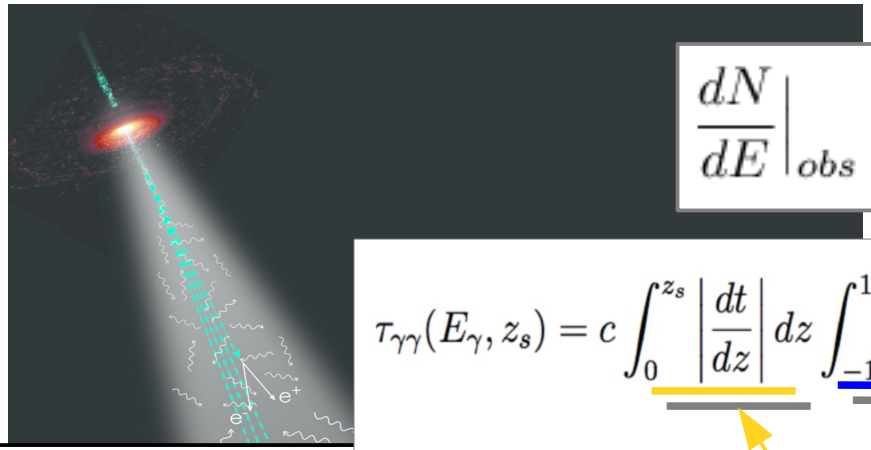
(2) Average Galaxy Extinction



Tension on H_0 Measurements



Gamma-ray Attenuation



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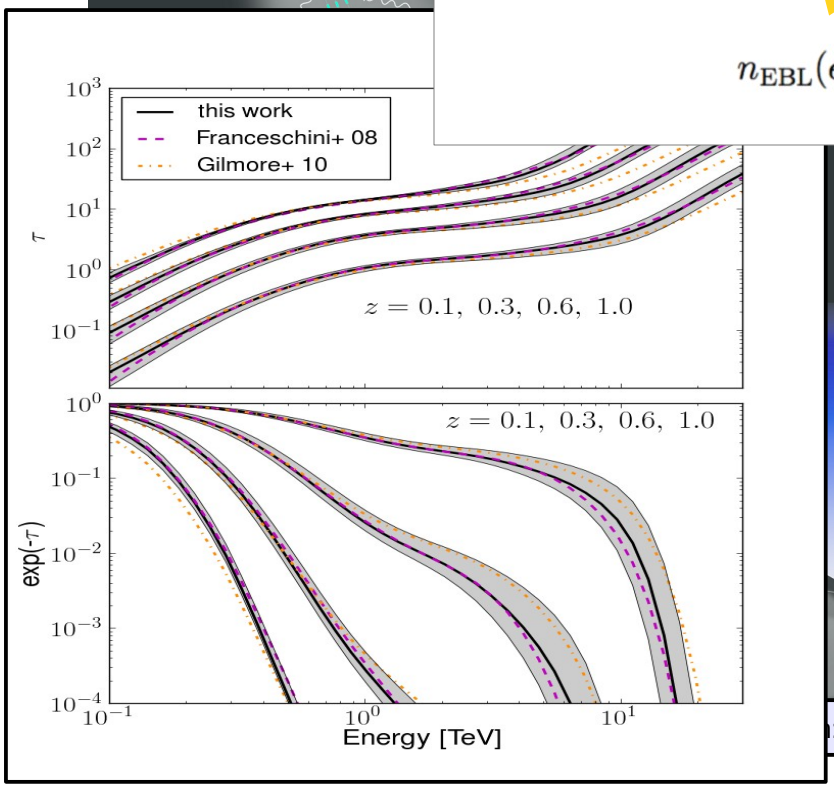


distance

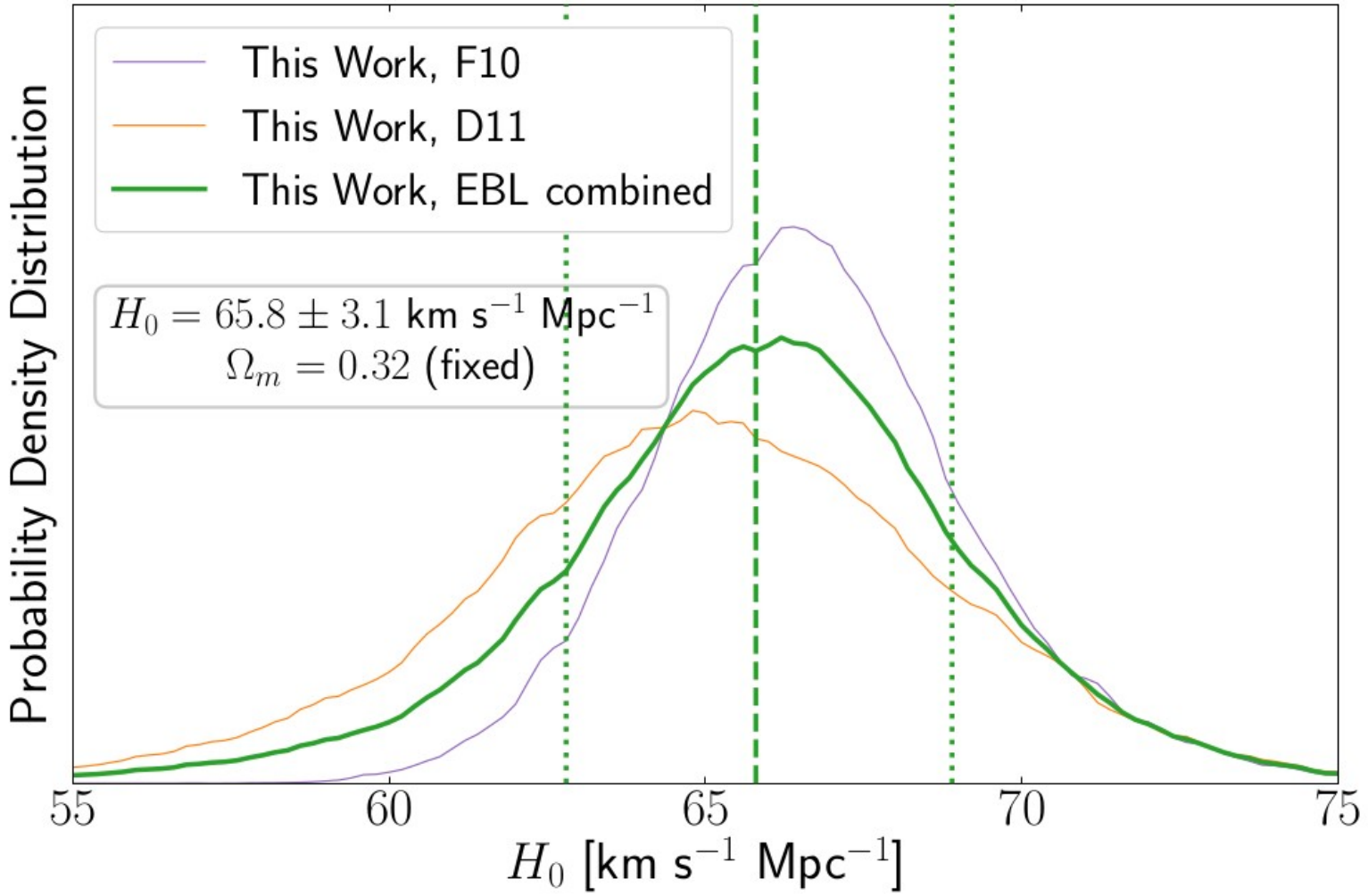
cross section

EBL photon density evolution

See Domínguez & Prada 13,
Biteau & Williams 15

: Nina McCurdy & Joel Primack

Measuring H_0 with Gamma-ray Attenuation



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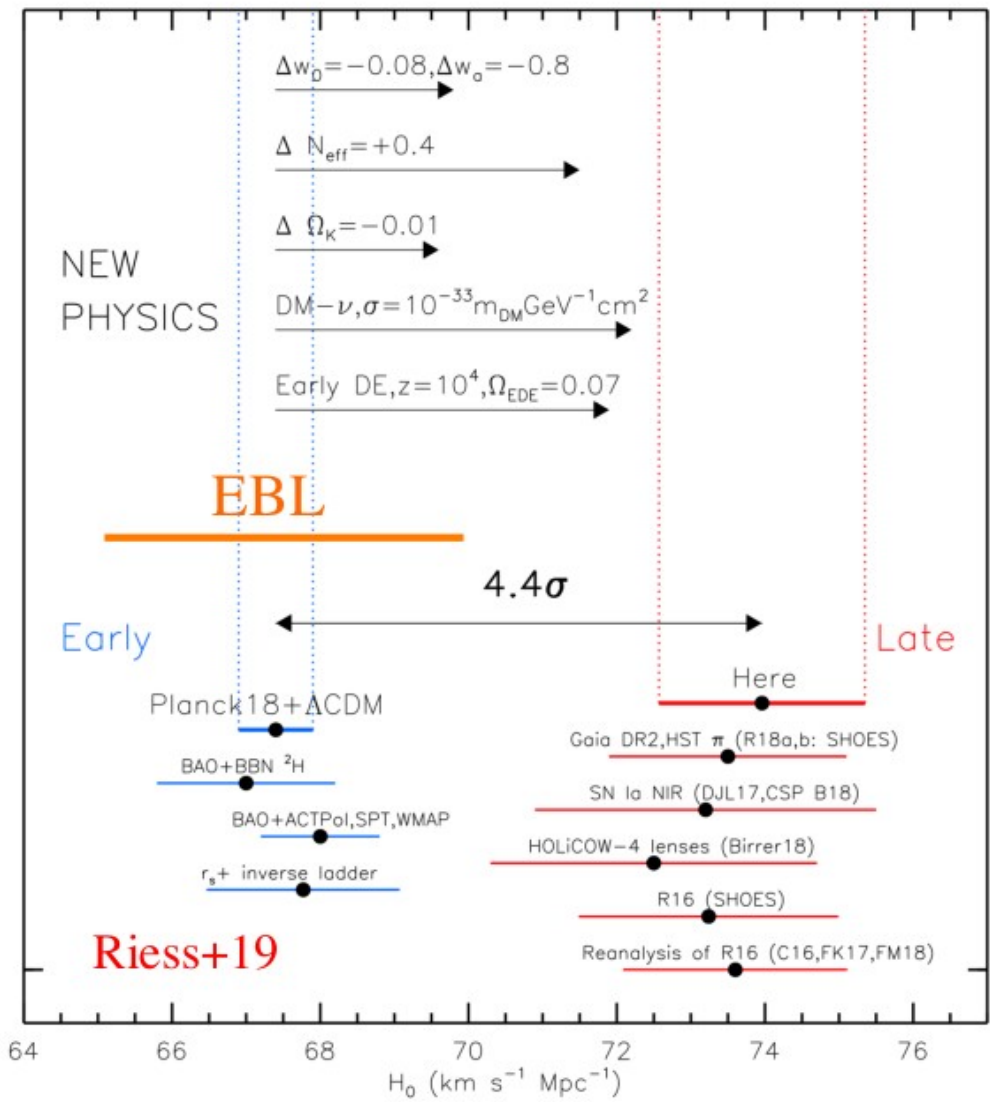

Take Home Messages

The EBL attenuates gamma rays that propagates through cosmological distances and needs to be consider for the study of these photons.