# Advancements in the Hubble Constant Estimation via Gamma-Ray Attenuation

**Alberto Domínguez**

**IPARCOS / Universidad Complutense de Madrid**

Astroparticle Symposium @ Institut Pascal, Paris

November 2024

# Advancements in the Hubble Constant Estimation via Gamma-Ray Attenuation

**Alberto Domínguez**

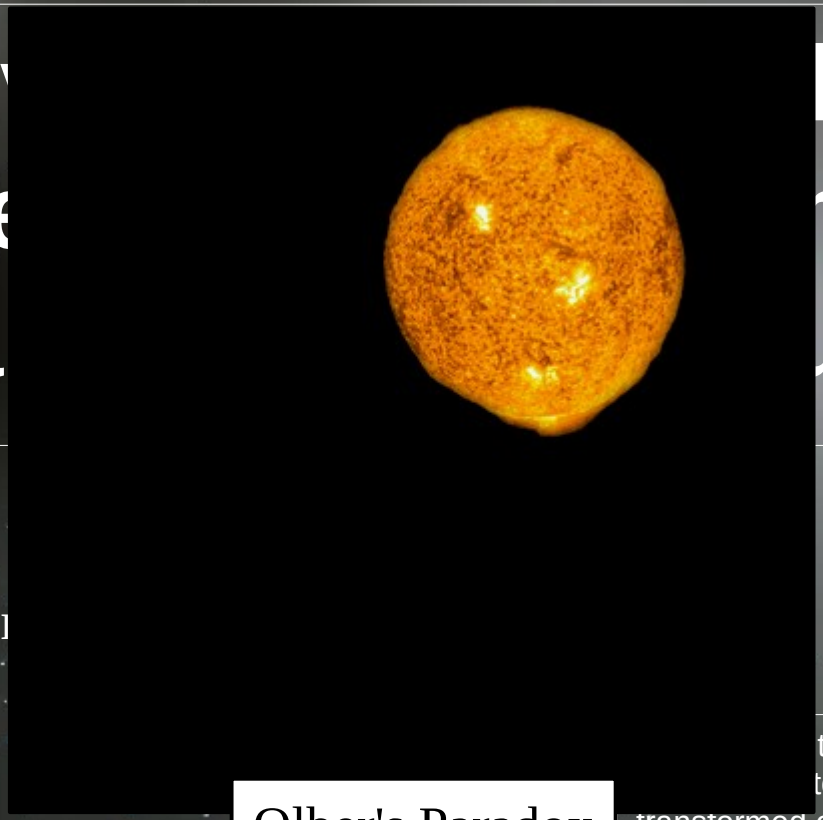
**IPARCOS / Universidad Complutense de Madrid**

See “Why is the sky dark at night? The 200-year history of a question that transformed our understanding of the Universe”, The Conversation, June 2023

Astroparticle Symposium @ Institut Pascal, Paris

November 2024

# Ad he Hubble nation via Ga uation



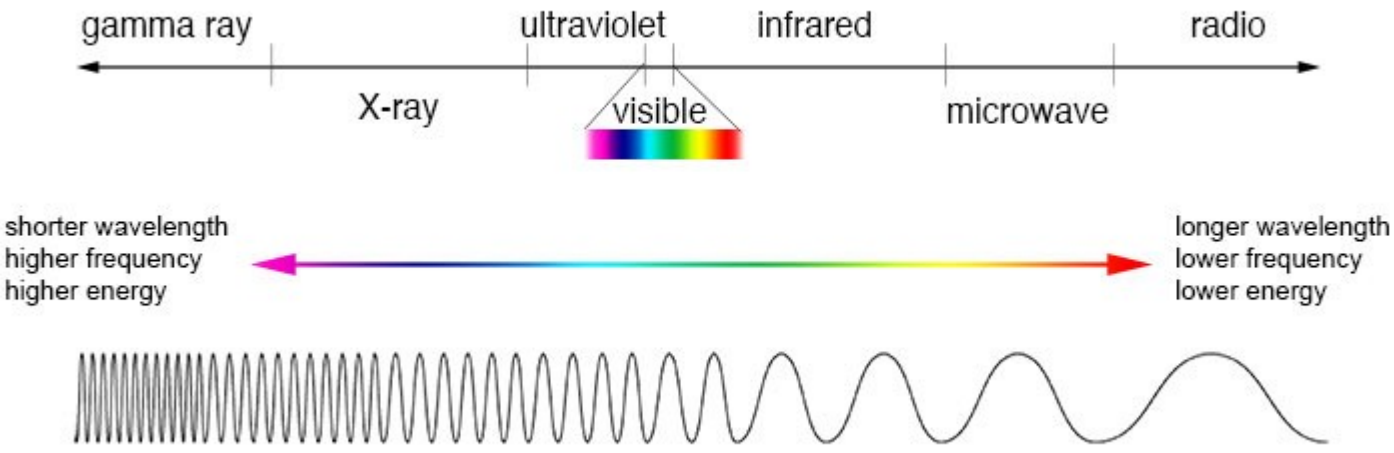
Olber's Paradox

the sky dark at night? The tory of a question that transformed our understanding of the Universe", The Conversation, June 2023

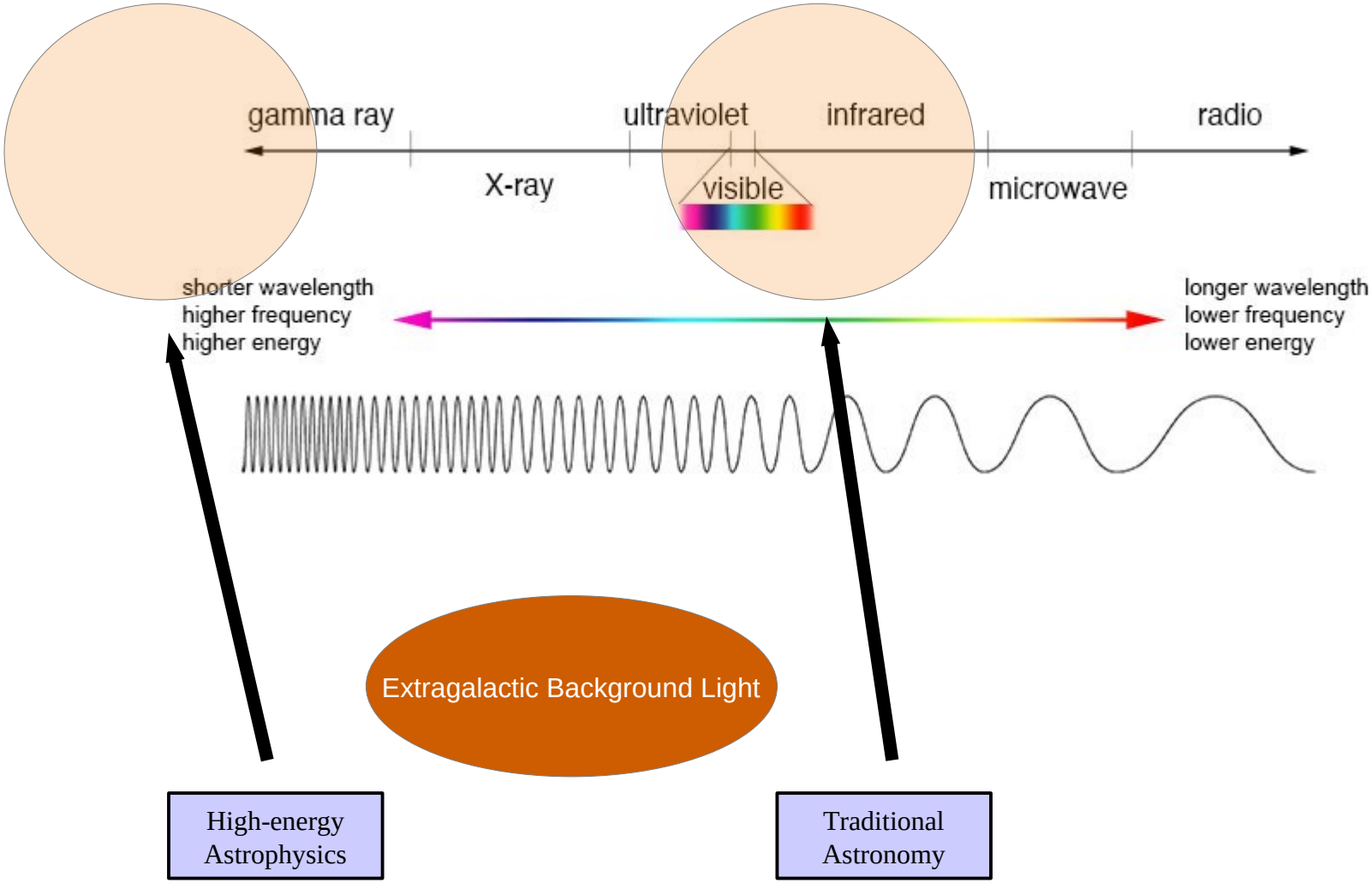
Astroparticle Symposium @ Institut Pascal, Paris

November 2024

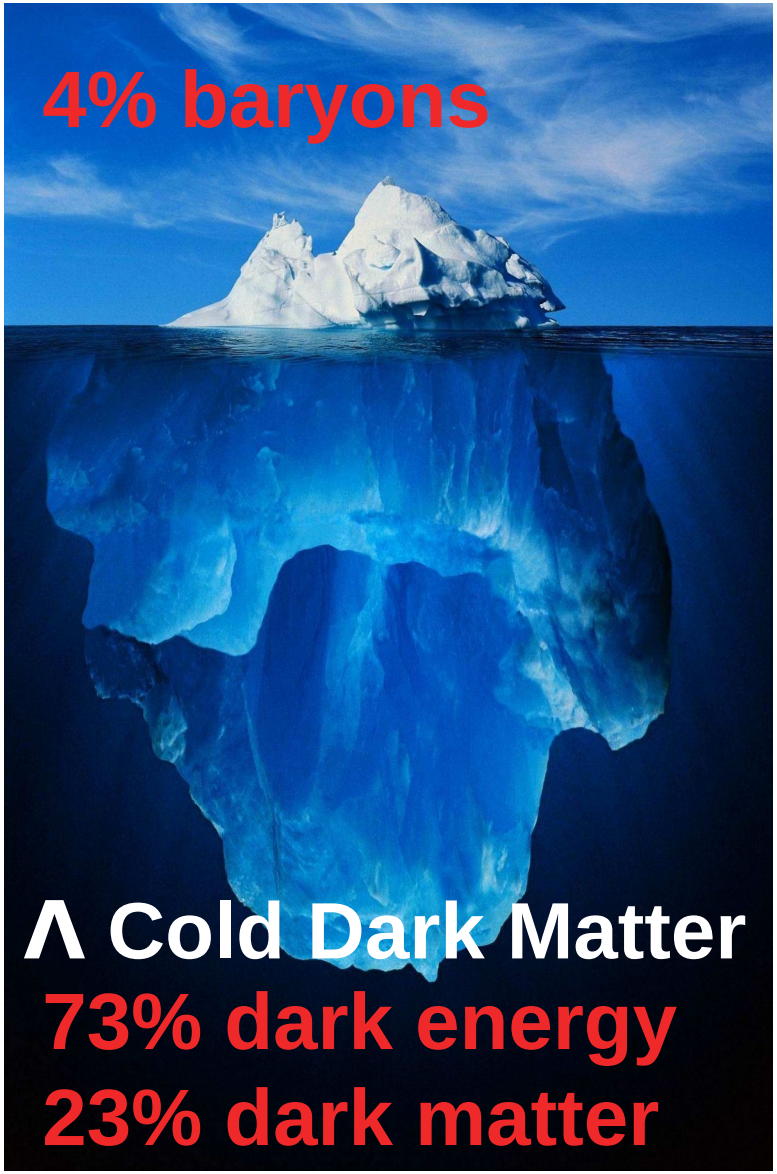
# Electromagnetic Spectrum

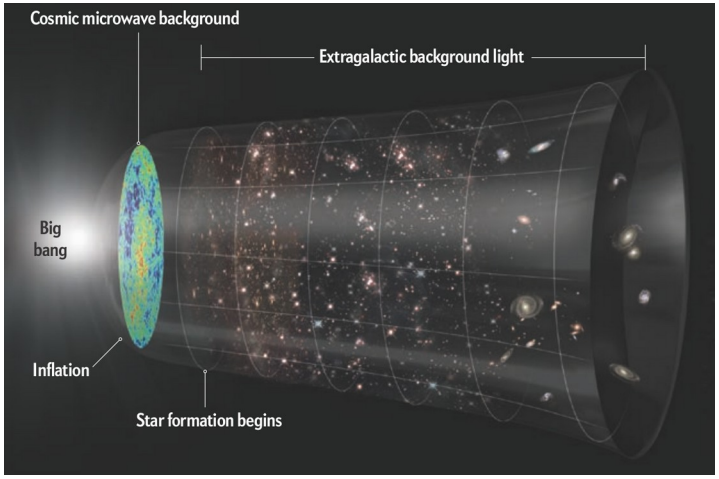


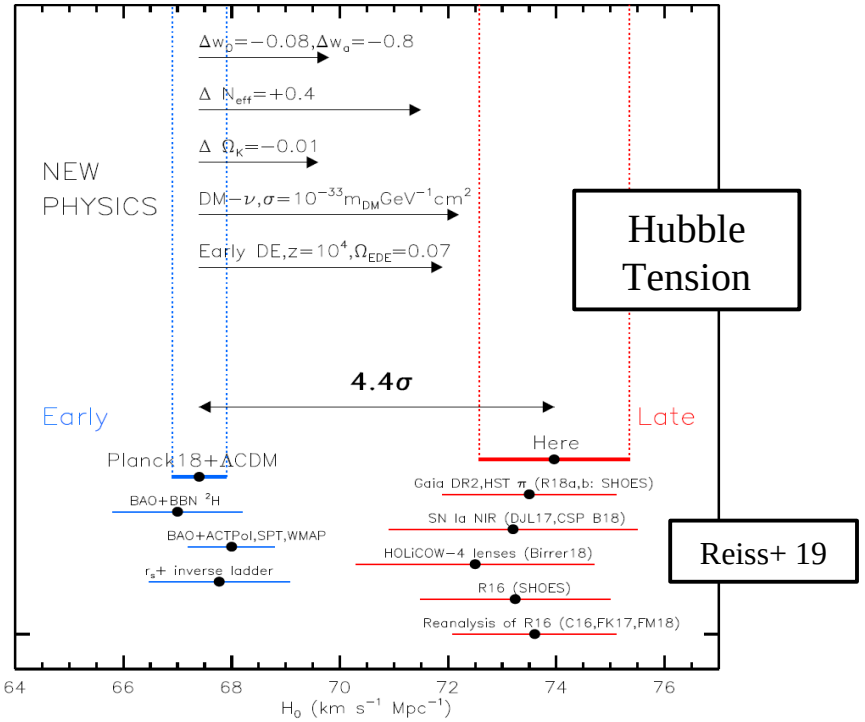
# Electromagnetic Spectrum



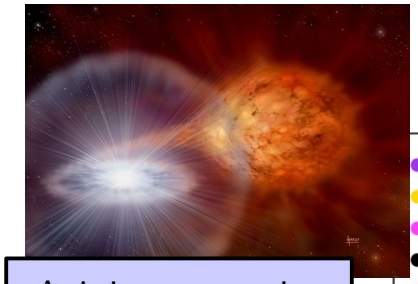
# Galaxy Evolution and Cosmology



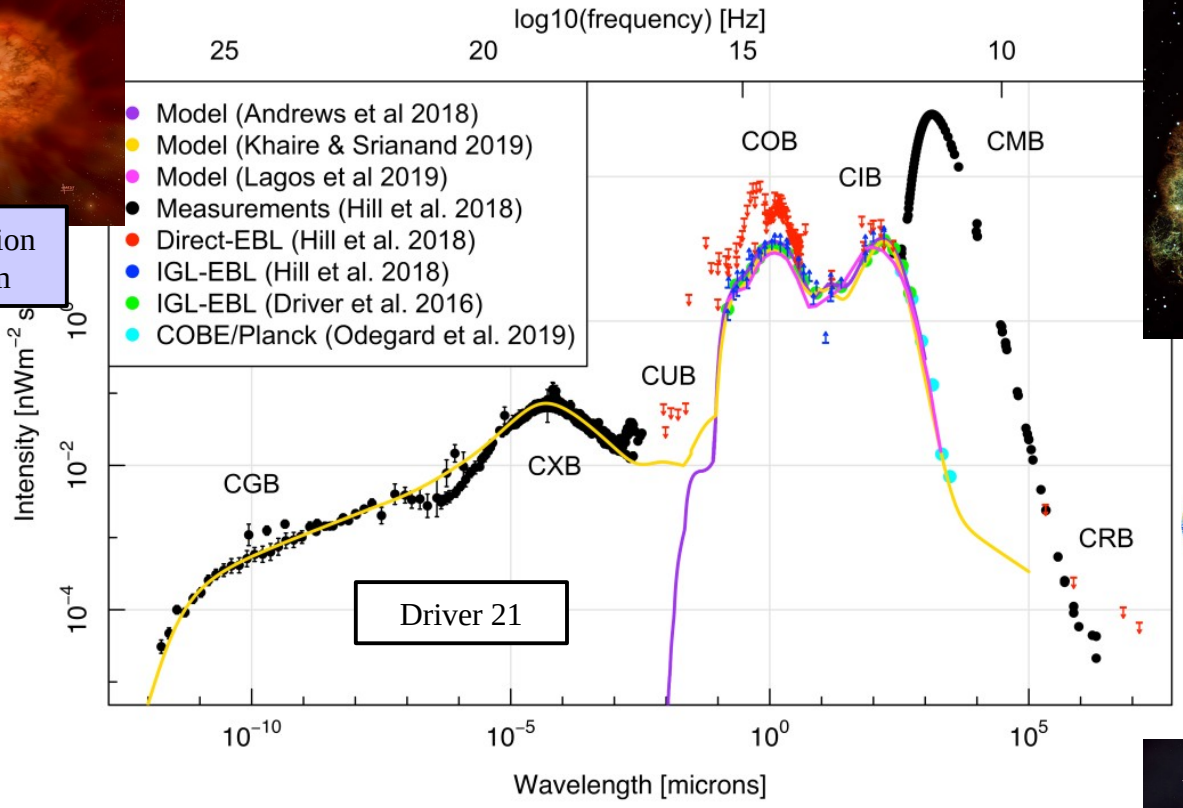



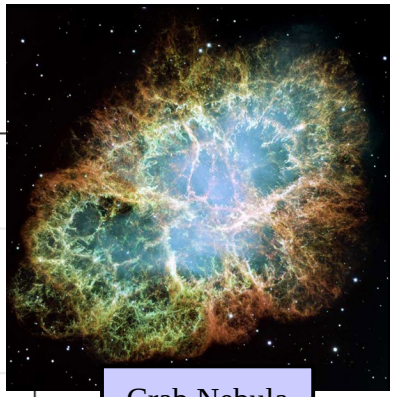
# Cosmic Diffuse Extragalactic Backgrounds



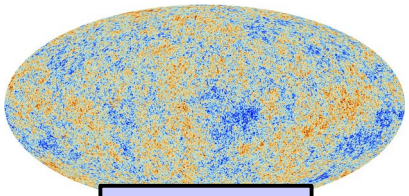
Artistic representation of a binary system



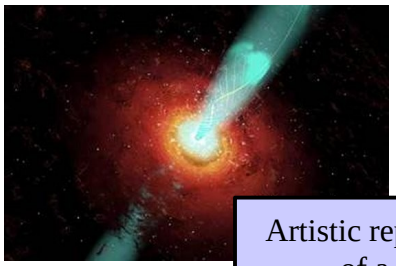

Driver 21



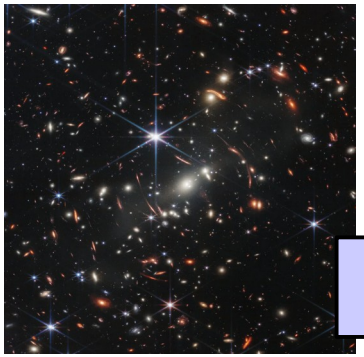
Crab Nebula



Planck CMB



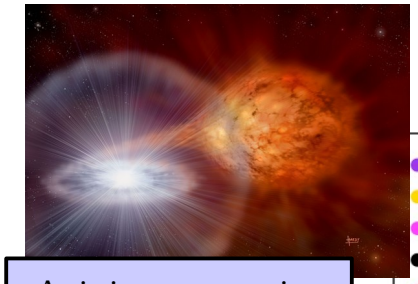
Artistic representation of a blazar



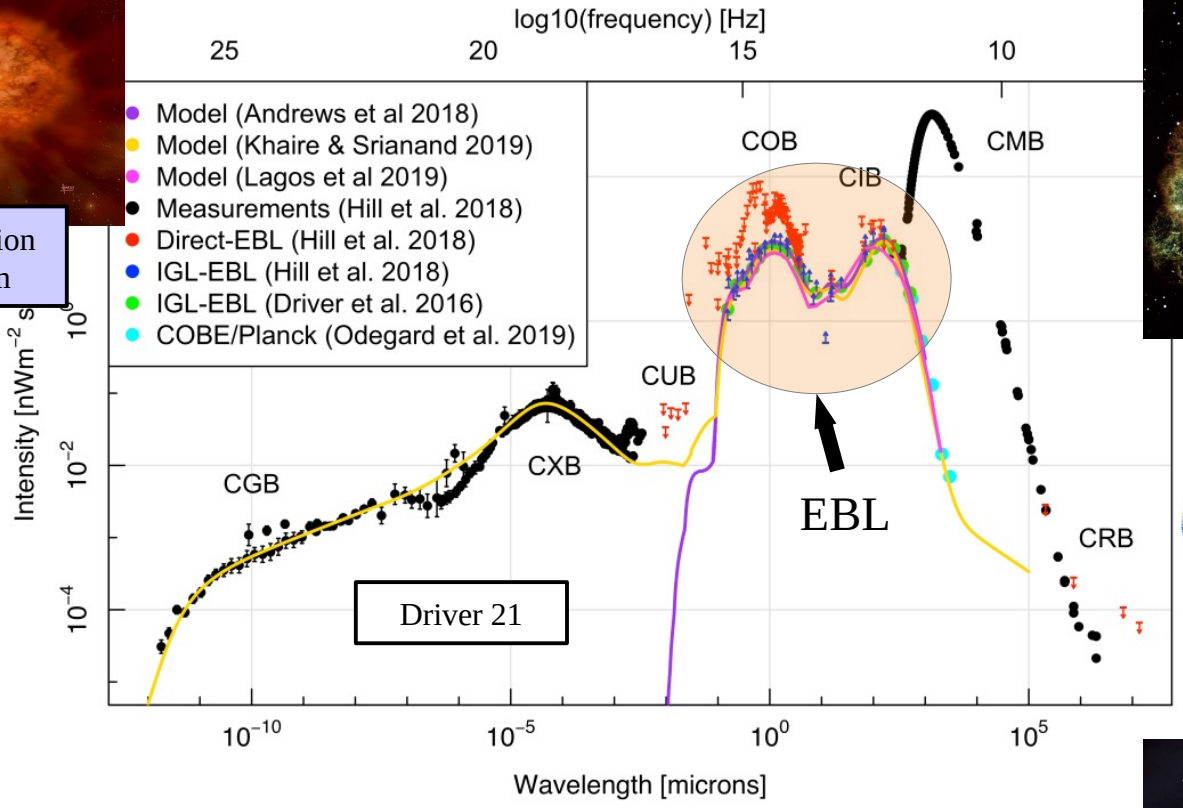
James Webb Space Telescope

Orion Nebula (birth place of stars)

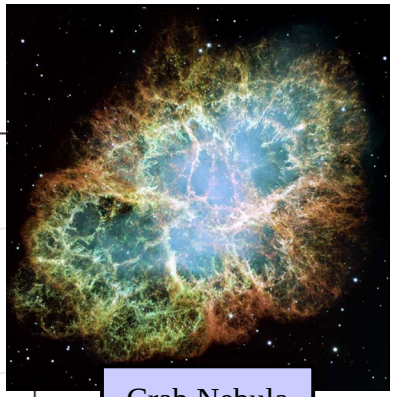
# Cosmic Diffuse Extragalactic Backgrounds



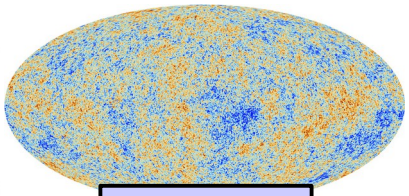
Artistic representation of a binary system



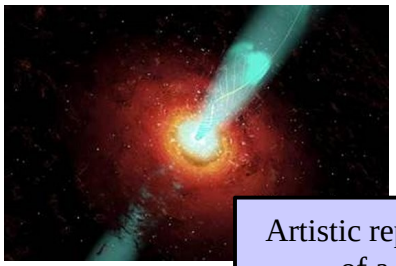

Driver 21



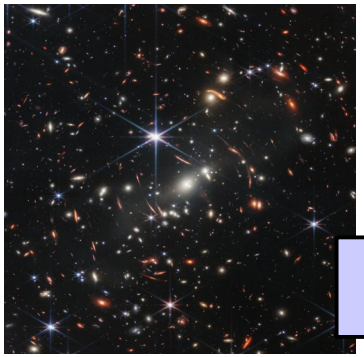
Crab Nebula



Planck CMB



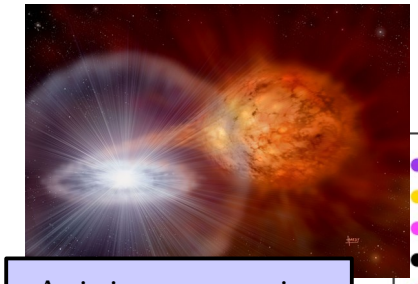
Artistic representation of a blazar



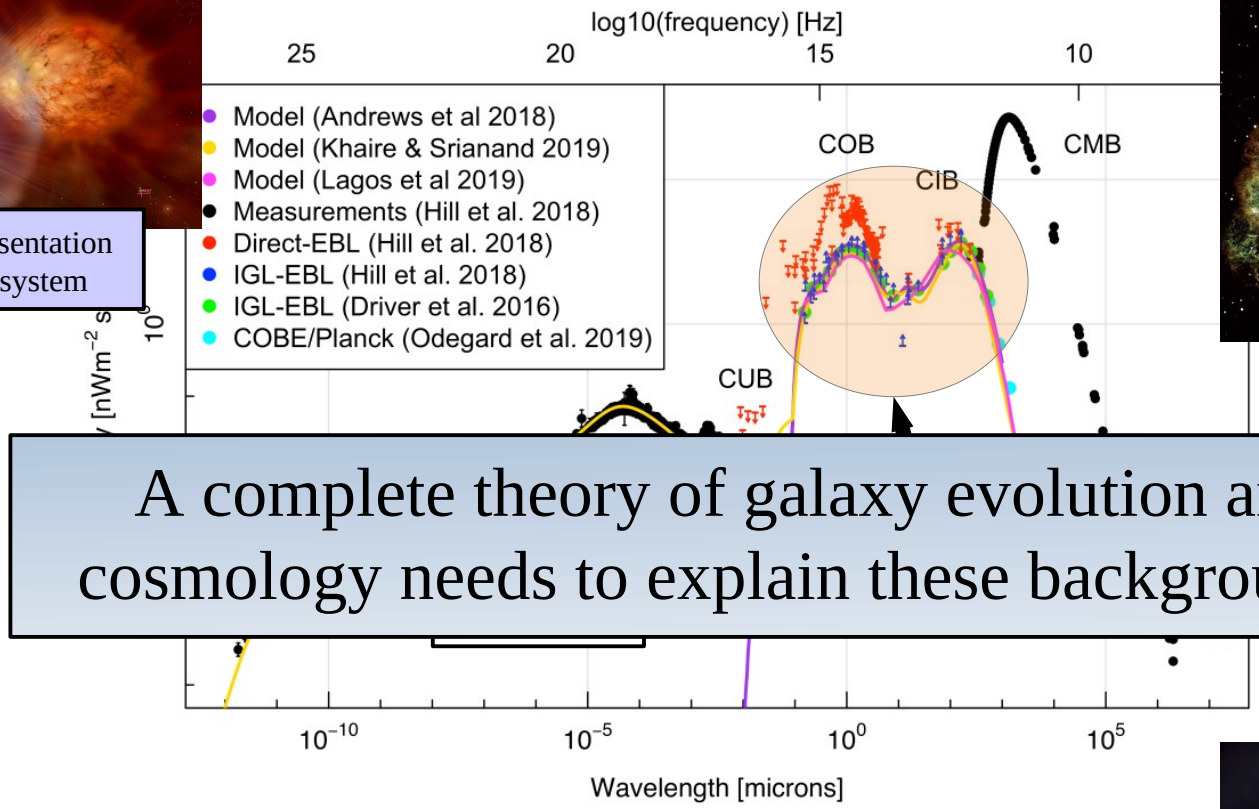
James Webb Space Telescope

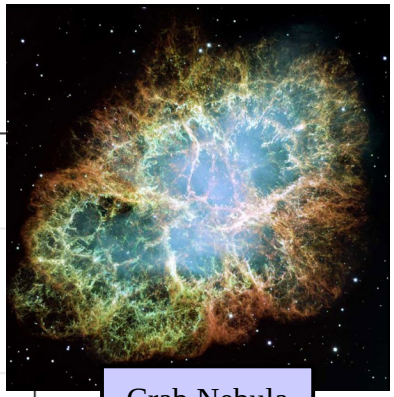
Orion Nebula (birth place of stars)

# Cosmic Diffuse Extragalactic Backgrounds



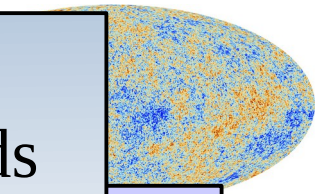
Artistic representation of a binary system



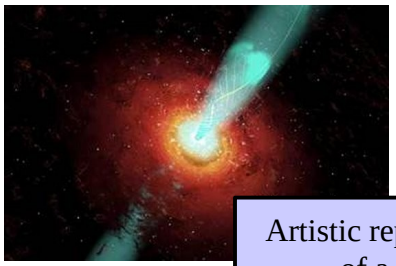



Crab Nebula

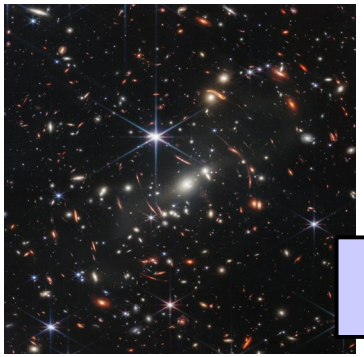
A complete theory of galaxy evolution and cosmology needs to explain these backgrounds



Planck CMB



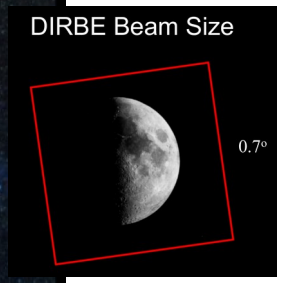
Artistic representation of a blazar

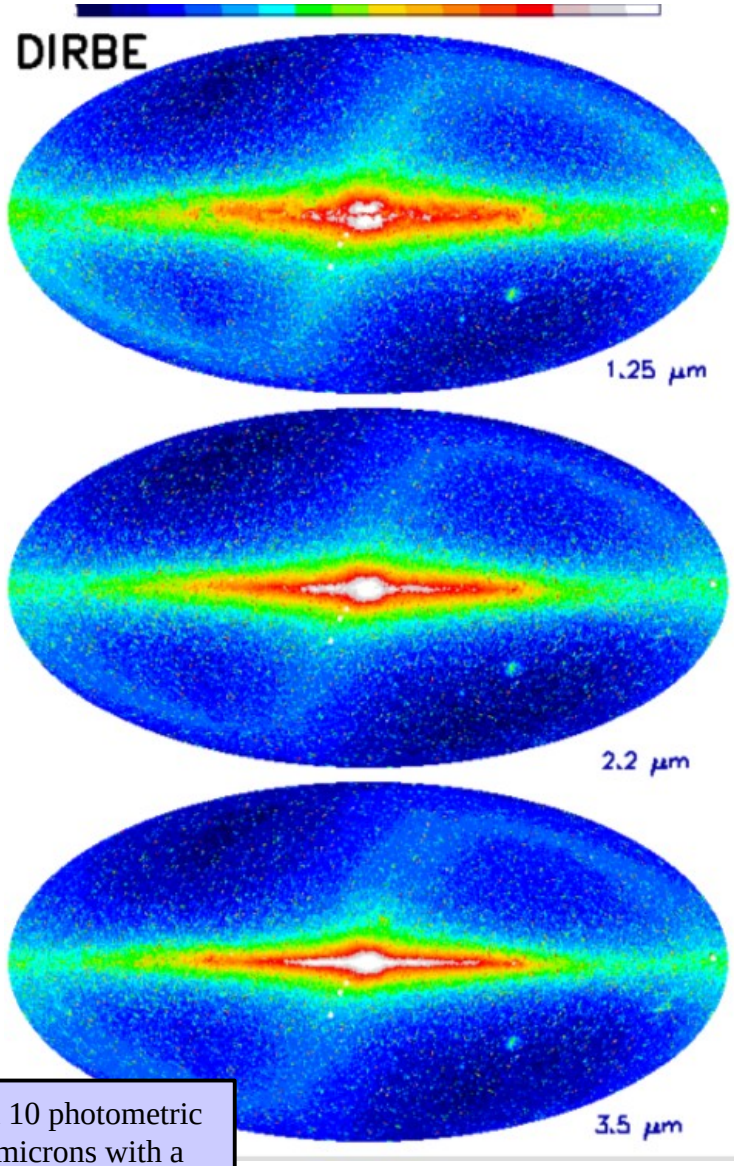


James Webb Space Telescope

Orion Nebula (birth place of stars)

# EBL Measurements (I): Direct Detection

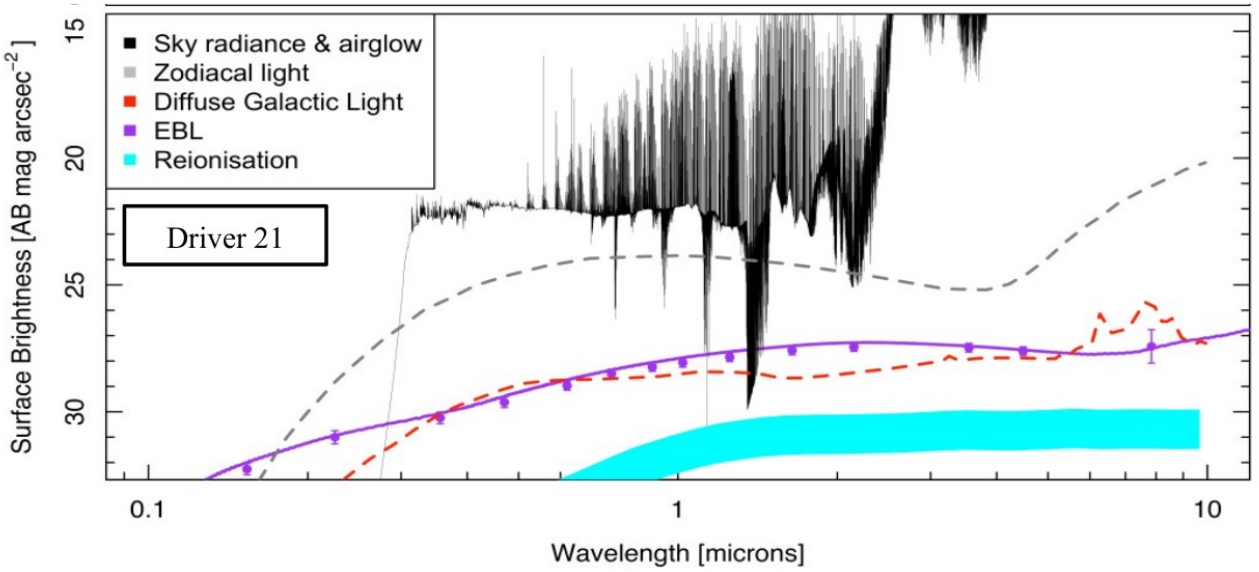




DIRBE imaged the sky in 10 photometric bands from 1.25 to 240 microns with a beam size of 0.7x0.7 sq. degrees

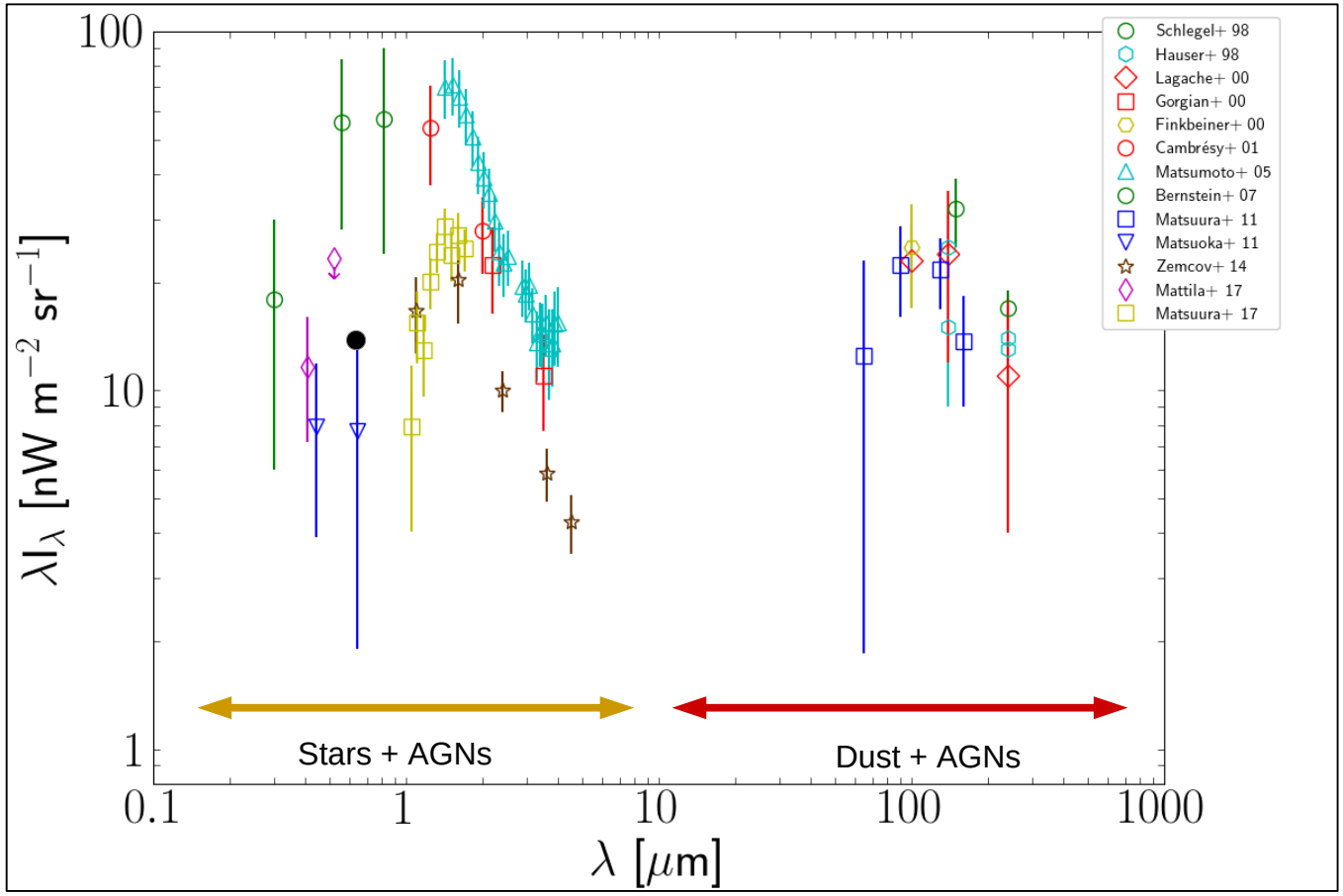
# EBL Measurements (I): Direct Detection

Zodiacal light, visible under the right conditions: typically after the sunset in Spring and right before sunrise in Autumn (approx. 10% dark site moon-less night sky)

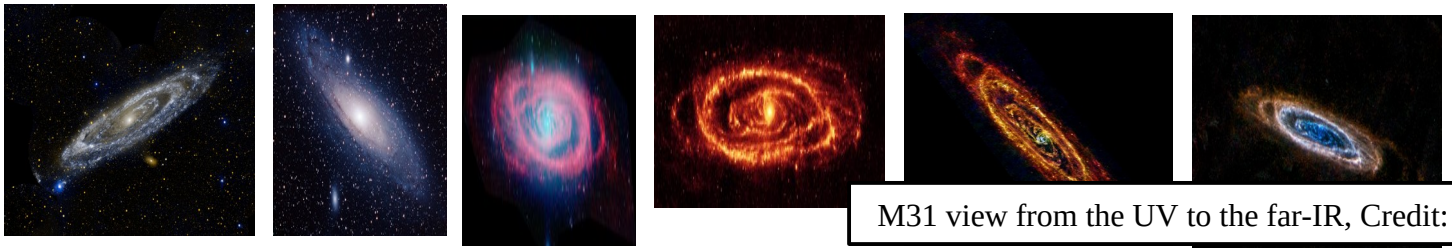



A 1 per cent systematic error in the subtraction of the Zodi can lead to a 100 per cent error in direct measurements of the EBL (Berstein 2007)

# EBL Measurements (I): Direct Detection

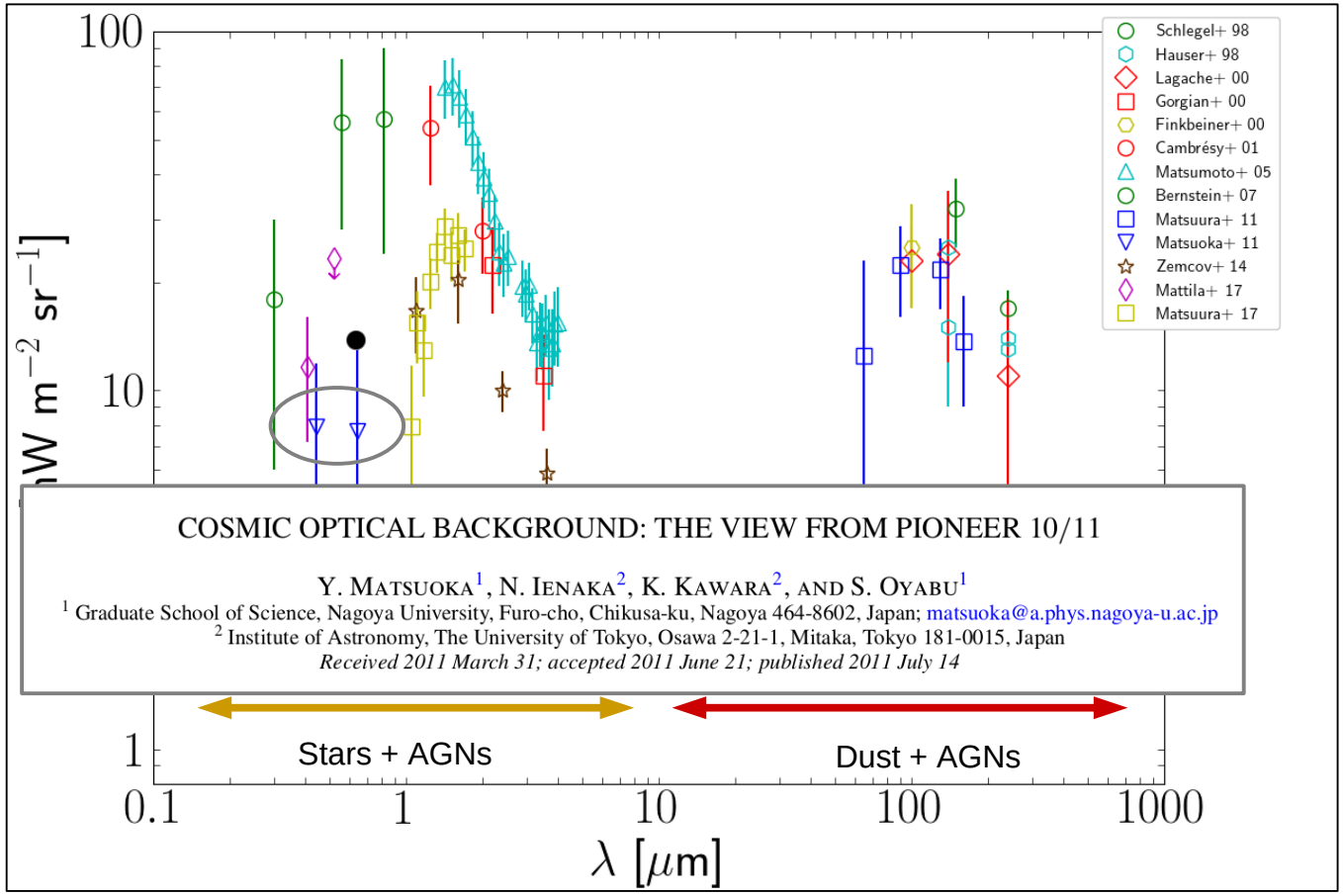



UV | optical | near-IR | mid-IR | far-IR



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

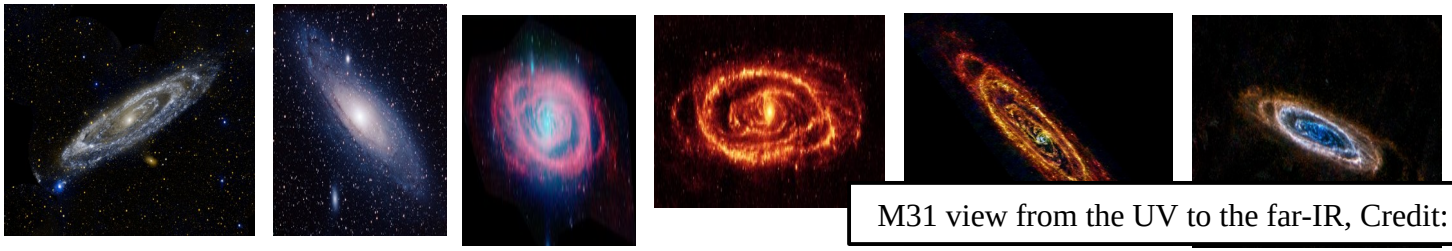
# EBL Measurements (I): Direct Detection




COSMIC OPTICAL BACKGROUND: THE VIEW FROM PIONEER 10/11

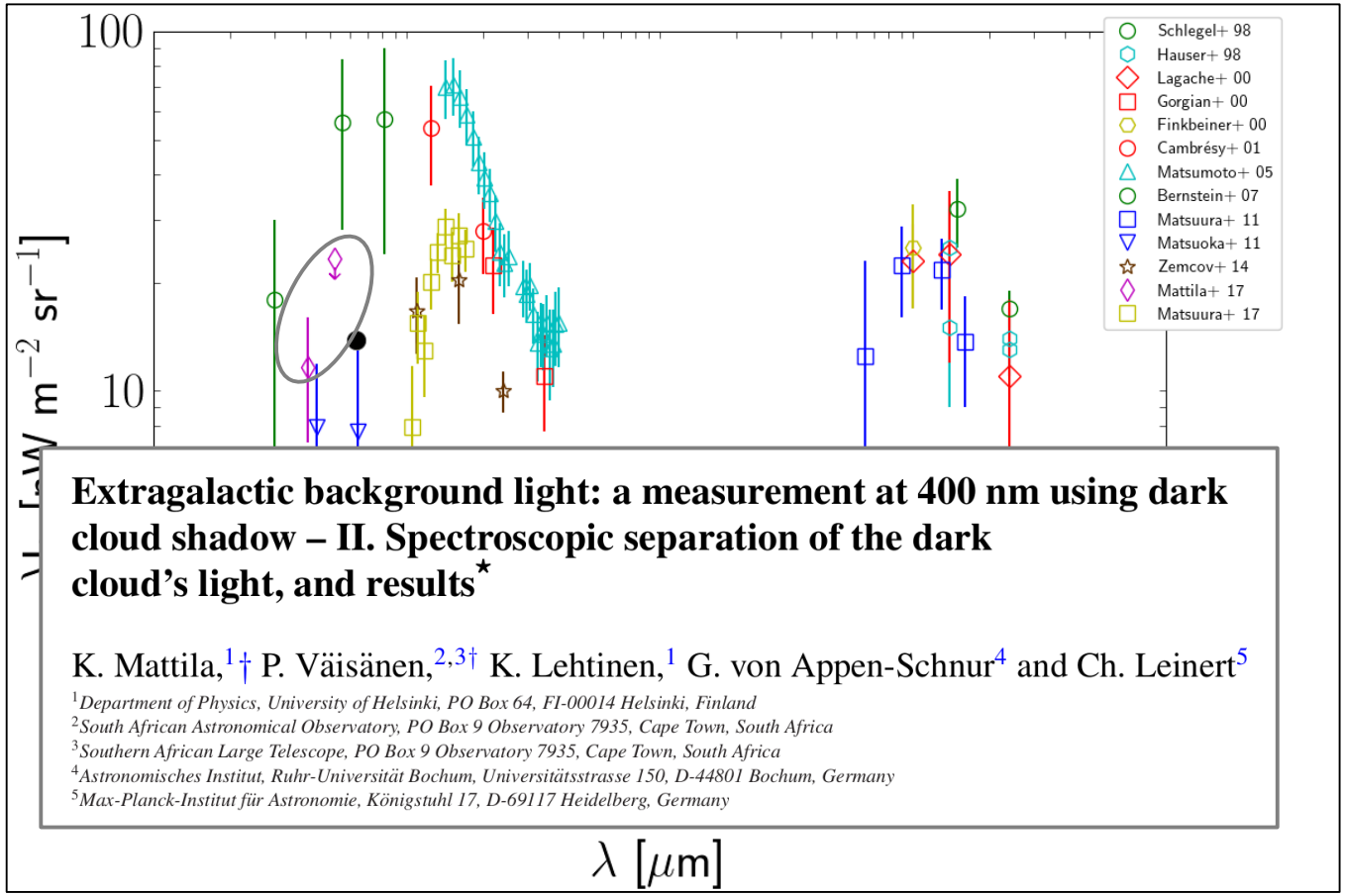
Y. MATSUOKA[1], N. IENAKA[2], K. KAWARA[2], AND S. OYABU[1]
[1] Graduate School of Science, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8602, Japan; matsuoka@a.phys.nagoya-u.ac.jp
[2] Institute of Astronomy, The University of Tokyo, Osawa 2-21-1, Mitaka, Tokyo 181-0015, Japan
*Received 2011 March 31; accepted 2011 June 21; published 2011 July 14*

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



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

# EBL Measurements (I): Direct Detection

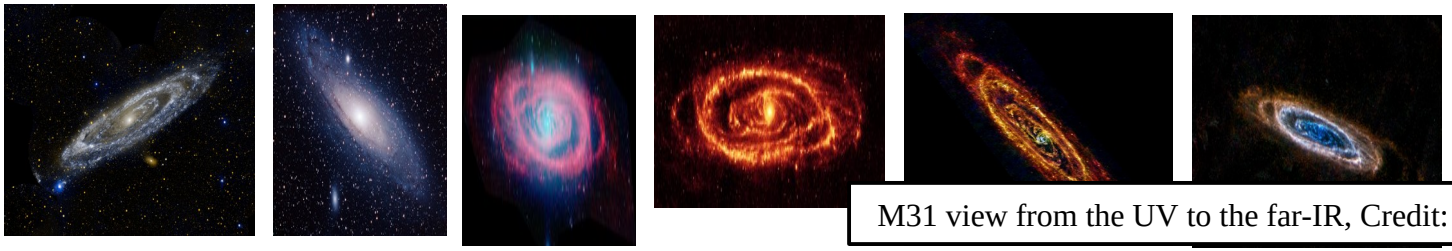



**Extragalactic background light: a measurement at 400 nm using dark cloud shadow – II. Spectroscopic separation of the dark cloud's light, and results**$^{\star}$


K. Mattila,[1]† P. Väisänen,[2,3]† K. Lehtinen,[1] G. von Appen-Schnur[4] and Ch. Leinert[5]

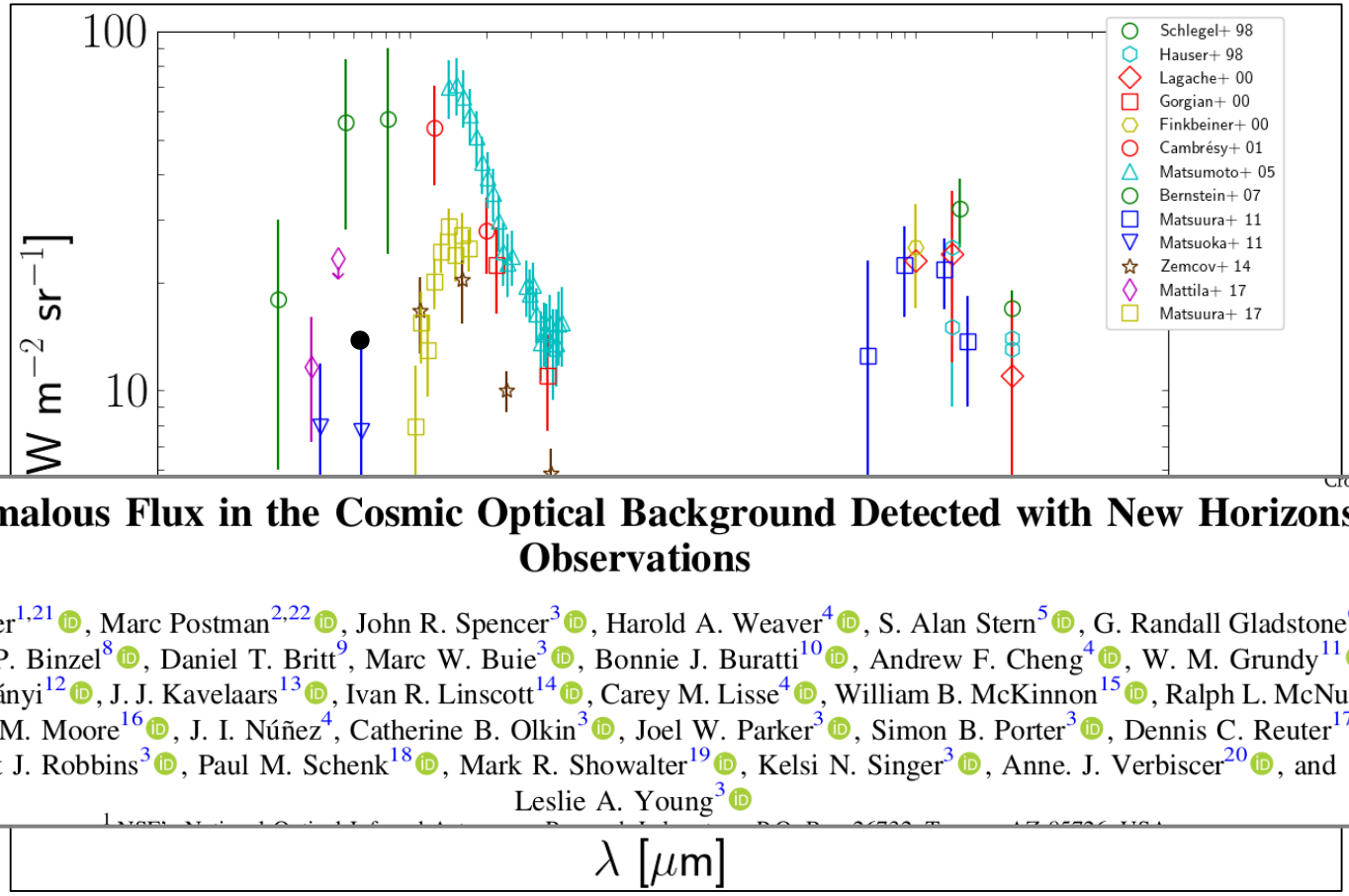
[1]*Department of Physics, University of Helsinki, PO Box 64, FI-00014 Helsinki, Finland*
[2]*South African Astronomical Observatory, PO Box 9 Observatory 7935, Cape Town, South Africa*
[3]*Southern African Large Telescope, PO Box 9 Observatory 7935, Cape Town, South Africa*
[4]*Astronomisches Institut, Ruhr-Universität Bochum, Universitätsstrasse 150, D-44801 Bochum, Germany*
[5]*Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany*


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



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

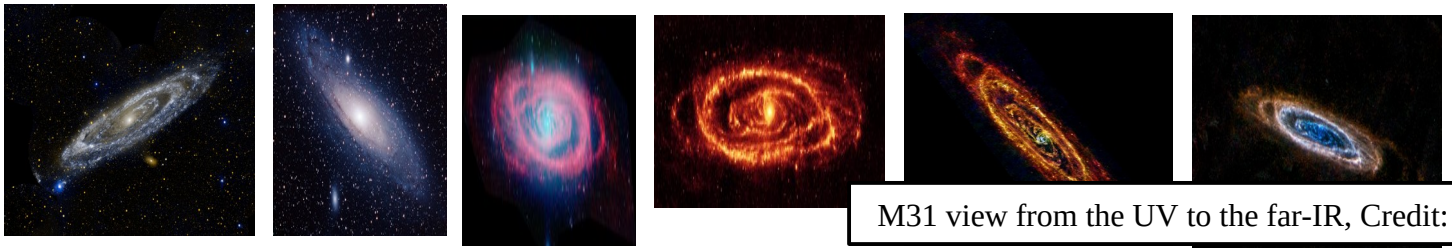
# EBL Measurements (I): Direct Detection




**Anomalous Flux in the Cosmic Optical Background Detected with New Horizons Observations**

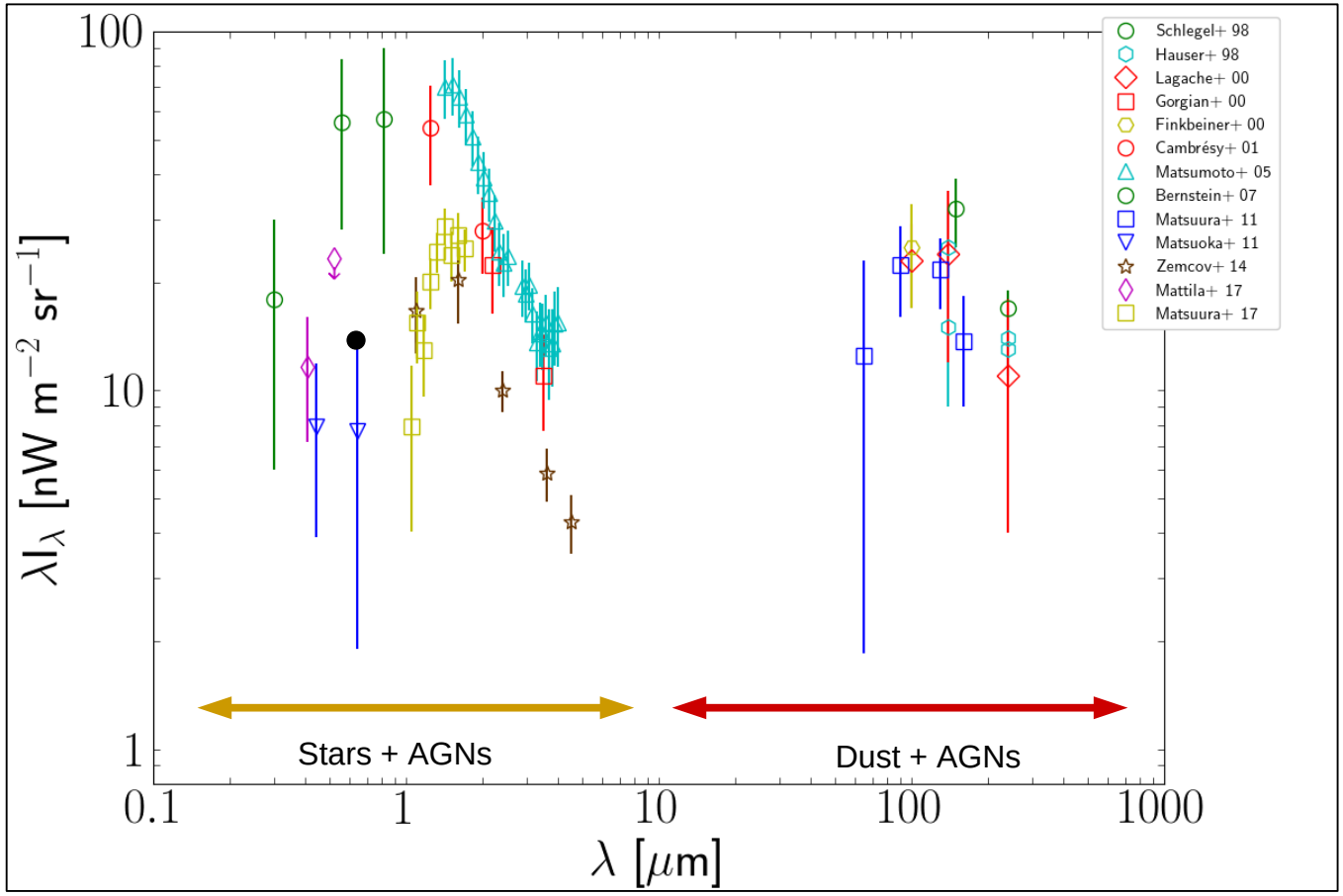

Tod R. Lauer[1,21], Marc Postman[2,22], John R. Spencer[3], Harold A. Weaver[4], S. Alan Stern[5], G. Randall Gladstone[6,7], Richard P. Binzel[8], Daniel T. Britt[9], Marc W. Buie[3], Bonnie J. Buratti[10], Andrew F. Cheng[4], W. M. Grundy[11], Mihaly Horányi[12], J. J. Kavelaars[13], Ivan R. Linscott[14], Carey M. Lisse[4], William B. McKinnon[15], Ralph L. McNutt[4], Jeffrey M. Moore[16], J. I. Núñez[4], Catherine B. Olkin[3], Joel W. Parker[3], Simon B. Porter[3], Dennis C. Reuter[17], Stuart J. Robbins[3], Paul M. Schenk[18], Mark R. Showalter[19], Kelsi N. Singer[3], Anne. J. Verbiscer[20], and Leslie A. Young[3]


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

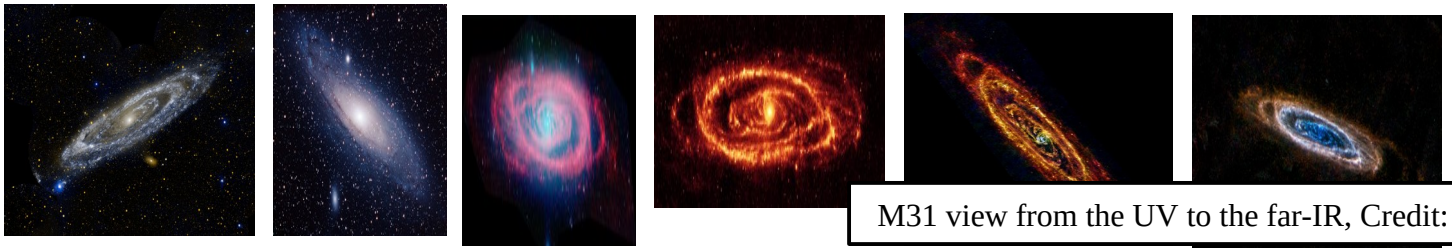


M31 view from the UV to the far-IR, Credit: NASA & ESA

# EBL Measurements (I): Direct Detection

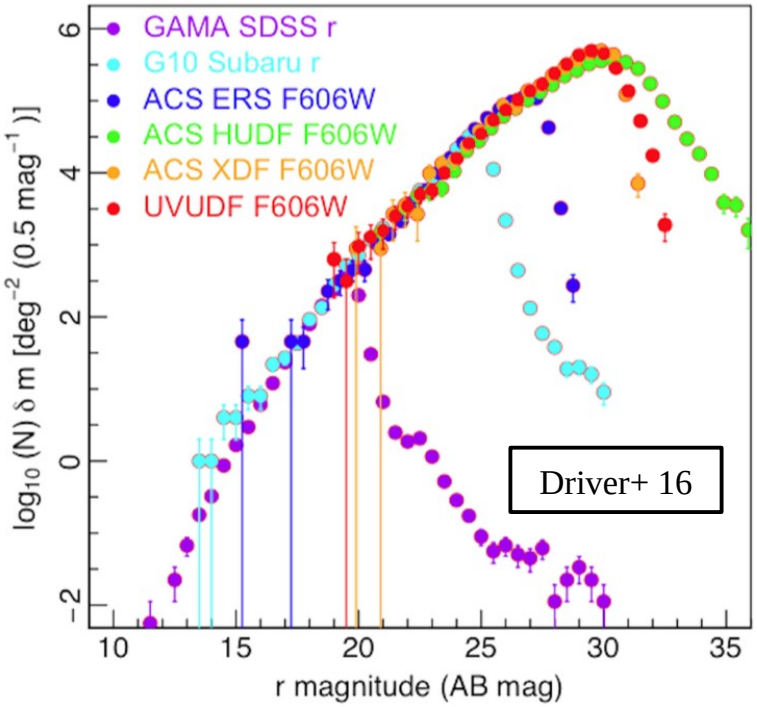



UV | optical | near-IR | mid-IR | far-IR



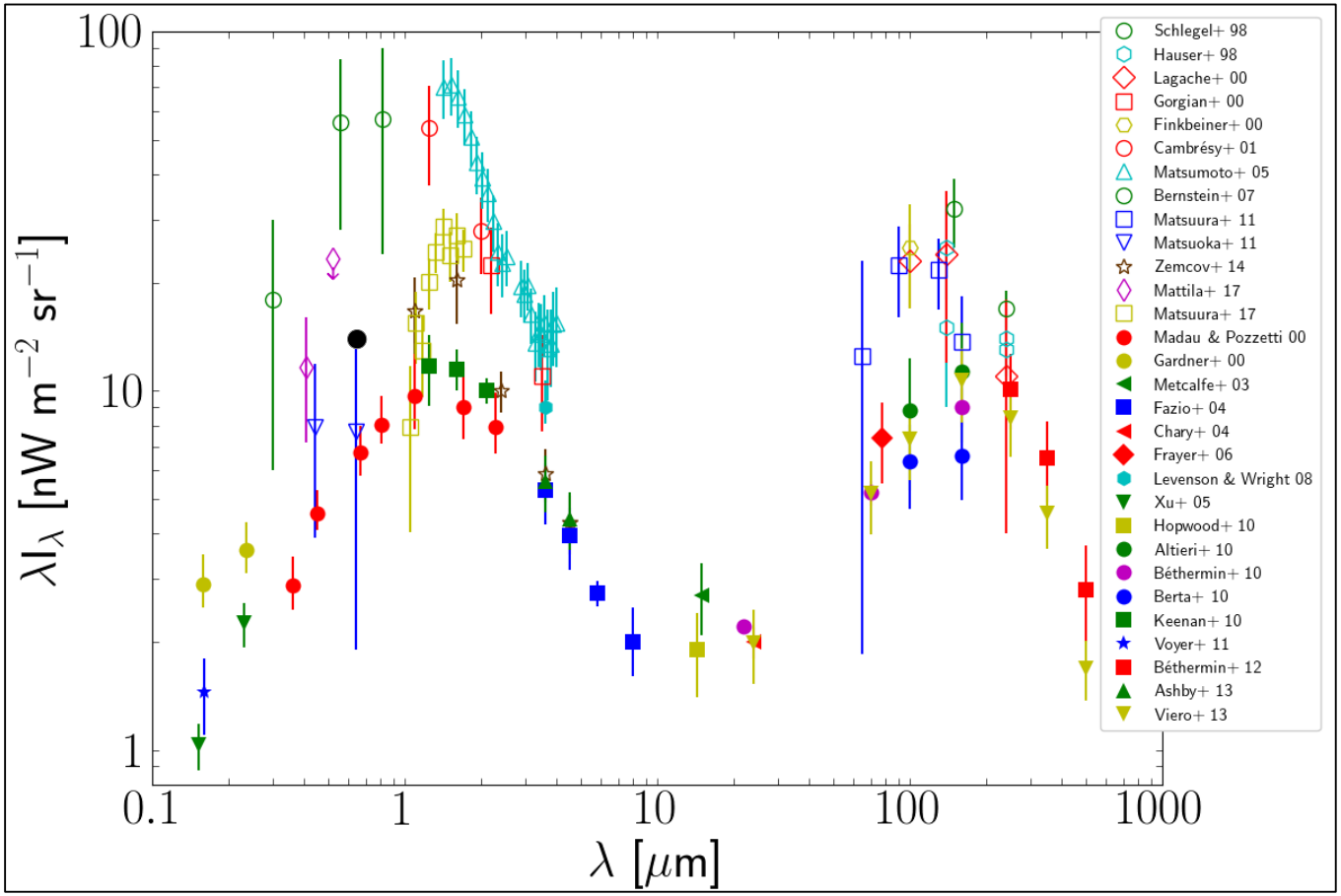
M31 view from the UV to the far-IR, Credit: NASA & ESA

# EBL Measurements (II): Galaxy Counts

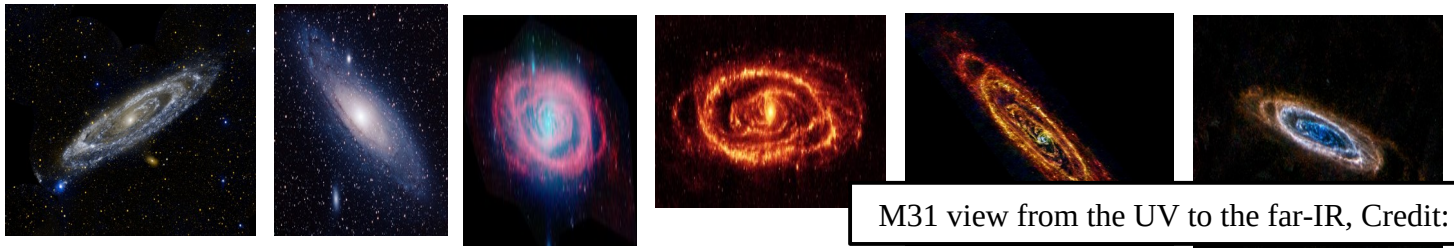



Galaxy number counts in deep fields
e.g. Madau & Pozzetti (2000),
Driver et al. (2016)

# EBL Measurements (II): Galaxy Counts

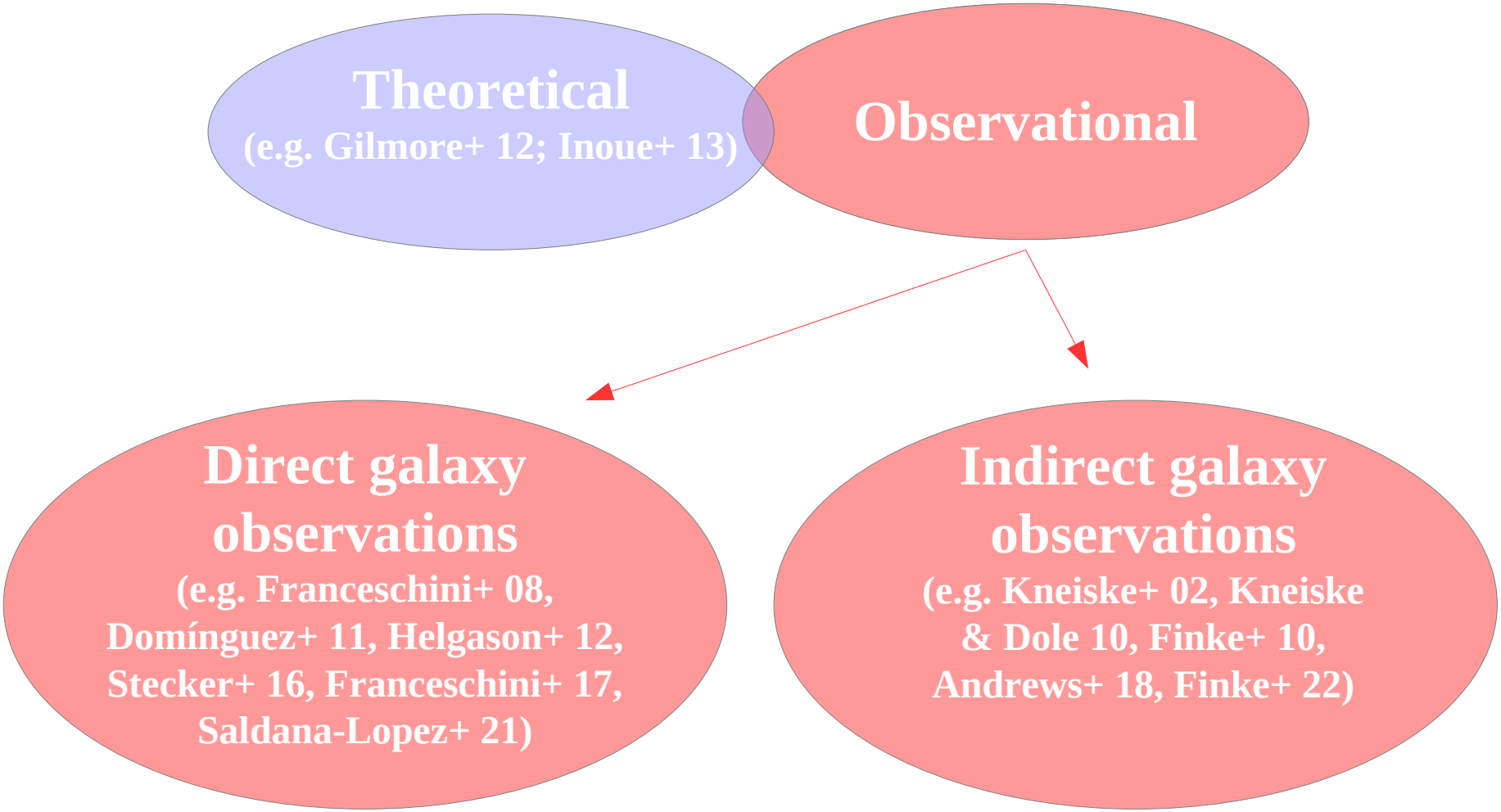



UV | optical | near-IR | mid-IR | far-IR

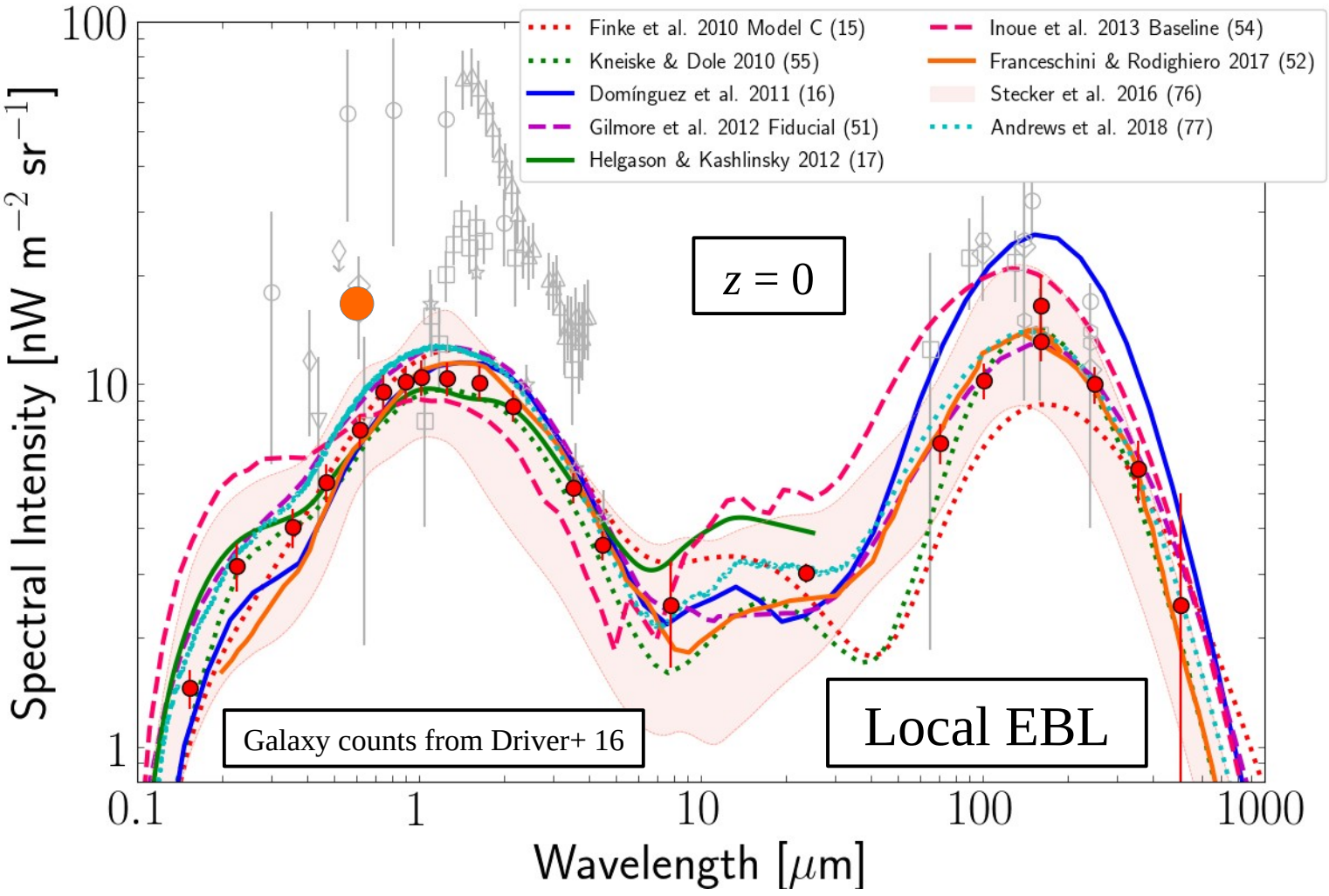


M31 view from the UV to the far-IR, Credit: NASA & ESA

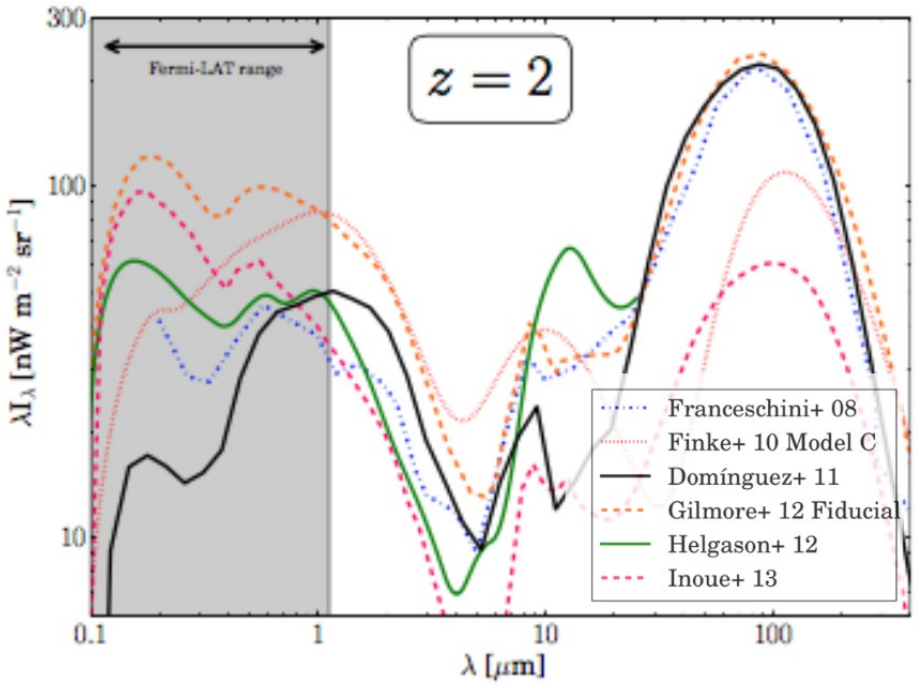
# EBL Measurements (III): Models

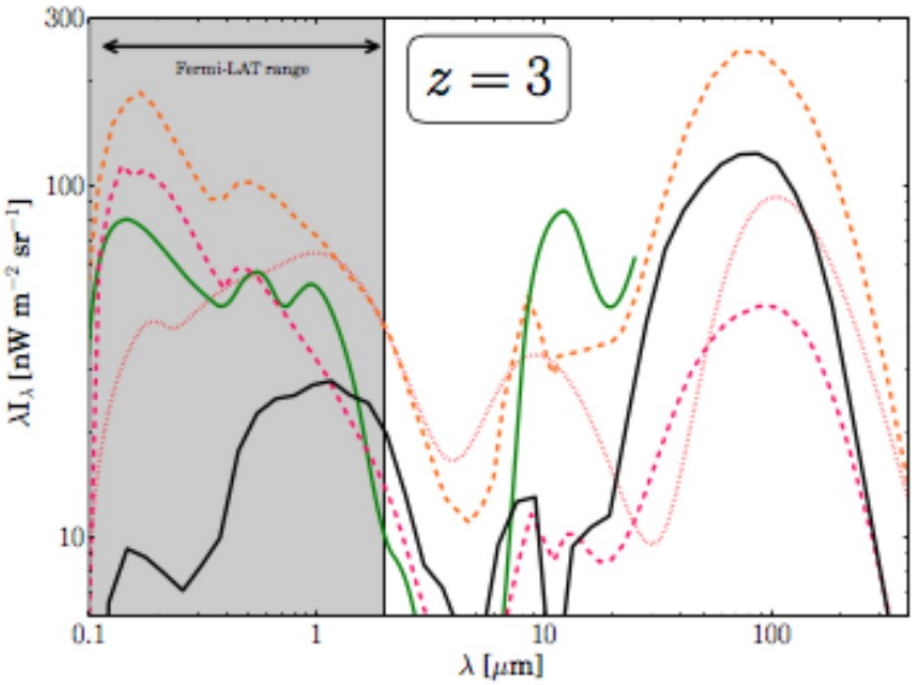


# EBL Measurements (III): Models



# EBL Measurements (III): Models



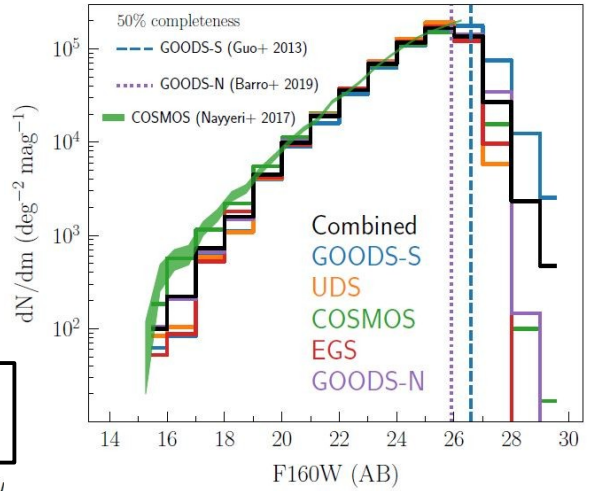




EBL evolution

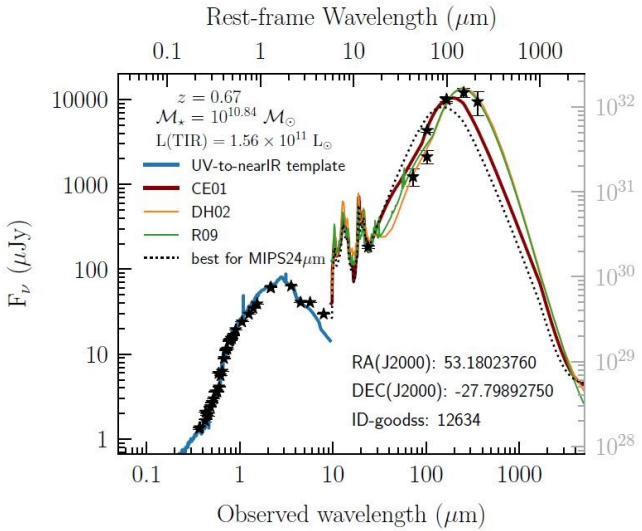
Strong divergence

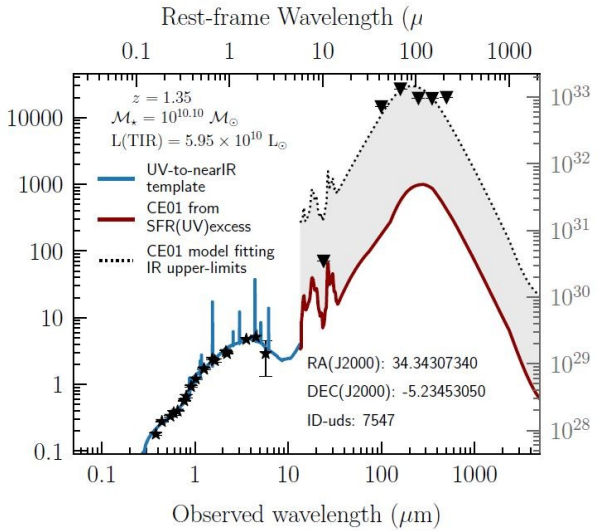
# EBL Measurements (III): Saldana-Lopez+ 21

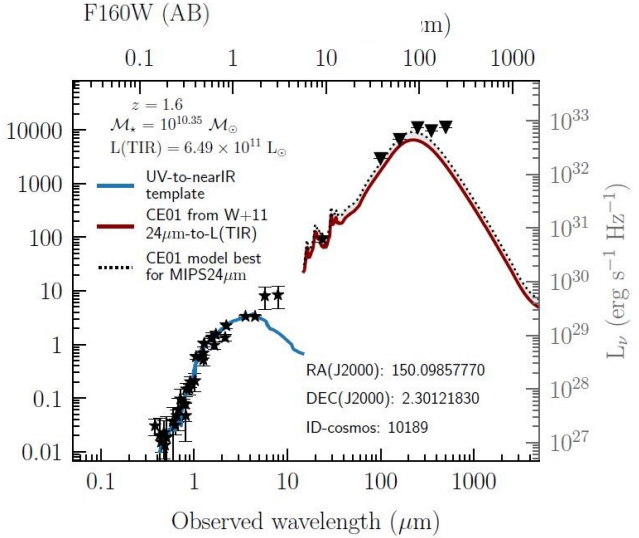
- 150,000 galaxies
- 0 < z < 6
- 5 CANDELS fields, reducing cosmic variance


Herschel observations for all galaxies, not necessarily detection




**Direct L(TIR) calculation**

**(Wuyts+ 11)**
**L(TIR)[Lo] = C(z) * Fnu(24um)[mJy]**

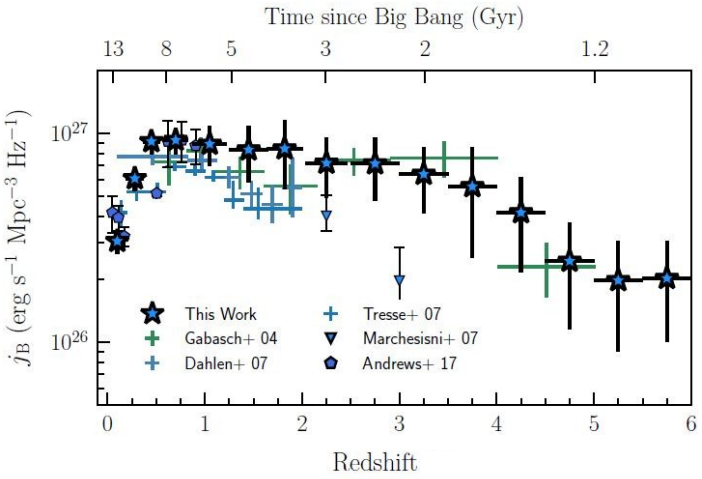
$$\Delta\mathrm{SFR}(2800) = \mathrm{SFR}(2800)_{\mathrm{corr}} - \mathrm{SFR}(2800)_{\mathrm{obs}}.$$

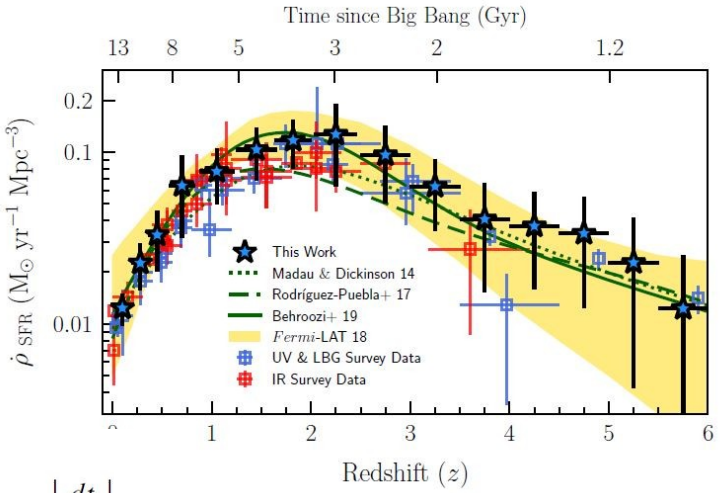
$$\mathrm{L(TIR)(erg\ s^{-1})} = 3.86 \times 10^{43} \Delta\mathrm{SFR}(2800).$$

$$\mathrm{SFR} = \mathrm{SFR(UV)} + \mathrm{SFR(TIR)},$$

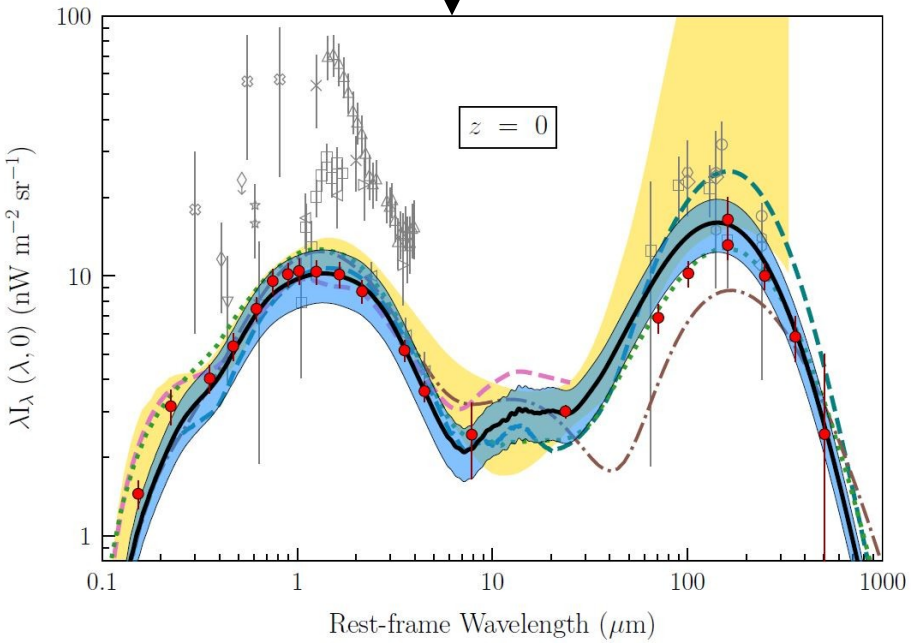
$$\mathrm{SFR}[\mathrm{M_\odot\ yr^{-1}}] = 1.07 \times 10^{-10}\,(3.3 \times \mathrm{L}(2800) + \mathrm{L(TIR)})\,/L_\odot,$$

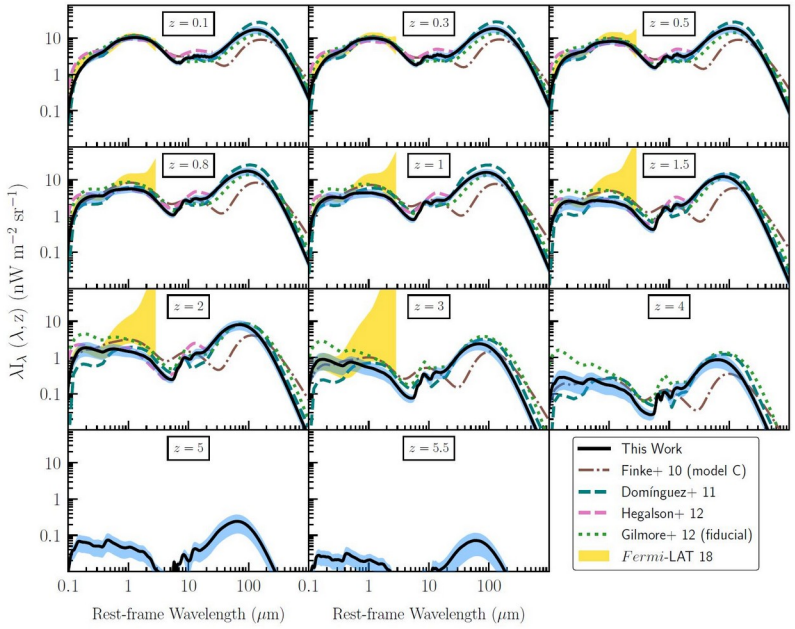
# EBL Measurements (III): Saldana-Lopez+ 21



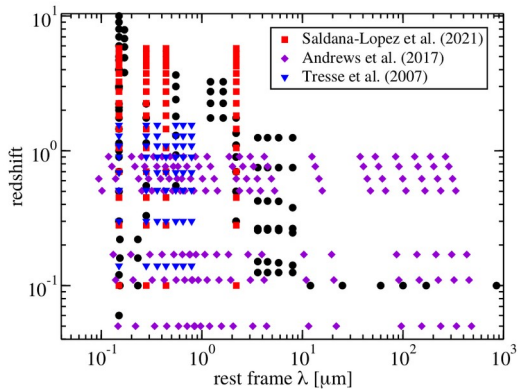



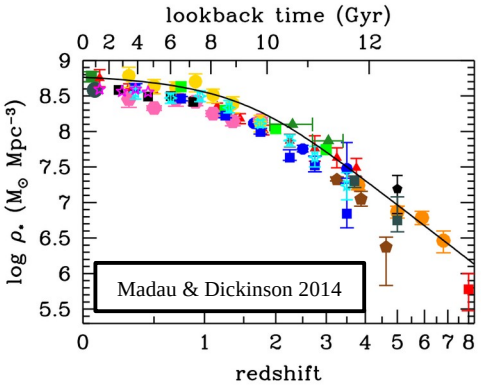

$$\lambda I_\lambda(\lambda, z_i) = \frac{c^2}{4\pi\lambda} \int_{z_i}^{z_{max}} j\left(\lambda(1+z_i)/(1+z'), z'\right) \left|\frac{dt}{dz'}\right| dz'$$

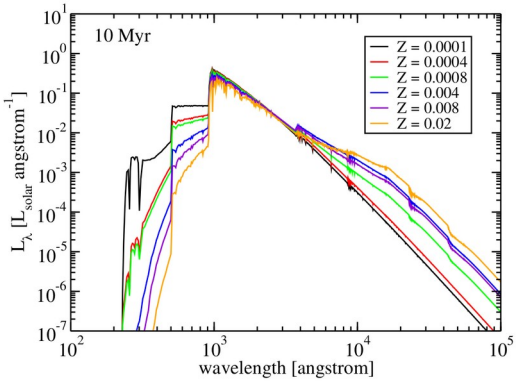


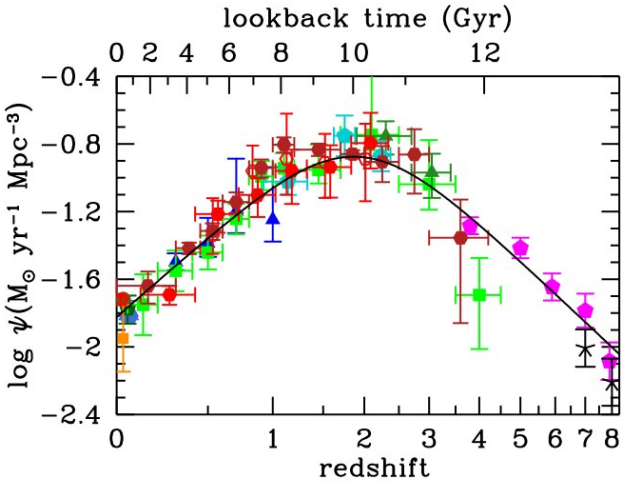



# EBL Measurements (III): Finke+ 22

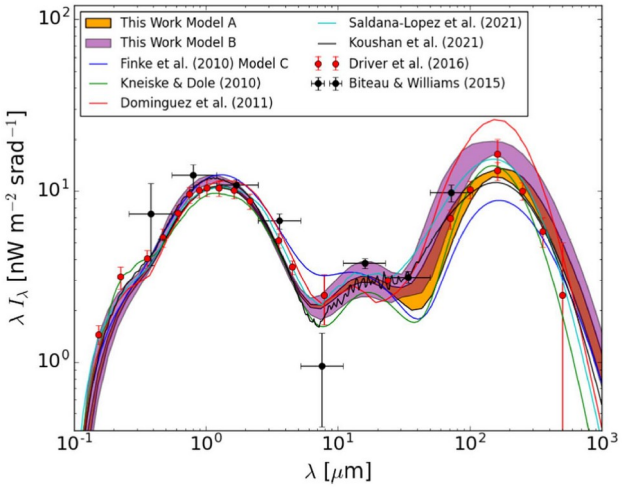


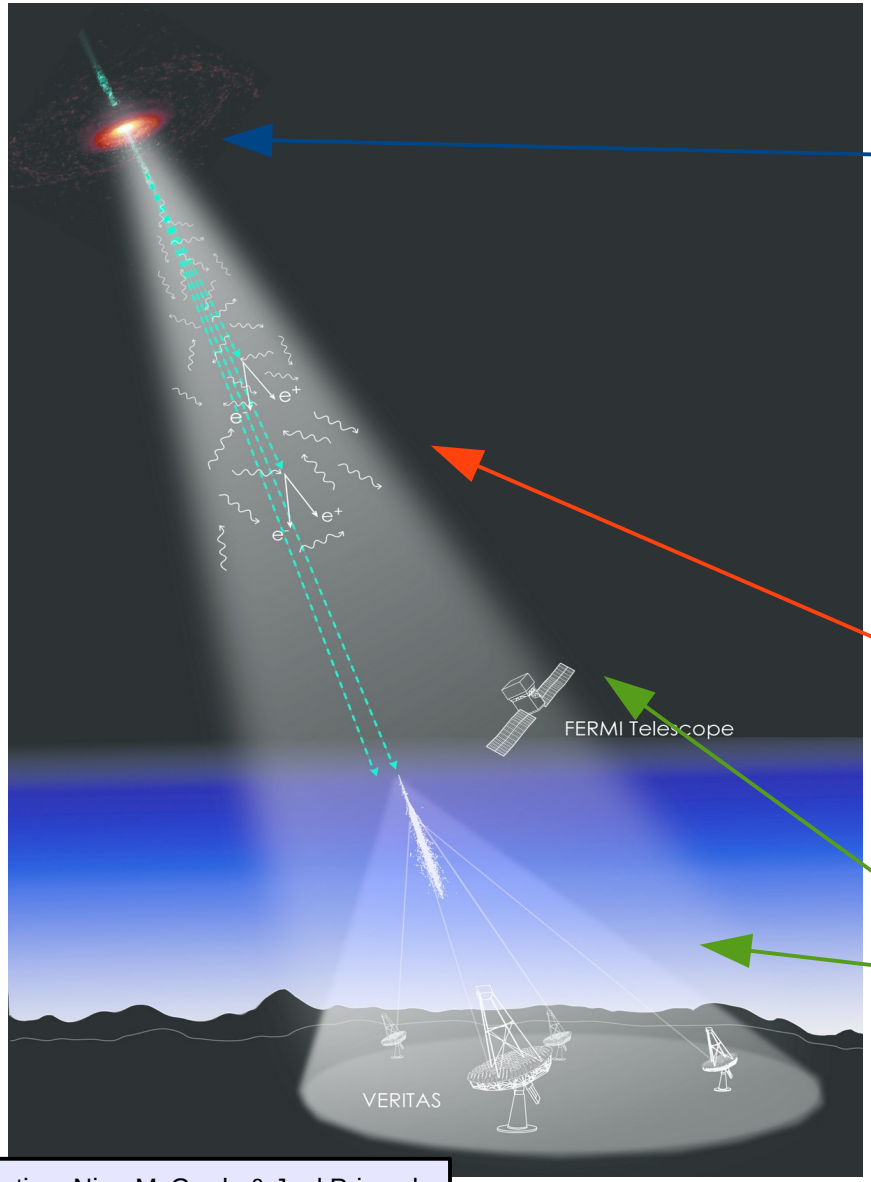




Evolving EBL



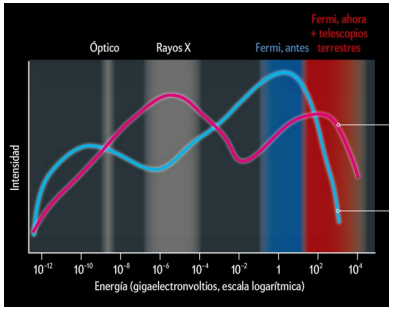
# EBL Measurements (IV): Gamma-ray Attenuation




Ilustration: Nina McCurdy & Joel Primack

Extragalactic source:
e.g. Blazar

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

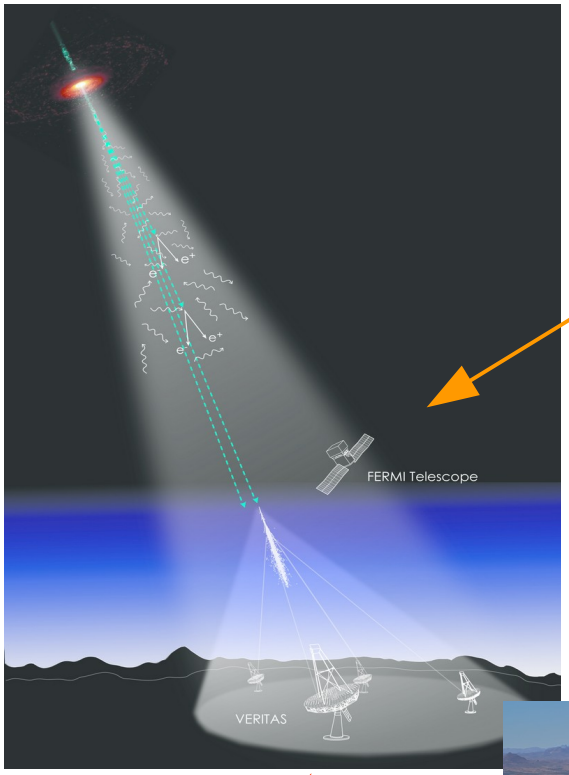



Pair-production interaction

**Reverse of most known electron-positron annhilation process**

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

# EBL Measurements (IV): Gamma-ray Attenuation



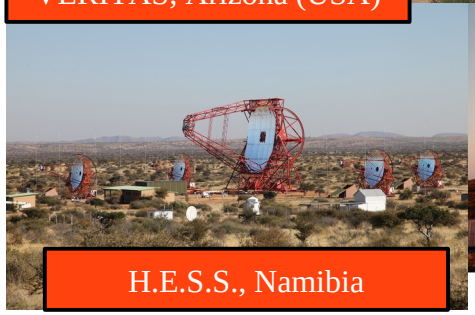

Fermi-LAT


All-sky, Energy range
100 MeV – 100s GeV

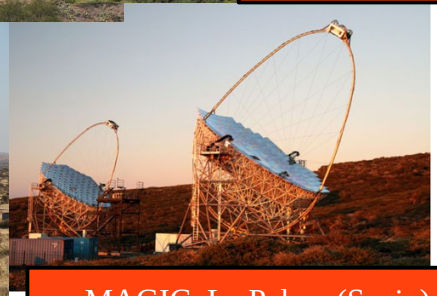
IACTs
Small field of view,
High sensitivity, Energy range
100 GeV – 10s TeV

VERITAS, Arizona (USA)

CTA North, La Palma (Spain)

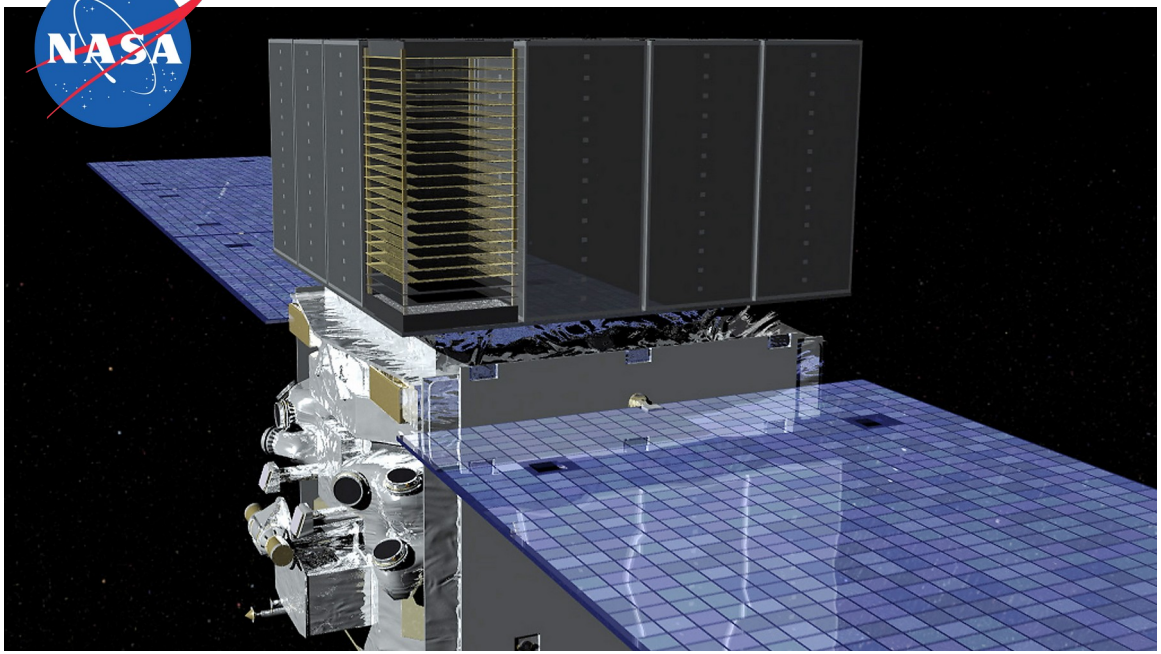


H.E.S.S., Namibia



MAGIC, La Palma (Spain)

# EBL Measurements (IV): Fermi-LAT



**Launch June 11, 2008**

**1. Tracking system:**

- converts an incident gamma ray to an electron-positron pair
- reconstructs the gamma-ray direction from the tracks of the pair

**2. Calorimeter:**

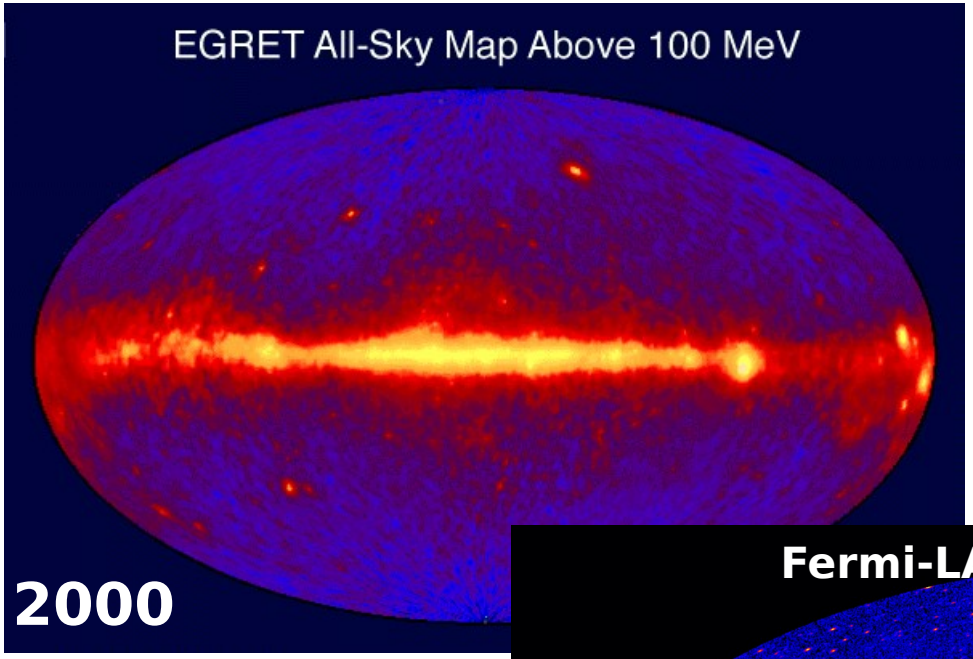
- measures the photon energy

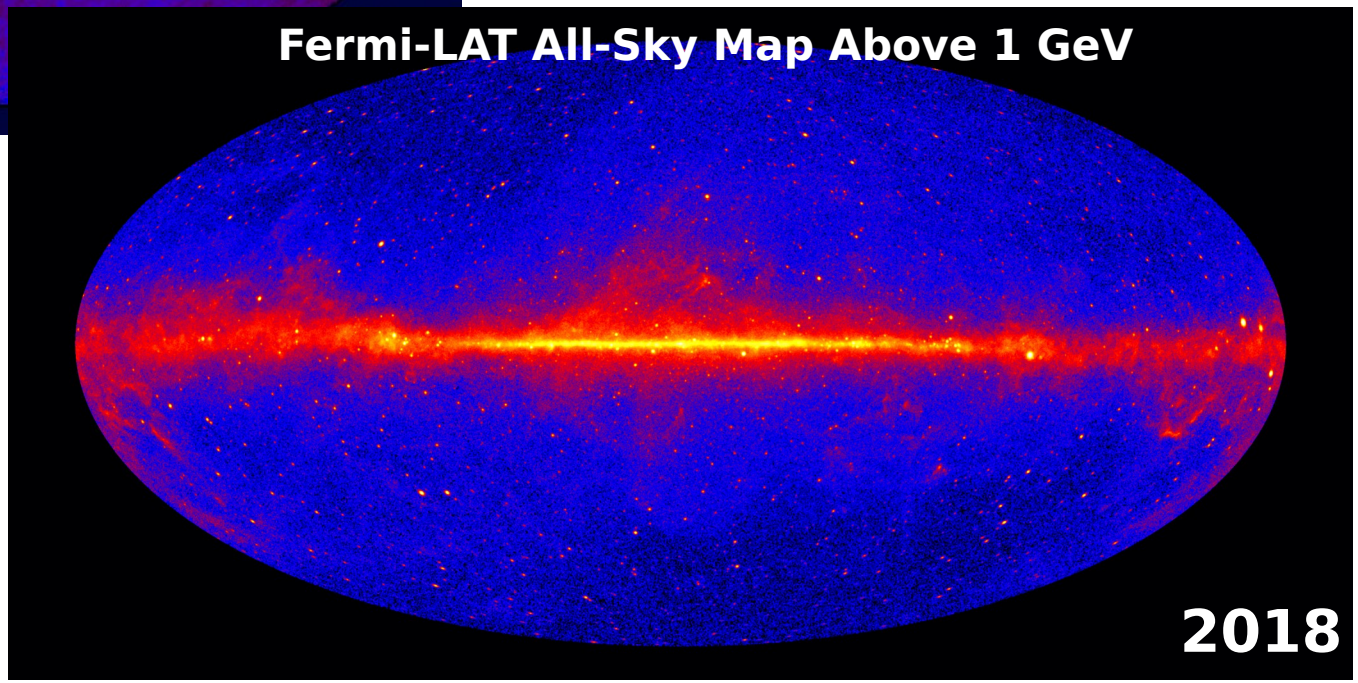
**3. Anti-coincidence detector:**

- limits the cosmic-ray background

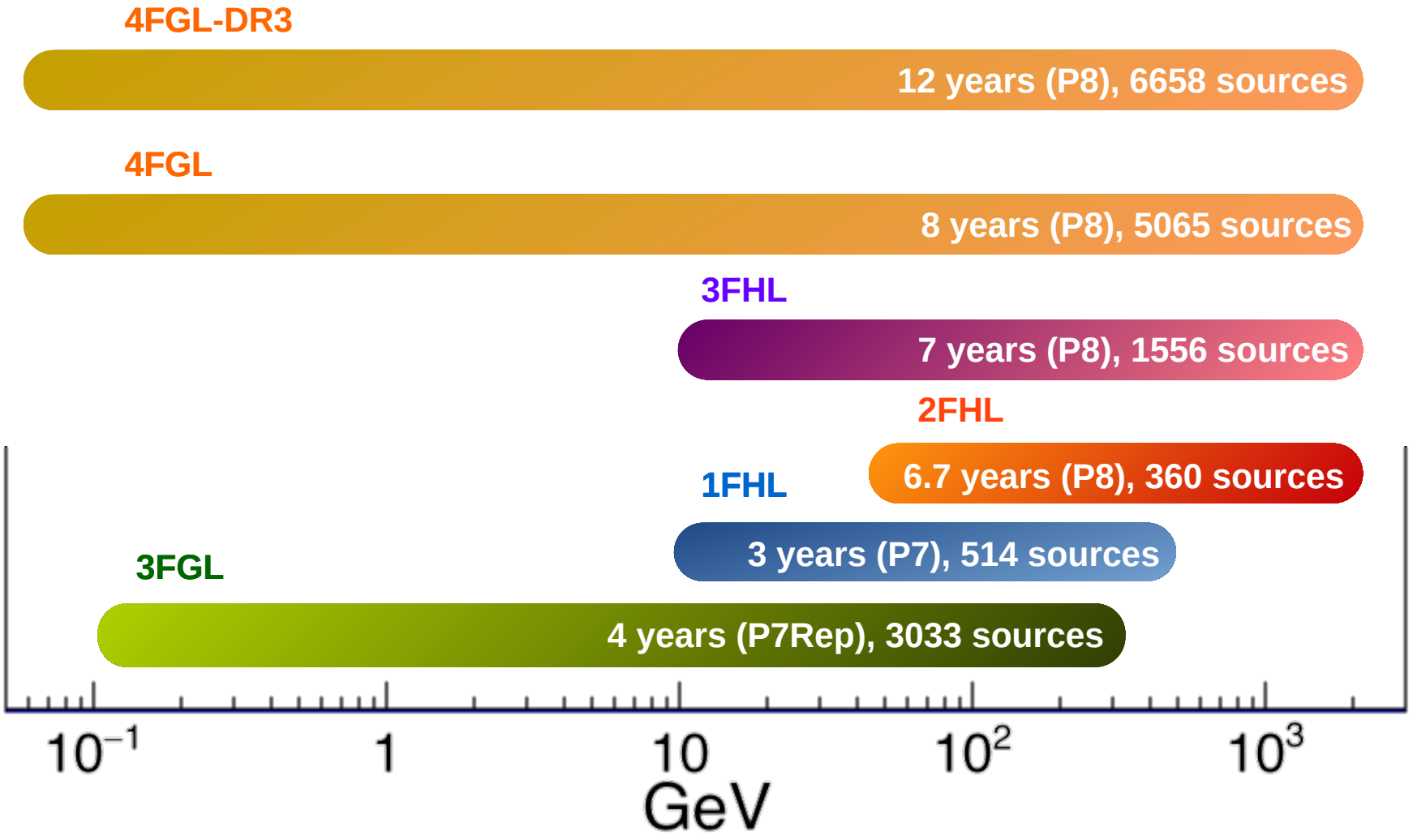
- **Wide field of view (2.4 sr, 20% of the sky)**
- **Large effective area (~0.9 $m^2$ above 1 GeV)**
- **Low dead time (~27 μs)**

# EBL Measurements (IV): Fermi-LAT

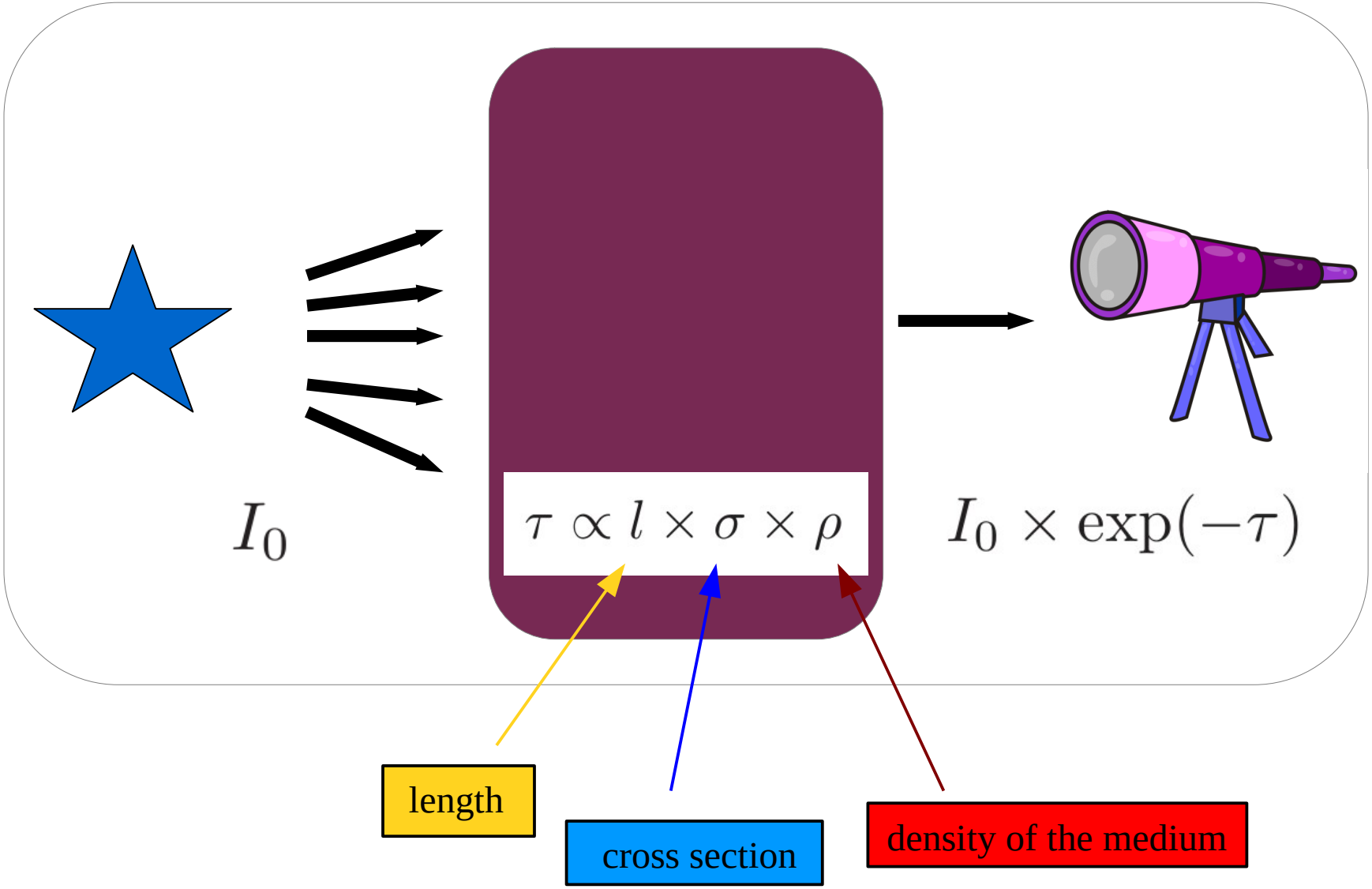


# EBL Measurements (IV): Fermi-LAT

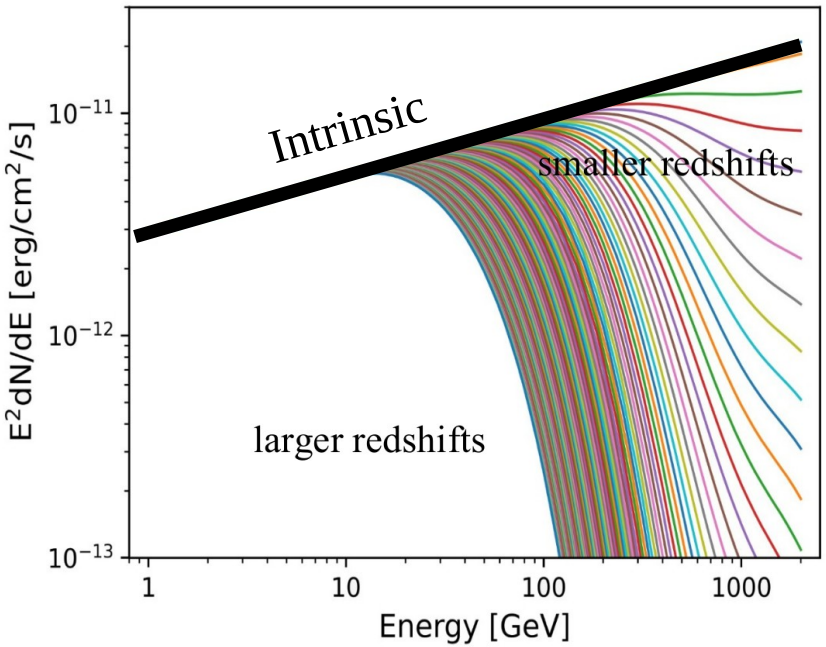


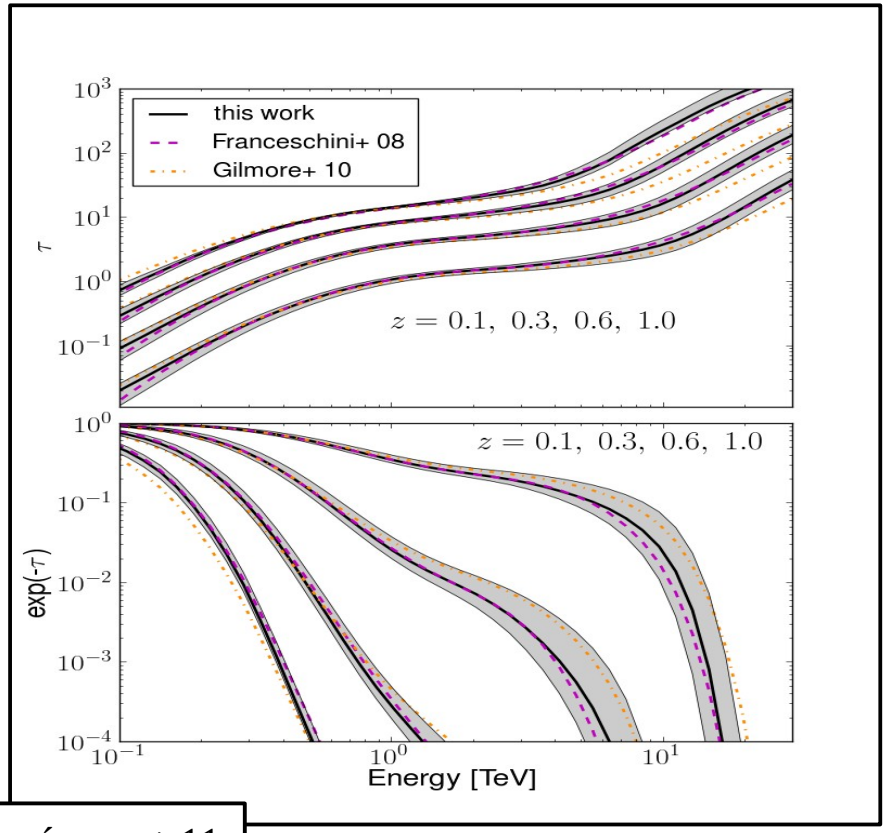
# EBL Measurements (IV): Gamma-ray Attenuation



# EBL Measurements (IV): Gamma-ray Attenuation

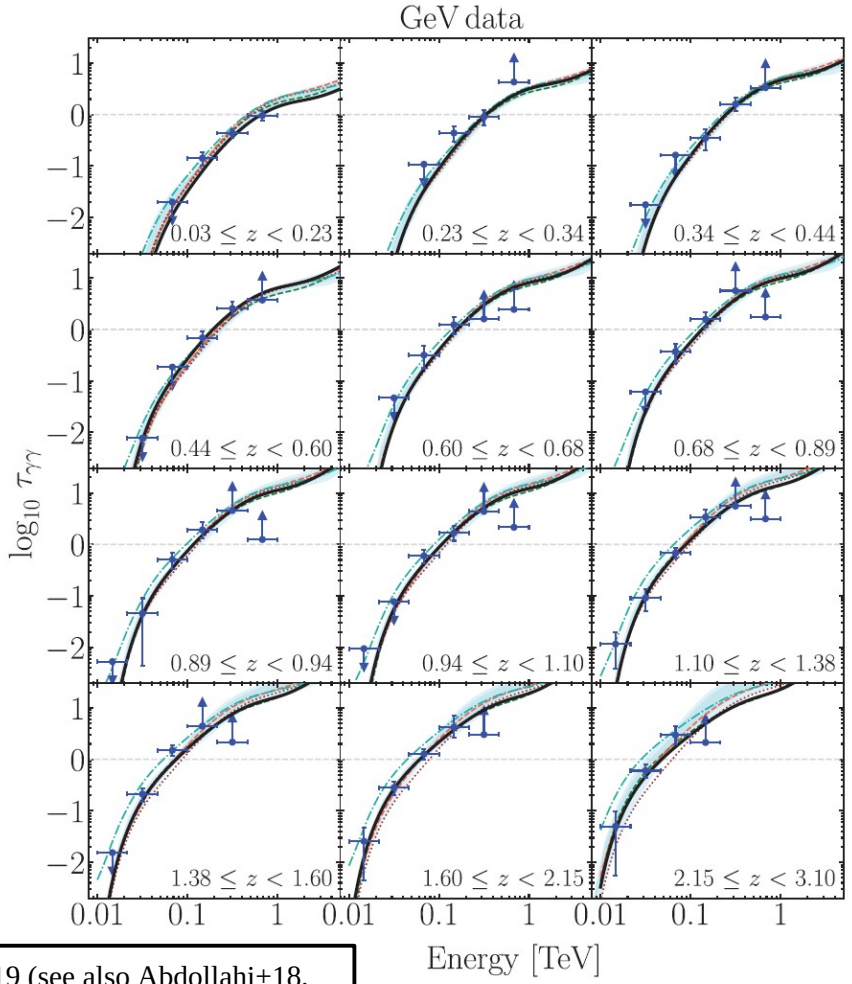
$$\left.\frac{dN}{dE}\right|_{obs} = \left.\frac{dN}{dE}\right|_{int} \exp\left[-\tau(E,z)\right]$$

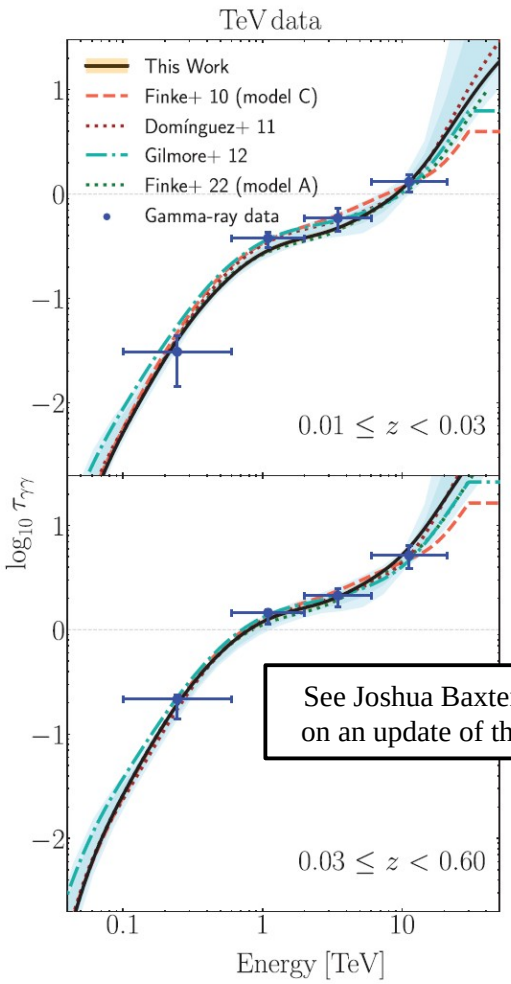



Domínguez+ 11

# EBL Measurements (IV): Gamma-ray Attenuation



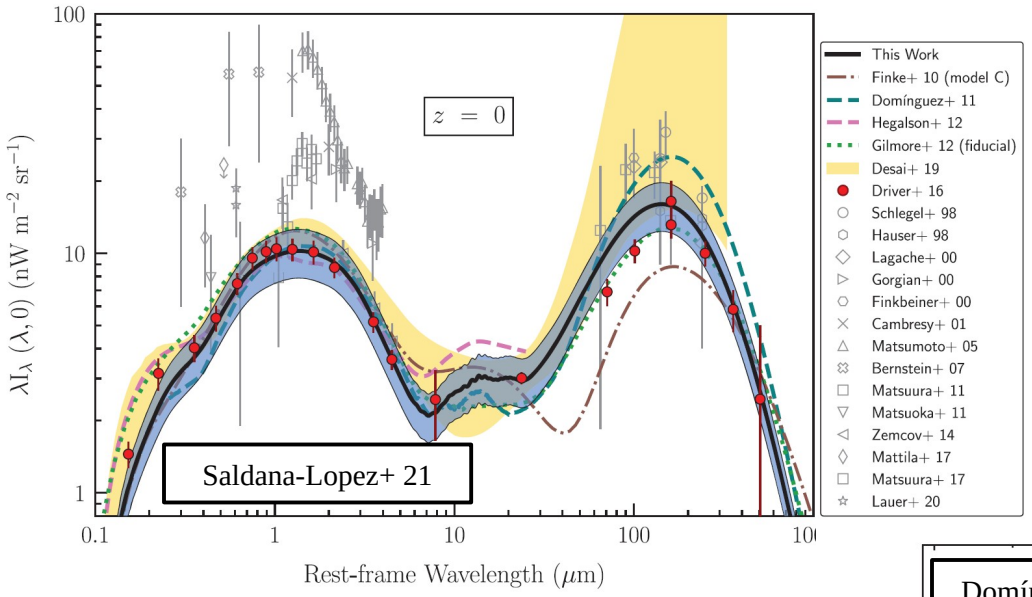




Desai+ 19 (see also Abdollahi+18, Domínguez+ 24)

See Joshua Baxter's talk later today on an update of these measurements

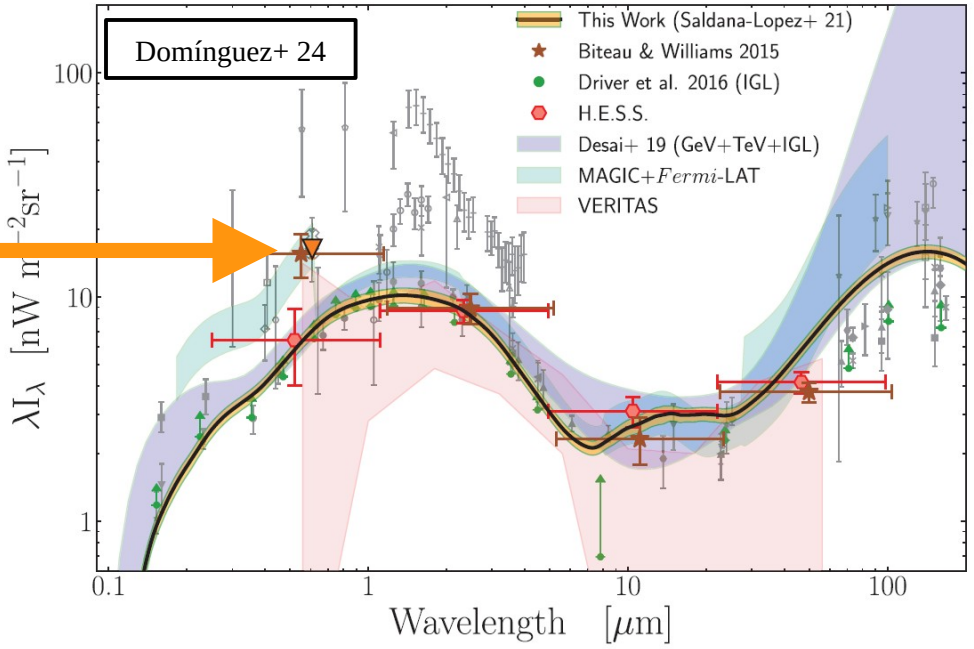
Optical Depths from Fermi-LAT and IACTs

# Extragalactic Background Light (Local)

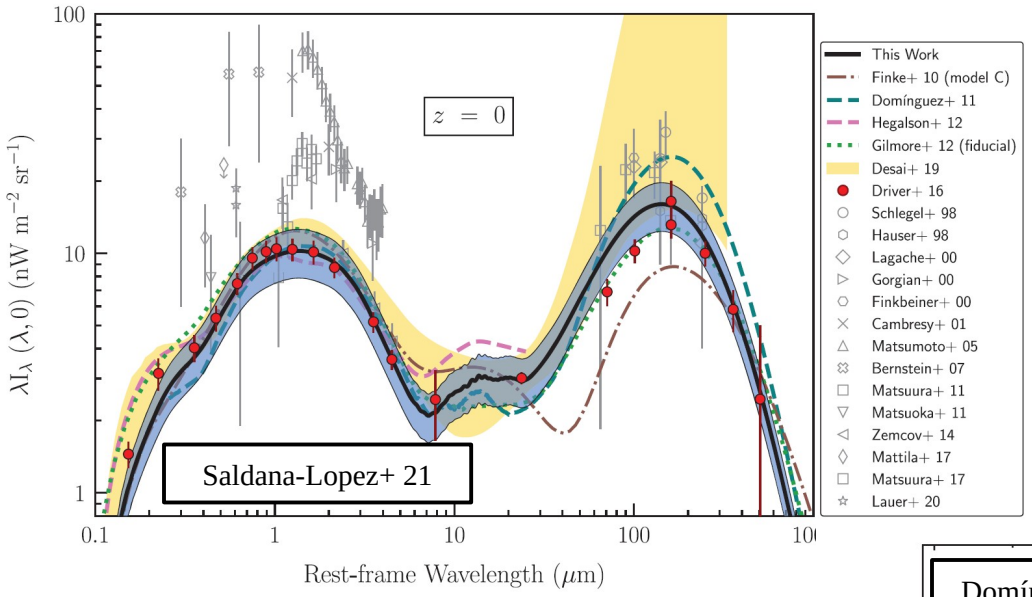



Galaxy counts, EBL models, and gamma-ray attenuation data agree but direct detection tends to be at larger intensities,
zodiacal light contamination?

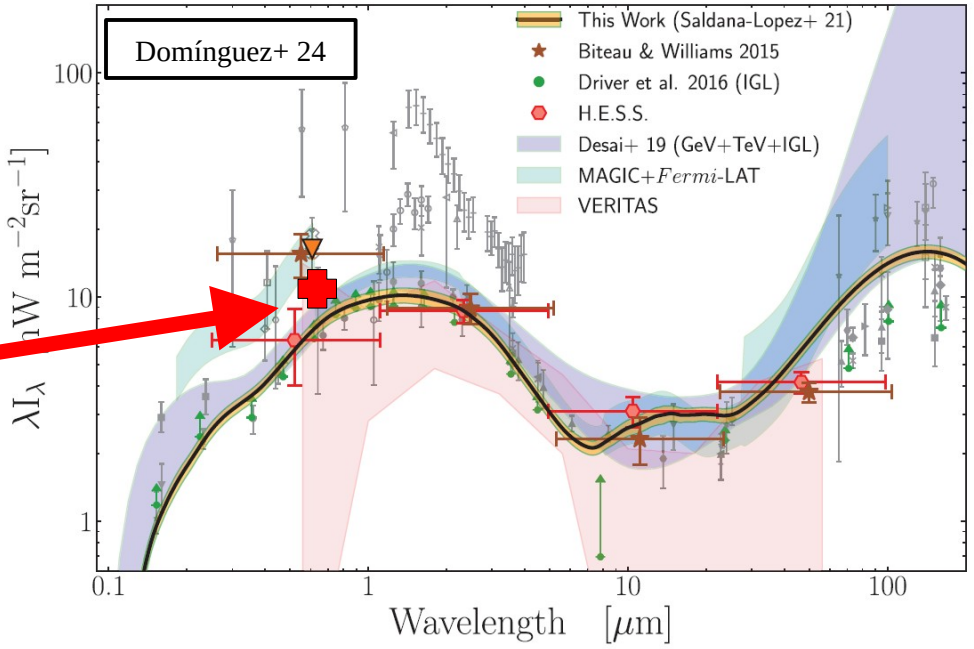
Lauer+ 22 from New Horizons



# Extragalactic Background Light (Local)



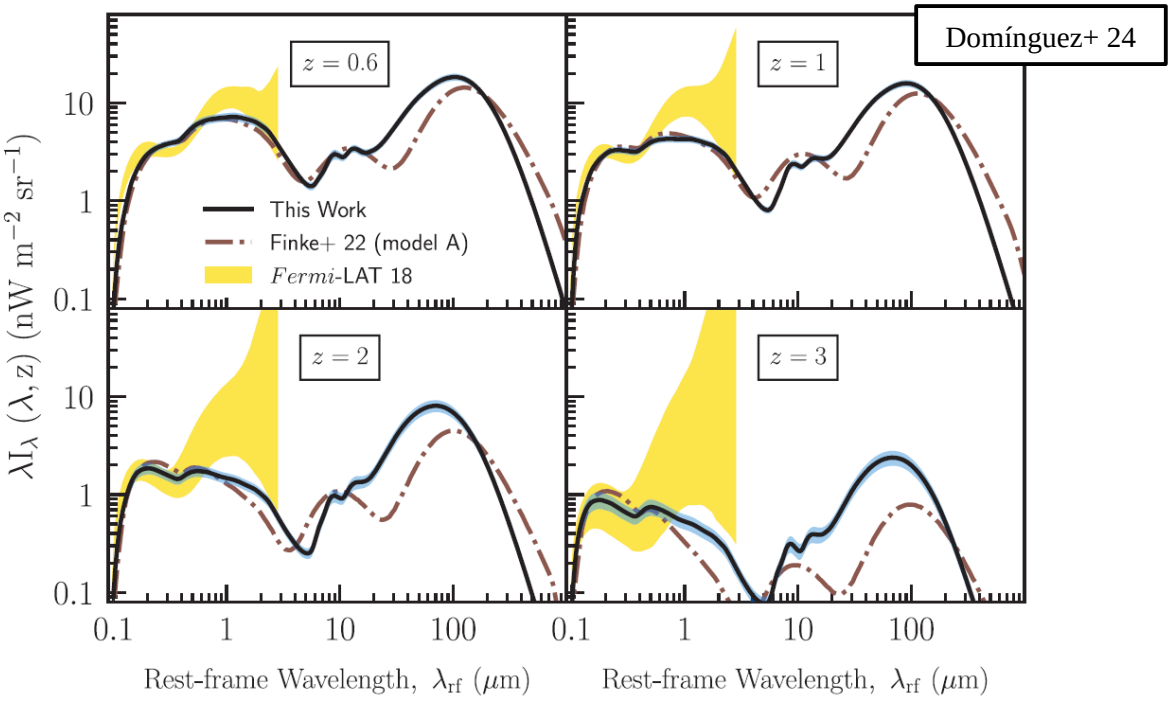

Galaxy counts, EBL models, and gamma-ray attenuation data agree but direct detection tends to be at larger intensities, zodiacal light contamination?




Postman+ 24 from New Horizons

Galaxy counts, EBL models, gamma-ray attenuation data, and now direct detection, all converge!

# Extragalactic Background Light (Evolution)




EBL models and gamma-ray attenuation data agree within 1sigma in the UV/optical and within 2sigma in the near IR

# Optical Depths

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

distance

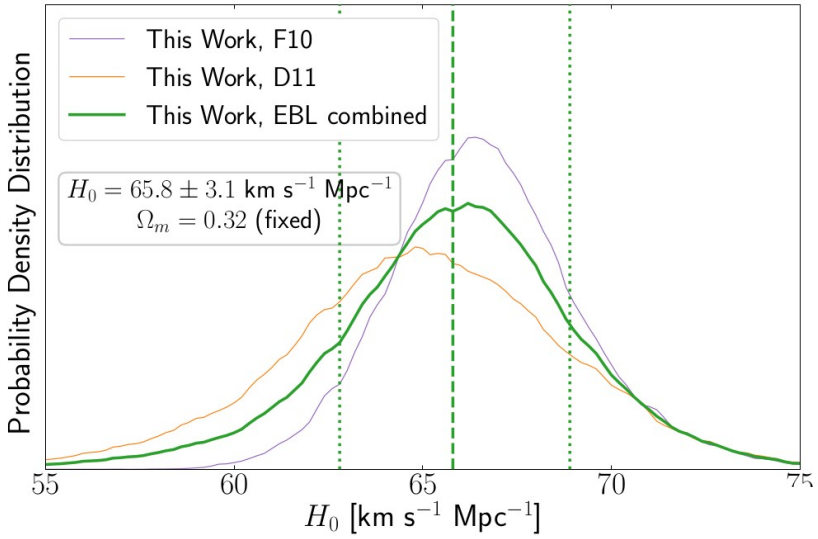
cross section

EBL photon density evolution

The cosmology dependence is on the distance and EBL photon density evolution factors

See Domínguez & Prada 13, Biteau & Williams 15, Gréaux+ 24

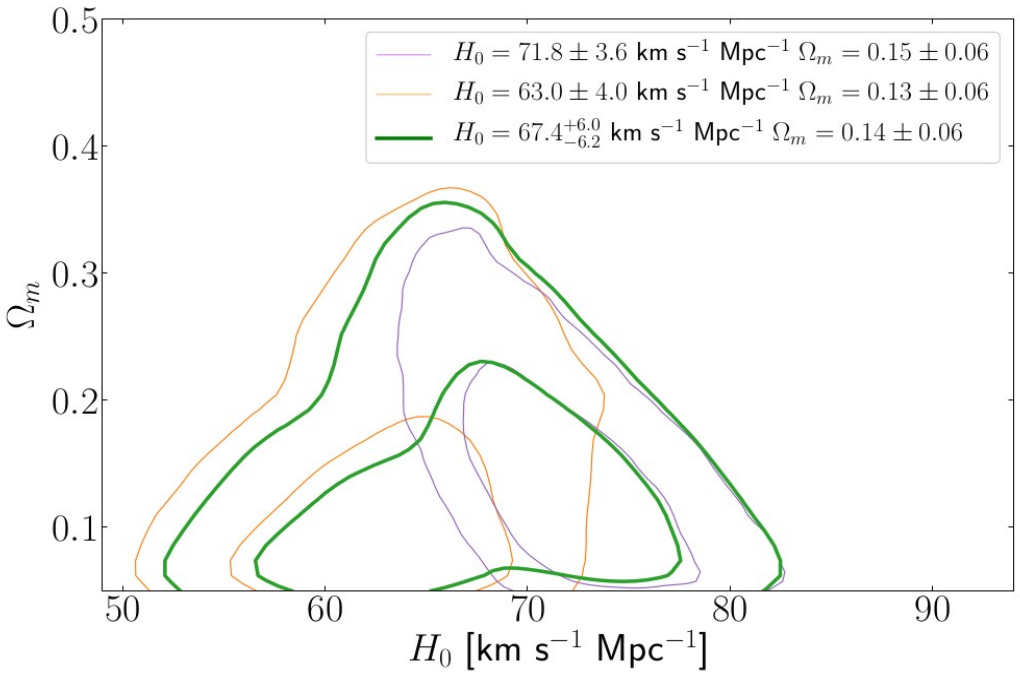
# Measuring $H_0$ with Gamma-ray Attenuation



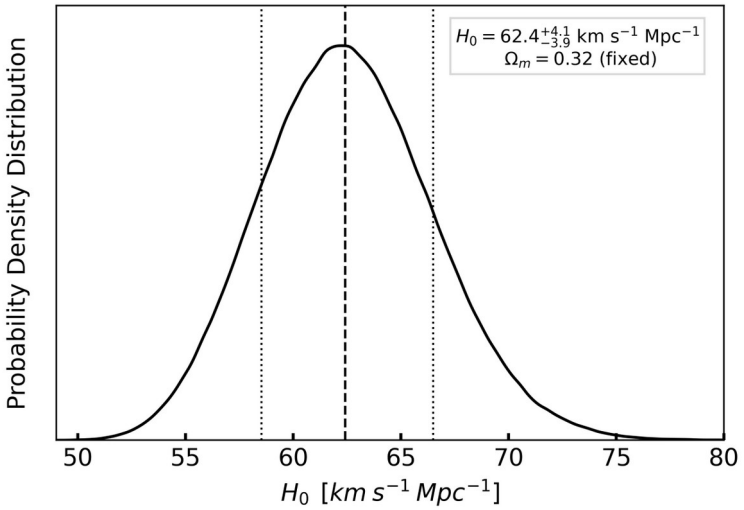

H0 derivation fixing Om

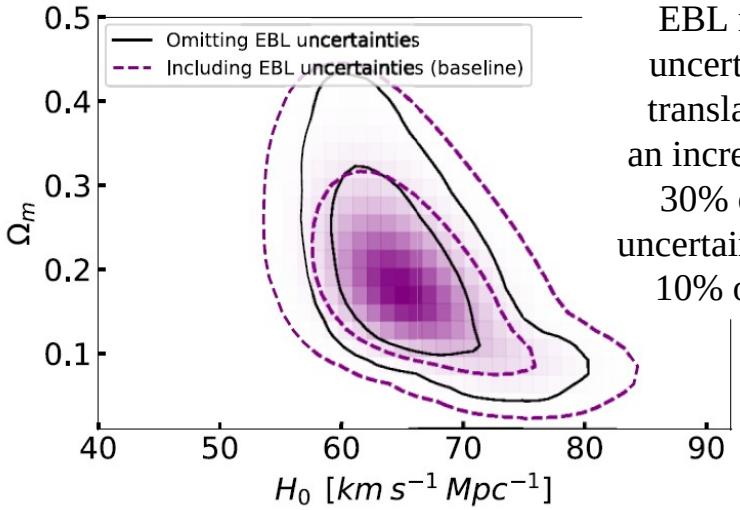
Domínguez+ 19

H0 & Om free



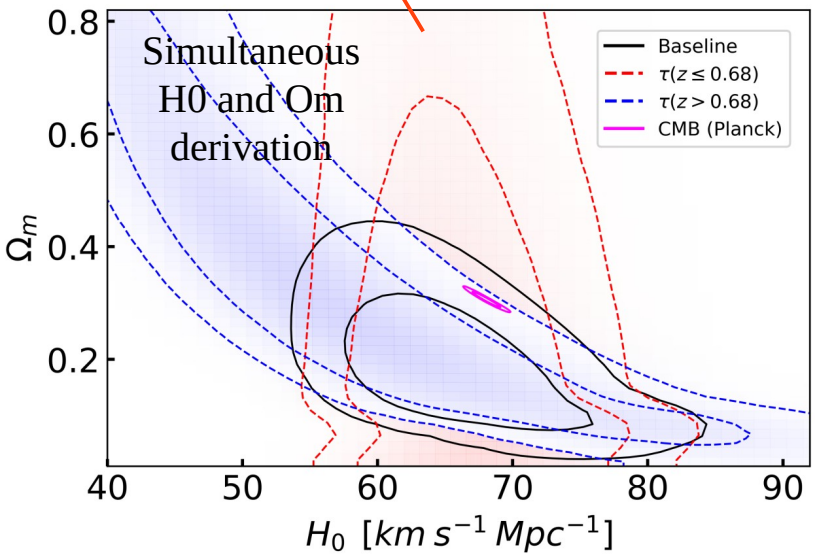
# Results on measuring Cosmology with Gamma rays



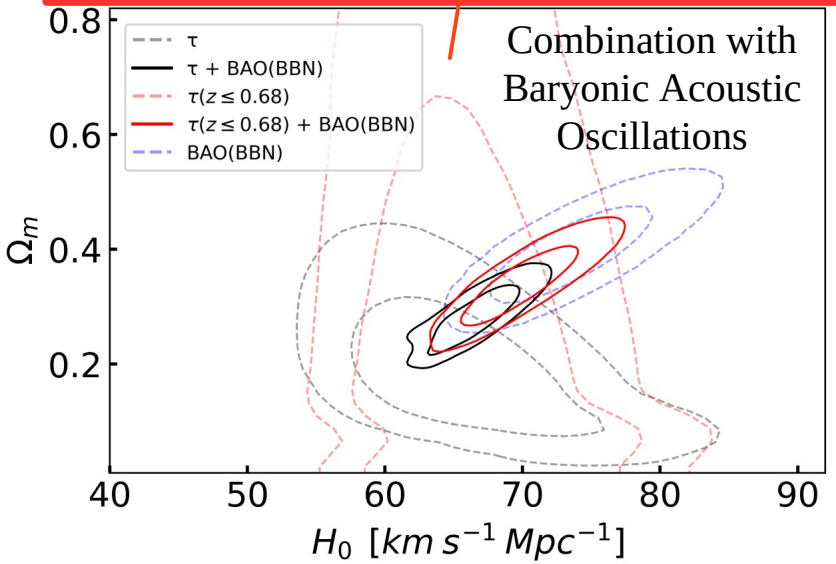




EBL model uncertainties translate into an increment of 30% on H0 uncertainties and 10% on Om

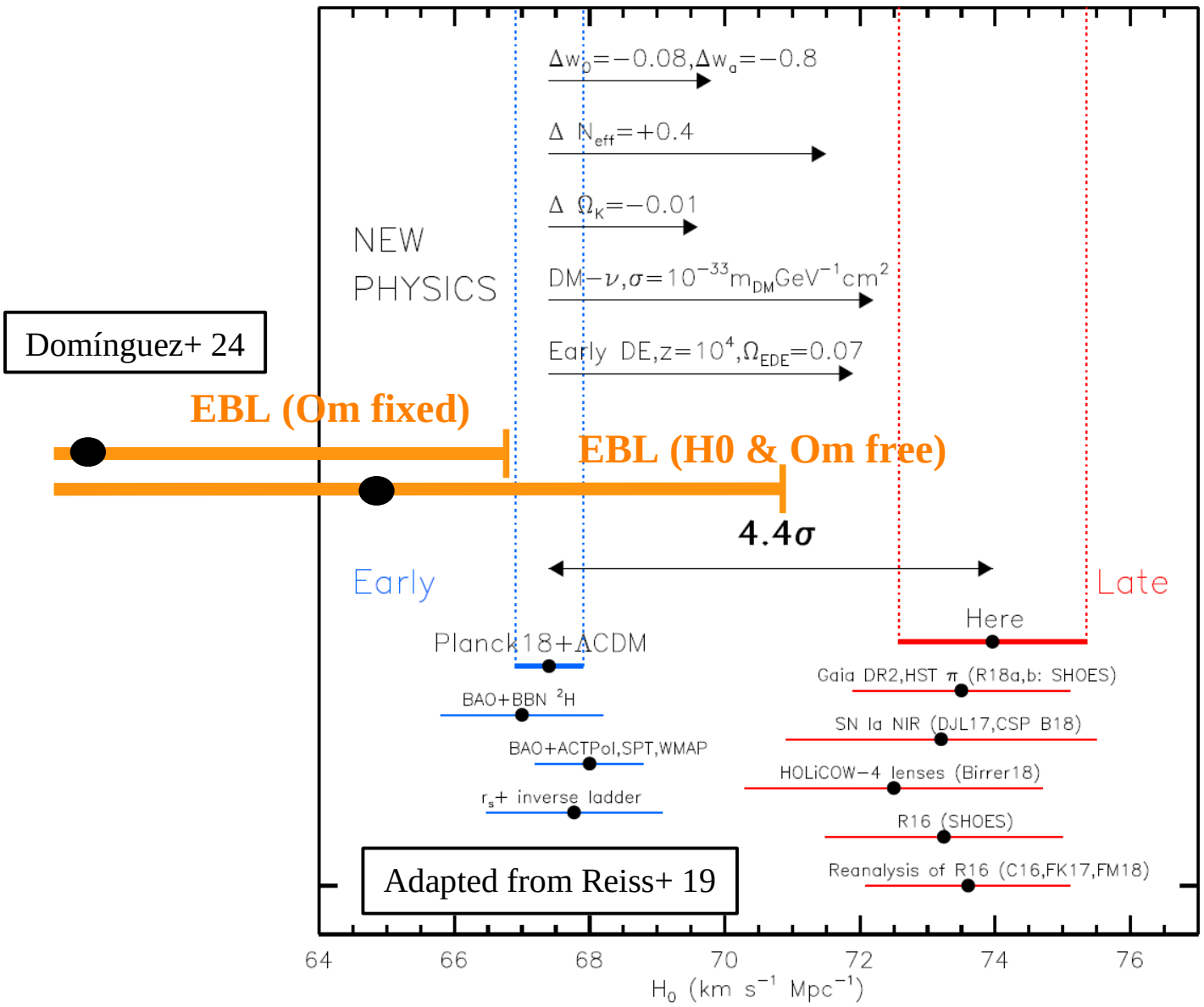
| $H_0$(km s$^{-1}$ Mpc$^{-1}$) | $\Omega_m$ |
|---|---|
| $65.1^{+6.0}_{-4.9}$ | $0.19 \pm 0.08$ or ($< 0.35$ (95 %)) |




| $H_0$(km s$^{-1}$ Mpc$^{-1}$) | $\Omega_m$ |
|---|---|
| $66.5^{+2.2}_{-2.1}$ | $0.28 \pm 0.04$ |



# Comparison on $H_0$ Measurements



# Take Home Messages

1) After decades of research, different methodologies such us galaxy counts, EBL models, gamma-ray attenuation data and direct detection techniques are finally converging, at least in the optical, in the estimate of how much light there is in the Universe.

2) H0 from gamma-ray attenuation seems to be aligned (although still at low significance) with the methodologies that results in lower values, aka cosmological methodologies.

3) Really compelling synergies between high-energy astrophysics and traditional astronomy.

# Backup

# Cosmology Dependence on the Optical Depth