Modeling Extragalactic Background Light – FIR to Gamma-rays

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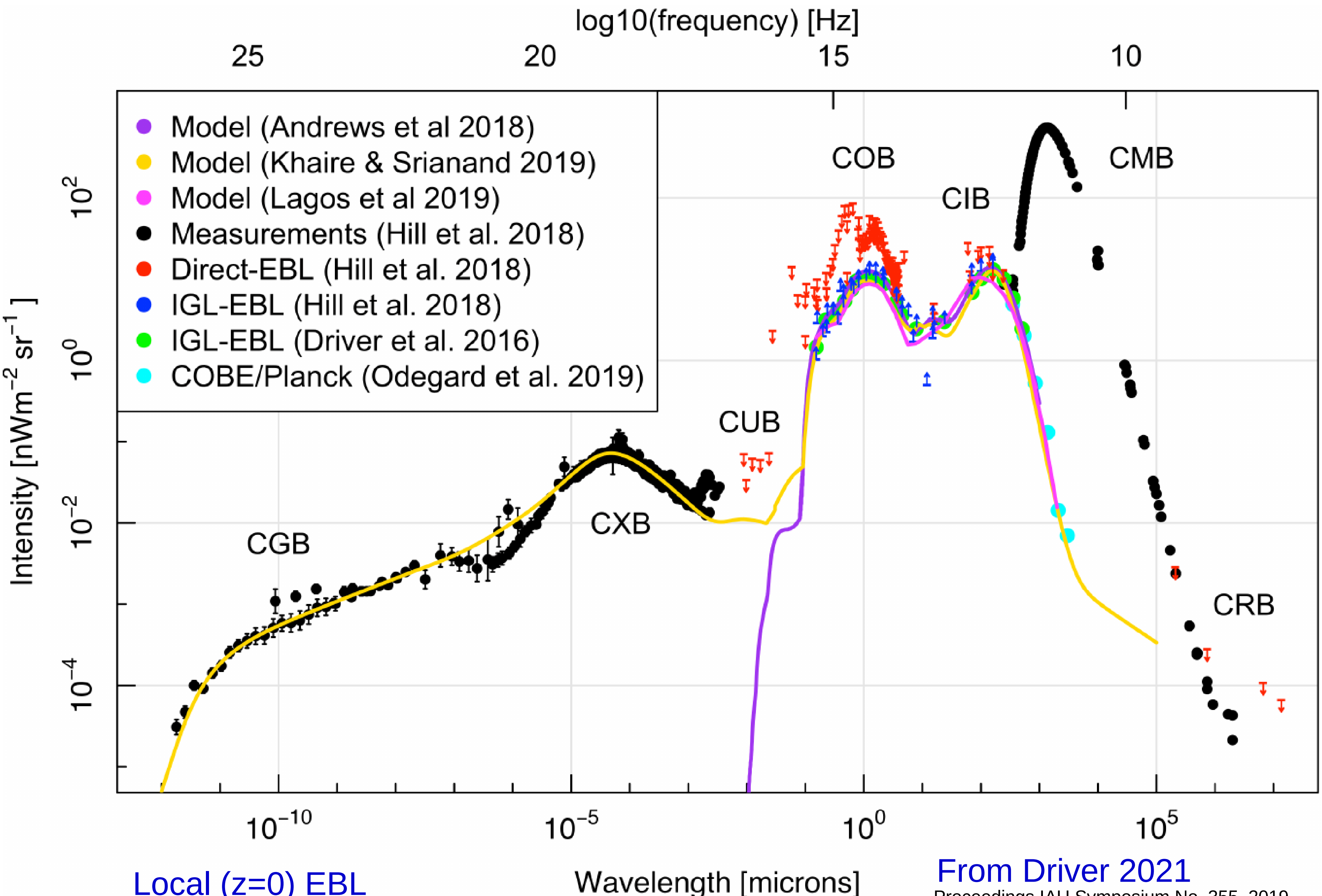
Need for modeling? - only local measurements!



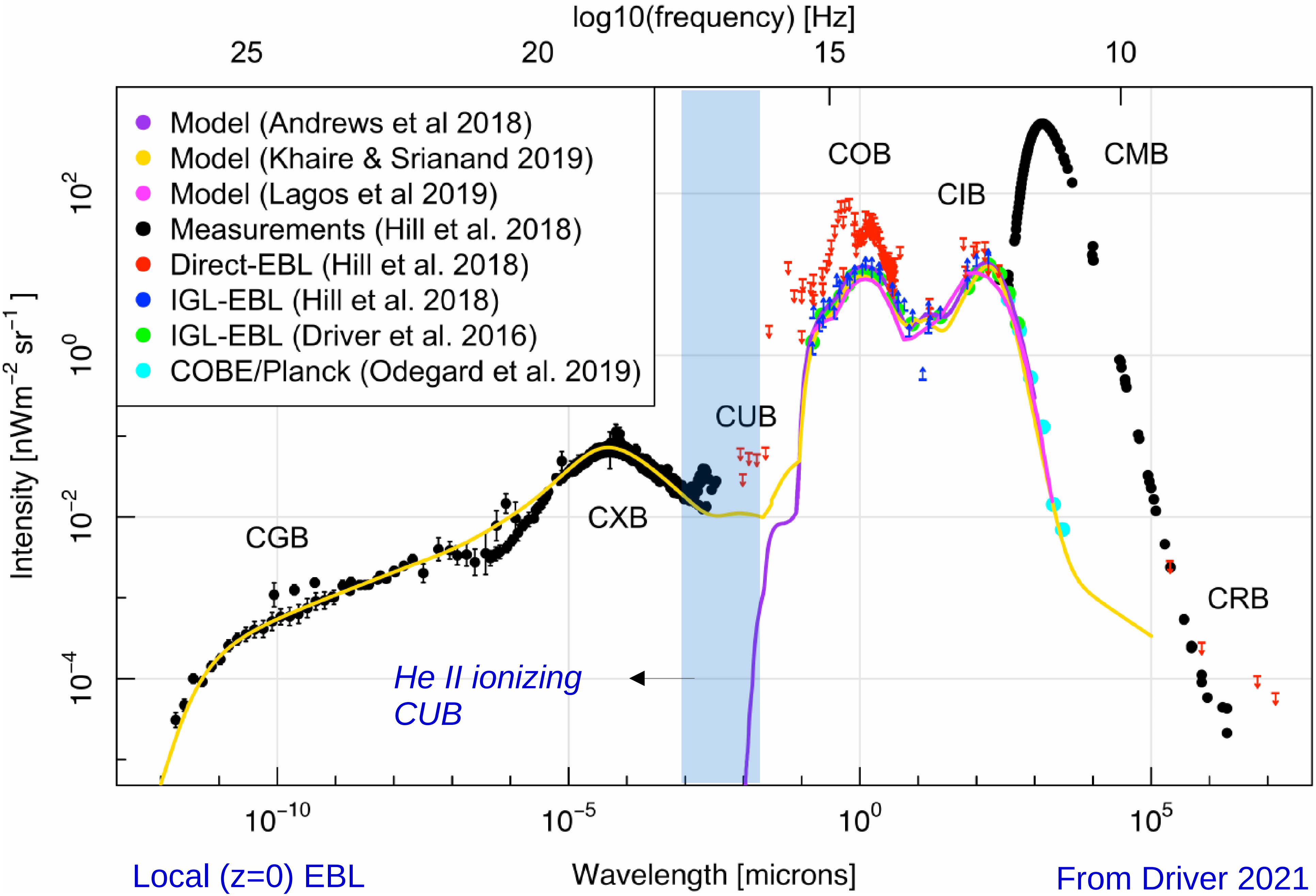
Local (z=0) EBL

From Driver 2021

Proceedings IAU Symposium No. 355, 2019

arXiv 2102.12089

Need for modeling? - only local measurements!



Local (z=0) EBL

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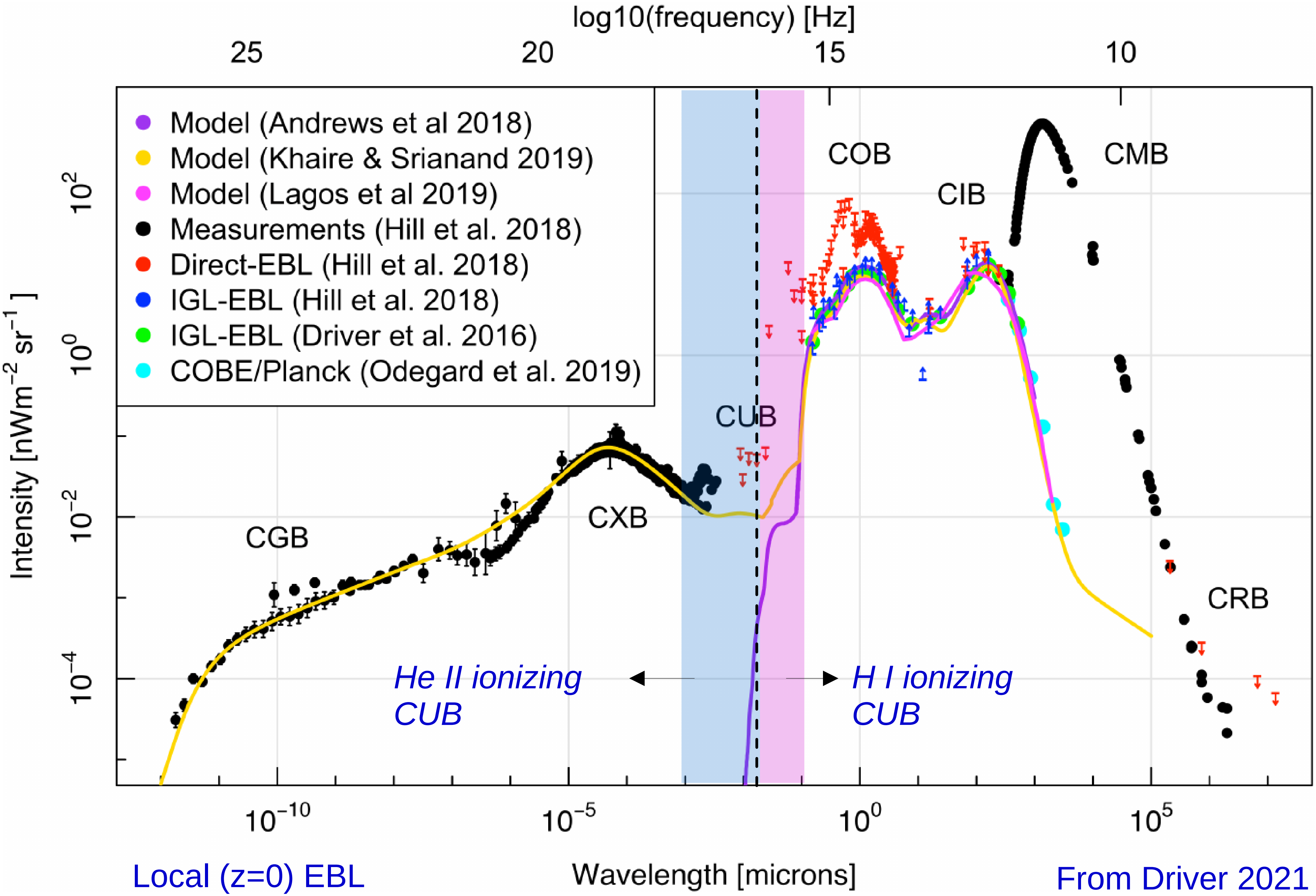
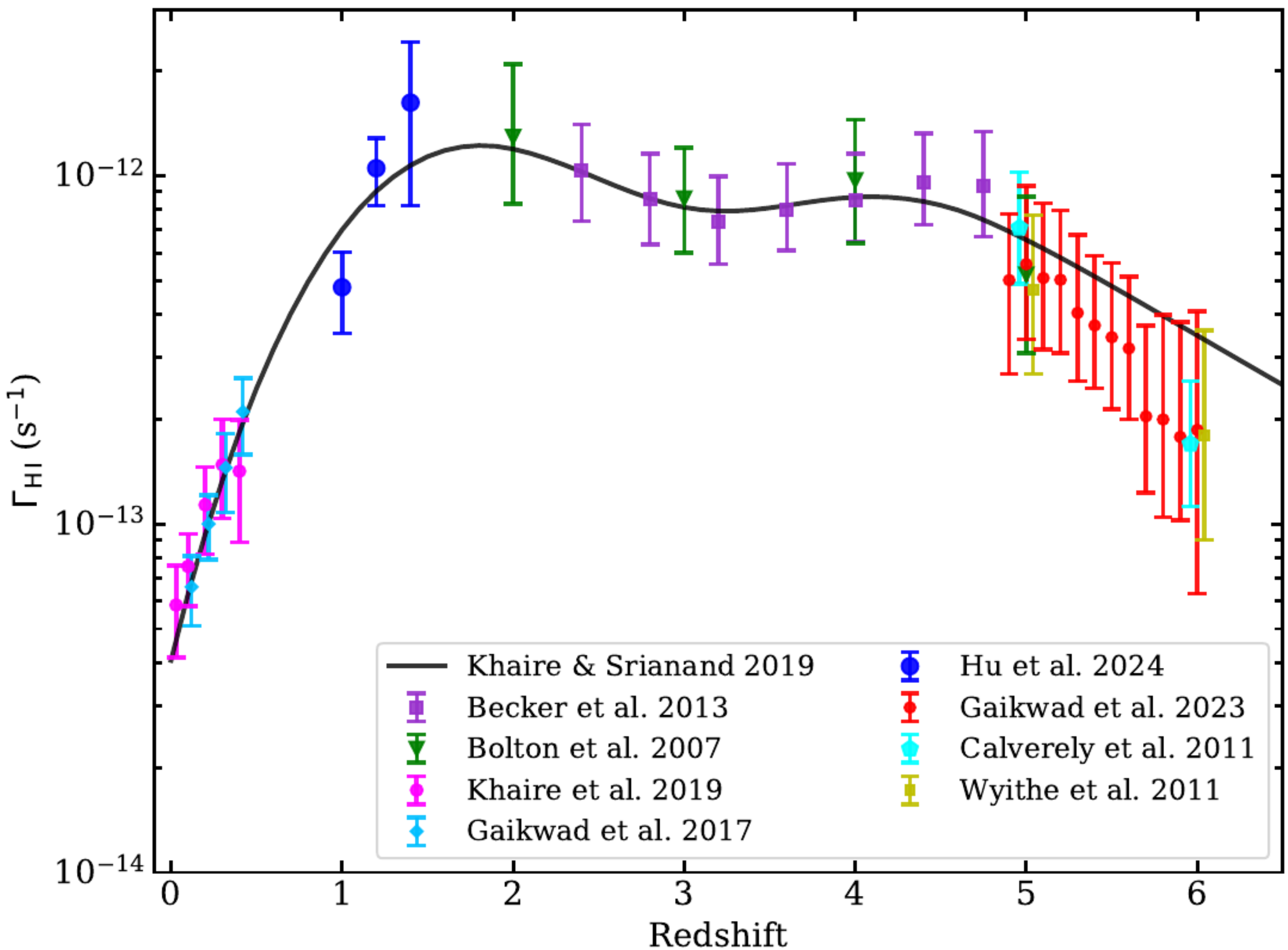


Local (z=0) EBL

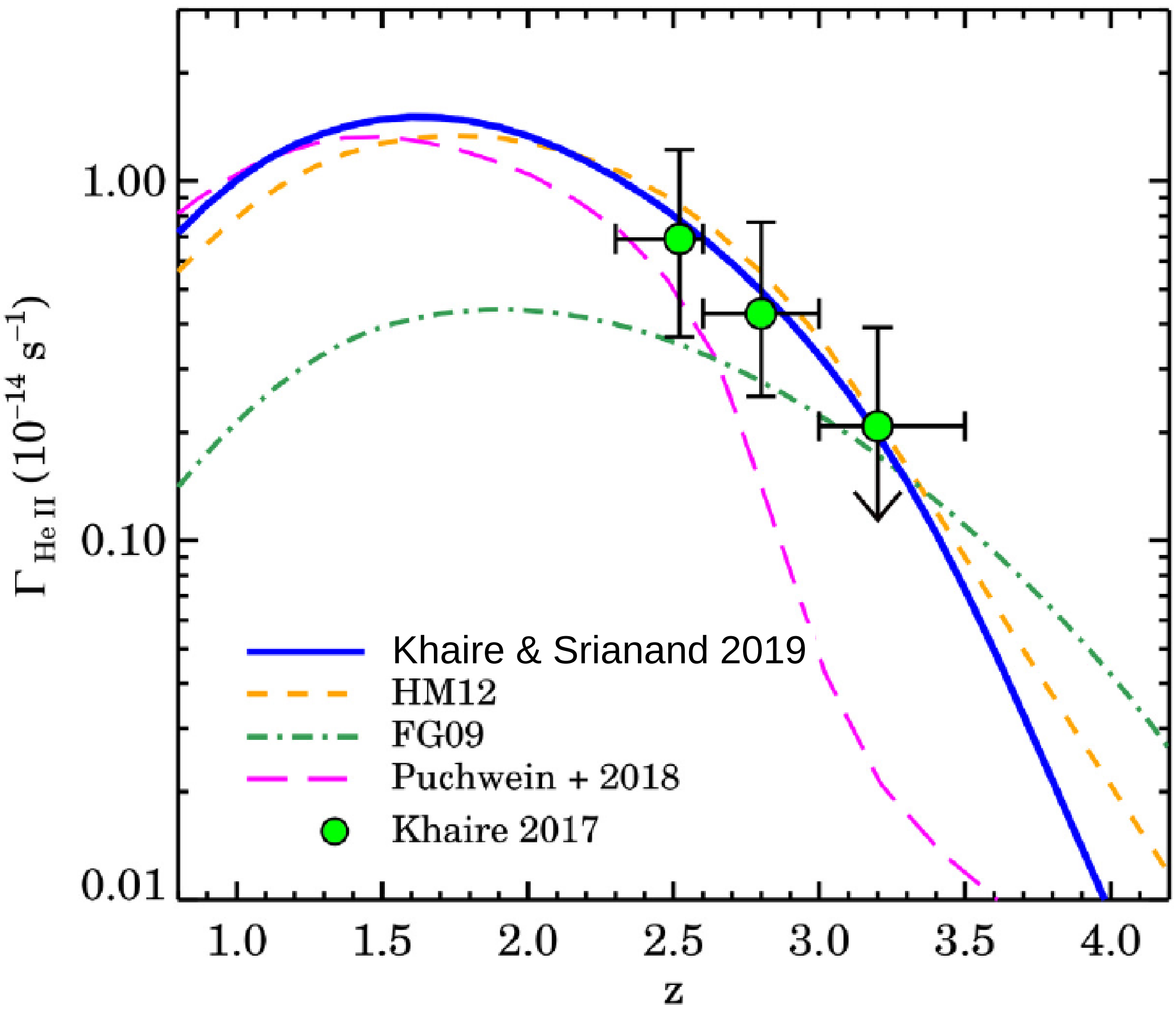
From Driver 2021

High redshift observations – extreme UV

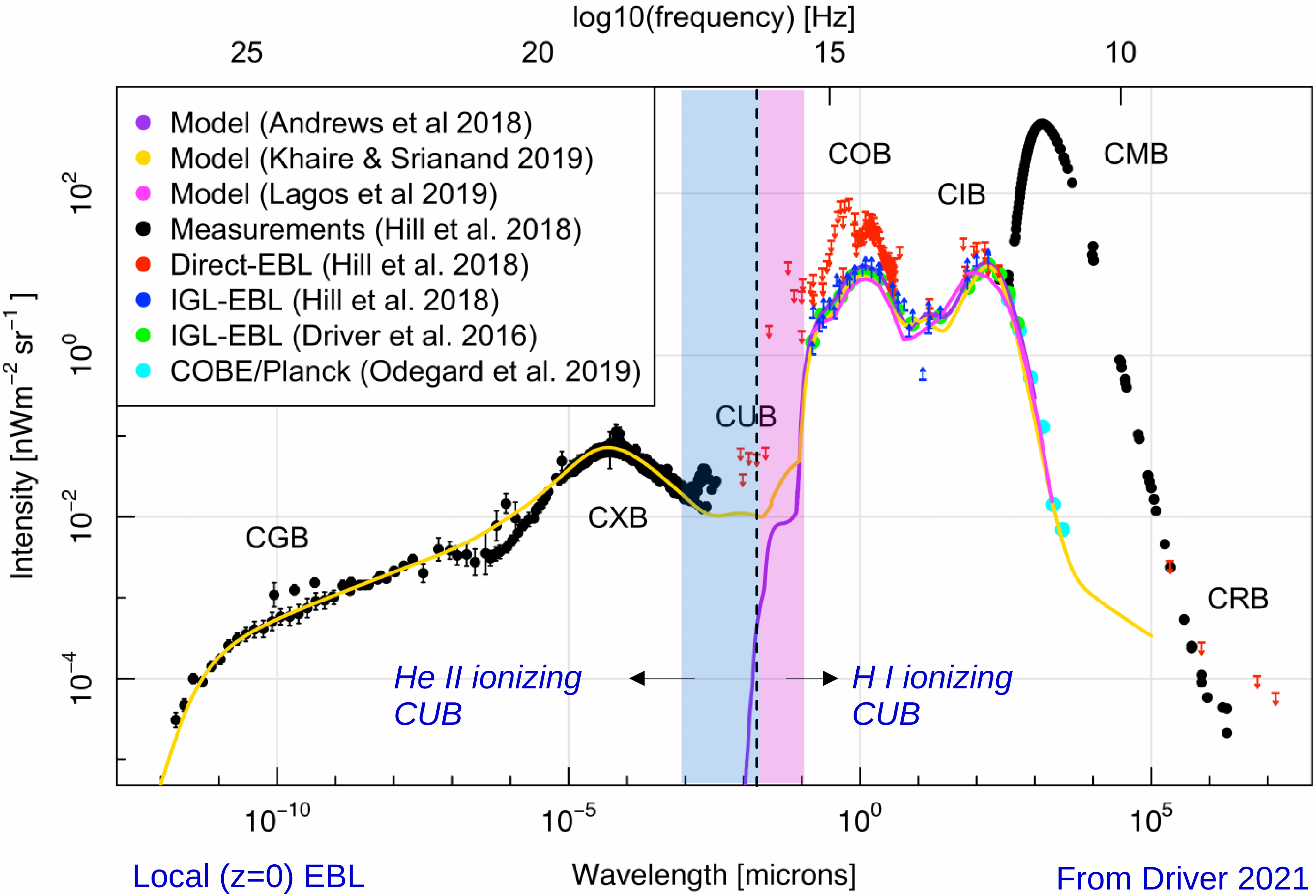


Photoionization rates $\Gamma_x(z_0) = \int_{\nu_x}^{\infty} d\nu \, \frac{4\pi \, J_\nu(z_0)}{h\nu} \sigma_x(\nu)$

High redshift observations – extreme UV



Need for modeling -- to get time evolution of EBL



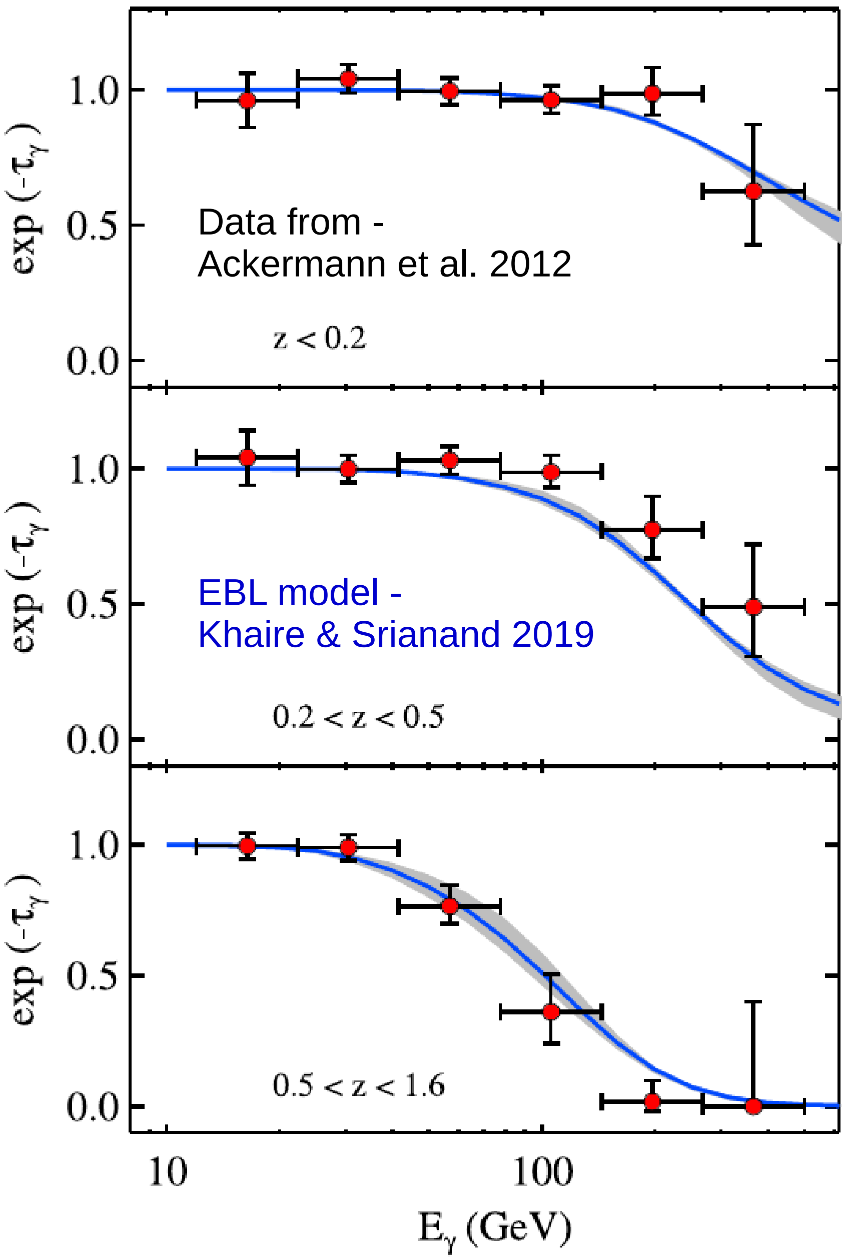
Local (z=0) EBL

From Driver 2021

Why modeling EBL is it important?

In optical and IR

To understand high energy gamma-ray opacity



Why modeling EBL is it important?

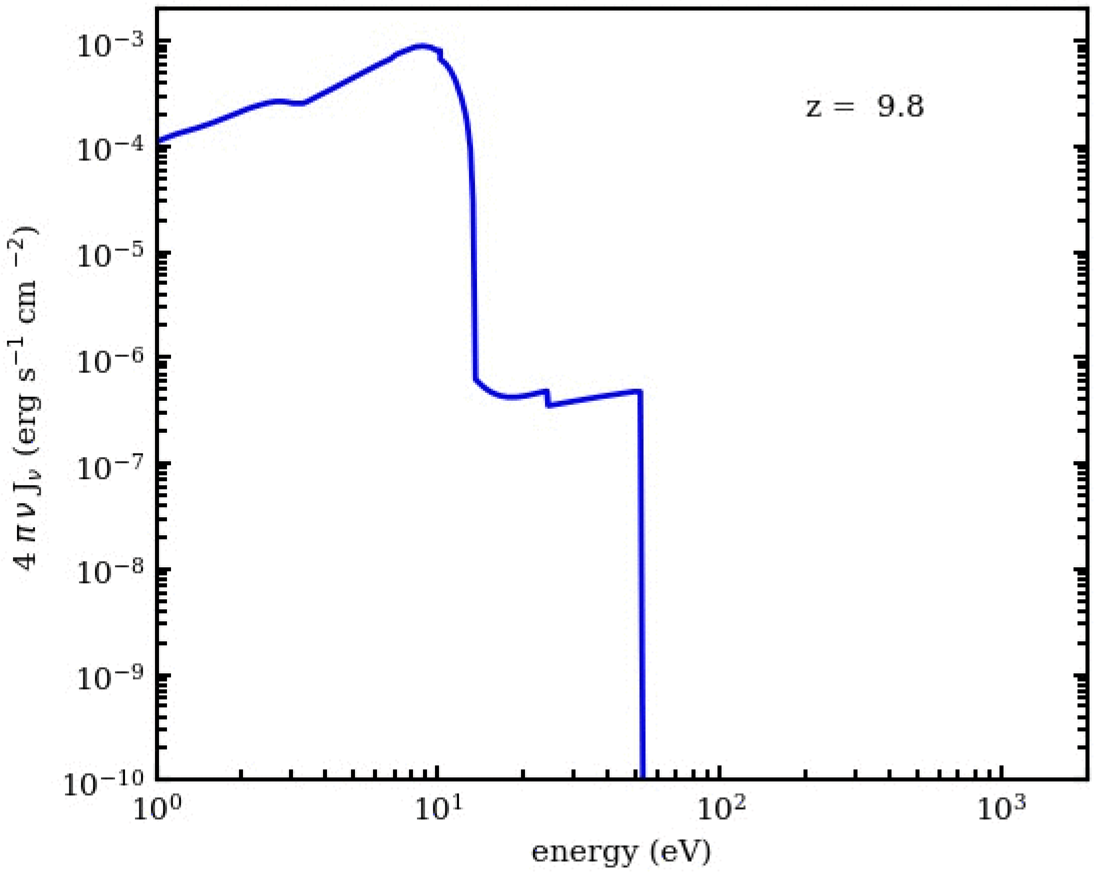
In extreme UV (~200 eV< E < 13.6 eV)

”The cosmic UV background”

Most studies of the intergalactic and circumgalactic medium!

- Hydrogen Reionization
- Helium Reionization
- Temperature of the Intergalactic Medium
- Ionization corrections for metal absorption lines tracing the intergalactic and circumgalactic medium

In last 5 years – three CUB models
1) Khaire & Srianand 2019
2) Puchwein et al. 2020
3) Faucher-Giguere 2020
→ total citations ~500



EBL models

1)

Reconstructing EBL using multiwavelength luminosity functions

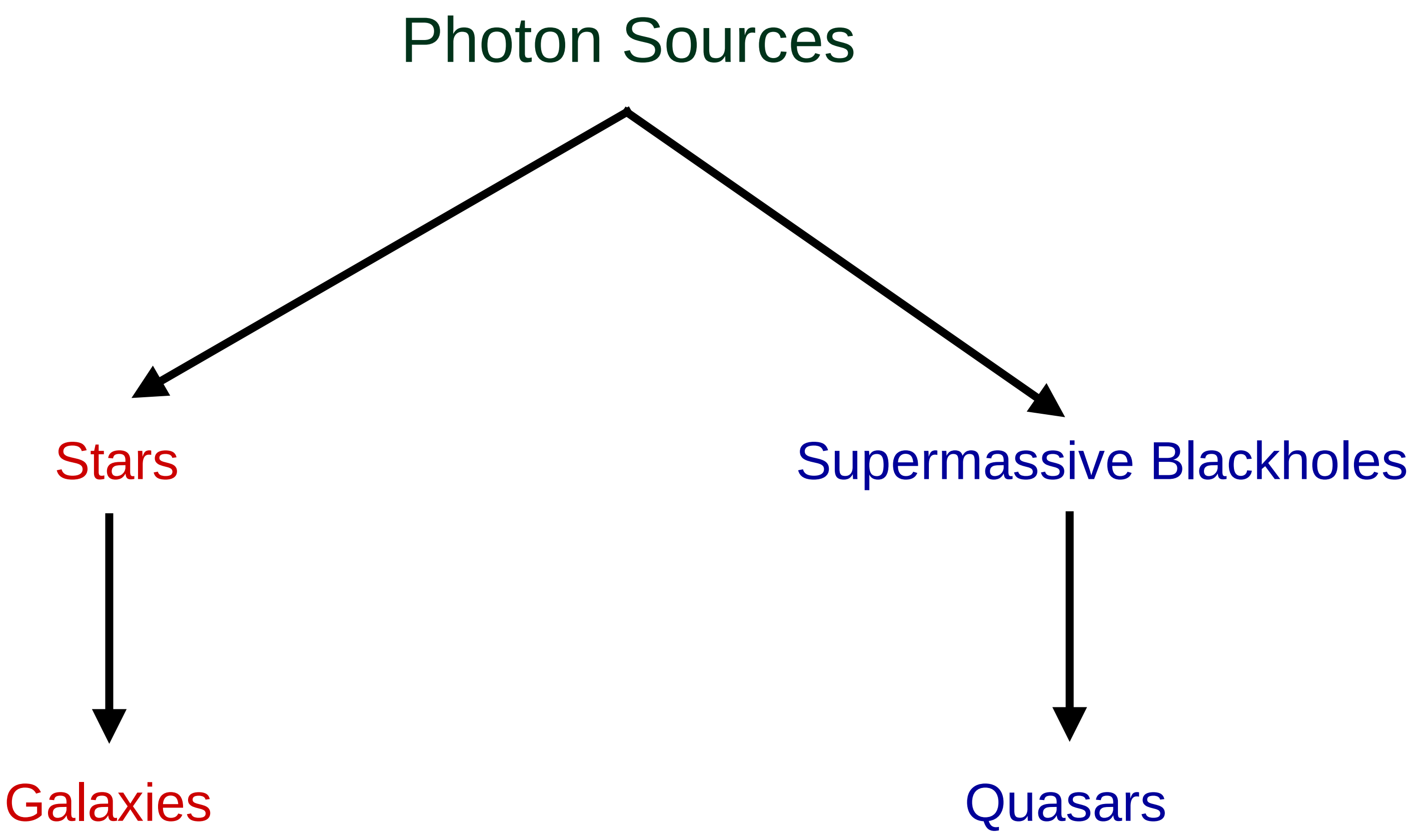
- Franceschini et al. 2008, Helgason et al 2012, Stecker et al. 2012, Scully et al. 2014 etc.

2)

Synthesis models - using star formation history along with population synthesis models + dust emission models

– Finke et al 2012, 2022, Gilmore et al 2012, Khaire & Srianand 2015, Inoue et al 2013, Andrews et al 2018 etc.

Synthesis – from FIR to Gamma-rays



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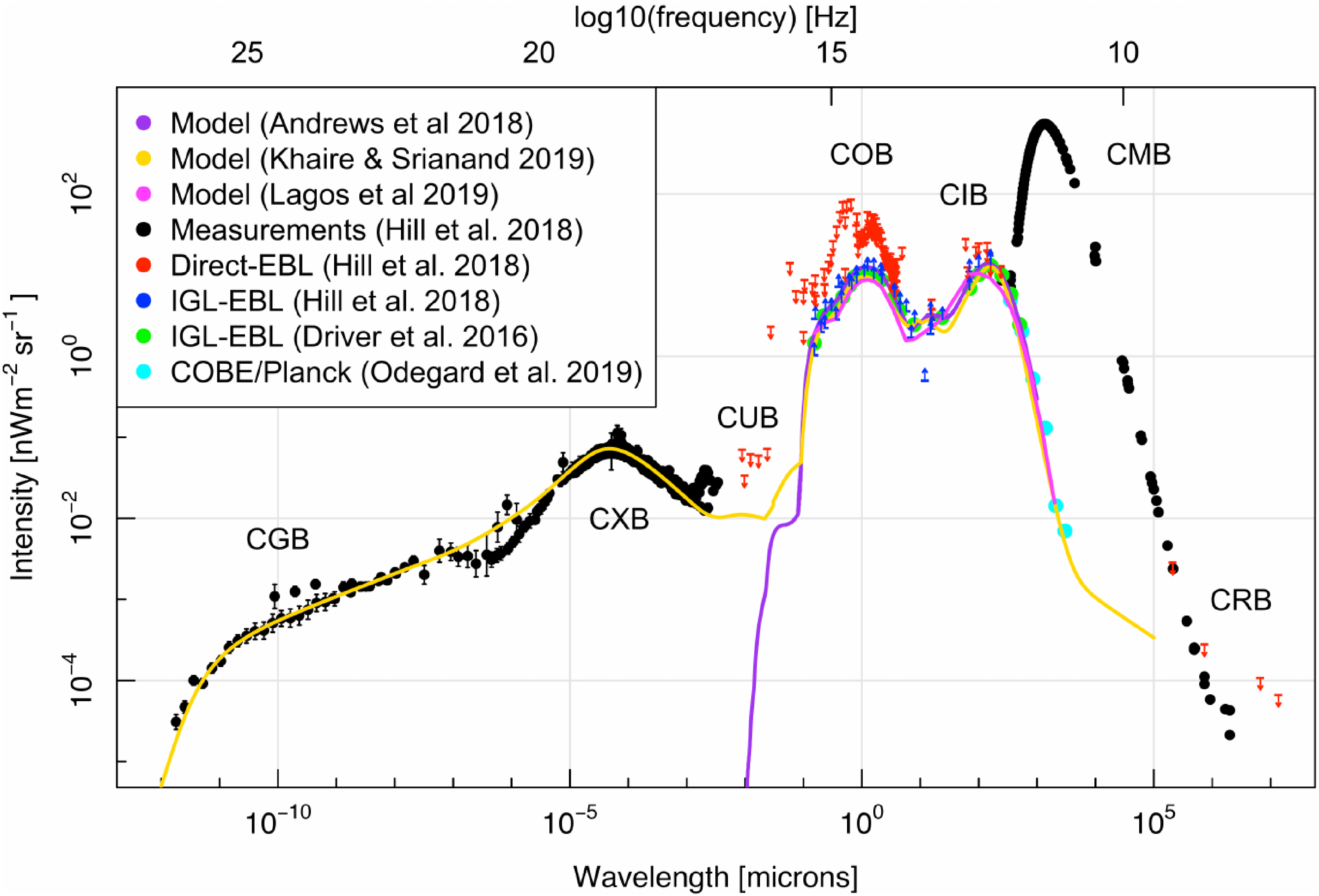

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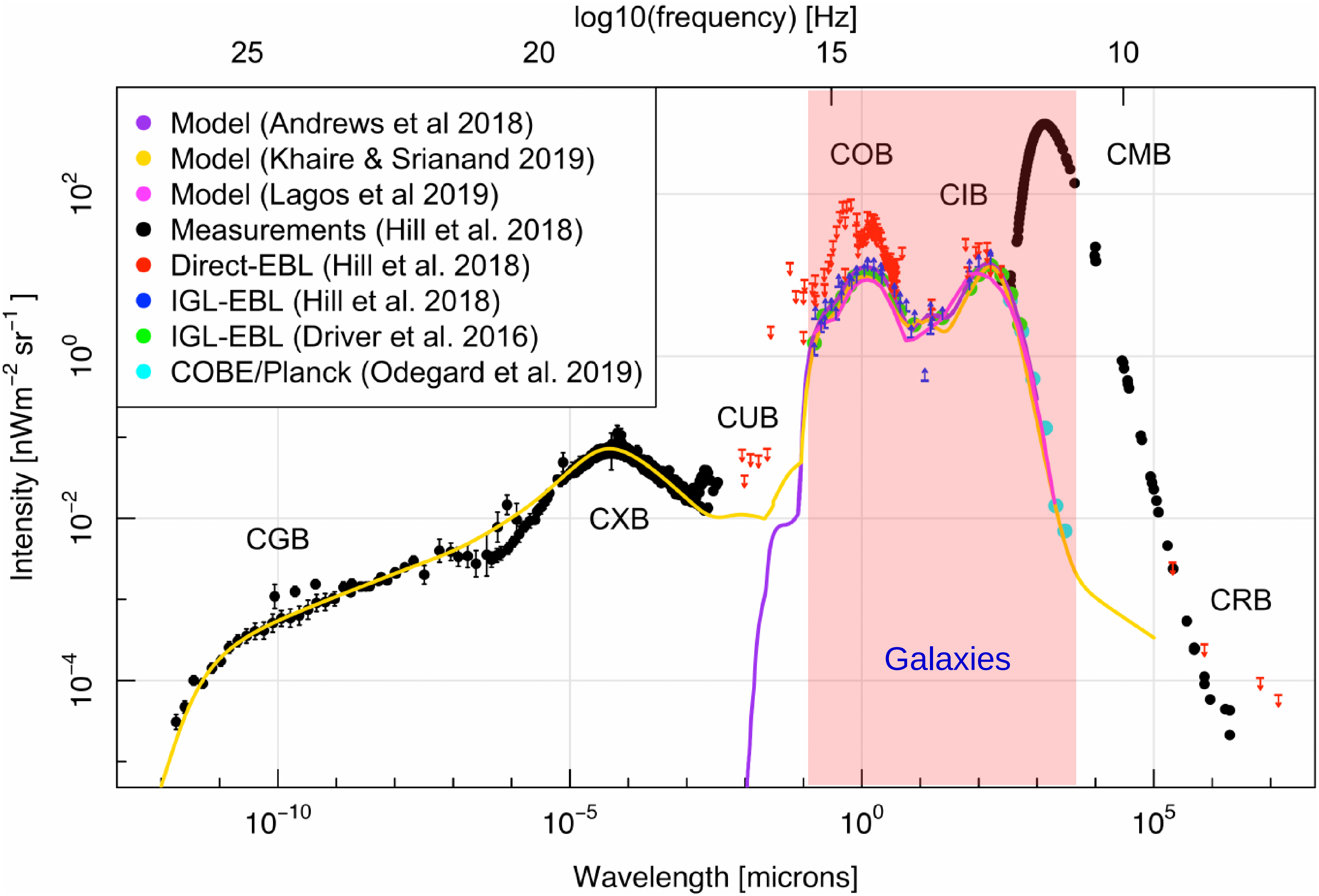

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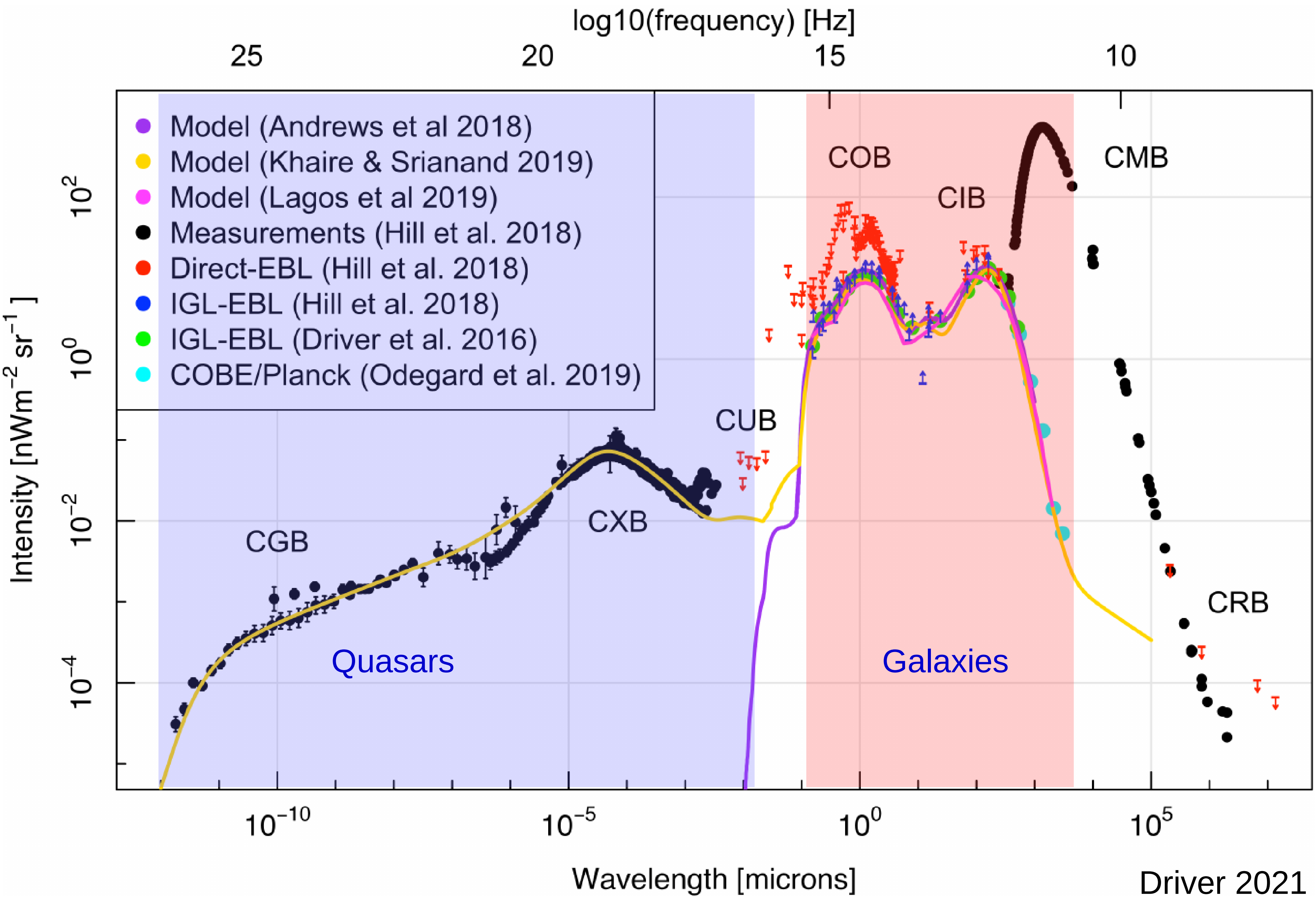
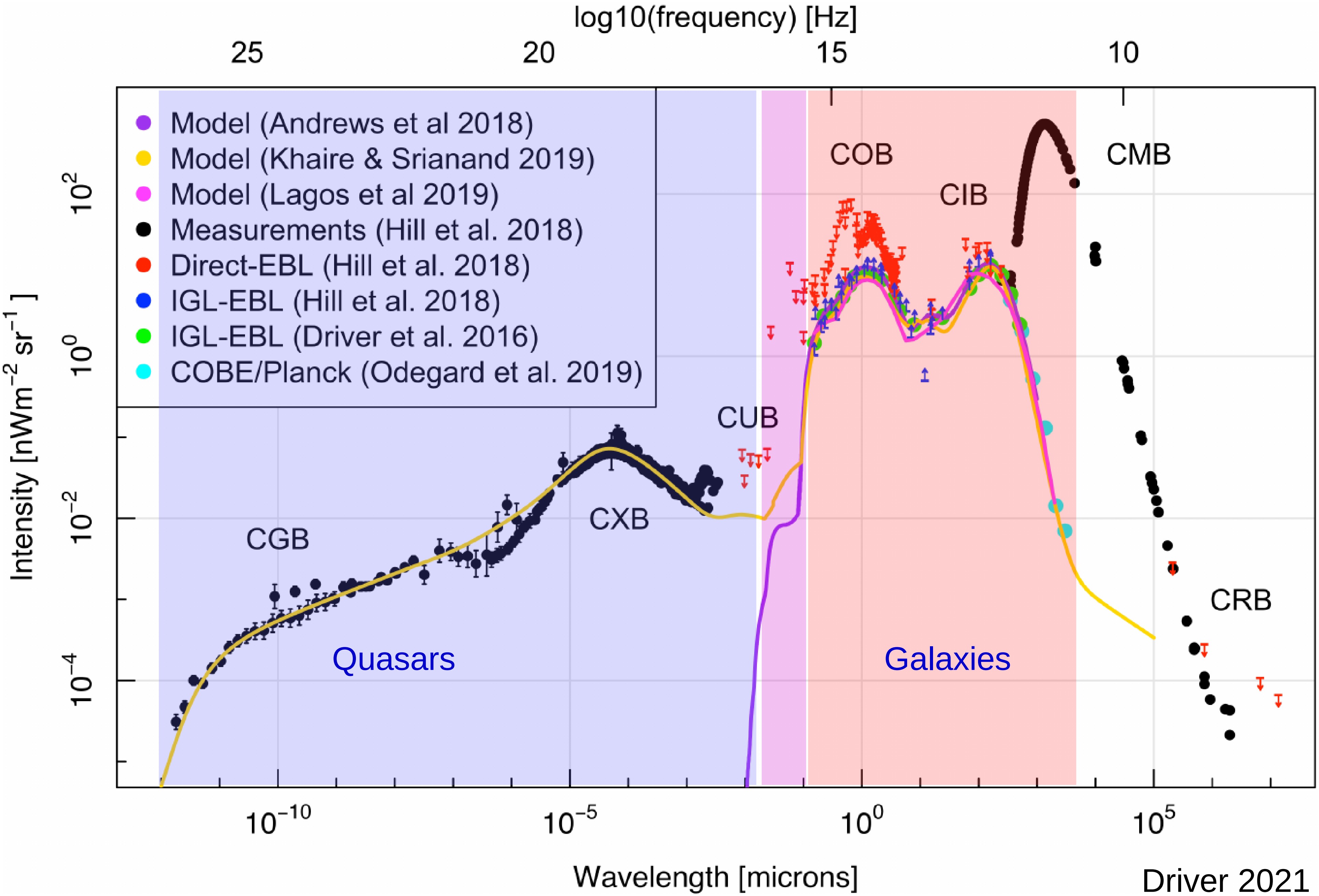


Driver 2021

Synthesis – from FIR to Gamma-rays



Driver 2021

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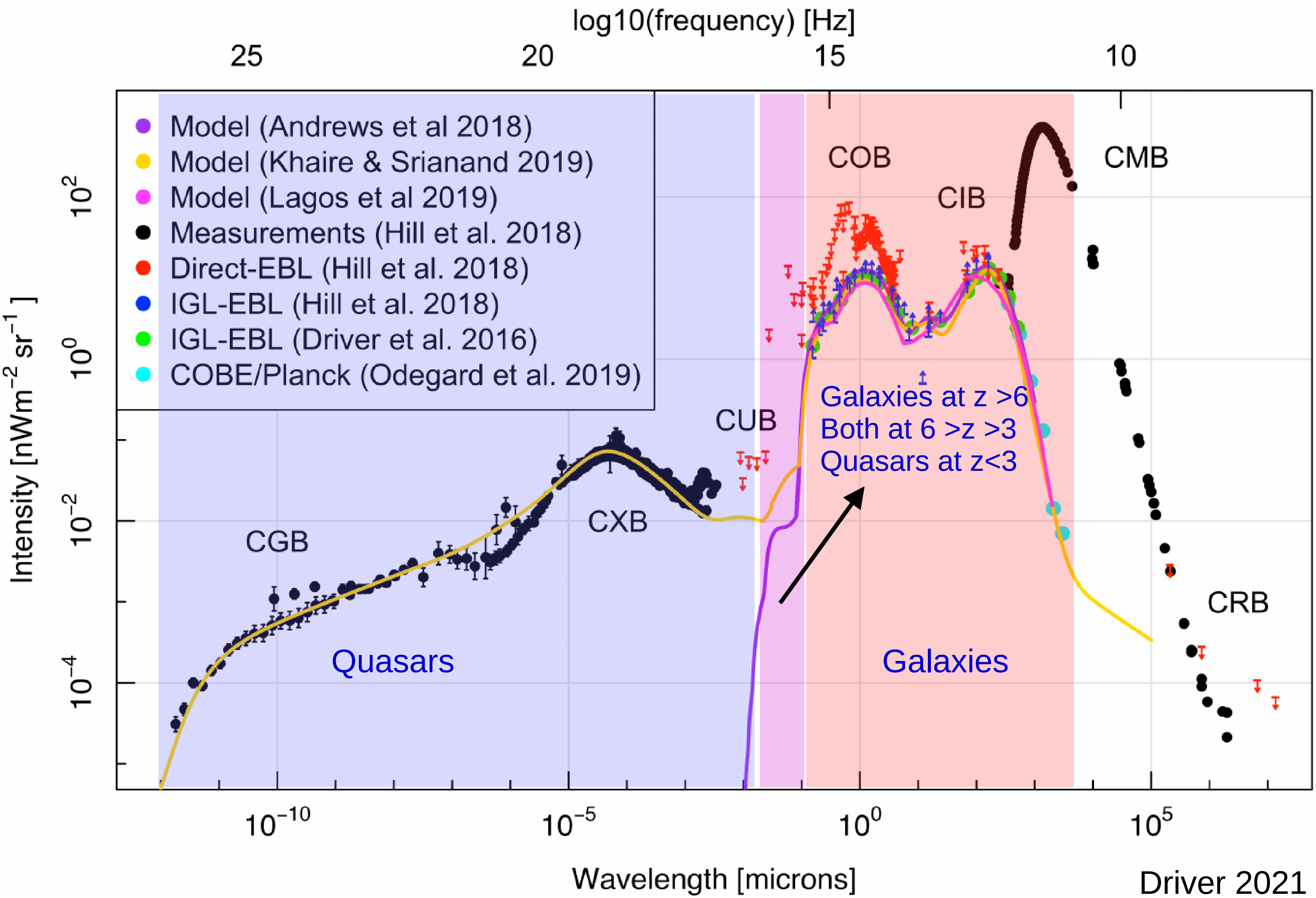
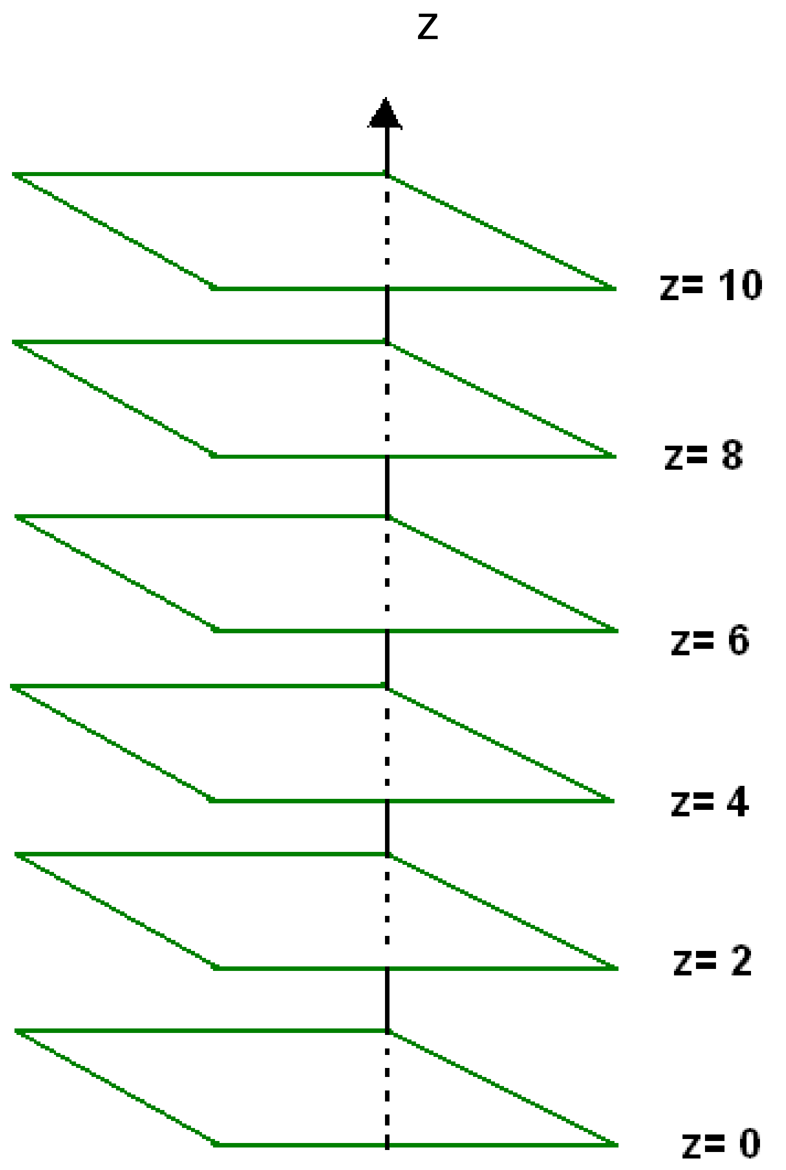


Driver 2021

The EBL



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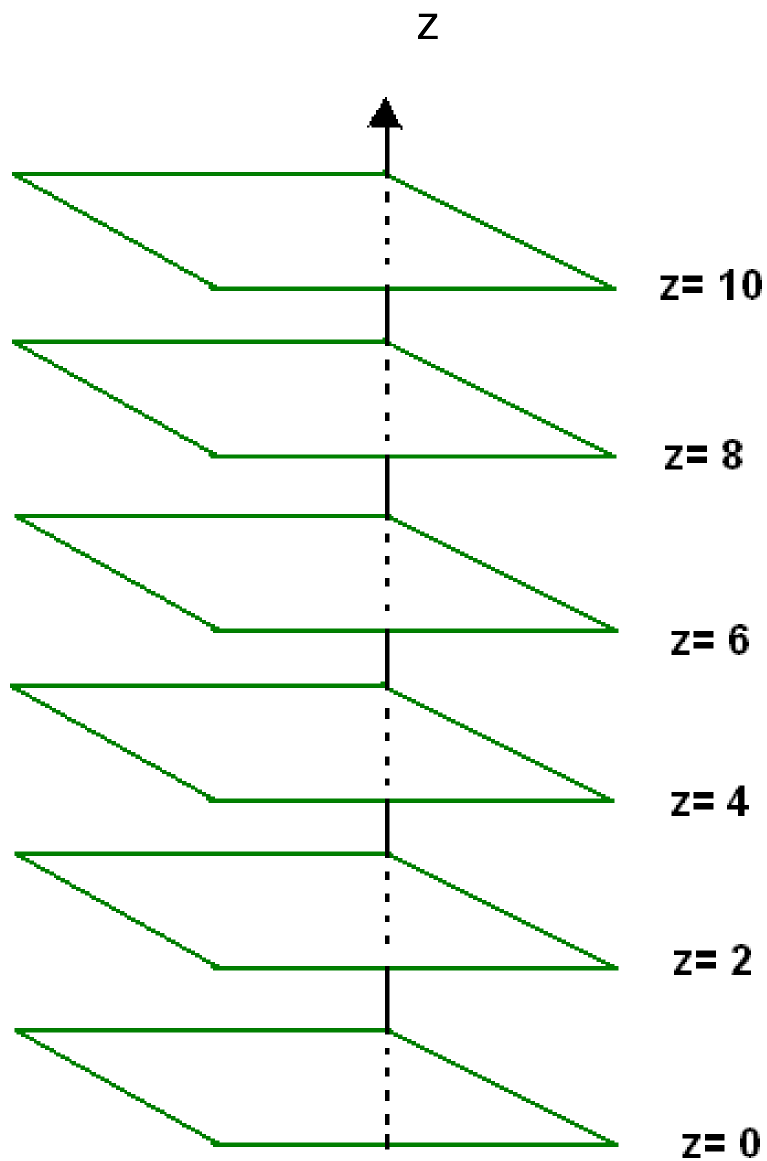
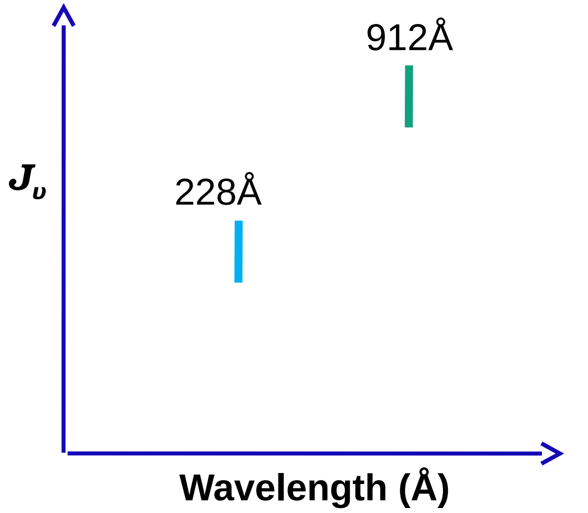
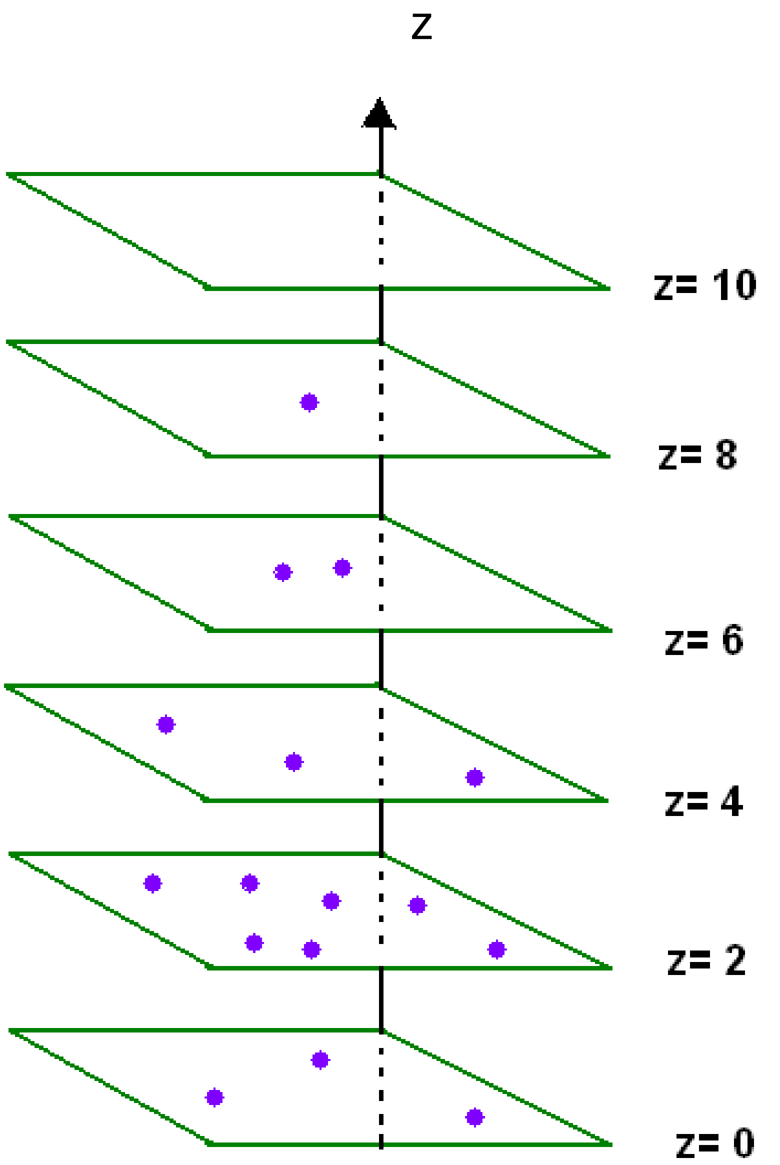
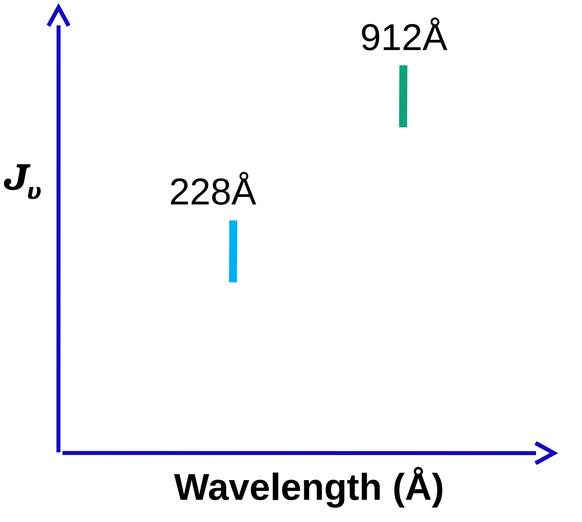




The EBL

Quasars





The EBL

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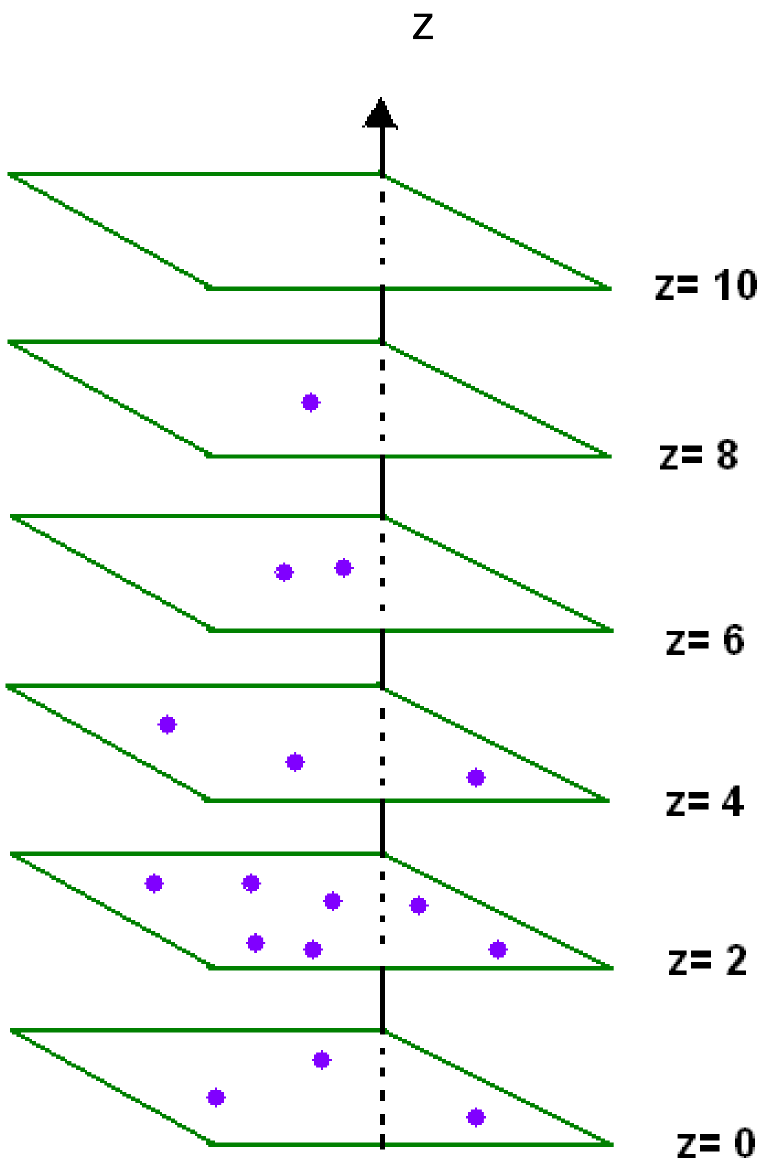
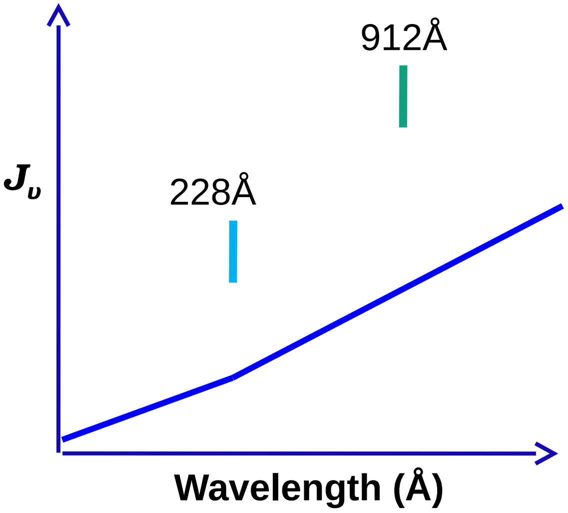
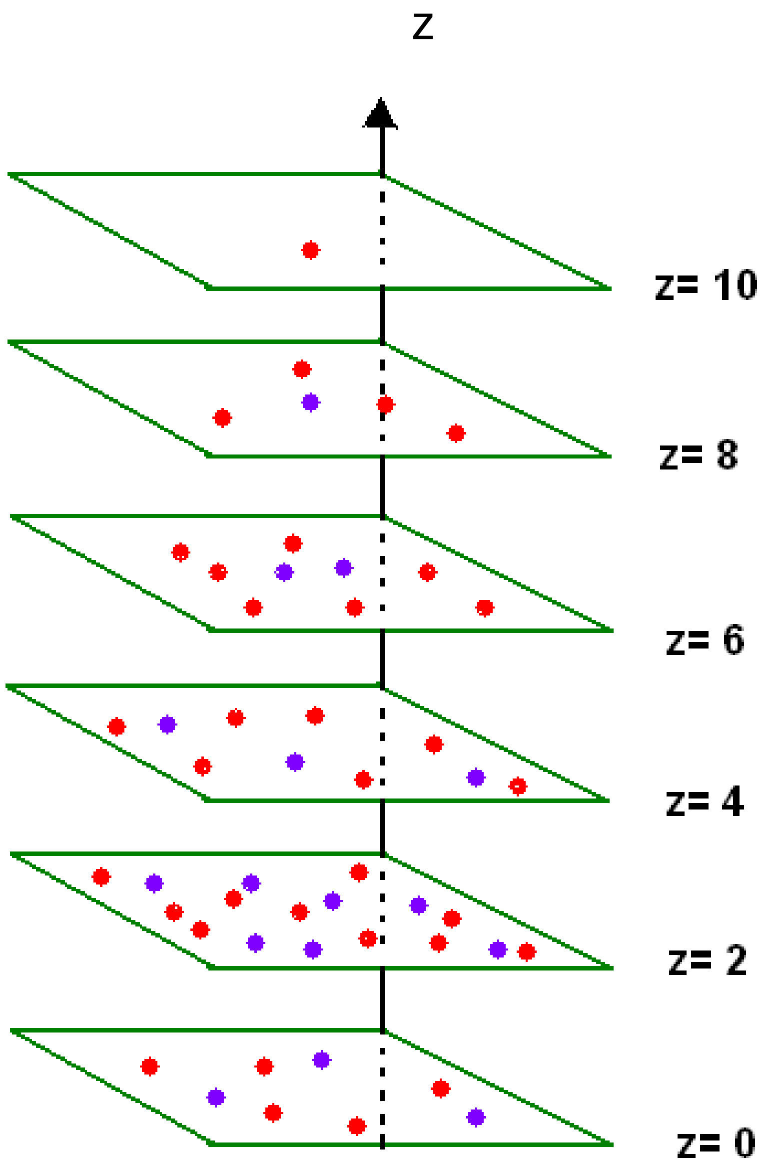


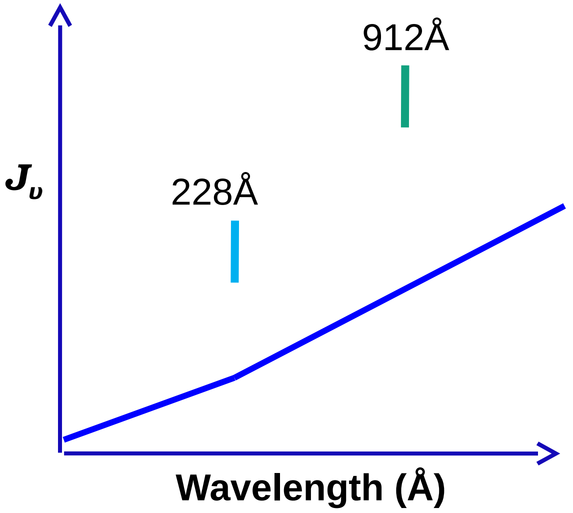


The EBL

Quasars

\+
Galaxies





The EBL

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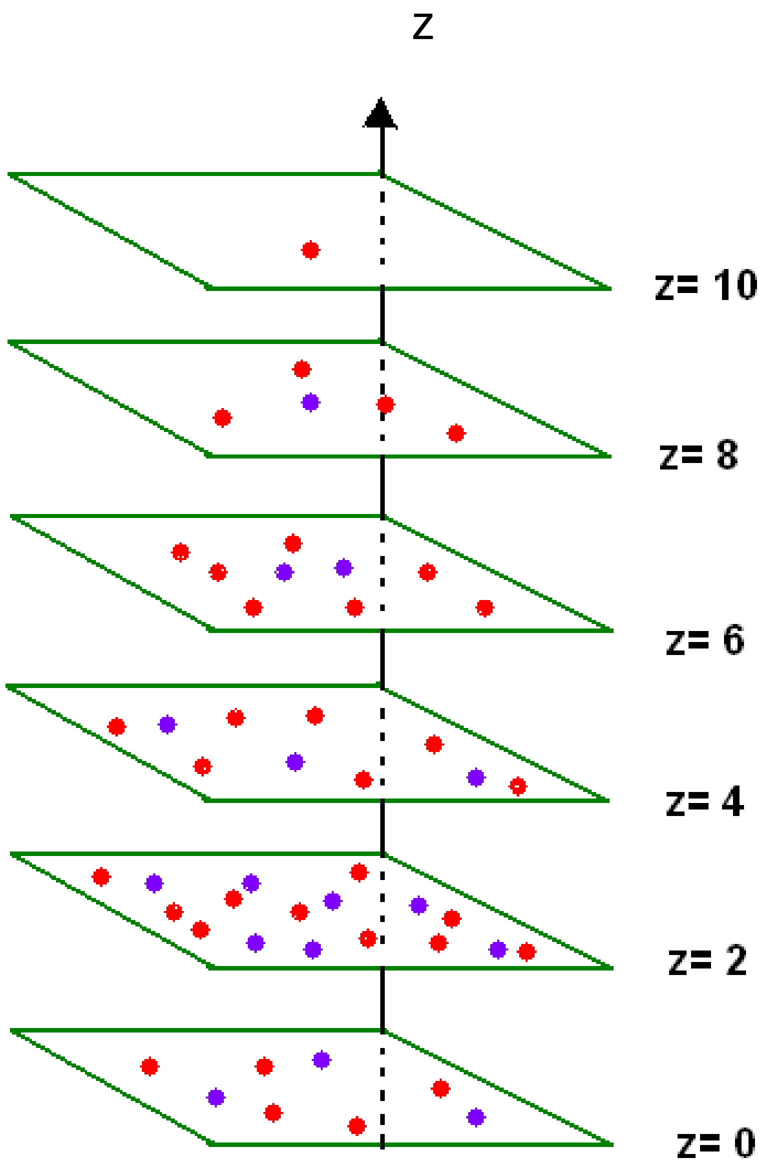

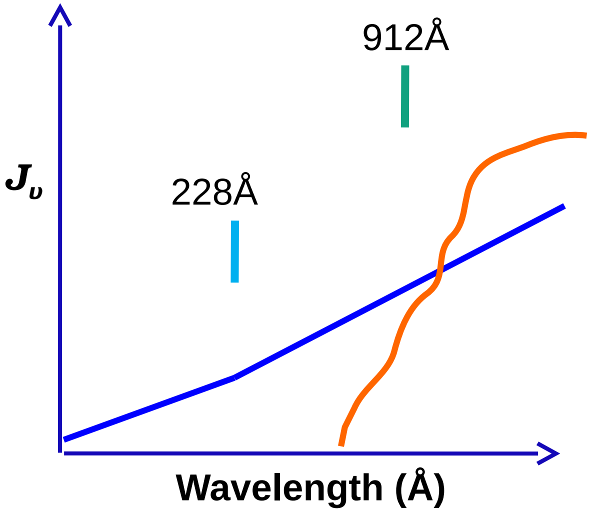

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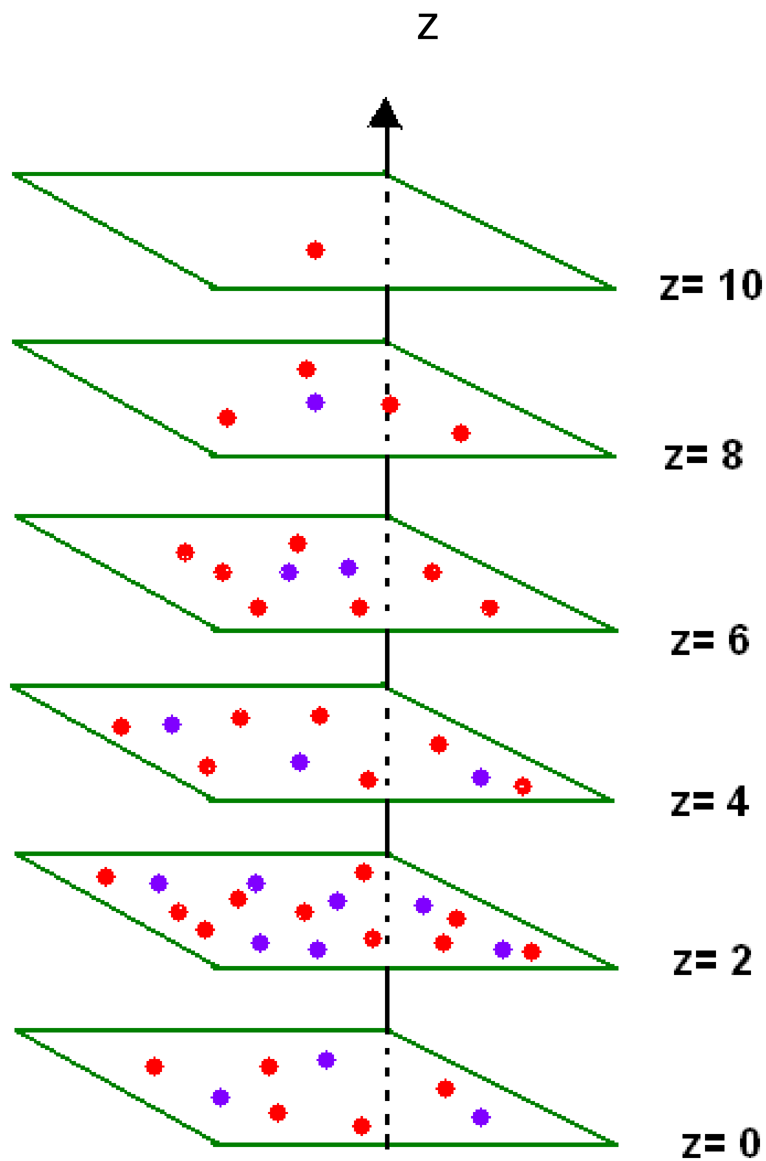
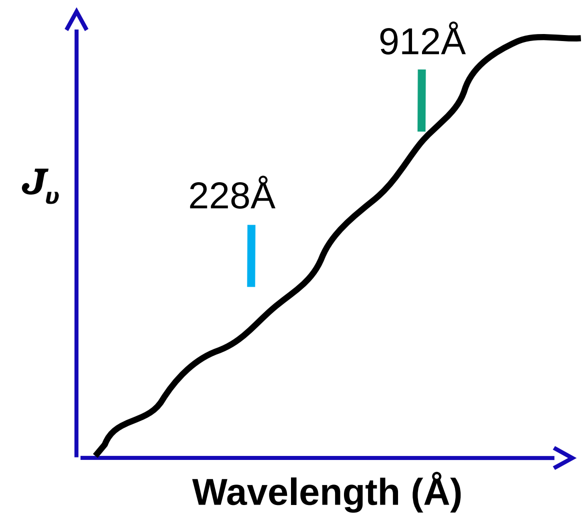


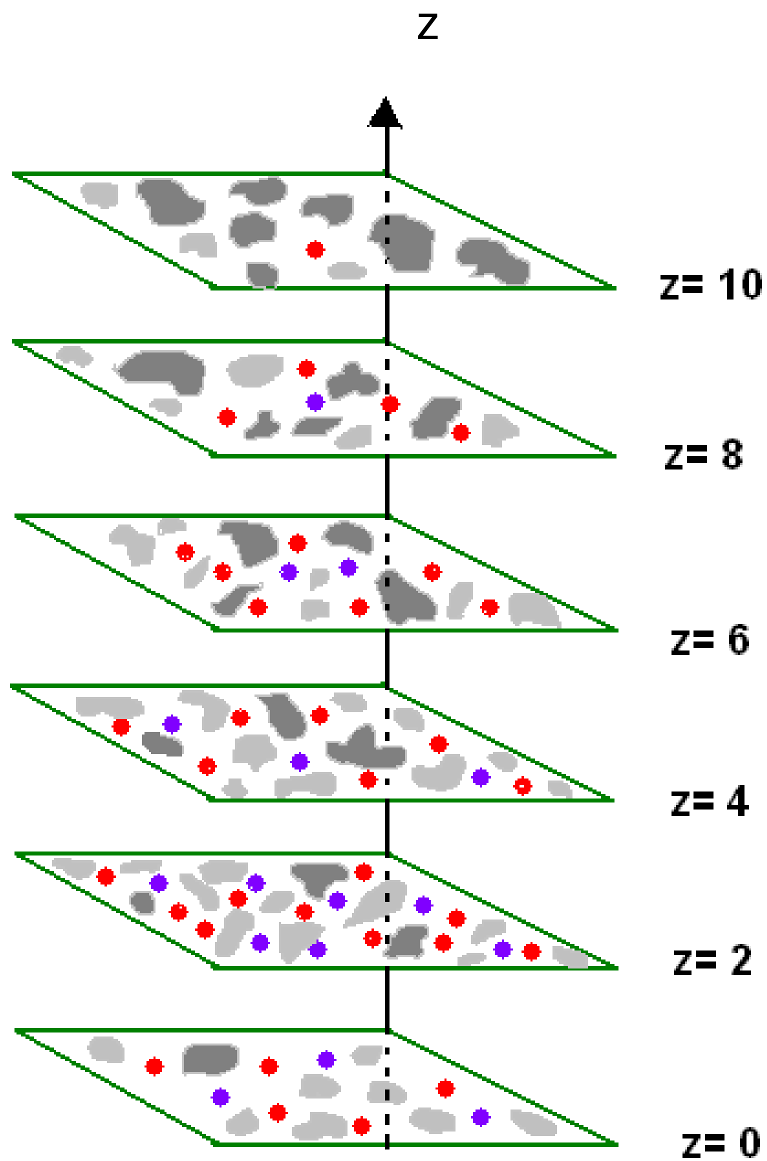


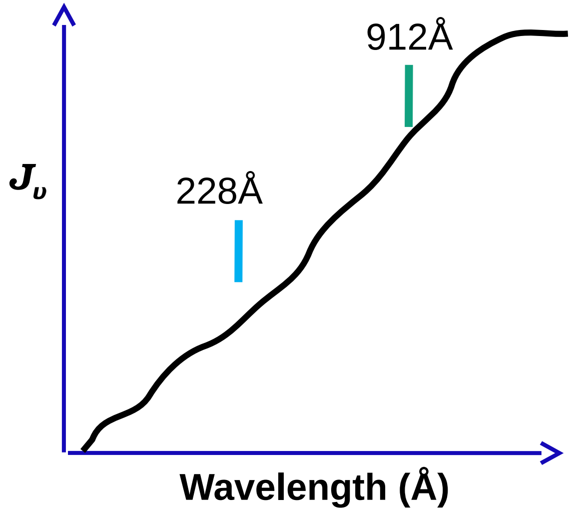
The EBL

Quasars

+
Galaxies

+
Intergalactic medium



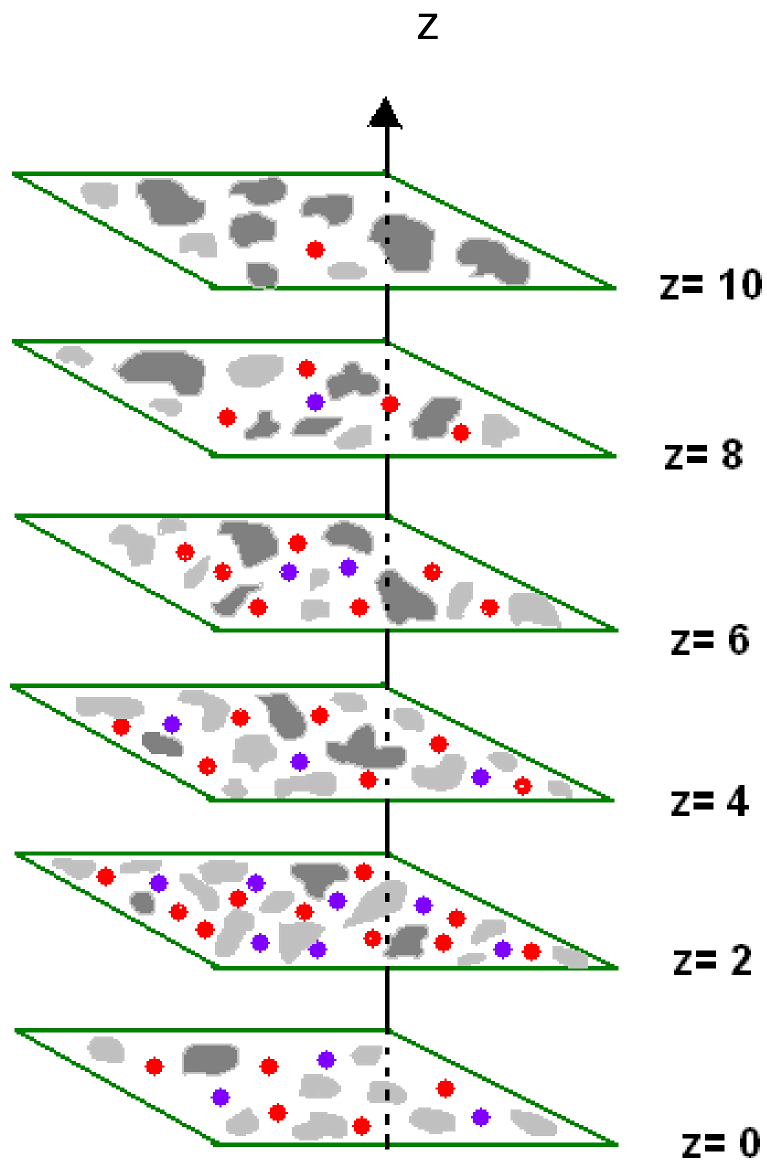


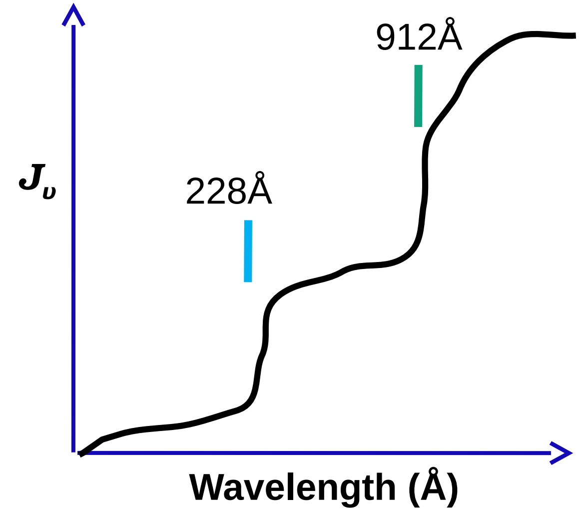
The EBL

Quasars

+
Galaxies

+
Intergalactic medium



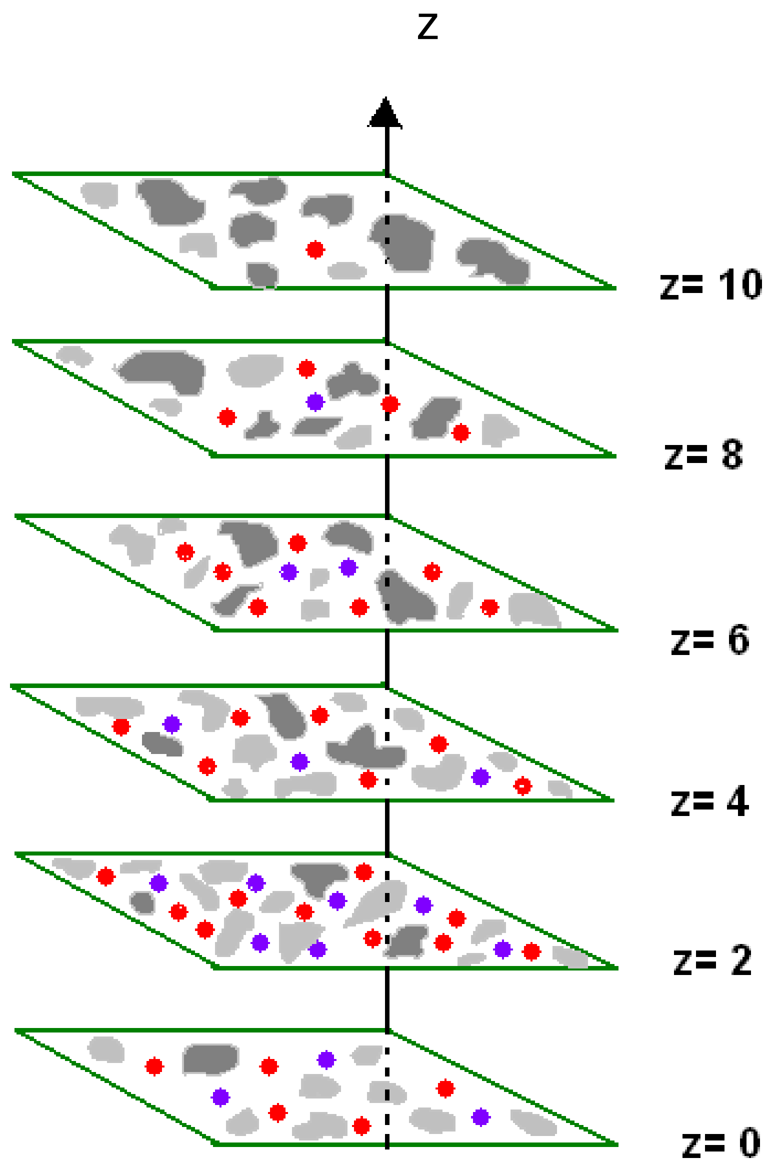


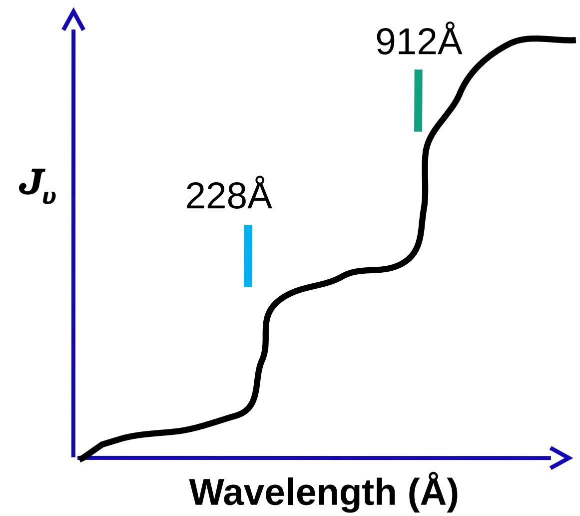
The EBL

Quasars
(Khaire & Srianand 2015a; Khaire 2017)

+
Galaxies
(Khaire & Srianand 2013, Khaire & Srianand 2015b, Khaire et al. 2016)

+
Intergalactic medium





Synthesis – from FIR to Gamma-rays

$$J_{\nu_0}(z_0) = \frac{1}{4\pi} \int_{z_0}^{\infty} dz \, \frac{dl}{dz} \, (1+z_0)^3 \, \epsilon_\nu(z) \, e^{-\tau_{\rm eff}(\nu_0, z_0, z)}$$

(erg/s/cm^2/Hz/sr)

[$z \geq z_0$; $\nu \geq \nu_0$]

$$\nu = \nu_0 (1+z)/(1+z_0)$$

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[z ≥ z_0; ν ≥ ν_0]

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Source Emissivity

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Source Emissivity

IGM attenuation

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$[z \geq z_0;\ \nu \geq \nu_0]$

(erg/s/cm^2/Hz/sr)

Source Emissivity

IGM attenuation

↓

HI distribution of IGM
(Inoue et al 2014)

Synthesis – from FIR to Gamma-rays

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Source Emissivity

Quasars + Galaxies

IGM attenuation

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Source Emissivity

IGM attenuation

Quasars + Galaxies

HI distribution of IGM
(Inoue et al 2014)

+ SED

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(erg/s/cm^2/Hz/sr)

[$z \geq z_0$; $\nu \geq \nu_0$]

Source Emissivity

Quasars + Galaxies

+ SED

Star formation rate density

IGM attenuation

HI distribution of IGM (Inoue et al 2014)

Synthesis – from FIR to Gamma-rays

$$J_{\nu_0}(z_0) = \frac{1}{4\pi} \int_{z_0}^{\infty} dz \, \frac{dl}{dz} \, (1+z_0)^3 \, \epsilon_\nu(z) \, e^{-\tau_{\rm eff}(\nu_0, z_0, z)}$$

[$z \geq z_0$; $\nu \geq \nu_0$]

(erg/s/cm^2/Hz/sr)

Source Emissivity

IGM attenuation

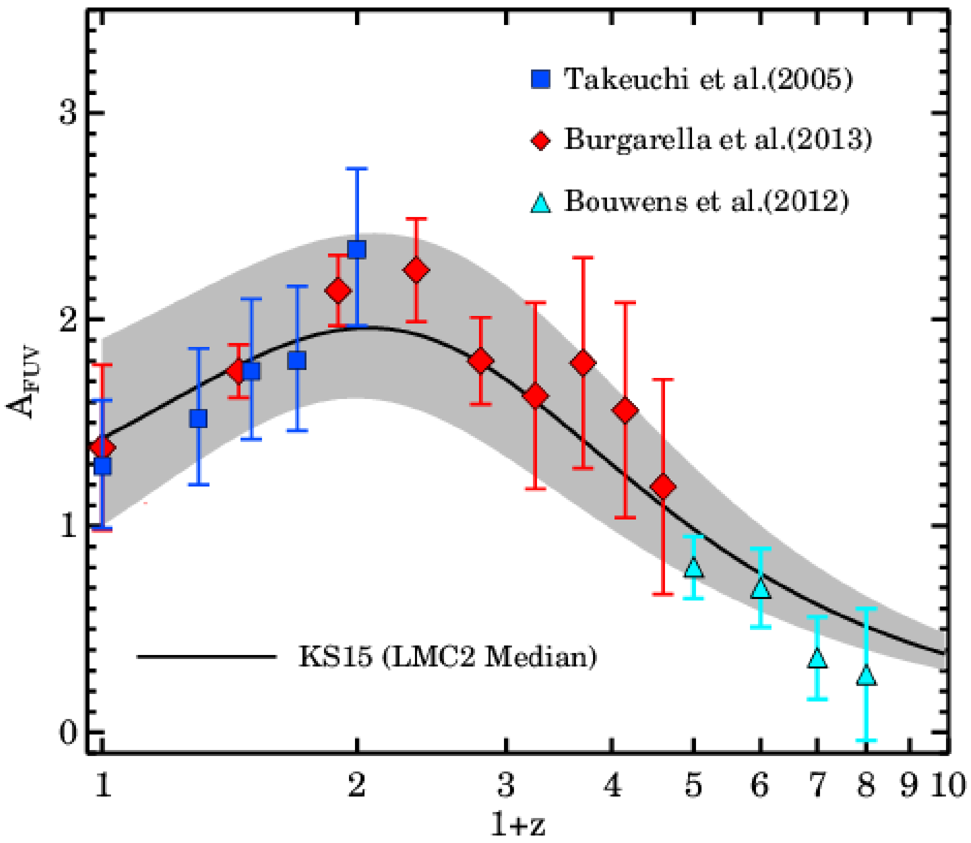
Quasars + Galaxies

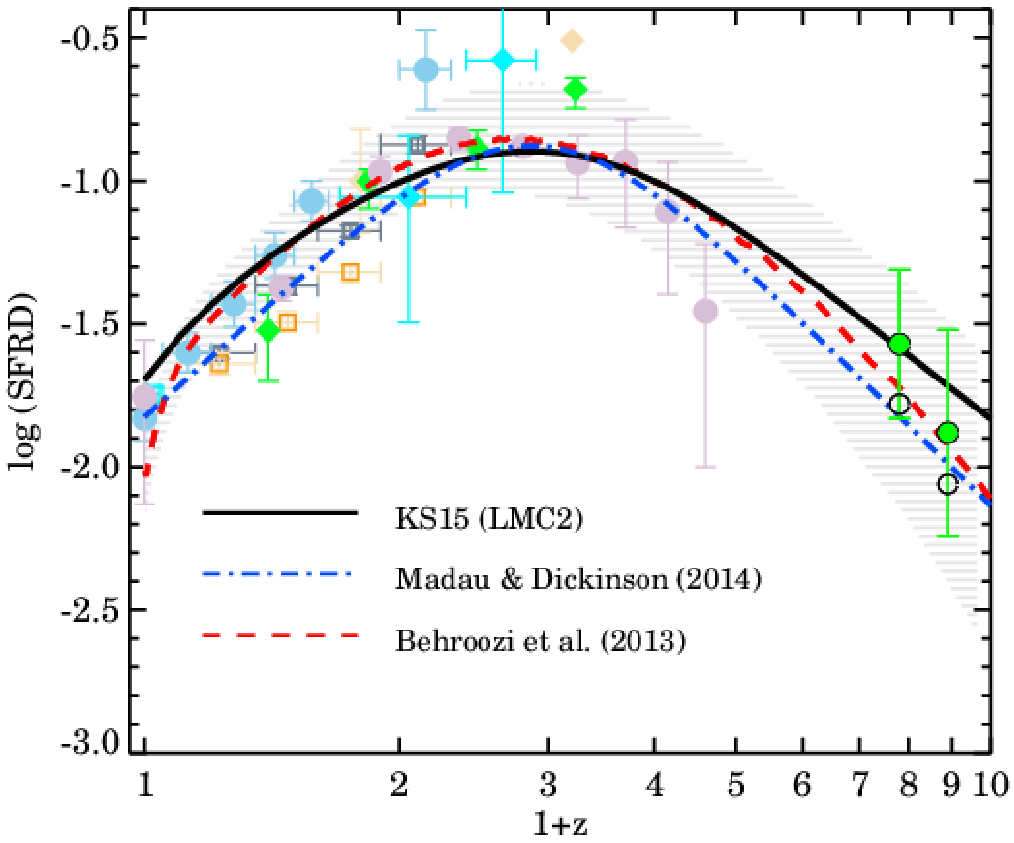
HI distribution of IGM (Inoue et al 2014)

+ SED

Star formation rate density & Average escape fraction (f_{esc})

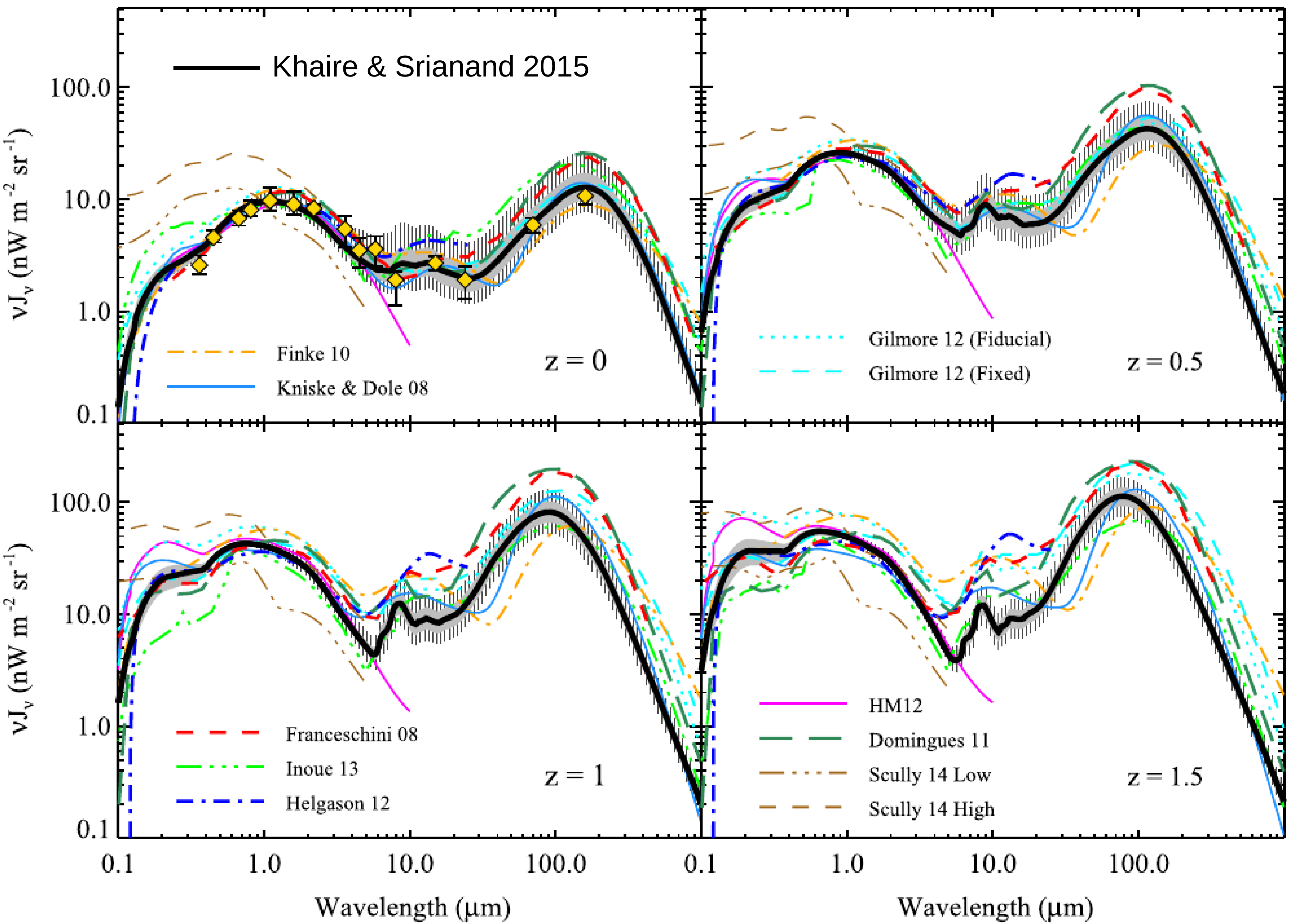
Dust and Star Formation Rate Density



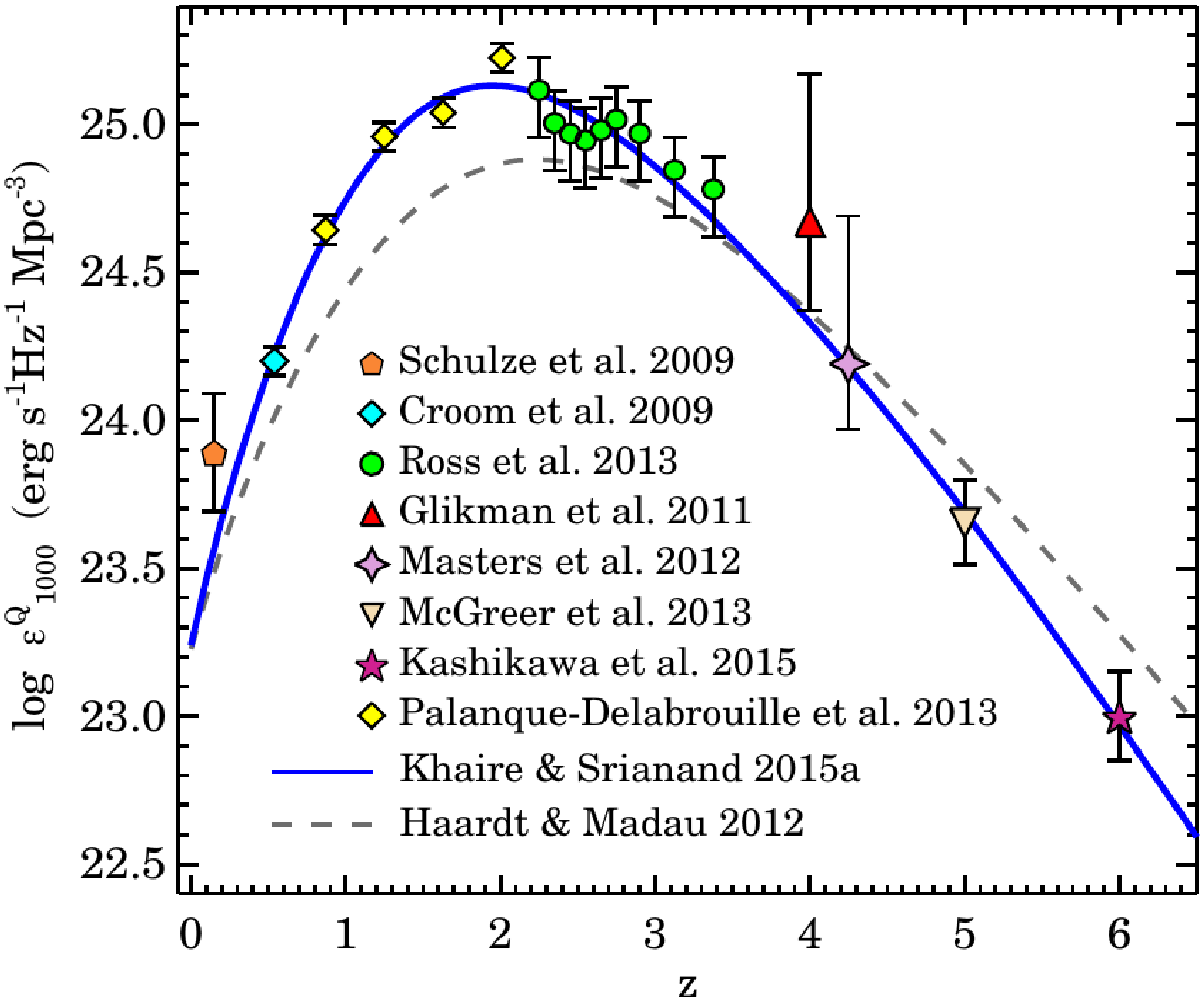


KS15 → Khaire & Srianand 2015

EBL only from Galaxies

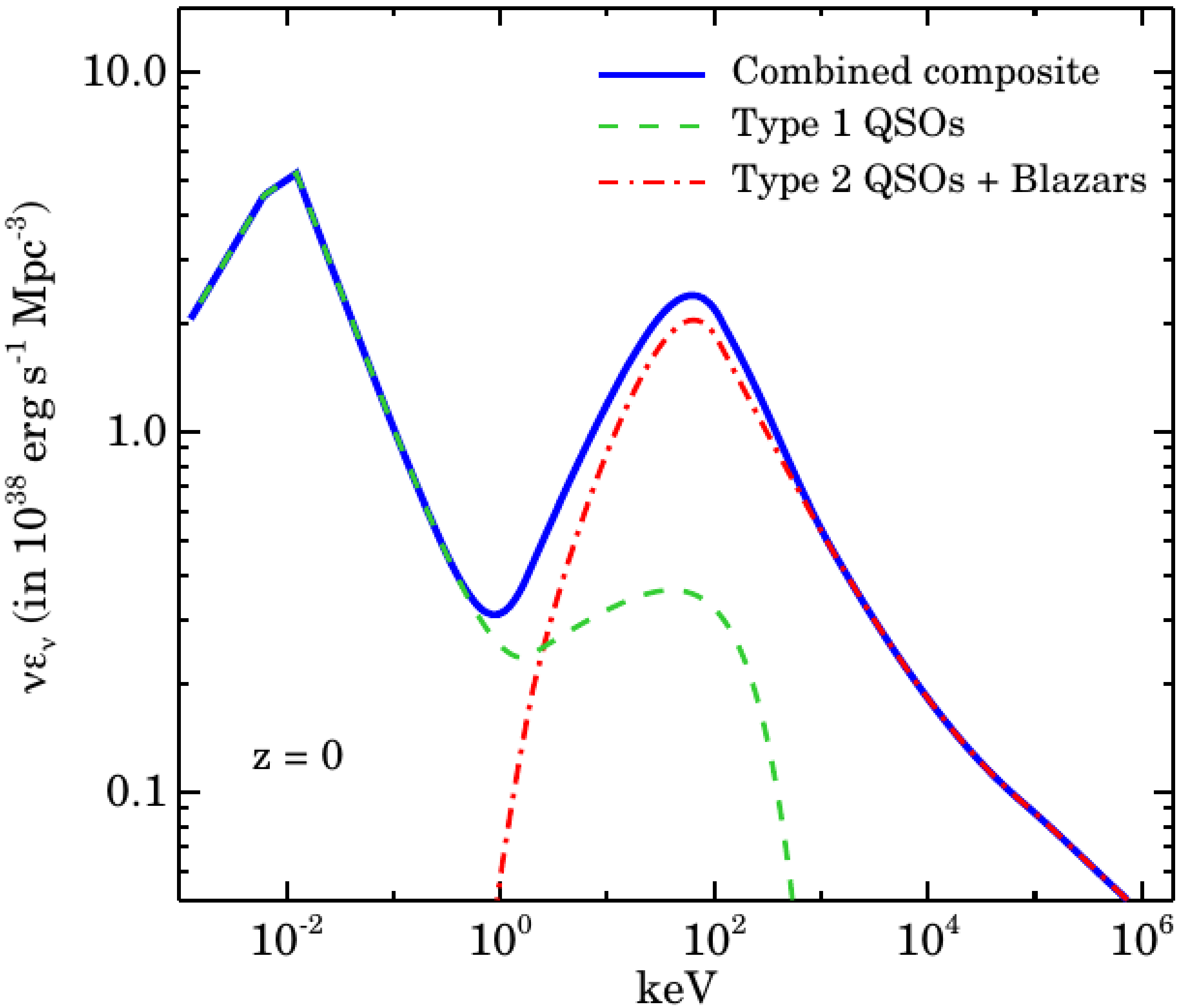


Quasar Luminosity Density



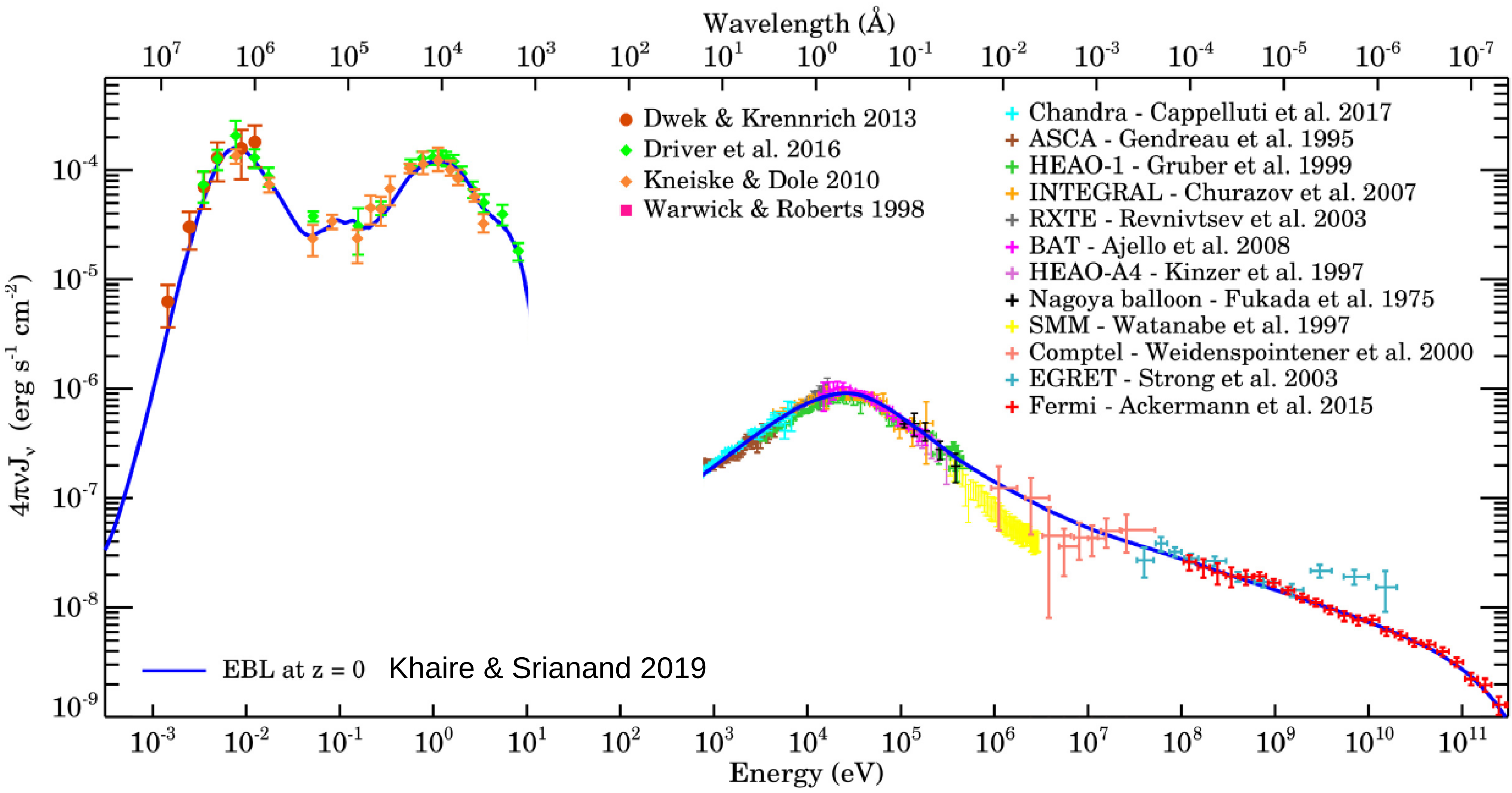
Khaire & Srianand 2019

Quasar SED

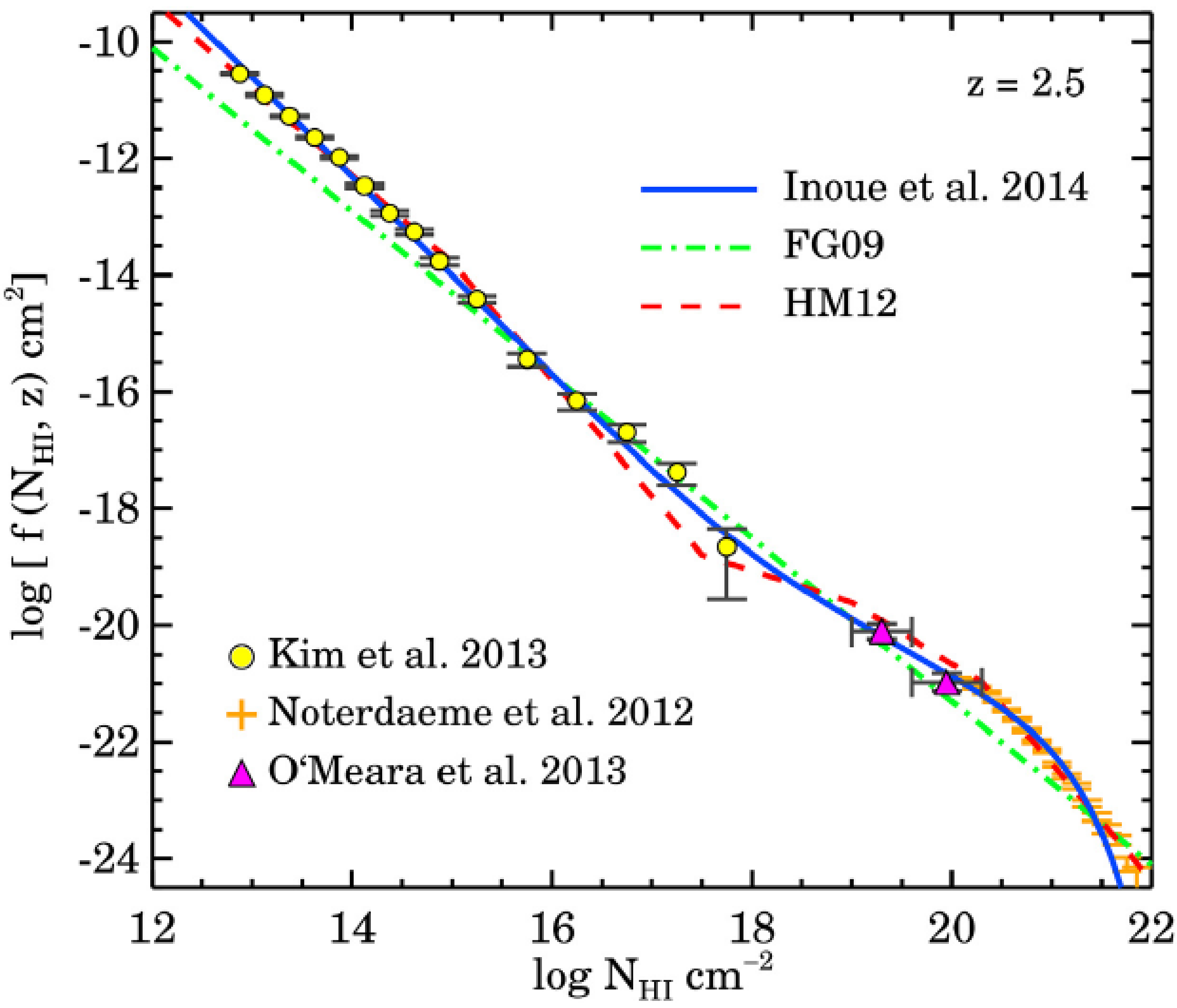


Khaire & Srianand 2019

No IGM opacity

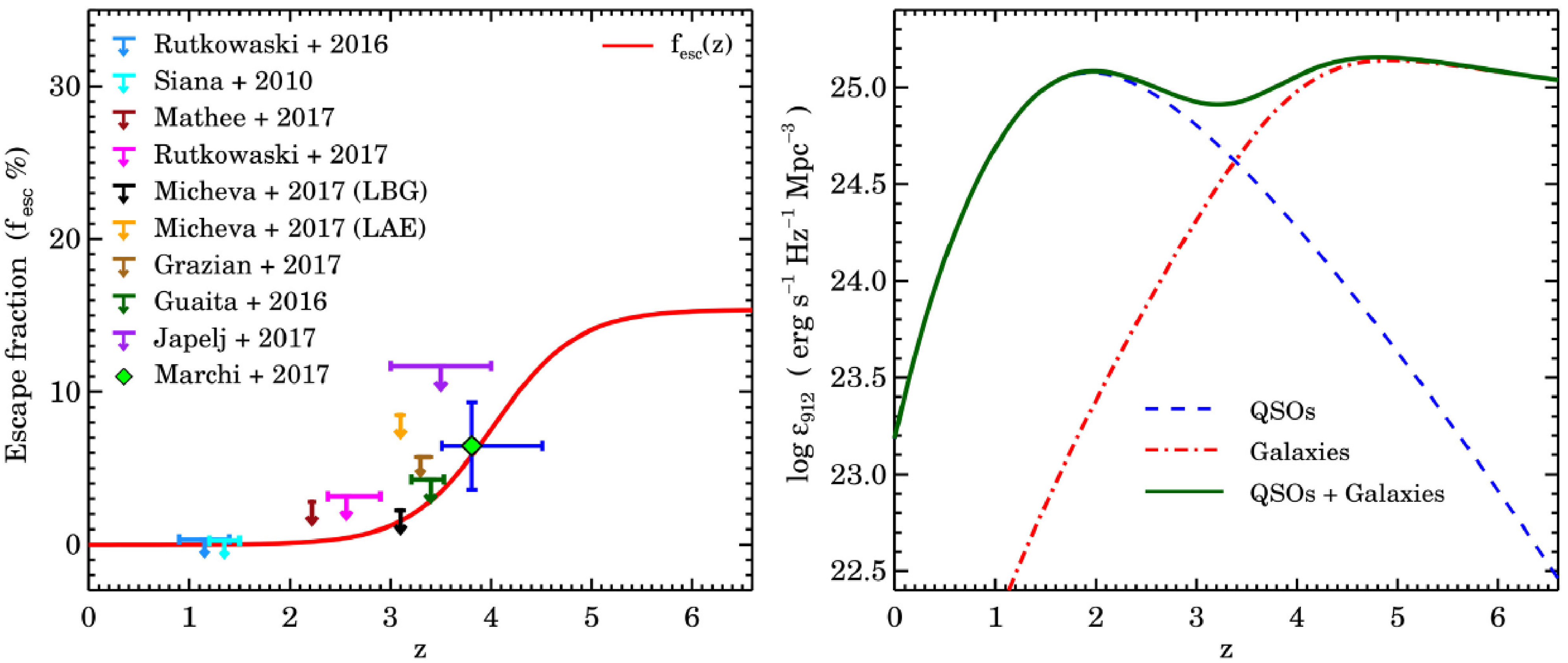


For UV Background



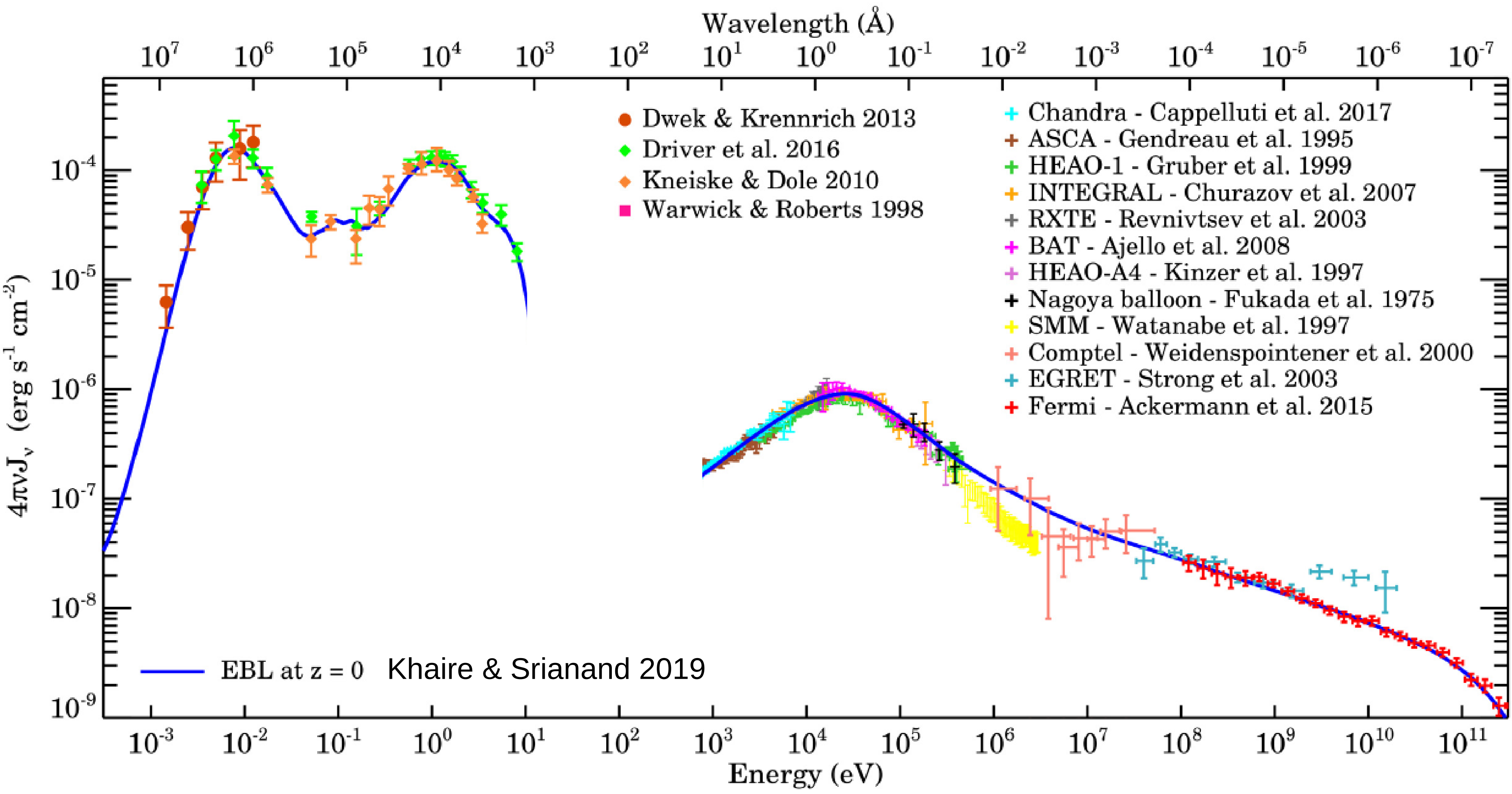
Khaire & Srianand 2019

For UV Background



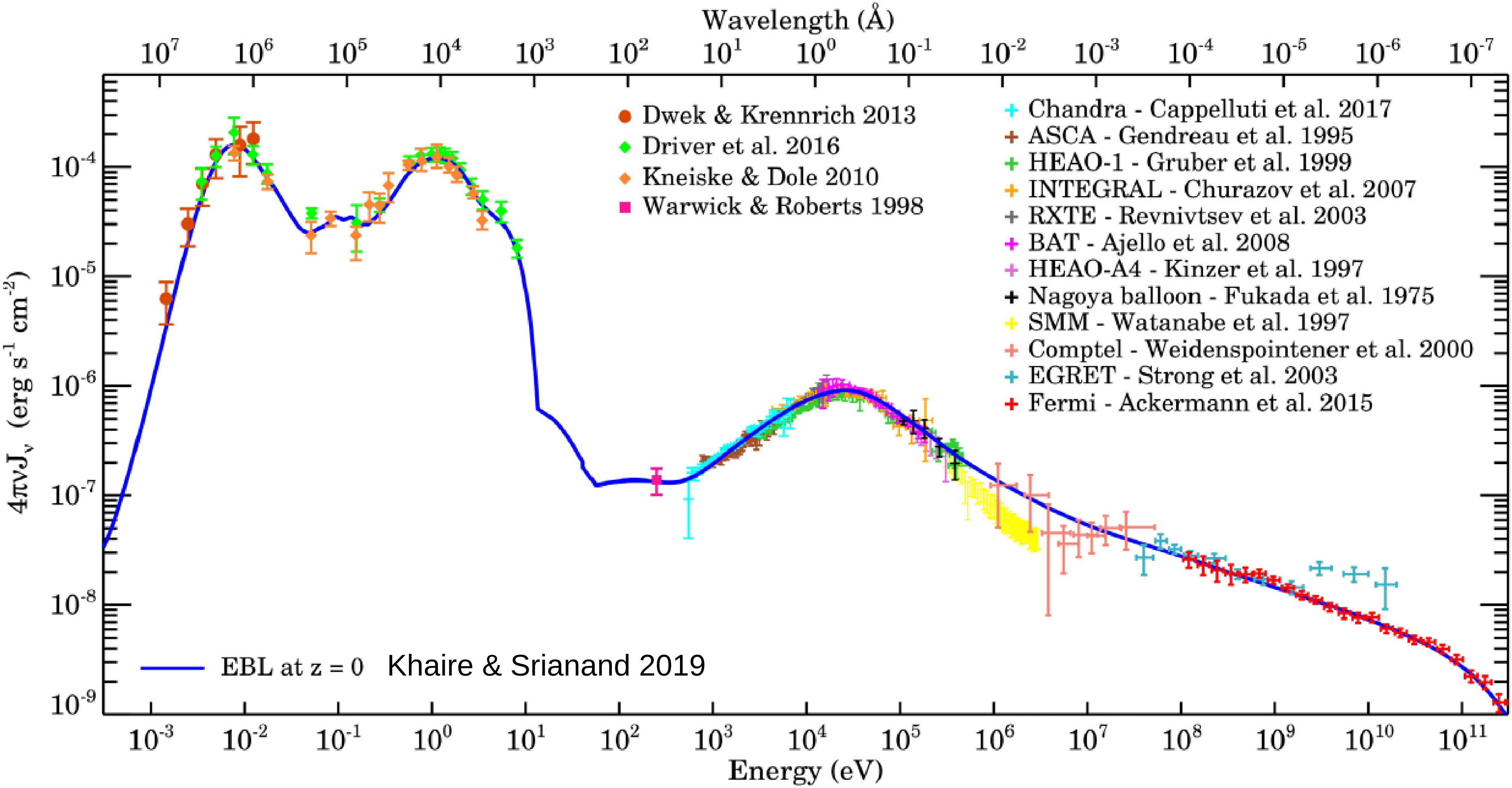
Khaire & Srianand 2019

Full EBL



Wavelength (Å)
10^7 10^6 10^5 10^4 10^3 10^2 10^1 10^0 10^-1 10^-2 10^-3 10^-4 10^-5 10^-6 10^-7
Dwek & Krennrich 2013
Driver et al. 2016
Kneiske & Dole 2010
Warwick & Roberts 1998
Chandra - Cappelluti et al. 2017
ASCA - Gendreau et al. 1995
HEAO-1 - Gruber et al. 1999
INTEGRAL - Churazov et al. 2007
RXTE - Revnivtsev et al. 2003
BAT - Ajello et al. 2008
HEAO-A4 - Kinzer et al. 1997
Nagoya balloon - Fukada et al. 1975
SMM - Watanabe et al. 1997
Comptel - Weidenspointener et al. 2000
EGRET - Strong et al. 2003
Fermi - Ackermann et al. 2015
4πνJ_ν (erg s^-1 cm^-2)
10^-4 10^-5 10^-6 10^-7 10^-8 10^-9
EBL at z = 0
Khaire & Srianand 2019
10^-3 10^-2 10^-1 10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^10 10^11
Energy (eV)

Full EBL



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Khaire & Srianand 2019
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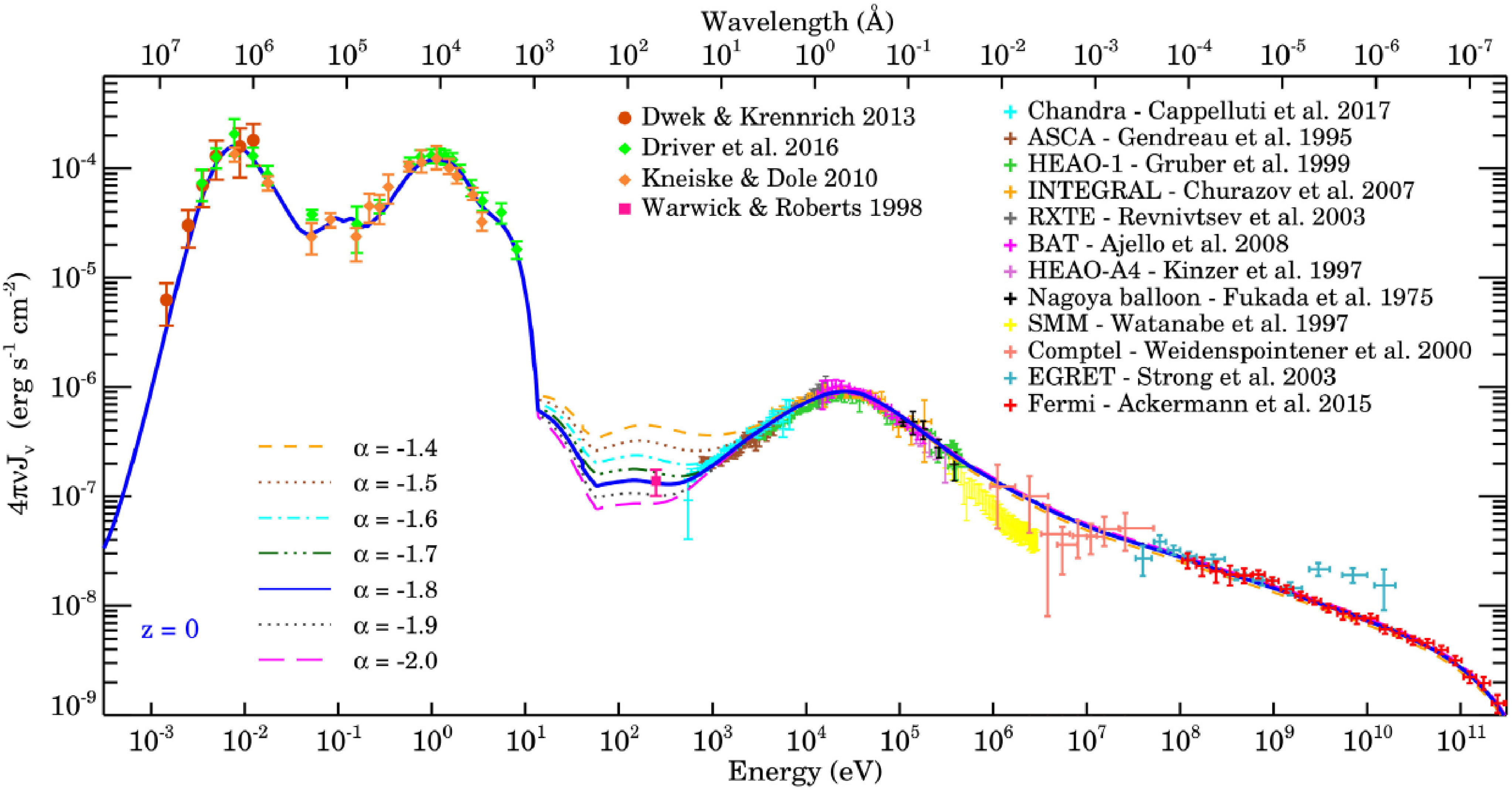
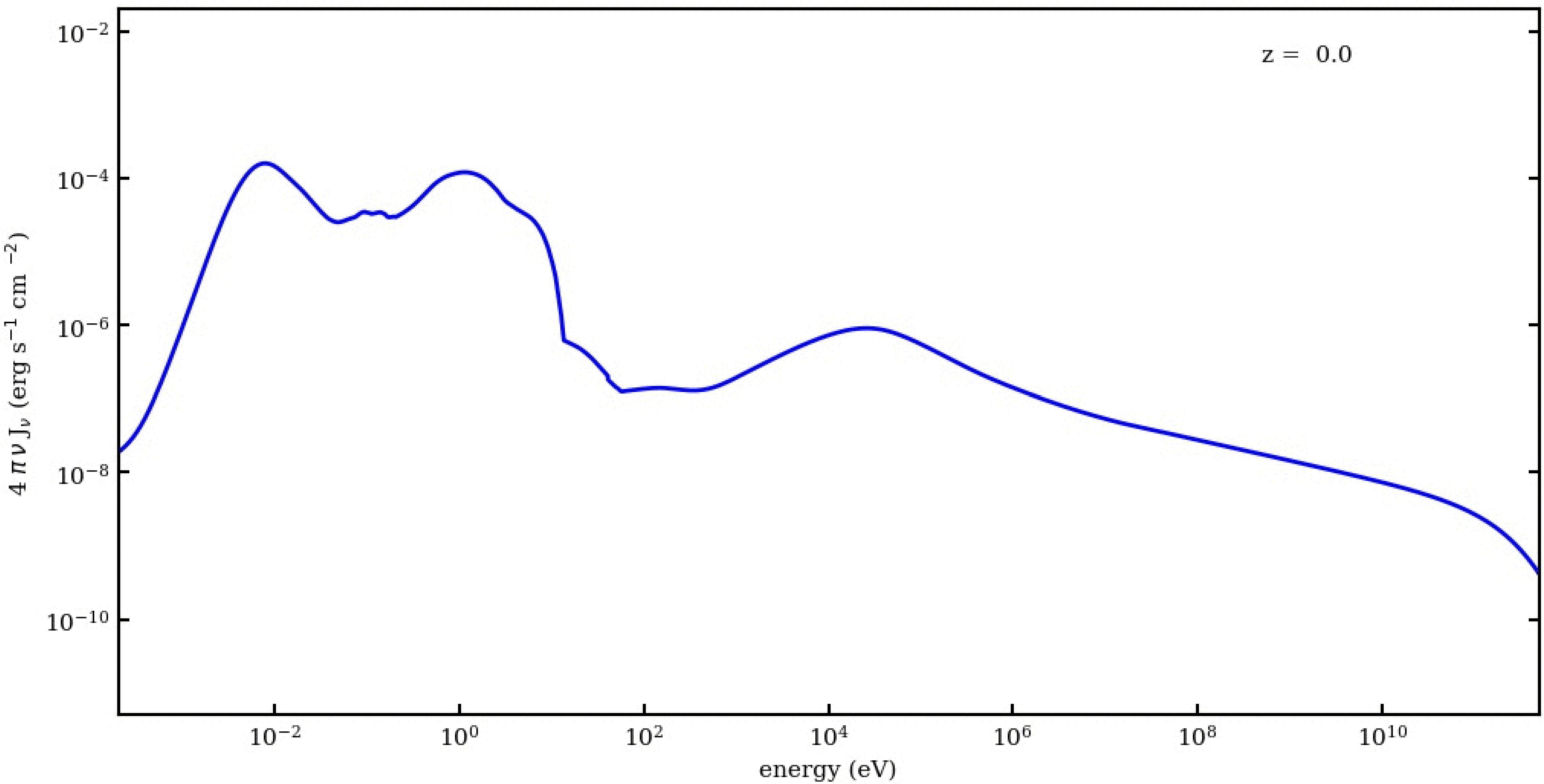
Full EBL



Khaire & Srianand 2019

Full EBL



z = 0.0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
$4\,\pi\,\nu\,J_\nu$ (erg s^{-1} cm $^{-2}$)
10^{-2}
10^{0}
10^{2}
10^{4}
10^{6}
10^{8}
10^{10}
energy (eV)

What’s in the future?

EBL models need revisions with new observations

→ Impact of JWST galaxy luminosity function on EBL?
→ What about Little Red Dots?

Fluctuations in FIR background? -- CIBER/Spitzer

Dust in high-z universe?

Background in Radio?

Refining UV background!

Summary

We can accurately model EBL from Far IR to TeV gamma-rays.

Given the influx of data from wide and deep suveys – including JWST/EUCLID/SPHEREx – we expect even more improvements on data and modeling.

The most uncertain part of the EBL is extreme UV background. We are trying to understand it using various observations.

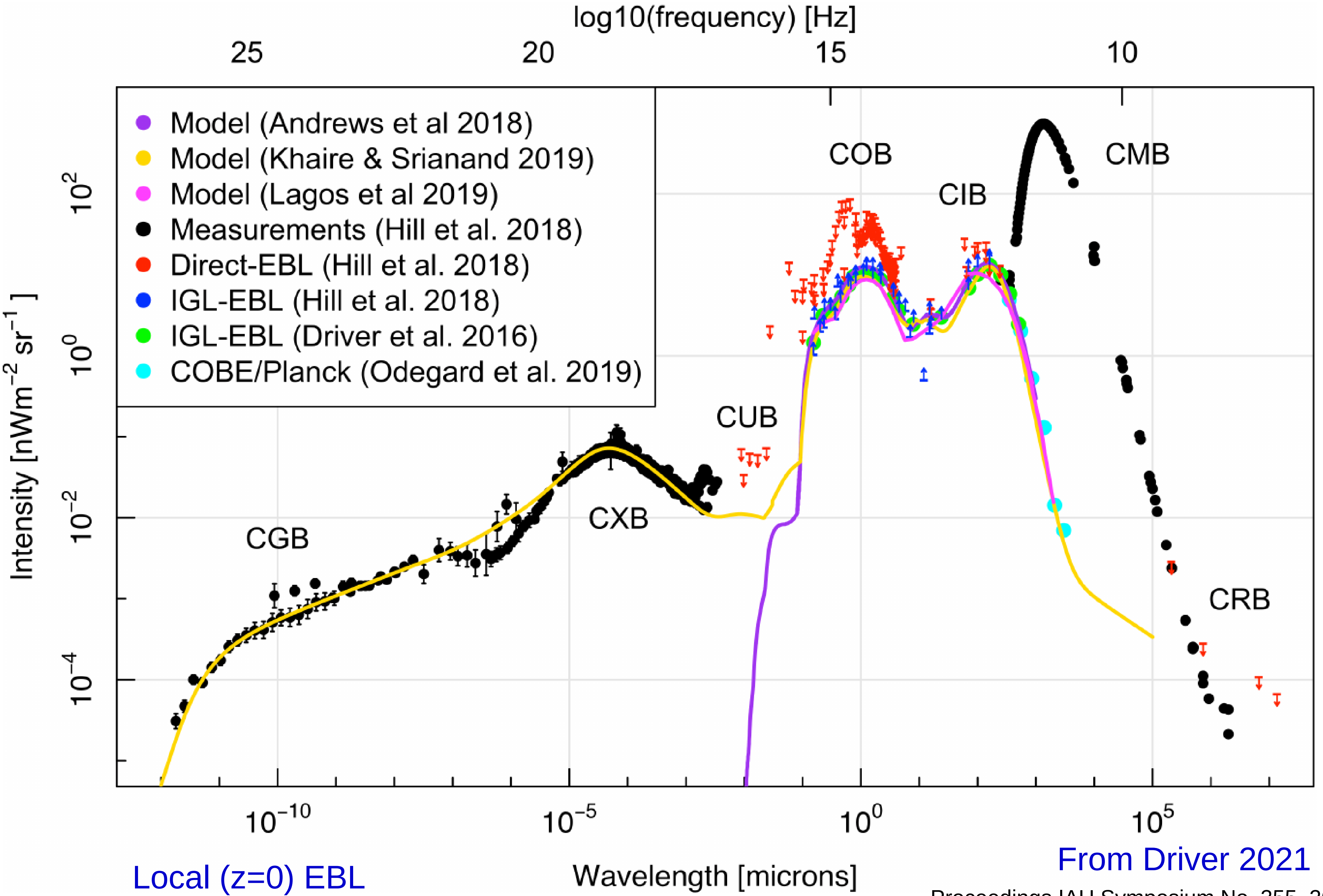
It would be interesting to see where the field goes →
Intra-halo light?
How much room we have to measure cosmology parameters like Hubble constant? (e.g. Greaux et al 2024 – talk by Alberto Dominguez on 14th Nov)
What about photons from dark matter annihilations?

"The study of the extragalactic background light is undergoing a renaissance."
- Simon Driver

Thank you!

Extra slide - Why do we say extragalactic ?

EBL or Cosmic (radiation) Background



Local (z=0) EBL

From Driver 2021

Proceedings IAU Symposium No. 355, 2019