# Determining the Intergalactic Photon Densities from Deep Galaxy Surveys and the $\gamma$-ray Opacity of the Universe

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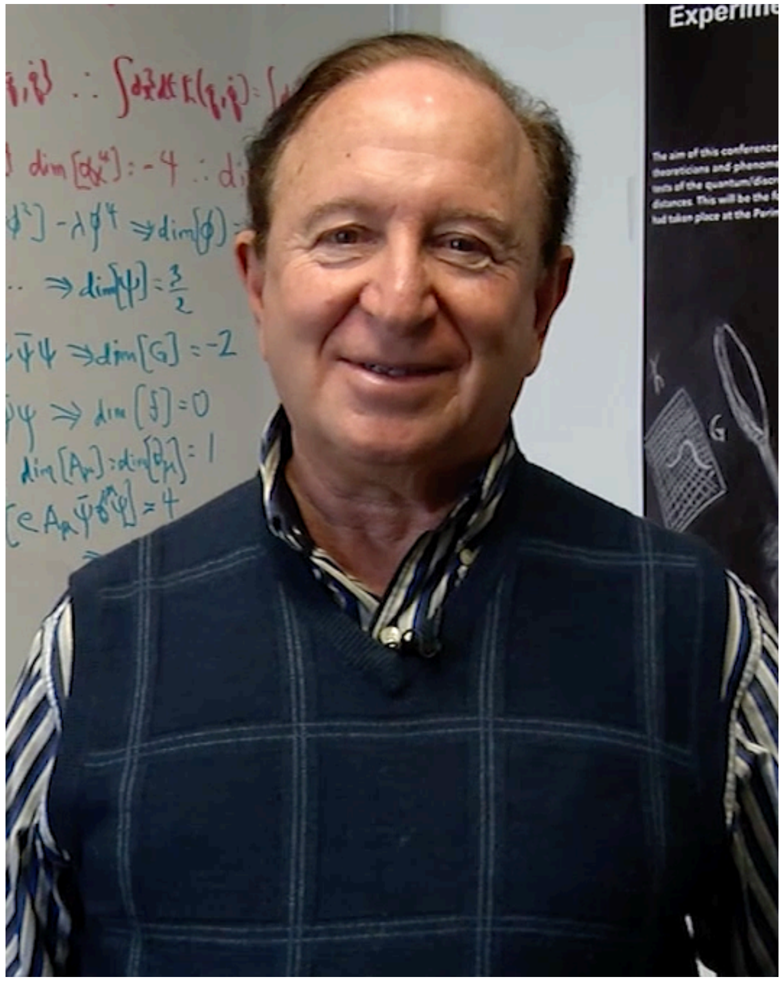


Stecker (GSFC)

Malkan (UCLA)

Scully (JMU)

# *Intergalactic Photon Fields*

*Emission from stars and dust re-radiation of starlight in galaxies produces IR, optical and UV photons.*

*These low energy photons escape to intergalactic space.*

*If we know enough about galaxy UV-Op-IR spectra as a function of redshift from deep astronomical surveys, we can calculate the evolution of intergalactic photon densities.*

# Our Motivations

*The intergalactic background light can now be fully constructed using deep galaxy survey data covering the whole wavelength range from the far UV to the far IR.*

*This has the advantage over modeling galaxy SEDs, since we are using real, observationally determined error bands on galaxy luminosity densities.*

*This approach compliments blazar γ-ray absorption method approach suggested by Stecker et al. (1992) for determining the γ-ray opacity of the universe and for probing modification of γ-ray spectra by axions, Lorentz invariance violation or secondary γ-ray components.*

**FUV**

Budavari 05
Schiminovich 05
Burgarella 07
Iwata 07
Bouwens 07
Sawicki 06
Paltani 07
Reddy 08
Yoshida 06
Reddy 08
Ly 09
Ryder 05
Dahlen 07
Tresse 07
Bouwens 10
Oesch 10
Cucciati 12
Bouwens 12
Bouwens 14

**NUV**

Budavari 05
Dahlen 07
Wyder 05
Tresse 07
Cucciati 12
Wolf 03

**U**

Tresse 07
Dahlen 07

**B**

Tresse 07
Dahlen 05
Faber 07
Marchesini 07
Wolf 03

**V**

Tresse 07
Marchesini 07
Marchesini 12

**R**

Dahlen 05
Tresse 07
Marchesini 07
Chen 03
Wolf 03

**I**

Tresse 07

**J**

Hill 10
Stephanon
Jones
Pozzetti 03
Feulner03

**K**

Arnouts 07
Heath 06
Bell 03
Kochanek
Hill 10
Feulner 03
Cole 01
Pozzetti 03

**8 μm**

Magnelli 11
Caputi 07
Huang 06
Rodighiero 10
Goto 15

**12 μm**

Toba 14
Perez-Gonzalez 05
Rodighiero 10
Goto 15

**15 μm**

Xu 98
Pozzi 04
LeFloc'h 05
Magnelli 09
Magnelli 11
Rodighiero 10

**24 μm**

Shupe 98
Rujopakarn 10
Magnelli 11
Rodighiero 10
Babbedge 06

**35 μm**

Magnelli 11
Gruppioni 13

**60 μm**

Gruppioni 10
Gruppioni 13

**90 μm**

Gruppioni 10
Gruppioni 13
Lapi 10

**250 μm**

Lapi 10
Guy 12

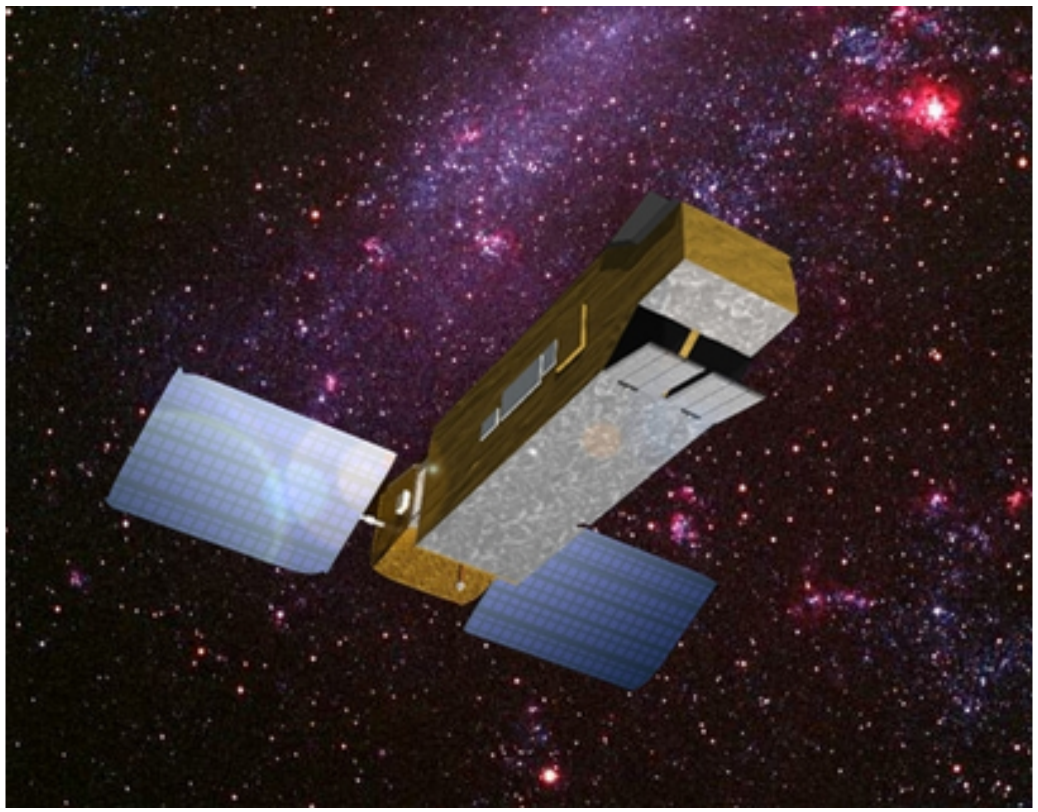
**350 - 850 μm**

Negrello 13

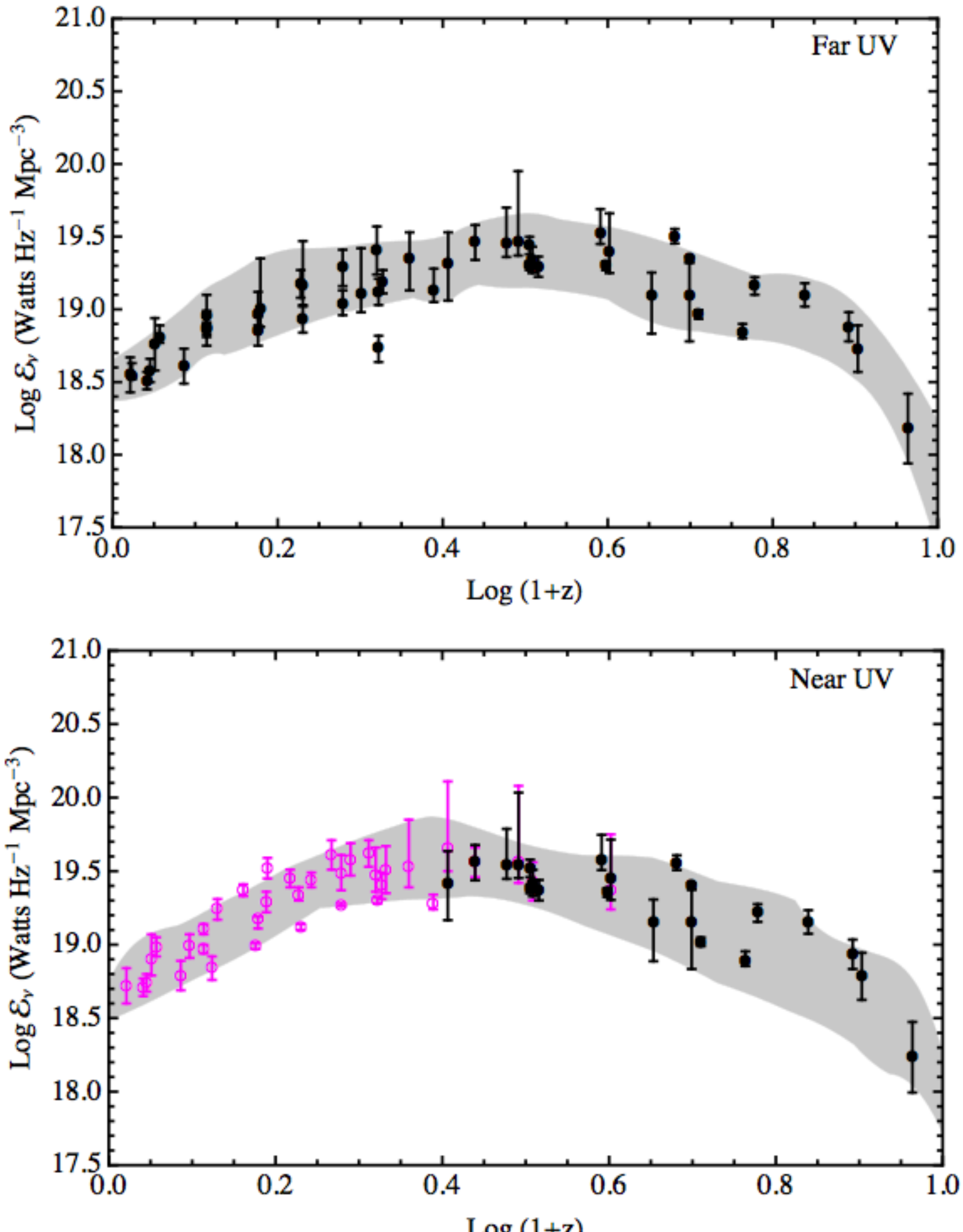
**β's**

Bouwens 09
Budavari 05
Castellano 12
Cucciatti 12
Dunlop 12
Wilcot 12
Wyder 05
Arnouts 07
Brammer 11
Tresse 07
Ly 09
Marchesini 07
Gonzalez 11
Dai 09
Kriek 10
Kriek 11

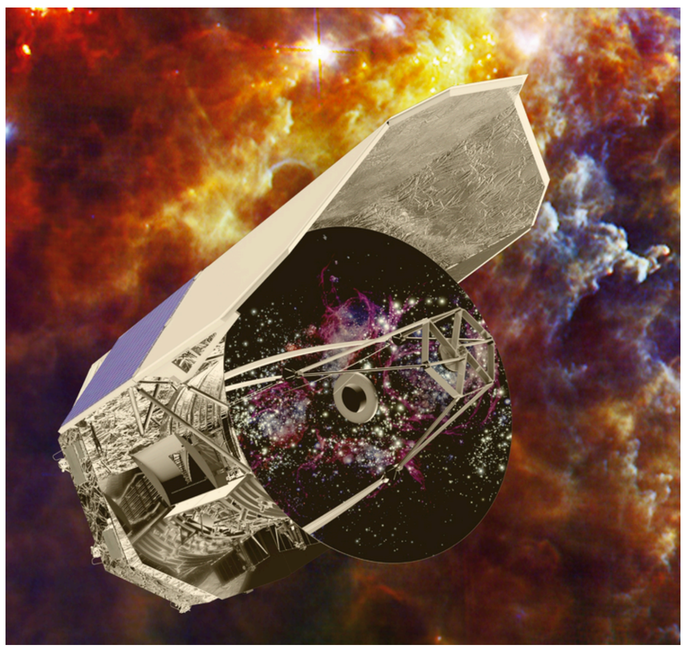
# UV Luminosity Densities:



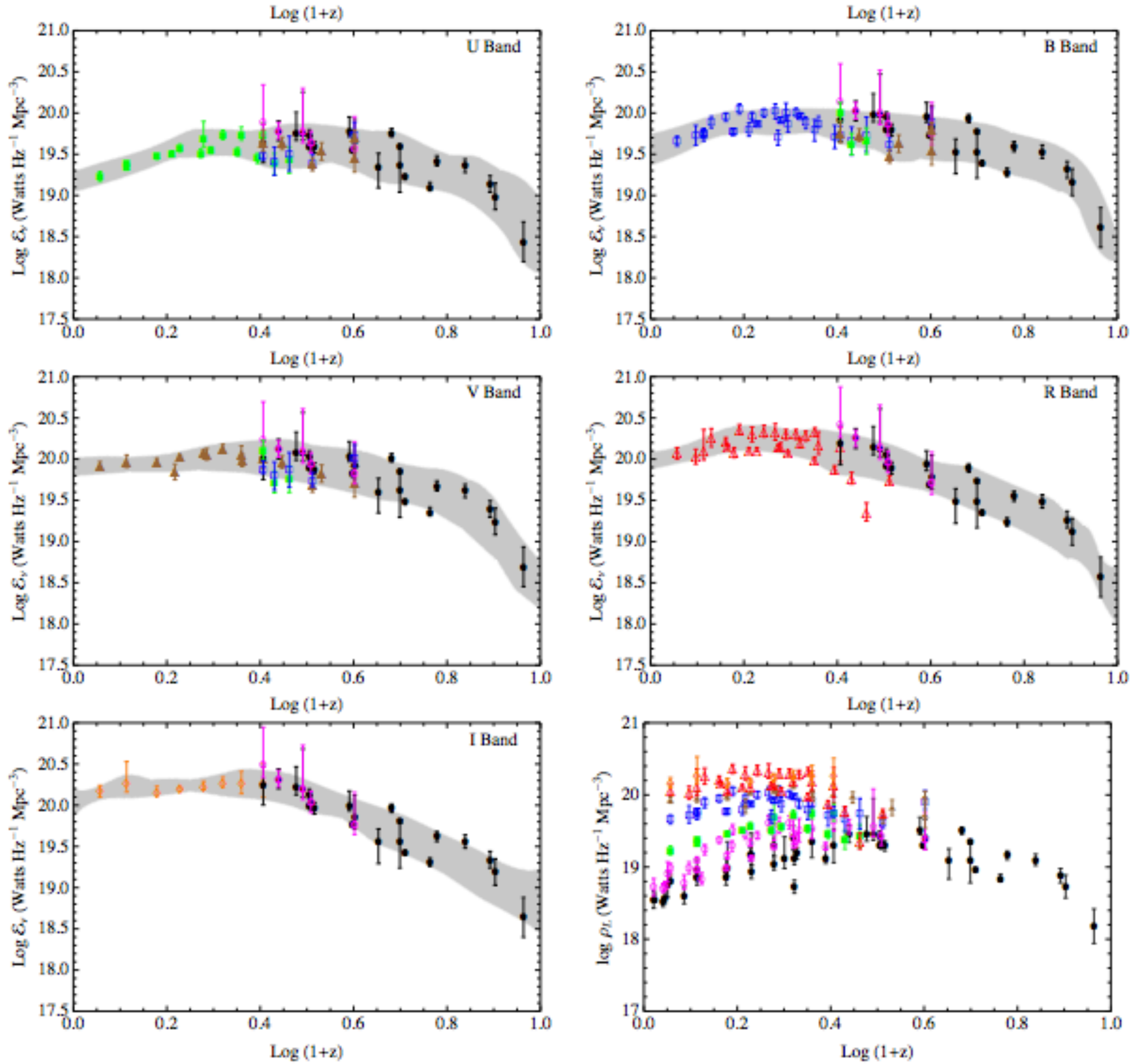
Galaxy Evolution Explorer



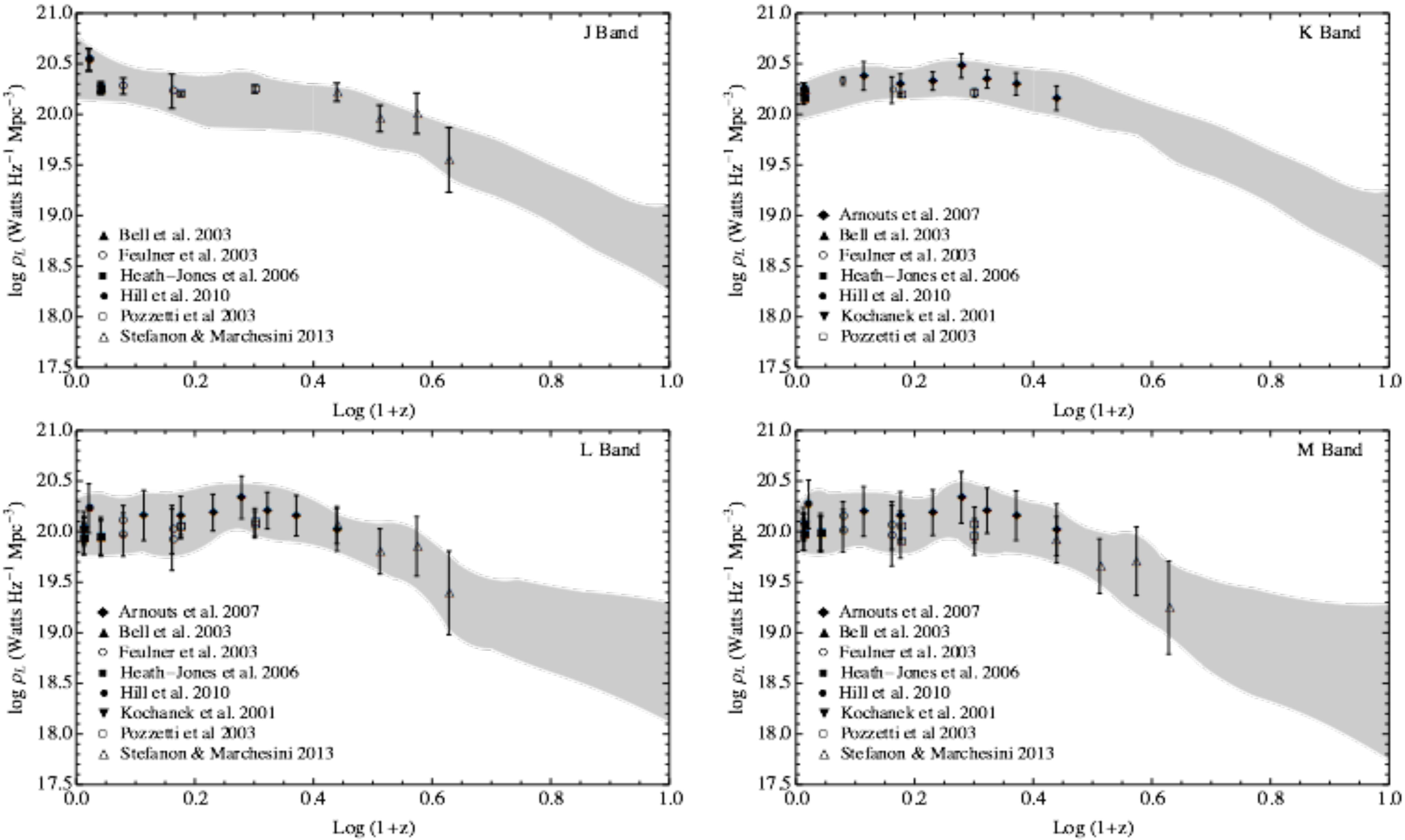
# Optical Luminosity Densities:



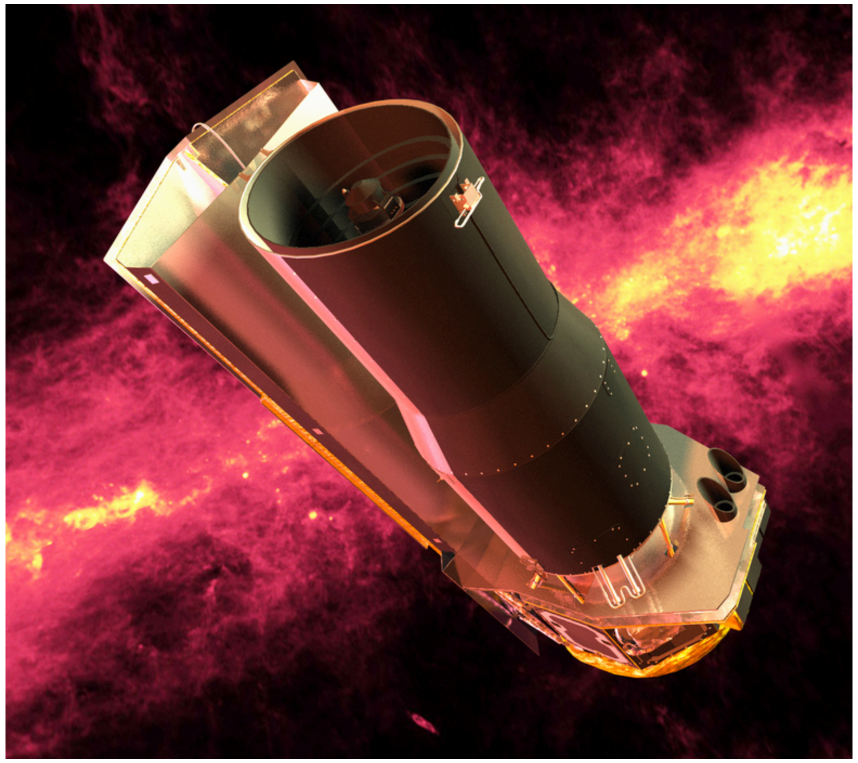
Hubble



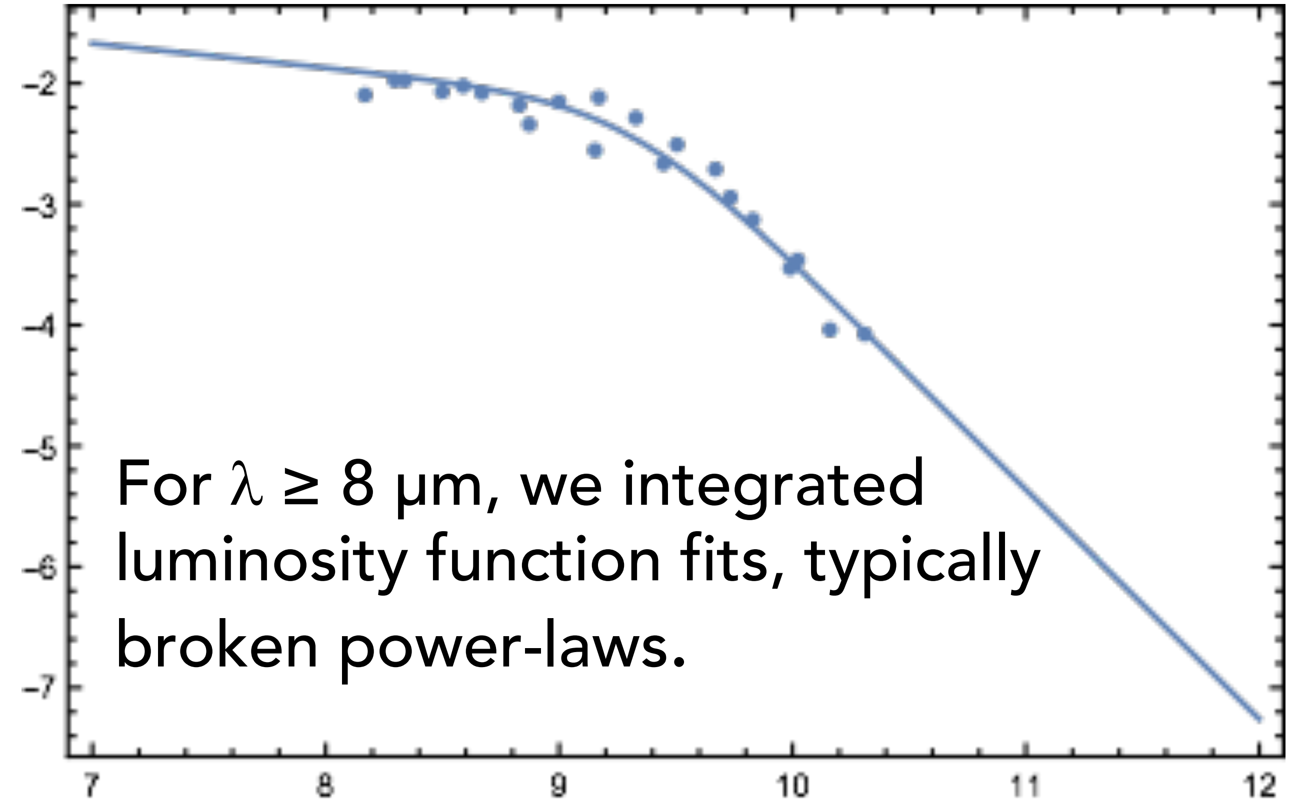
# Near IR Luminosity Densities:



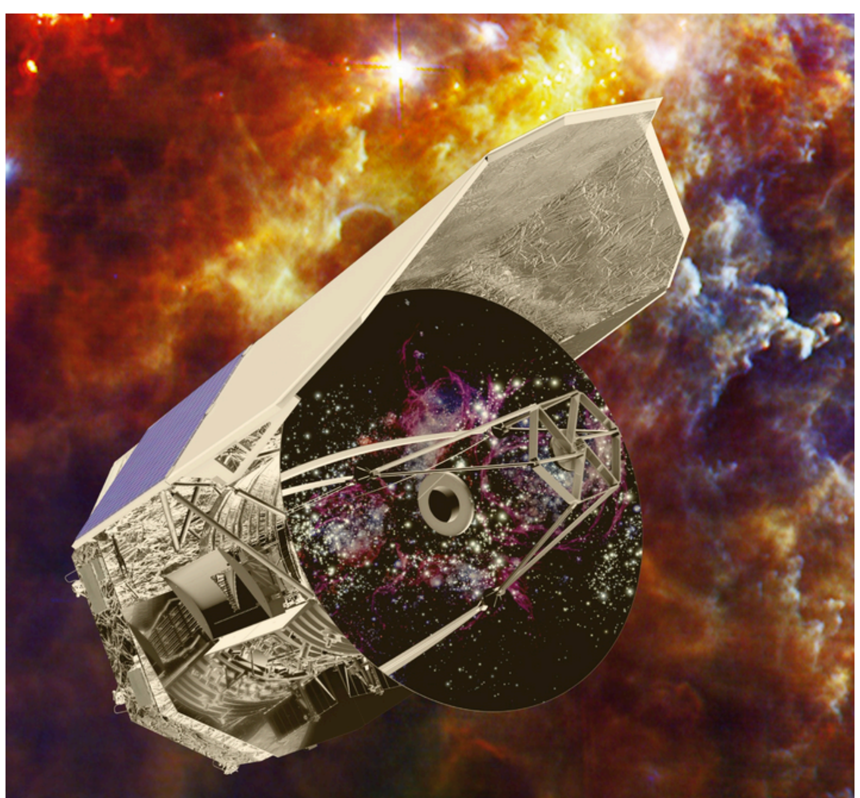
# Mid-IR and far-IR Luminosity Densities



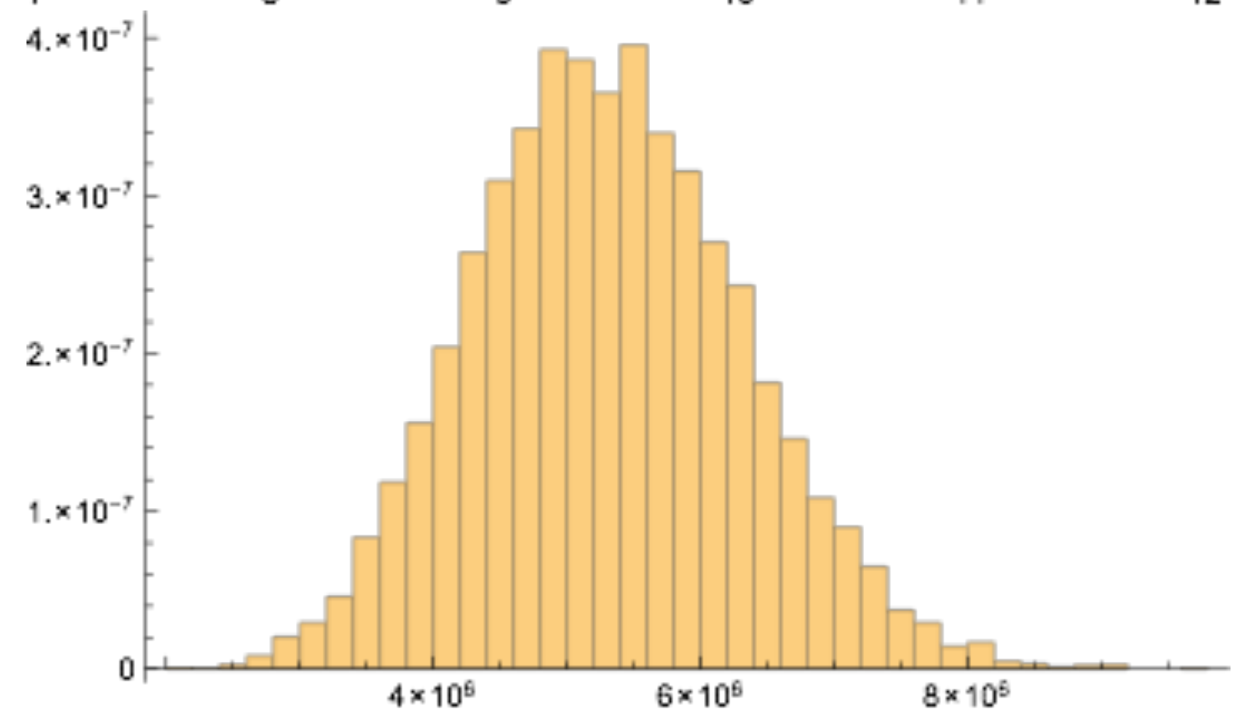
Spitzer




For λ ≥ 8 μm, we integrated luminosity function fits, typically broken power-laws.

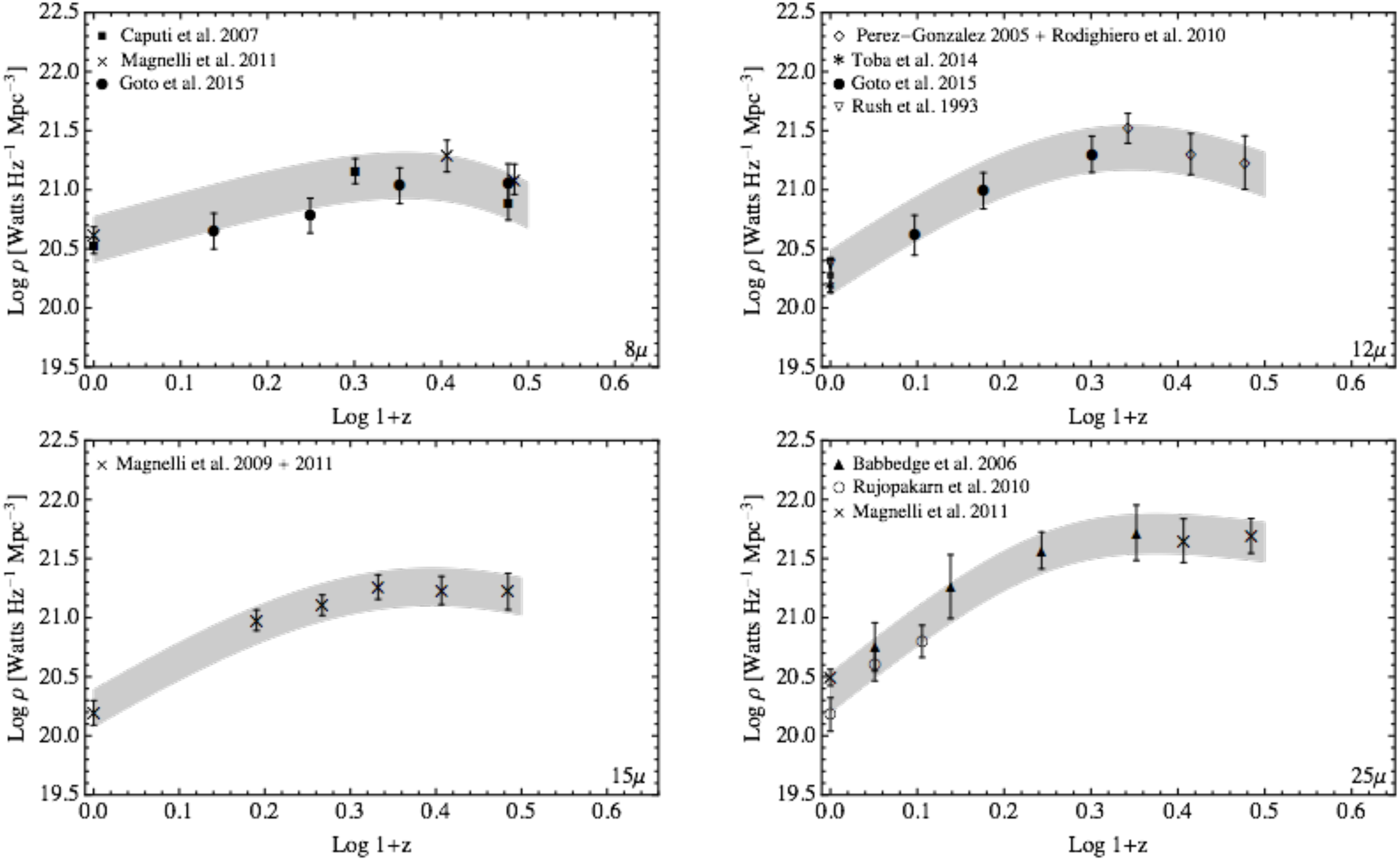


Herschel

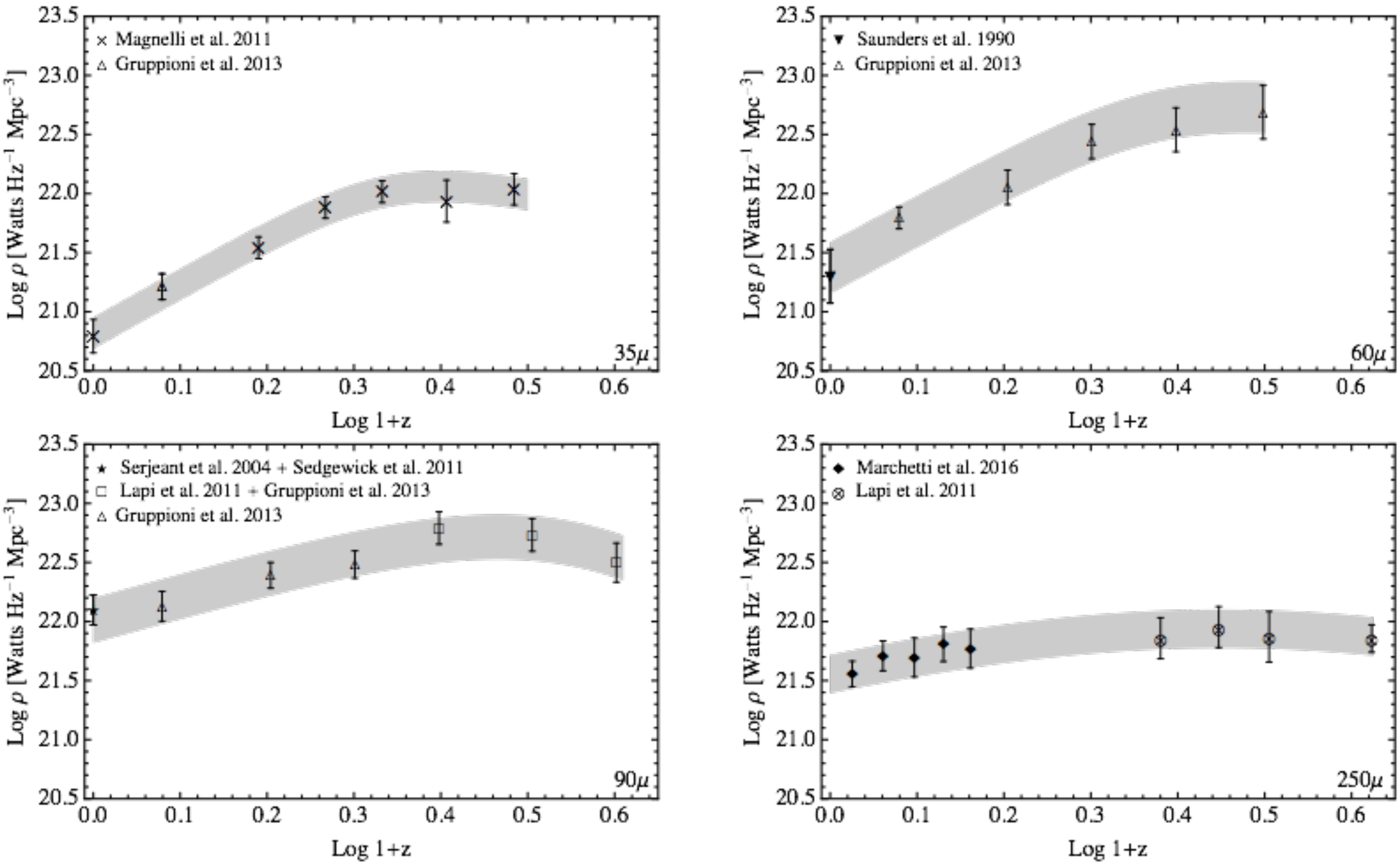



We generated 10,000 realizations of the fit parameters to characterize the errors.

# 8 to 25 Micron Luminosity Densities:

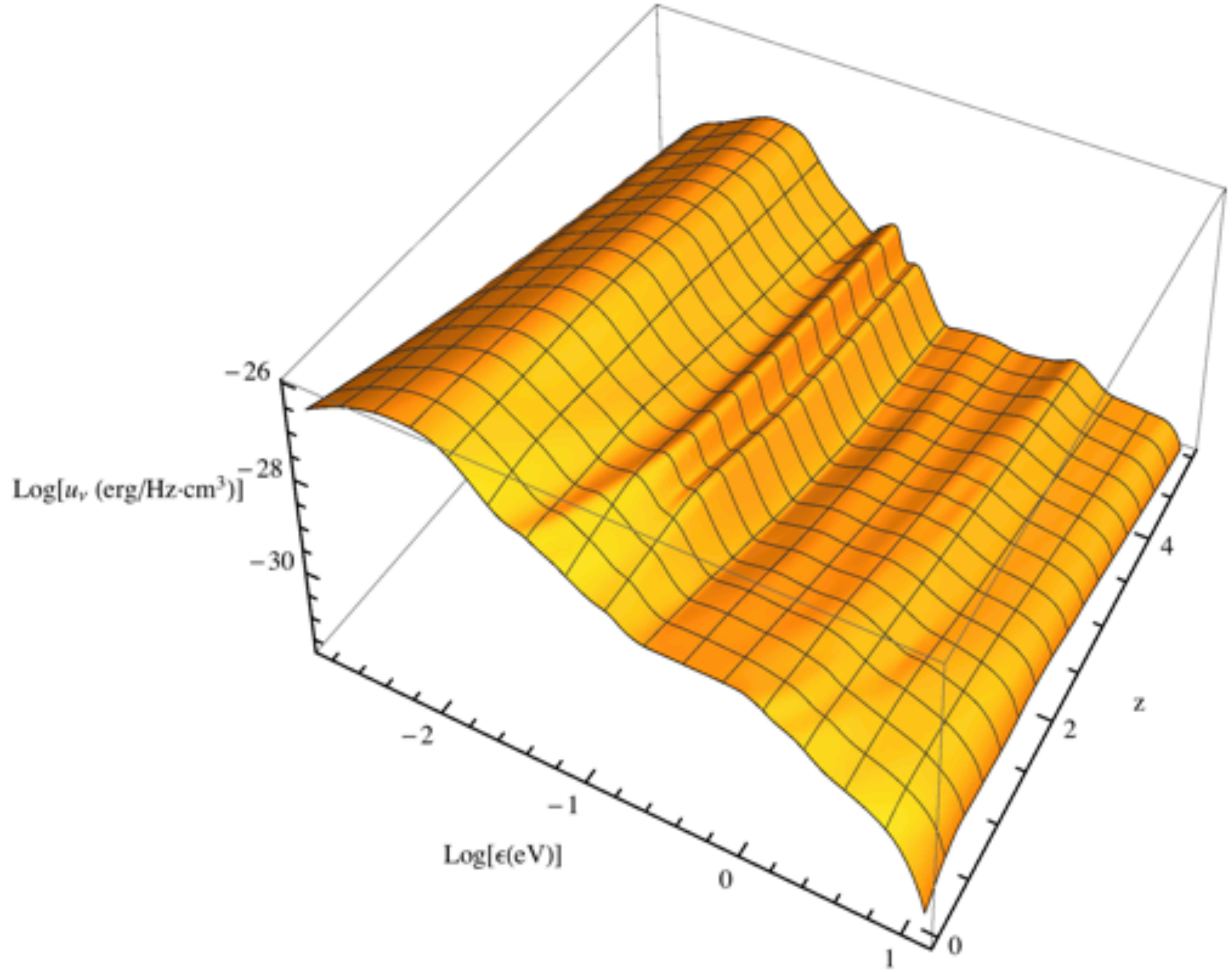


# 35 Micron to 250 Micron Luminosity Densities:

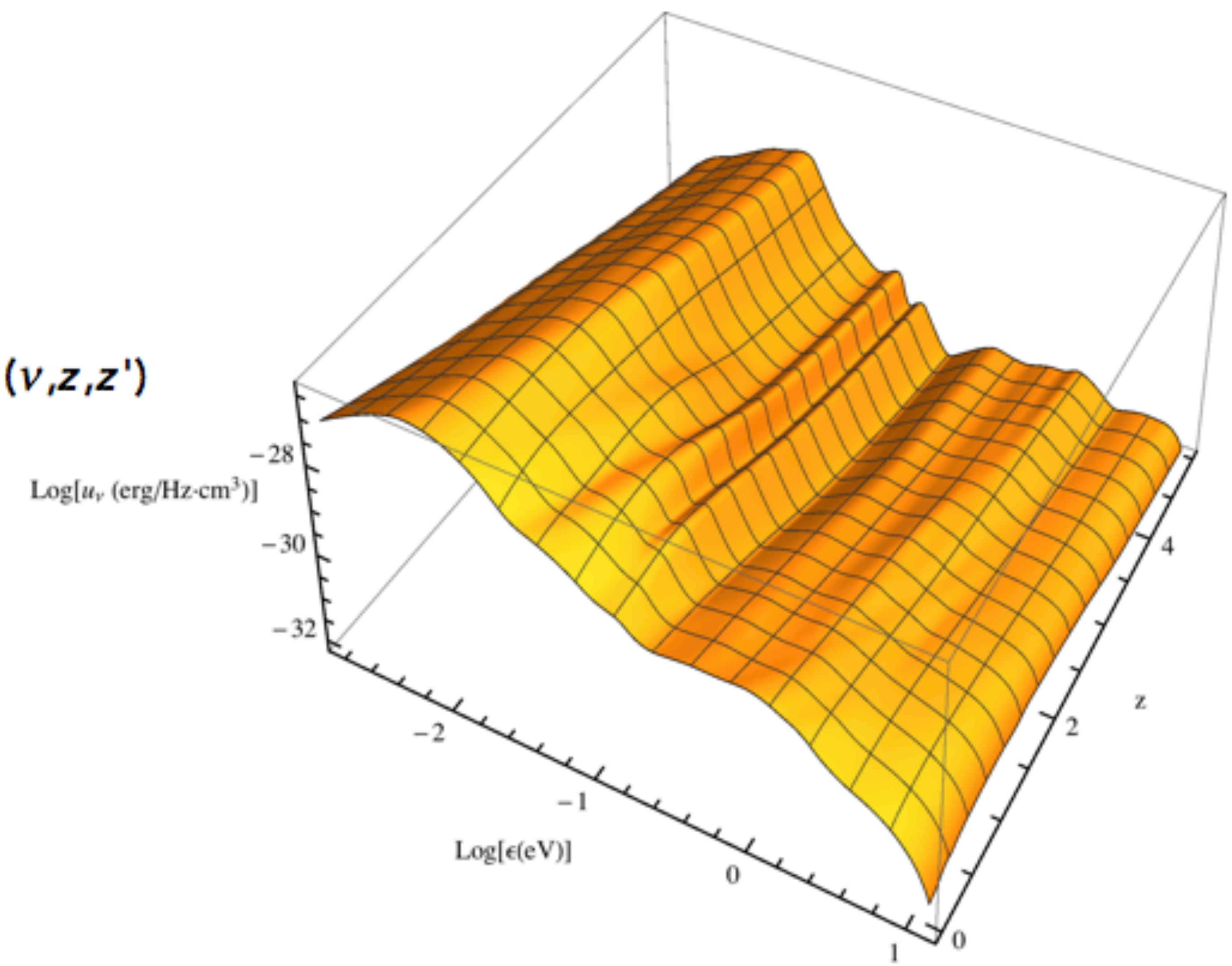


# Coming Soon!

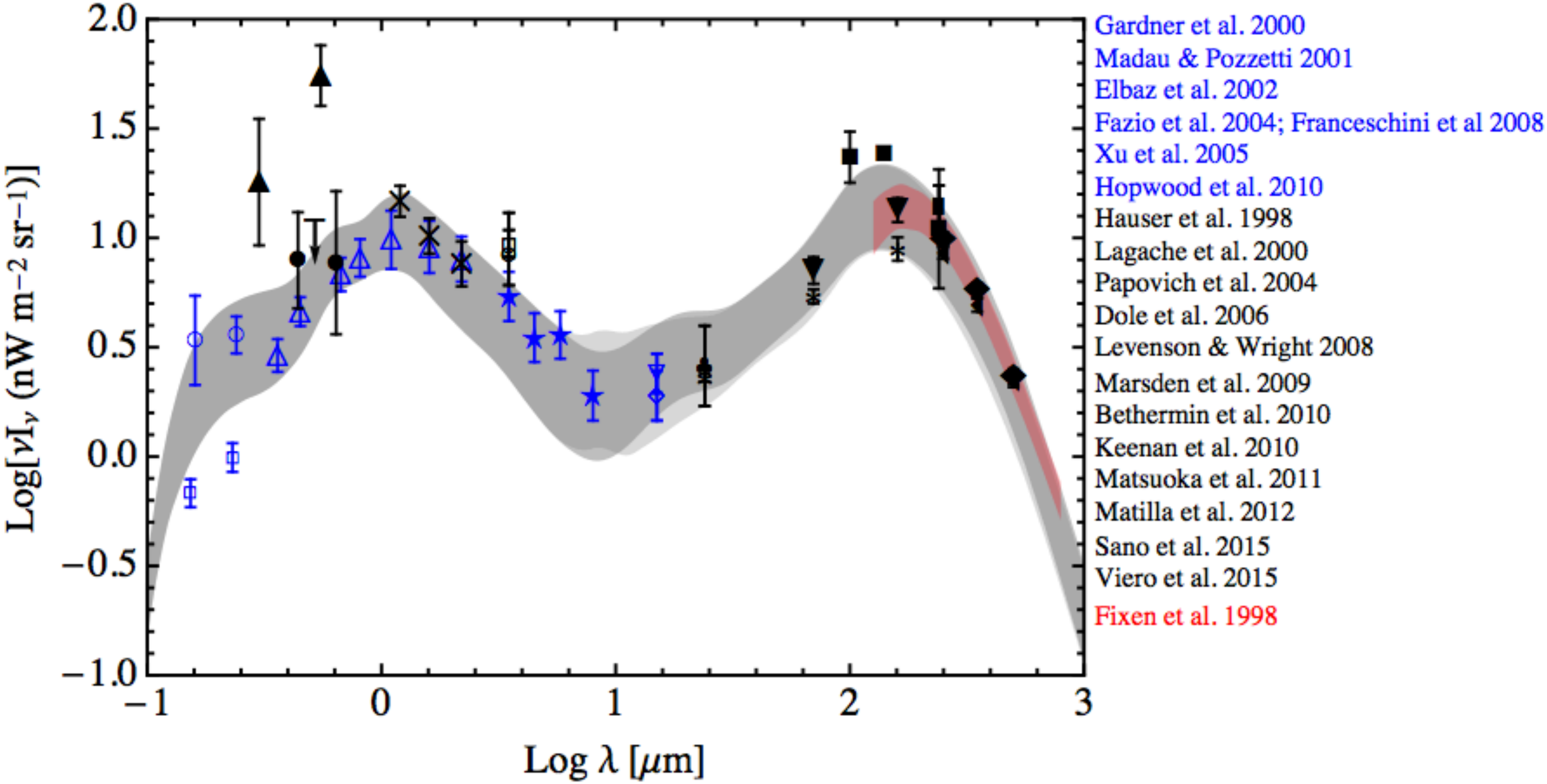
James Webb Space Telescope




$$u_\nu(z) = \int_z^{z_{max}} dz' \varepsilon_{\nu'}(z') \frac{dt}{dz}(z') e^{-\tau_{eff}(\nu,z,z')}$$



# Spectral Energy Distribution of the EBL: Comparison of our uncertainty band with measurements (black) and lower limits (blue)



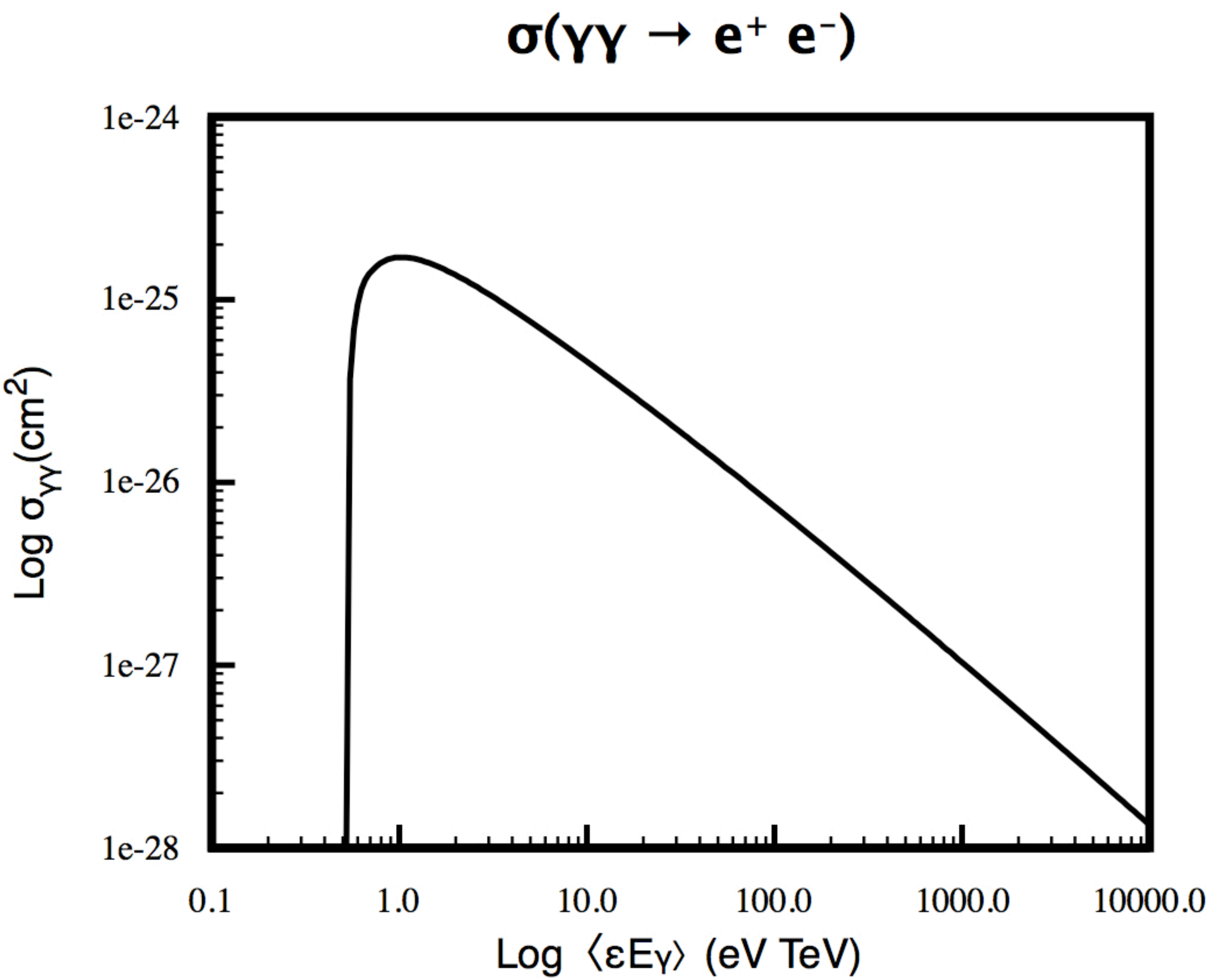
# *γ-ray Opacity from Pair Production from Deep Survey Data Compared with Observations*

*γ-ray extinction through mutual annihilation with intergalactic UV-IR photons.*

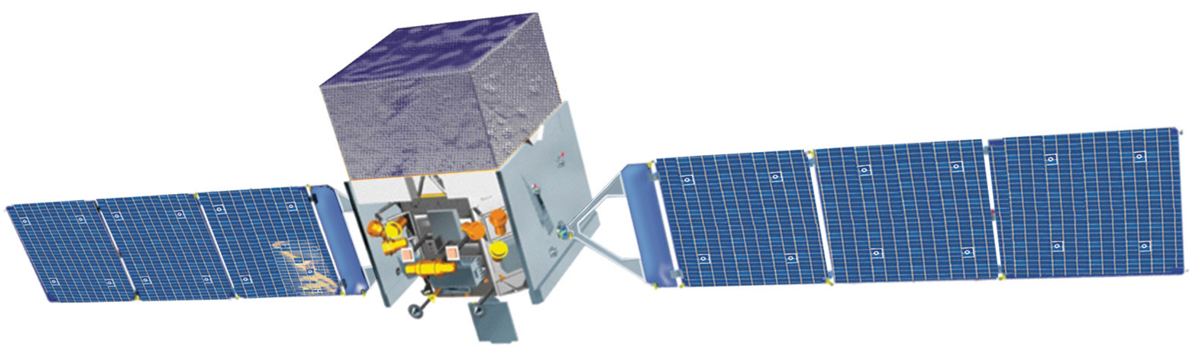
High energy γ-rays can interact with UV-IR photons emitted by galaxies through annihilation into electron-positron pairs:

$$\gamma + \gamma \longrightarrow e^{+} + e^{-}$$

# *Pair Production Cross Section*



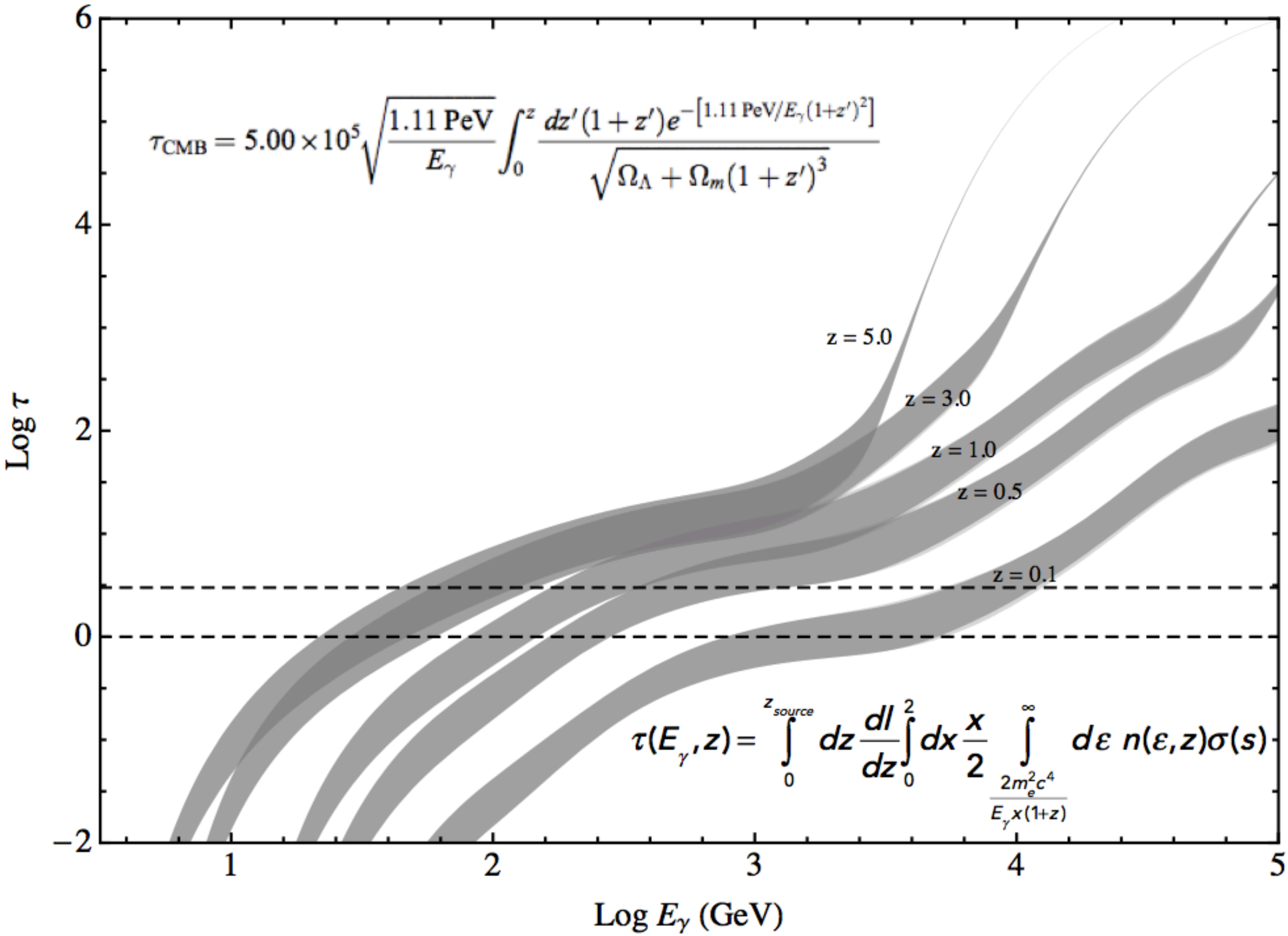
# Our opacity results cover the whole energy range of the *Fermi* Space Telescope and Air Cherenkov Telescopes

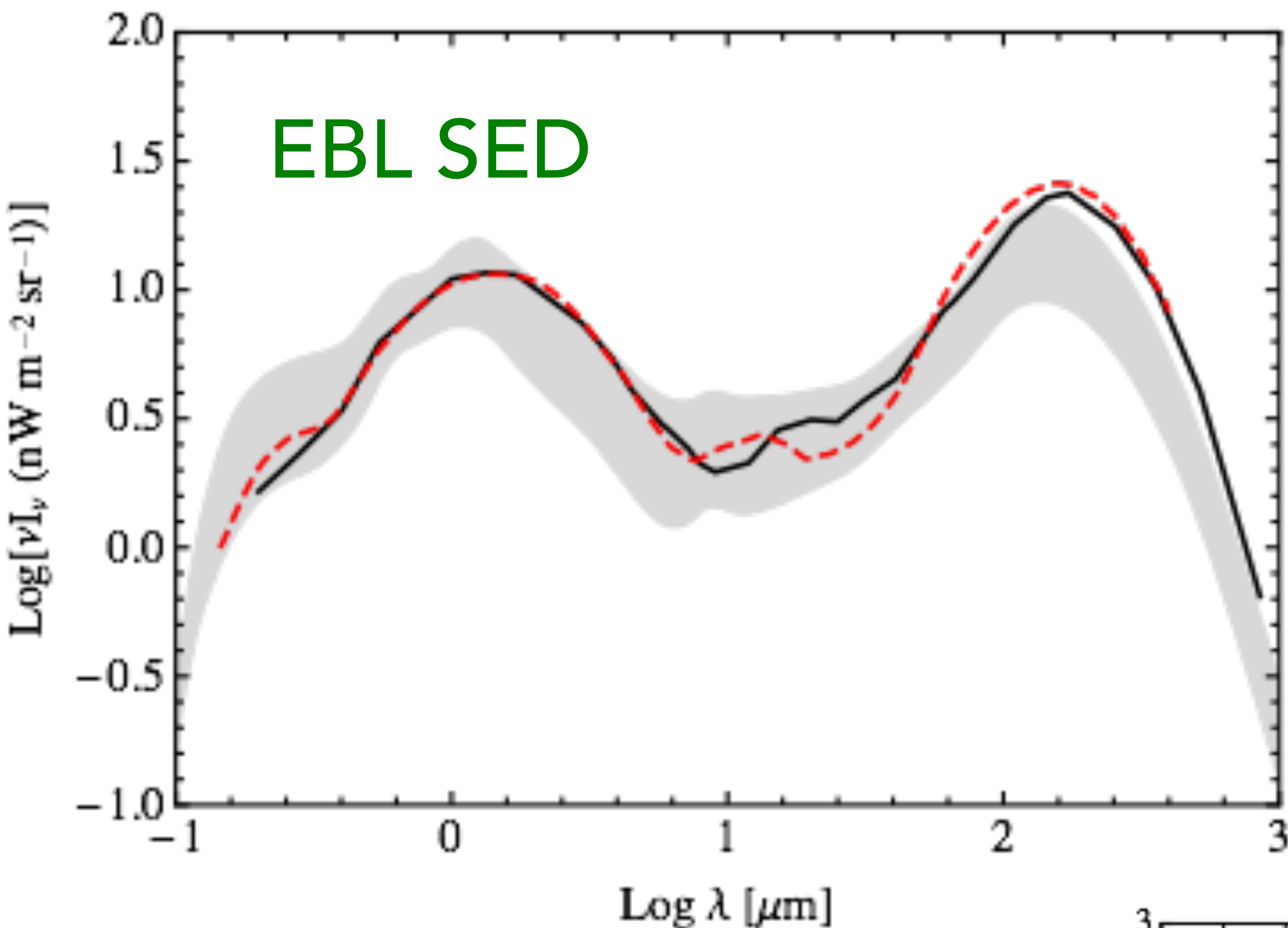


*Fermi* Space Telescope
(GeV energies)

Future Cherenkov Telescope Array
(TeV energies)

# γ-ray opacity through pair production versus energy



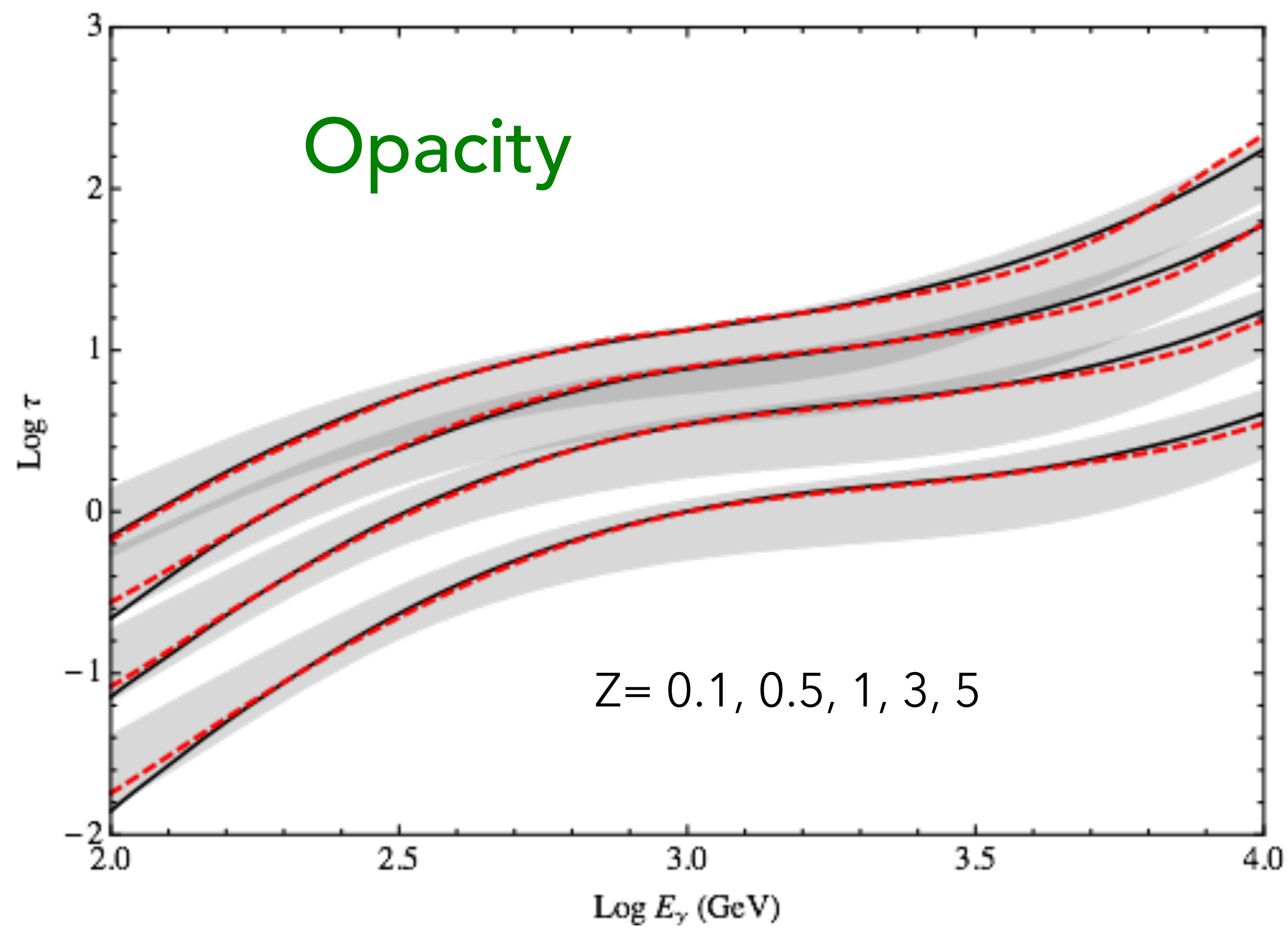



Comparison of our
68% confidence bands
with previous model results

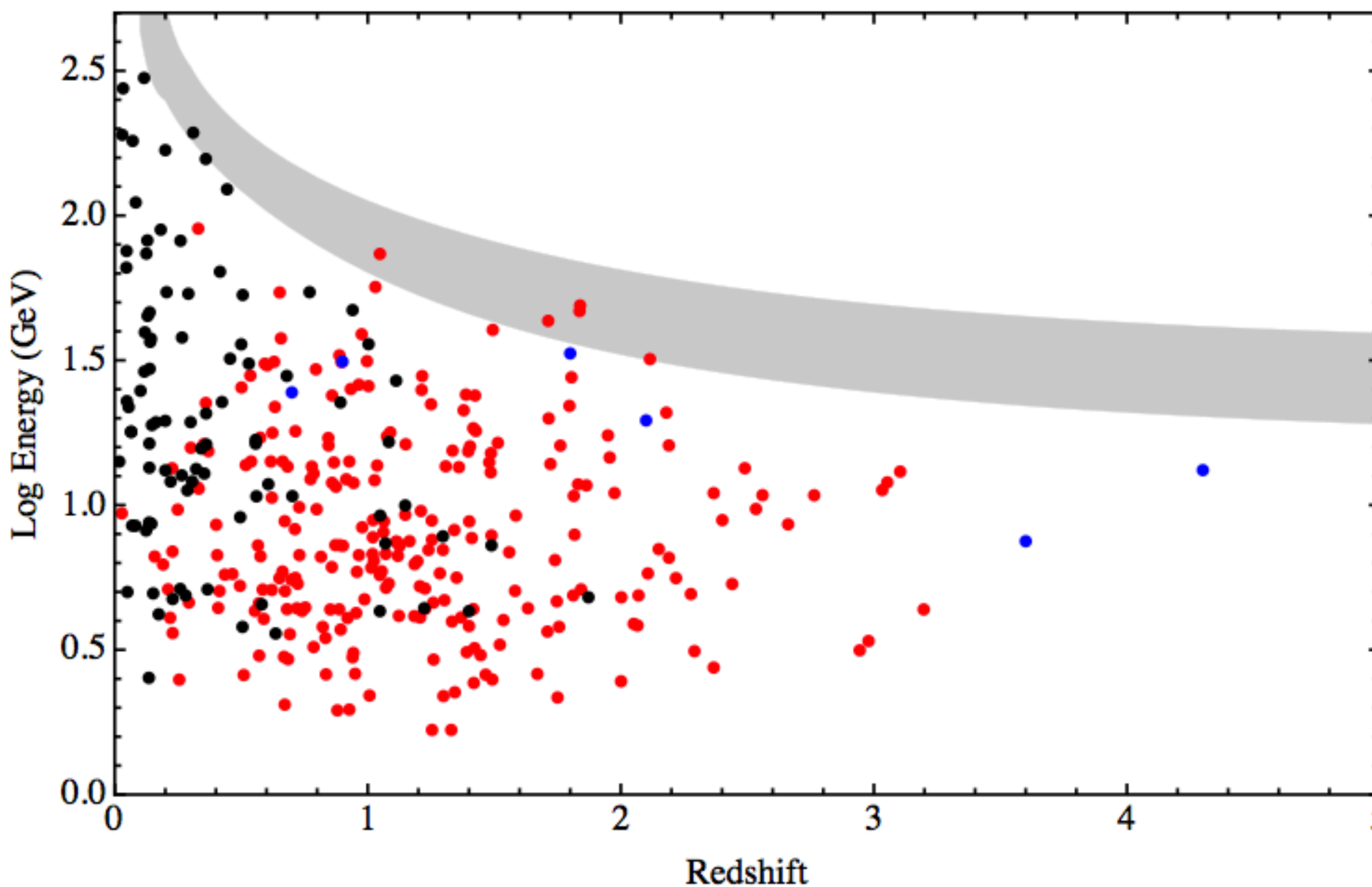
Solid black lines:
Franceschini et al. 2008*

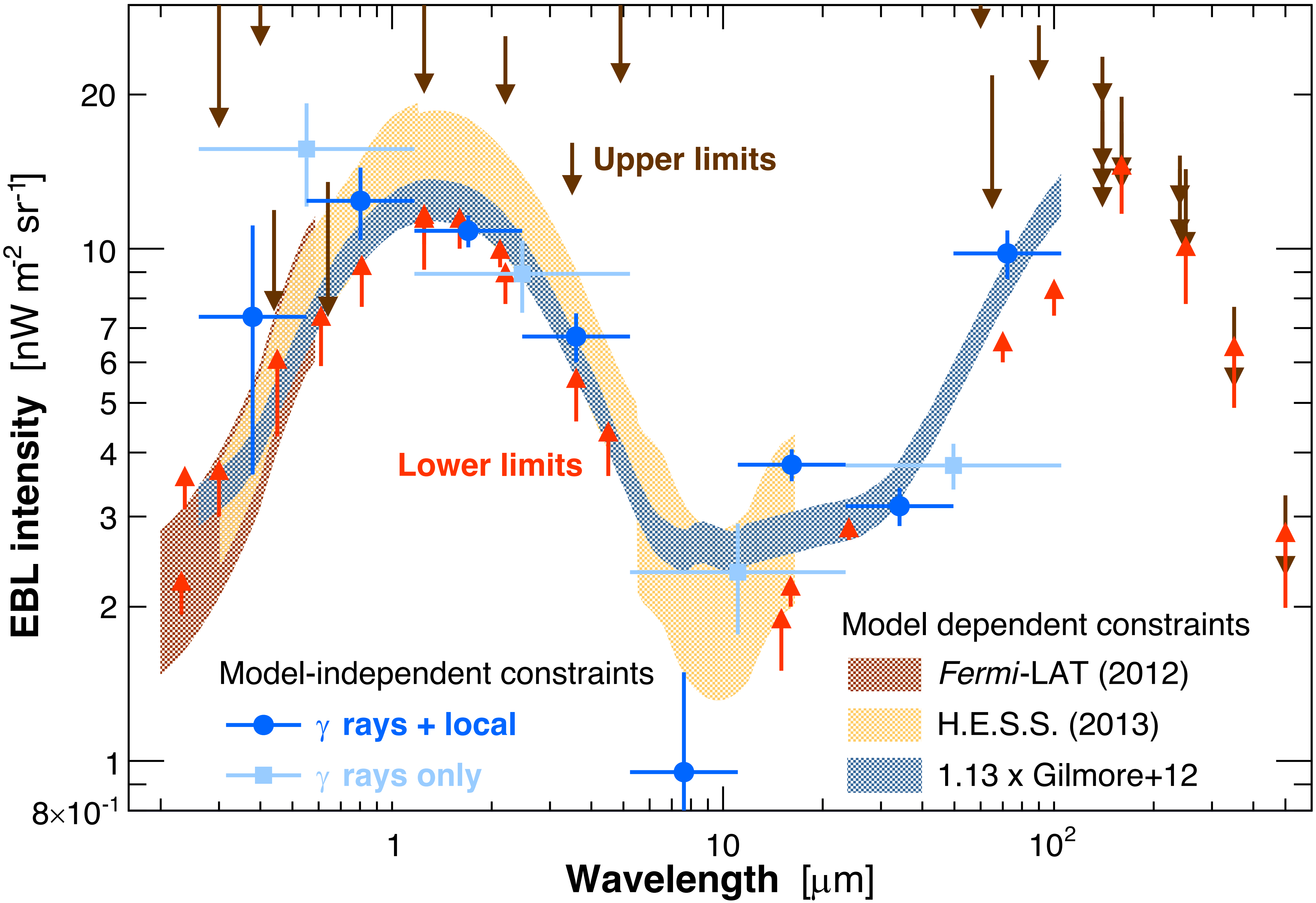
Dashed red lines:
Dominguez et al. 2011

*new model of Franceschini & Rodighero (2017)
gives a smaller FIR flux at ~ 100 microns.



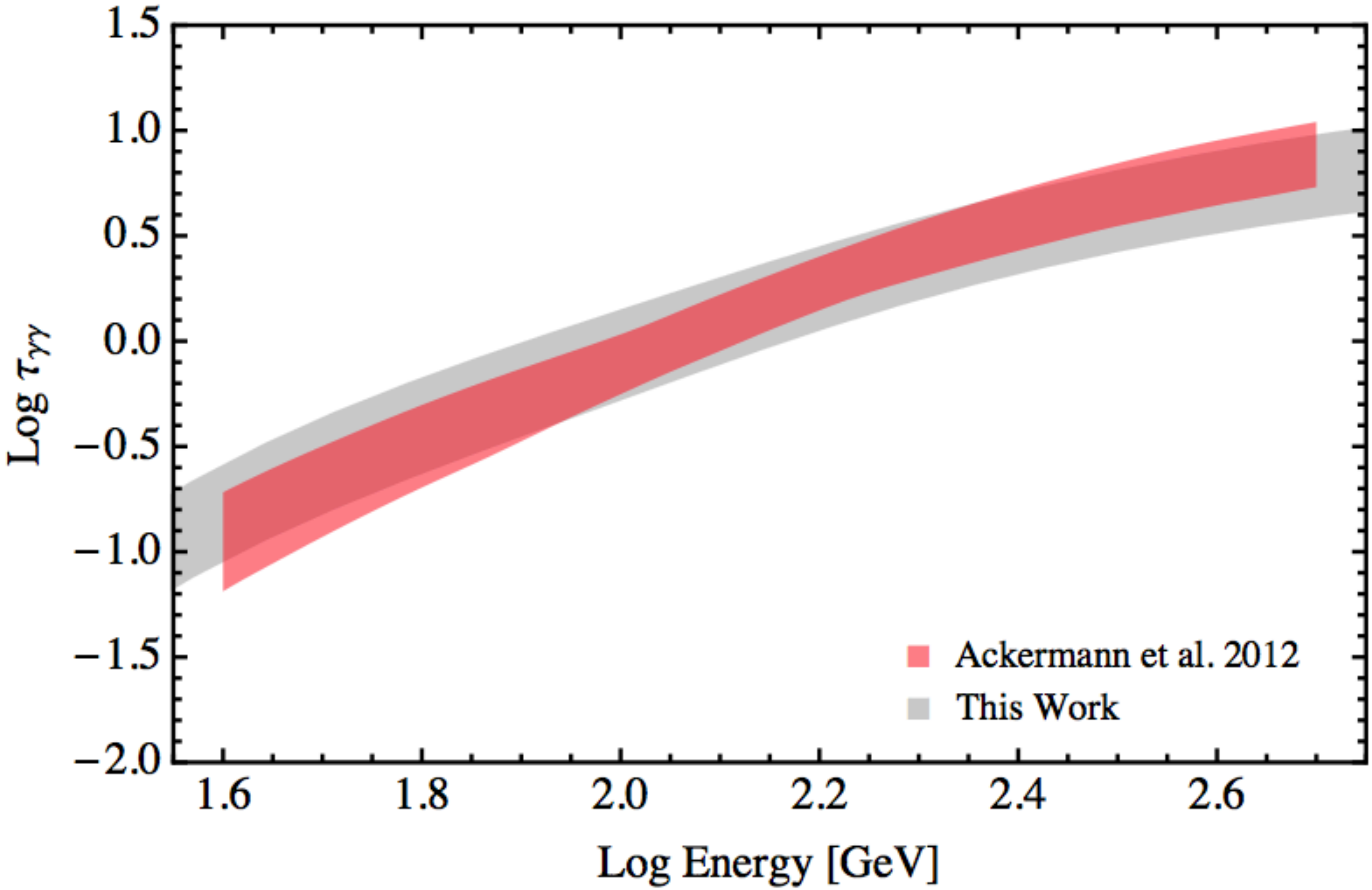
A τ = 1 energy-redshift plot (Fazio & Stecker 1970) showing our uncertainty band results compared with the Fermi plot of their highest energy photons from FSRQs (red), BL Lacs (black) and GRBs (blue) vs. redshift (from Abdo et al. 2010).






EBL from γ-ray observations (Biteau & Williams 2015)

A comparison of our *z = 1* opacity band with the results derived from *Fermi* data given by Ackermann et al. (2012).



# Conclusions

*Our results as obtained by using deep galaxy survey data generally agree with recent results from modeling, but our method allows us to derive real empirically-based error bars and uncertainties.*

*The overlap of our absorption results with previous results derived from Fermi γ-ray spectral data implies that there is no evidence for other modifications of γ-ray spectra from effects such as photon-axion oscillations or secondary γ-ray components.*

*Next generation ground-based γ-ray telescopes such as the Cherenkov Telescope Array will probe the universe in the tens of TeV range. Our far-IR results will enable the interpretation of extragalactic source spectra from these telescopes and can also place strong constraints on Lorentz invariance violation.*