The Intergalactic IR Luminosity Density $\rho_L(\lambda,z)$ and the γ-ray Opacity of the Universe

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Determining the EBL using Deep Galaxy Surveys

- Has the advantage over modeling galaxy SEDs by determining real, observationally based error bands on luminosity densities, $\rho_L(\lambda,z)$ (Helgason et al. 2012; Stecker et al. 2012).

- Compliments the Blazar γ-ray Absorption Method (Stecker et al 1992) in probing for other potential effects modifying γ-ray spectra: *e.g.*, axions, Lorentz invariance violation, secondary components. Can compare our galaxy survey method with recent such studies (Ackermann et al. 2012; Biteau & Williams 2015).

- Does not depend on assuming a blazar source spectrum shape in order to determine the EBL.

- Our new work extends our previous studies into the MIR and FIR using surveys from *AKARI, Herschel*, and *Spitzer*.

Goal is to Determine the Opacity of the Universe to γ-rays over the Whole Energy Range of the Fermi Space Telescope and Air Cherenkov Telescopes

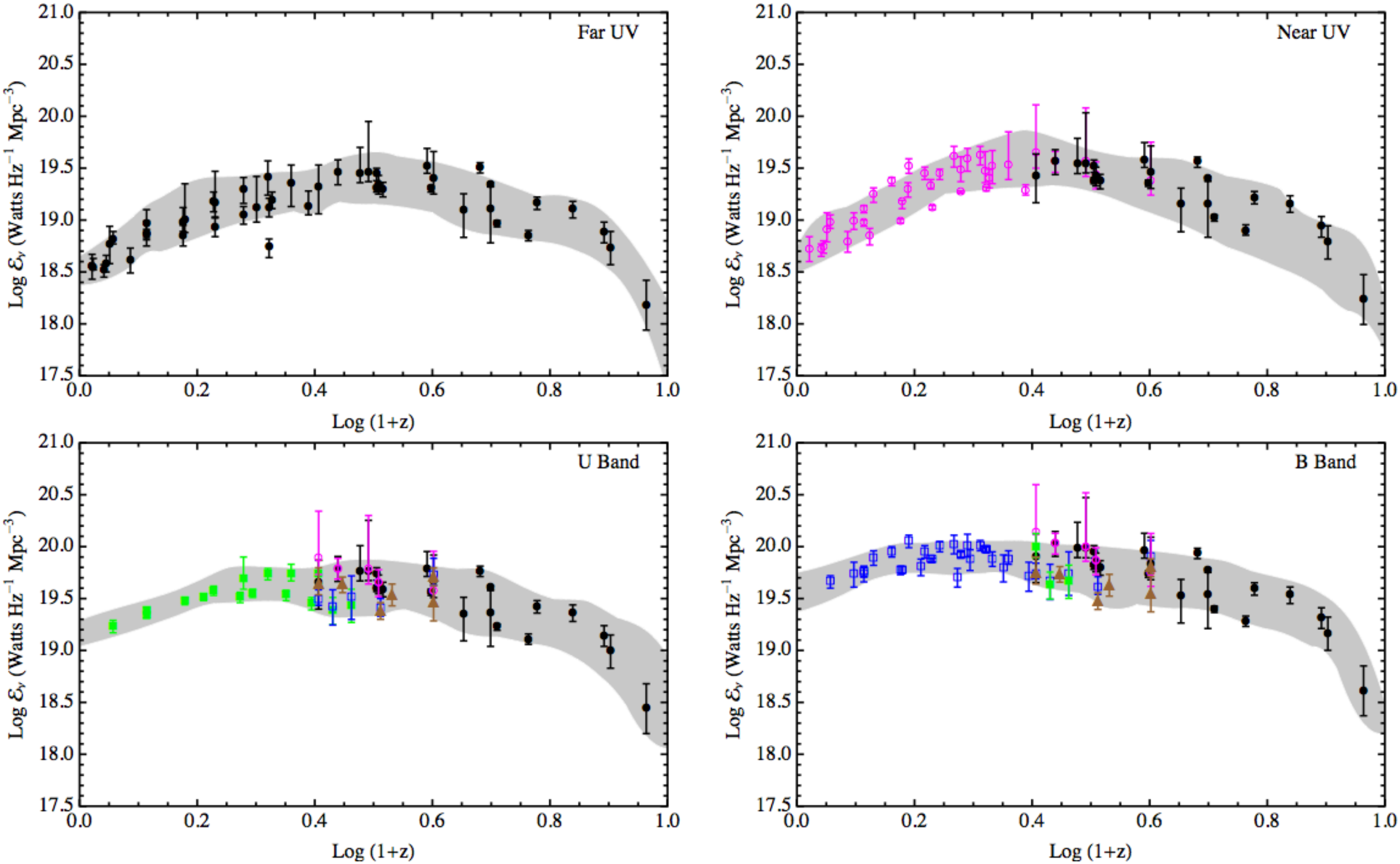
Fermi Space Telescope

Cherenkov Telescope Array

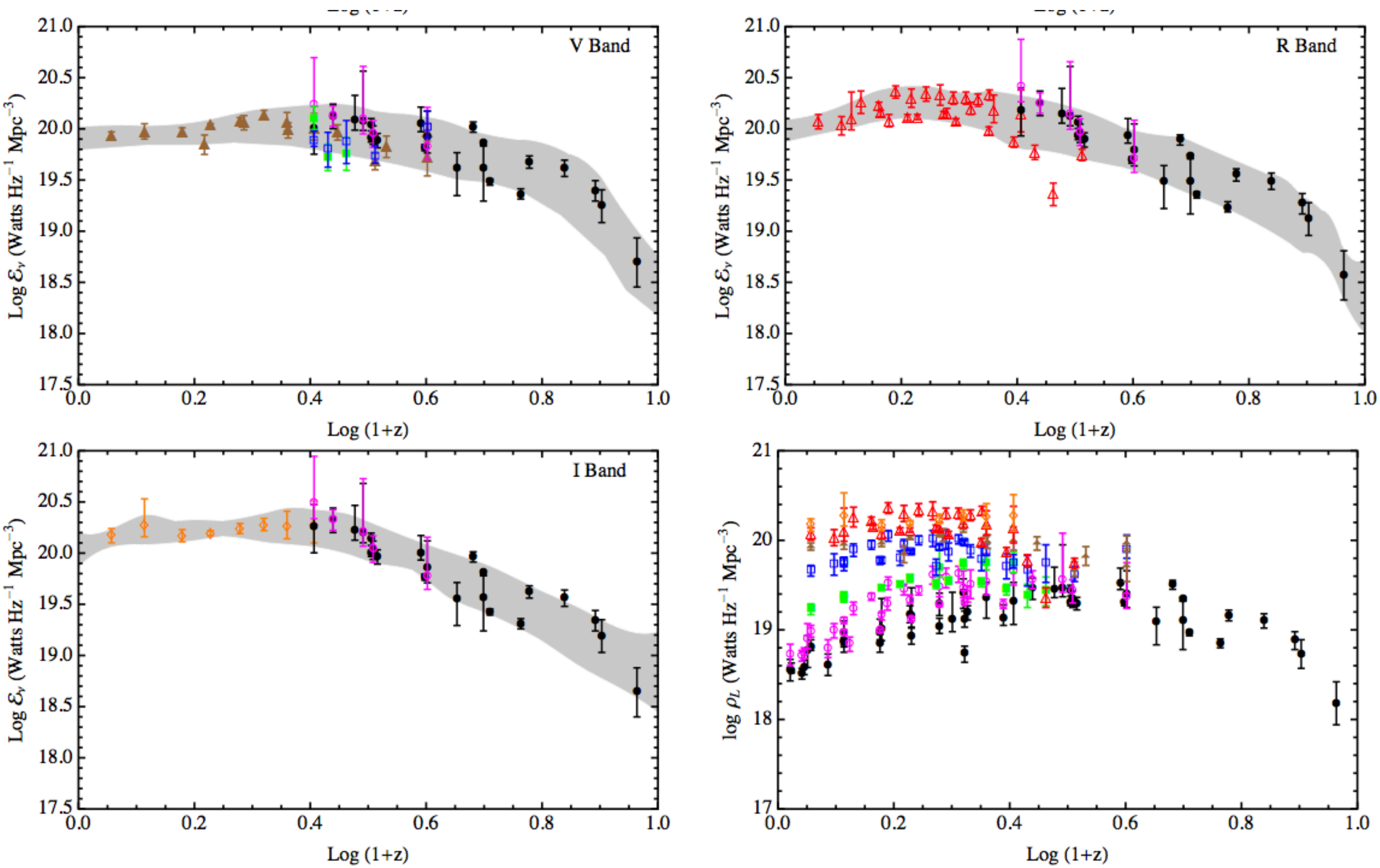
Observations of galaxy luminosity densities at UV to NIR wavelengths with 68% confidence bands (in gray) derived from Monte Carlo treatment of observational errors using a robust fitting function in redshift (next 3 slides) .

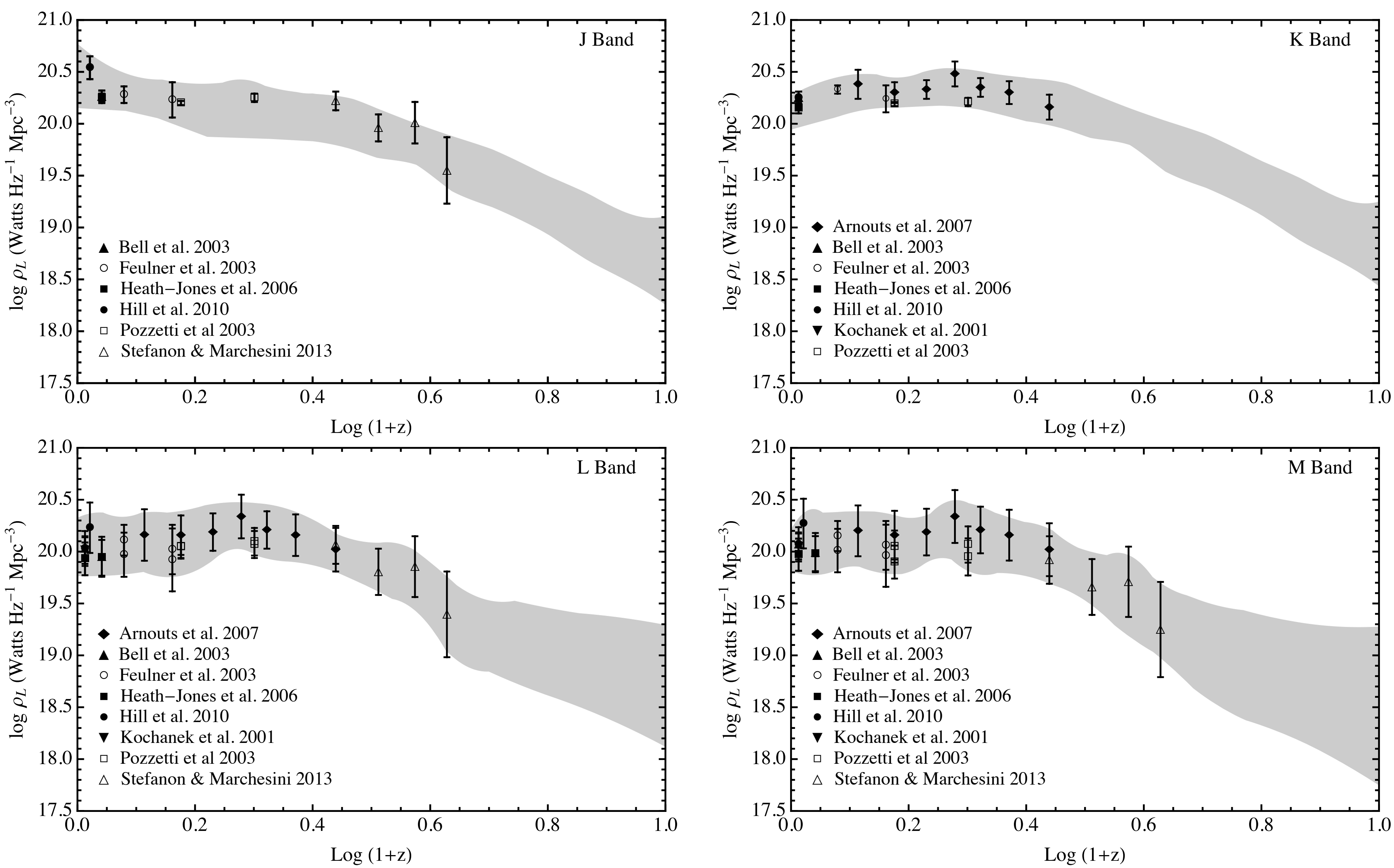
Stecker, Malkan & Scully 2012, ApJ 761:128

Scully, Malkan & Stecker 2014, ApJ 784:138

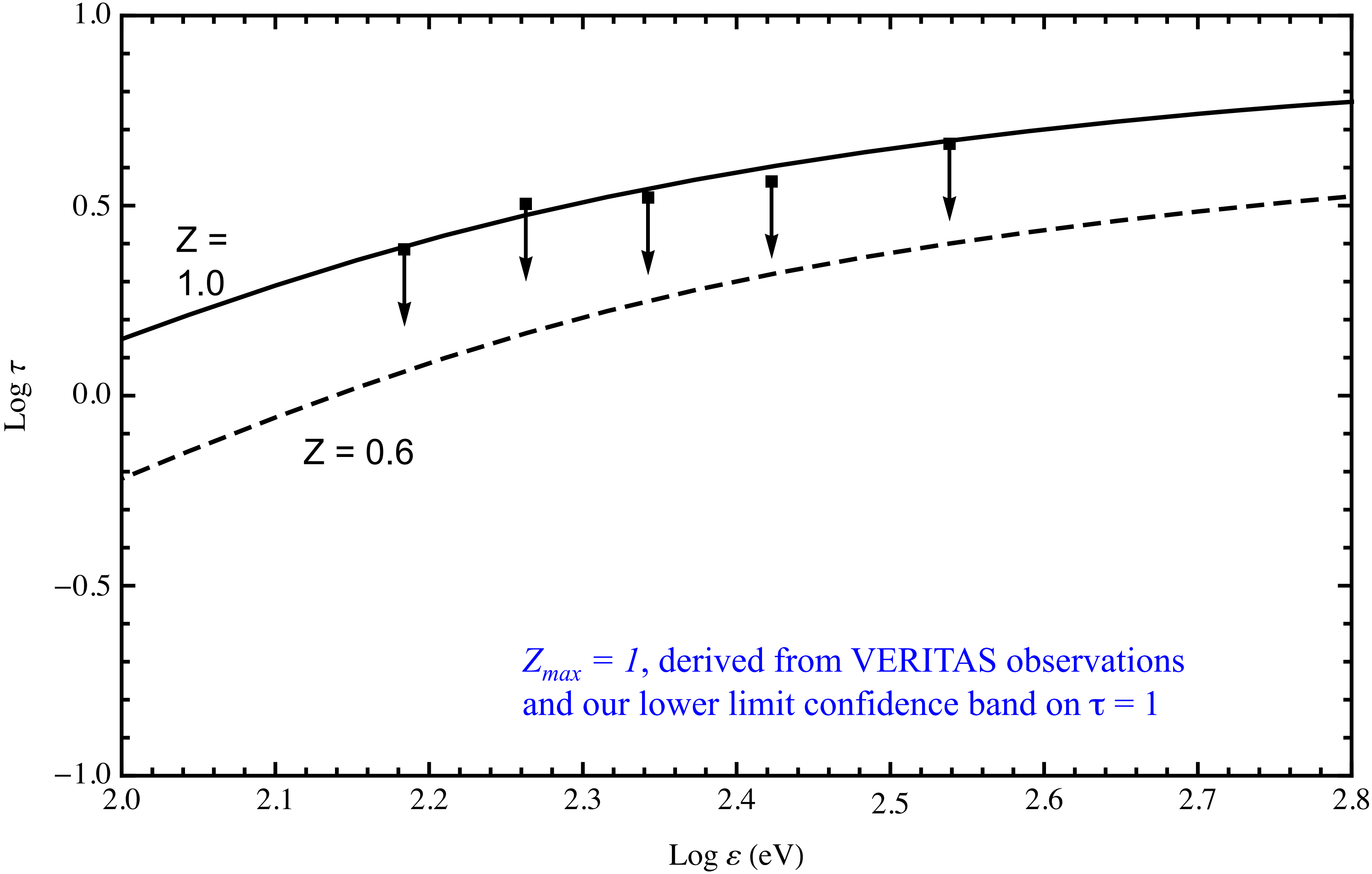


Far UV
Near UV
U Band
B Band
Log $\mathcal{E}_\nu$ (Watts Hz^{-1} Mpc^{-3})
Log (1+z)
21.0
20.5
20.0
19.5
19.0
18.5
18.0
17.5
0.0
0.2
0.4
0.6
0.8
1.0


V Band
R Band
I Band
Log $\mathcal{E}_\nu$ (Watts Hz^{-1} Mpc^{-3})
log ρ_L (Watts Hz^{-1} Mpc^{-3})
Log (1+z)

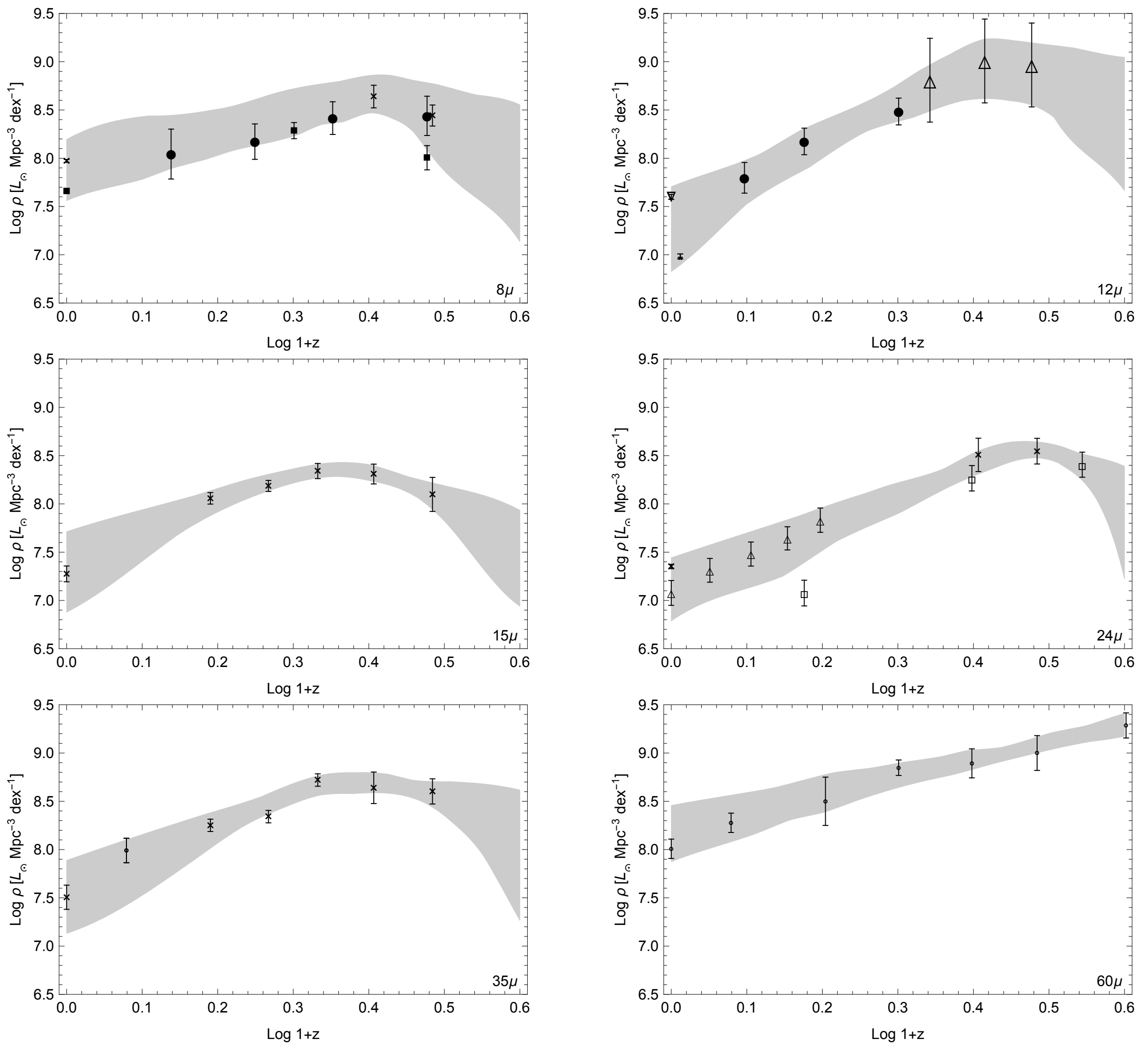

J Band
K Band
L Band
M Band
log ρ_L (Watts Hz^{-1} Mpc^{-3})
Log (1+z)
Arnouts et al. 2007
Bell et al. 2003
Feulner et al. 2003
Heath−Jones et al. 2006
Hill et al. 2010
Kochanek et al. 2001
Pozzetti et al 2003
Stefanon & Marchesini 2013

Opacity Upper Limit on the Redshift of PKS1424+240

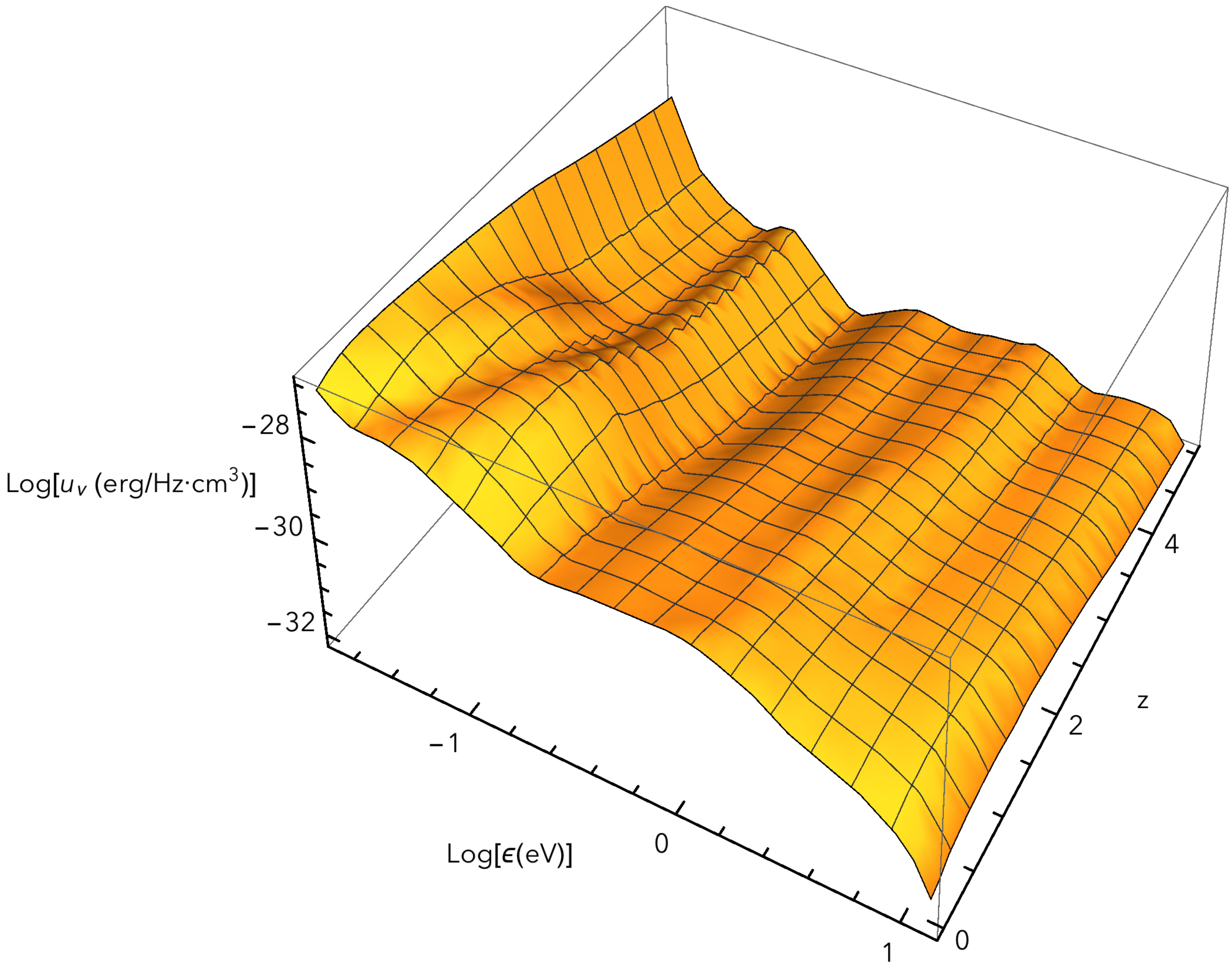


New Results on Luminosity Densities from Galaxy Surveys from *AKARI*, *Spitzer*, *Herschel* allow us to Extend our Calculations into the MIR and FIR

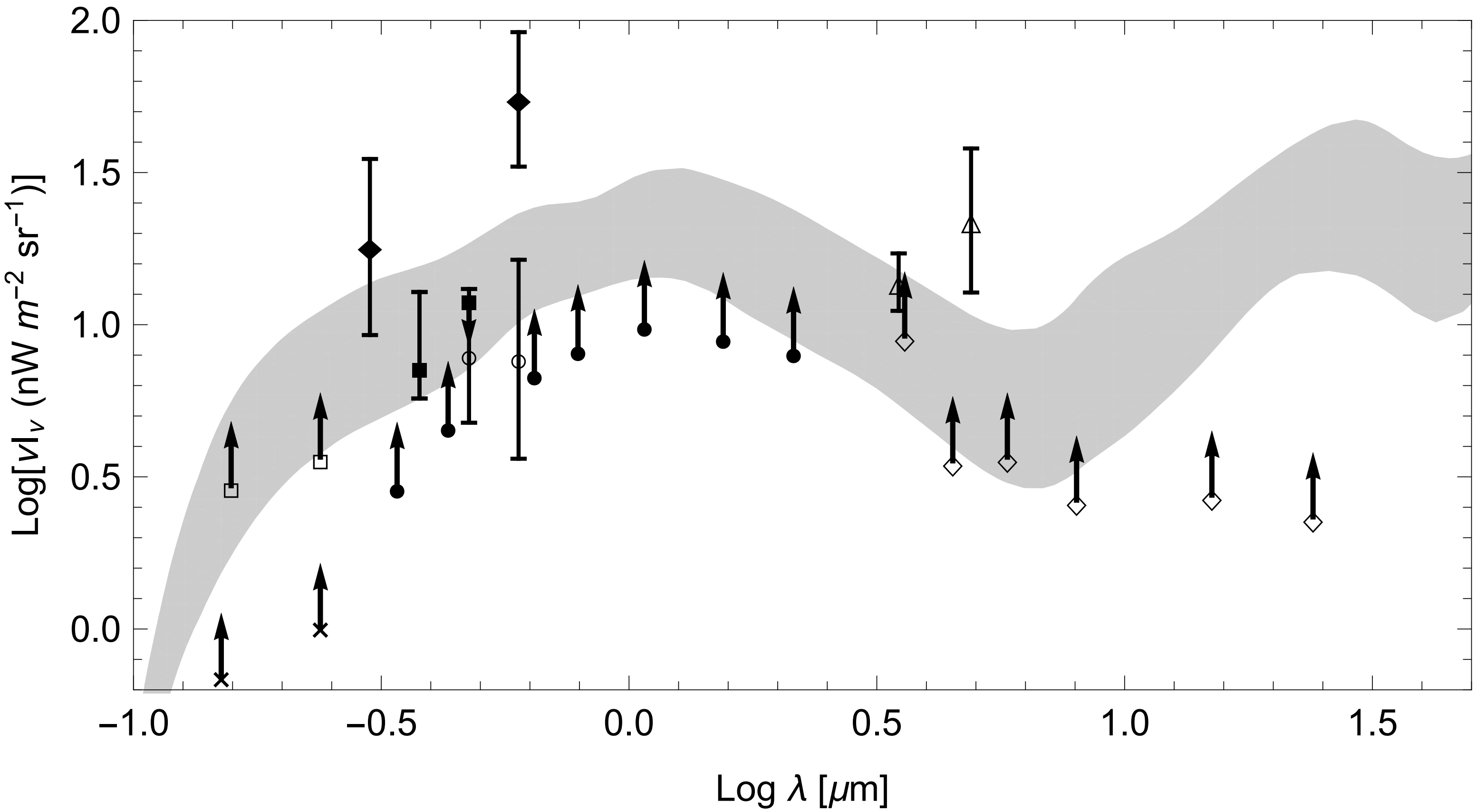
IR Luminosity Densities



Comoving Photon Energy Densities

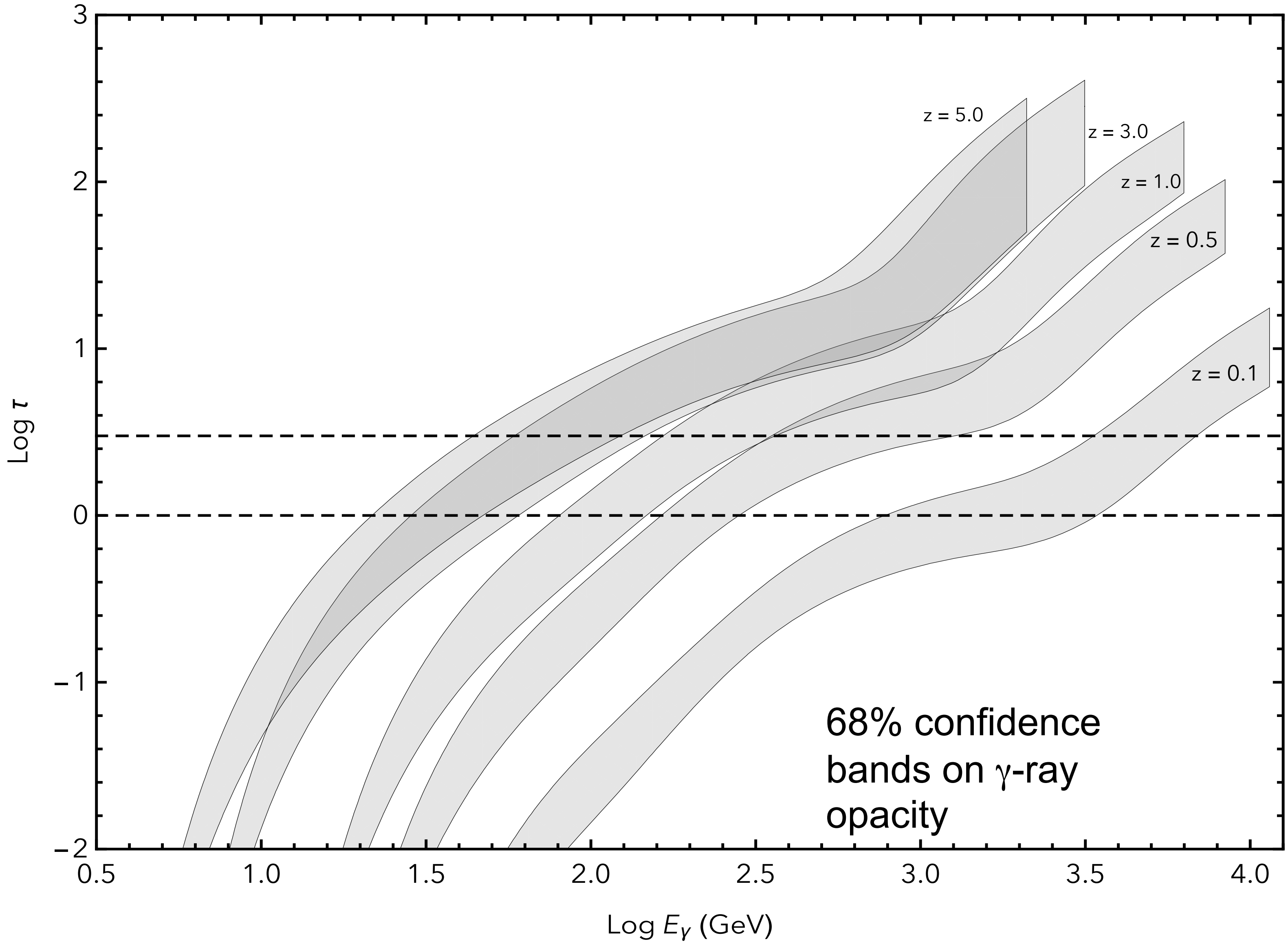


Extragalactic Background Light

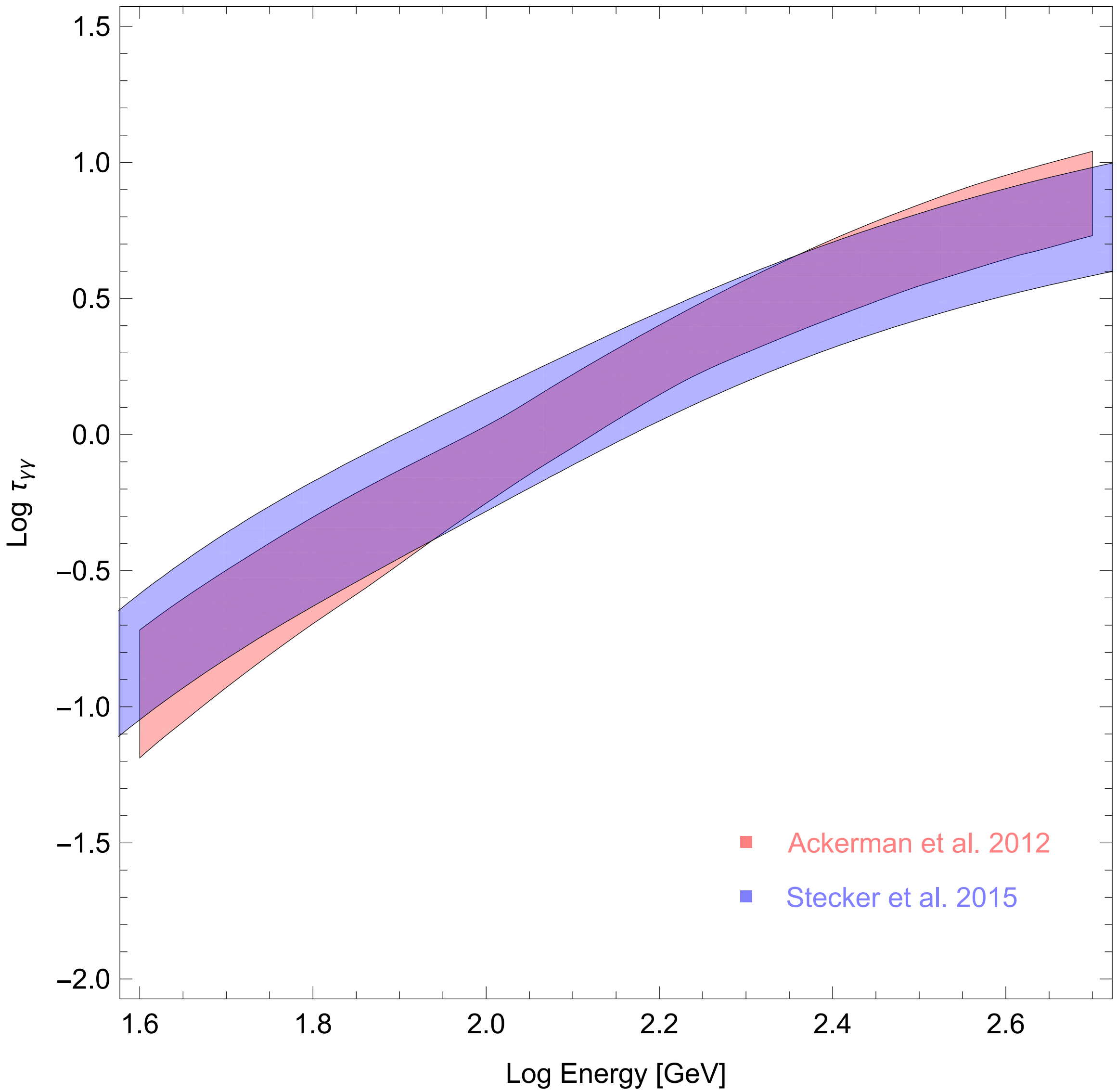


Our empirically-based determination of the *z = 0* EBL together with lower limits from Madau & Pozzetti (2000)[Black Circles] and Xu et al.(2005) [Crosses] and upper limits from Gardner et al.(2000).

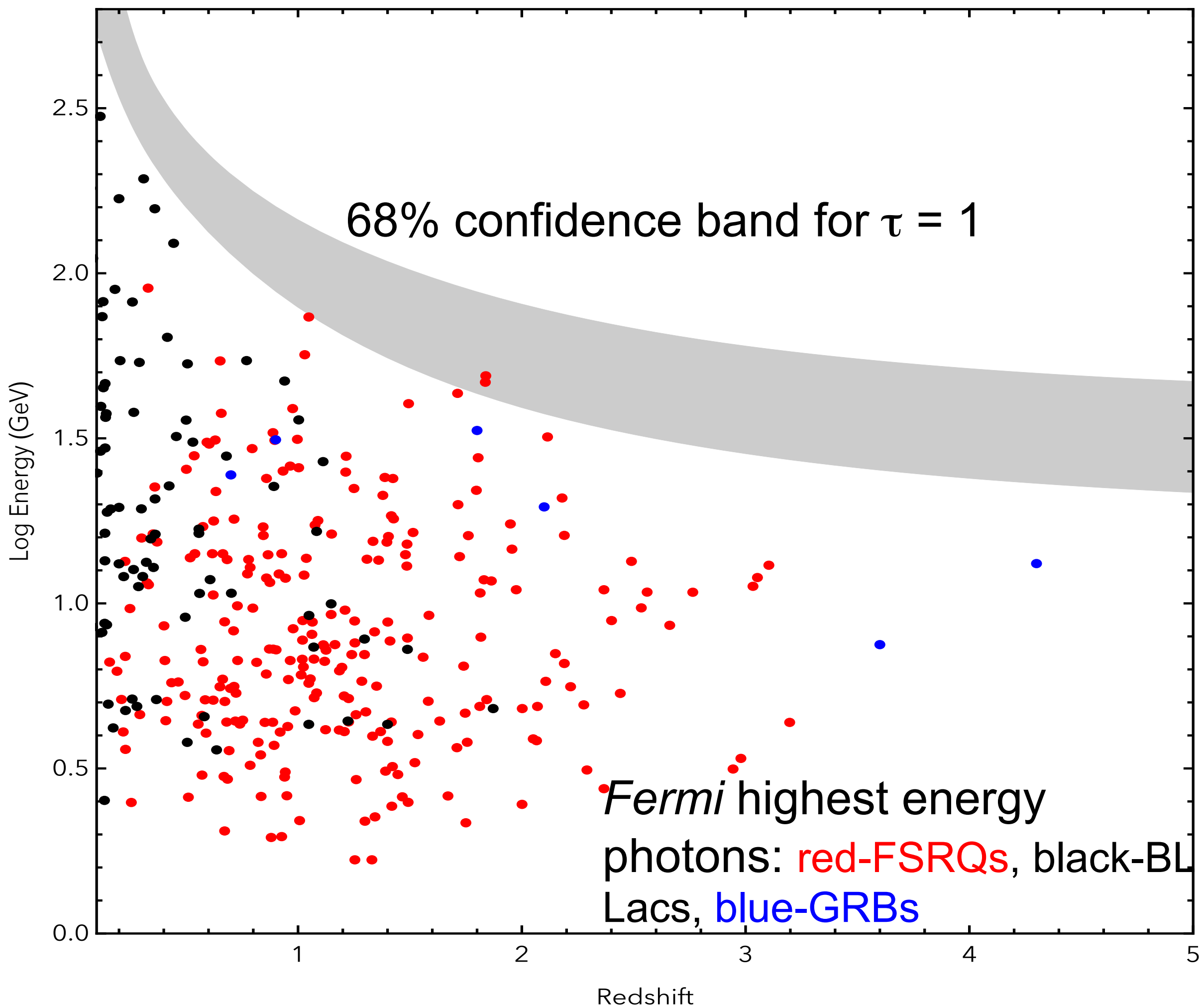
γ-ray Opacity Results
(Accurate up to $E_{max} = 0.21\ \lambda\ (\mu m)/(1+z)$ TeV)



Comparison with Fermi Results for z = 1 (Ackermann et al. 2012)



Fermi Photons are Within Our Confidence Band $\tau = 1$



A $\tau = 1$ 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 and GRBs (blue) vs. redshift (from Abdo et al. 2010).

We are presently extending our results to 250 μm and will also include the effect of interactions with the 2.7 K CBR.

The optical depth of the universe to the CMB is given by

$$\tau_{\mathrm{CMB}} = 5.00 \times 10^5 \sqrt{\frac{1.11\,\mathrm{PeV}}{E_\gamma}} \int_0^z \frac{dz'\,(1+z')e^{-\left[1.11\,\mathrm{PeV}/E_\gamma(1+z')^2\right]}}{\sqrt{\Omega_\Lambda + \Omega_m(1+z')^3}}$$

(Fazio & Stecker 1970; Stecker et al. 2006).

We note that interactions with the CBR dominated over those of the EBL at energies above

$E_c \sim 10^3/(1+z)^2$ TeV.