

*The Intergalactic IR Luminosity  
Density  $\rho_L(\lambda, z)$  and the  $\gamma$ -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  $\gamma$ -ray Absorption Method (Stecker et al 1992) in probing for other potential effects modifying  $\gamma$ -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  $\gamma$ -rays over the Whole Energy Range of the Fermi Space Telescope and Air Cherenkov Telescopes*



Fermi Space Telescope

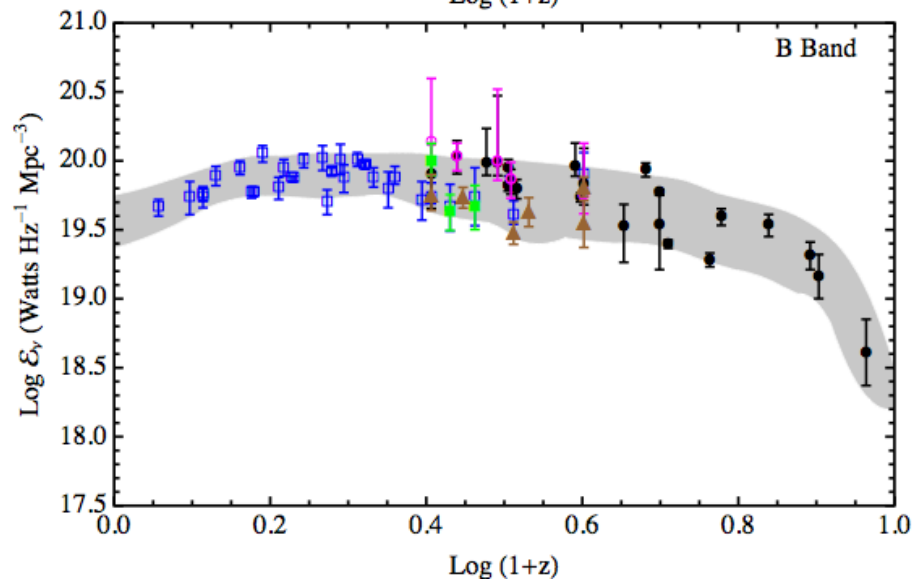
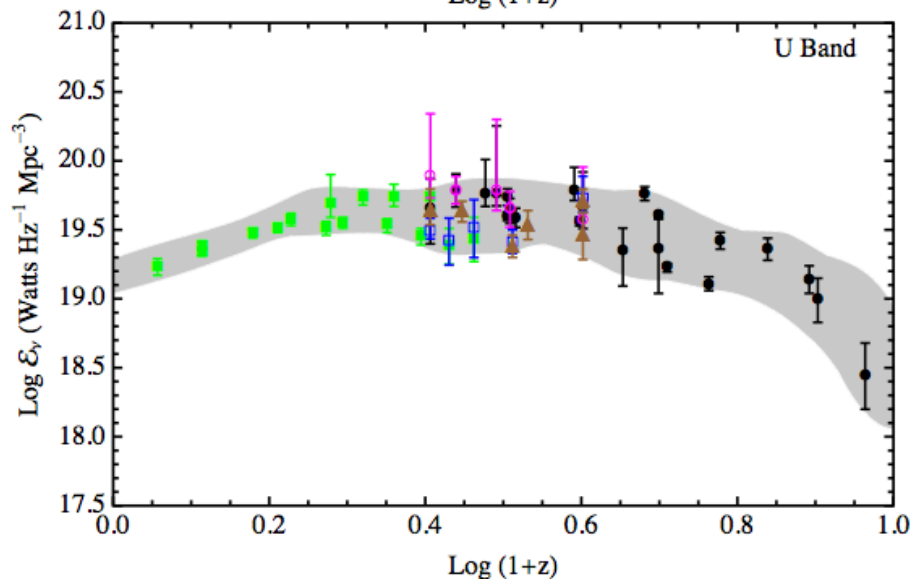
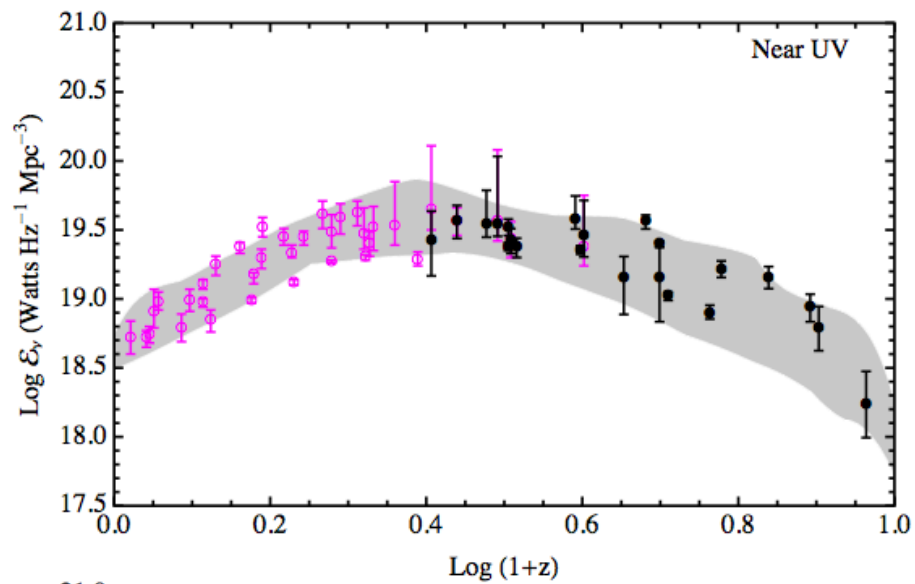
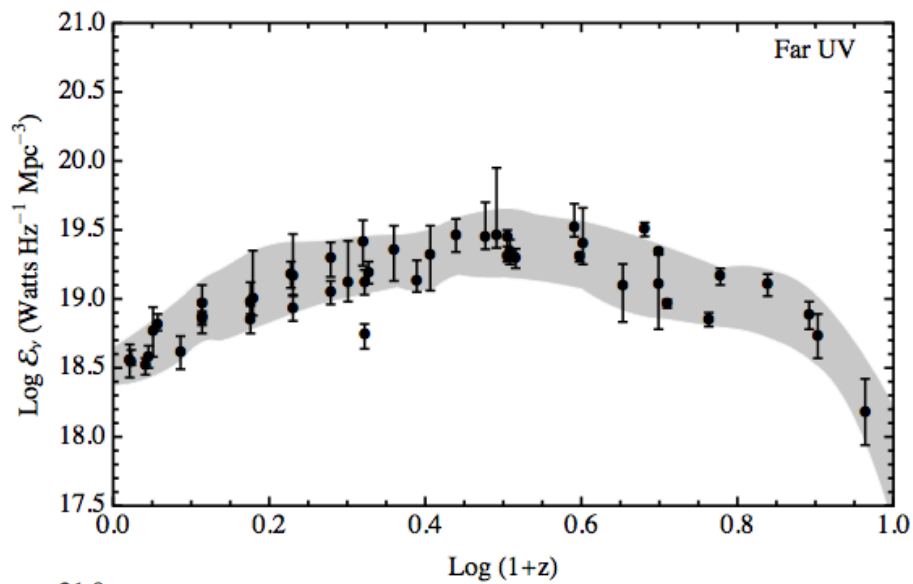


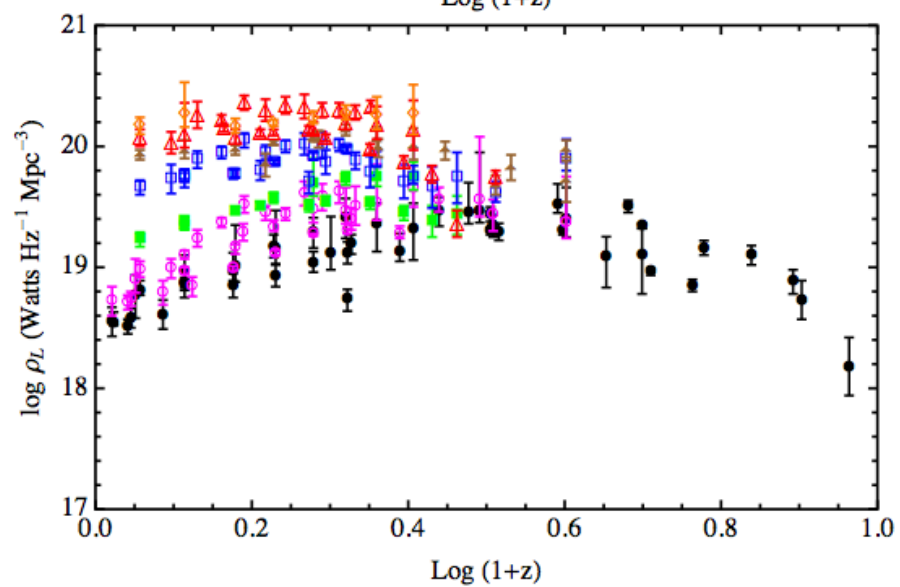
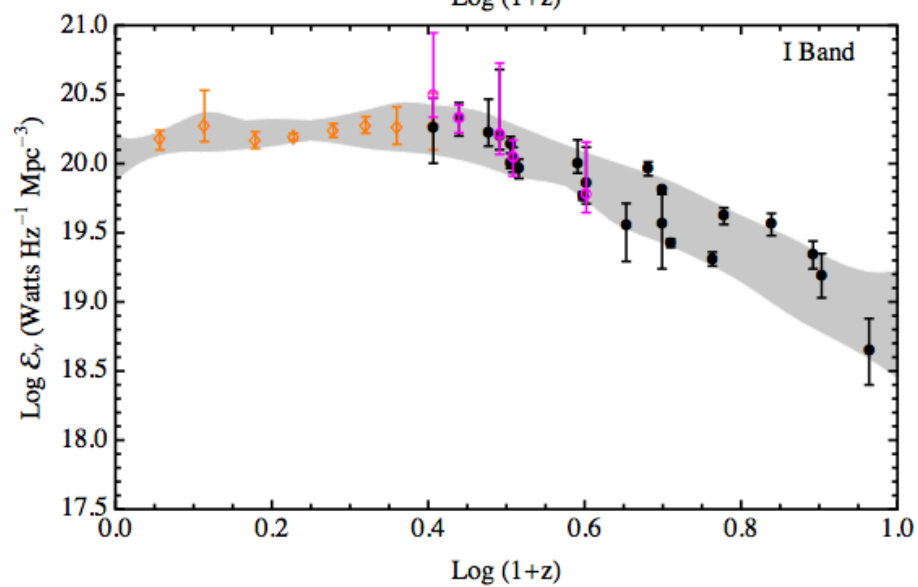
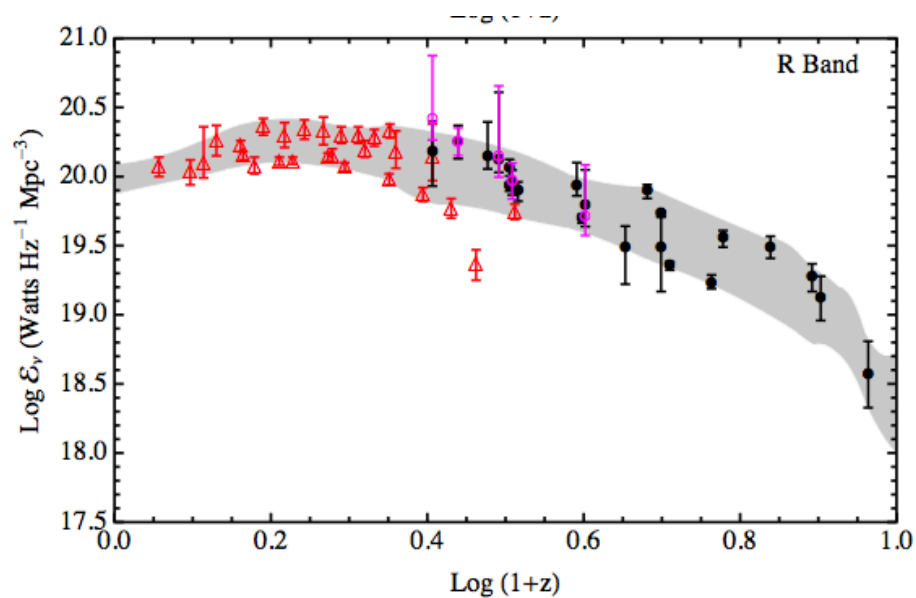
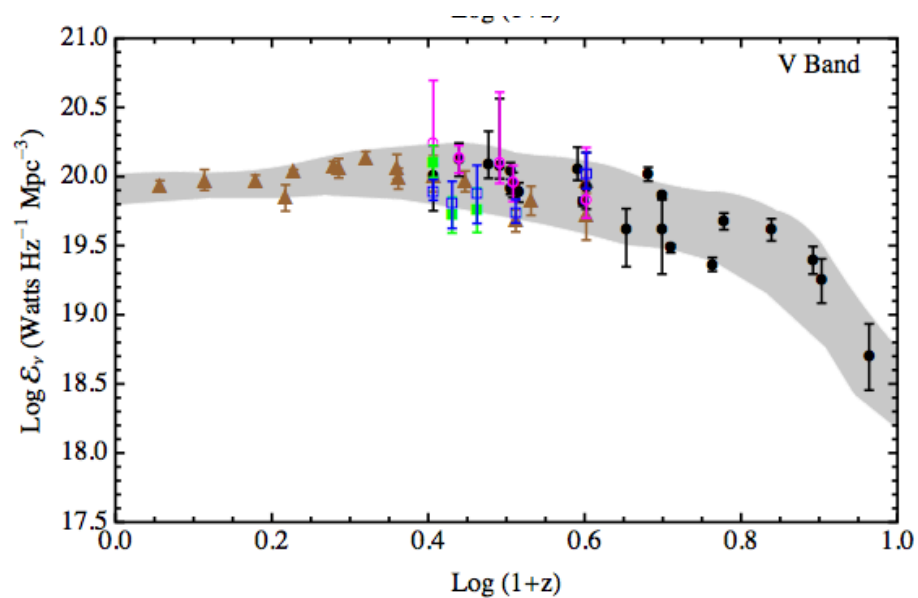
Cherenkov Telescope Array

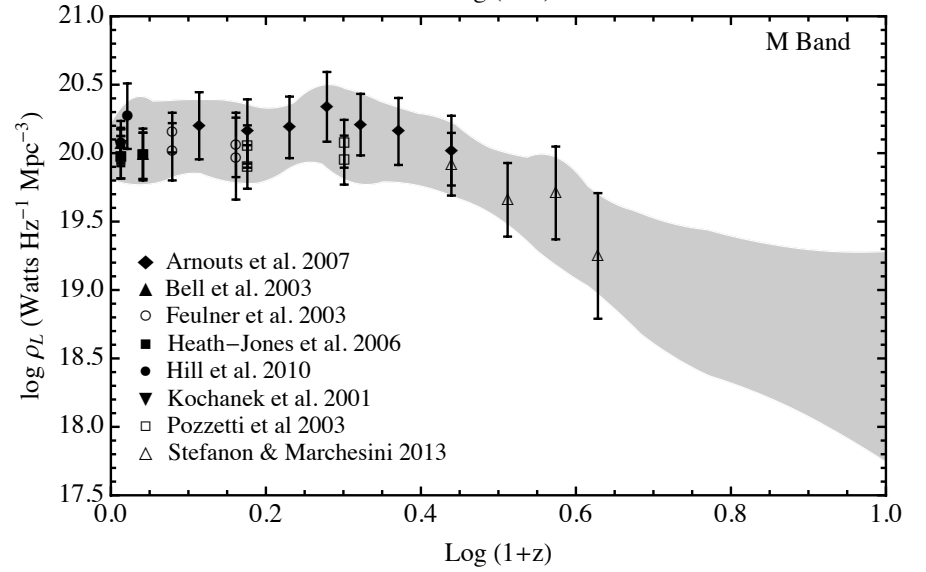
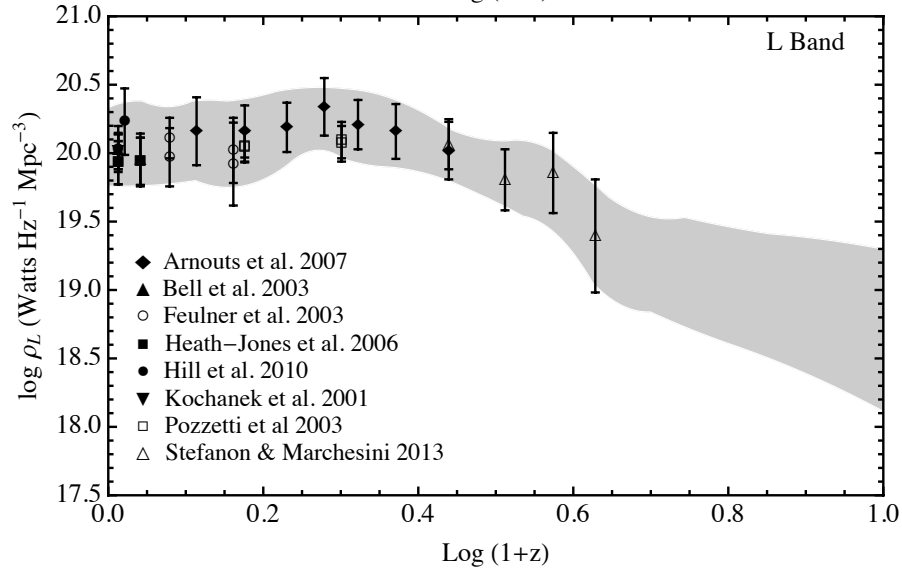
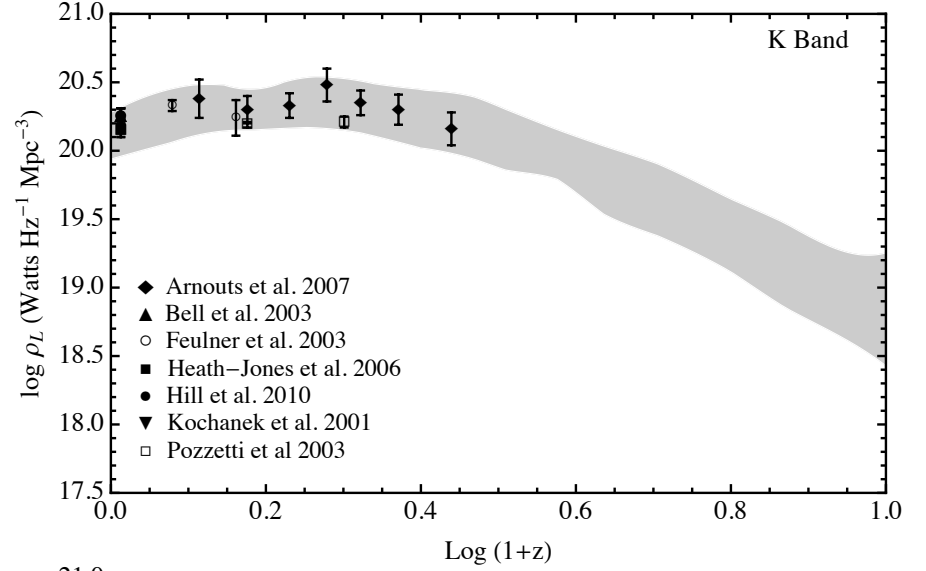
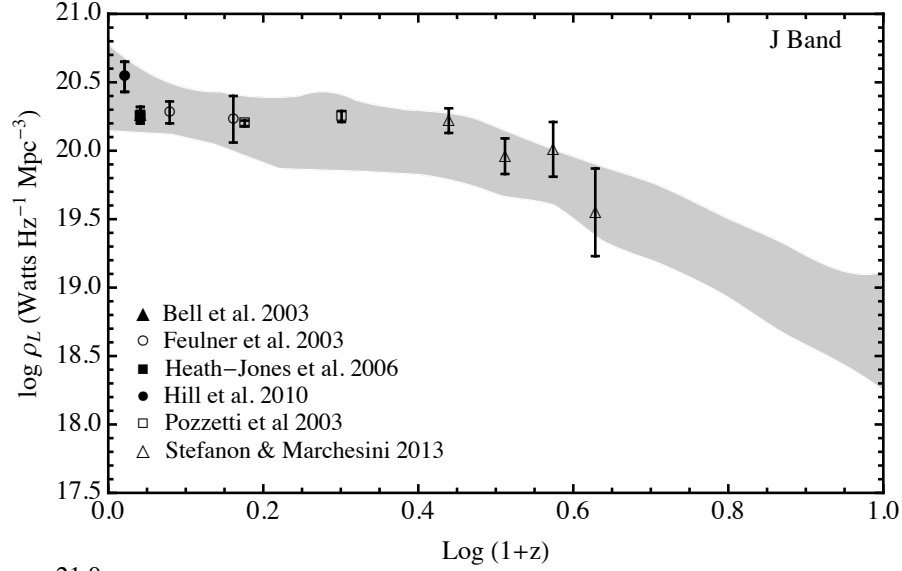
*Observations of galaxy luminosity densities at UV to NIR wavelengths with 68% confidence bands (in gray) derived from Monte Carlo treatment of observational errors using a robust fitting function in redshift (next 3 slides) .*

*Stecker, Malkan & Scully 2012, ApJ 761:128*

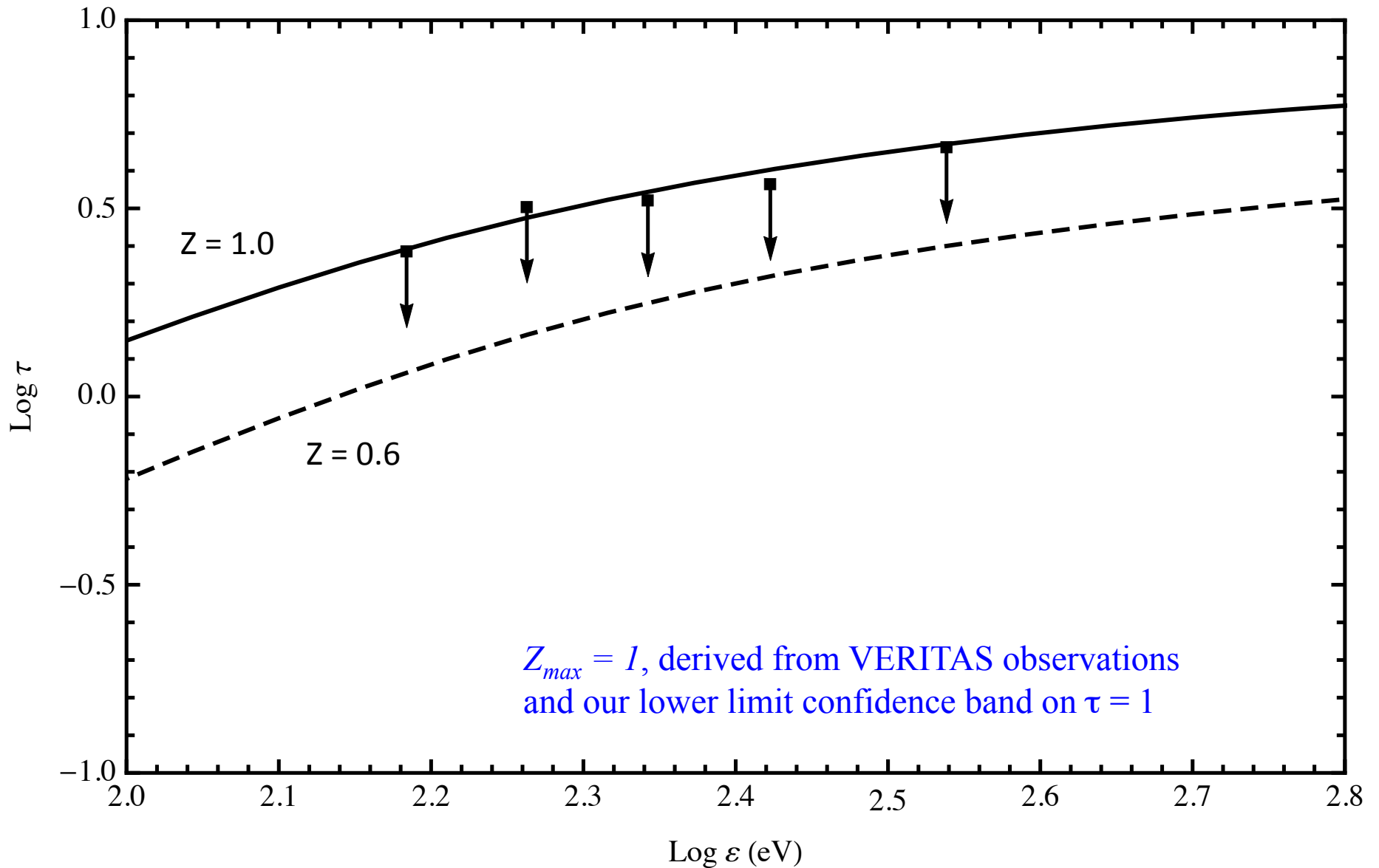
*Scully, Malkan & Stecker 2014, ApJ 784:138*







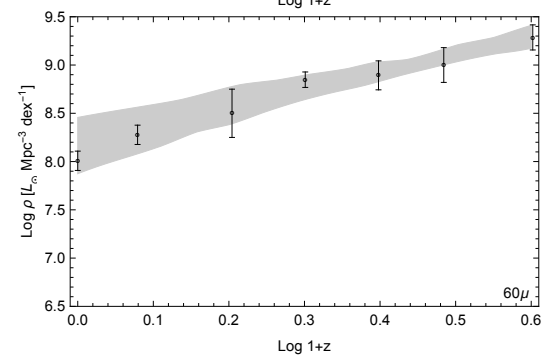
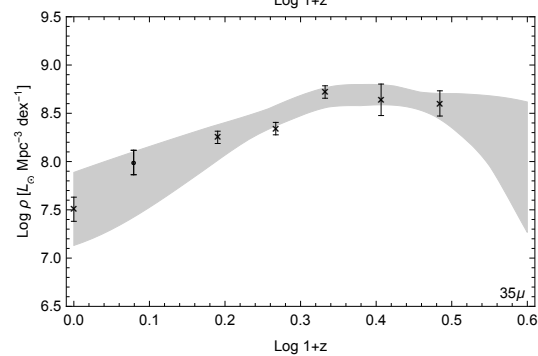
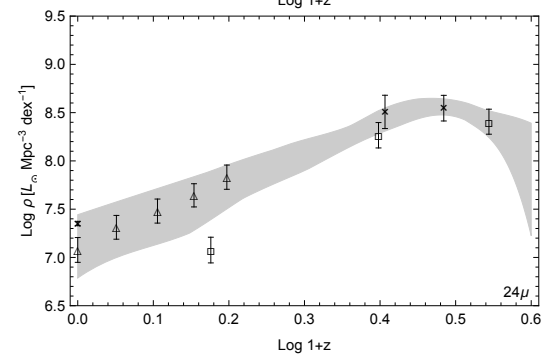
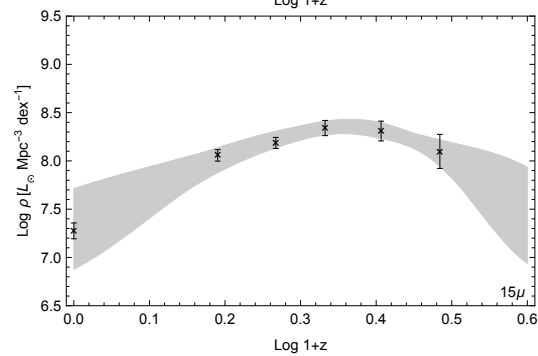
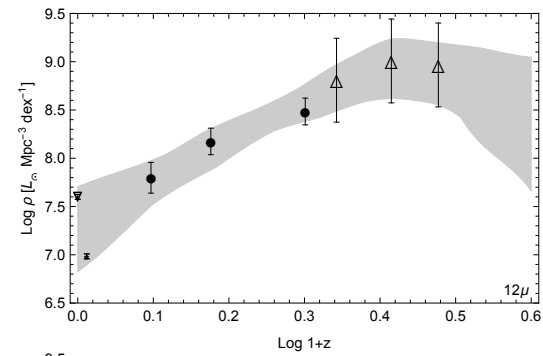
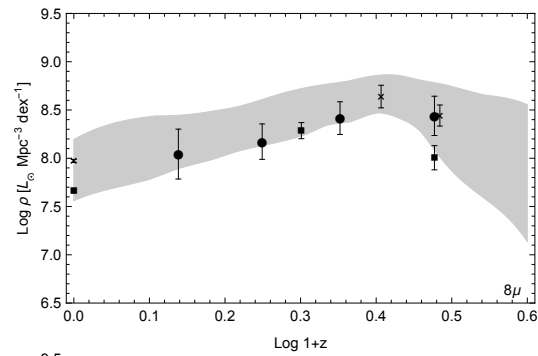
# Opacity Upper Limit on the Redshift of *PKS1424+240*



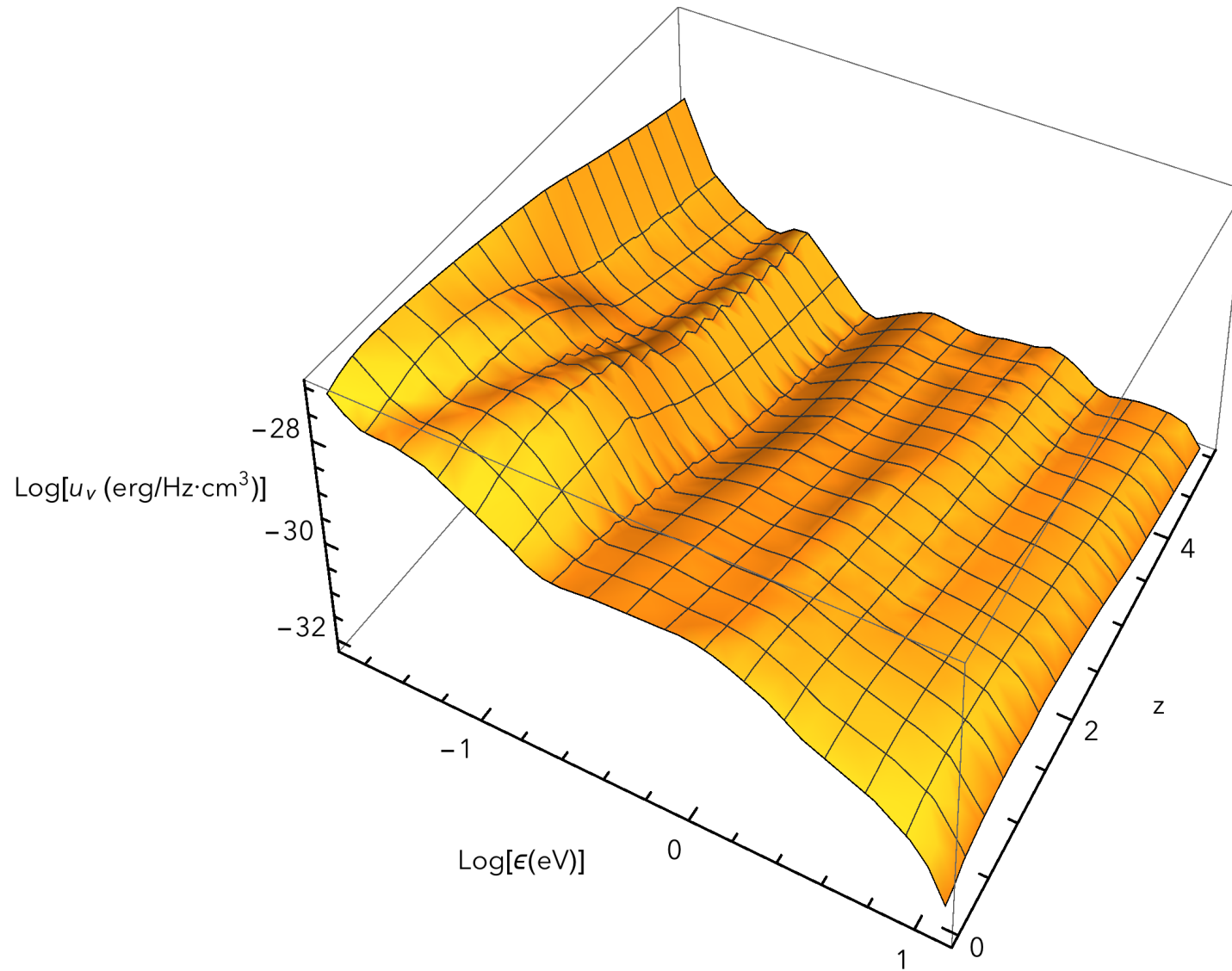


New Results on Luminosity Densities  
from Galaxy Surveys from *AKARI*,  
*Spitzer*, *Herschel* allow us to Extend  
our Calculations into the MIR and FIR

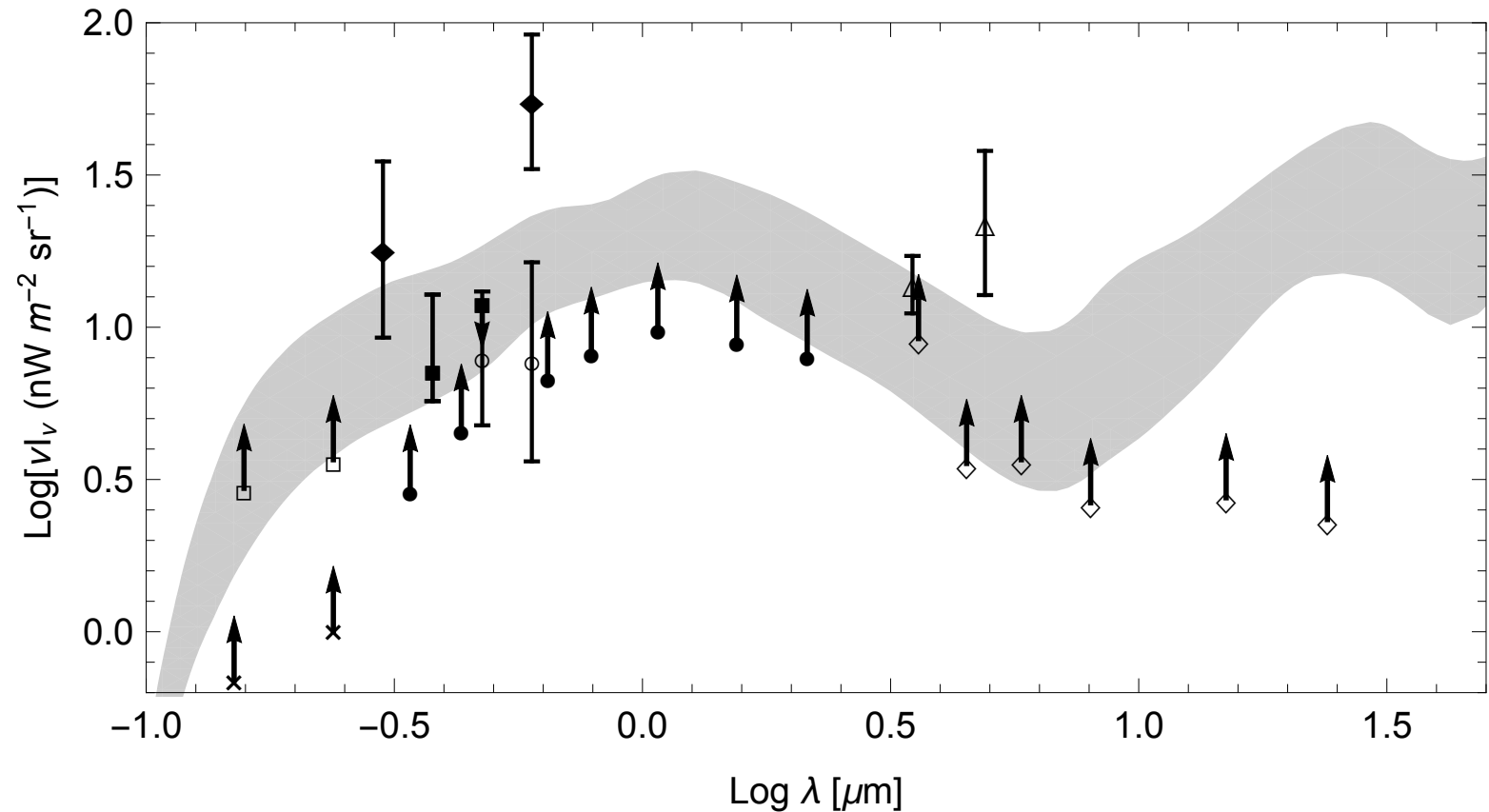
# Mid-IR Luminosity Densities



# Comoving Photon Energy Densities



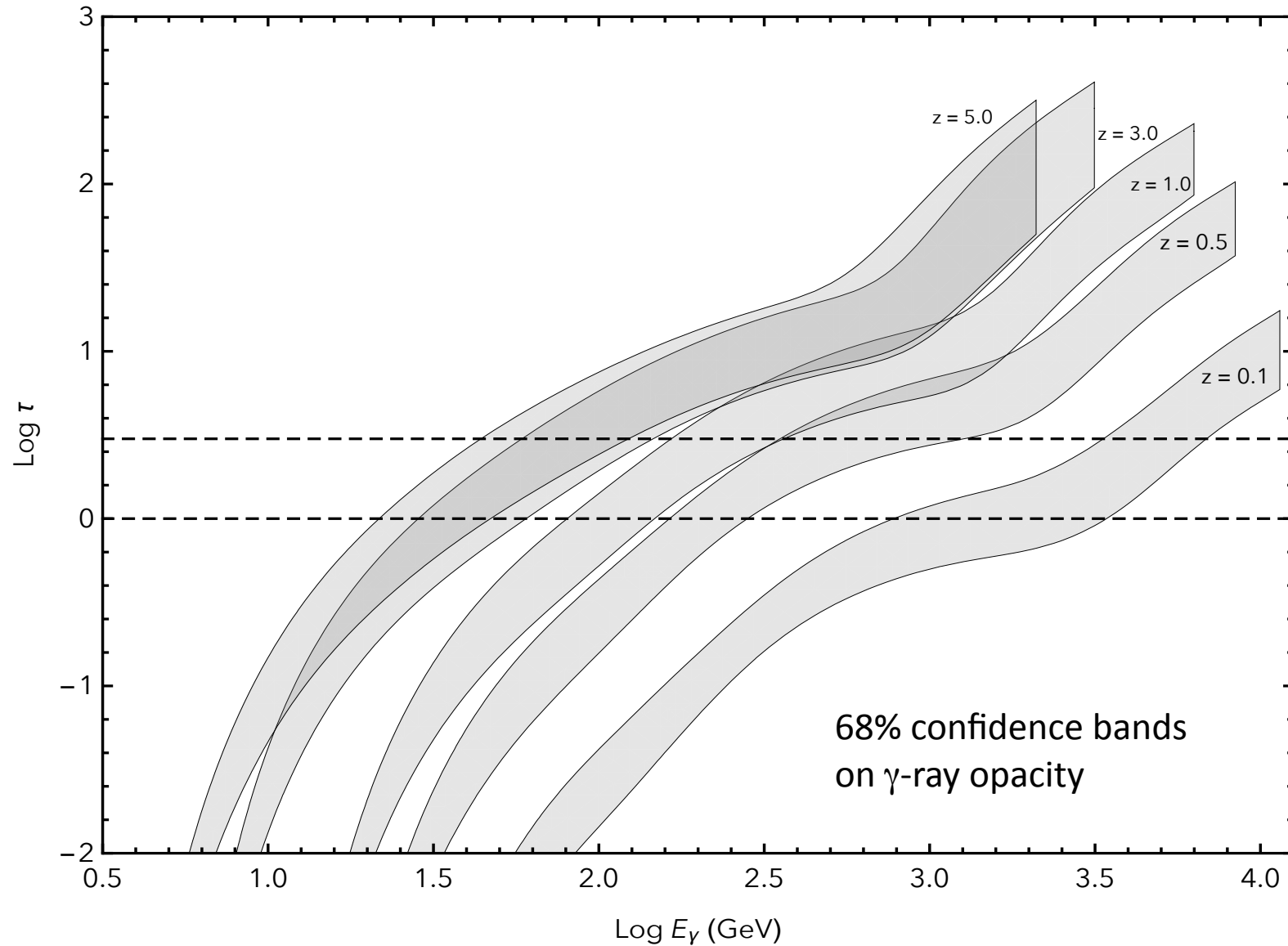
# Extragalactic Background Light



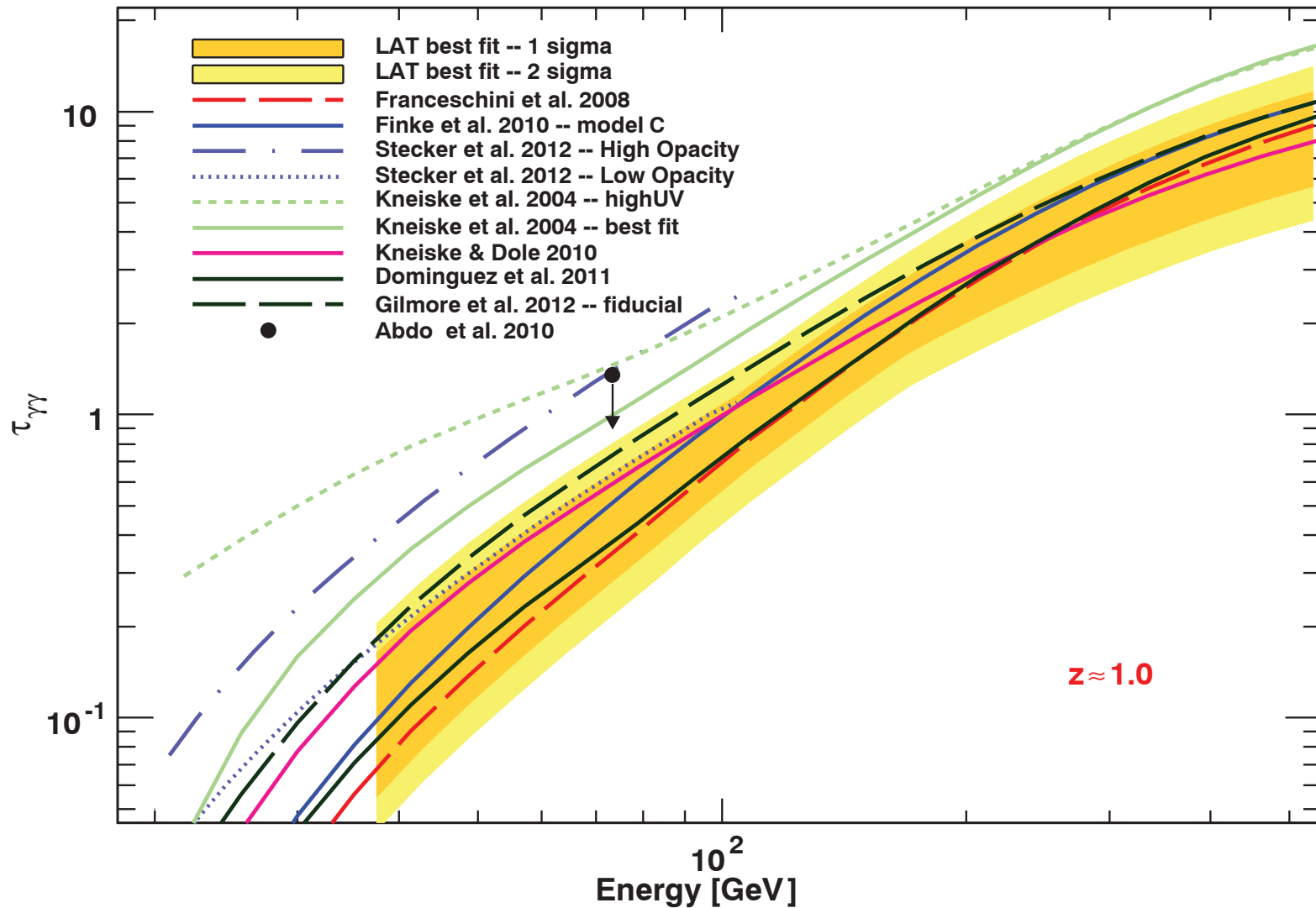
Our empirically-based determination of the  $z = 0$  EBL together with lower limits from Madau & Pozzetti (2000)[Black Circles] and Xu et al.(2005) [Crosses] and upper limits from Gardner et al.(2000).

# $\gamma$ -ray Opacity Results

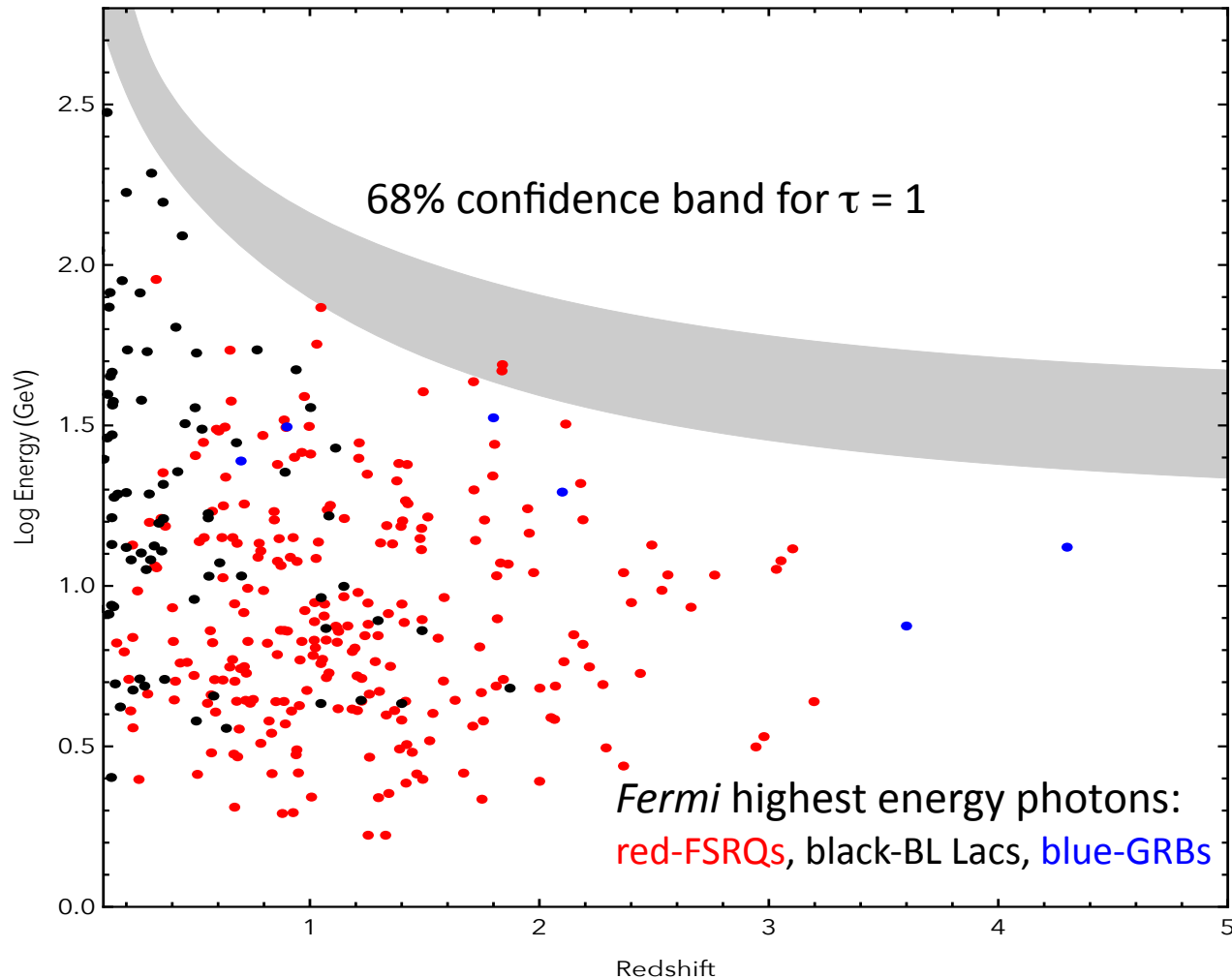
(Accurate up to  $E_{max} = 0.21 \lambda (\mu m)/(1+z)$  TeV)



# Partial Comparison with Fermi Results (Ackermann et al. 2012)



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



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 GRBs (blue) vs. redshift (from Abdo et al. 2010).

We are presently extending our results to 250  $\mu\text{m}$  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

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

(Stecker 1969; Stecker et al. 2006).

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

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