Reionization signatures in gamma-ray spectra

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Outline

✓ Review: Modeling the evolving extragalactic background

✓ Gamma-ray constraints on the EBL

✓ Limits on pop-III star formation with high-z Fermi sources

Part 1: The Extra-Galactic Background Light (EBL)

Photon population created by cosmological structure formation (stars+AGN +others?)

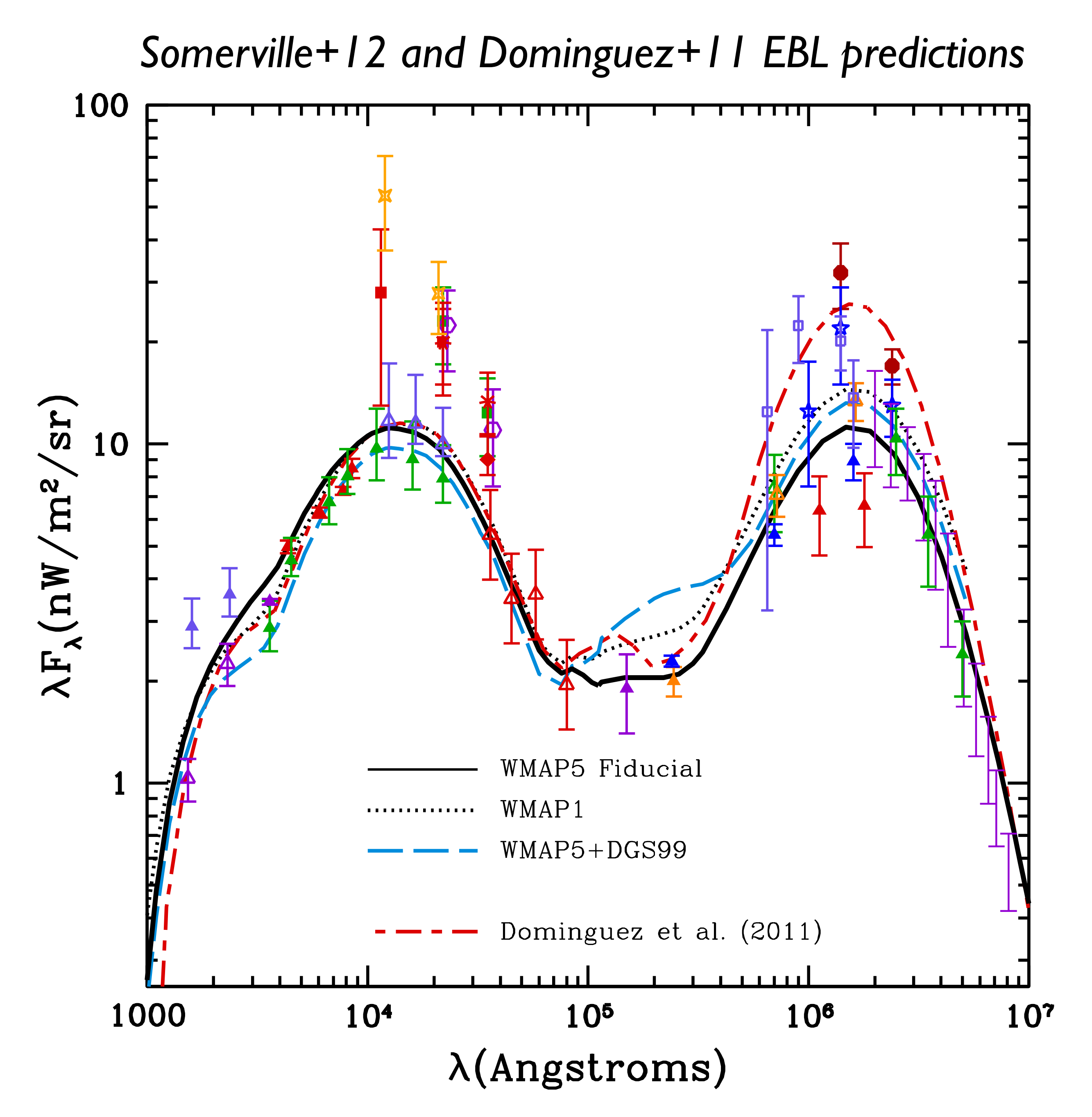
- can include unknown sources, or those too faint to see

Determining the EBL from observations is difficult:

★ Direct photometry measurements must contend with difficult foreground subtraction and calibration issues!

★ Number counts of resolvable sources available at many wavelengths, but may miss faint source populations

★ In general, sophisticated modeling is required to treat evolving galaxy population



Modeling of the galaxy population

➢ Observationally-based models - *Use evolution that is either inferred or directly observed in some astrophysical parameter(s) as a basis for model*

Kneiske et al. 2004;
Finke et al. 2010 - models based on inferred star formation rate density, stellar synthesis models, dust reradiation

Dominguez et al. 2011 - based on K-band LFs evolution plus galaxy population from analysis of >5000 AEGIS SEDs

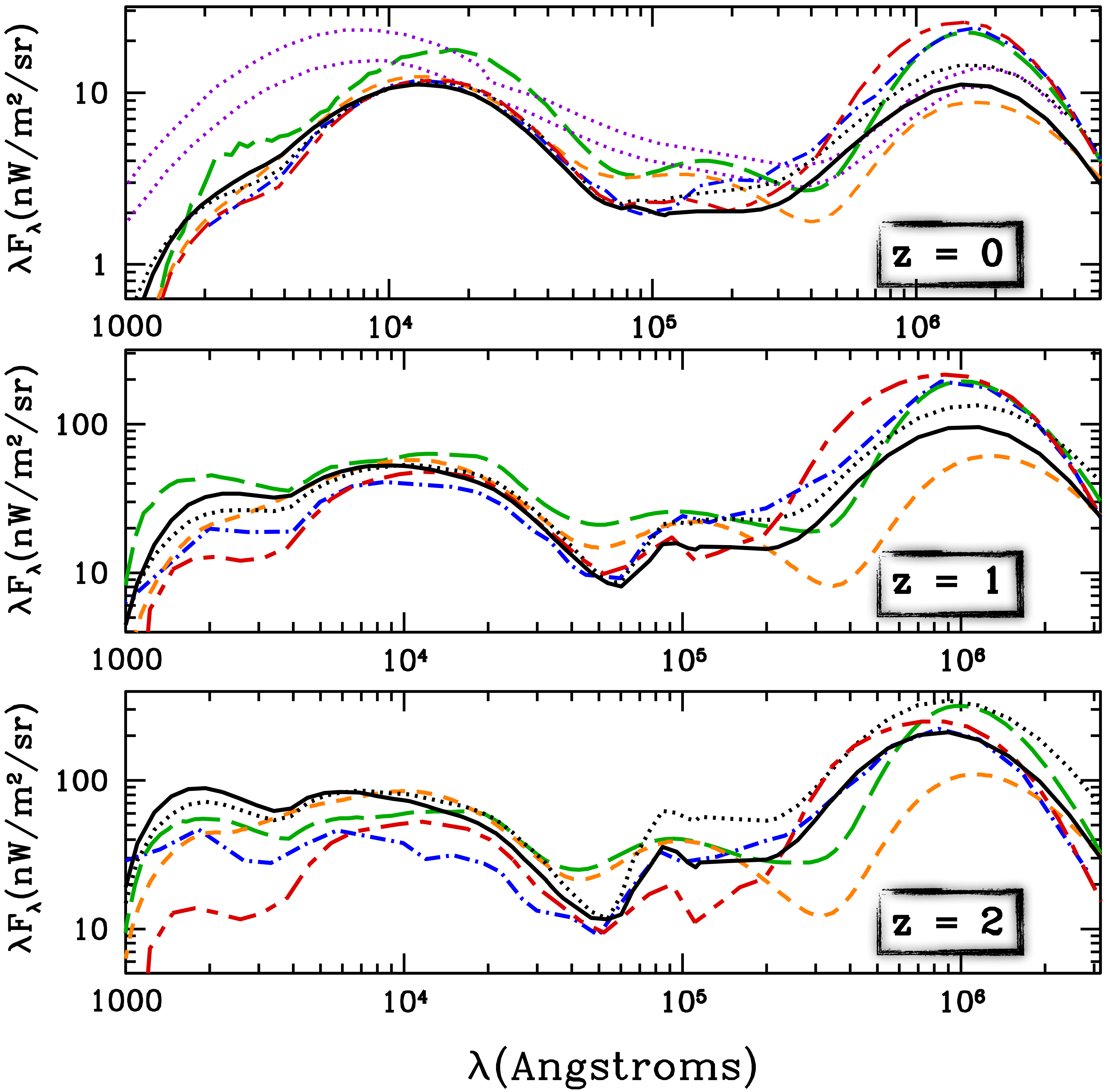
➢ Backwards evolution - *evolve local galaxy population to higher redshift according to assumed prescription*

Stecker et al. 2006 - based on power law evolution of existing galaxy pop.

Franceschini et al. 2008 - more sophisticated model based on measured LFs, separate treatment of optical and IR, and different galaxy population.

➢ Forward evolution - *compute growth of galaxies forward in time, begin from cosmological initial conditions and accounting for relevant physical processes that drive growth*

Primack et al. 1999, 2001, 2005;
Gilmore et al. 2009;
Somerville 2012/Gilmore 2012 - trace galaxy evolution from high redshift, based on LCDM cosmology, allow comparison with a wide range of data



Comparison of redshift evolution in recent EBL models

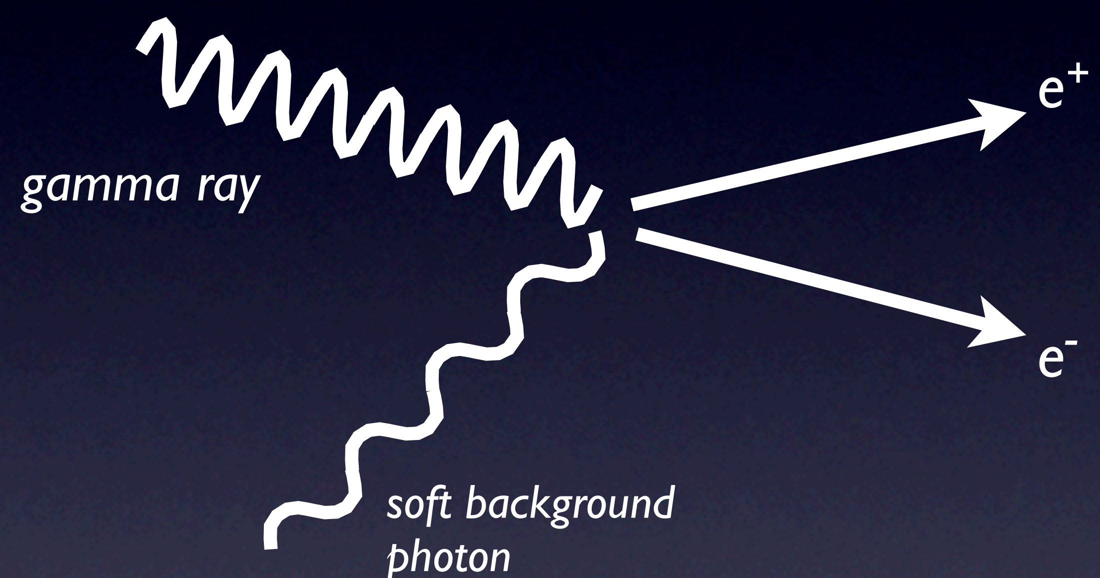
- newer models show convergence in low-z prediction from resolvable sources

Part 2: Absorption of Gamma Rays by EBL

- Gamma-ray attenuation via e^+e^- pair production provides a link between galaxy history and high energy astrophysics.

- Opacity based on integrated EBL flux, tends to increase with energy:

Max cross-section:
$\lambda \sim 1.24(E_\gamma / \mathrm{TeV})\ \mu\mathrm{m}$
(at 90^o interaction)

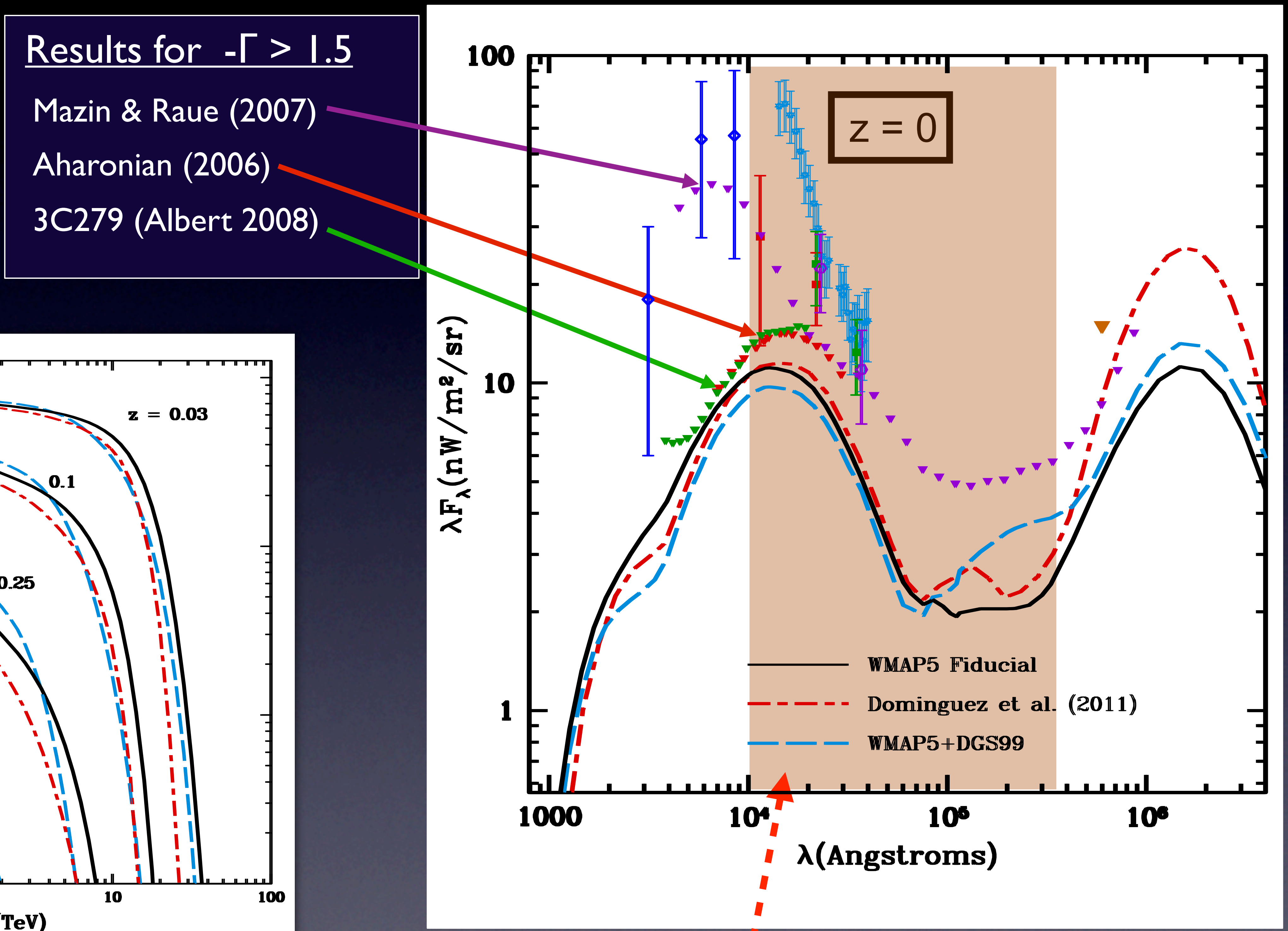


$$E\epsilon(1-\cos\theta) \geq 2(m_e c^2)^2$$

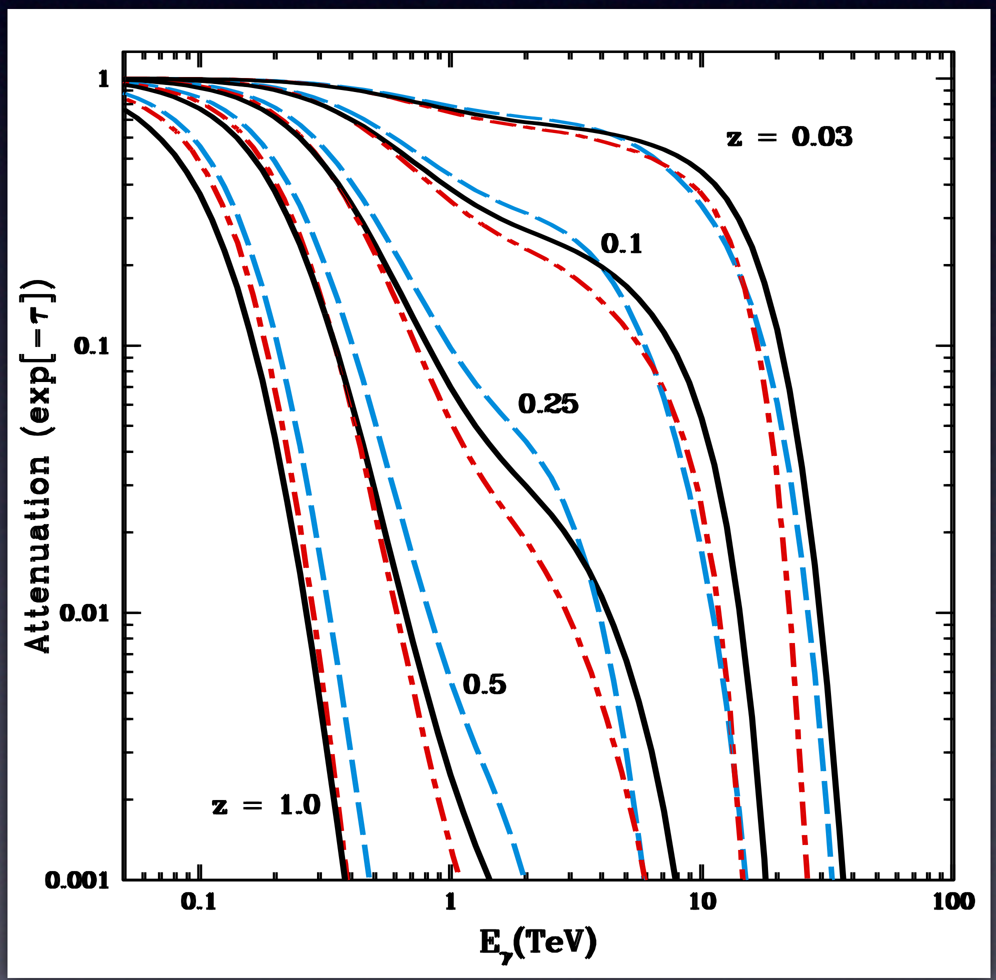
$$\tau(E_o, z_s) = \int_0^{z_s} dz \frac{dl}{dz} \int_{-1}^{1} d(\cos\theta)(1-\cos\theta) \int_{\epsilon_{th}}^{\infty} d\epsilon n(\epsilon, z)\sigma(E, \epsilon, \theta)$$

- This leads to softening and cutoff in gamma ray spectra of distant extragalactic sources (blazars and GRBs), as well as gamma-ray horizon.

Some of our strongest *upper* limits on the EBL are from gamma-ray constraints

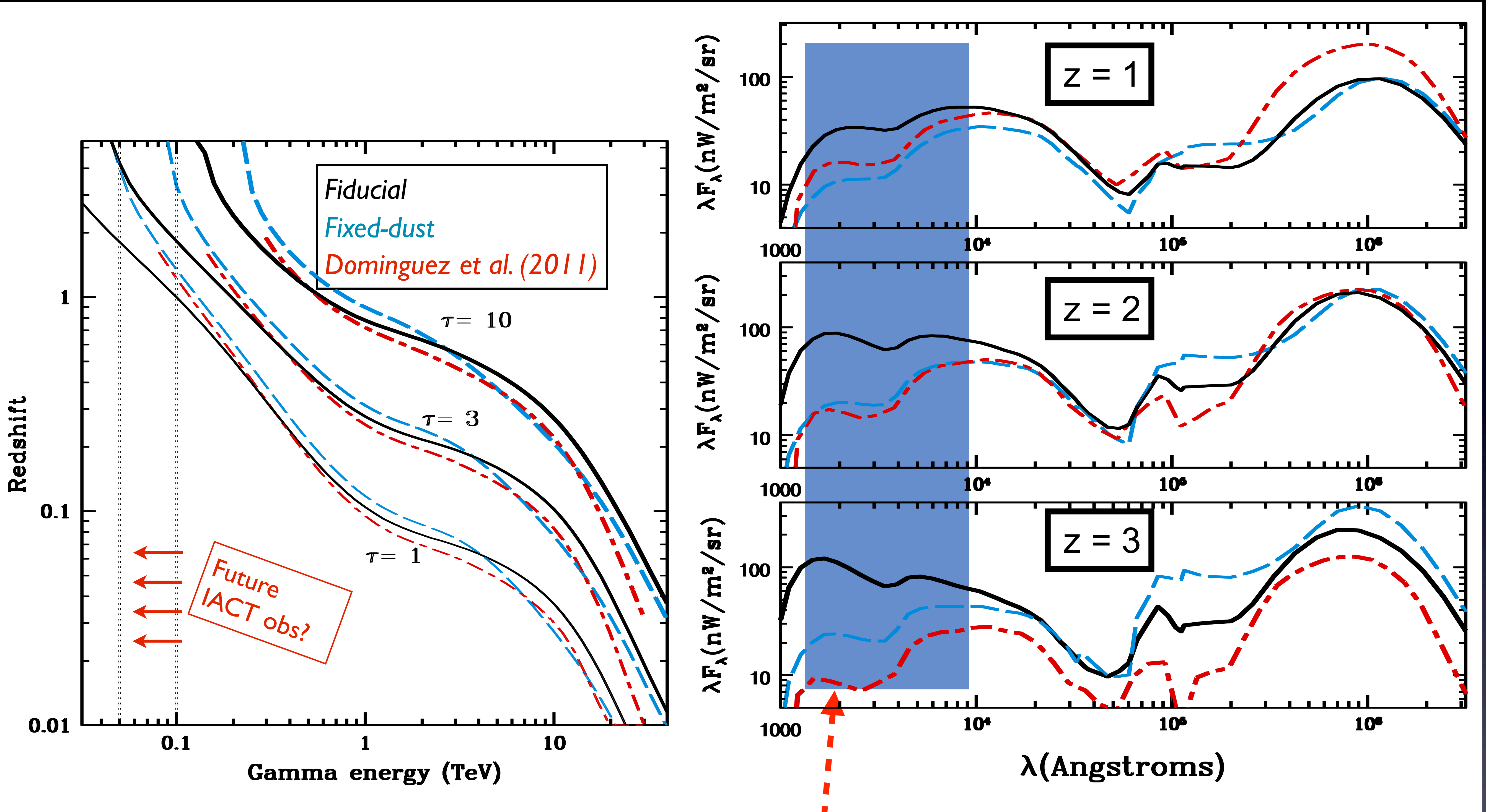


Gamma ray constraints from IACT TeV blazars at z < 0.5 constrain IR background



Gamma-ray attenuation

Gamma-ray optical depth vs energy at several redshifts



Optical/UV light produces cutoffs in GR spectra in the 10-100 GeV range above redshift 1

High redshift gamma-ray observations can potentially test differences between models

Cosmological "Attenuation Edge"

Contours of constant tau in redshift and observed energy

Results from Fermi first-year data for EBL limits from AGN and GRBs (Abdo et al. 2010, ArXiv 1005.0996)

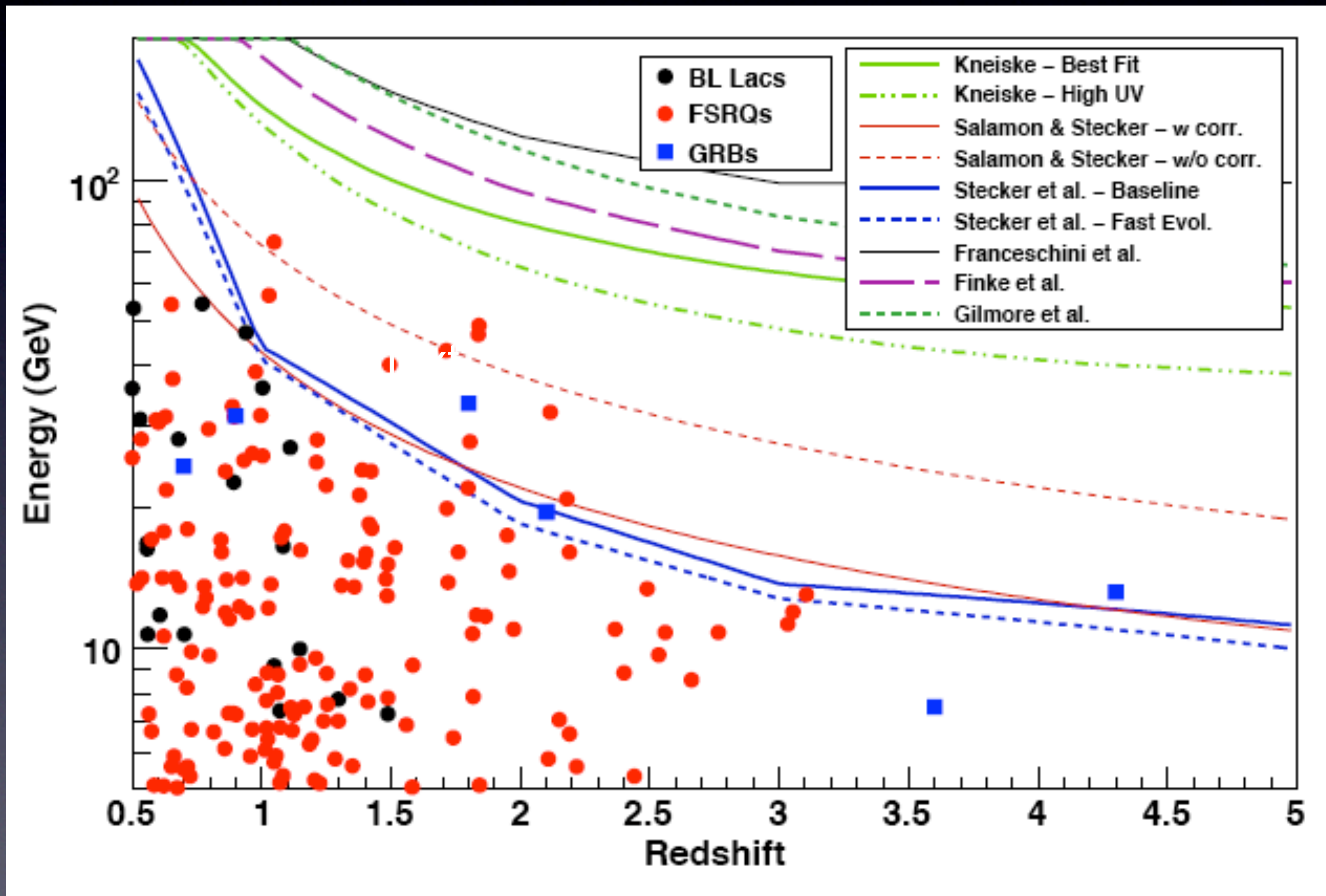
Redshift and observed energy of highest-energy photons

- Lines show opacity of 3τ

- First-year Fermi data disfavors only the highest EBL models

- GRBs key source at high redshift?

- GRBs avoid background problems of long-term AGN observations, and LAT bursts generally have harder spectra than most FSRQs



Part 3: Limits on a Pop-III contribution to the EBL

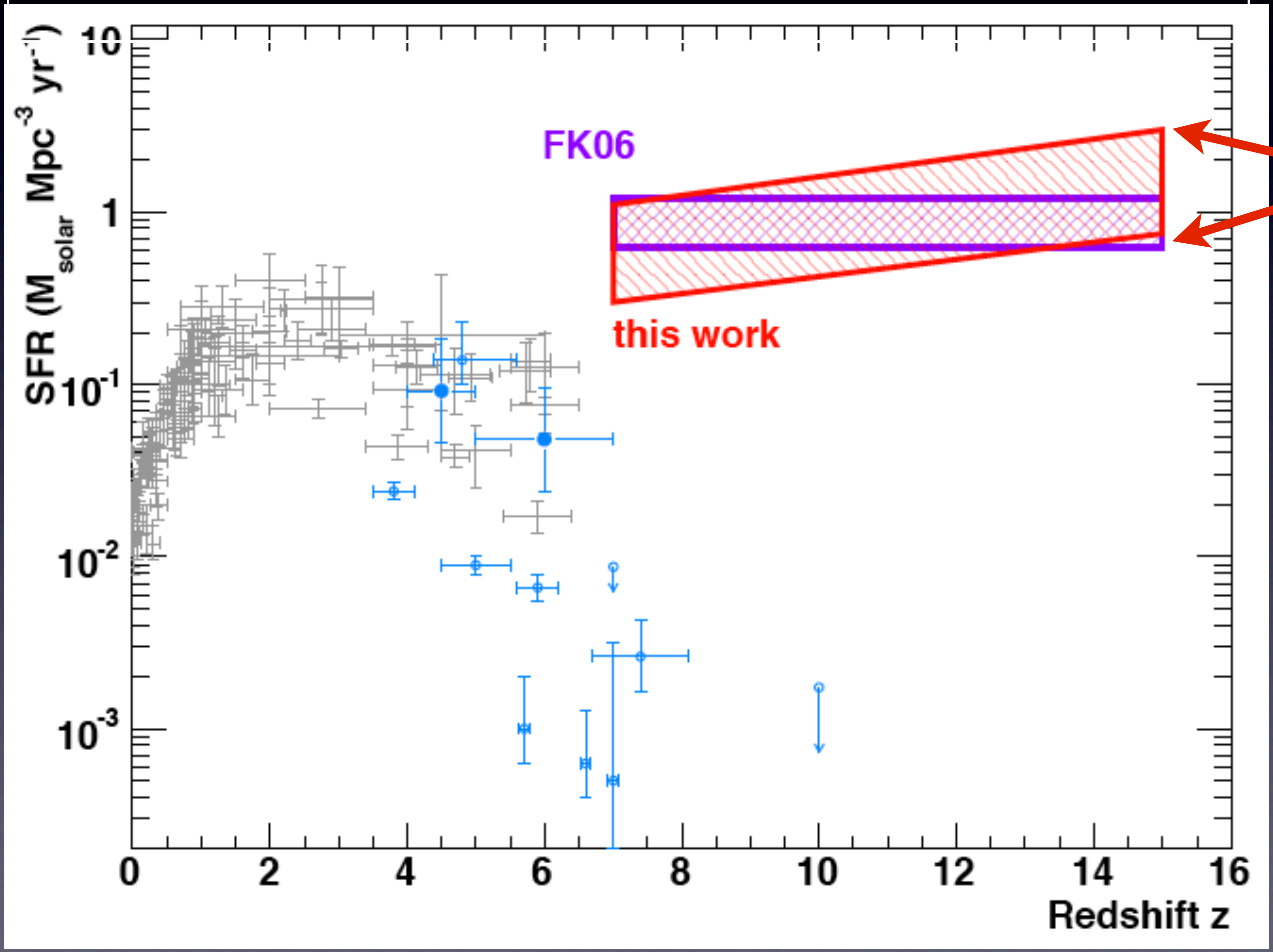
- Can gamma-ray observations limit a reionization-era component in the EBL ('rEBL')?

- Several authors suggest that pop-III stars could contribute substantially to near-IR EBL (e.g., Kashlinsky 2004; Cooray 2004; Matsumoto 2005, 2010)

- Observations of TeV blazars can limit a large contribution (Raue+09)

Raue, Kneiske, & Mazin 2009:

- Considered EBL signature from high-z stars
- Range of upper limits based on restriction of reionization EBL contribution at 2μm to ≤5 nW/m^2/sr



Variation in metallicity and SFR density redshift evolution

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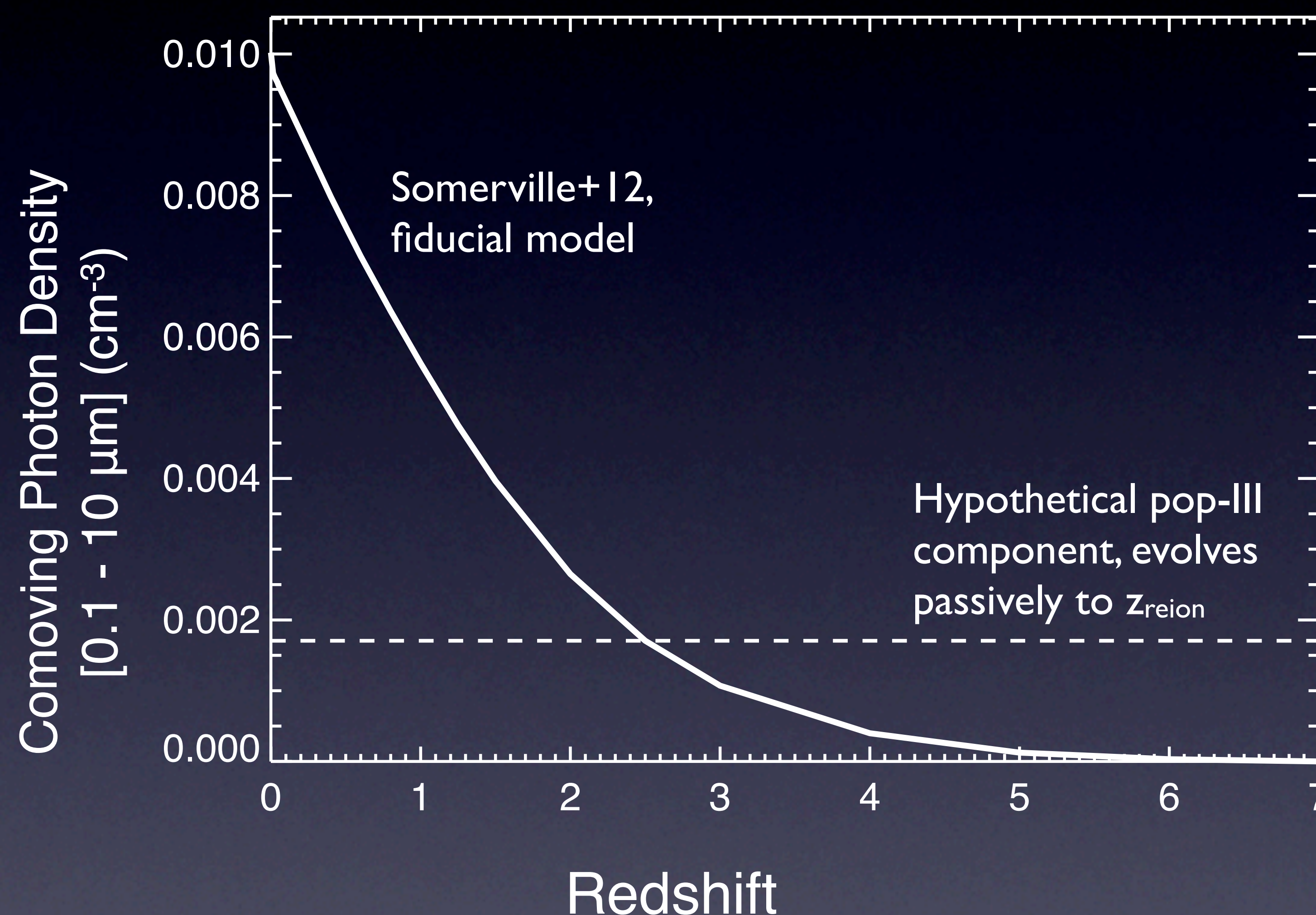
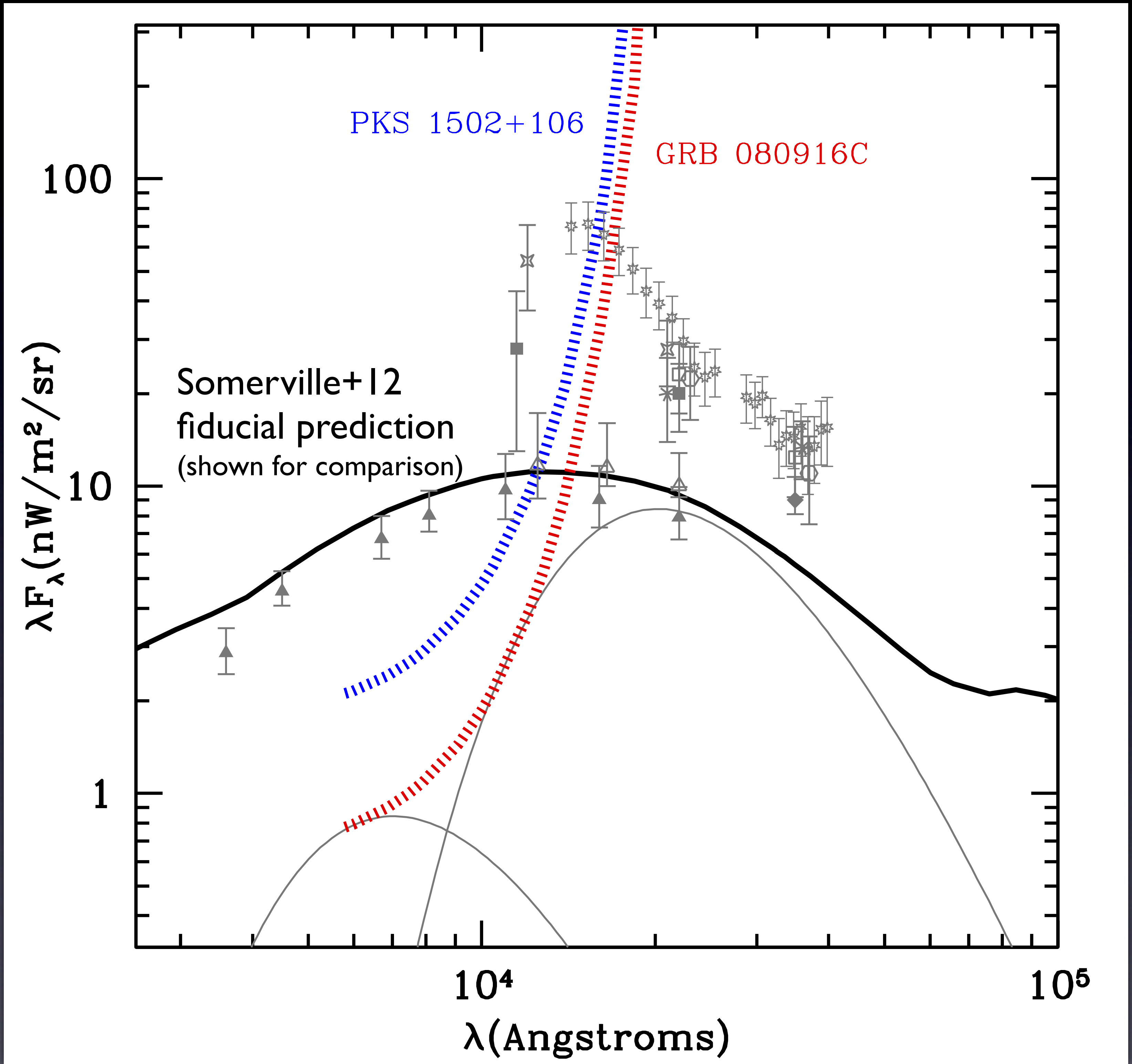
Gilmore 2012, MNRAS 420, 800
ArXiv:1109.0592



Attenuation in high-z GeV spectra have advantage of isolating a Population-III contribution

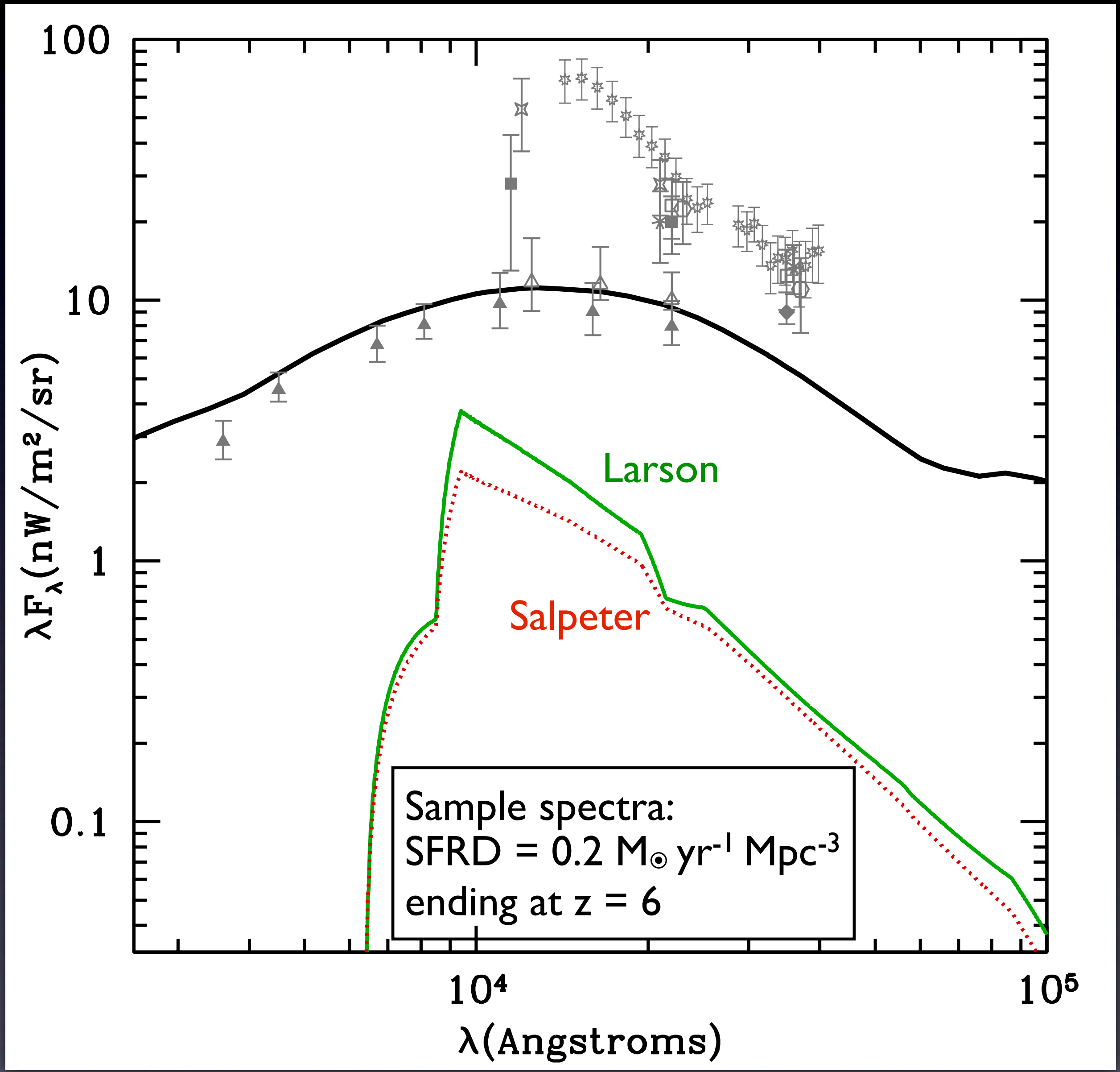
Limits on local background originating from high-z:



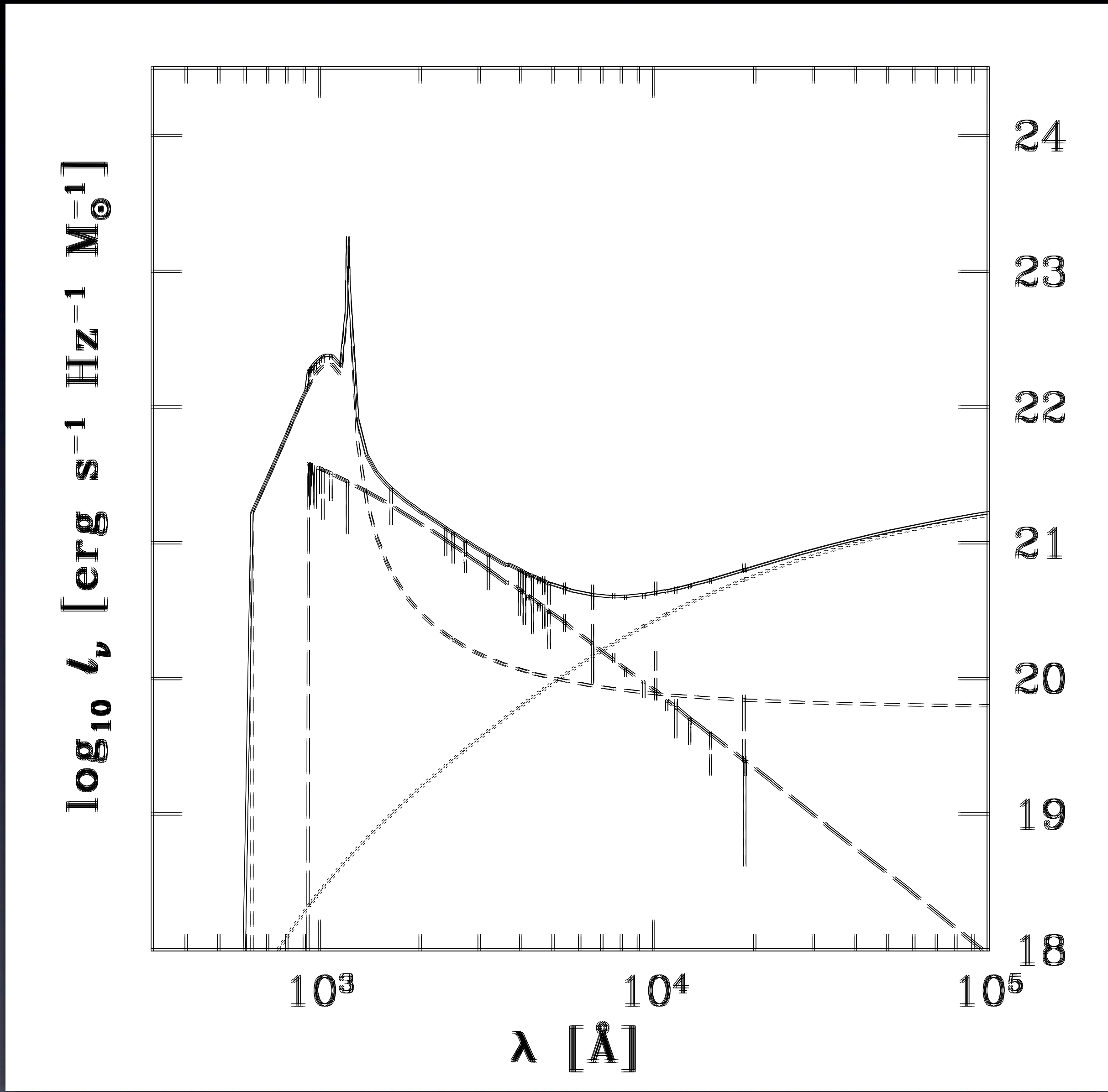
- Optical thinness requirement puts upper limit on the EBL contribution from high redshift.
- Highest energy photons:
  - GRB 080916C (z=4.35): 13.6 GeV
  - PKS 1502+106 (z=1.84): 49.2 GeV
- In general, highest redshift sources are most constraining.
- Thermal rEBL spectra assumed

Limits on pop-III star-formation rate density (SFRD)

• Upper bounds on the contribution to the EBL can be translated to upper bounds on SFRD by assuming a spectral model for pop-III contribution



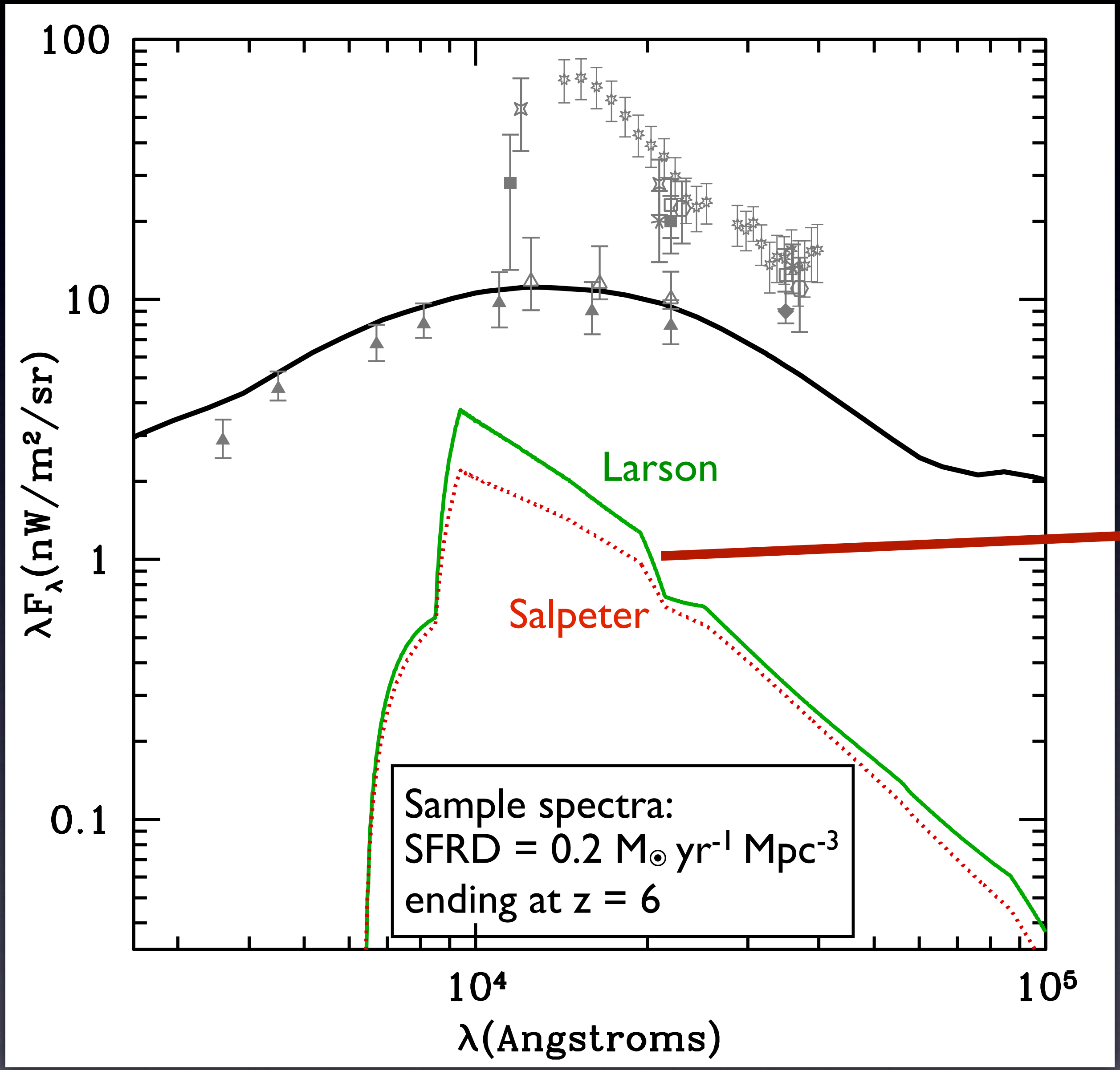
We develop spectra templates for pop-III emission following Santos+02 and Fernandez & Komatsu 06, and using 2 possible IMFs (Salpeter and the top-heavy Larson (1998) IMF)

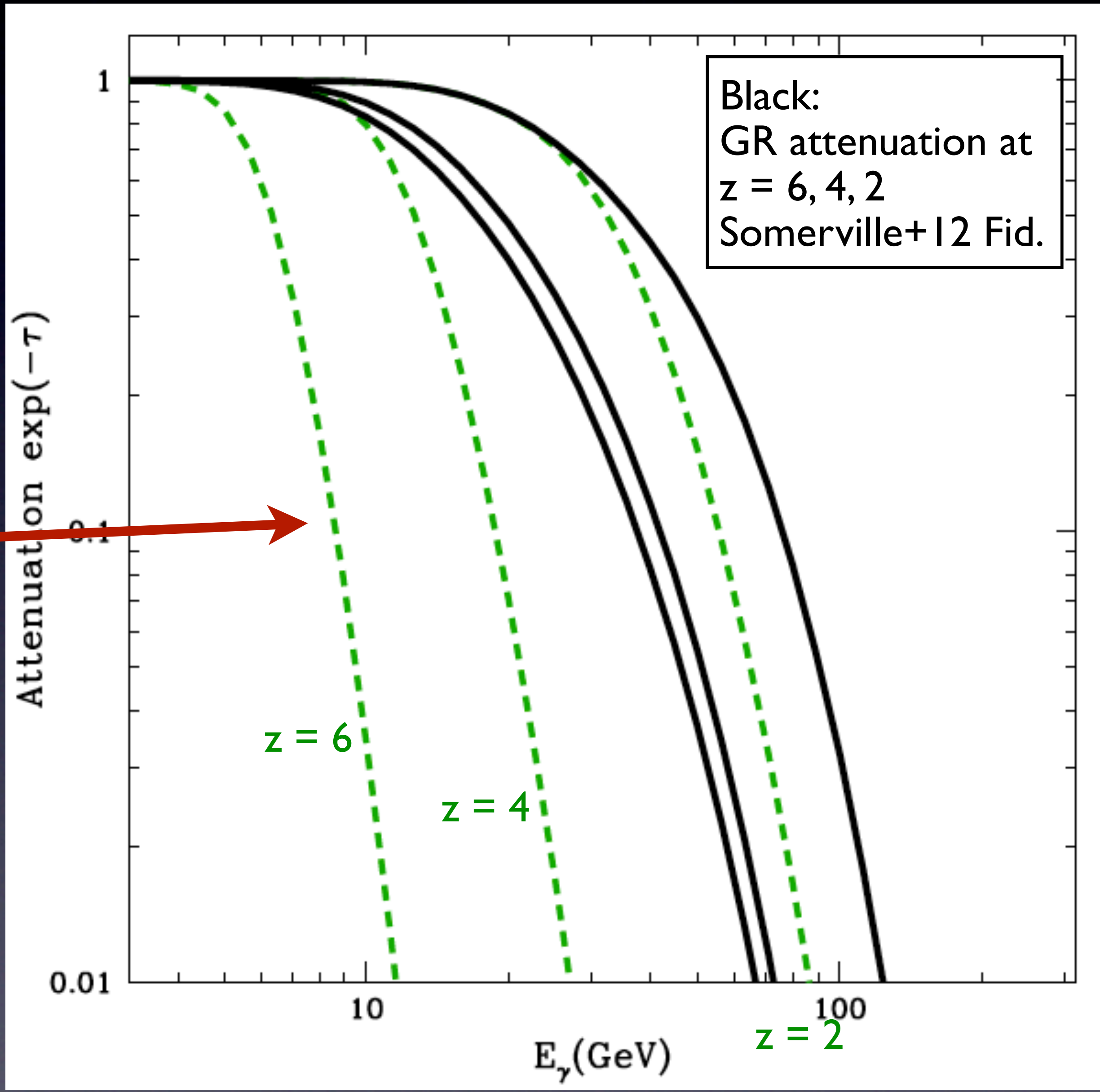


Santos, Bromm & Kamionkowski (2002)

Limits on pop-III star-formation rate density (SFRD)

• Subdominant contributions to the EBL from high redshift can dominate attenuation profile for high-z gamma-ray sources.





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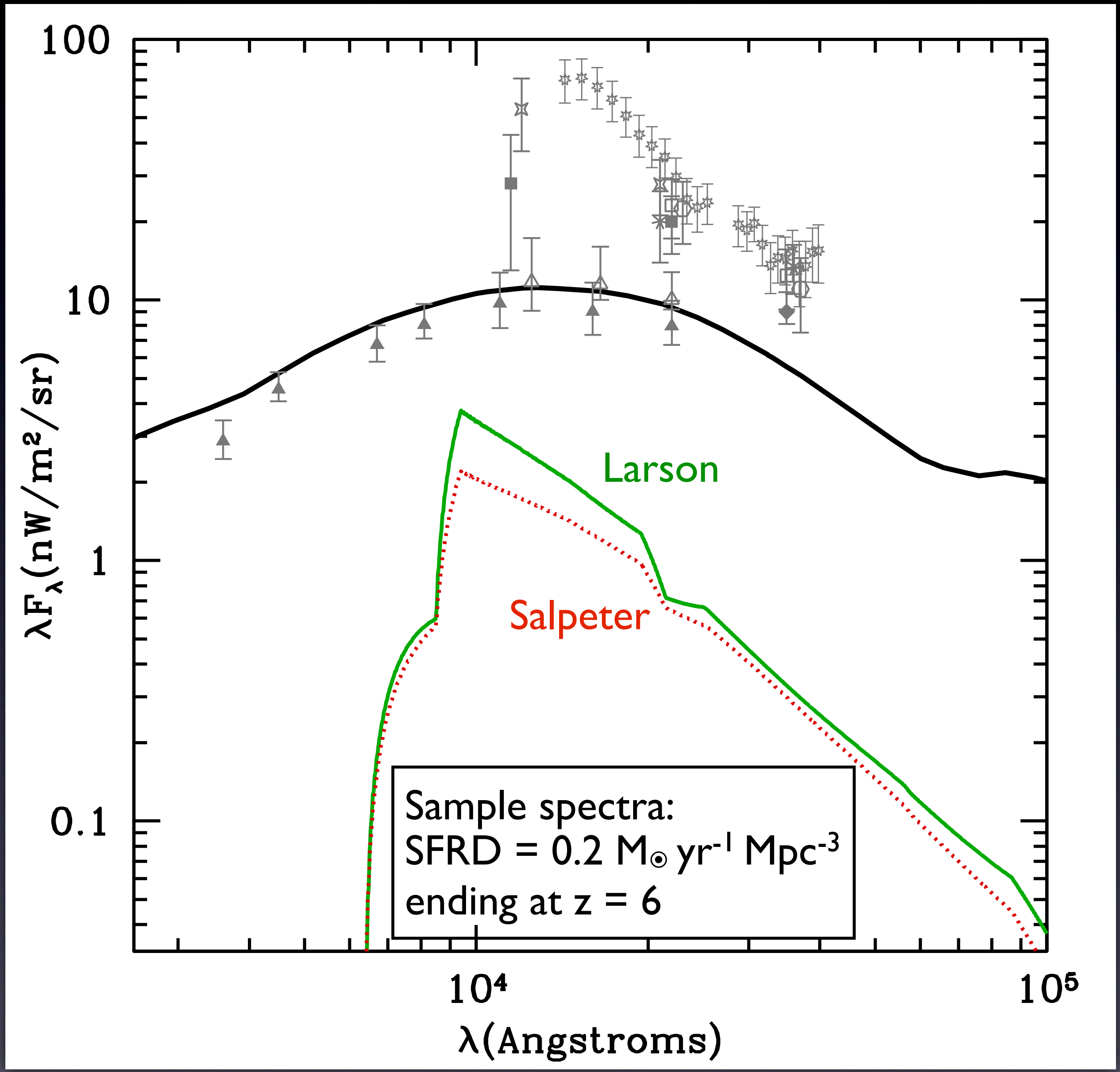

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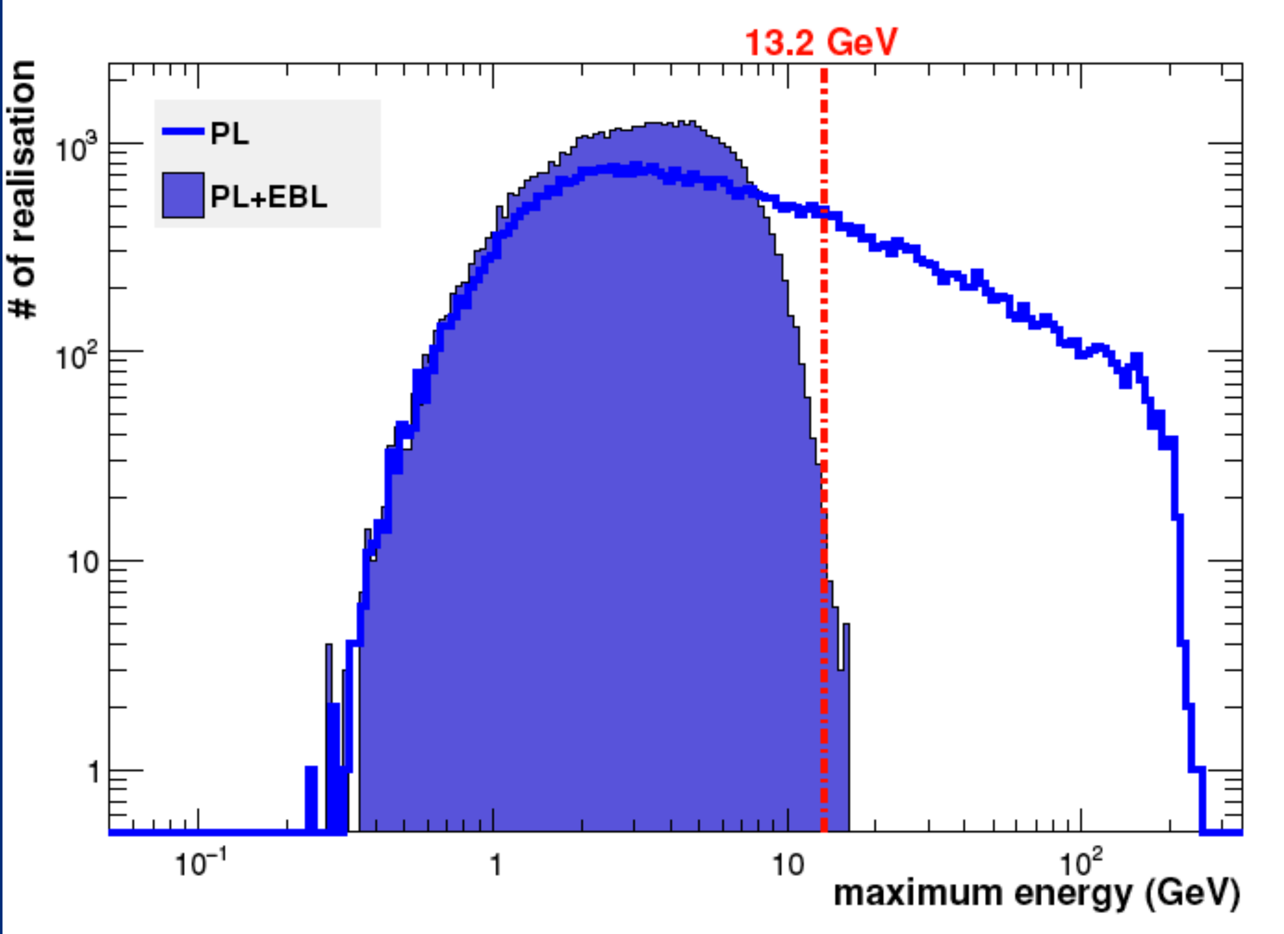
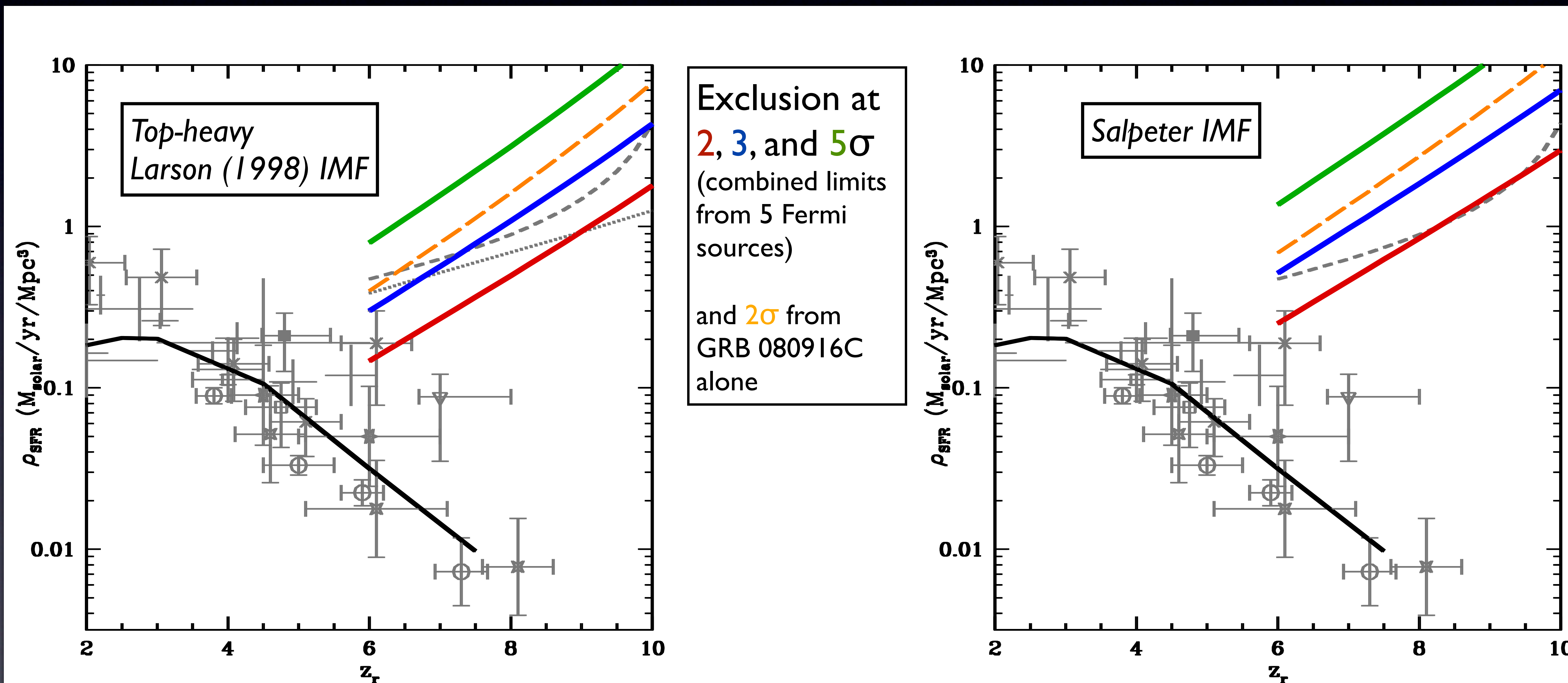
- Exclusion of pop-III scenarios uses method similar to 'highest energy' method in Abdo+10 (shown as example)



Limits on pop-III star-formation rate density (SFRD)

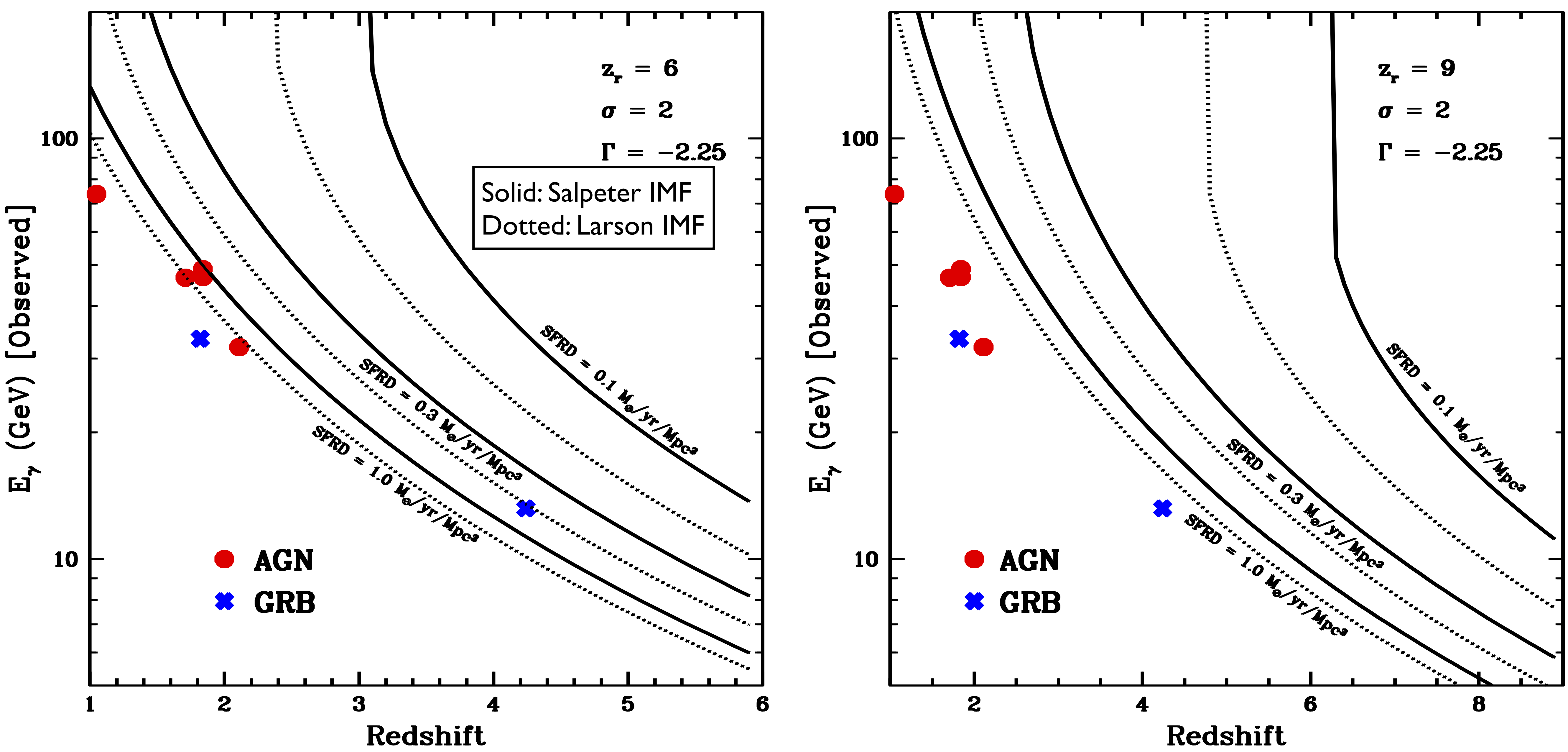
• SFRD limit set using 'highest energy photon' method of Abdo+10, and gamma-rays observed from 5 Fermi LAT sources

(GRB080916C, PKS 0227-369, PKS 1502+106, PKS 0805-07, J1016+0513)



Future prospects for these types of limits

- Gamma rays at higher energy and/or higher redshift could improve our constraints on high-z SF
- High-z GRB would be the most likely source of these GRs
- Composite limits from several sources can be even stronger than shown below



Conclusions

✦ Recent models of the EBL (Somerville 2012, Franceschini 2008, Finke 2010, Dominguez 2011) generally agree on contribution of galactic sources at low-z

✦ ...However, these models cannot rule out possibility of large reionization-era contribution to the EBL

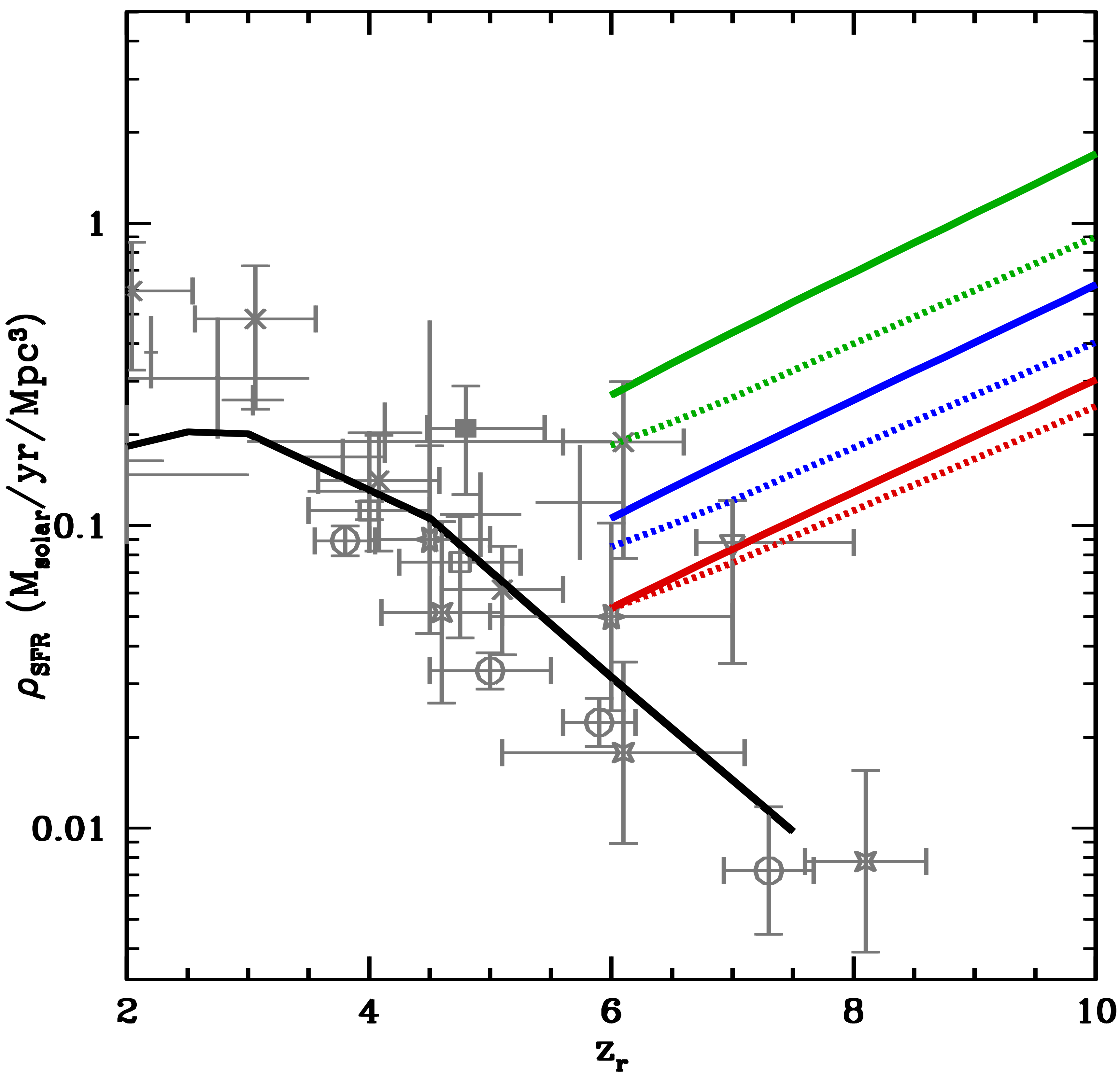
✤ Observations of the highest redshift Fermi sources can put upper limits on pop-III contribution to the EBL

✤ Corresponding limits on pop-III star-formation can rule out a large upturn in the global SFRD in the late stages of reionization

✤ Future observations could strengthen these results

✤ most helpful sources are high-z GRBs observed with Fermi

- or CTA; see Gilmore+2012 (ArXiv:1201.0010) and Kukawa+2012 (ArXiv:1112.5940)



1
0.1
0.01
ρ_{SFR} (M_{solar}/yr/Mpc^3)
2
4
6
8
10
z_r