Cosmological Background Radiation and Extragalactic Gamma-ray Opacity

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Outline

✓ The Evolving Extragalactic Background Light

✓ Constraining the UV/optical Background with High-z Gamma-ray Sources

✓ Background Studies with GRBs

The Extra-Galactic Background Light (EBL)

Photon population created by structure formation (stars and AGN)

- We can measure the local background directly, through astronomical observations (direct photometry and galaxy number counts)

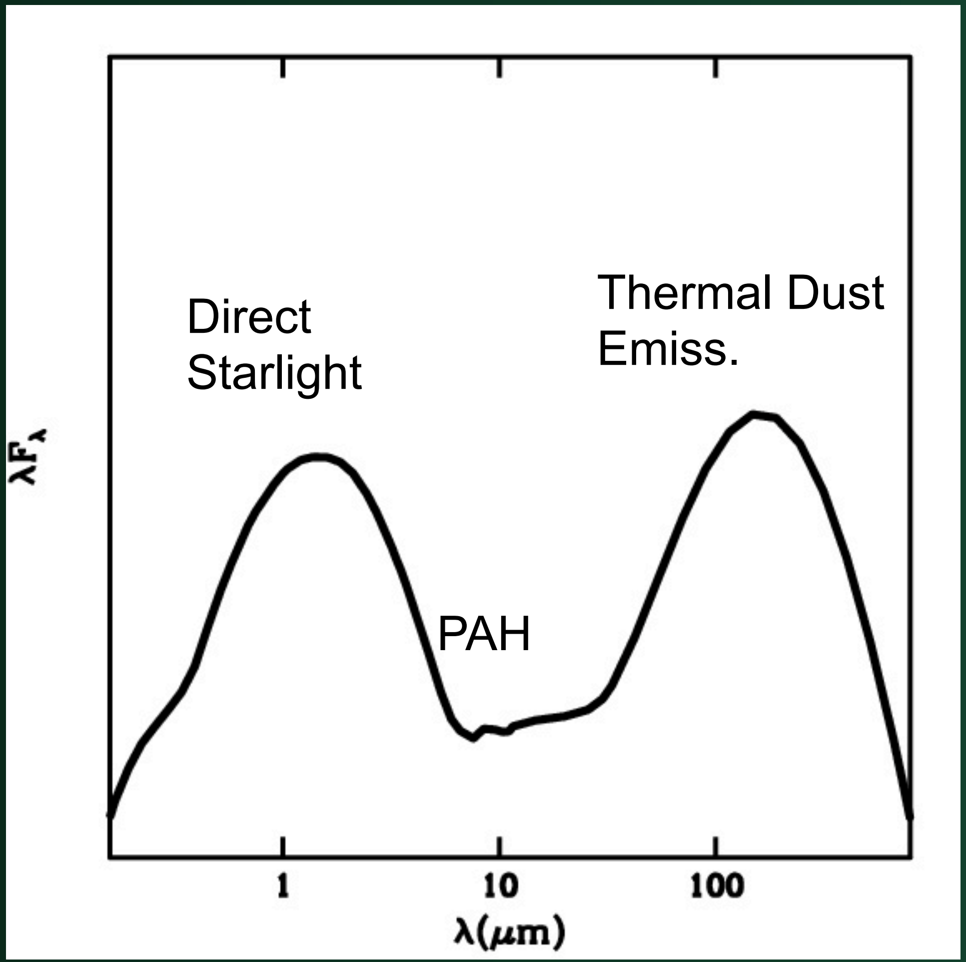
- Observations of extragalactic gamma-ray sources give another type of constraint, based on integrated line-of-sight photon density.

Fully understanding the creation and evolution of this photon population requires sophisticated modeling

Observationally-based models:
Kneiske et al. (2004); Finke et al. (2009);
Dominguez et al. (MNRAS in press)

Forward evolution (semi-analytic) models:
Primack et al. (2005, 2008);
Gilmore et al. (2009, in prep.)

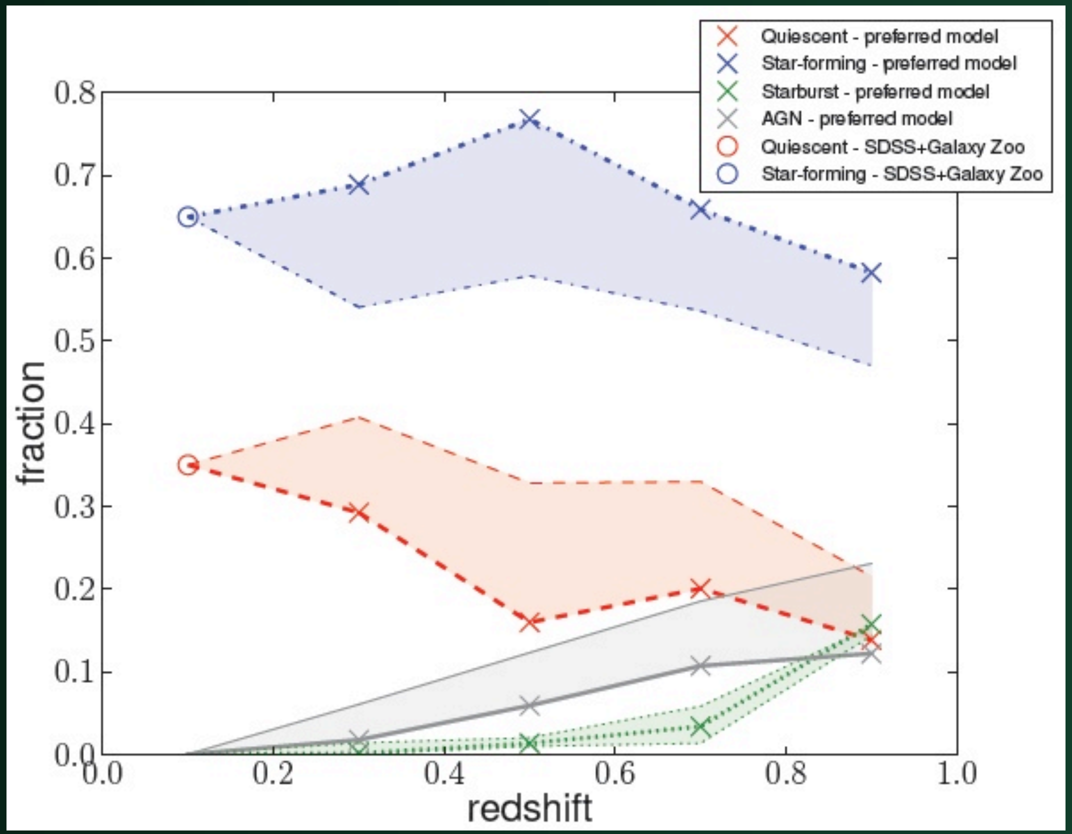
Backward evolution:
Stecker et al. (2006); Franceschini et al. (2008)



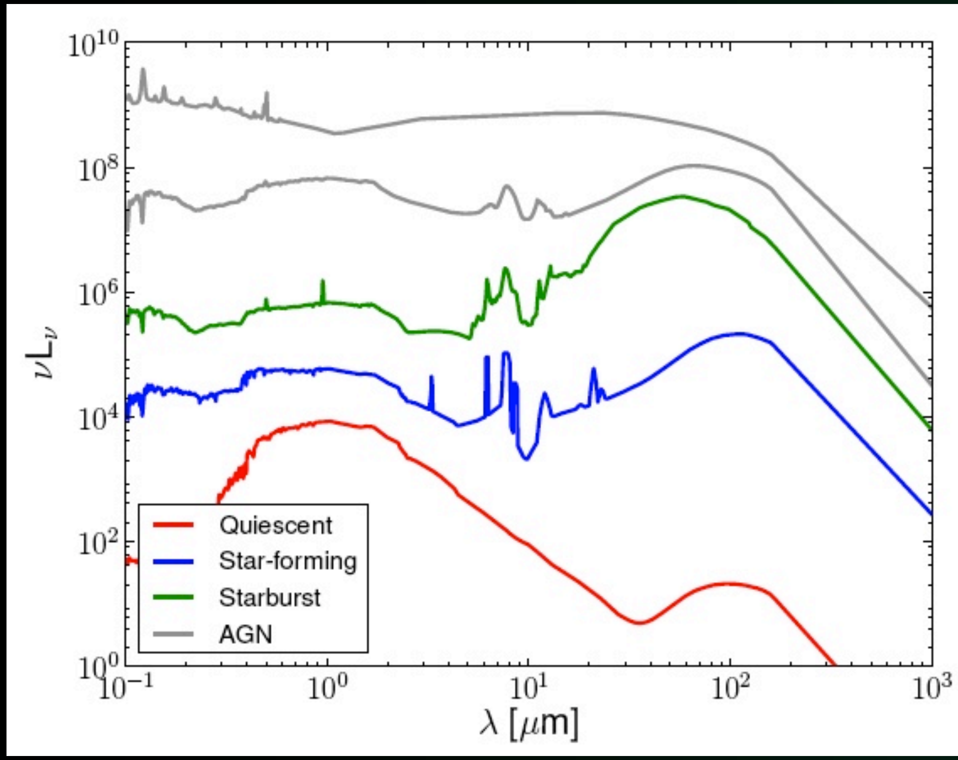
<u>EBL from observations:</u> Dominguez et al., ArXiv:1007.1459

Uses evolution galaxy number fraction across 25 spectral types seen in some 6000 AEGIS galaxies, with normalization to K-band luminosity functions (Cirasuolo 2010)

AGN and starburst-like spectral type fractions increase with redshift to z~1, while quiescent decrease.



5 sample templates:



• AEGIS multiwavelength data covers several optical and NIR bands, IR (IRAC and MIPS), and UV (GALEX)

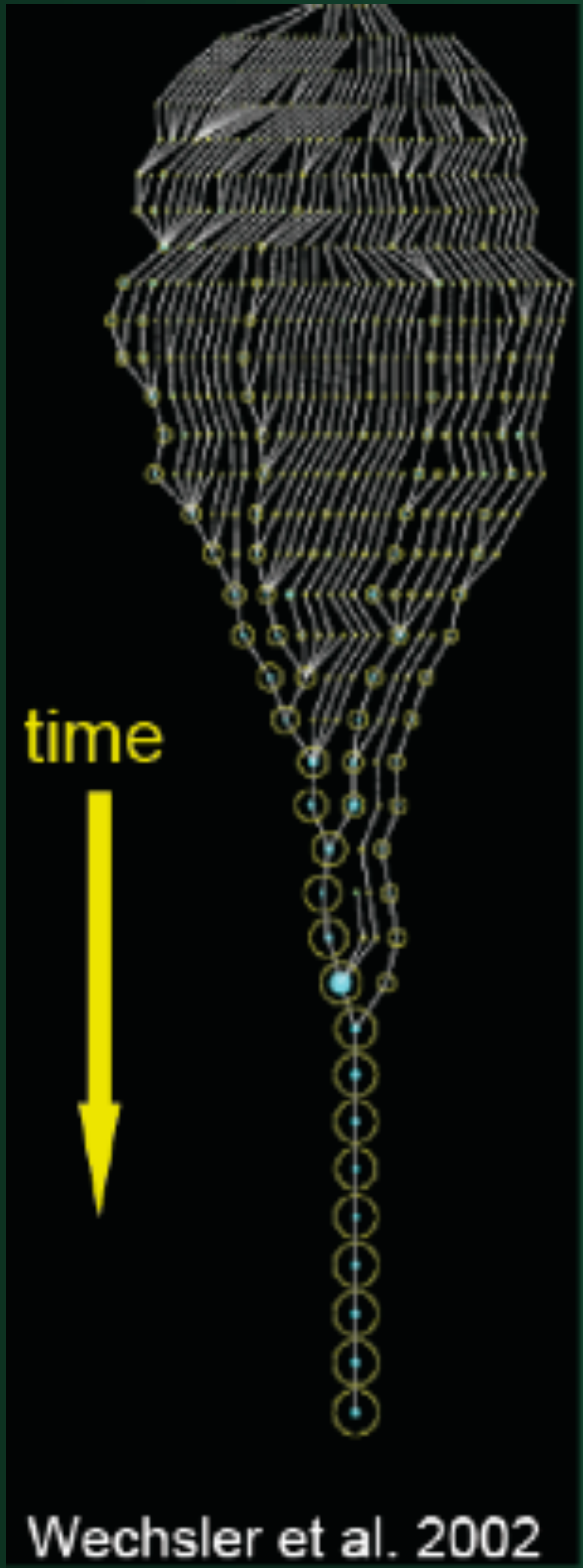
• High redshift (z > 1): 2 assumptions about evolution of SED types were considered

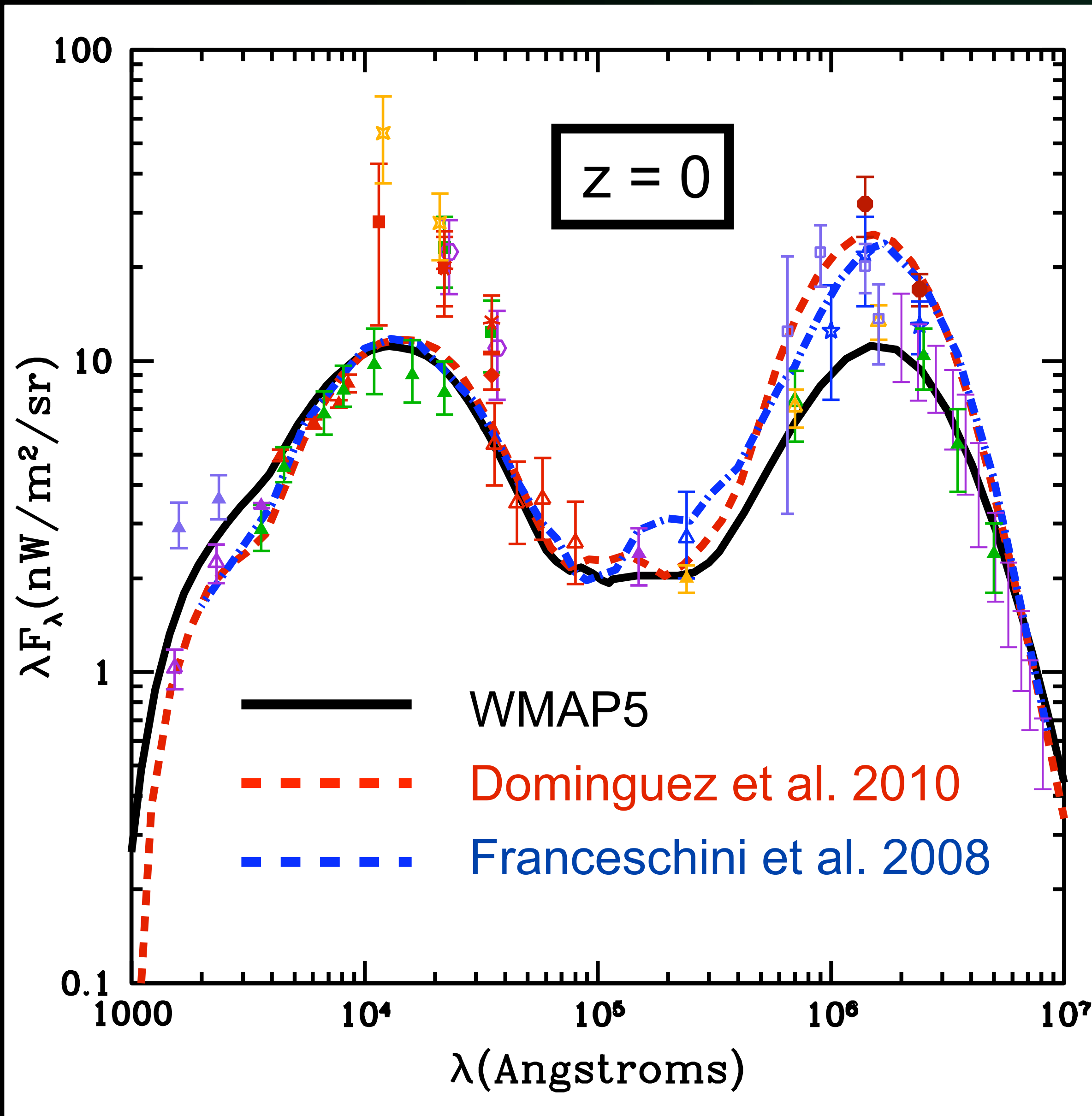
EBL from semi-analytic models

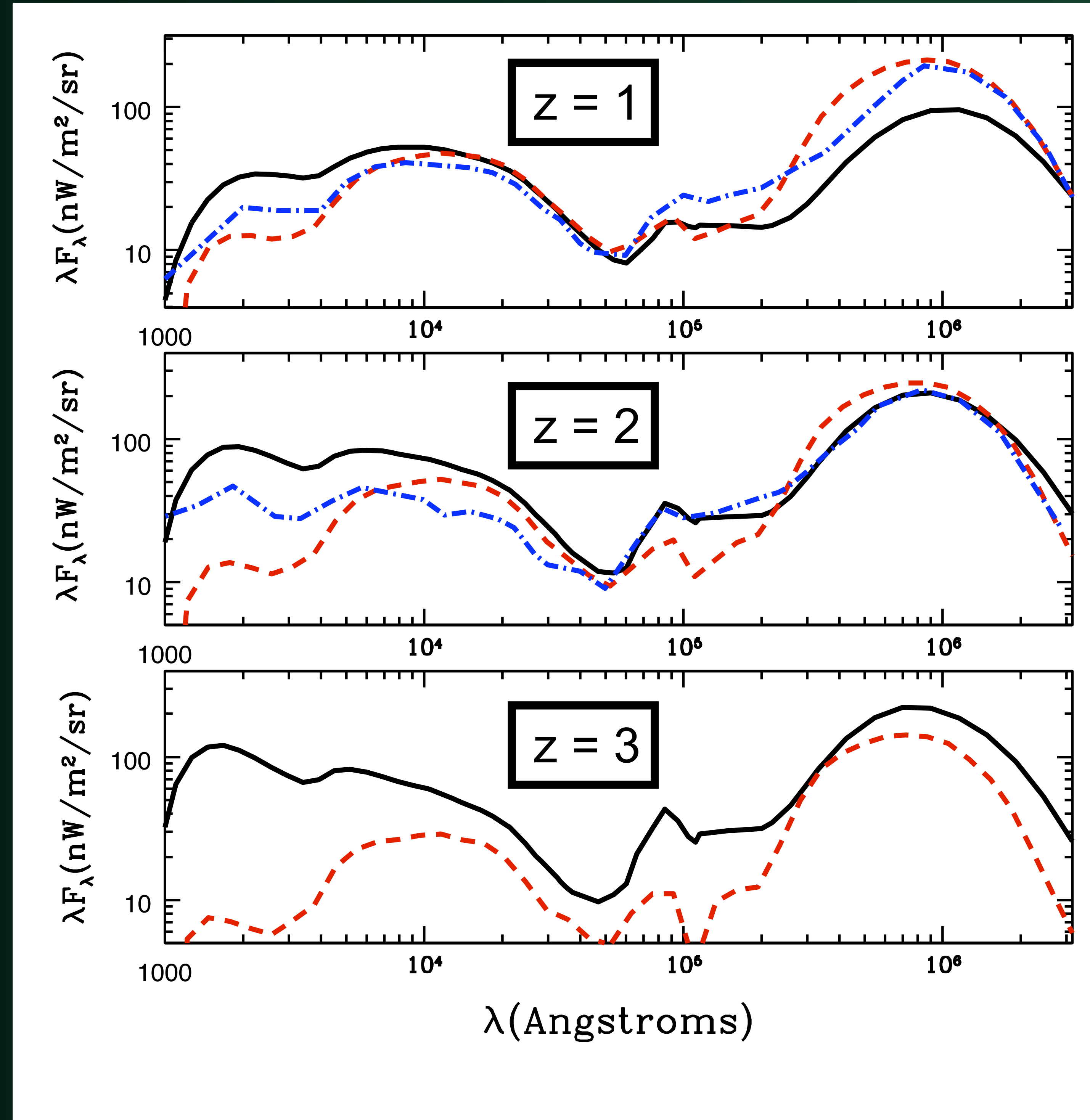
- Treats co-evolution of AGN, black holes, and galaxies in ΛCDM framework
- Based on model of Somerville et al. (2008), including
  - Galaxy formation based on hierarchical buildup of cold dark matter halos.
  - Star formation in quiescent and burst modes, with regulation by AGN feedback
  - Optical and UV starlight absorbed using dust model of Charlot & Fall (2000), IR re-emission based on Spitzer templates (Rieke et al. 2009)

➡ “WMAP1” model based on concordance cosmology (Primack, Gilmore, Somerville 2008, Gilmore et al. 2009)

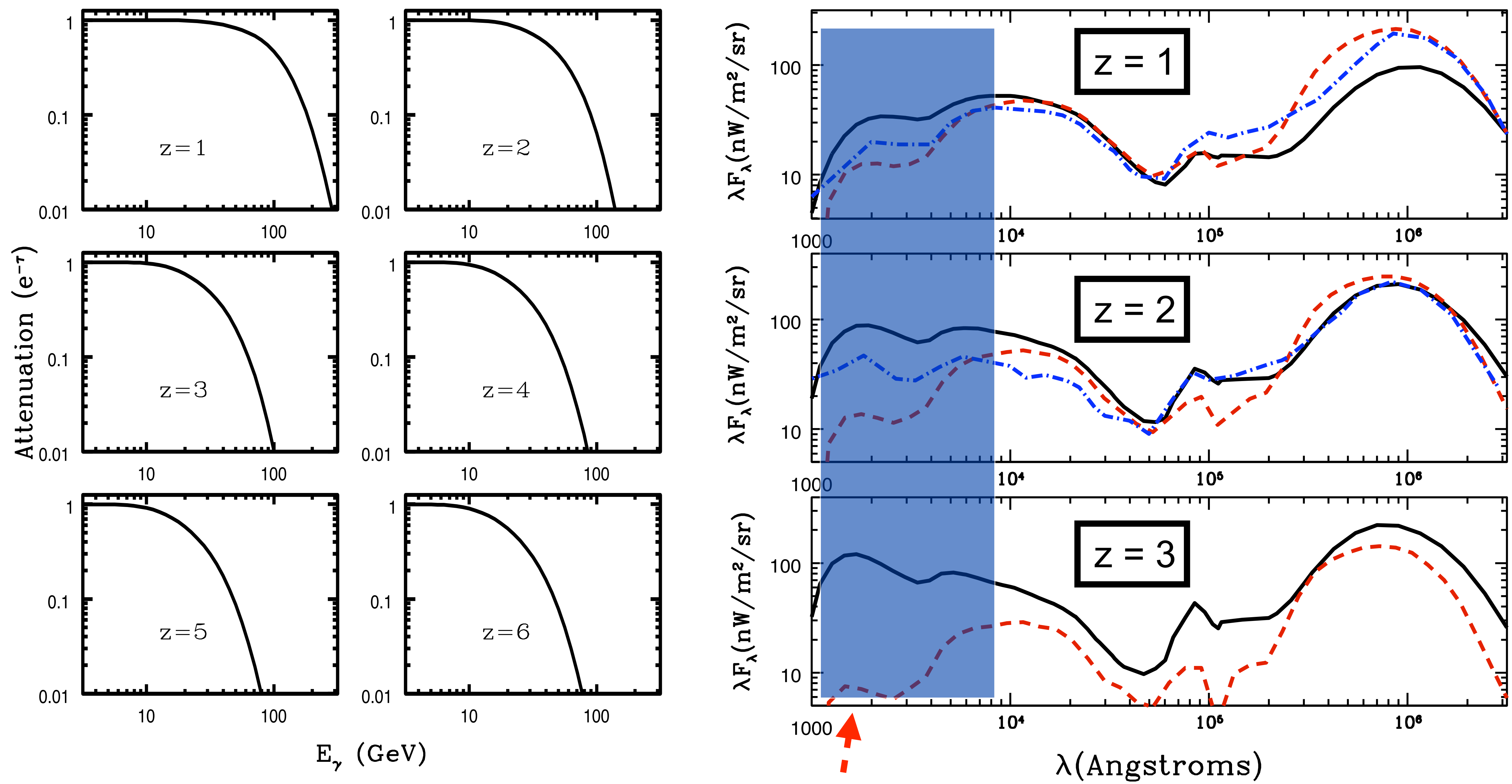
➡ new WMAP5/7 model with updated cosmological parameters nearly complete (Gilmore, Somerville, Primack, Dominguez in prep.)







- ✦ Models which predict very similar local background flux can have different redshift evolution.
- ✦ High-redshift gamma ray sources probe the integrated background flux



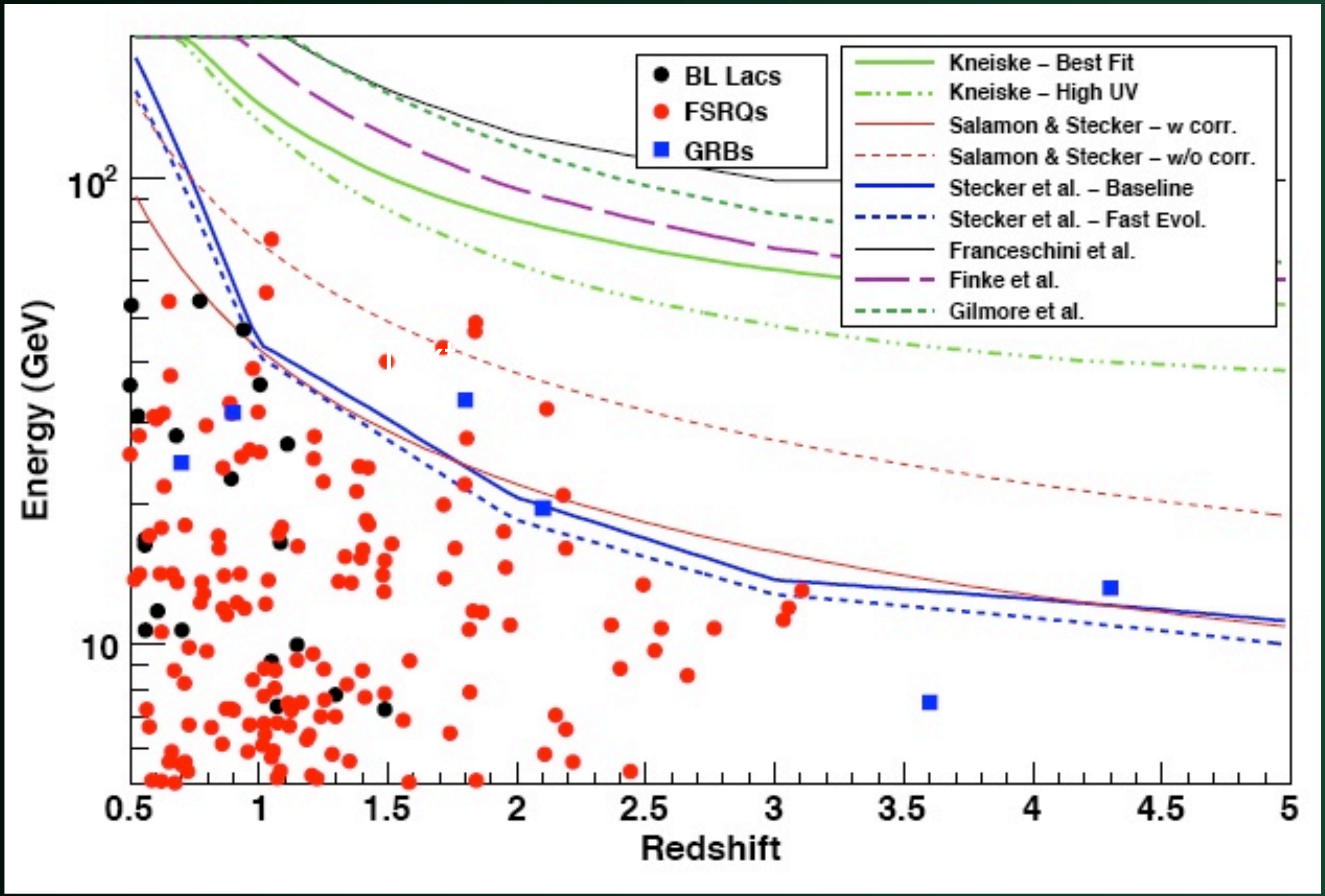
Gilmore et al 2009, "fiducial" model

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

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



Studying optical/UV background with GRBs

While AGN have typically been the focus of EBL studies, GRBs are an interesting source, and may provide answers about the background at $z > 1$.

- Fermi LAT: ~20 GRBs, including 4 with >10 GeV (observed) emission
- Several campaigns are in place to detect GRBs from the ground with IACTs

What are the prospects for studies with current and future instruments?

Gilmore, Prada, Primack (2010) - simulated multiyear observations with Fermi LAT and MAGIC telescopes, using Swift burst population at $z > 1$.

Gilmore, Prada, Primack 2010, MNRAS 402, 565

Fermi: We predict 3-4 events with high-energy emission detectable by LAT each year. Small number >10 GeV events

MAGIC: 20-30% chance of seeing GRB with low energy threshold per year, 10s to 1000s of photons for a bright burst.

Results for MAGIC

Considerations for ground-based GRB detection:

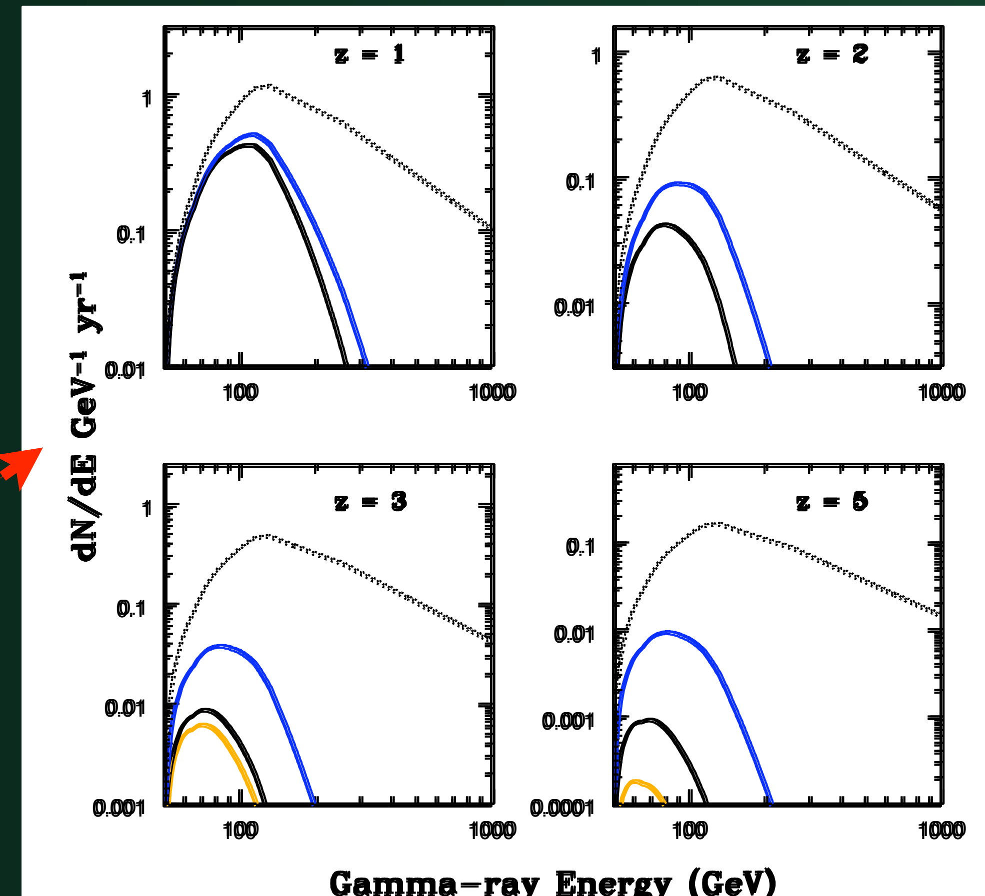
- Response time of instrument (45 sec here)
- Low energy effective area, as a function of zenith angle and energy

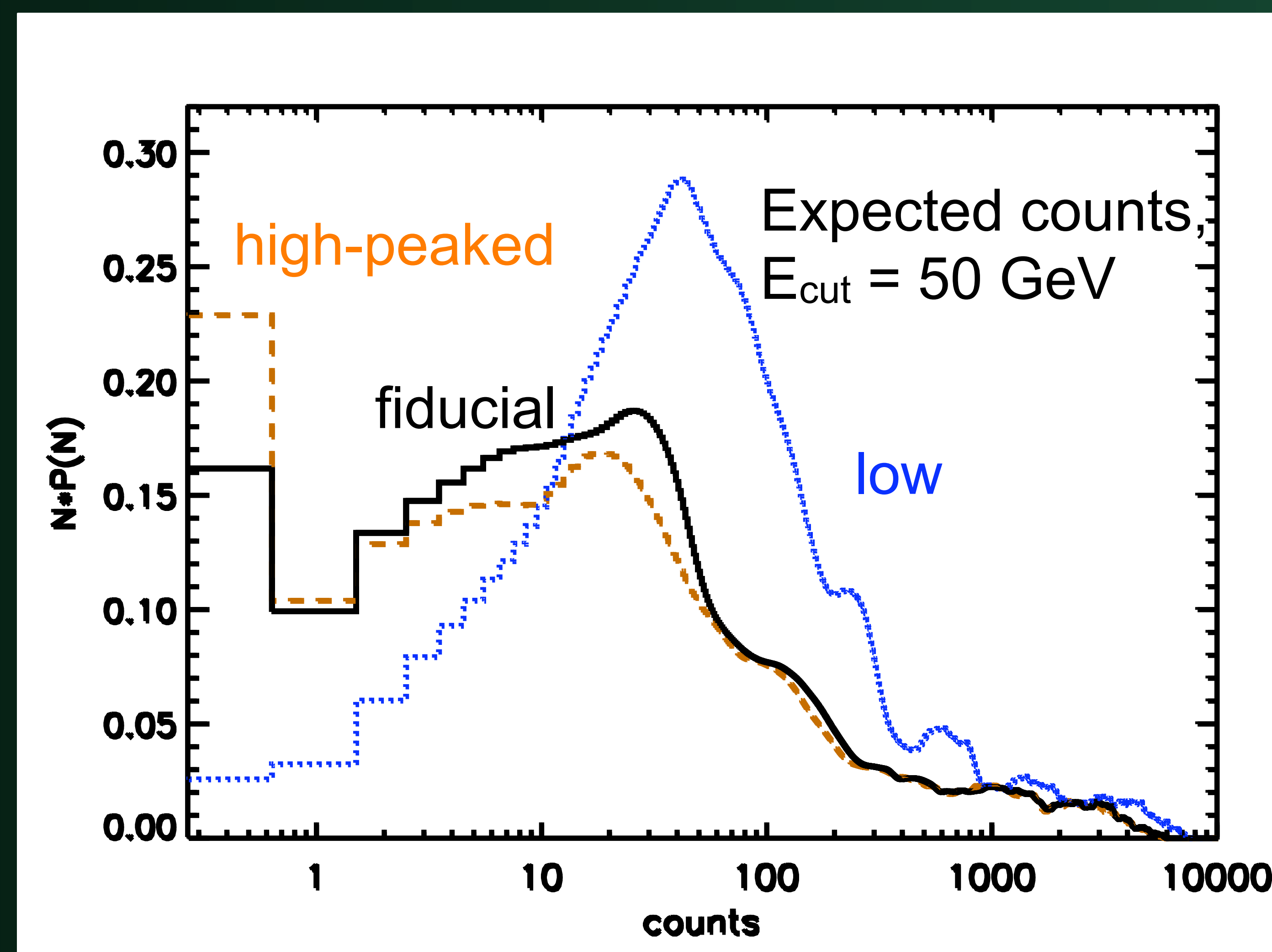
For IACT like MAGIC: duty cycle * sky coverage ≈ 1%

Probability of seeing ≥1 GRB/yr ≈ 30%

Results highly dependent on low-energy telescope sensitivity and EBL

Expected spectrum for various z_{source} and EBL models (arbitrary y-units)





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Ongoing work - updated model for next-generation IACT (ACTA)

- Improved sensitivity at 20 - 100 GeV will improve photon statistics
- But some IACT limitations are unavoidable (triggering requirements, duty cycle)

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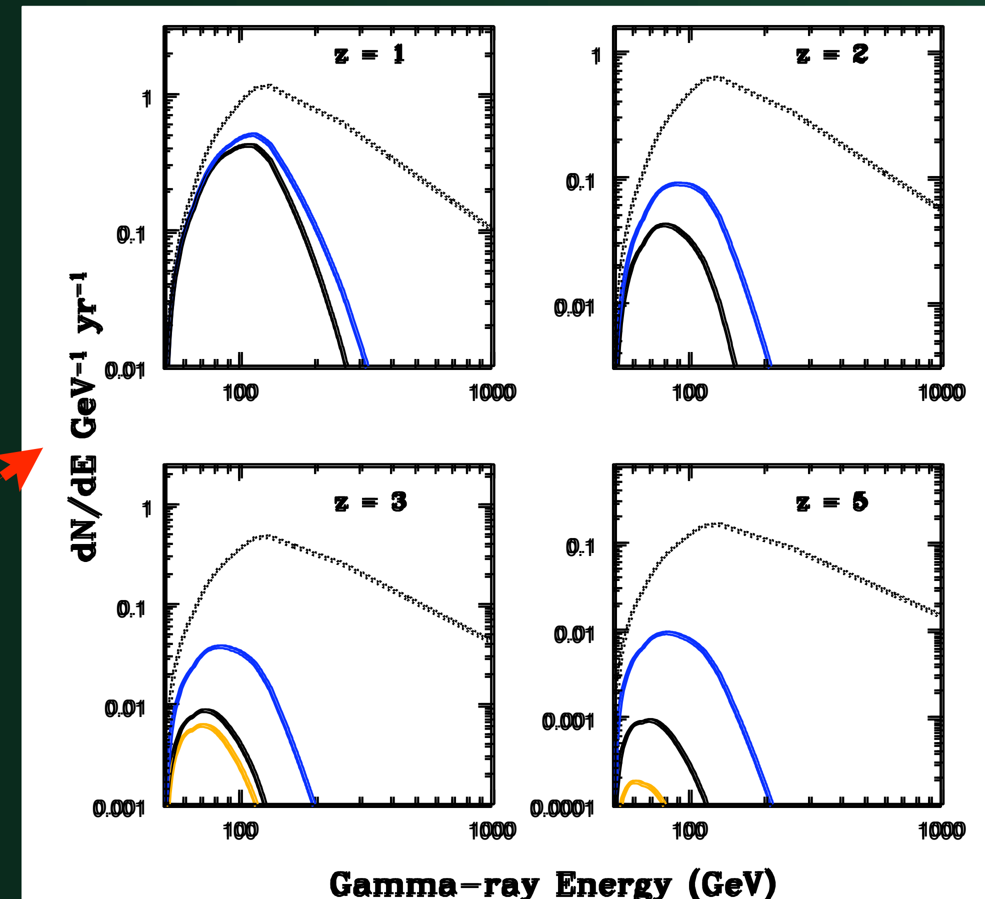
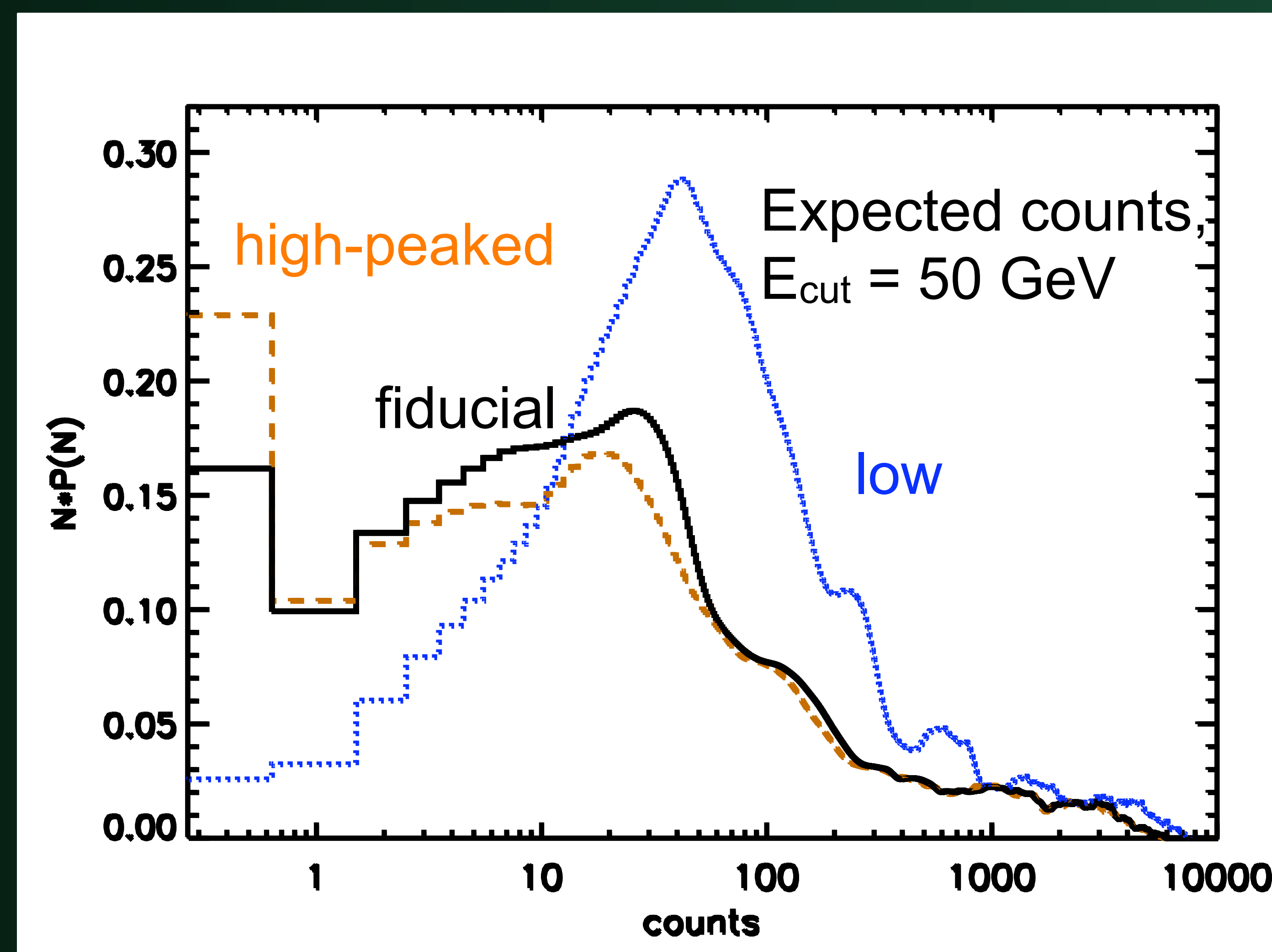




Opacity of Star-Forming Galaxies

Can UV fields in compact, rapidly star-forming galaxies (typical LGRB hosts) produce a cutoff in GR spectra?

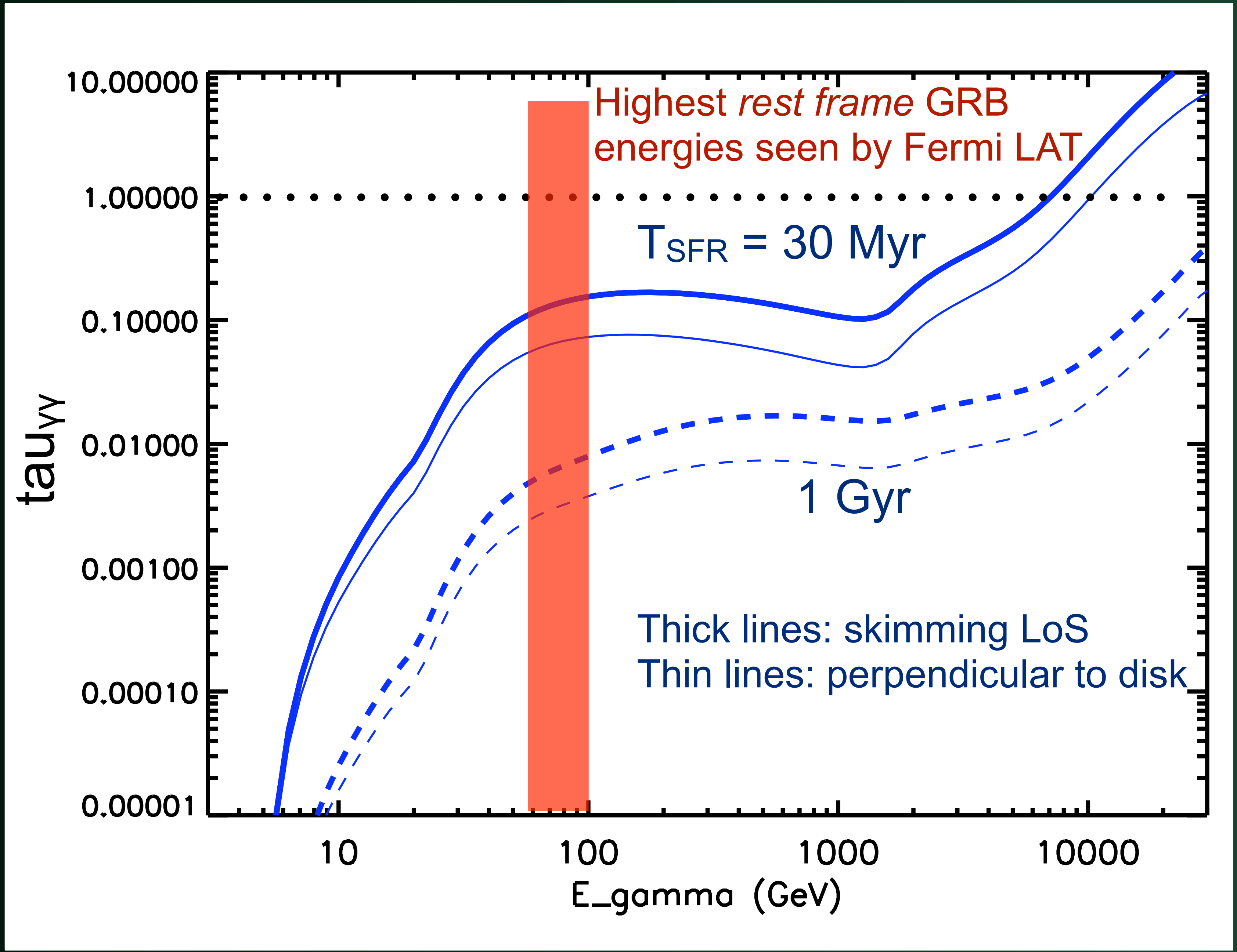
Gilmore & Ramirez-Ruiz
(ApJ in press)

We undertook this calculation using realistic LGRB host galaxy spectra and dust processing of starlight

➡ All galaxies optically thin < 1 TeV

➡ Most galaxies have a cutoff at a few TeV, due to IR fields

Results for a 10^{10} M_{sun} galaxy, considering two different star formation timescales and two line-of sight geometries



Conclusions

- Much progress has been made recently in understanding the local EBL, with a convergence in results between very different modeling techniques

- Large uncertainties remain at high redshift

- GRB observations could be important to constraining the high-z UV background

High-energy gamma rays from GRBs

- Fermi may be able to constrain high EBL with several years' data for redshifts 1 -- 3, with 10's of counts in 10~50 GeV range

- MAGIC could detect a large number of gammas within a narrow energy band from single GRB, but annual probability of detection is low

- Currently investigating prospects for next-gen IACT (ACTA)

Local absorption of GRB emission

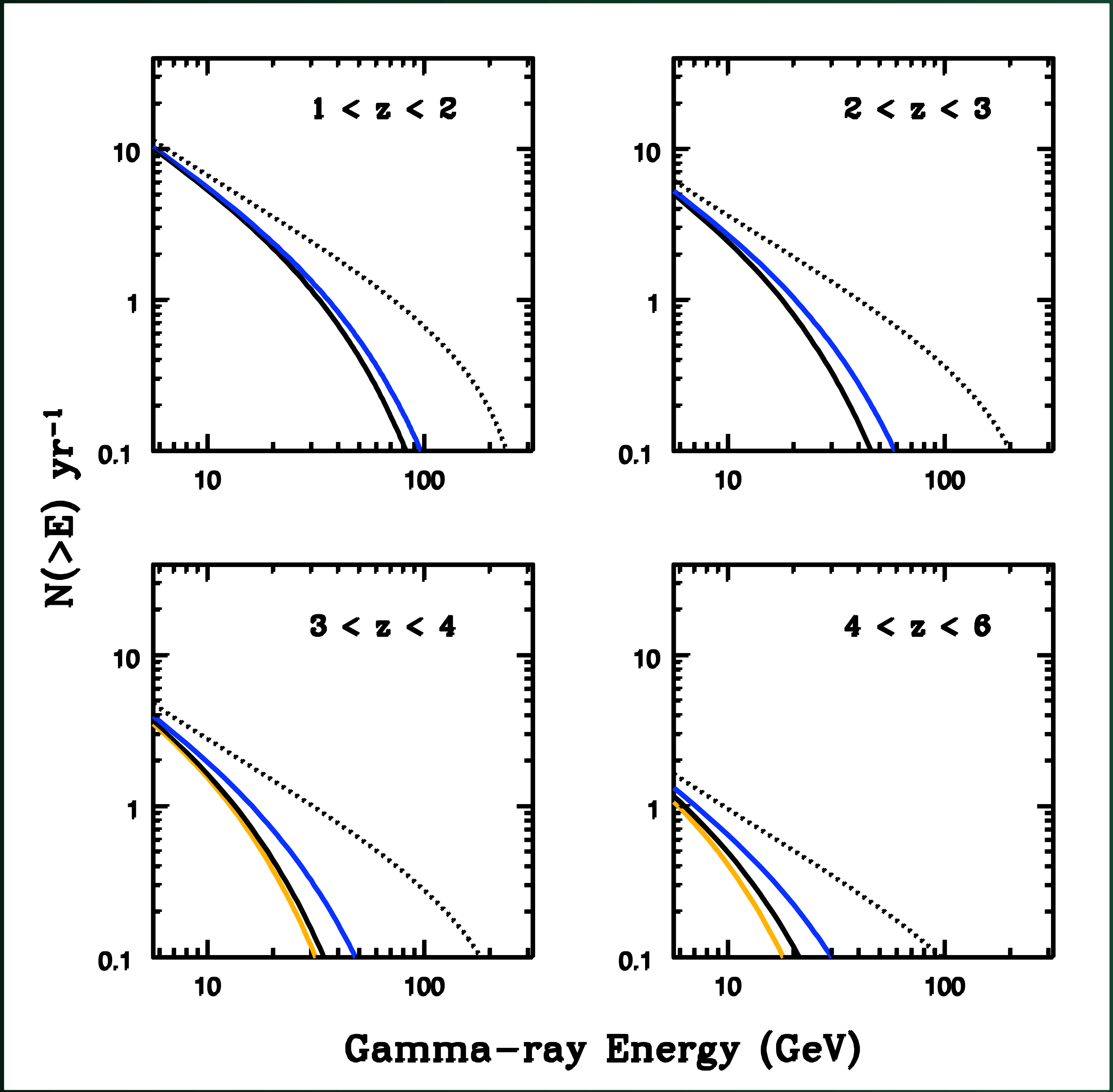
- Unlikely that GeV gammas (Fermi energies) could be significantly affected

- Cutoff at ~10 TeV for large, IR-bright galaxies due to FIR emission peak...but EBL produces larger opacity for almost all GRB of known z

Results for Fermi

- We predict 3-4 events with high-energy emission detectable by LAT each year
- Small number >10 GeV events

Annual integrated GRB photons for 4 redshift bins, with attenuation



Results for MAGIC

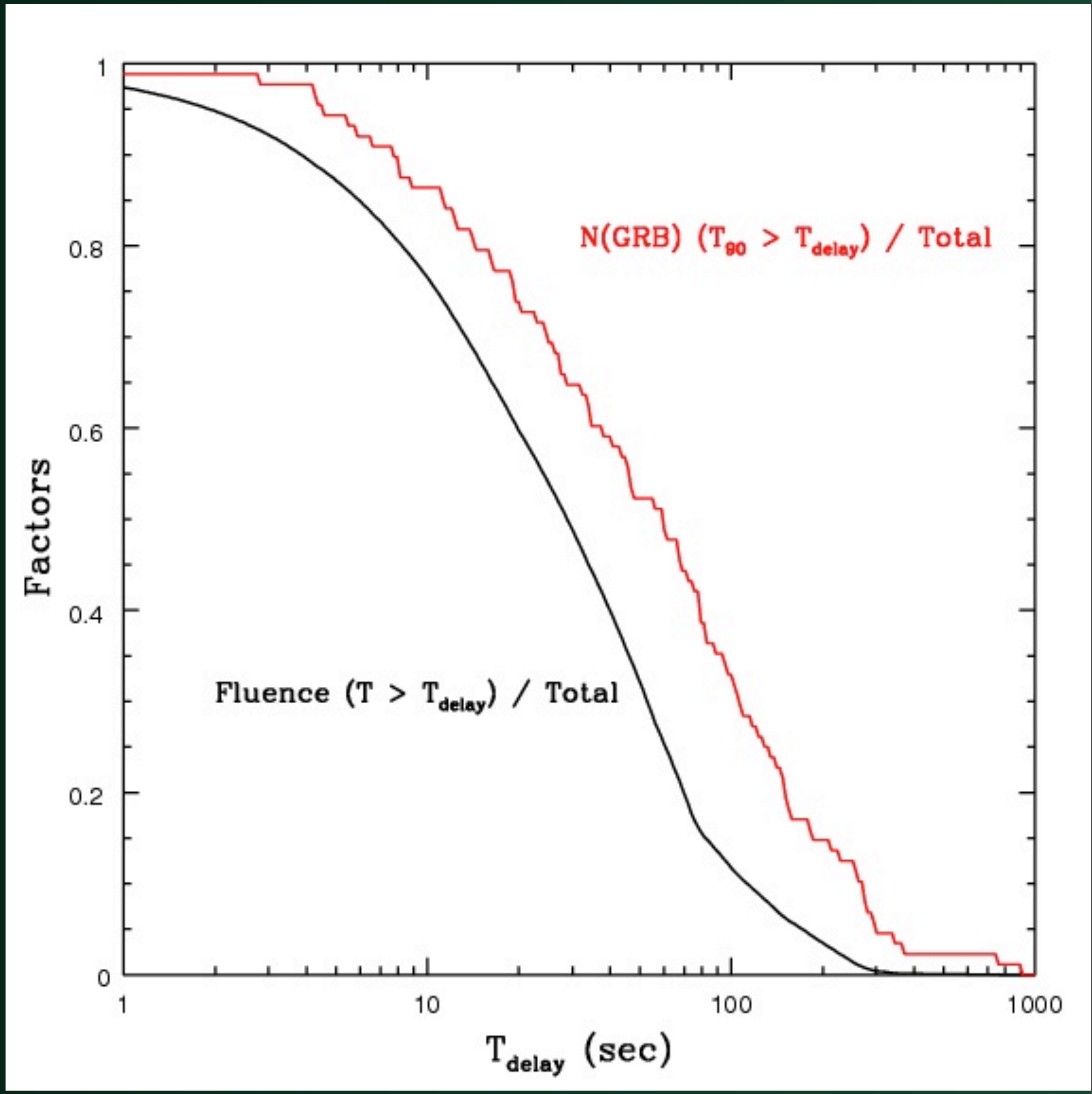
• IACT response time to GCN alert is same order as typical T_{90}

- Fastest response to date: 43 sec; ≥100 sec more typical
- We will be optimistic, and assume 45 sec

• MAGIC has much larger peak effective area than Fermi LAT (~10^5 vs ~0.8 m^2), however:

- rapid decline area for E_γ < 100 GeV
- EBL becomes important at these energies

Distribution of GRB "T_{90}" times in the Swift sample



Absorption of Gamma Rays by EBL

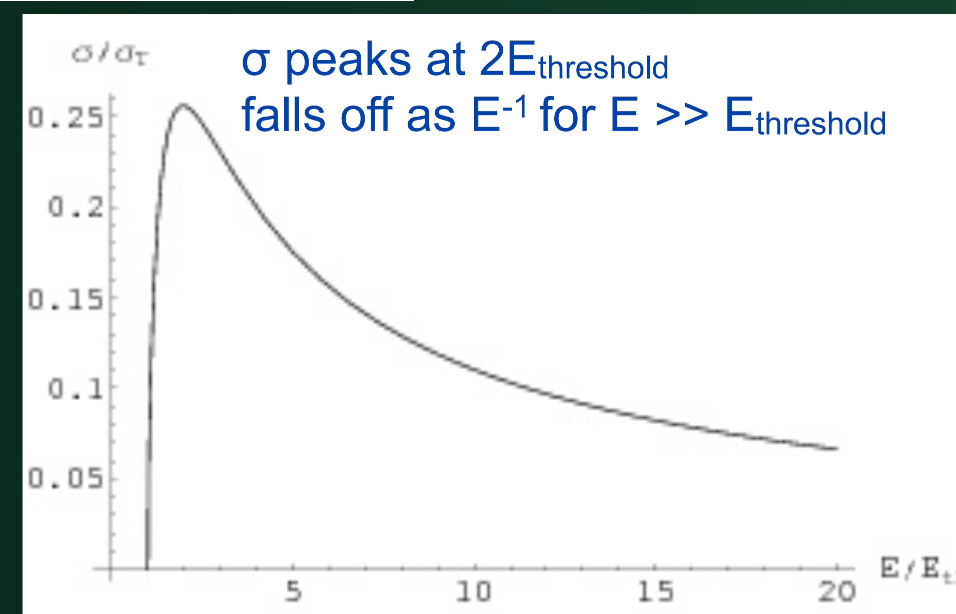
- Gamma-ray attenuation via e^+e^- pair production provides a link between galaxy history and high energy astrophysics.

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

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

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

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



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

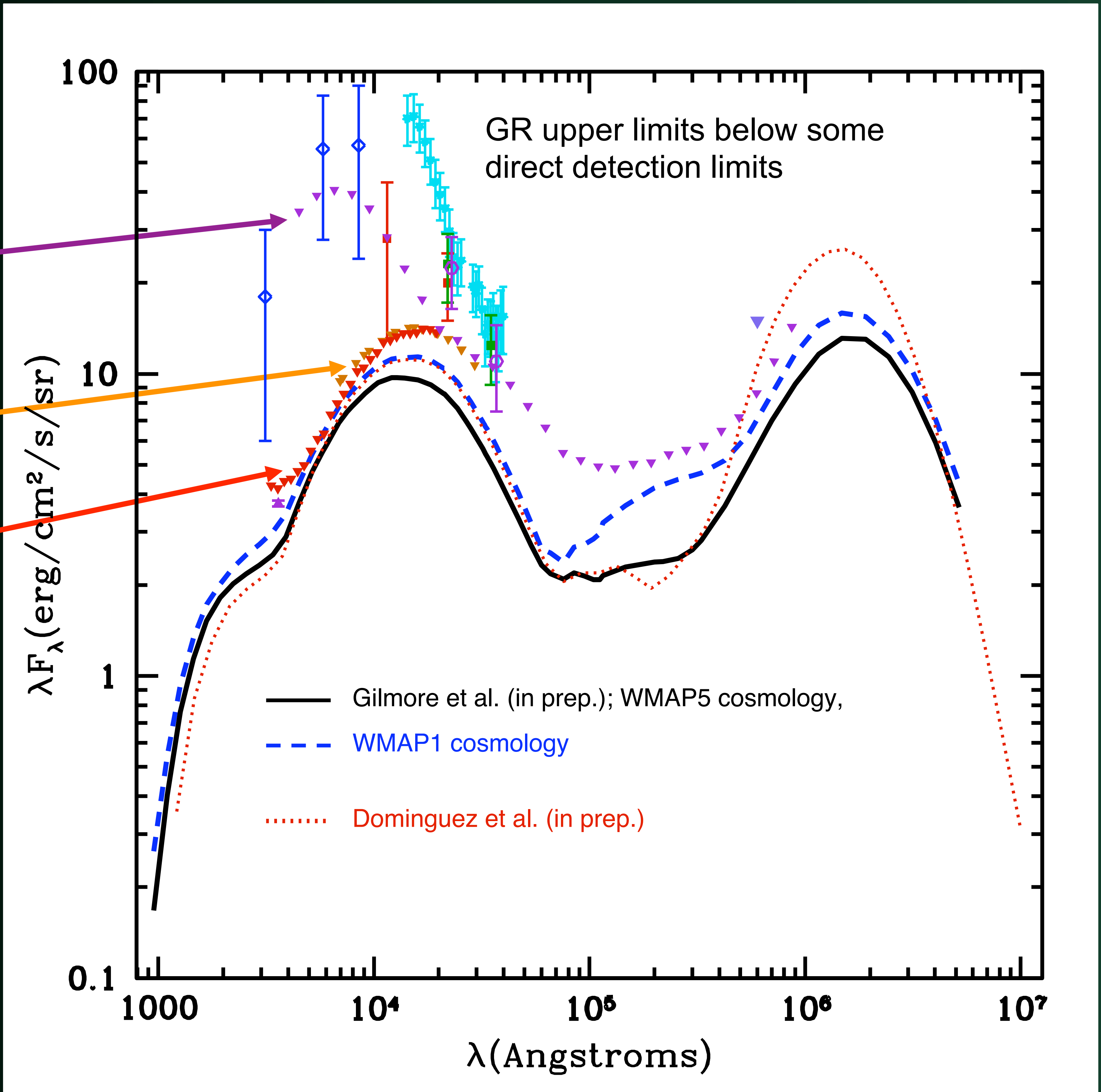
Our models with gamma-ray upper limits

Our models are within new low bounds set by blazar observation

(Mazin & Raue 2007)

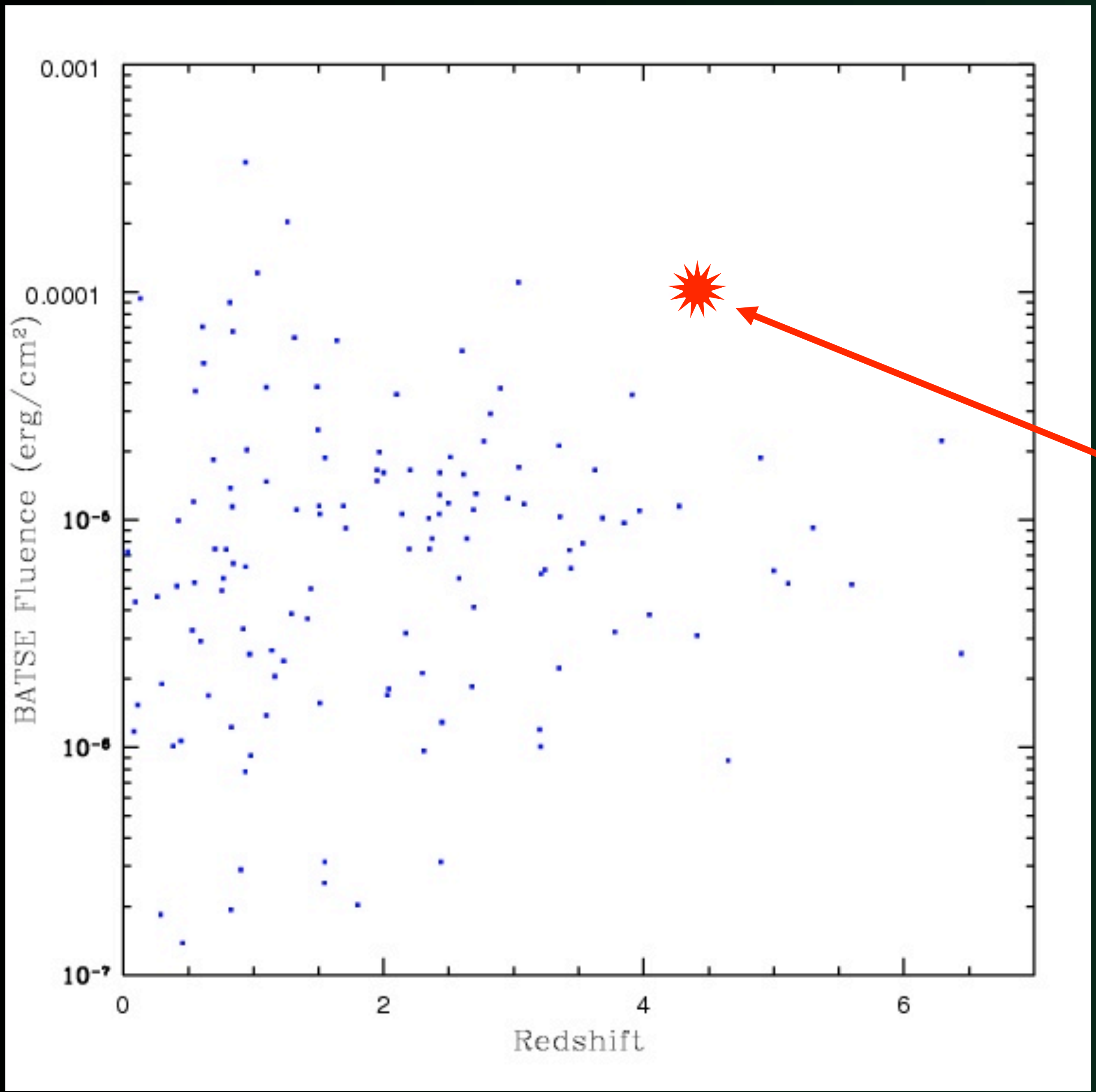
H 2356-309 and 1ES 1101-232 (z=0.165 and 0.186) (Aharonian 2006)

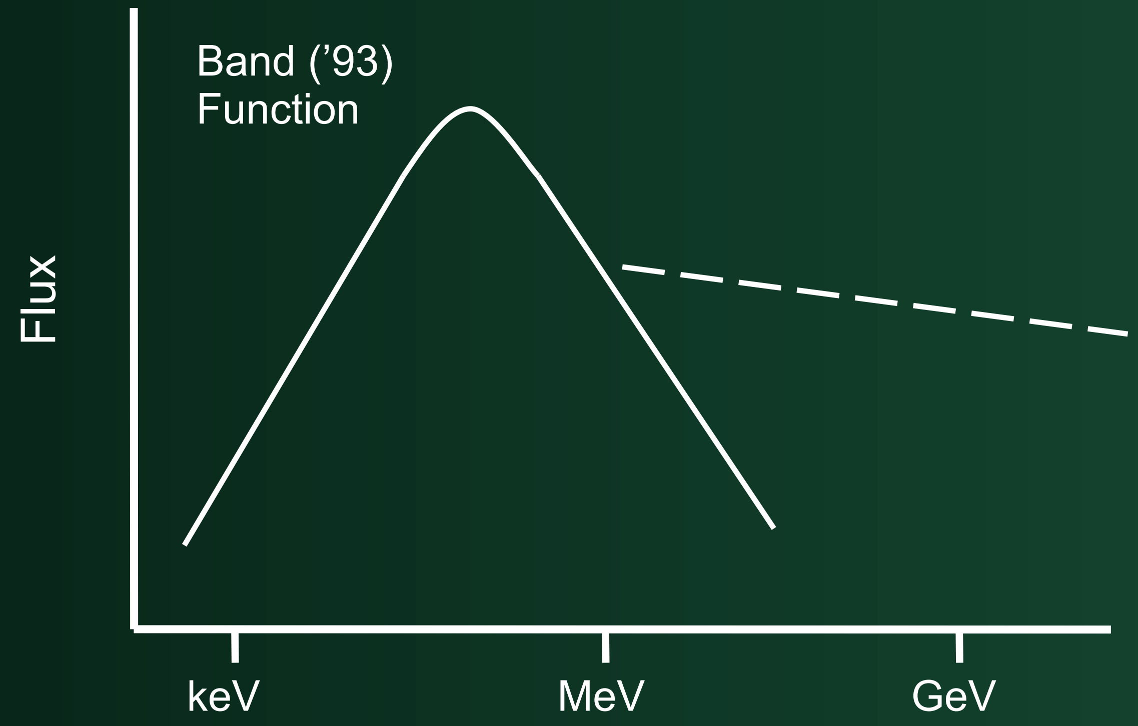
3C279 (z=0.536) (Albert 2008)



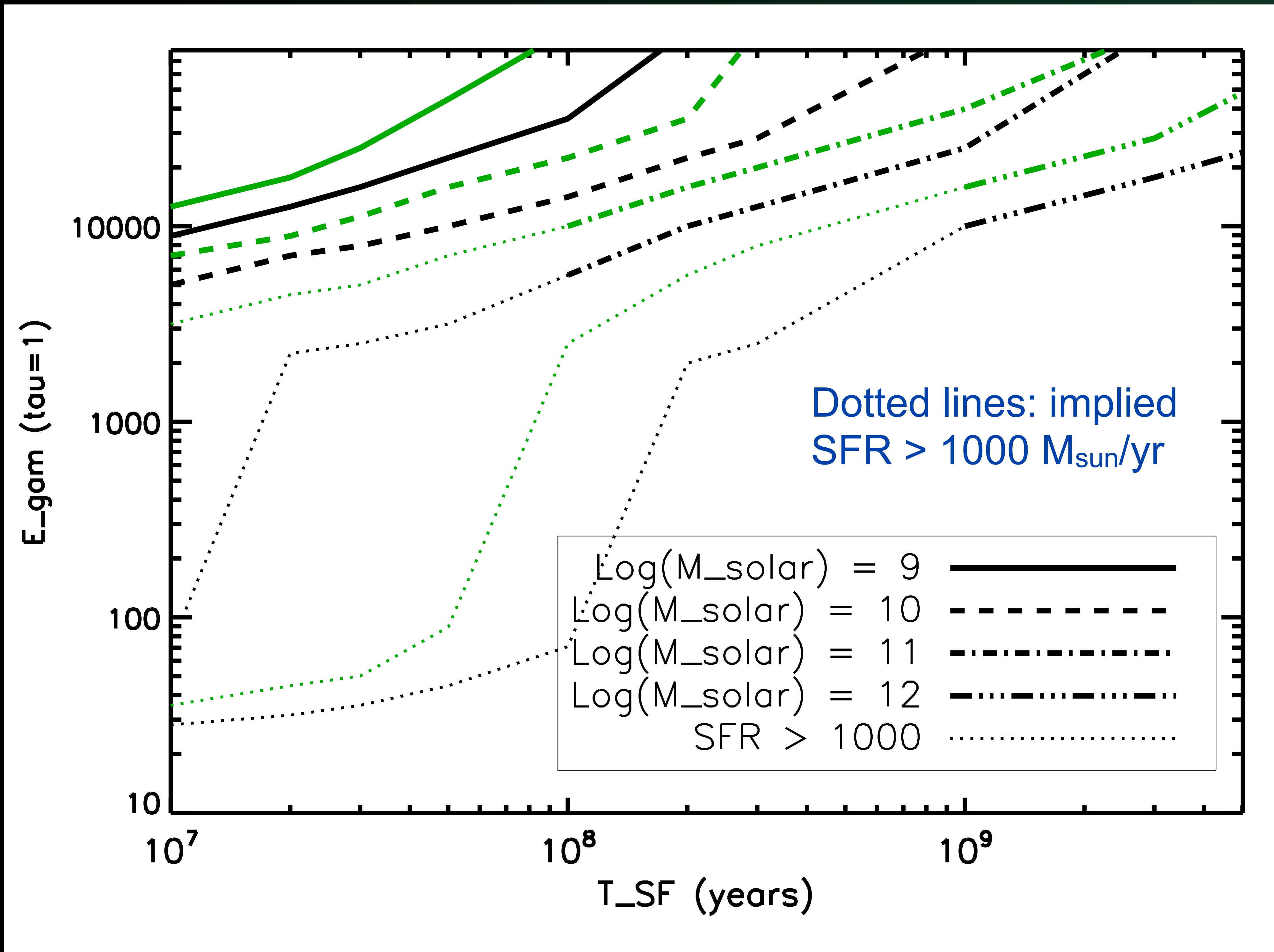
Our model: use Swift population with known z, and CGRO EGRET--BATSE fluence relations (Le & Dermer 2008 and Ando et al. 2008)

- Dai et al. (2008): this population similar to all optically detected GRBs





GRB 080916C, based on GBM flux: reasonable match between LAT data and our model predictions



Lowest GR energy for which photon field from galactic disk produces opacity

$\tau > 1$