The EBL and Gamma Ray Attenuation

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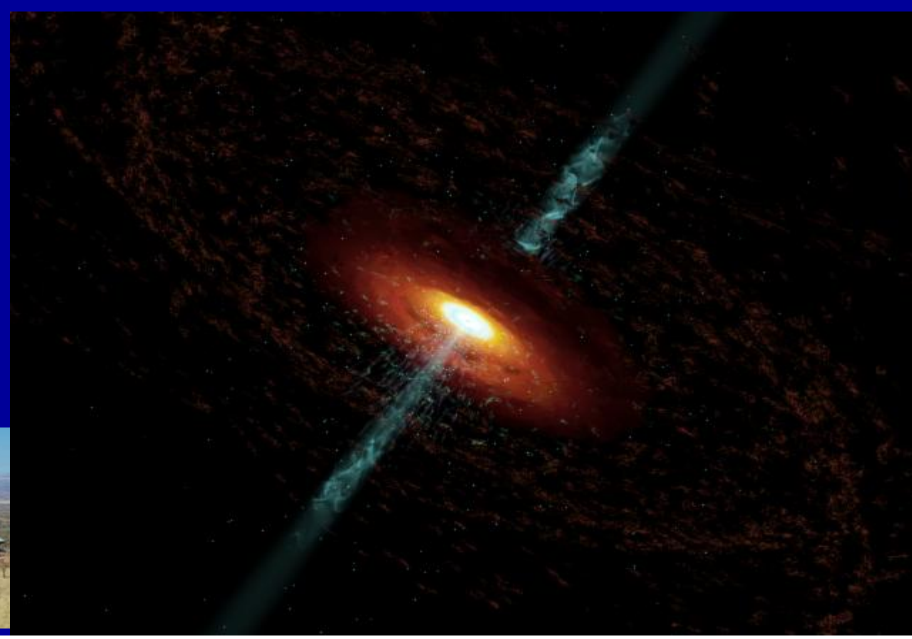
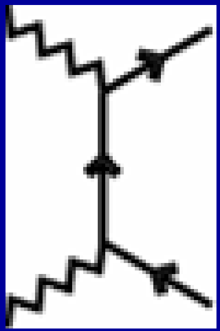


Absorption of Gamma Rays

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

• The interaction cross-section peaks at twice the threshold energy; specific wavelengths are associated with certain gamma energies:



$$\lambda \sim 1.24(E_\gamma/\mathrm{TeV})\ \mu\mathrm{m}$$

• Opacity $\tau(E_\gamma, z)$ based on integrated extragalactic background light (EBL) flux, and tends to increase with energy.

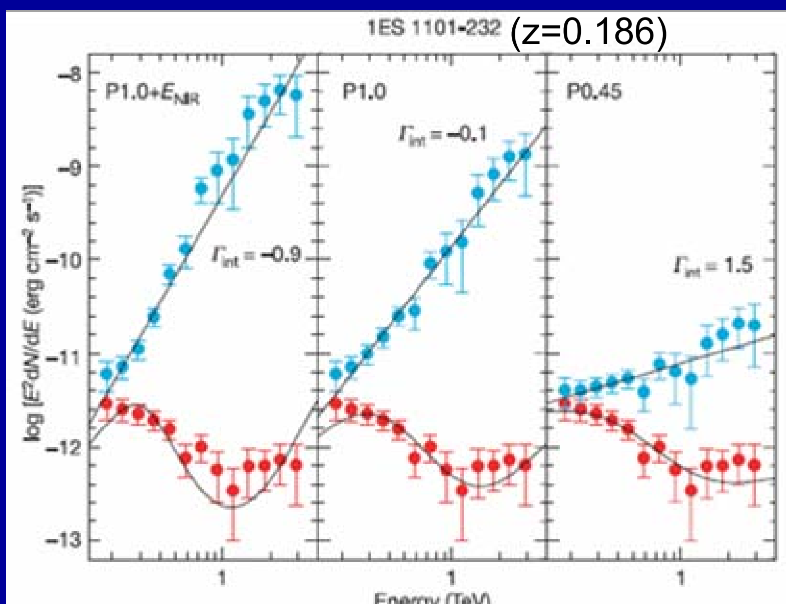
• This leads to softening and cutoff in gamma ray spectra of distant extragalactic sources (blazars and GRBs), as well as gamma ray horizon.

• Observations of ‘nearby’ gamma-ray blazars have been used to place limits on the extragalactic background light (EBL) in the optical and IR.

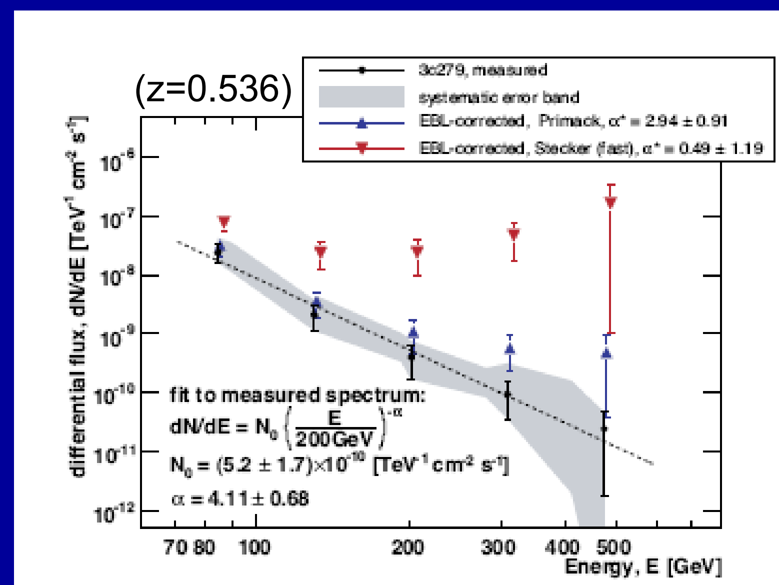
GALAXY EVOLUTION

GAMMA-RAY ASTROPHYSICS

$\Gamma > 1.5$ for photons produced from typical electron population



Aharonian et al., (2006) Nature 440, 1018



MAGIC Collab., Science 320, 1752 (2008)

The Semi-Analytic Model

Treats evolution of AGN, black holes, and galaxies in LCDM framework

Described in detail in Somerville et al. (submitted to MNRAS); based on code described in Somerville & Primack (1999) and Somerville, Primack & Faber (2002)

Galaxy formation based on hierarchical buildup of cold dark matter halos.

2 Models (‘Fiducial’ and ‘Low’) created, based on WMAP1 and WMAP3 values for sigma_8 (WMAP5 is intermediate to these)

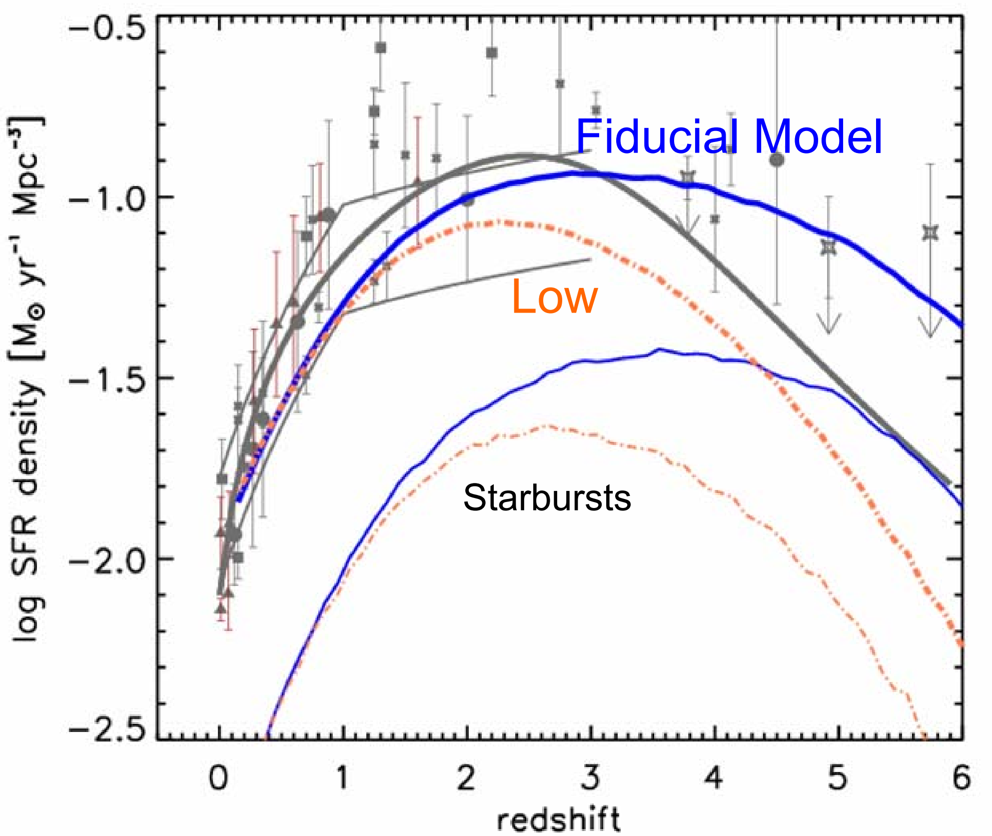
Stars and AGN:

- Star formation can occur in quiescent and burst modes.
  - Quiescent mode uses Schmidt-Kennicutt prescription
  - Burst occurs during merger, dependent upon available gas and efficiency parameter, SFR falls exponentially.
  - Universal Chabrier IMF assumed

- AGN operate in ‘bright’ and ‘radio’ modes, former switched on by high accretion rate.

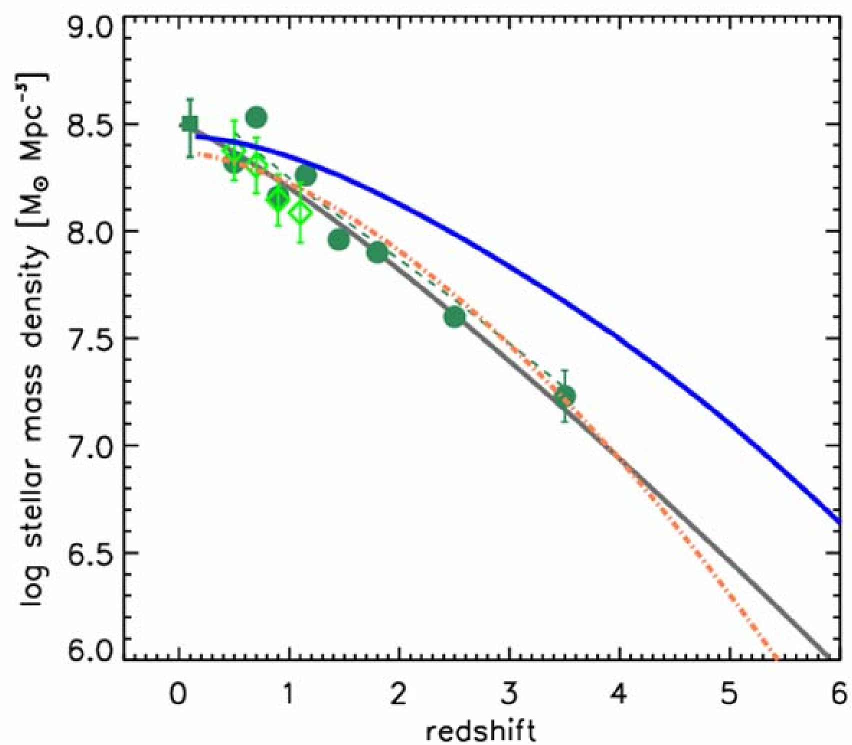
- Long-term radio mode accretion prevents gas inflow for large galaxies, model does good job reproducing color bimodality.

- We use dust reemission templates of Devriendt & Guiderdoni, and 2-component dust model Charlot & Fall (2000).



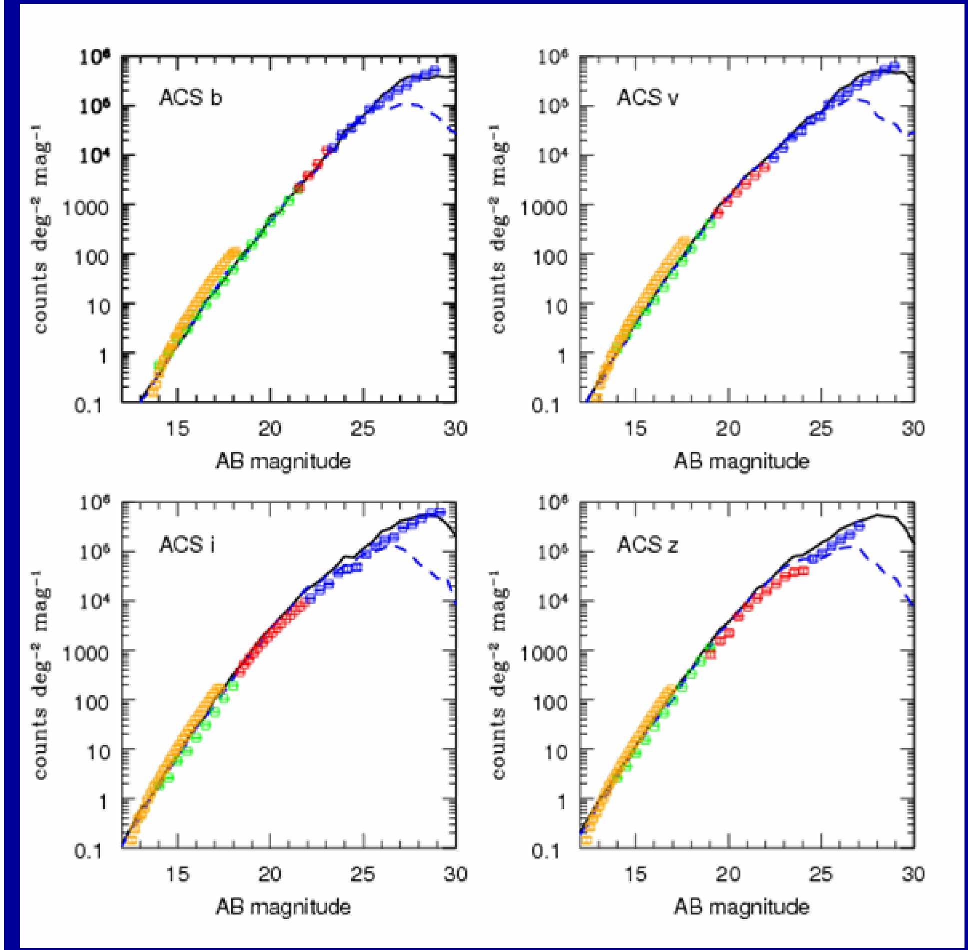
Star Formation Rate Density

Integrated Stellar Mass

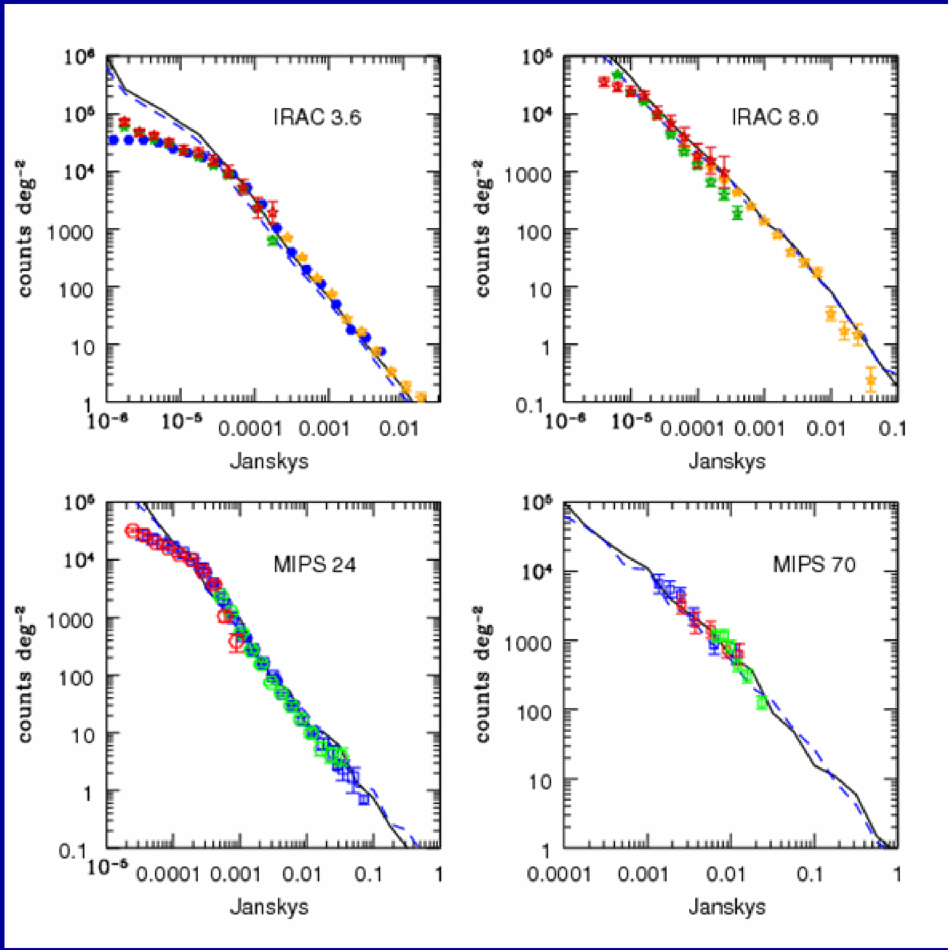


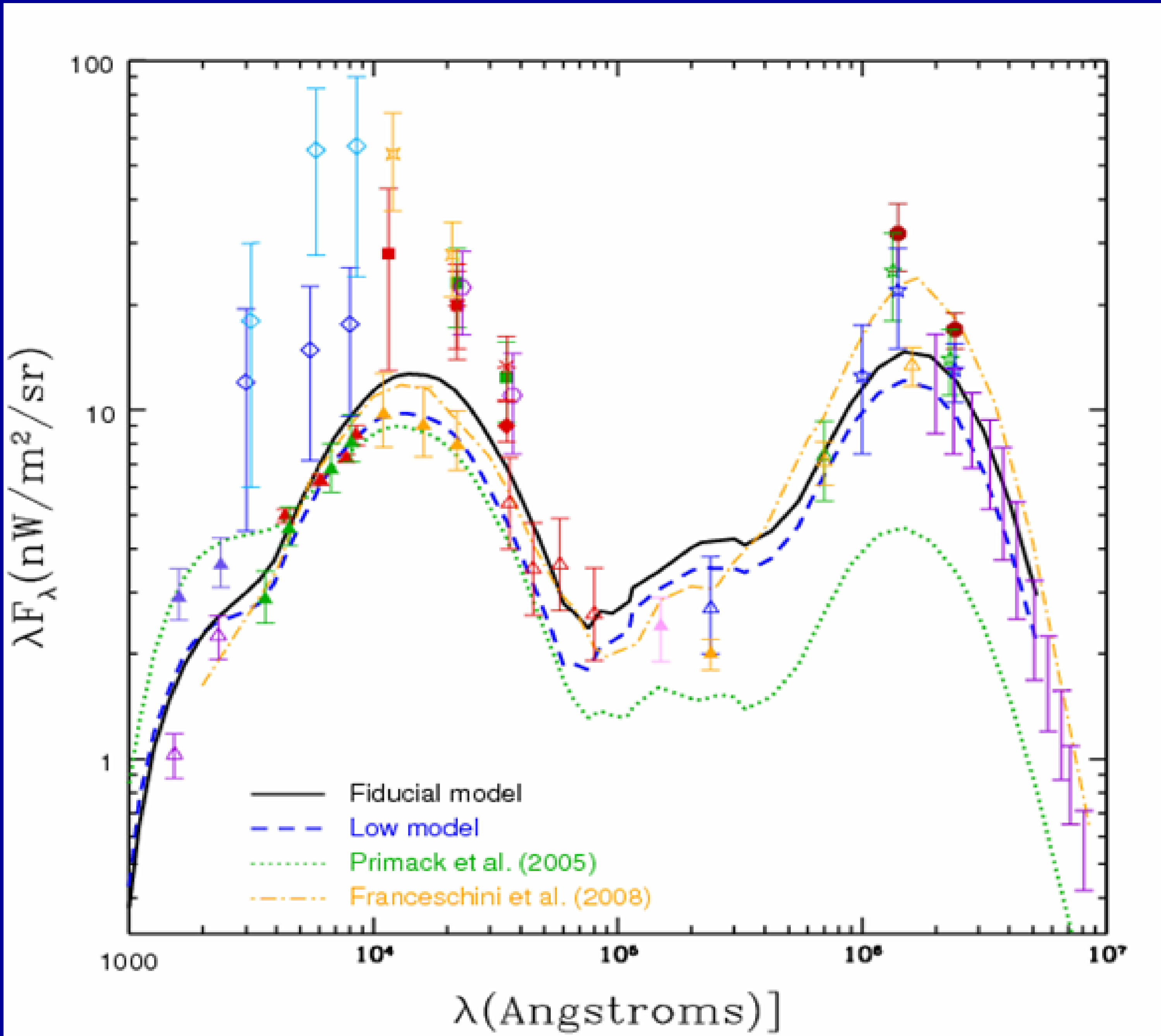
Number Counts

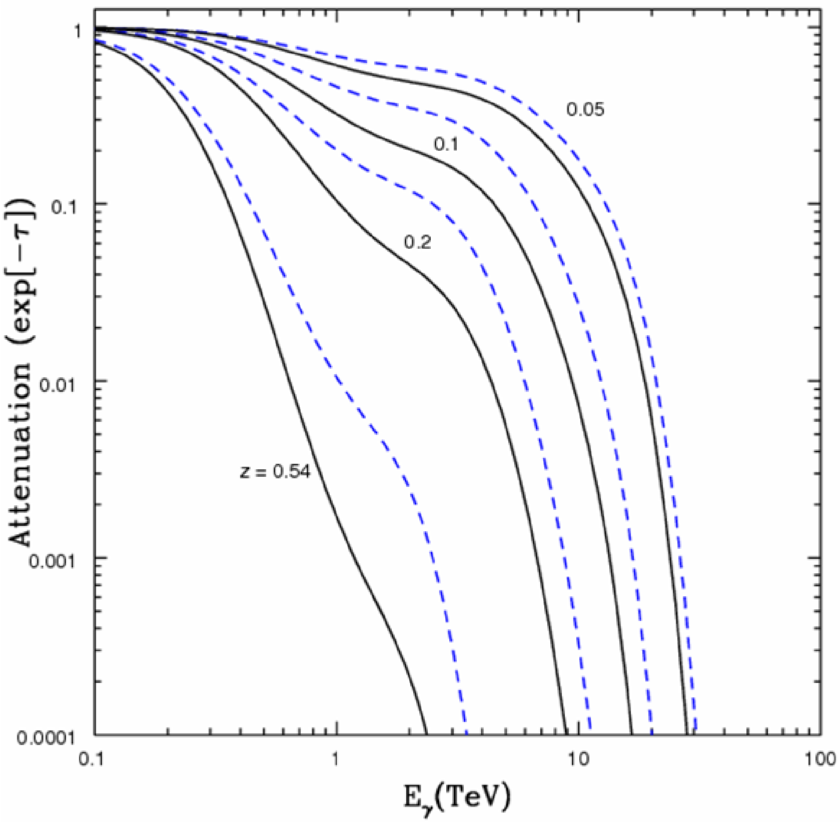
Optical (SDSS + ACS)



Infrared (IRAC + MIPS)

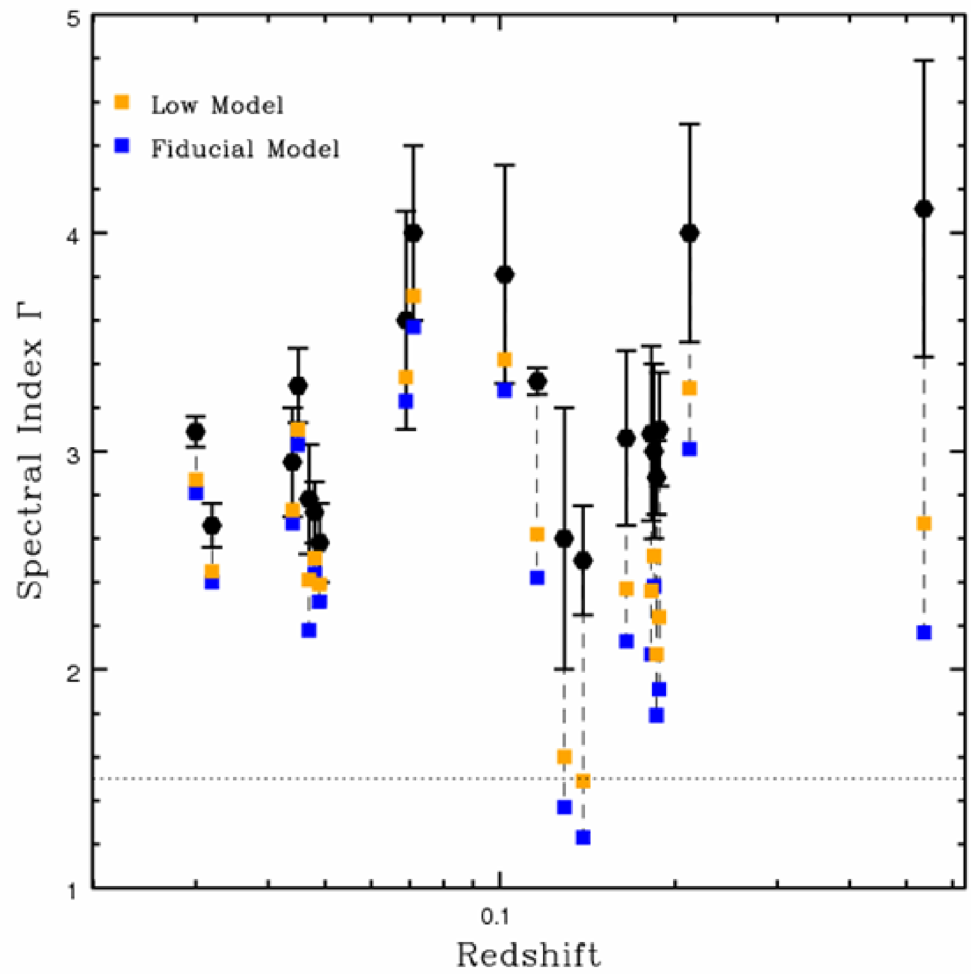



100
10
1
1000
10^4
10^5
10^6
10^7
λF_λ(nW/m^2/sr)
λ(Angstroms)]
Fiducial model
Low model
Primack et al. (2005)
Franceschini et al. (2008)



Optical depth vs Energy at several redshifts

Hardening of spectra for observed blazars ($dN/dE \sim E^{-\Gamma}$)



Conclusions (Part 1)

- We have created 2 models of the background from the UV to far-IR, varying primarily in uncertain CDM normalization parameter sigma_8

- Both have match with number counts, local luminosity functions, and luminosity density

- Both models are below most direct detection claims, except in far-IR, and are near level of resolved light over wide range of wavelengths.

- Good agreement with limits from gamma-ray experiments.

Next Mystery: The UV Background

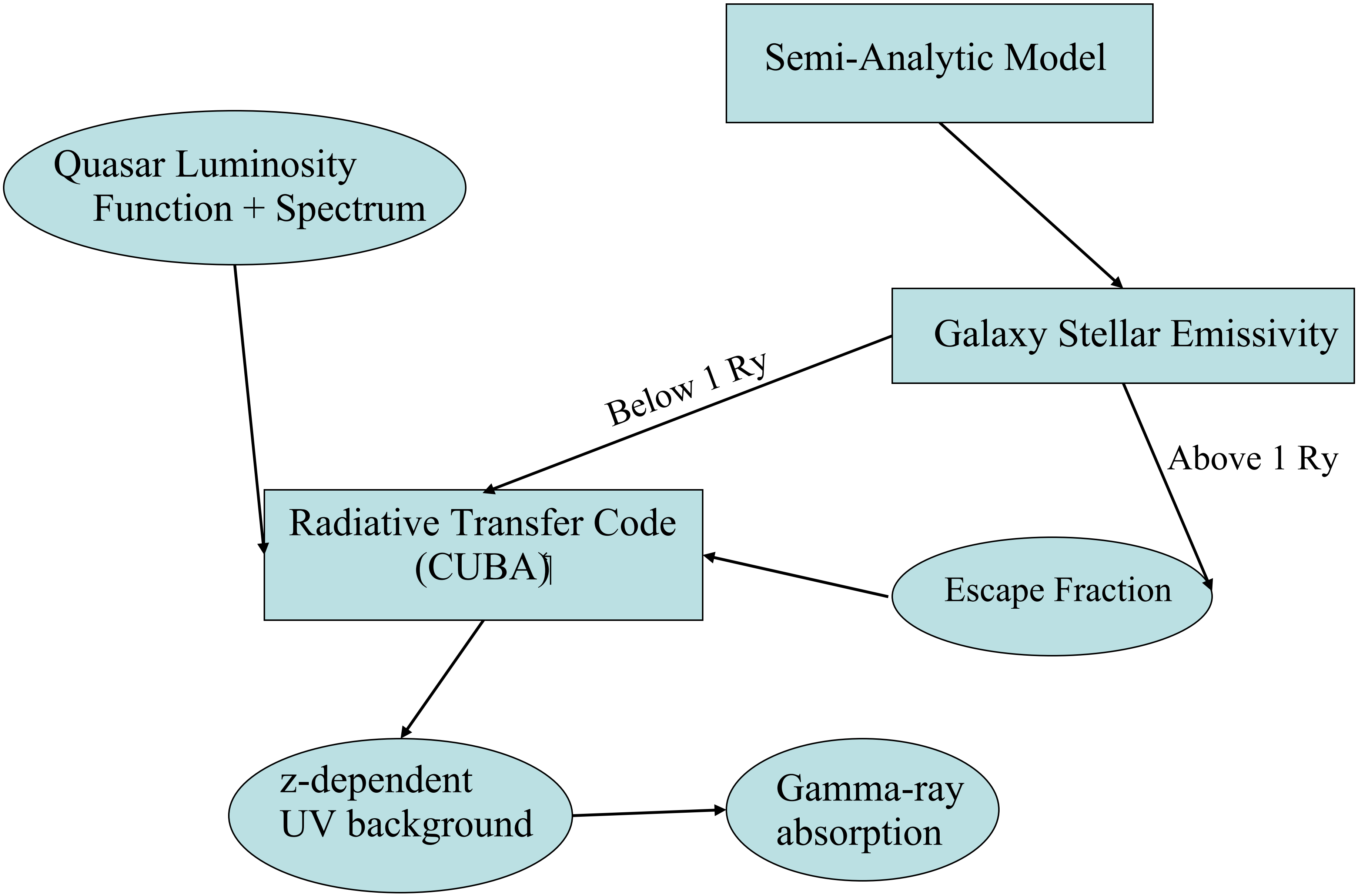
- Gamma rays < 300 GeV interact primarily with UV photons. <~100 GeV, ionizing background responsible for absorption.

- Fermi LAT will study little-understood energy decade of 10-100 GeV.

- Next generation of ground based experiments (MAGIC-II, H.E.S.S.-II) will observe gamma-rays down to < 50 GeV.

- The UV background presents several theoretical challenges:
  - direct observations are very limited
  - ionizing photons are reprocessed by the IGM
  - quasars become an important contributor to the background
  - high-energy sources of interest are no longer local → must account for UV background evolution.

Basic Research Plan



The CUBA Radiative Transfer Code

A numerical code for simulating the propagation of ionizing radiation through the IGM, (see Haardt and Madau 1996).

<u>The f_{esc} from star-forming galaxies</u>

• Widely-varying values in the literature; probably < 0.10 at z~1.

• Recent galaxy simulations suggest even lower values (Gnedin 2008).

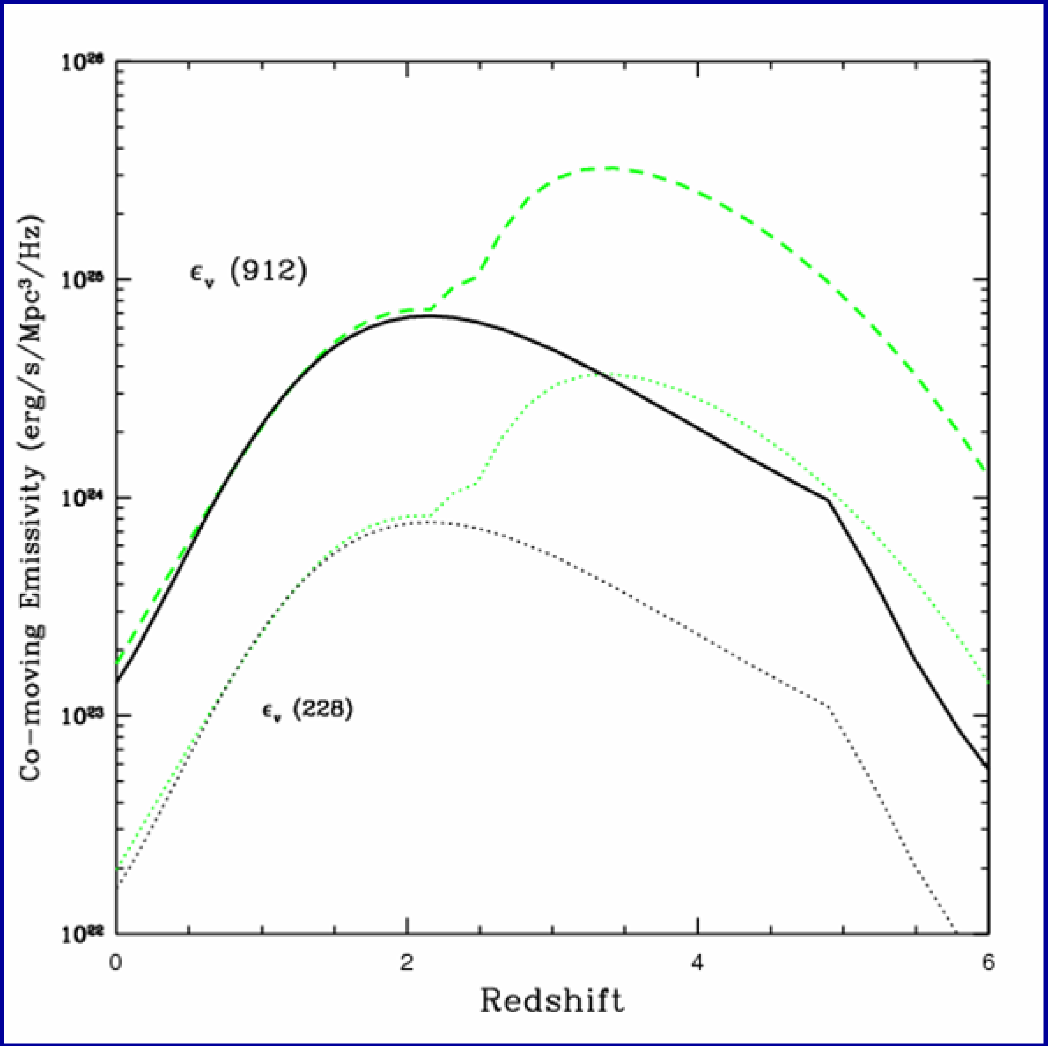
• Also possible that f_{esc} varies widely among similar galaxies.

<u>The quasar luminosity function</u>

• The bright end of the quasar LF is well-understood, but faint end unexplored at high redshift.

• Increasing QSO emission at z~3 believed to be responsible for He reionization.

Quasar Luminosity Densities



Black line:

Hopkins et al. (2007); Evolving QSO LF based on wide range of observations.

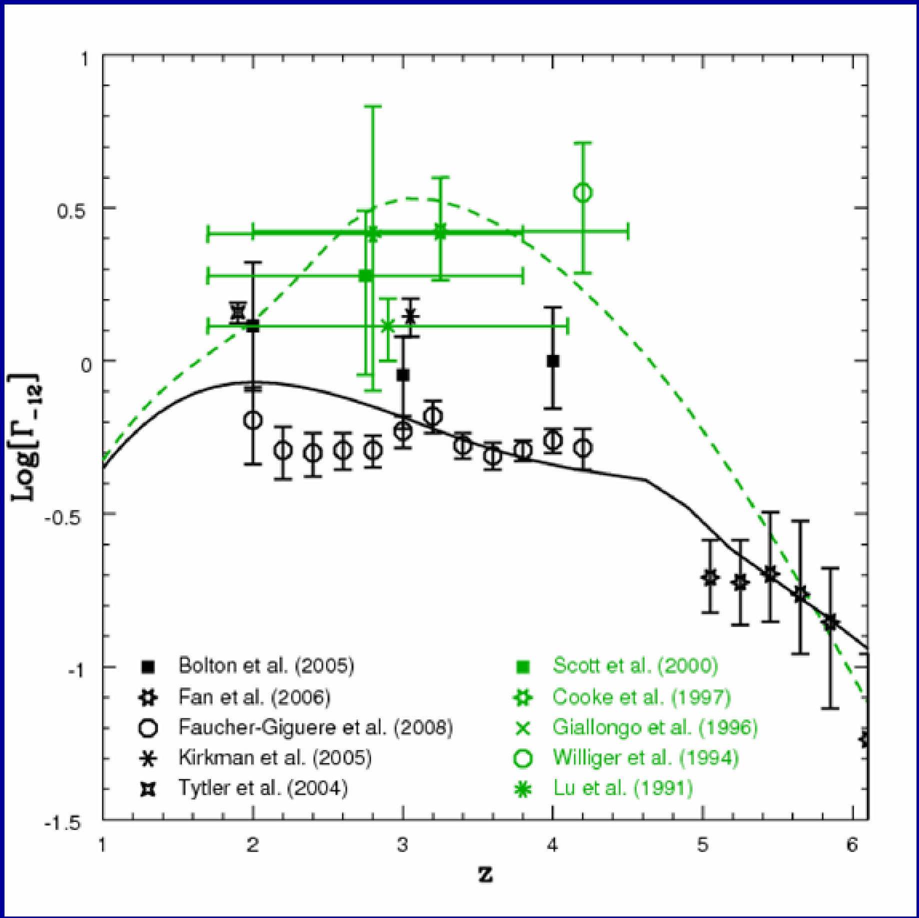
Green line:

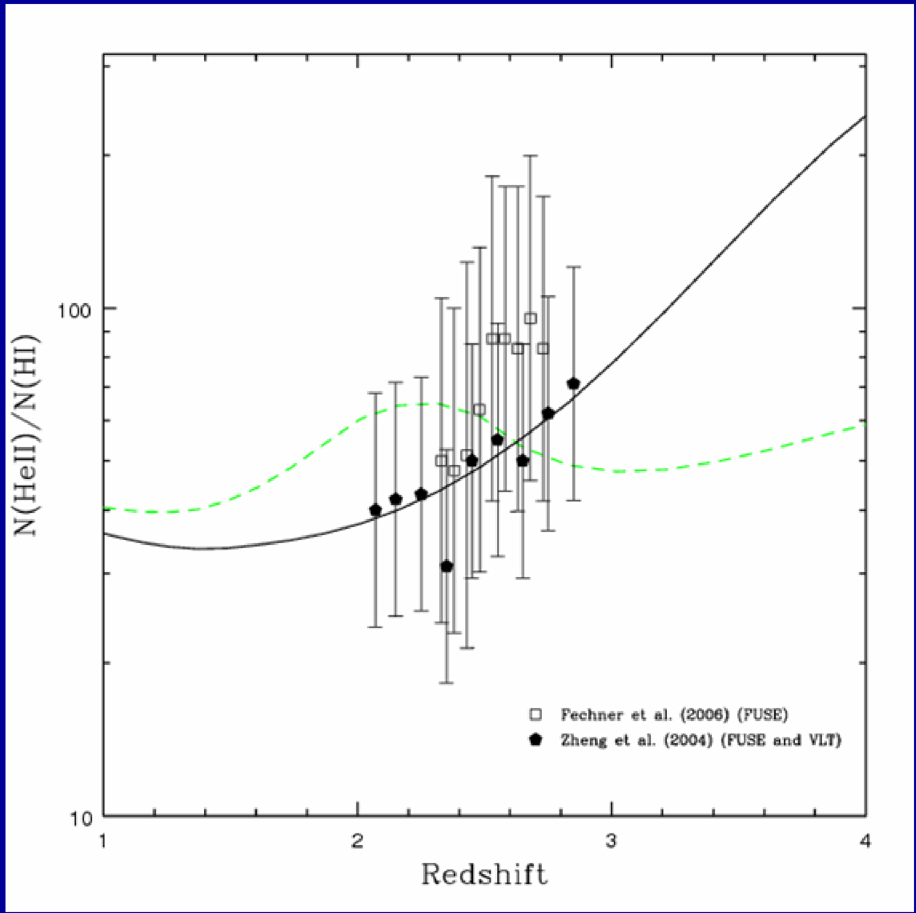
Higher quasar contribution suggested by proximity effect measurements, based on Schirber & Bullock (2003).

Hopkins et al. 2007, f_{esc} =0.10

S&B Model 'C', f_{esc} =0.02

Ionization Rates, as inferred from Lyman opacities
Green = data from proximity effect

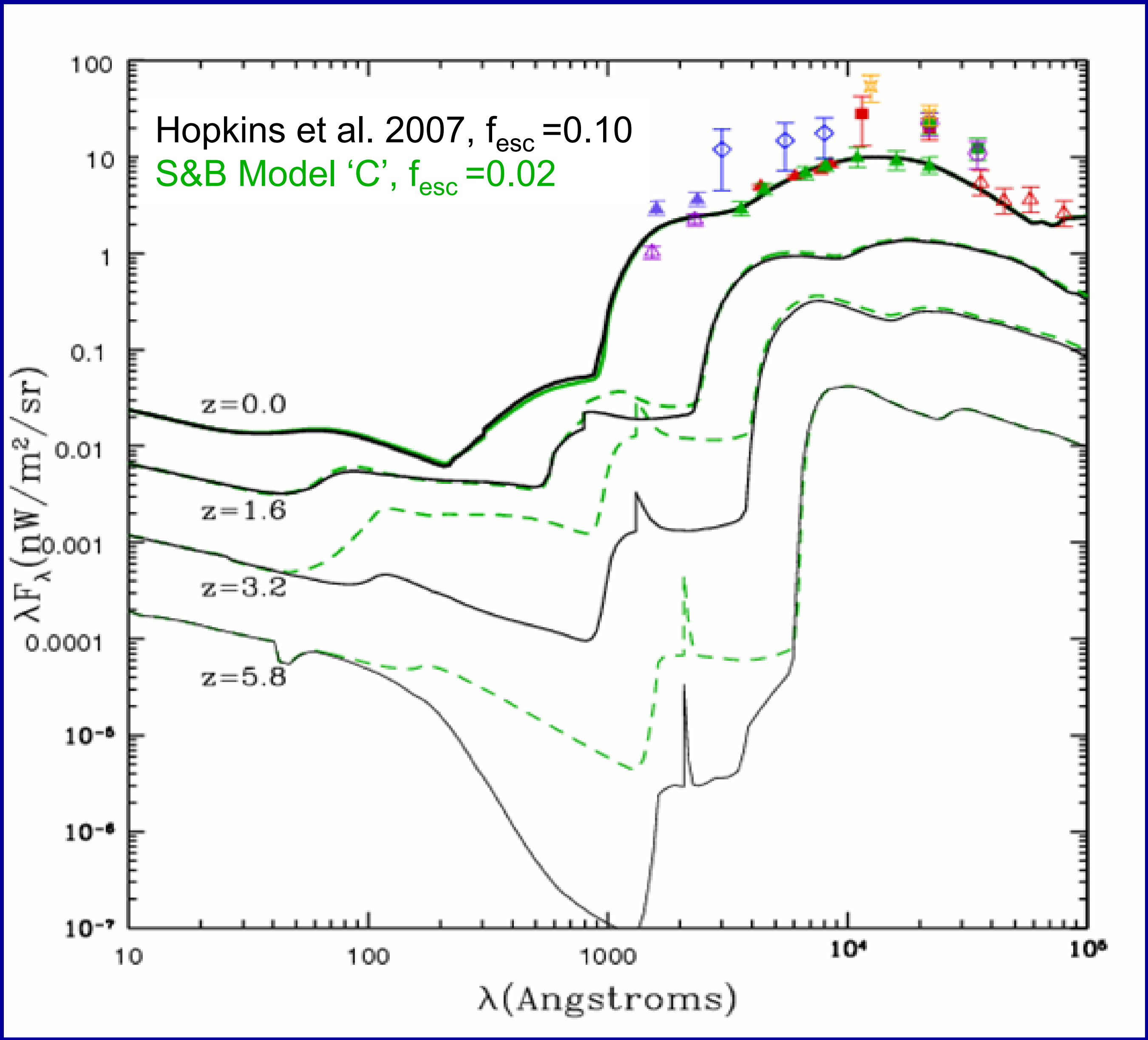




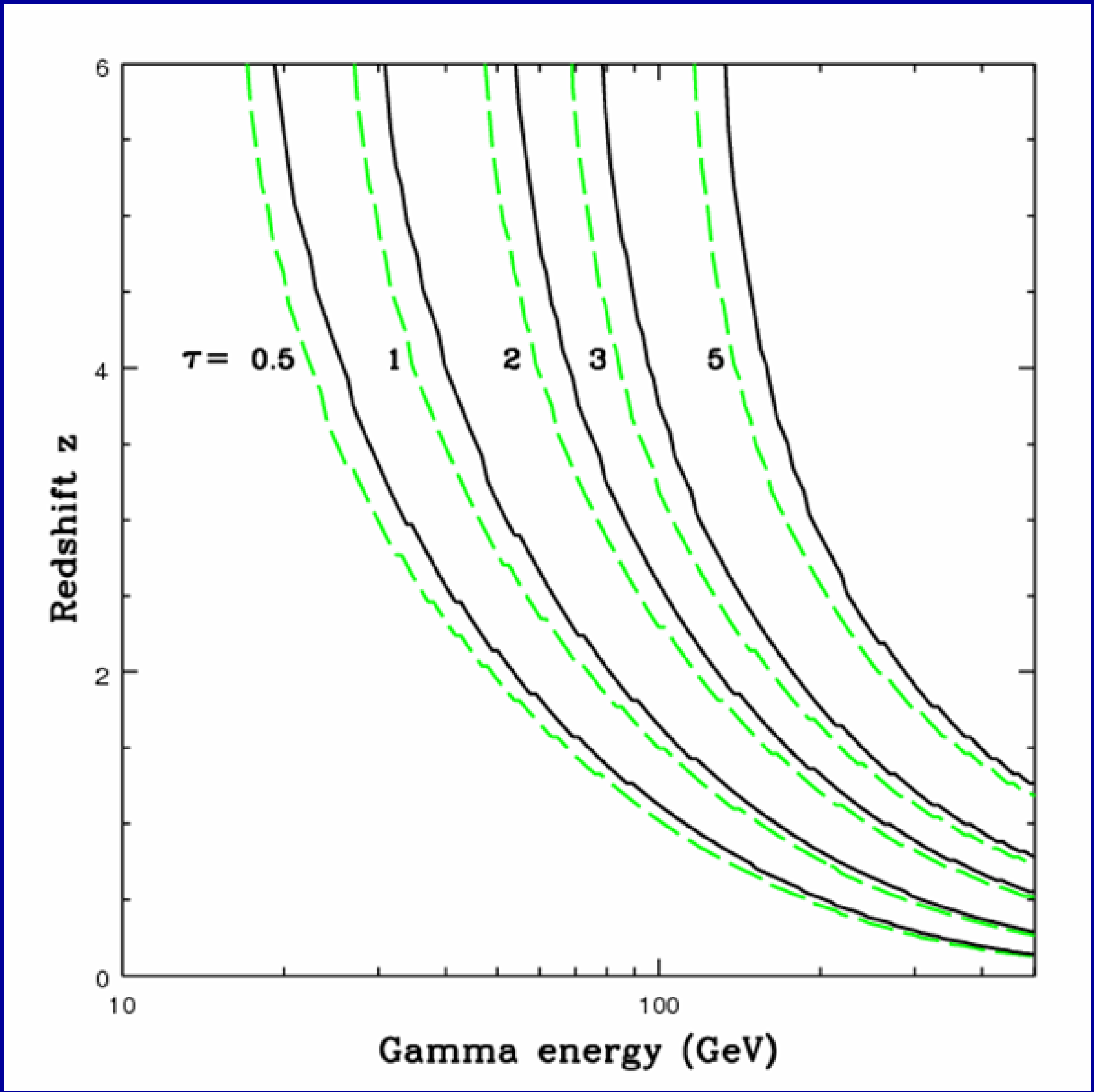
UV 'softness', HeII/HI

Hopkins et al. 2007, f_{esc} =0.10
S&B Model 'C', f_{esc} =0.02

UV EBL Flux History



Gamma-ray Attenuation Edge



Contours of constant opacity plotted in redshift and gamma energy

Hopkins et al. 2007, f_{esc} =0.10
S&B Model 'C', f_{esc} =0.02

Conclusions

- Strong evolution of attenuation edge for z ~ 1 to 4
  - Large number of blazars detectable by Fermi (Chen, Reyes, and Ritz 2004).

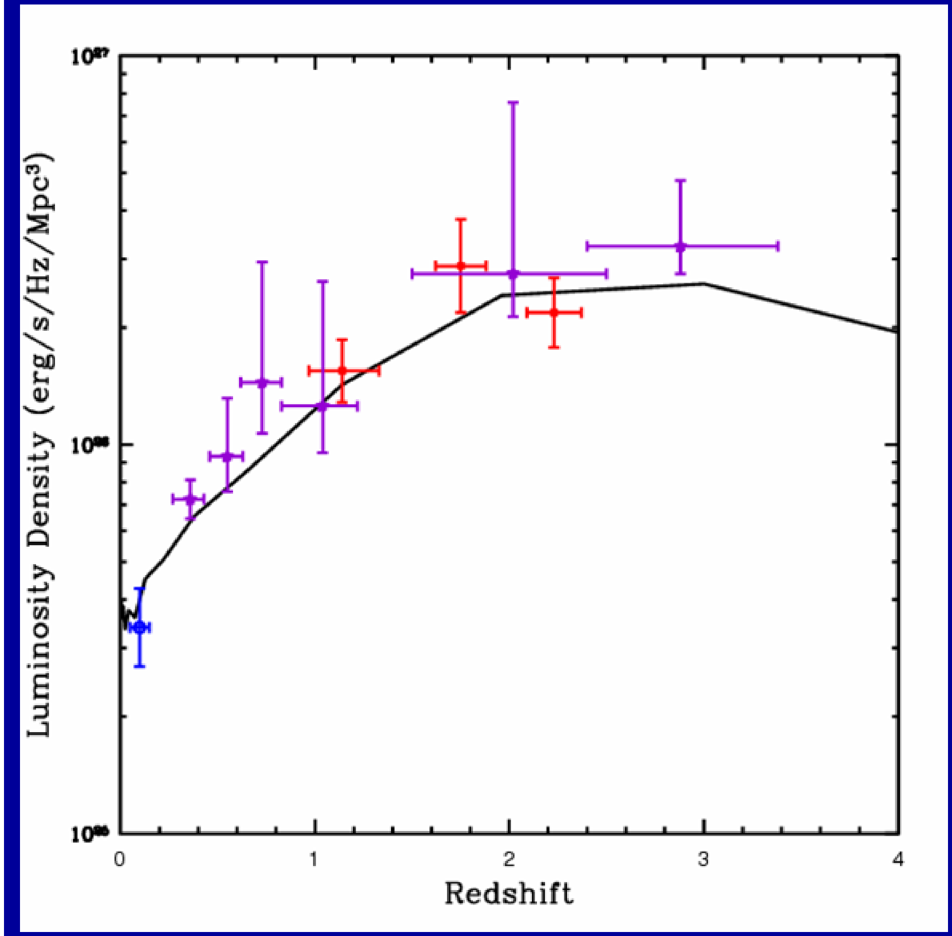
- Attenuation and redshift evolution may be observable by Fermi and upgraded ground-based experiments.

- UV from unseen source population at high redshift could have strong effect on gamma optical depths.

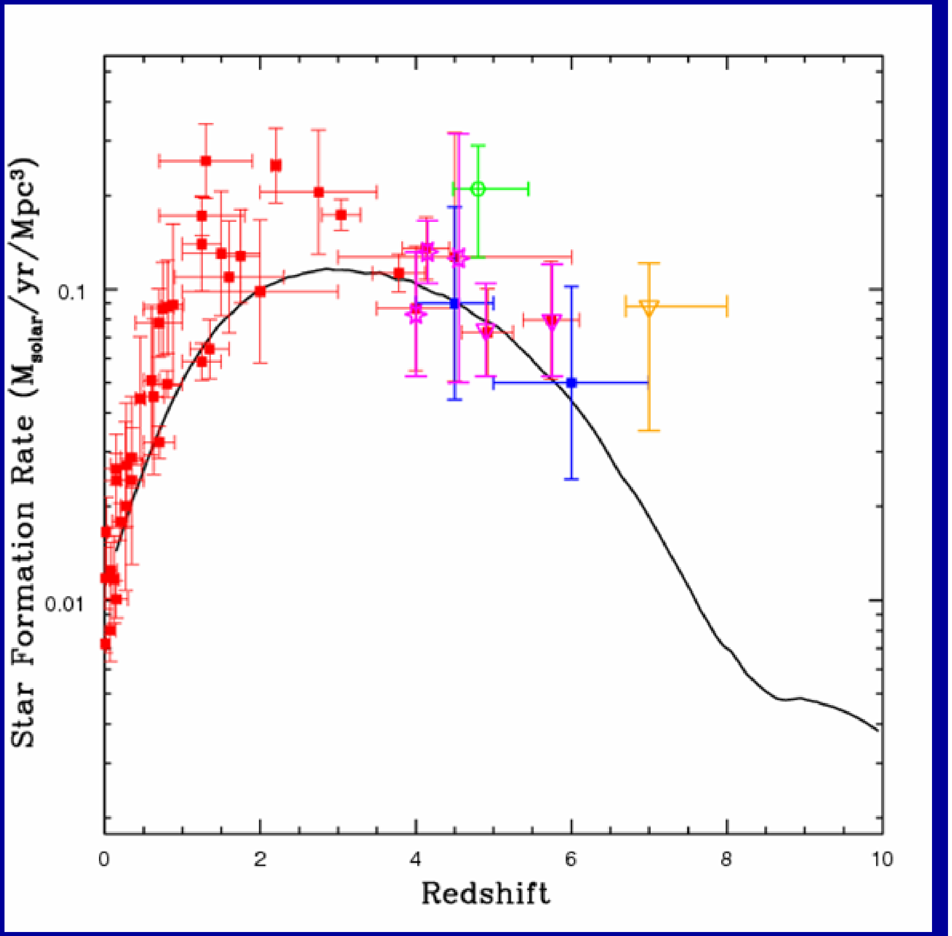
- Sufficient number of distant GRB with hard spectral component at 10-100 GeV are possible sources.

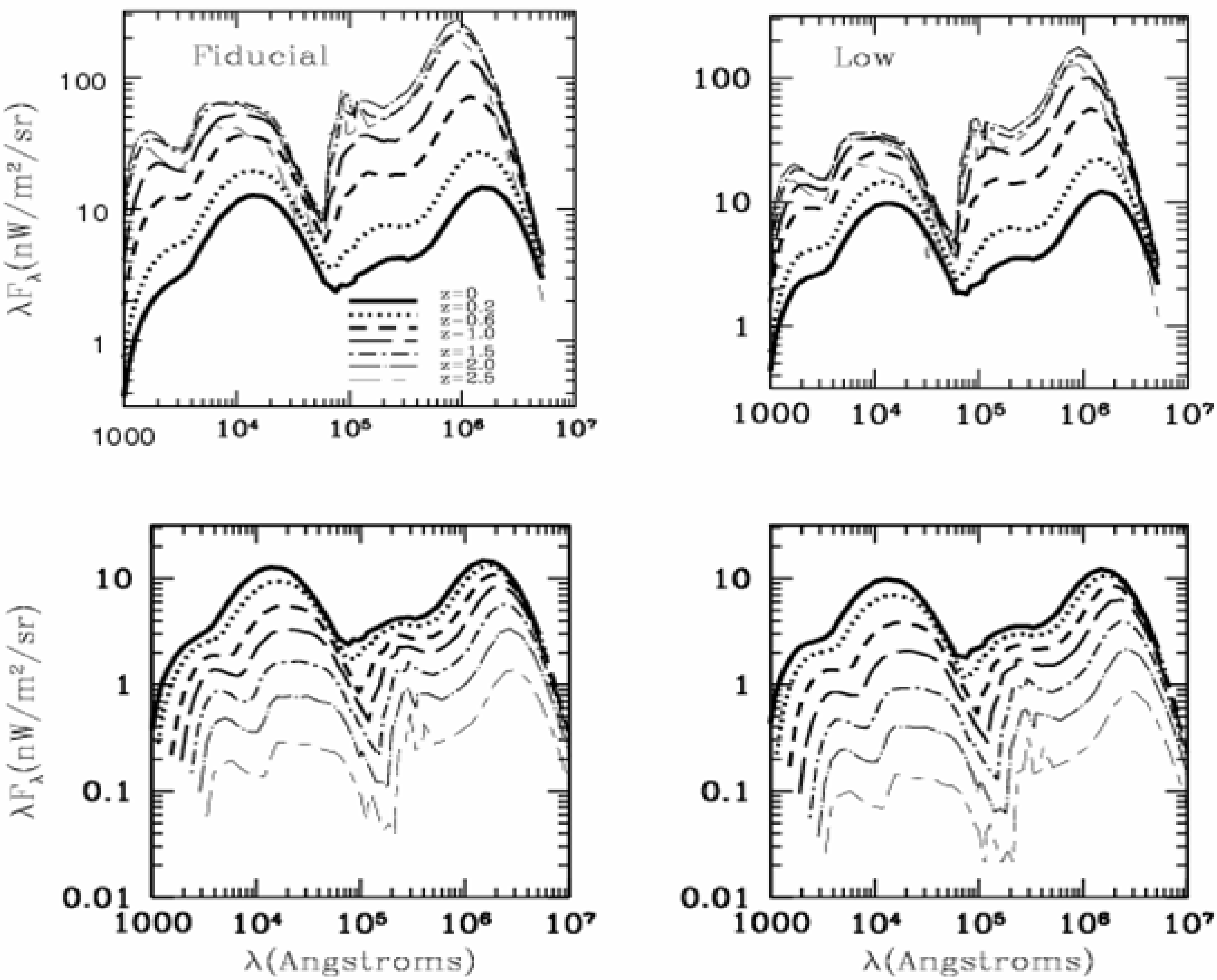
Semi-analytic model: UV emission

Luminosity Density at 1500 Angstroms



Specific Star Formation Rate





Fiducial
Low
z=0
z=0.2
z=0.6
z=1.0
z=1.5
z=2.0
z=2.5
λF_λ(nW/m^2/sr)
λ(Angstroms)
1000
10^4
10^5
10^6
10^7
0.01
0.1
1
10
100

Methods of Estimating the EBL

Directly from observations

• Direct Measurement with foreground subtraction (e.g. Bernstein 2002,2007, various attempts with DIRBE in NIR, and DIRBE and FIRAS in FIR.

• Lower limits from number counts (e.g. Madau & Pozzetti 2000)

Modeling of the galaxy population

• Evolution inferred from observations (Kneiske 2004, Franceschini 2008)

• Backwards evolution of the existing galaxy population (Stecker 2006)

• Forward evolution, begin from cosmological initial conditions (Primack 2001,2005)