Cosmological Background Radiation and Extragalactic Gamma-ray Opacity

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TeV Particle Astrophysics
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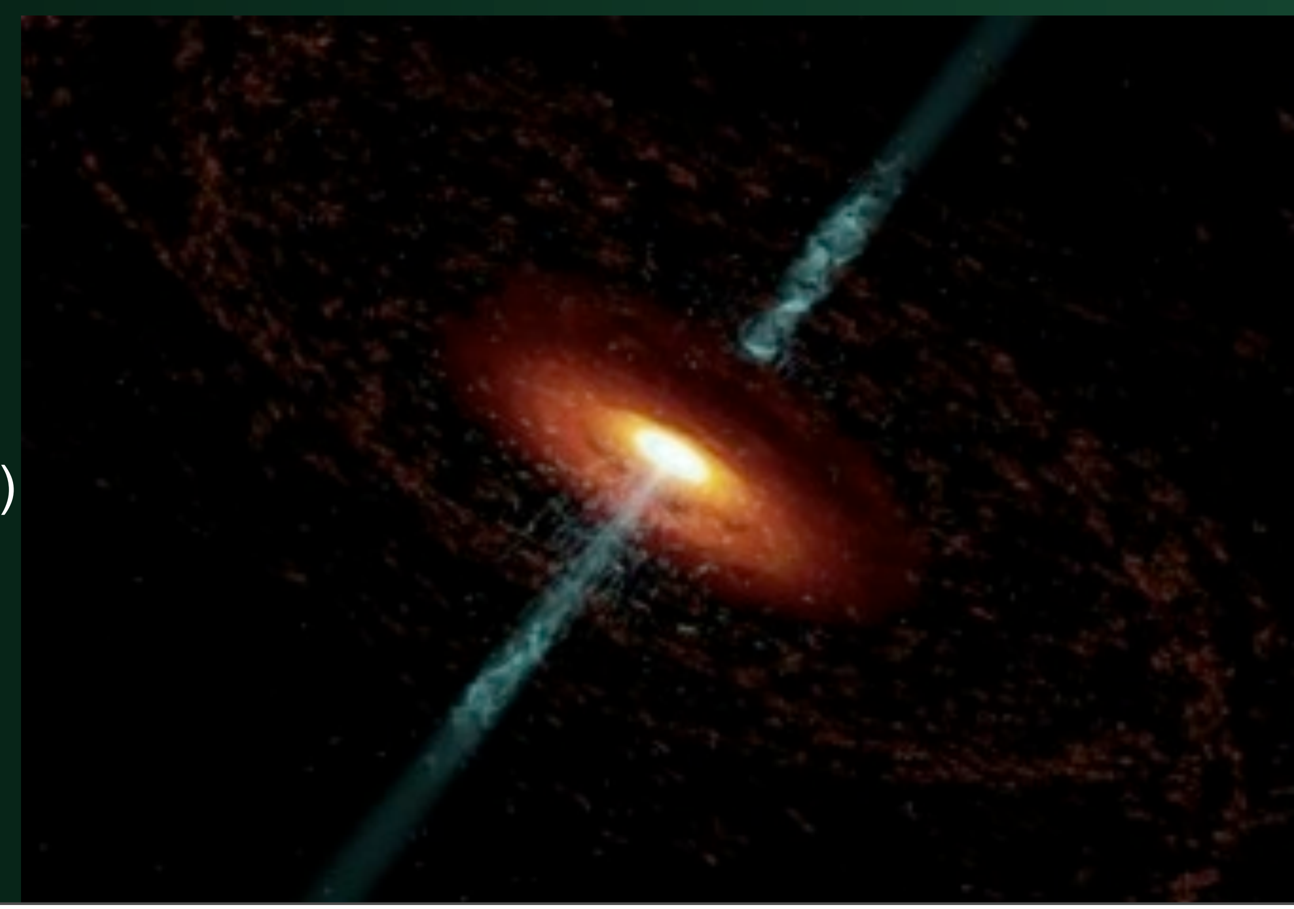


The Extra-Galactic Background Light (EBL)

Cumulative photon population created by structure formation

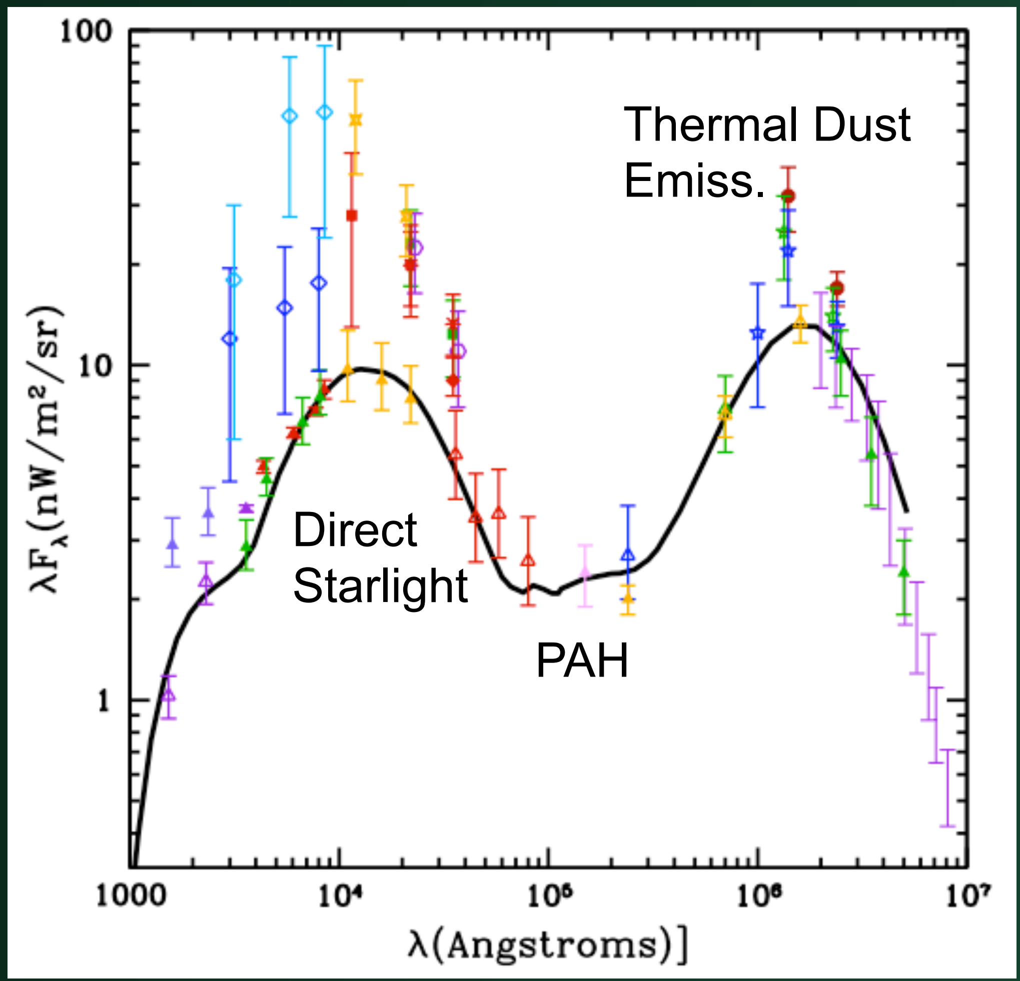
- Created by stars and AGN, modified by absorption and reemission by dust and processing by neutral hydrogen
- Roughly 1/20 the energy of the CMB in combined UV, optical and IR fields

➢ Modeling of galaxy formation allows us to understand evolution of this photon population

Motivation:

• Measurement of the UV-IR background ('photon archeology') gives us constraints on structure formation.

• The EBL has implications for observations of the highest energy (GeV and TeV) extra-galactic gamma-rays.



Measurement of the Local Background

Direct Measurement

• Photometry measurements must contend with difficult foreground subtraction and calibration issues!

Optical - Bernstein (2002, 2007) using Hubble and ground-based data in 3 optical bands

IR - DIRBE detections in near-IR (e.g. Wright 2001, Levenson et al. 2007) and far- IR (Hauser et al. 1998, Wright 2004)

FIRAS - absolute measurement of CMB and EBL >125 μm (Fixsen et al. 1998)

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Galaxy Number Counts

• Can provide robust lower limits, but degree of convergence often controversial

• Available in many bands, including UV (GALEX), optical/NIR (HST, various ground-based), mid and far IR (Spitzer, ISO), and submillimeter (SCUBA, BLAST)

• Limits in optical and near-IR generally below direct photometry estimates

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Extragalactic Gamma-ray Observations

• Assumption that intrinsic VHE spectra are softer than $-\Gamma = 1.5$ (e.g. Aharonian et al. 2006; Albert et al. 2008; also Costamante et al. 2004; Mazin & Raue 2007)

Modeling of the galaxy population

- Evolution inferred from observations

Kneiske et al. (2002, 2004); Finke et al. (2009) - models based on star formation rate density, stellar synthesis models, dust reradiation

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

Dominguez et al. (MNRAS submitted) - sophisticated model based on K-band LFs plus analysis of ~6000 AEGIS galaxy SEDs

- Backwards evolution of the existing galaxy population

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

- Forward evolution, from cosmological initial conditions

Primack et al. (1999, 2001, 2005, 2008) and Gilmore et al. (2009), and in prep.

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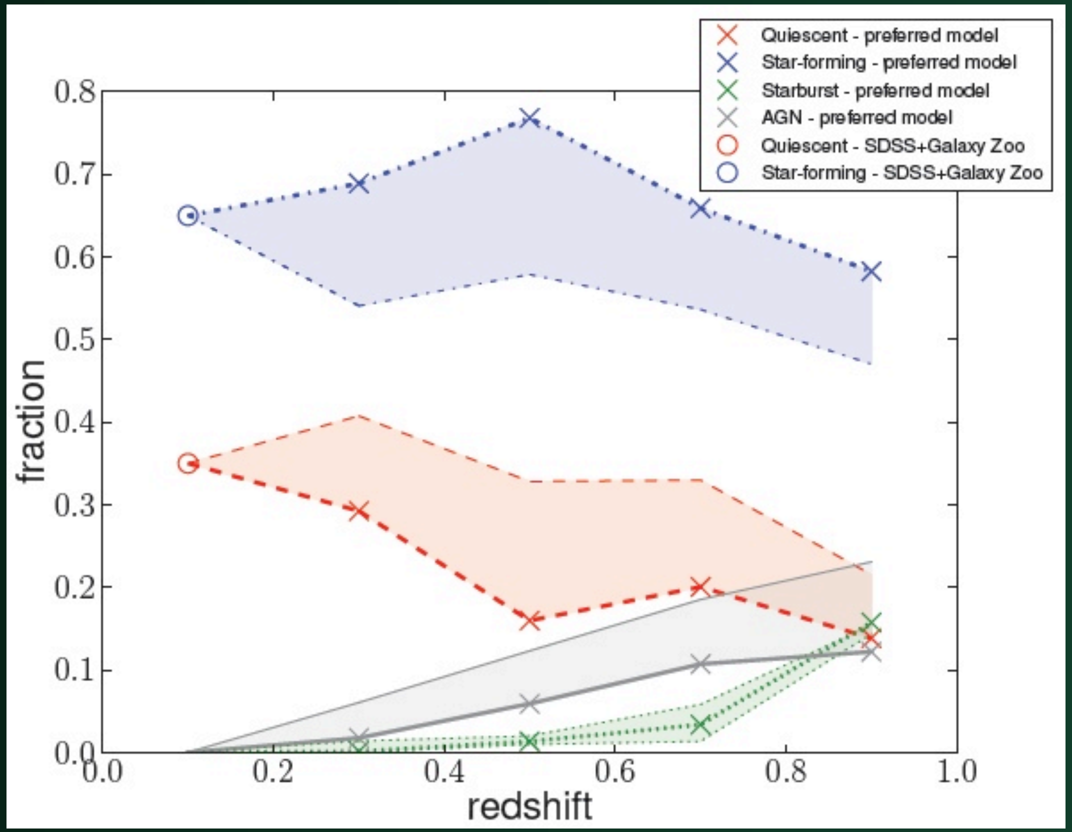
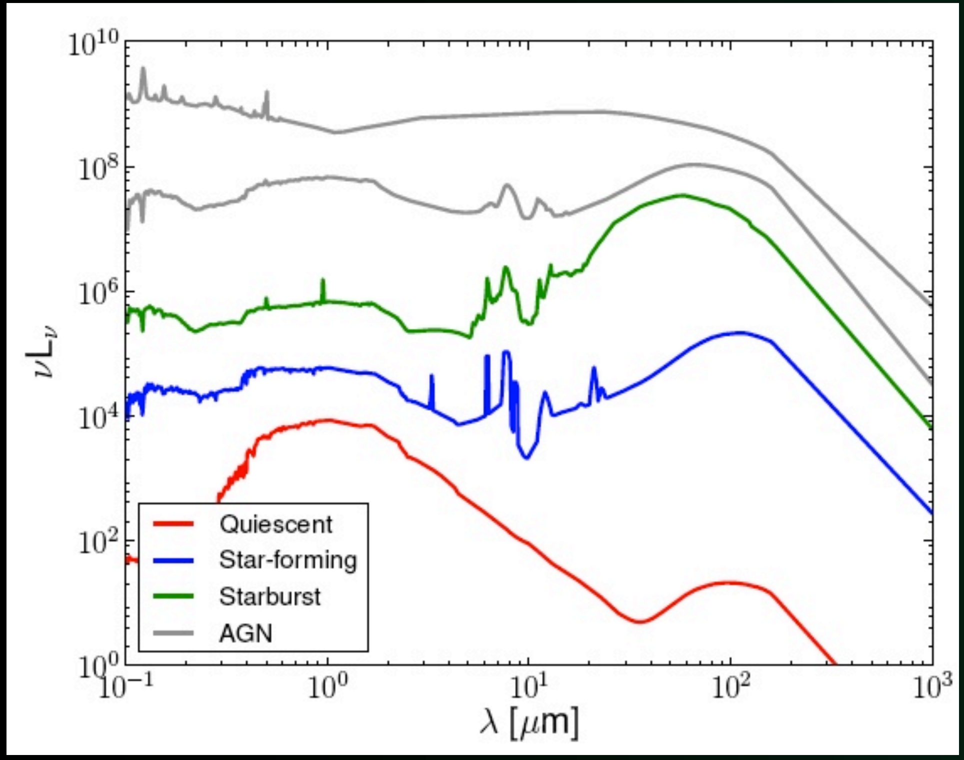
EBL from observations: Dominguez et al., ArXiv:1007.1459

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): assumptions about SED types here do not strongly affect local EBL

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

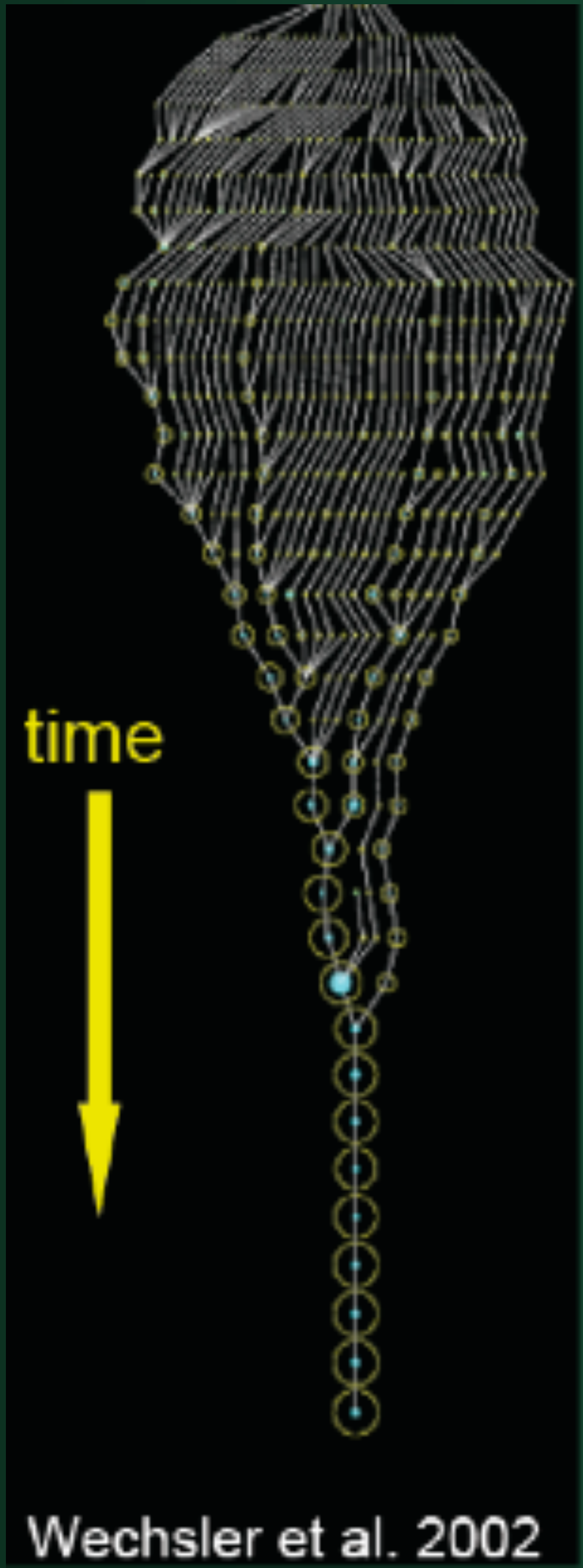
  - Galaxy formation based on hierarchical buildup of cold dark matter halos.

  - 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)

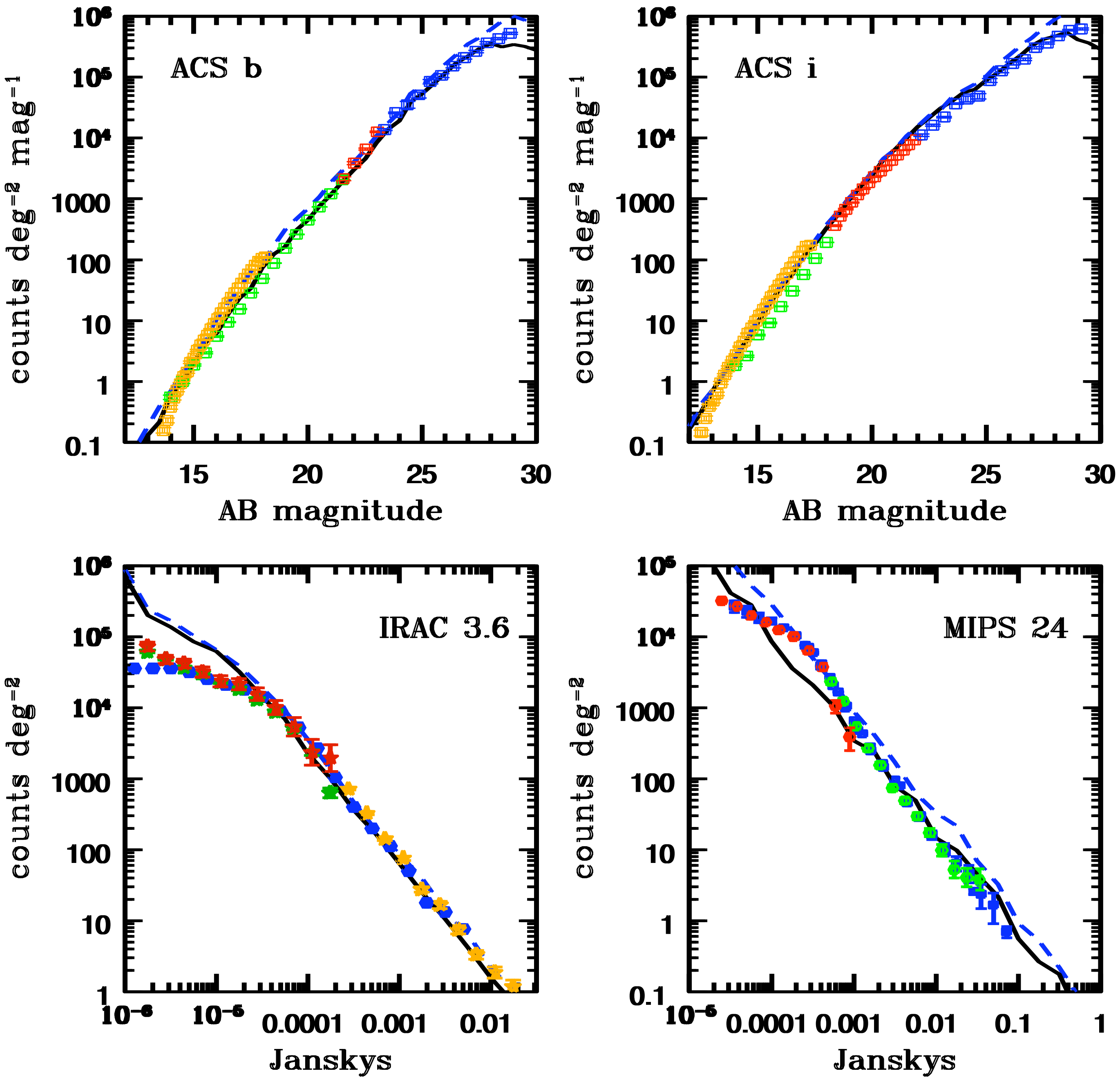
➡ "WMAP1" model based on concordance cosmology (Primack, Gilmore, Somerville 2008, Gilmore et al. 2009)

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

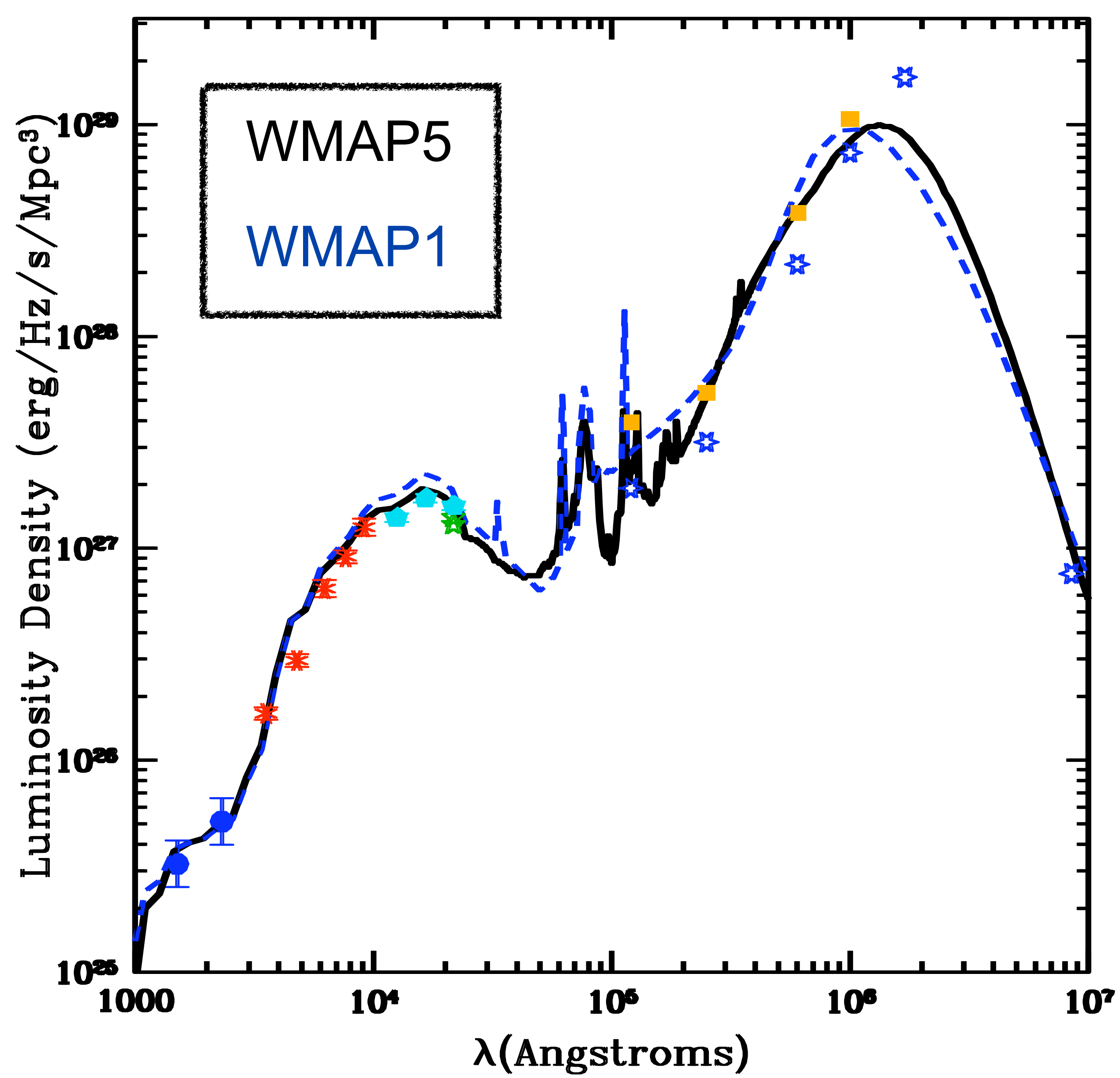


Galaxy Number Counts and Local Luminosity

Optical and IR counts



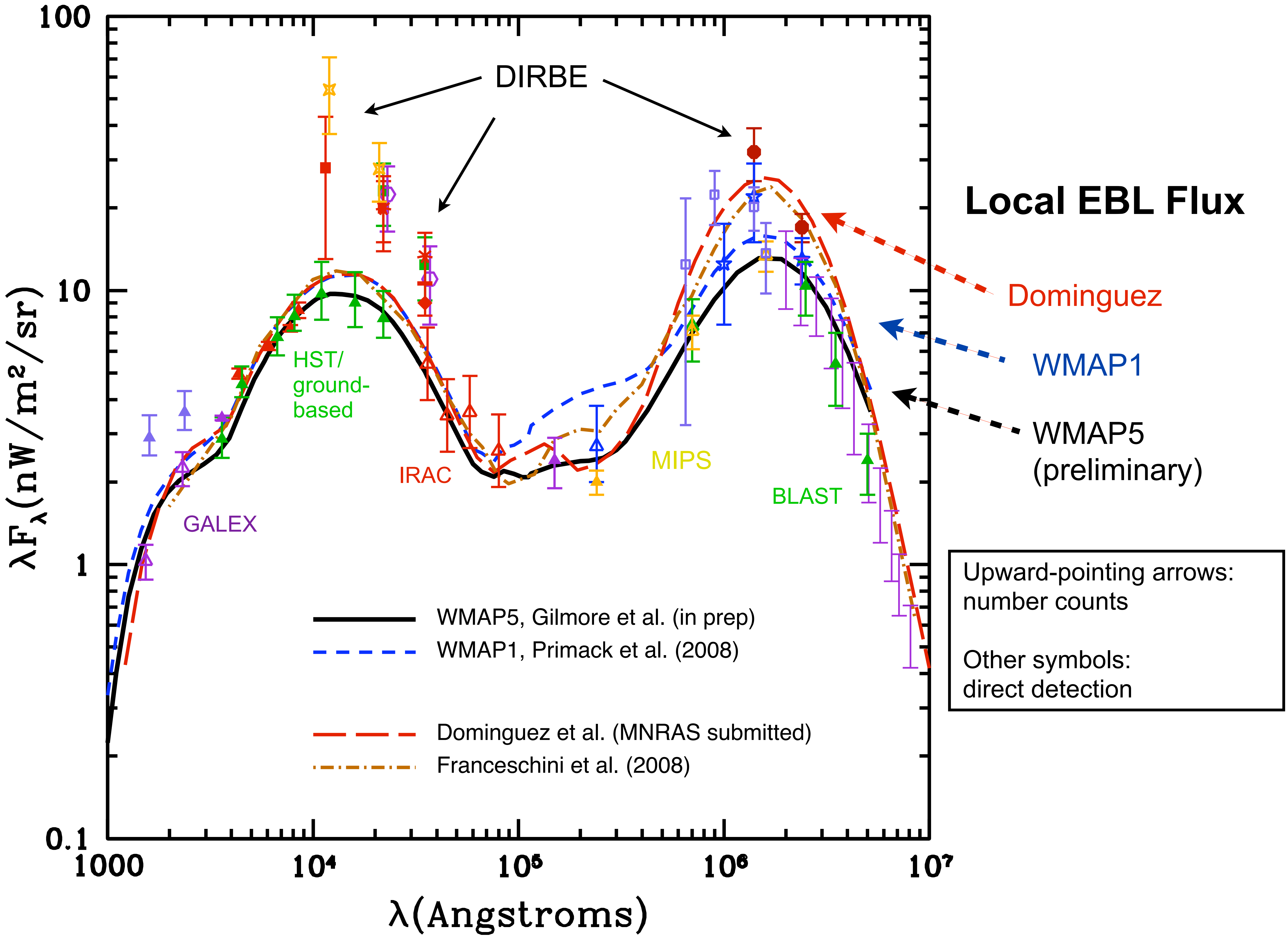
Local Emissivity



- WMAP5 model improves agreement with data, especially in mid-IR bands

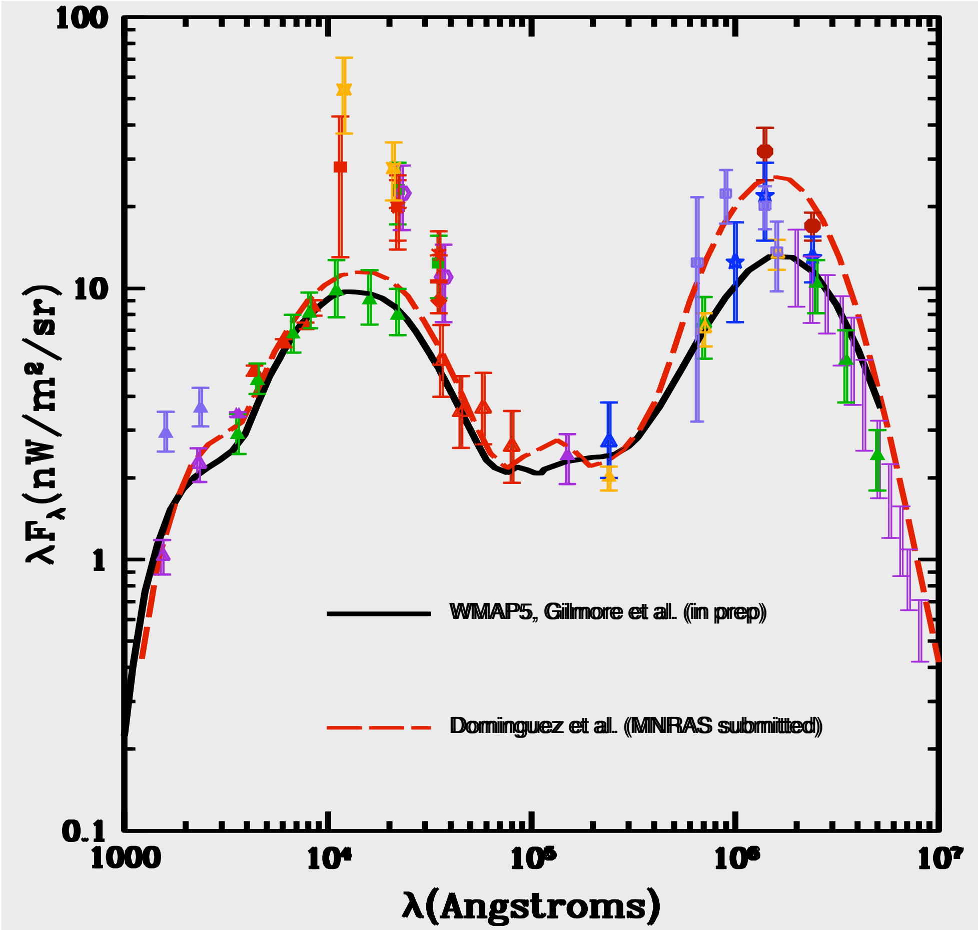
- Cosmology has only minimal effect on local galaxy emissivity

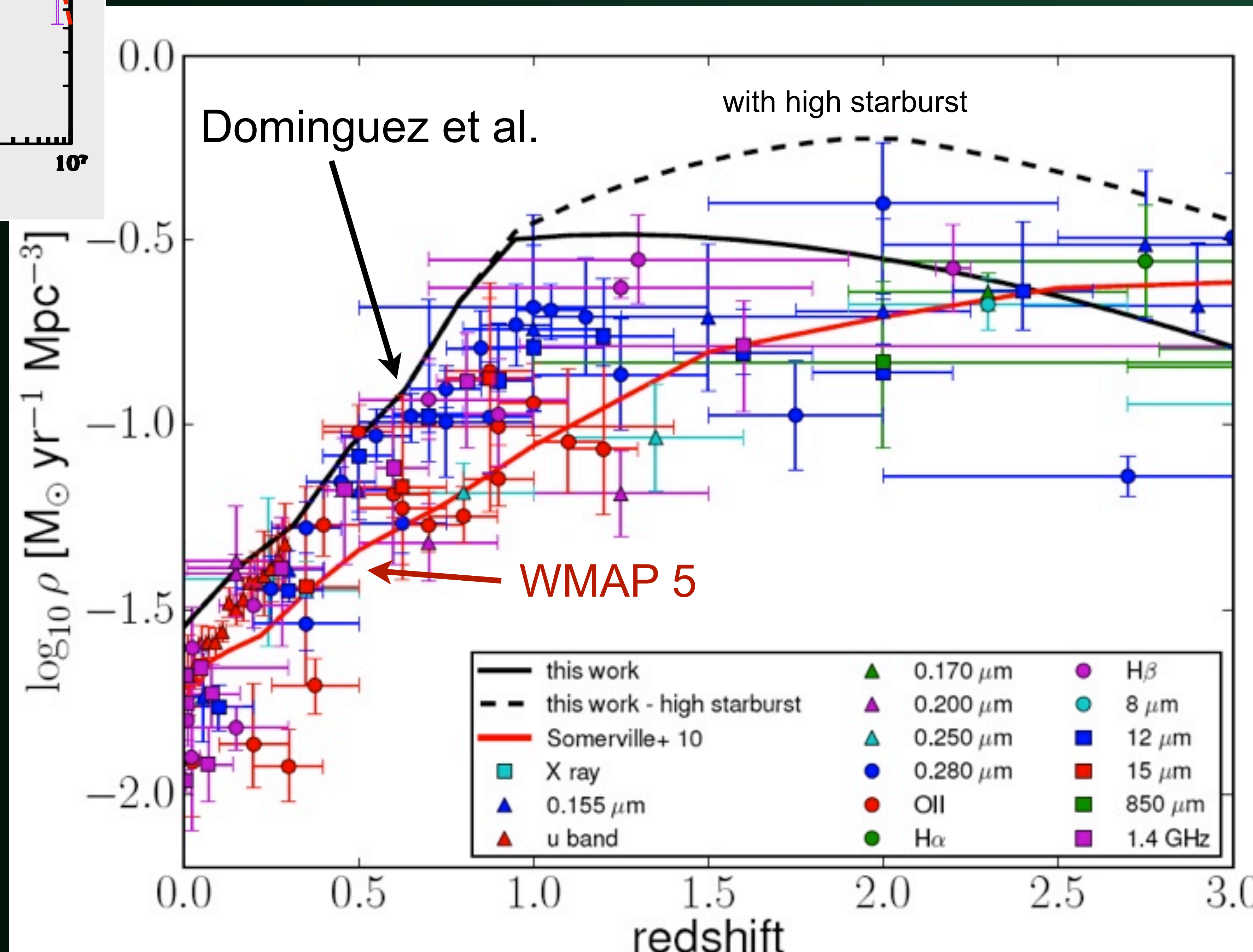
Agreement at low-redshift with both methods



Star-formation History

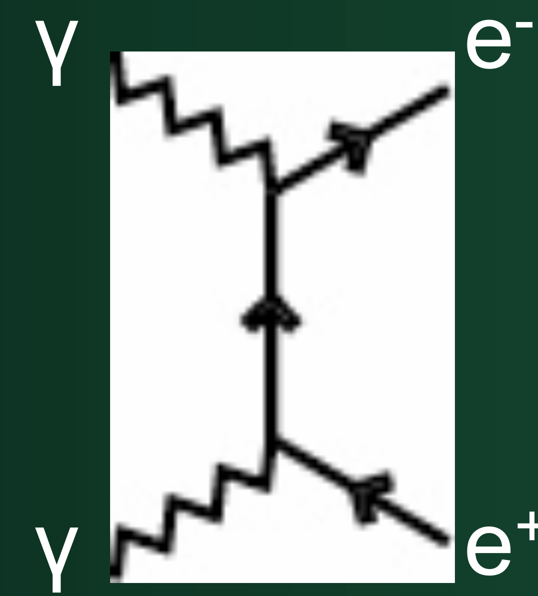
- Discrepant star formation histories in our model and that inferred from Dominguez et al.
- Difference in bolometric emission appears almost entirely in far-IR, bracketing uncertainty at those wavelengths





Dominguez et al. (MNRAS submitted)

Absorption of Gamma Rays by EBL



EBL leads to softening and cutoff in gamma ray spectra of distant extragalactic sources (blazars and GRBs):

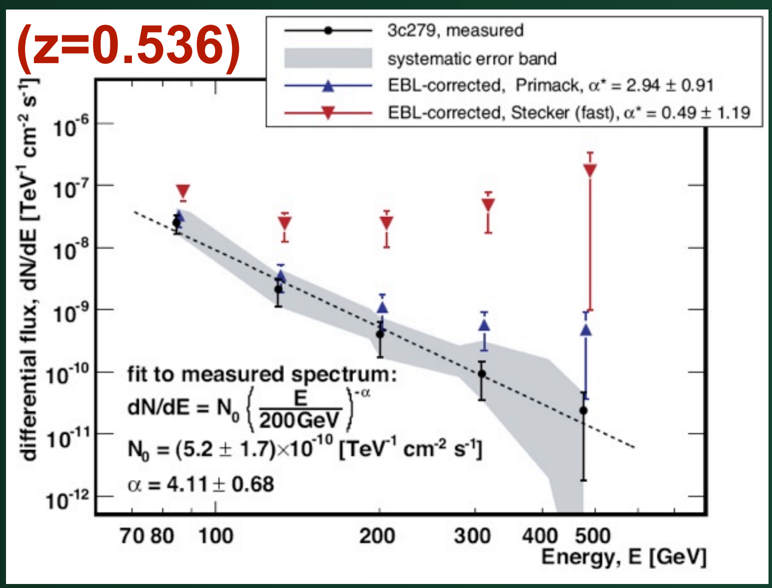
- Gamma-rays interact with background photons to produce e^+e^- pairs.

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

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

- This effect links high-energy observations to galaxy formation by softening observed GR spectra

FSRQ 3C279

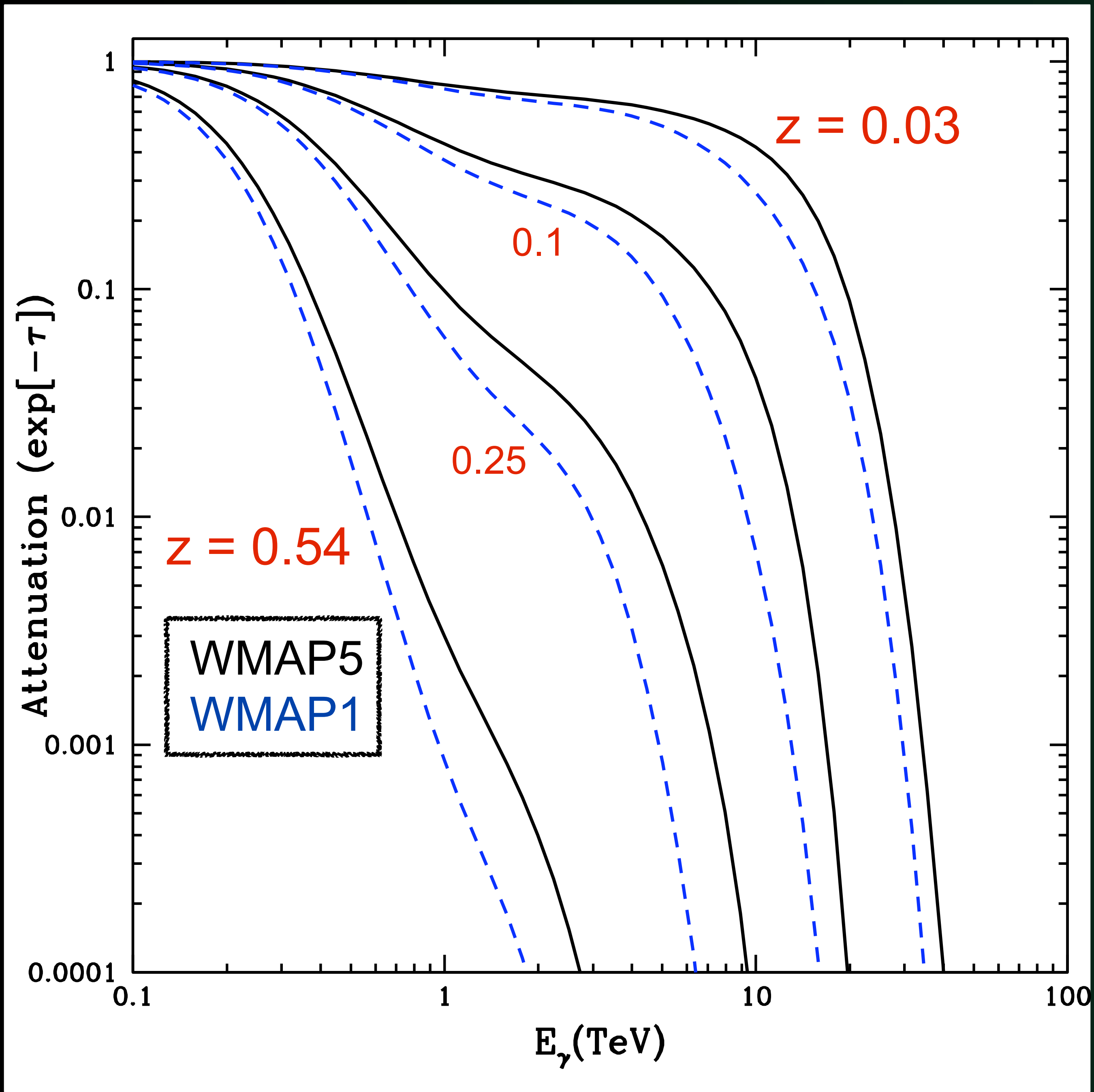


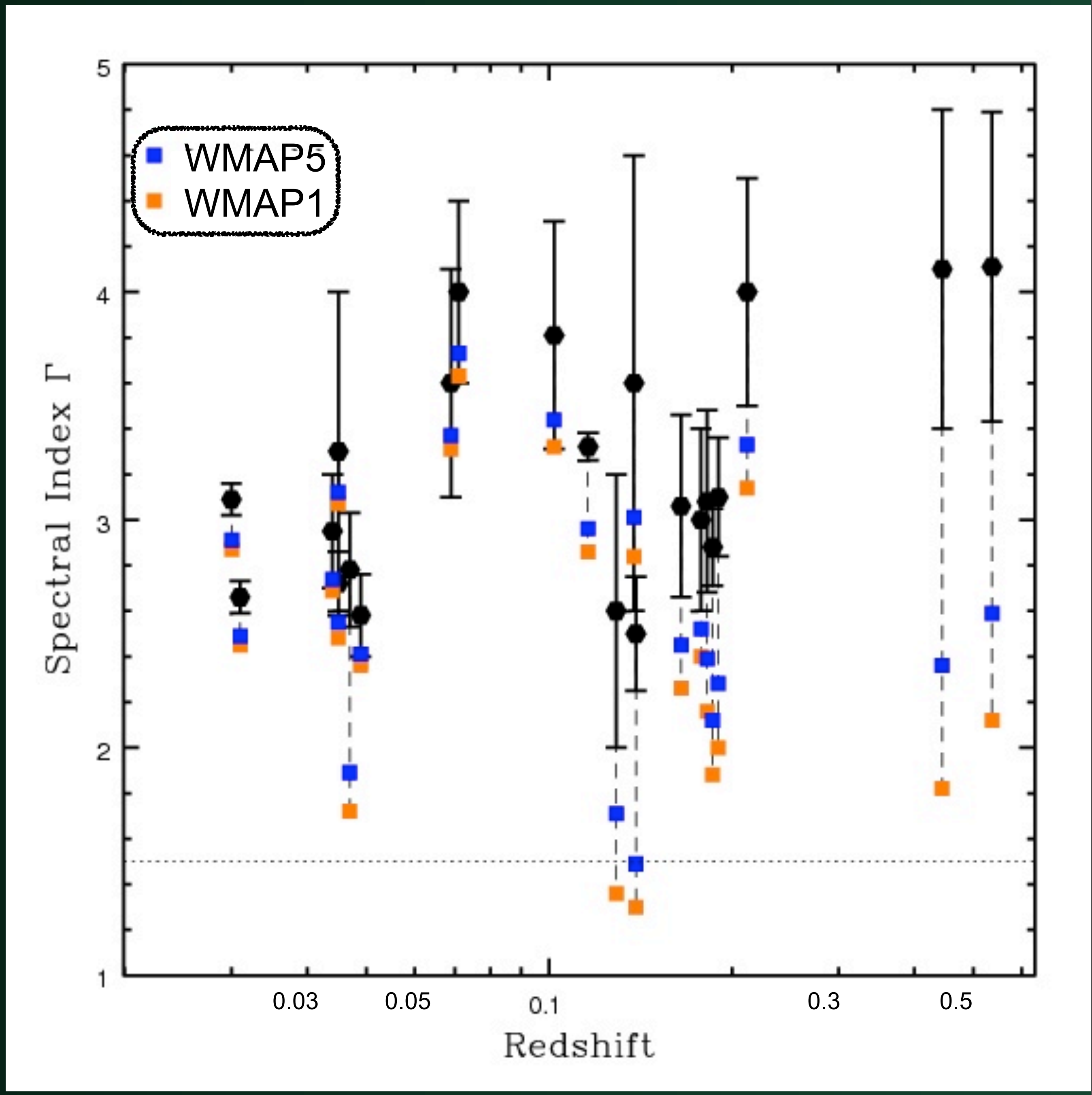
MAGIC Collab., Science 320, 1752 (2008)

Characteristic wavelength of interaction: $\lambda \sim 1.24(E_\gamma / \mathrm{TeV})\ \mu m$

(90° interaction, max σ)

Modification of VHE spectra in our semi-analytic model





Optical depth vs energy at several redshifts

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

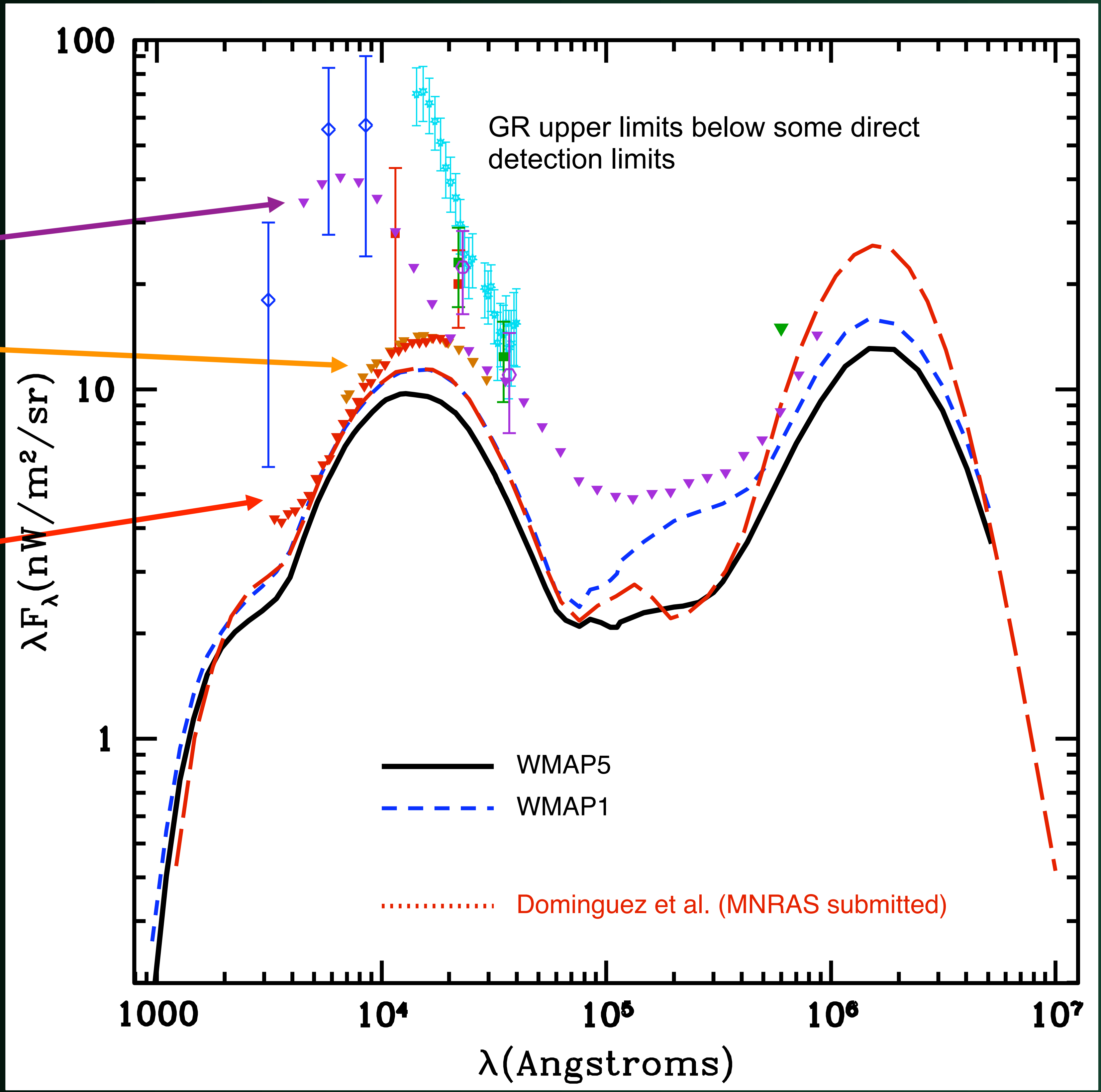
Our models with gamma-ray upper limits

Our models are within 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)



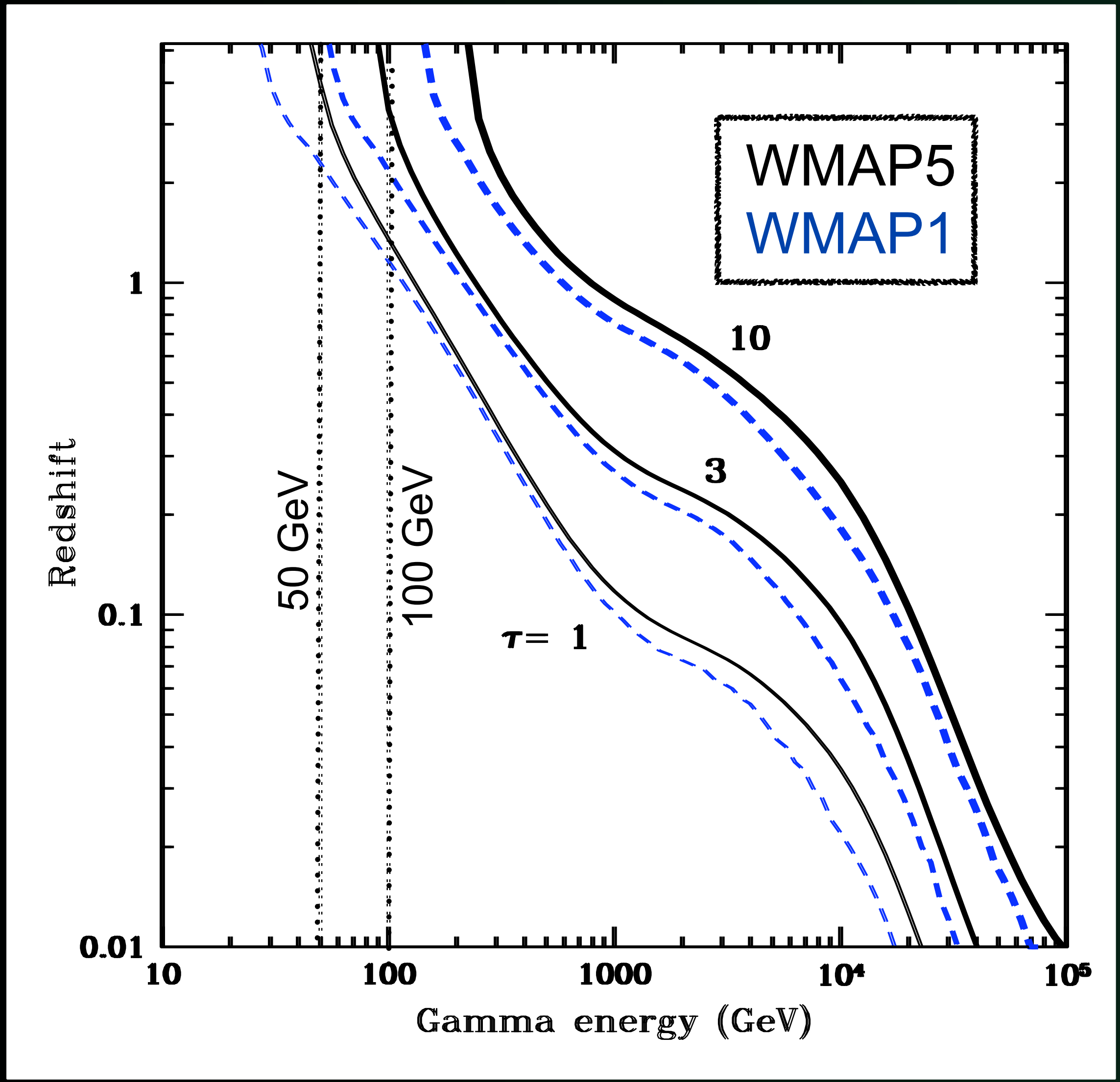
Future Prospects

We want to understand not only the present-day EBL, but also evolution in redshift

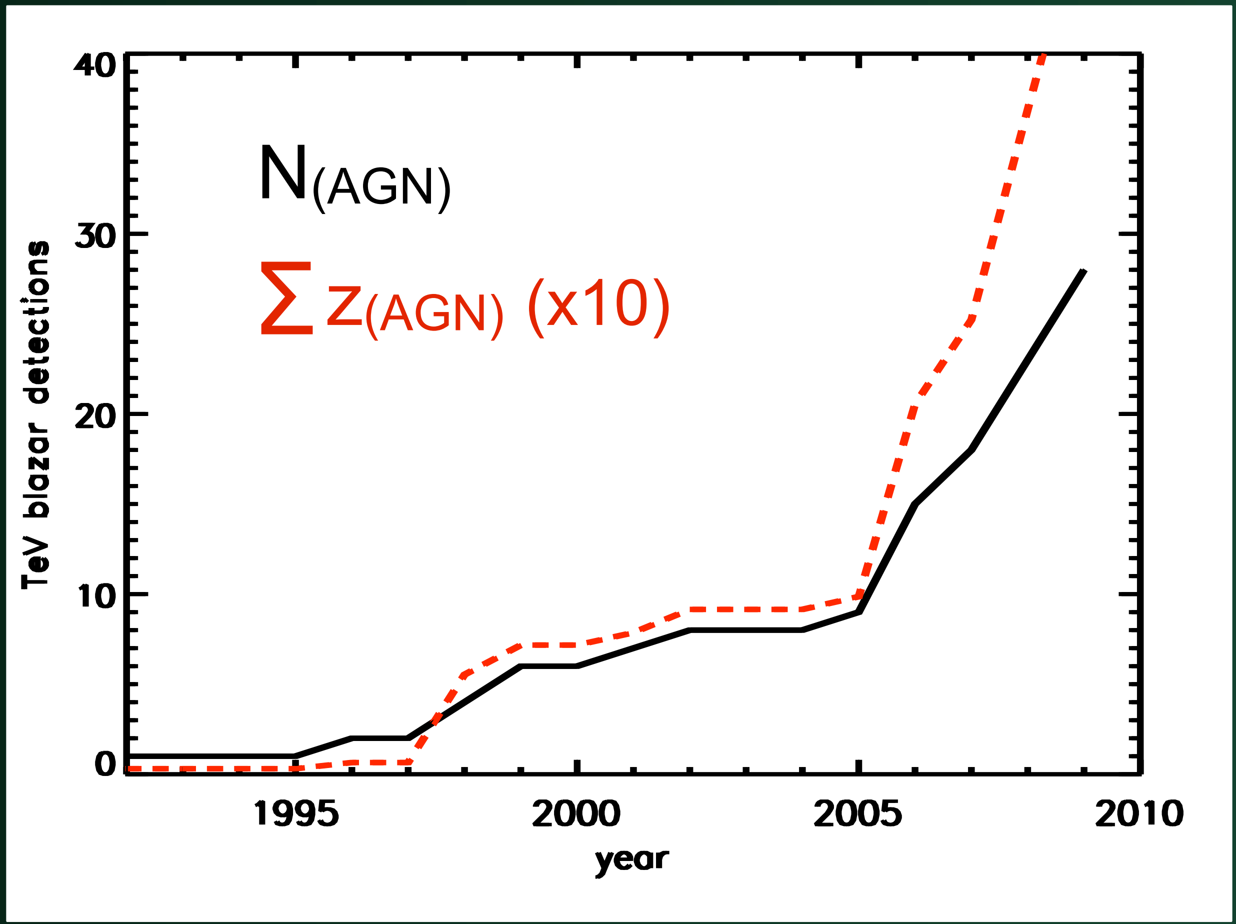
• Results from first year of Fermi AGN and GRB - Abdo et al. 2010, ArXiv:1005.0996
Highest models (Stecker 2006) strongly disfavored, no constraints yet on others.

• More distant gamma-ray sources (both AGN and GRBs) can probe UV background and help us constrain high-redshift star formation

Attenuation edge of gamma rays



Summary of blazar observation with IACTs



Source: TeVCAT

Conclusions

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

- Our latest WMAP5 model consistent with number counts, local luminosity functions, and luminosity density

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

- Good agreement with limits from gamma-ray experiments.

- Agreement with recent observationally-motivated models (Franceschini et al. 2008, Dominguez et al., submitted) out to z~1.

- Low-threshold IACTs should be able to view sources out to z > 1 without significant EBL attenuation