A Model of Extragalactic Background Light: >0.1 eV

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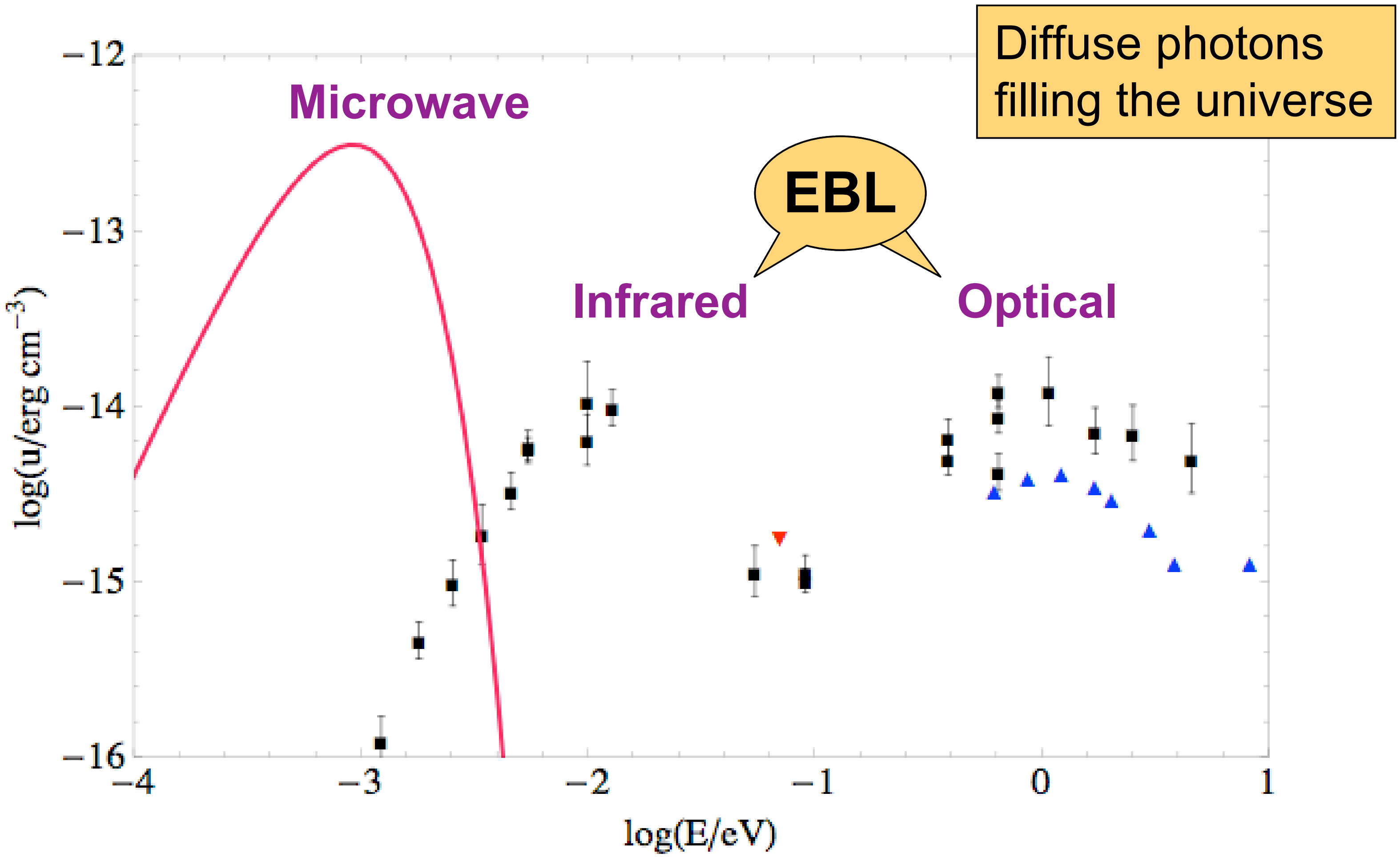
Cosmic Energy Densities

Electromagnetic ➔from radiative processes



Why do we care?

Affects propagation of ultrahigh-energy photons/cosmic-rays from their sources to Earth

Important for TeV γ-ray Astronomy

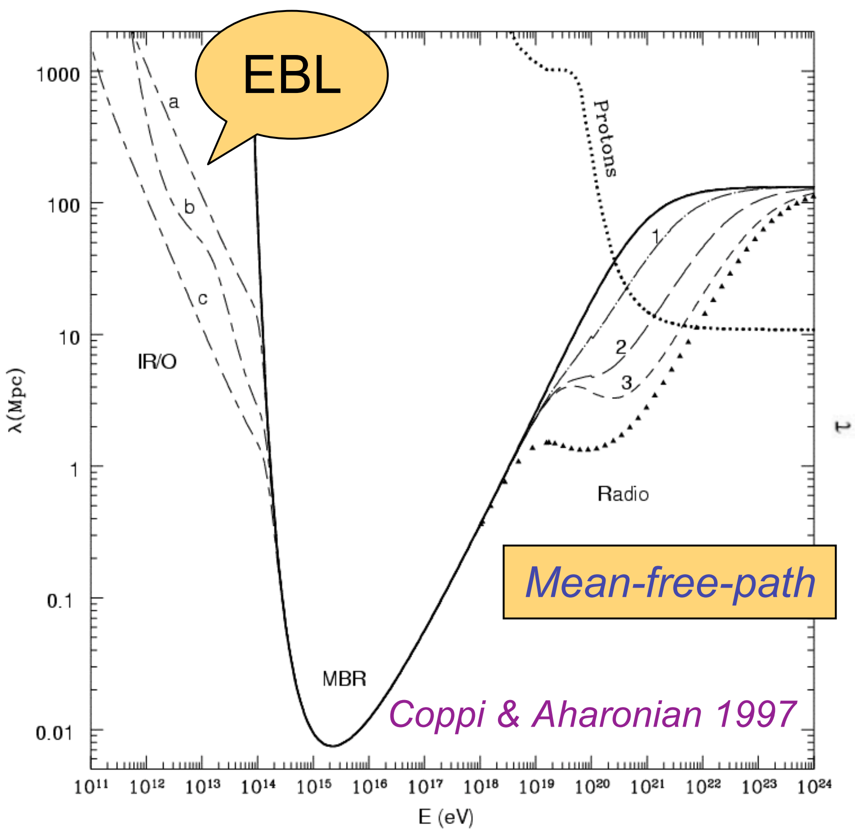
Charge particle Astronomy

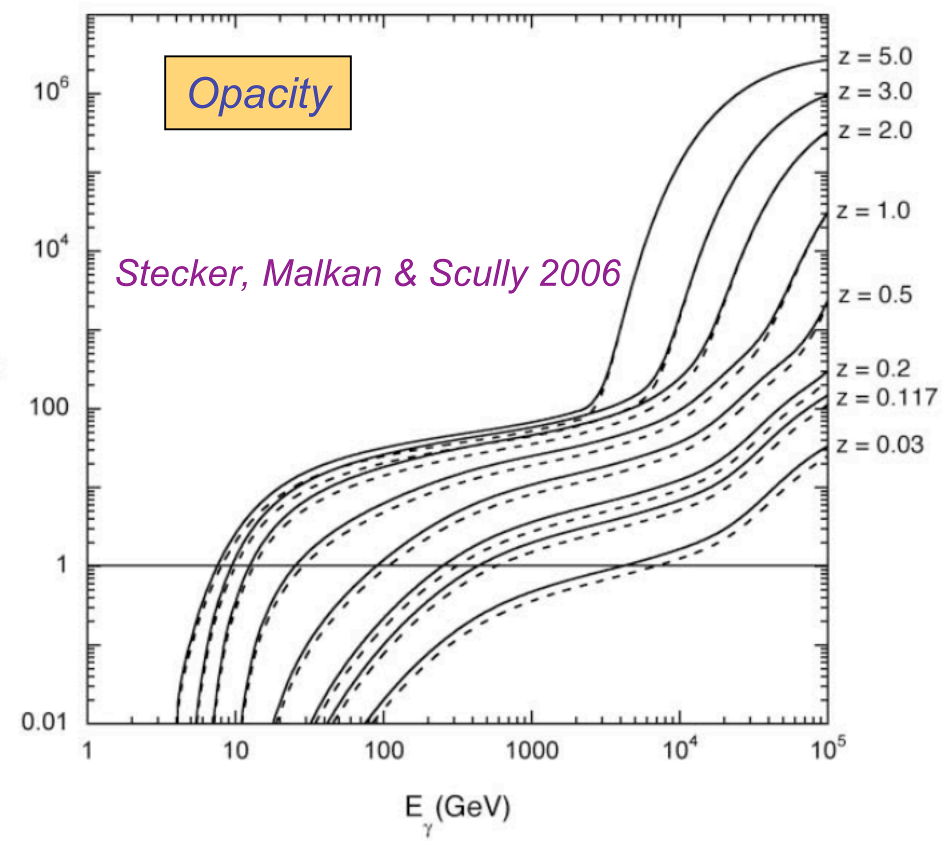
Important for source modeling, UHE emission mechanism

Cosmological probes, star formation, dust absorption

TeV γ-ray Spectra

- TeV γ-rays are absorbed by background photons ➔ limited horizon
- Measured TeV spectra from distant sources are steepened from production
  ➔ Source modeling, Cosmic-ray acceleration mechanism





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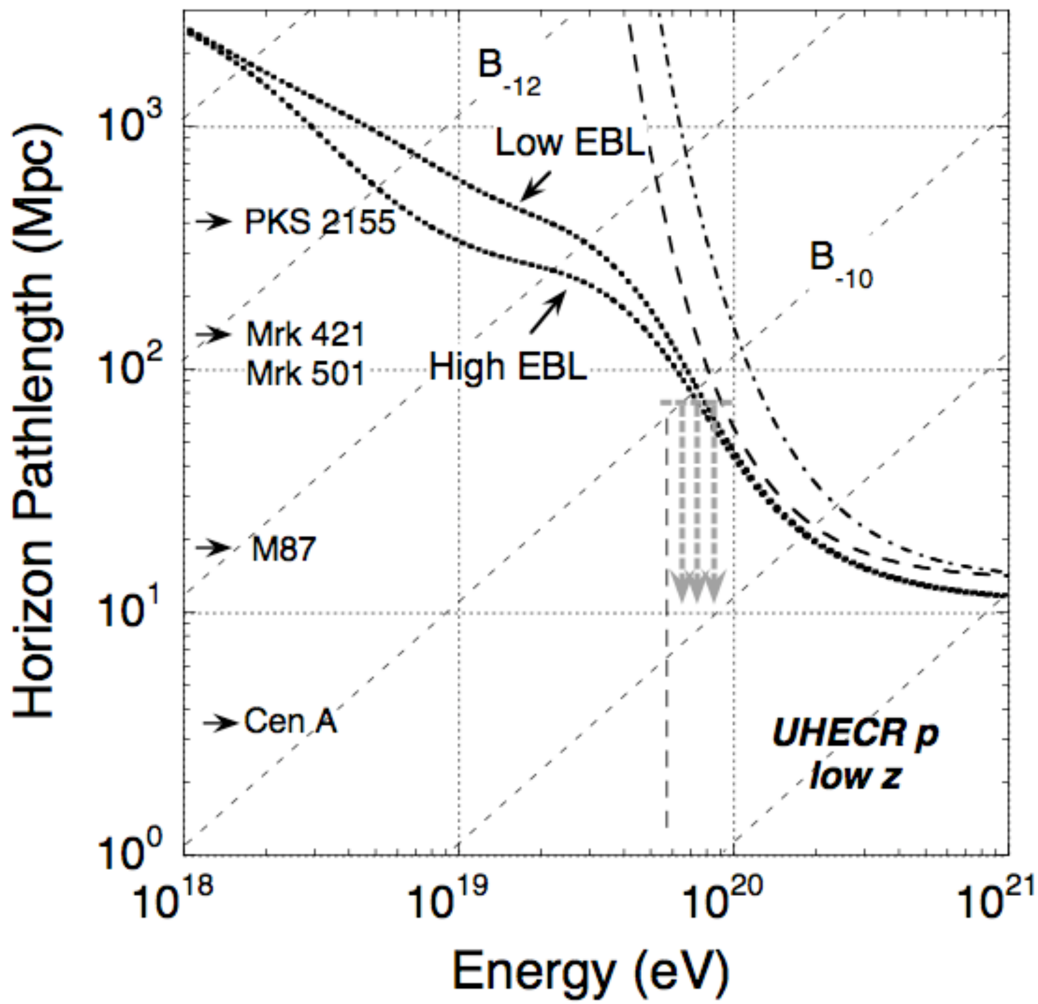
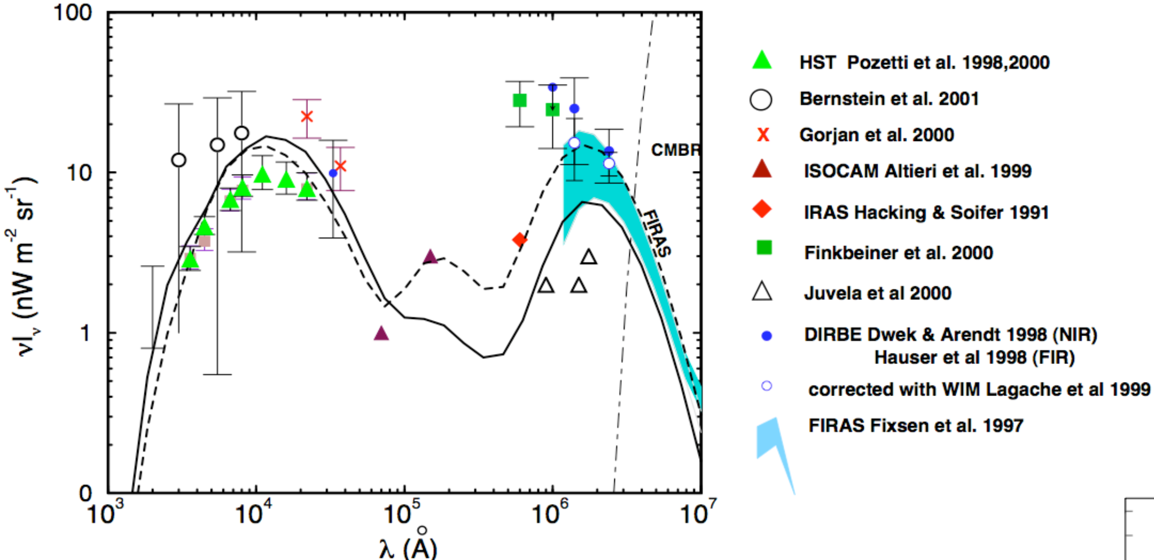
Cosmic-ray Spectra

- ❑ Energy losses by ultrahigh-energy cosmic-rays ➔ limited horizon (GZK effect)
- ❑ UHECR sources ➔ Source modeling, Cosmic-ray acceleration mechanism

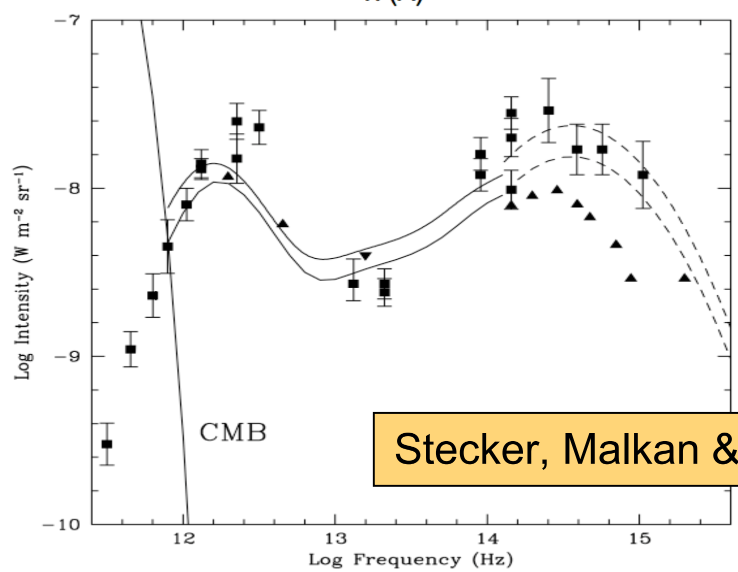


Dermer, Razzaque, Finke and Atoyan (in prep.)

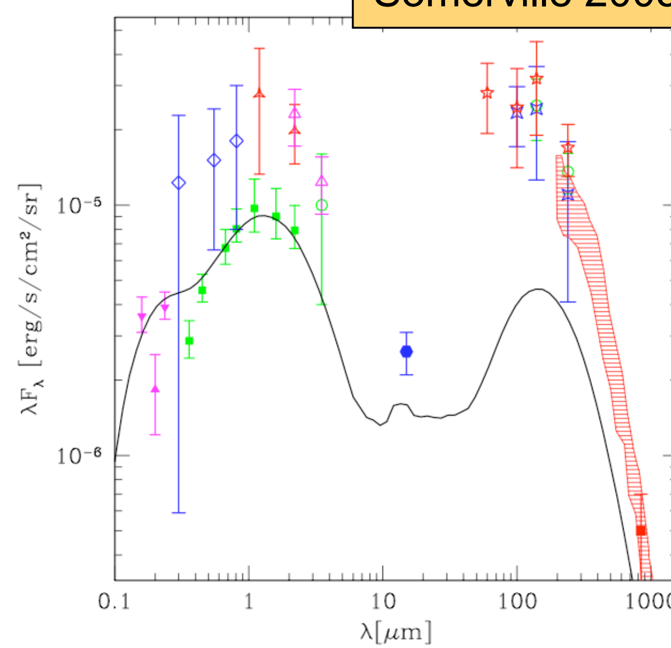
Popular Models



Kneiske, Mannheim & Hartmann 2002



Stecker, Malkan & Scully 2006



Primack, Bullock & Somerville 2005

What we propose to do

Calculate the total number of blackbody photons per unit energy interval emitted by a star of mass M born at redshift z over its main sequence lifetime

$$\frac{dN(\epsilon,M)}{d\epsilon} = \int_{\max[0,z_d(M)]}^{z} dz' \left|\frac{dt}{dz'}\right| \frac{dN(\epsilon',M)}{d\epsilon' dt}(1+z')$$

Number density of photons reaching us from all stars in all epochs

⇩

EBL starlight

$$\frac{dN(\epsilon)}{d\epsilon dV} = \mathcal{N} \int_0^{\infty} dz \left|\frac{dt}{dz}\right| \psi(z) \int_{M_{\min}}^{M_{\max}} dM \left(\frac{dN}{dM}\right) \times \int_{\max[0,z_d(M)]}^{z} dz' \left|\frac{dt}{dz'}\right| f_{\rm esc}(\epsilon') \frac{dN(\epsilon',M)}{d\epsilon' dt}(1+z')$$

SFR

IMF

Photon escape fraction

EBL infrared is reprocessed starlight by galactic dust

What we propose to do

Calculate the cosmic energy output or luminosity density ($W\ Mpc^{-3}$) in starlight by the galaxies in the local ($z \sim 0$) universe.

$$\epsilon L_\epsilon = \epsilon^2 \mathcal{N} \int_{M_{\rm min}}^{M_{\rm max}} dM \left(\frac{dN}{dM}\right) \times \int_0^{z_b(M)} dz' \left|\frac{dt}{dz'}\right| \psi(z') f_{\rm esc}(\epsilon') \frac{dN(\epsilon', M)}{d\epsilon' dt} (1+z')$$

➔ Choose models for star formation rate and initial mass function

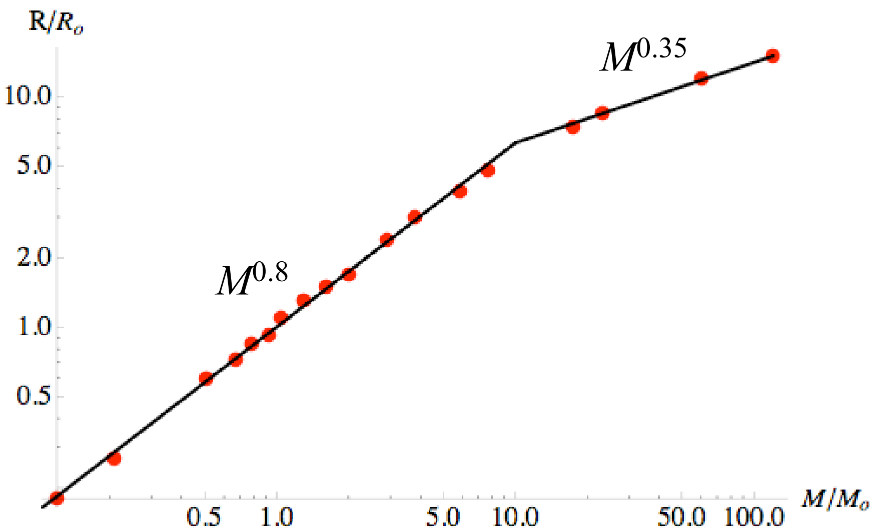
➔ Compare luminosity density models with point source data

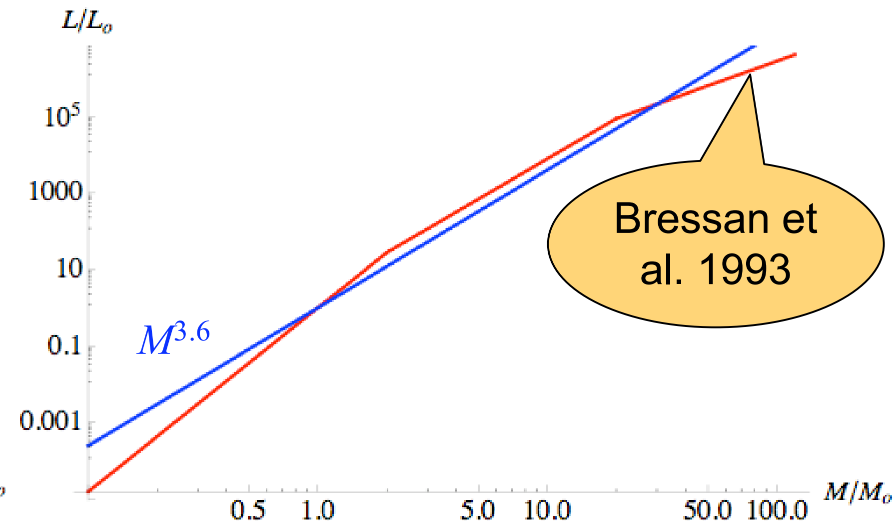
Fix normalization parameter

➔ Compare EBL model with diffuse photon data

➔ Find a "best fit" EBL model

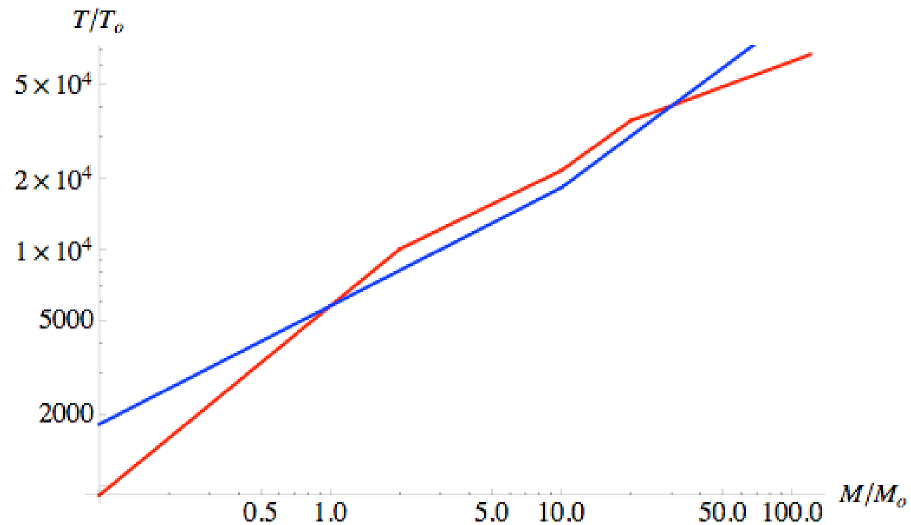
Stellar Relations





- ❑ Mass-Radius
- ❑ Mass-Luminosity
- ❑ Mass-Temperature

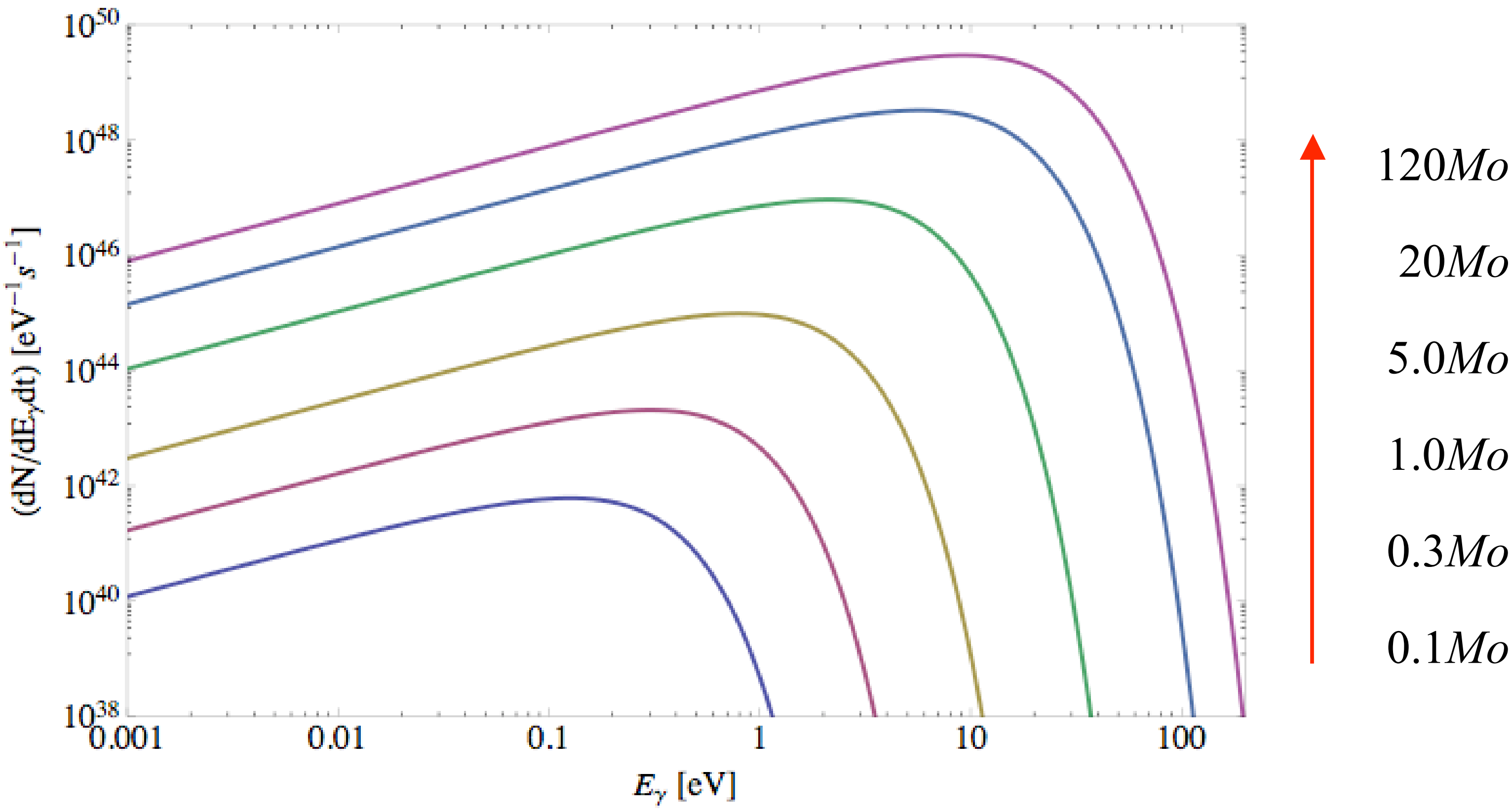
$$L = 4\pi R^2 \sigma T^4$$ ⇨



Stellar Model

Blackbody photon number density

Total number of photons radiated per unit energy and time intervals ⇨ $$\frac{dN(\epsilon,M)}{d\epsilon dt}=\pi R^2 c\ \frac{dN}{d\epsilon dV}$$



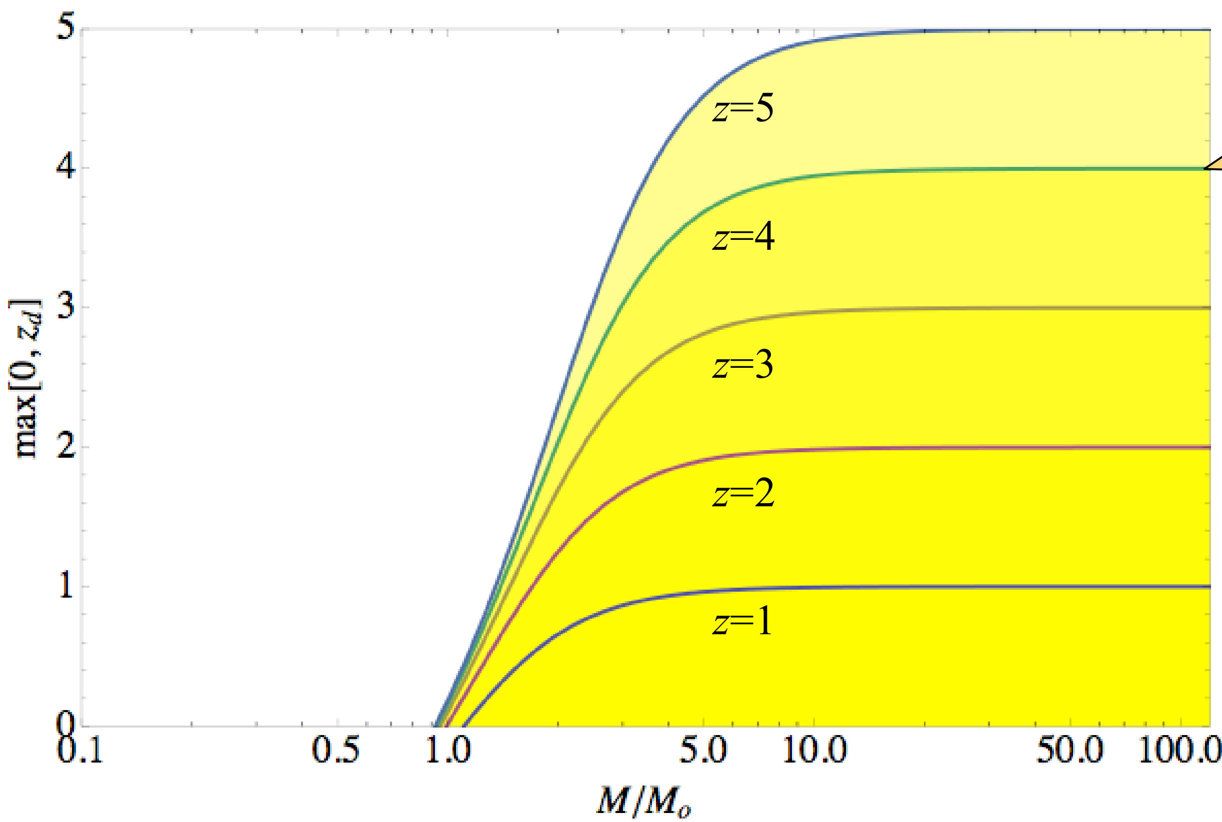
Stellar Lifetime

10 Gyr

$$t_*(M) = t_o\left(\frac{M}{M_o}\right)\left(\frac{L}{L_o}\right) = \int_{z_d}^{z} dz' \left|\frac{dt}{dz'}\right|$$

⇒Solve for $z_*(z,M)$ with cosmology $(h\ \Omega_m\ \Omega_\Lambda)=(0.7,0.3,0.7)$

Massive stars die fast. Stars with solar mass or less live almost Huble time

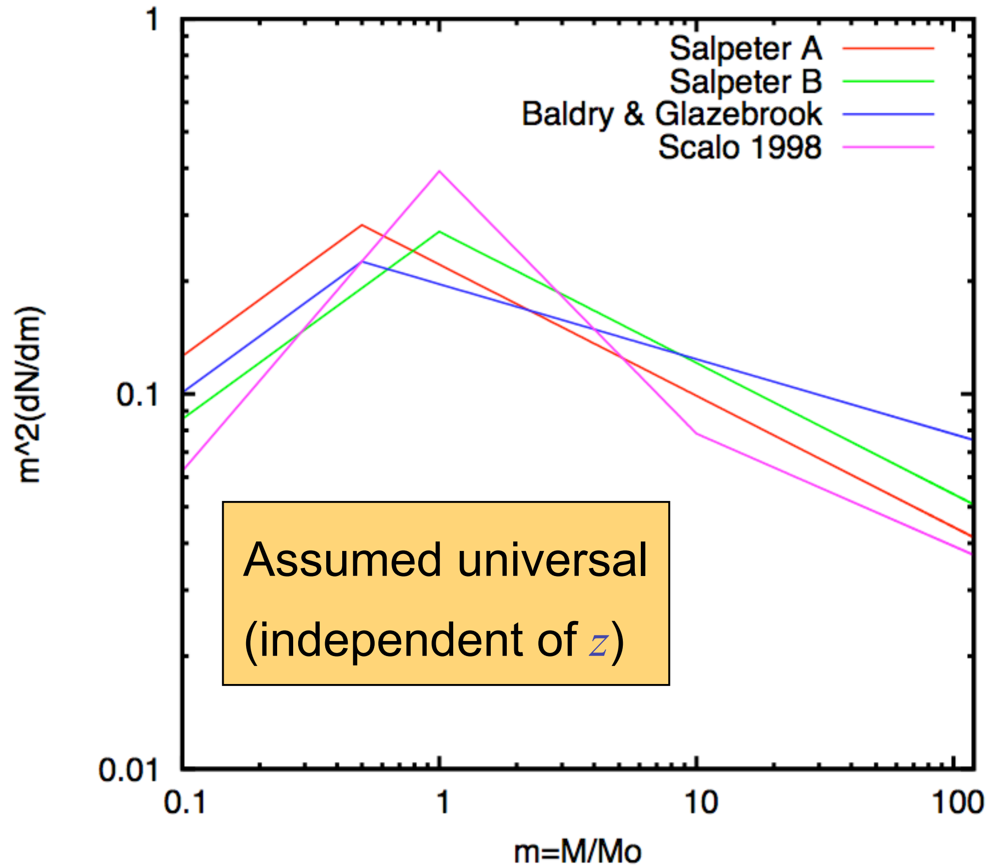


Birth redshift

Initial Mass Function

- Number of stars formed per unit solar mass
- Broken power-law: $dN/dM \sim M^{-\alpha}$
- $dN/dlnM$ is normalized to 1 in the range $0.1Mo$ -$120Mo$

Scalo 1998 IMF is currently disfavored



Salpeter A	α=1.5, $0.1Mo$ -$0.5Mo$	α=2.35, $0.5Mo$ -$120Mo$
Salpeter B	α=1.5, $0.1Mo$ -$1.0Mo$	α=2.35, $1.0Mo$ -$120Mo$
Baldry & Glazebrook	α=1.5, $0.1Mo$ -$0.5Mo$	α=2.20, $0.5Mo$ -$120Mo$

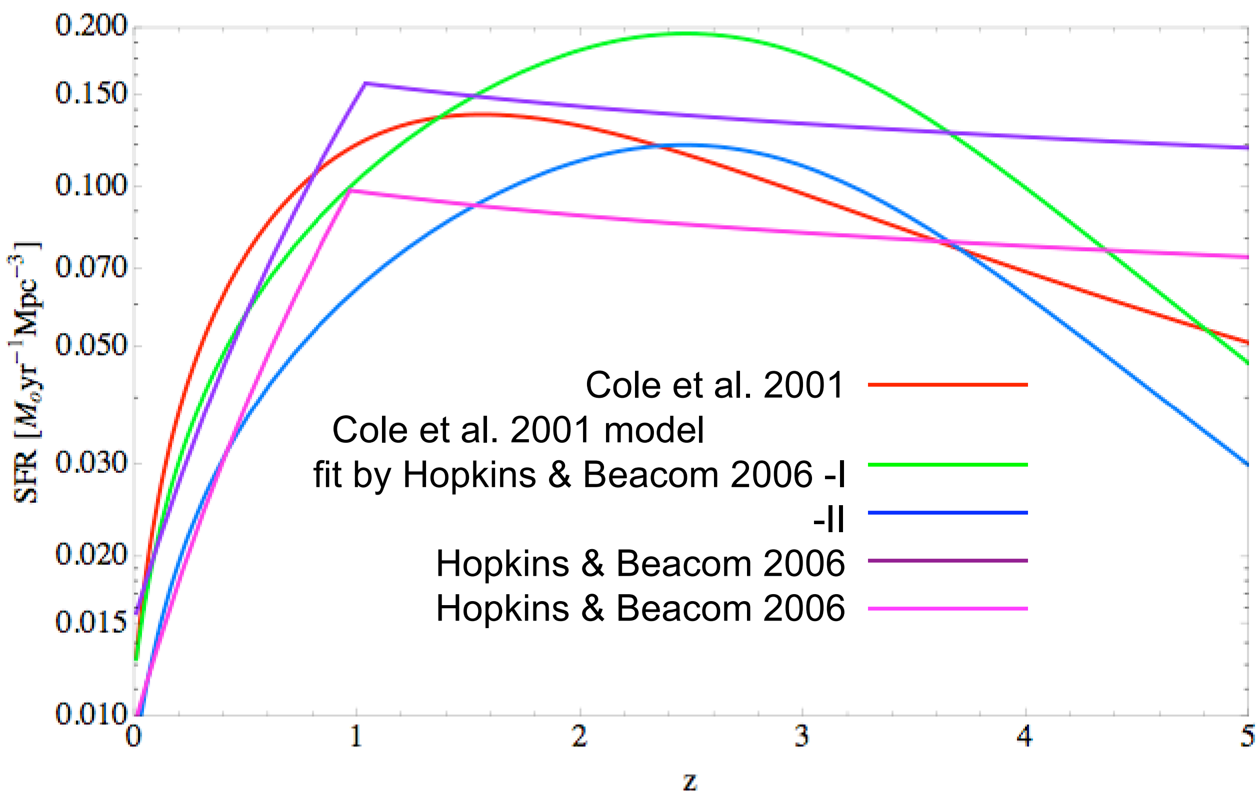
Star Formation Rate

$$\Psi(z) = h\,\frac{a + b\,z}{1 + (z/c)^d}$$

Parametric form by Cole et al. 2001

Large uncertainty

$(0.5\text{-}2.9)\times10^{-2}\ h_{70} Mo\ \mathrm{yr}^{-1}\mathrm{Mpc}^{-3}$ at z=0

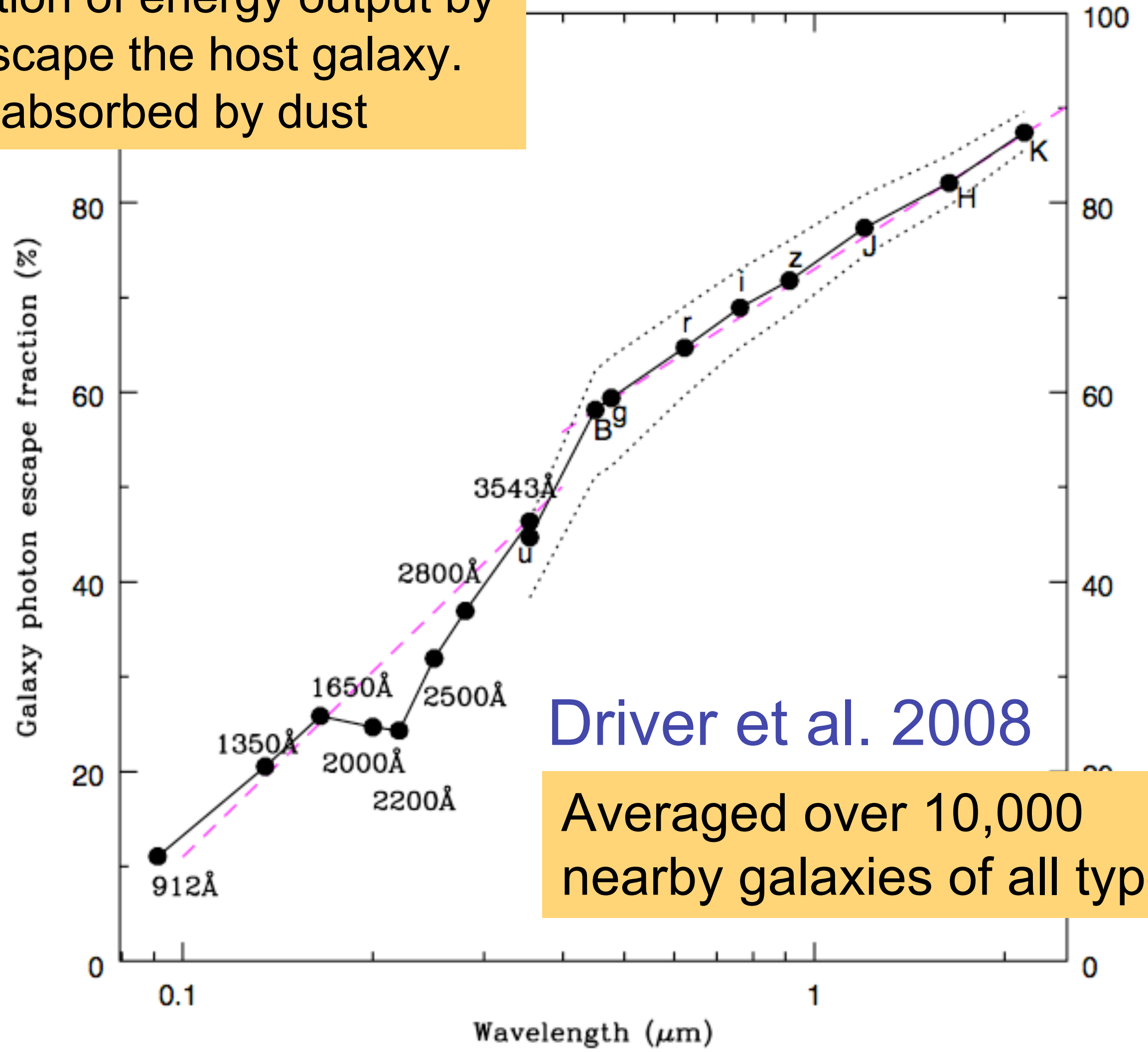


Choice of A Model

	SFR	IMF
Model A	Cole et al. 2001	Salpeter A
Model B	Cole et al. 2001 (fit by Hopkins & Beacom 2006)	Salpeter A
Model C	Cole et al. 2001 (fit by Hopkins & Beacom 2006)	Baldry & Glazebrook 2003
Model D	Hopkins & Beacom 2006	Salpeter A
Model E	Hopkins & Beacom 2006	Baldry & Glazebrook 2003

Dust Attenuation

Only a fraction of energy output by the stars escape the host galaxy. The rest is absorbed by dust



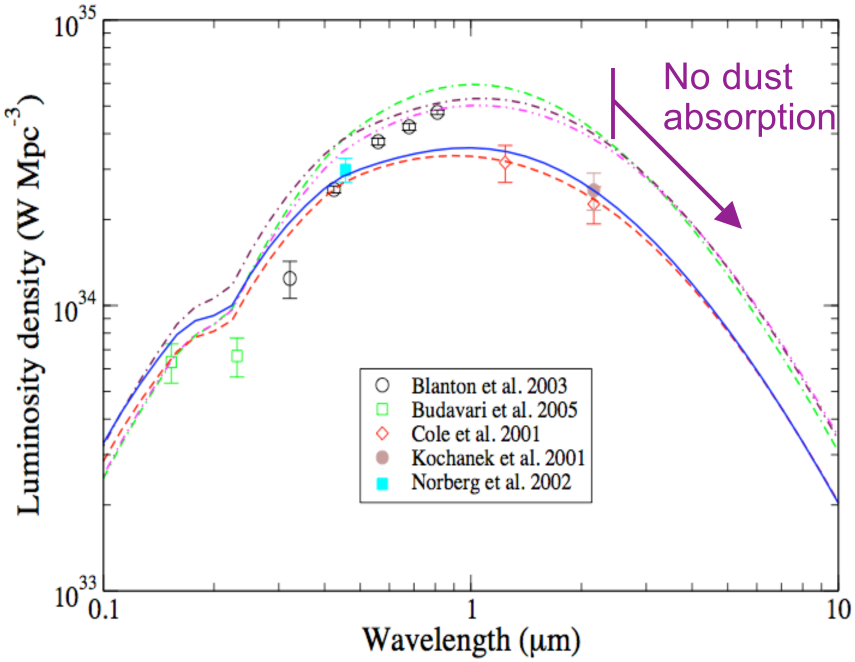
Driver et al. 2008

Averaged over 10,000 nearby galaxies of all types

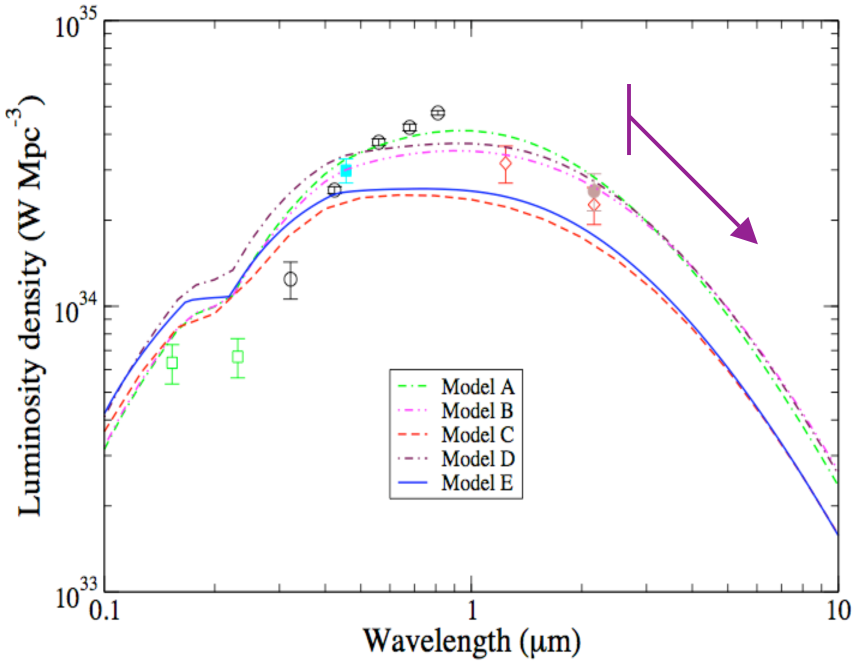
Local Energy Output

Integrated up to z=0, no adjustable free parameter!

Single power-law M/L ratio



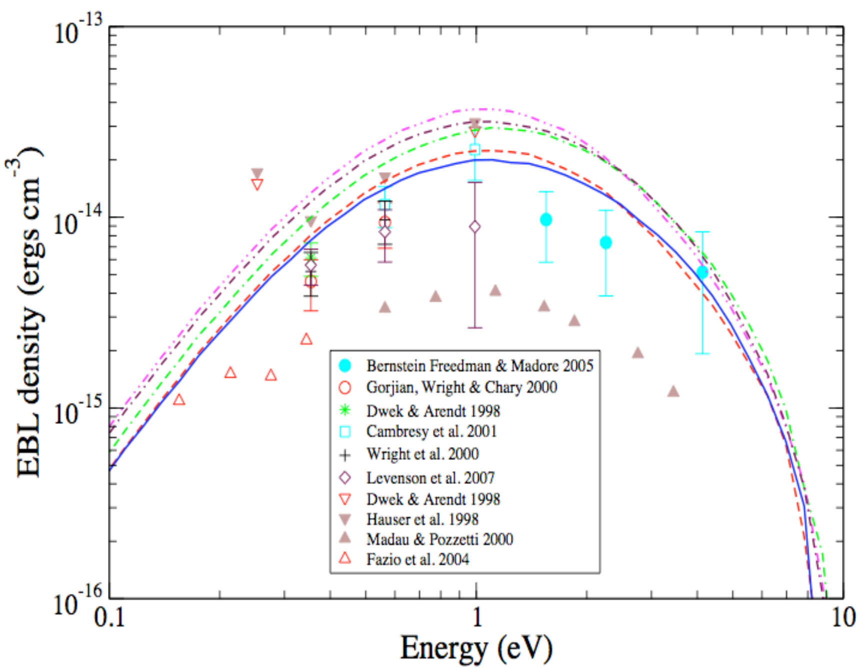
Bressan et al. '93 M/L ratio



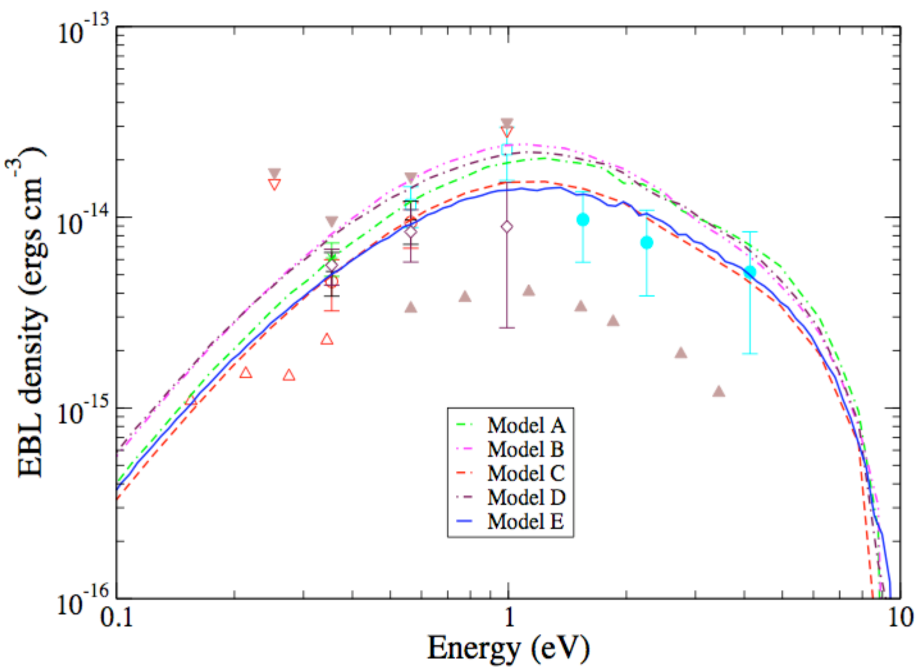
EBL Data and Models

Local (z=0) EBL energy density with the same models as in local luminosity density. Again, no adjustable free parameter!

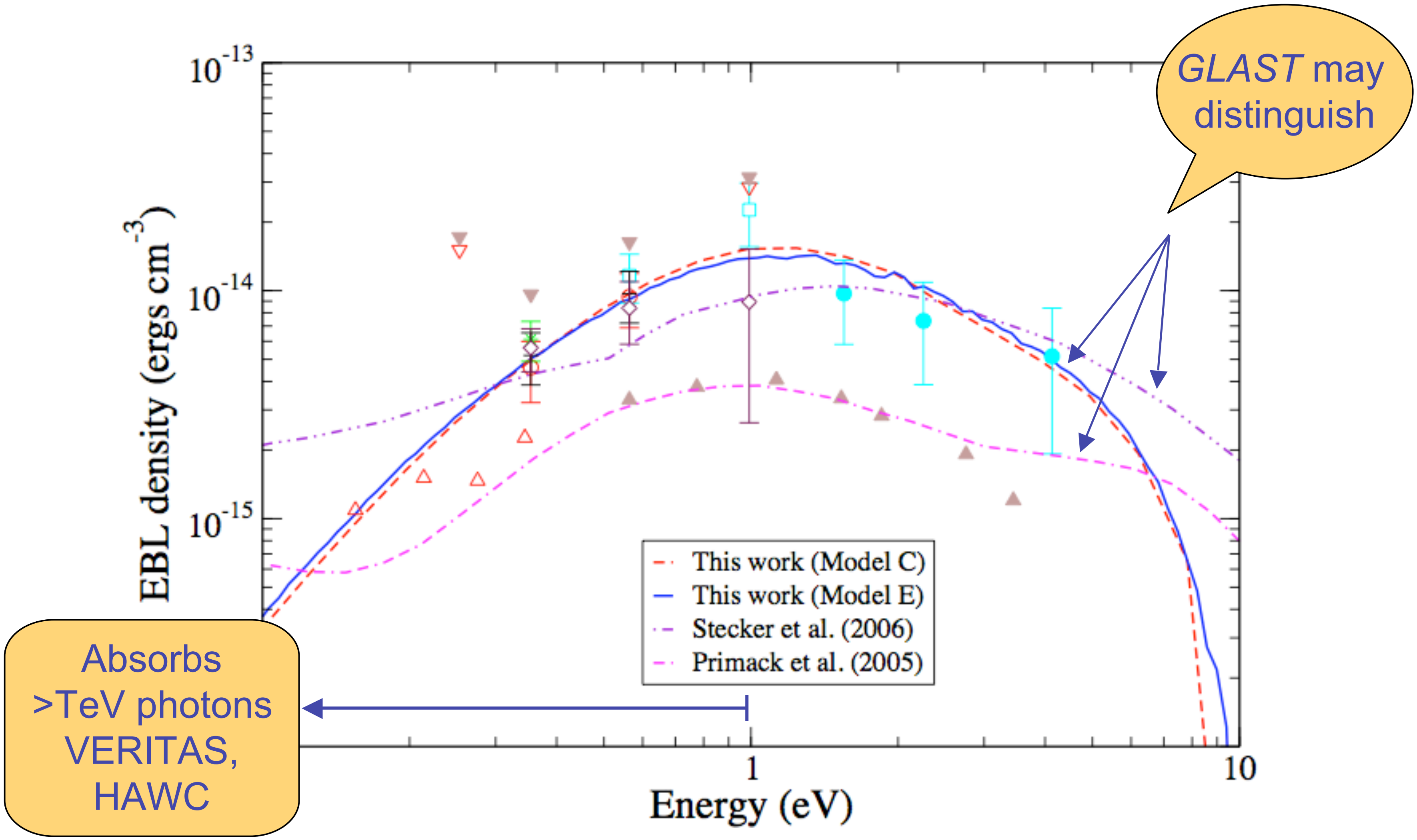
Single power-law *M/L* ratio



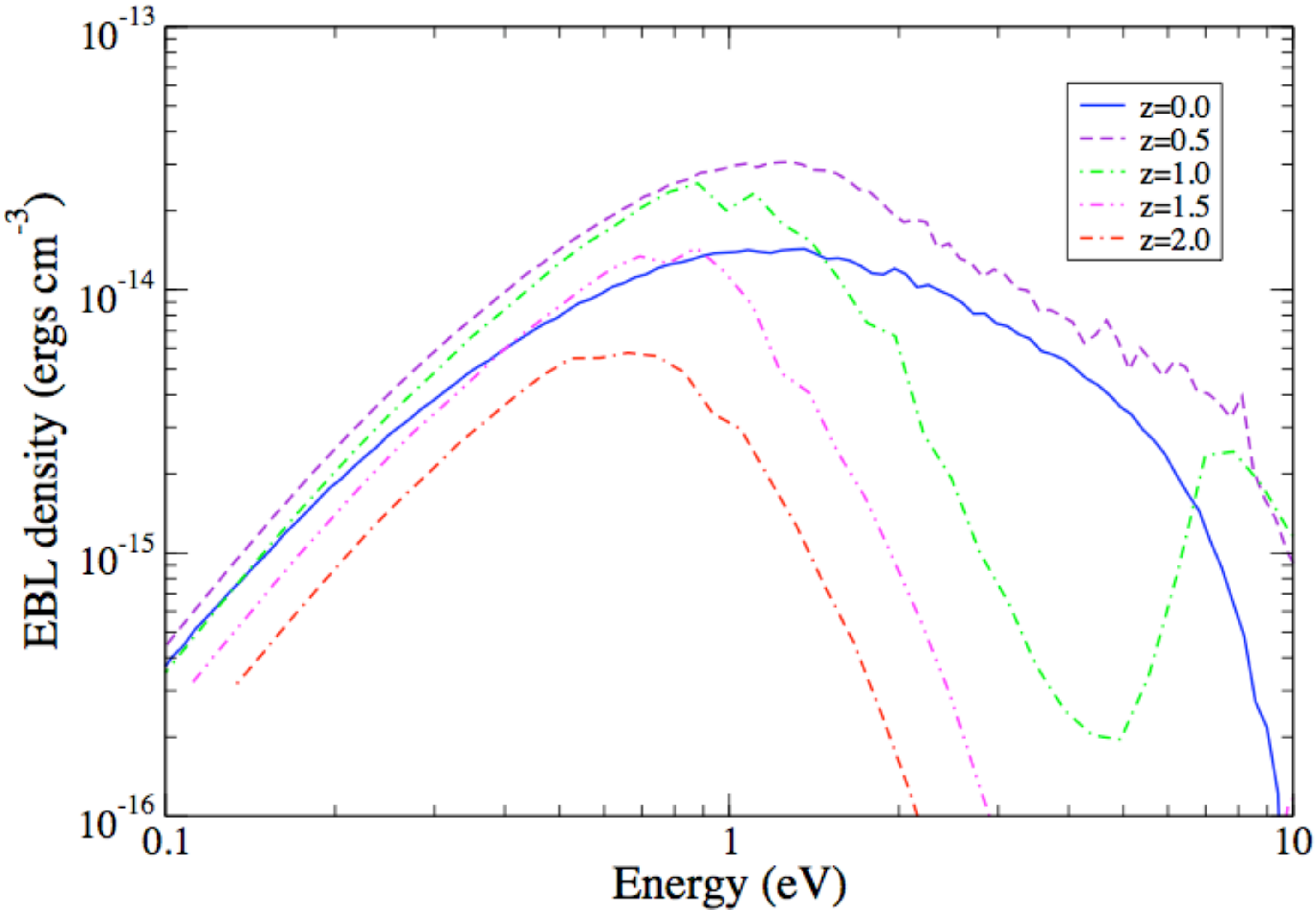
Bressan et al. '93 *M/L* ratio



Best "Eyeball Fit" Model

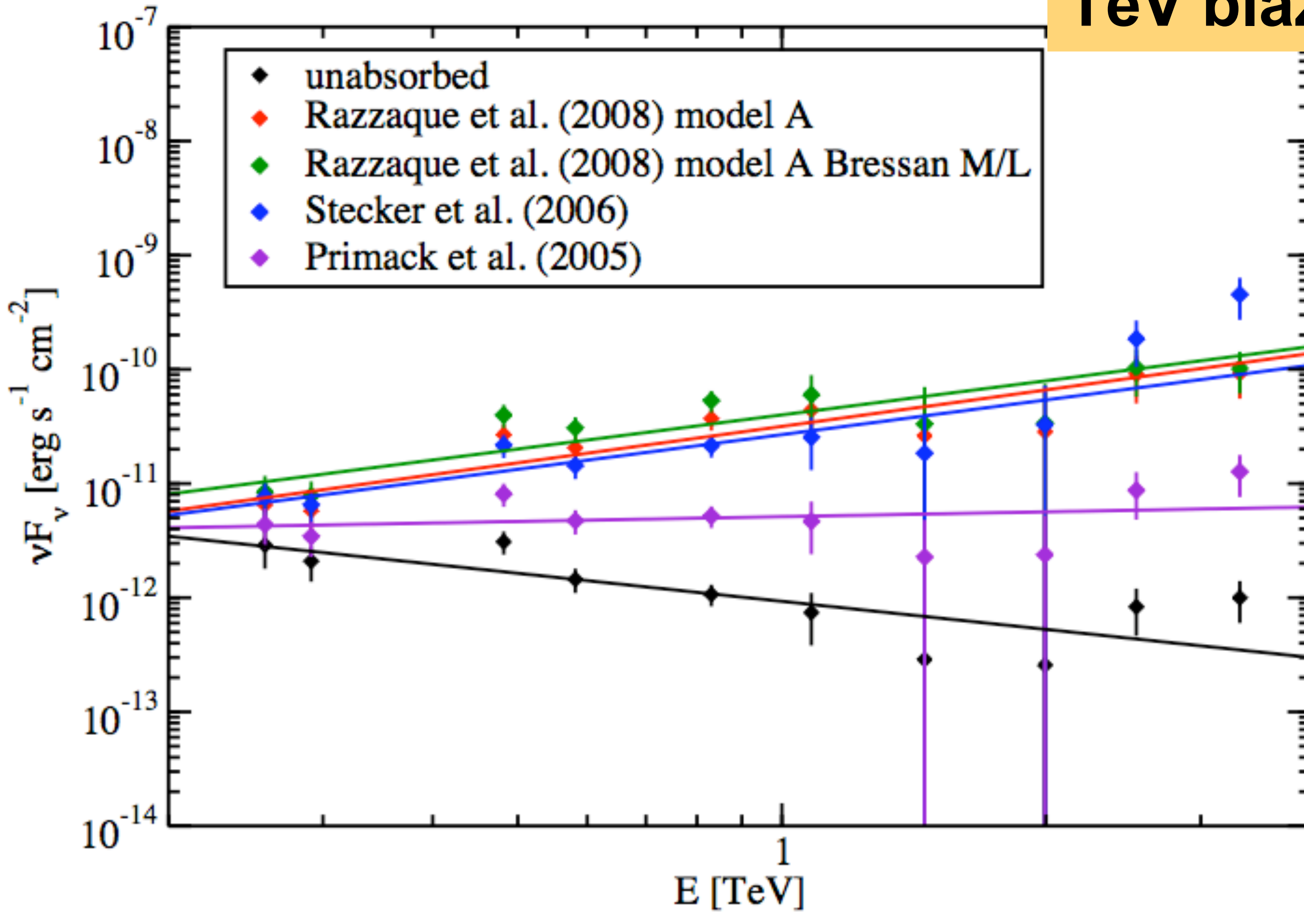


Evolving EBL



Fit to AGN Data

1ES1101-232
TeV blazar, z=0.186



$dN/dE \sim E^{-\Gamma}$

Γ=1.0
Γ=0.9
Γ=1.0

Γ=1.9

HESS Data
Γ=2.8

Summary and Outlook

- We proposed a very simple analytic model of EBL, which reasonably explains data
- Easy to calculate evolution of EBL with redshift
- Calculation of infrared emission from galactic dust heated by starlight is underway
- Your comments and suggestions to improve the model are greatly appreciated