Cosmic “Optical/Infrared” Background Radiation

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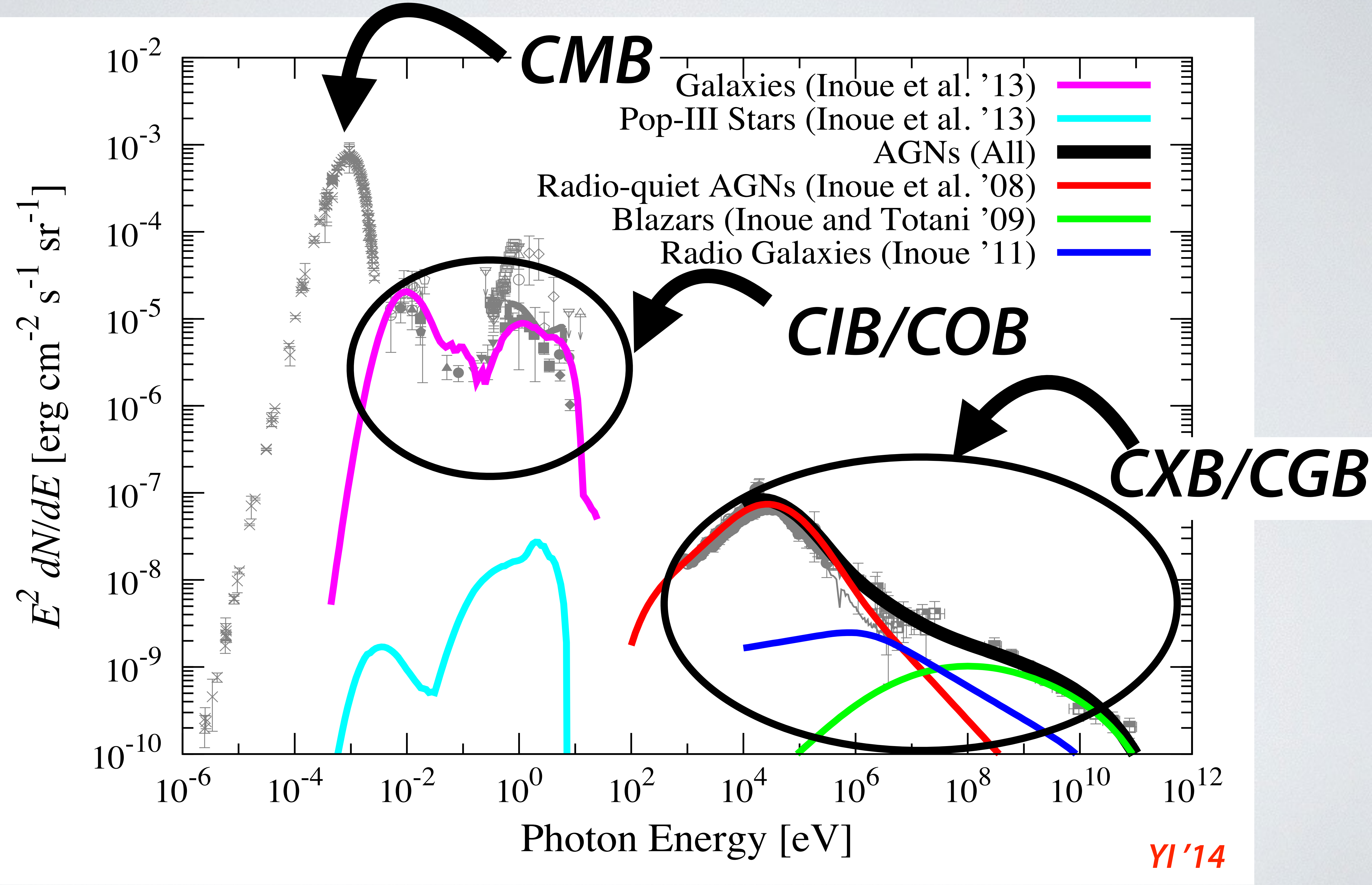
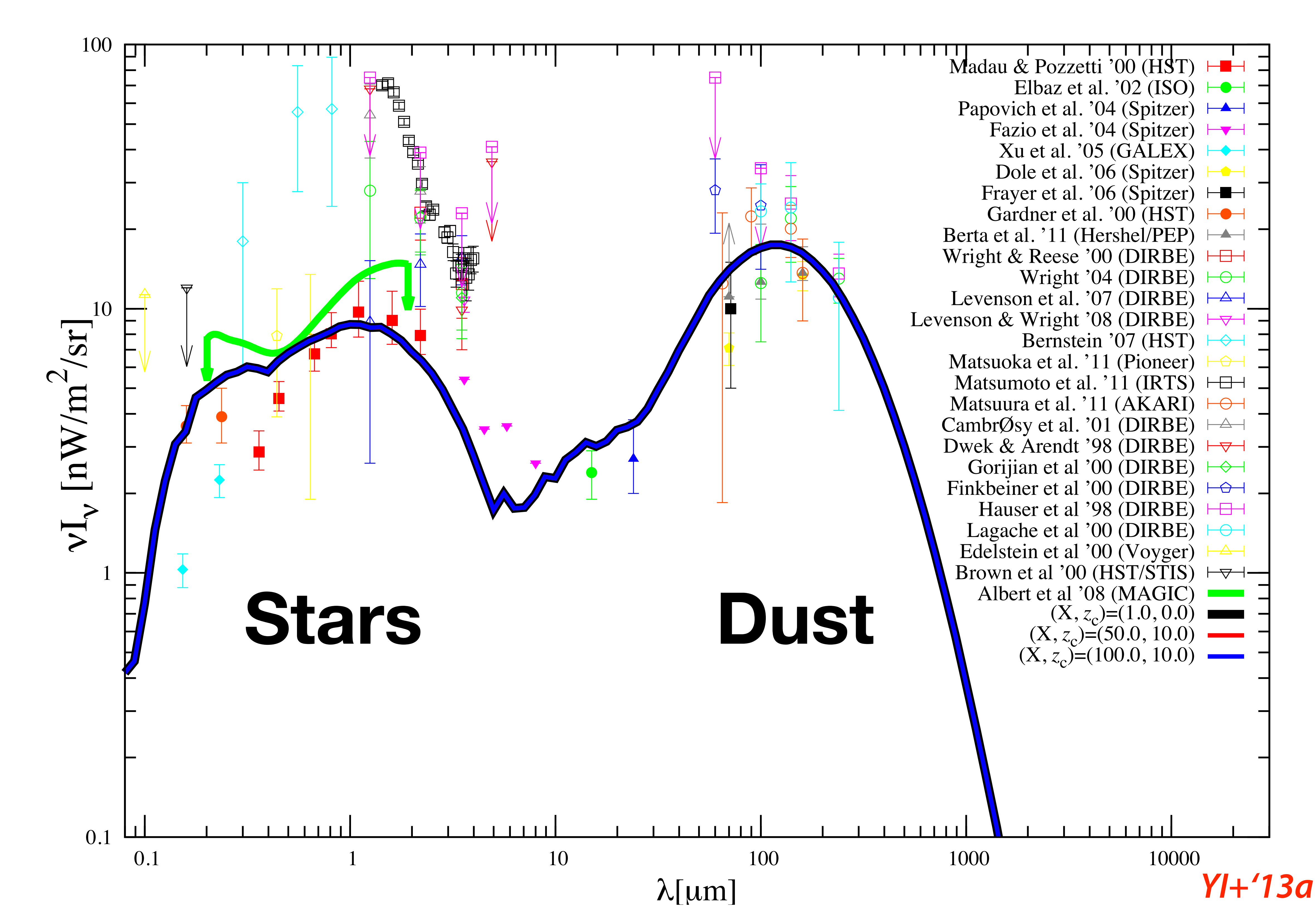
Cosmic Background Radiation Spectrum



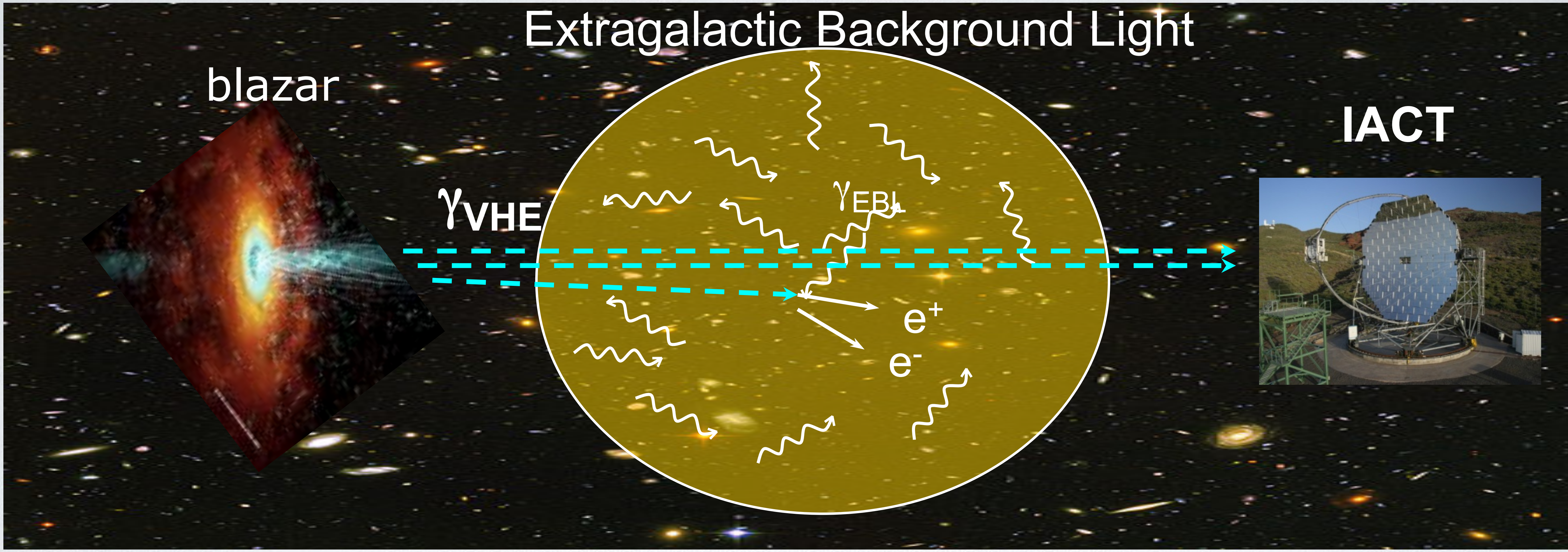
Cosmic Optical & Infrared Background (COB & CIB)

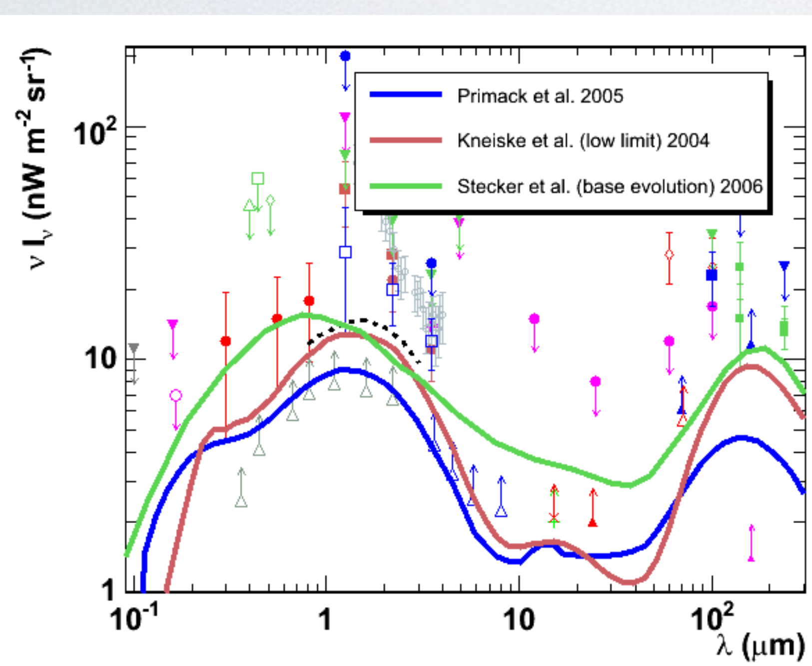


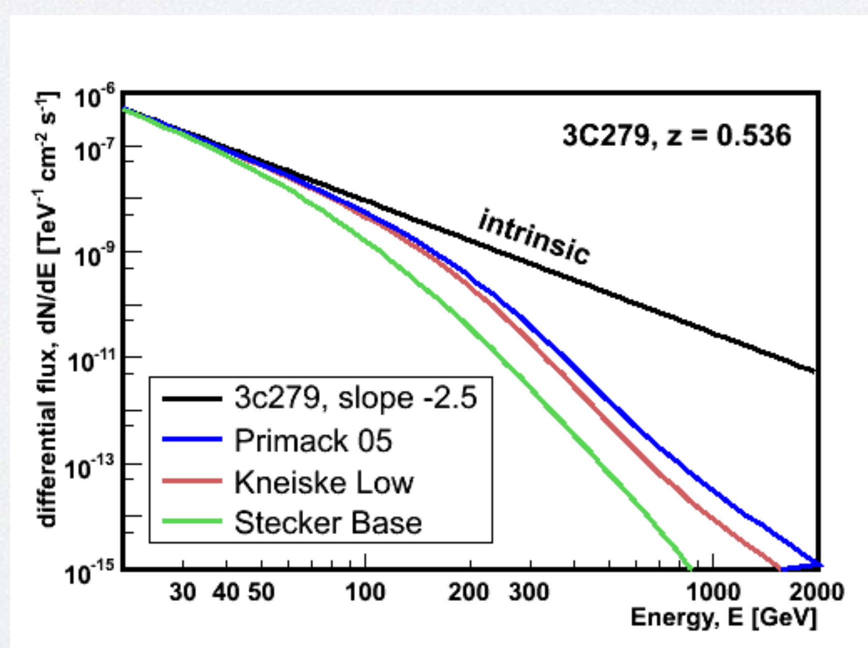
Yl+'13a

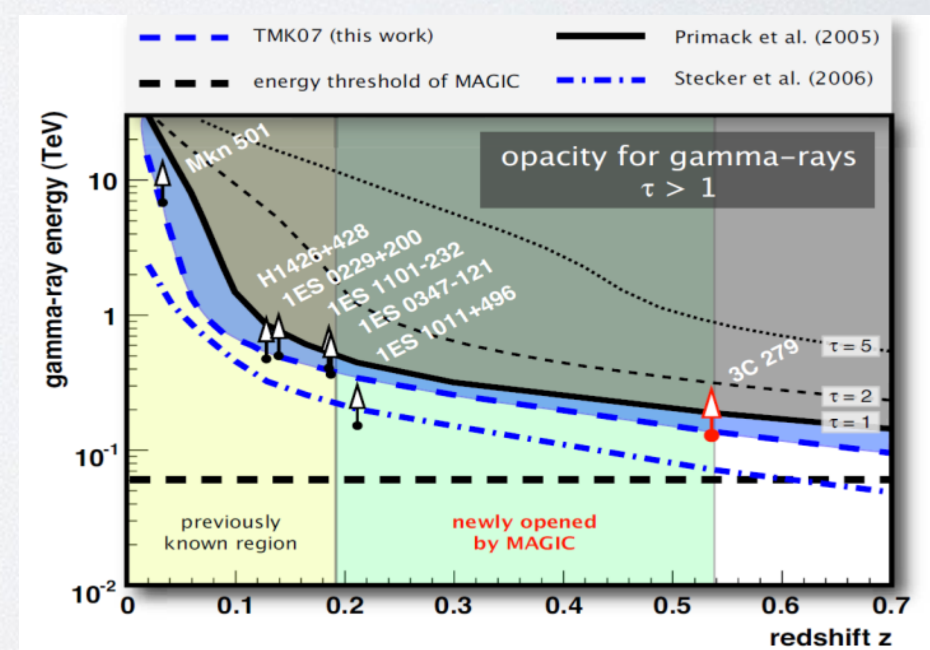
Gamma rays and COB/CIB

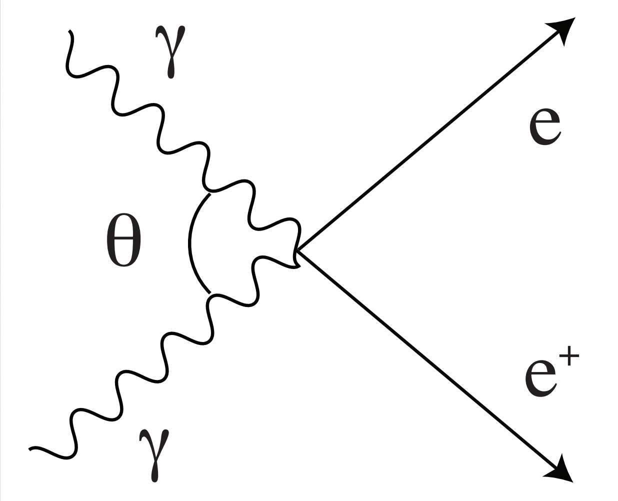
Gamma-ray Attenuation by Cosmic Optical & Infrared Background



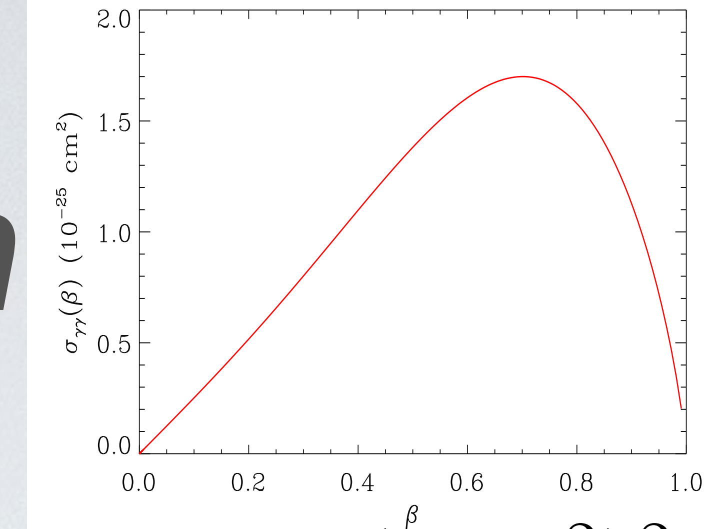








Pair Production



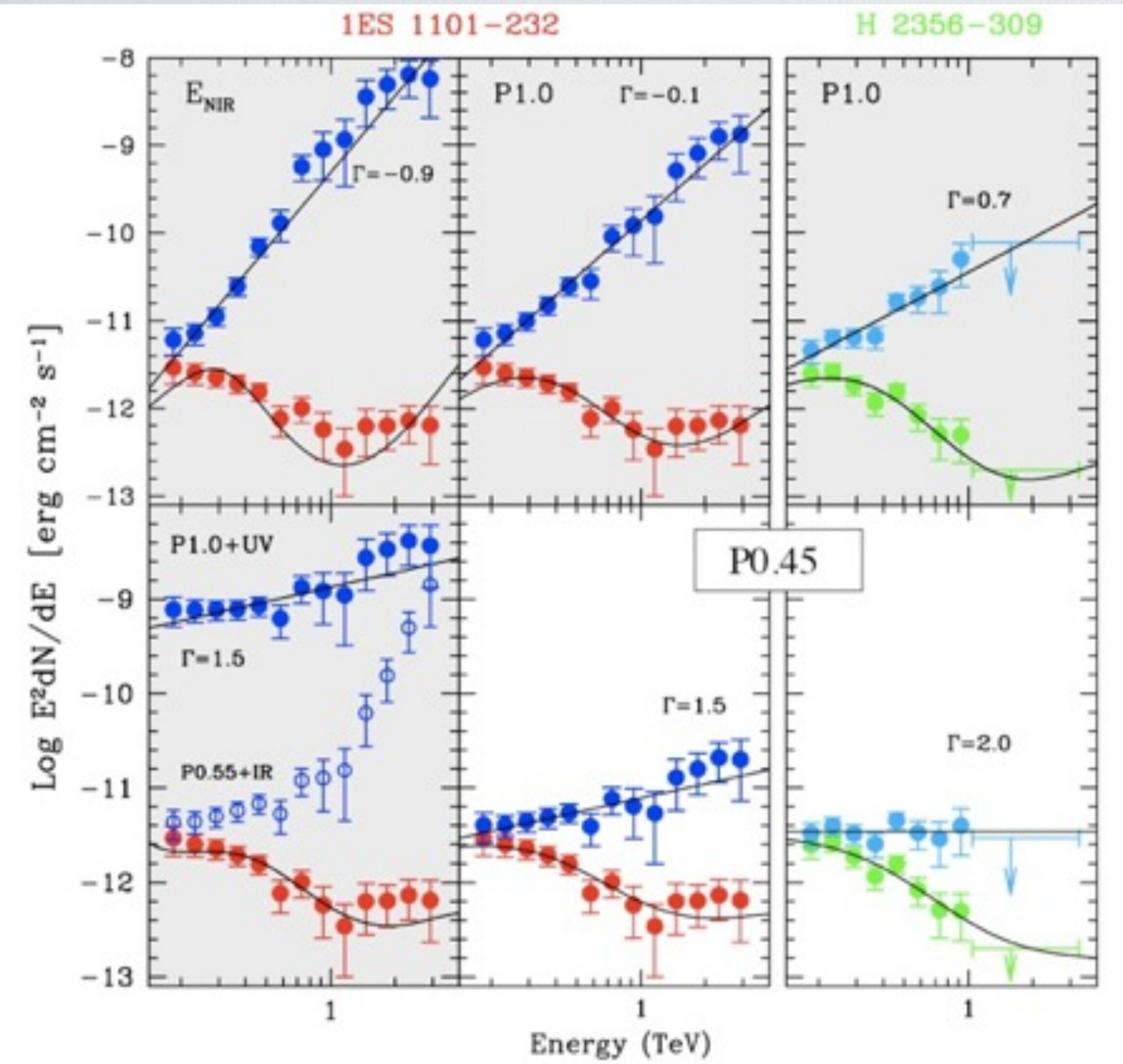
- Threshold energy for pair creation: $\epsilon_{th}(E_\gamma, \mu, z) = \dfrac{2\,(m_e\,c^2)^2}{E_\gamma\,(1-\mu)}$
- θ : the angle between two photons: $\mu \equiv \cos\theta$
- Pair production cross section (Heitler '54):

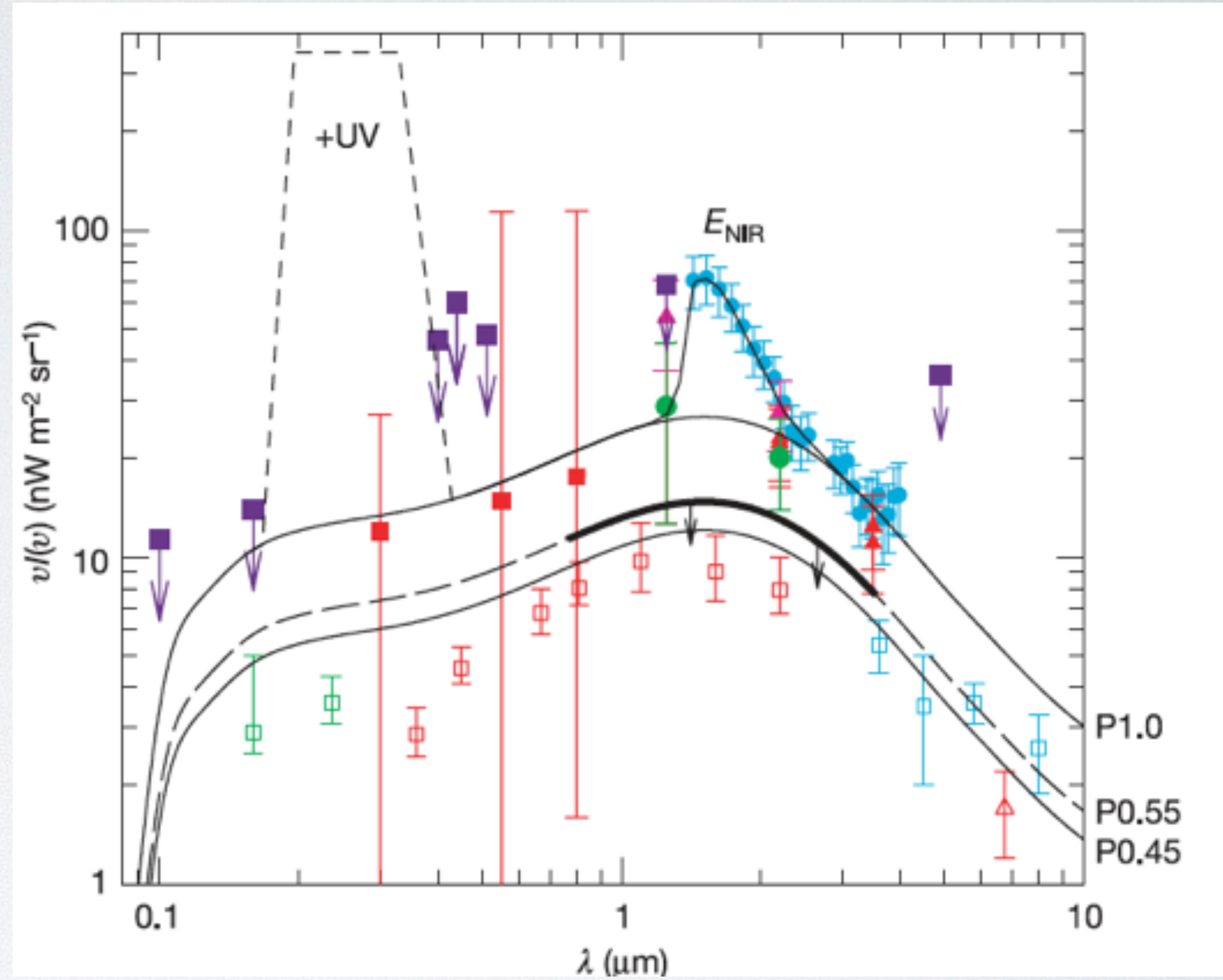
$$\sigma_{\gamma\gamma}(E_\gamma, \epsilon, \mu, z) = \frac{3\sigma_T}{16}\,(1-\beta^2)\left[2\beta\,(\beta^2-2) + (3-\beta^4)\,\ln\left(\frac{1+\beta)}{(1-\beta)}\right)\right]$$

where $\beta \equiv \sqrt{\left(1-\frac{\epsilon_{th}}{\epsilon}\right)}$

- Cross-section peak @ β=0.7
- Corresponding wavelength: $\lambda_{\rm peak} \simeq 2.4(E_\gamma\ [\mathrm{TeV}])\ \mu\mathrm{m}$

EBL Constraints from Gamma Rays (2006)

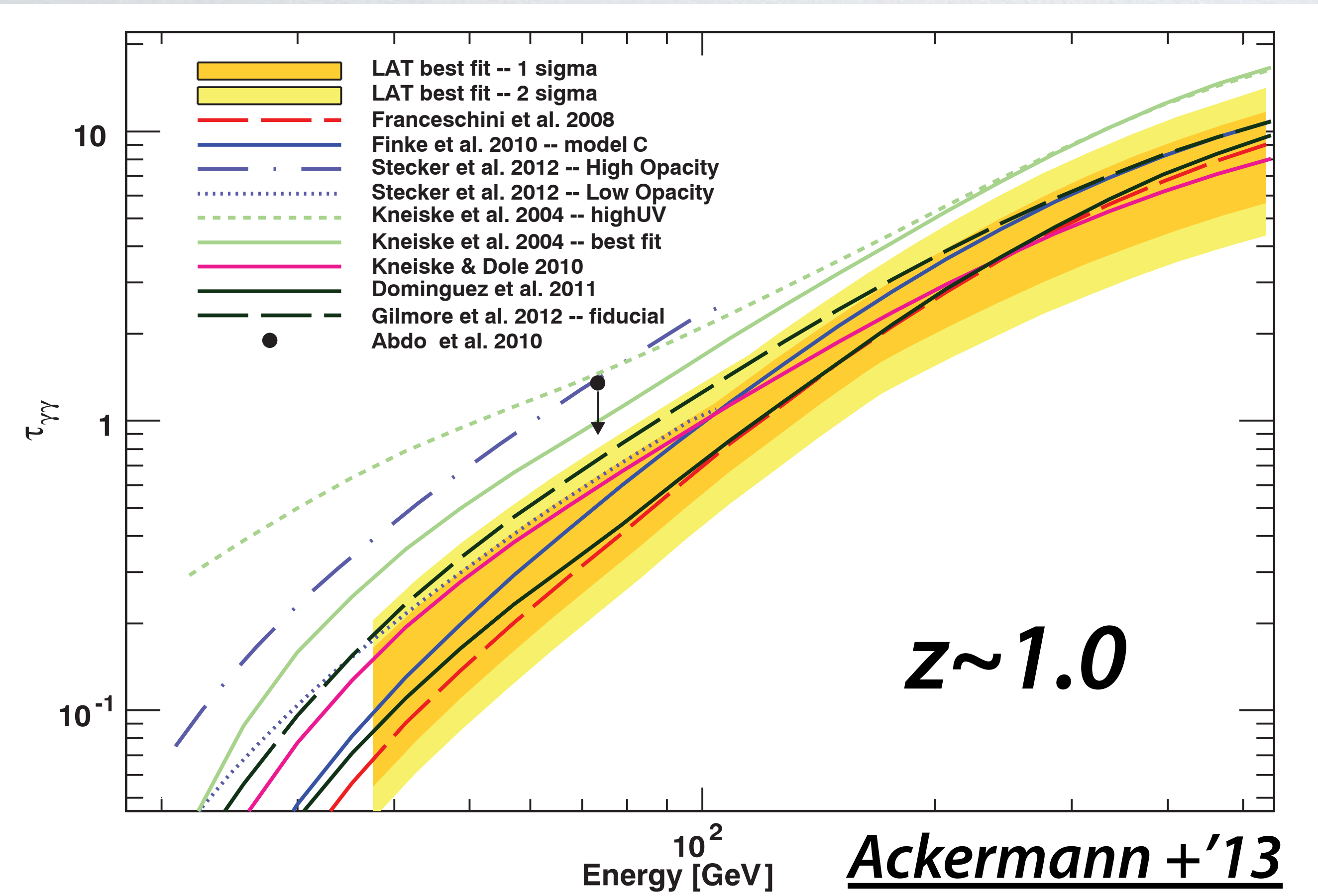




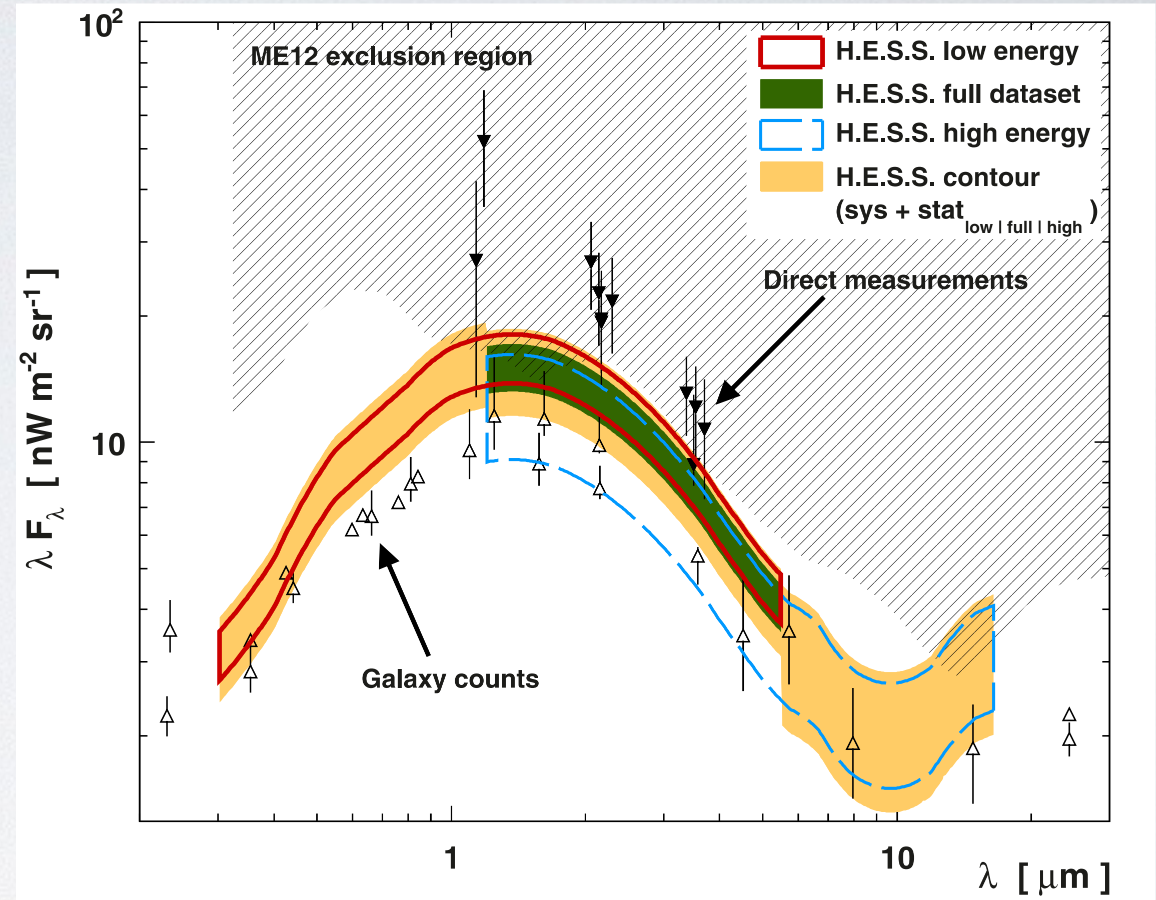
Aharonian+'06 (H.E.S.S.)

- disfavors NIR peak
- close to galaxy counts
- assuming photon index $\Gamma > 1.5$ ($dN/dE \propto E^{-\Gamma}$)

Constraints from Gamma rays



Ackermann +'13

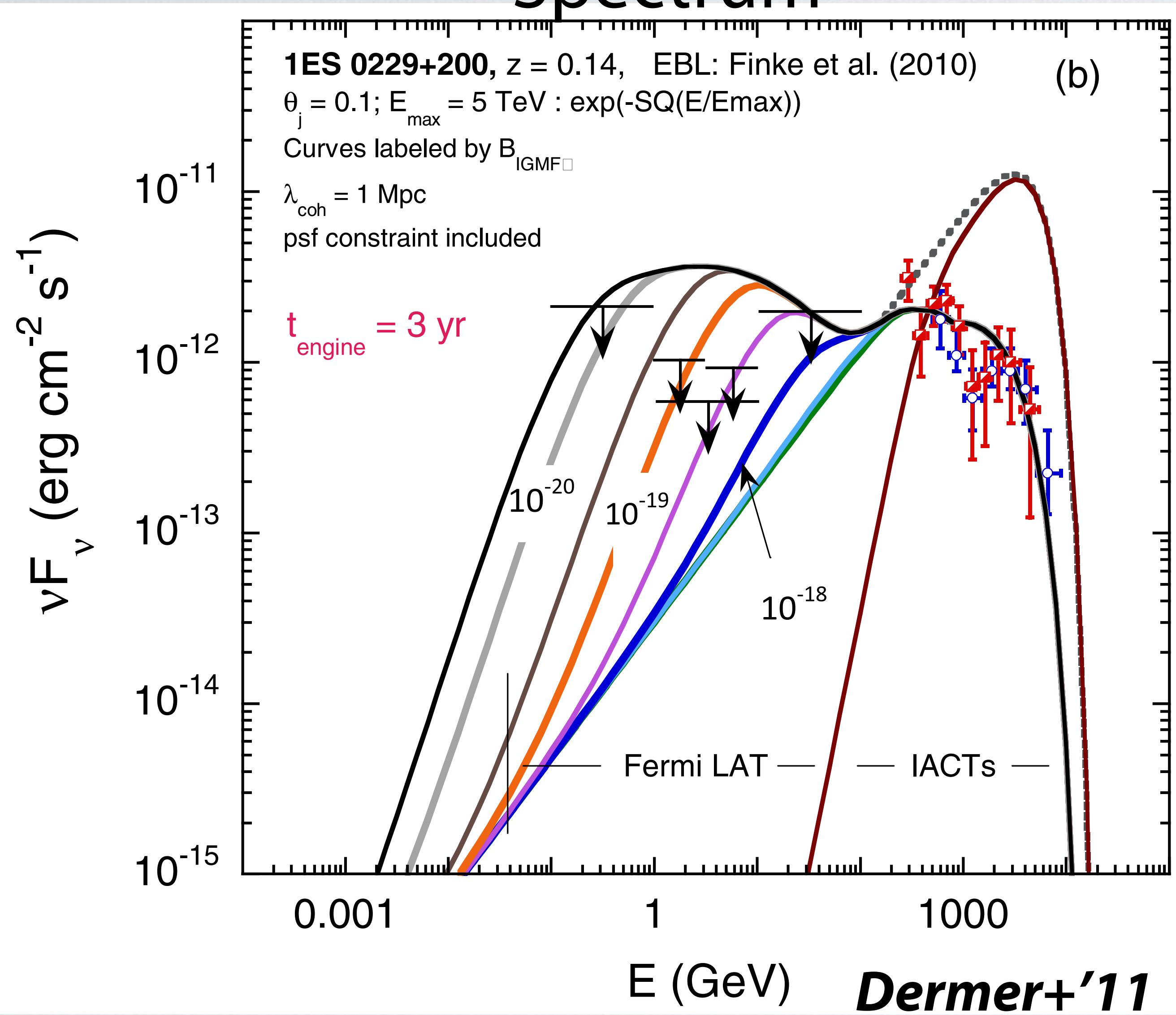


Abramowski +'13

- Fermi derived the COB opacity using the combined spectra of blazars (see also Gong & Cooray '13, Dominguez +'13).
- H.E.S.S. derived the COB intensity using the combined spectra of blazars.

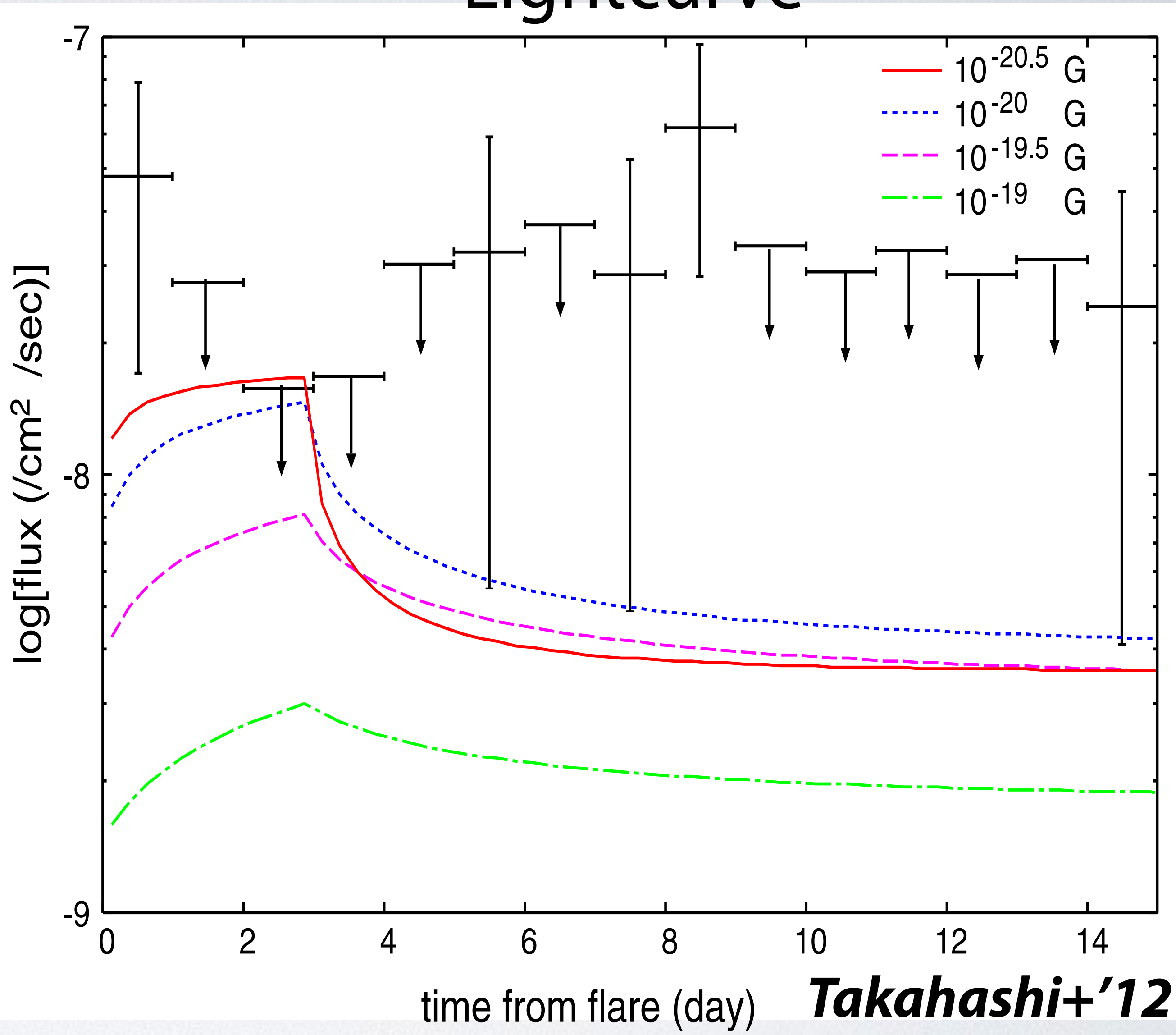
Constraints on the Intergalactic Magnetic Field

Spectrum



Dermer+'11

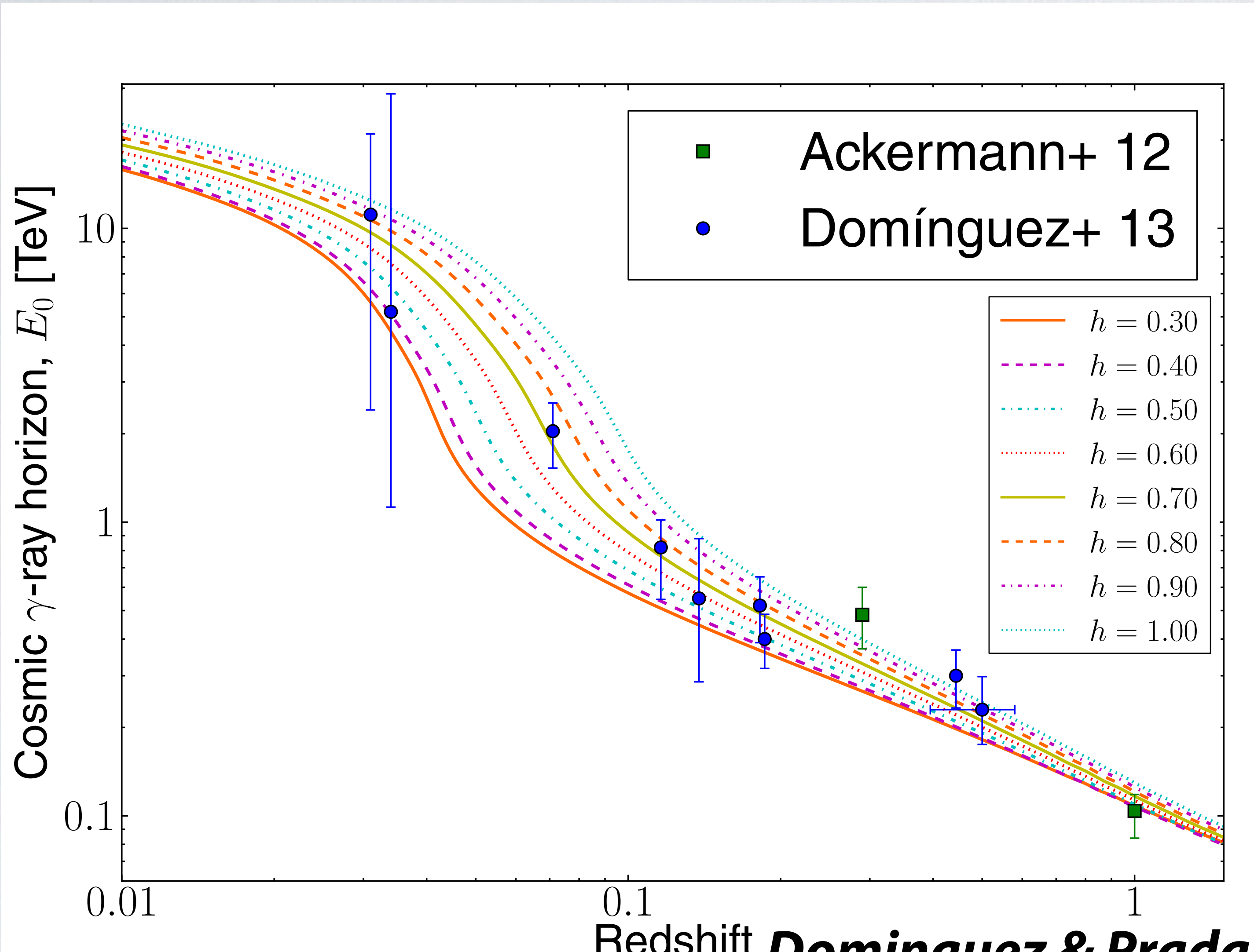
Lightcurve



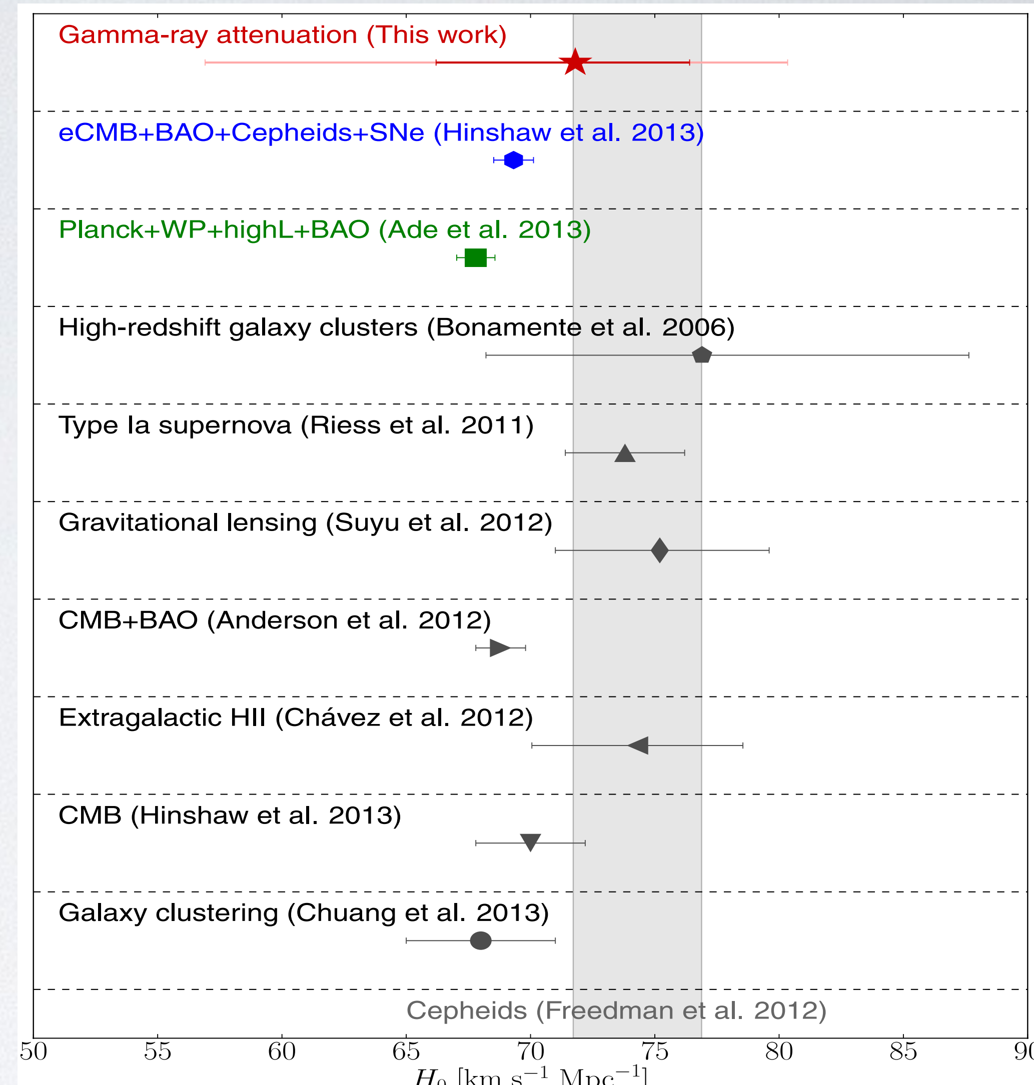
Takahashi+'12

- Intergalactic magnetic field can be constrained by the secondary emission (e.g. Plaga '95, Fan+'04, Ichiki+'08, Murase+'08)
- $B > 10^{-18}$ G (spectrum; Dermer+'11), $B > 10^{-20}$ G (light curve; Takahashi +'12)

Dark Energy & Gamma rays?



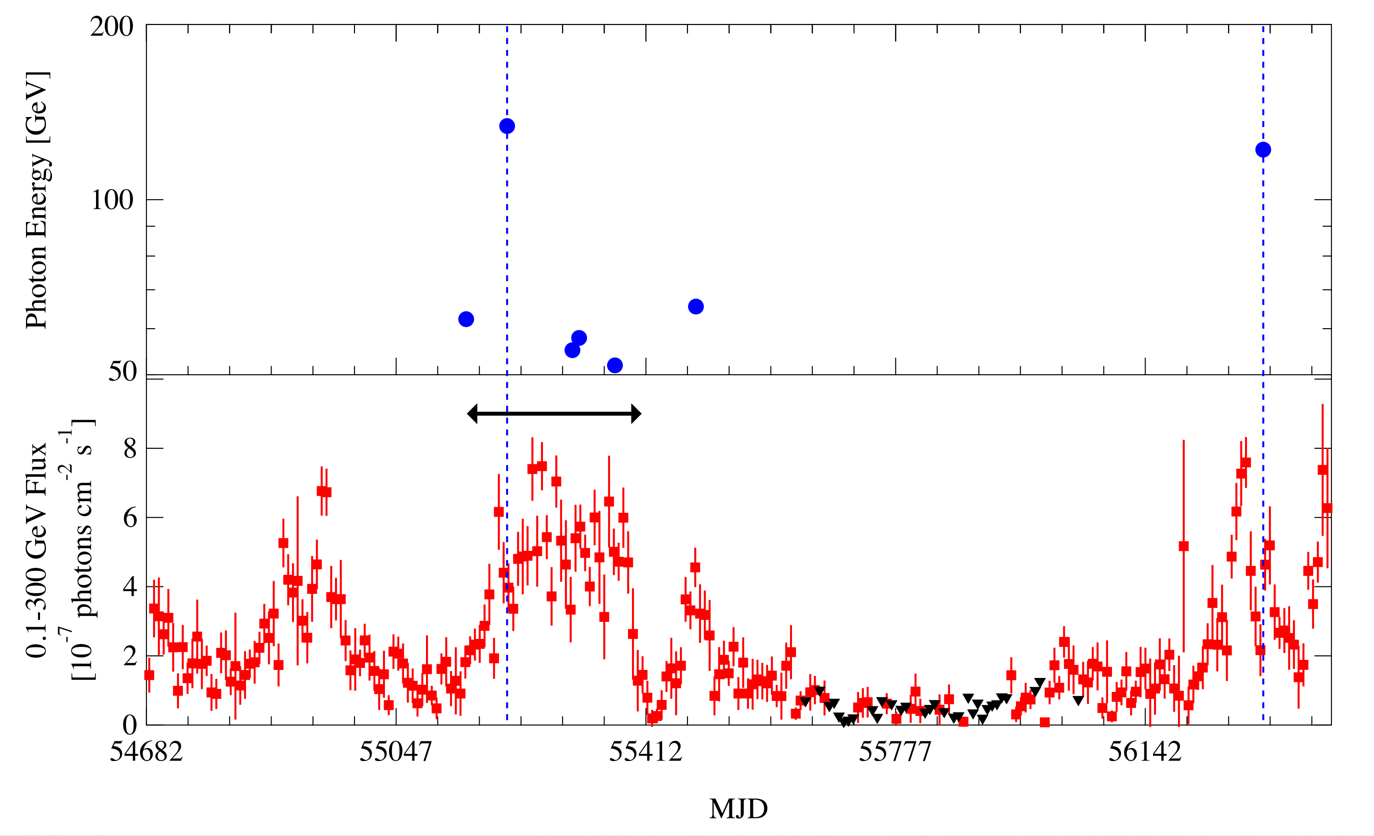
Dominguez & Prada '13

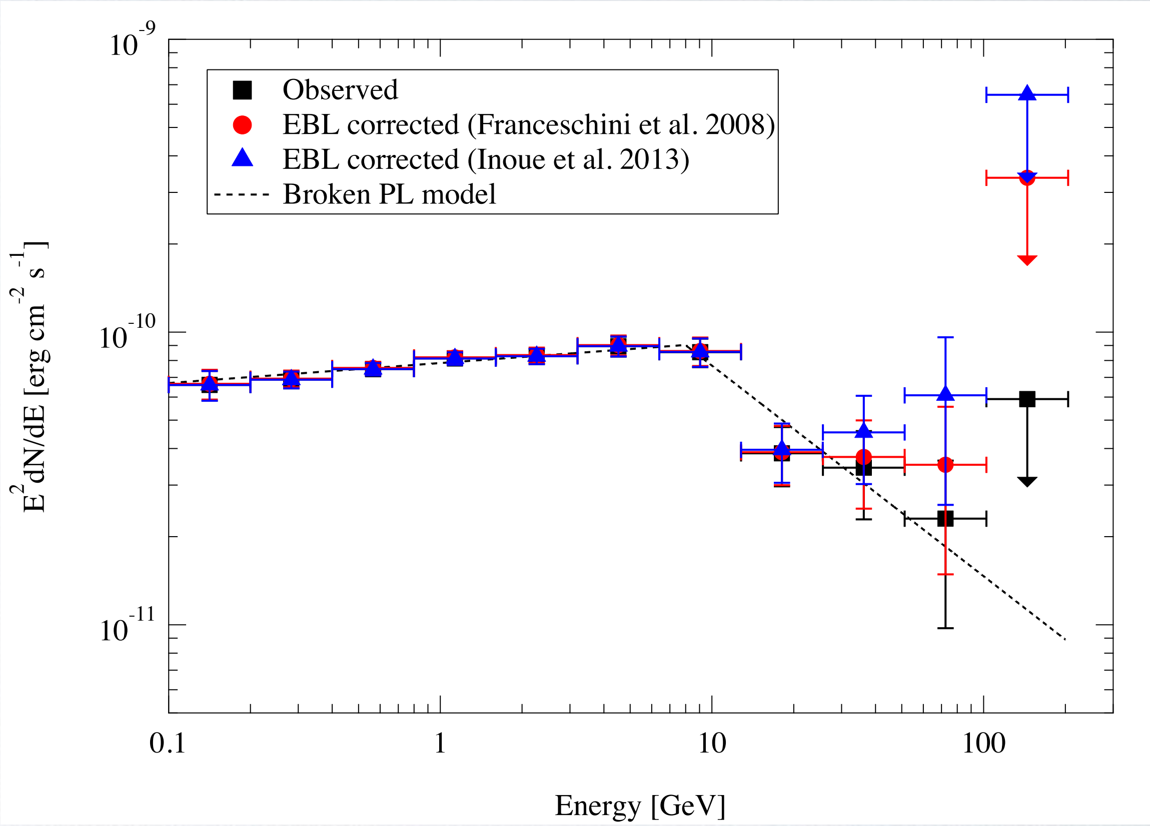


Dominguez & Prada '13

- Derive the cosmic expansion rate using gamma-ray horizon.
- Future data may allow to constrain cosmological parameters.

Two VHE (>100 GeV) gamma rays from PKS 0426-380 at z=1.1

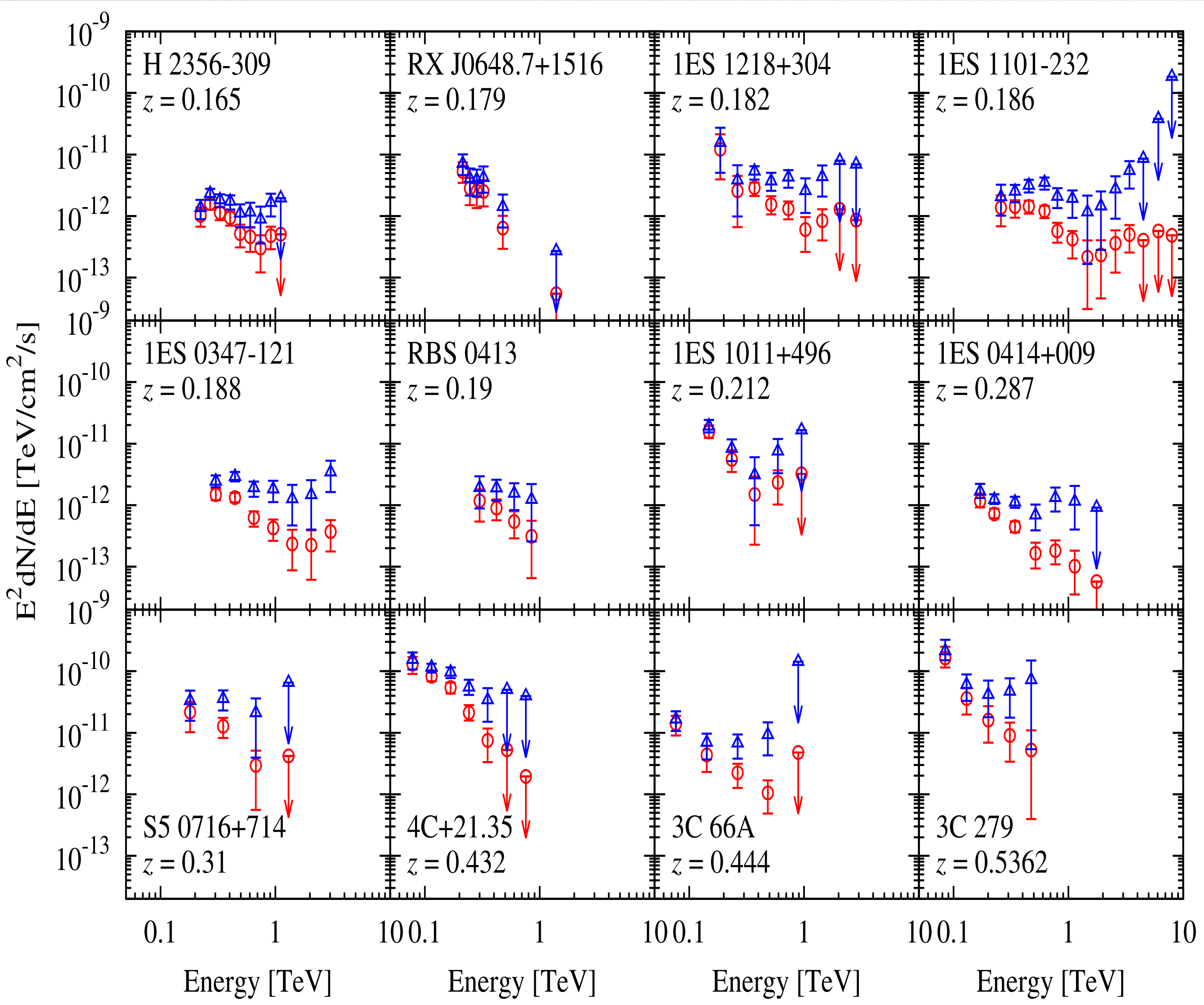




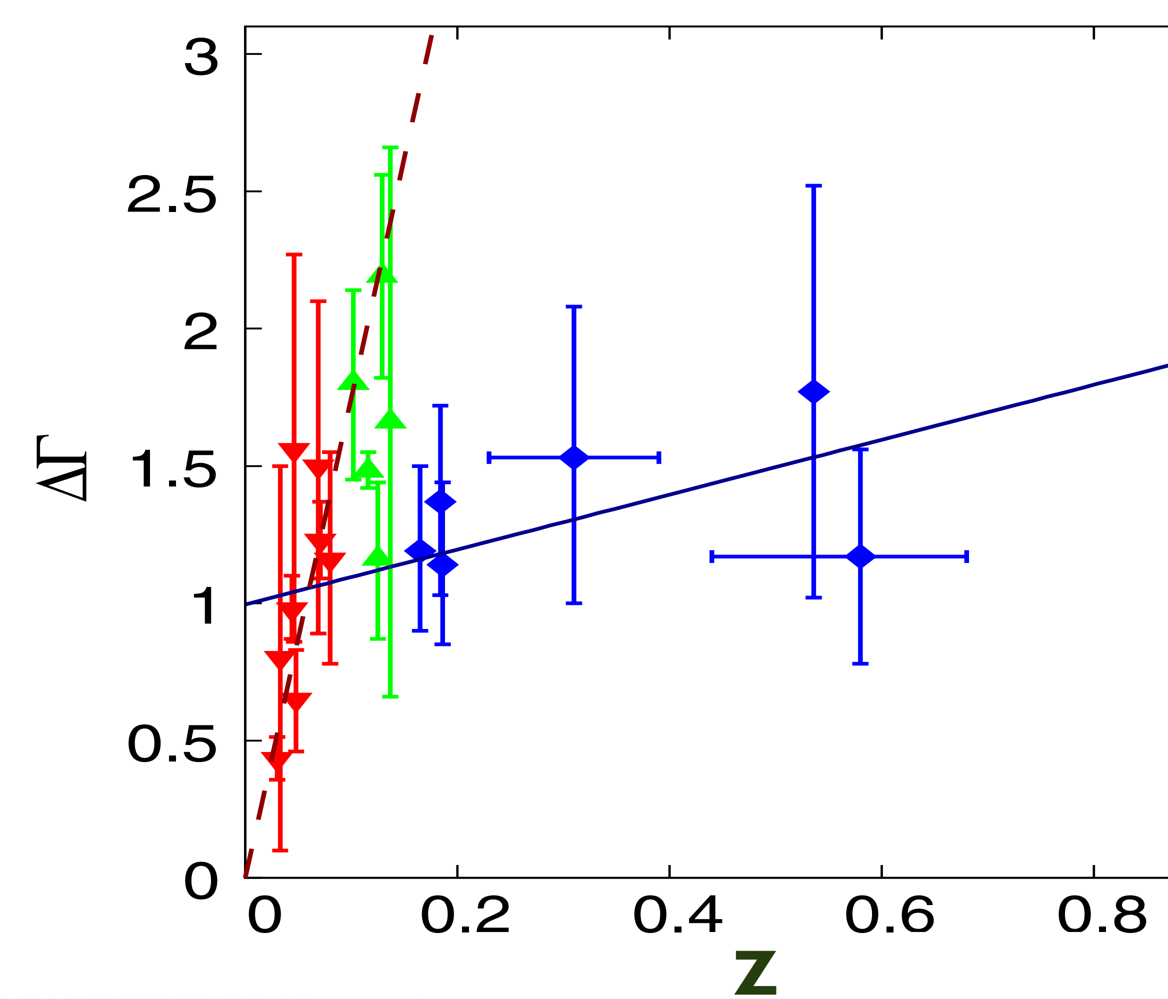
Tanaka, YI, +'13

- 2 VHE photons at flaring states, but not an exact correspondence to the peak of each flare.
- Spectral hardening from ~30 GeV.

Is VHE Spectral Hardening Universal?



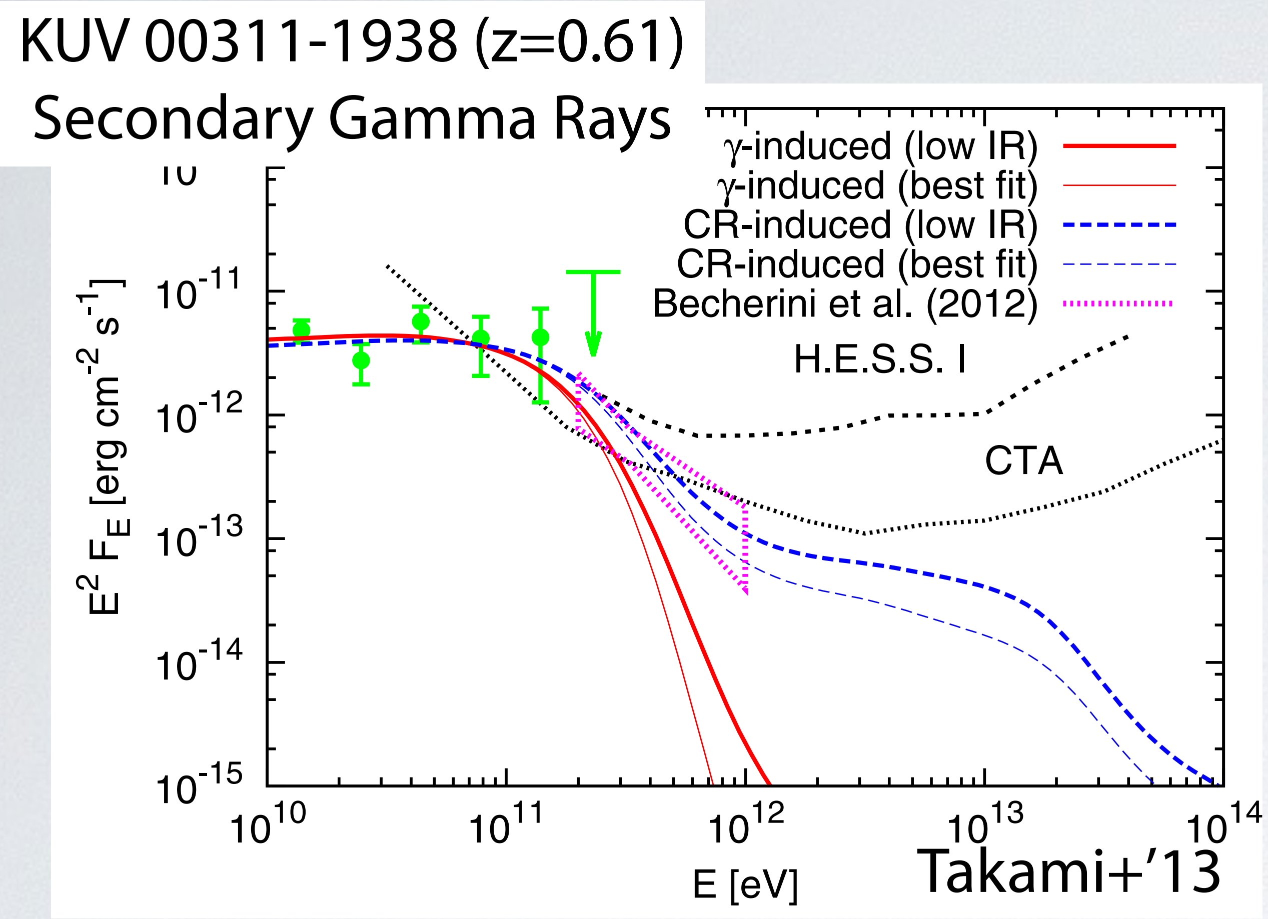
Yl+'13a

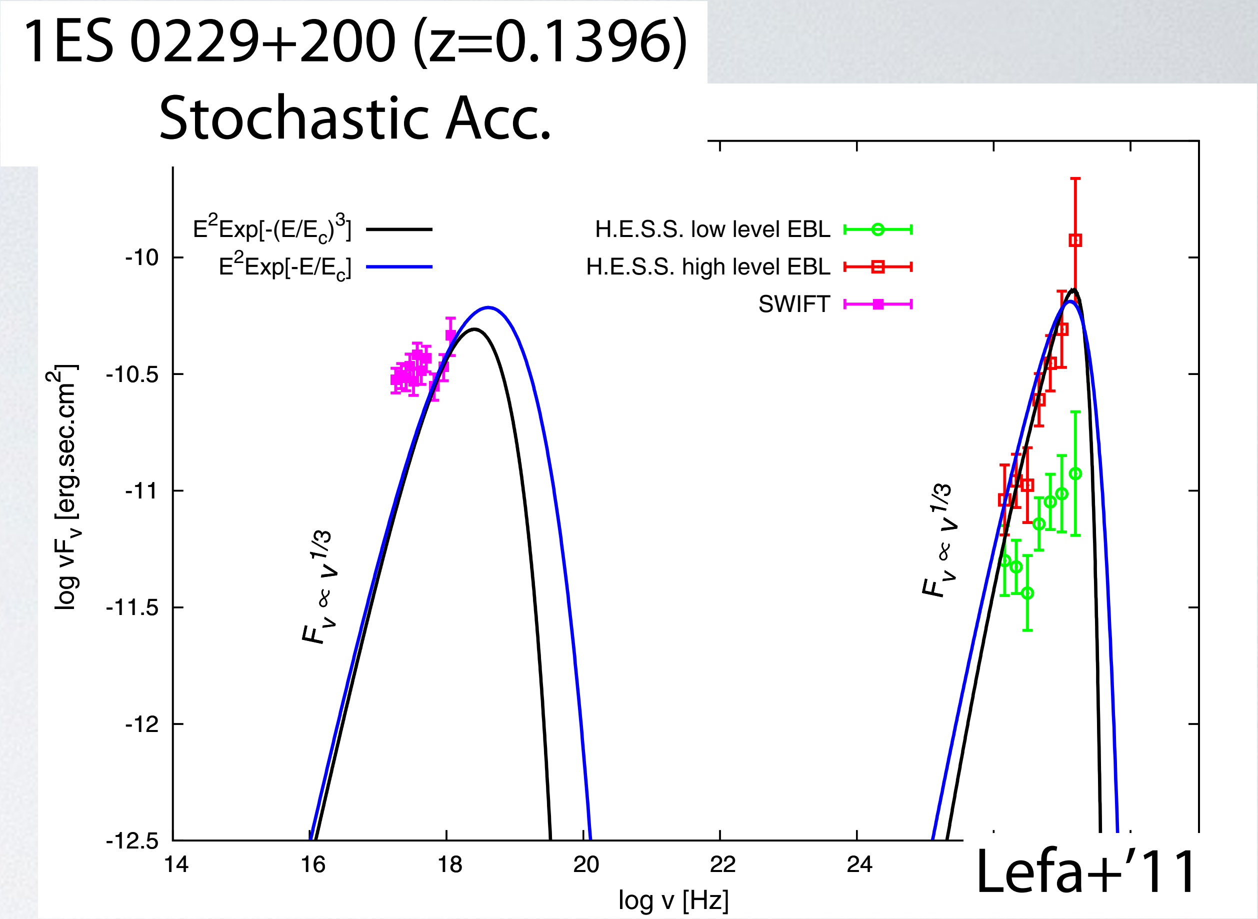


Essey & Kusenko '12

- Spectra of blazars at z > 0.15 show hardening from a few hundred GeV.

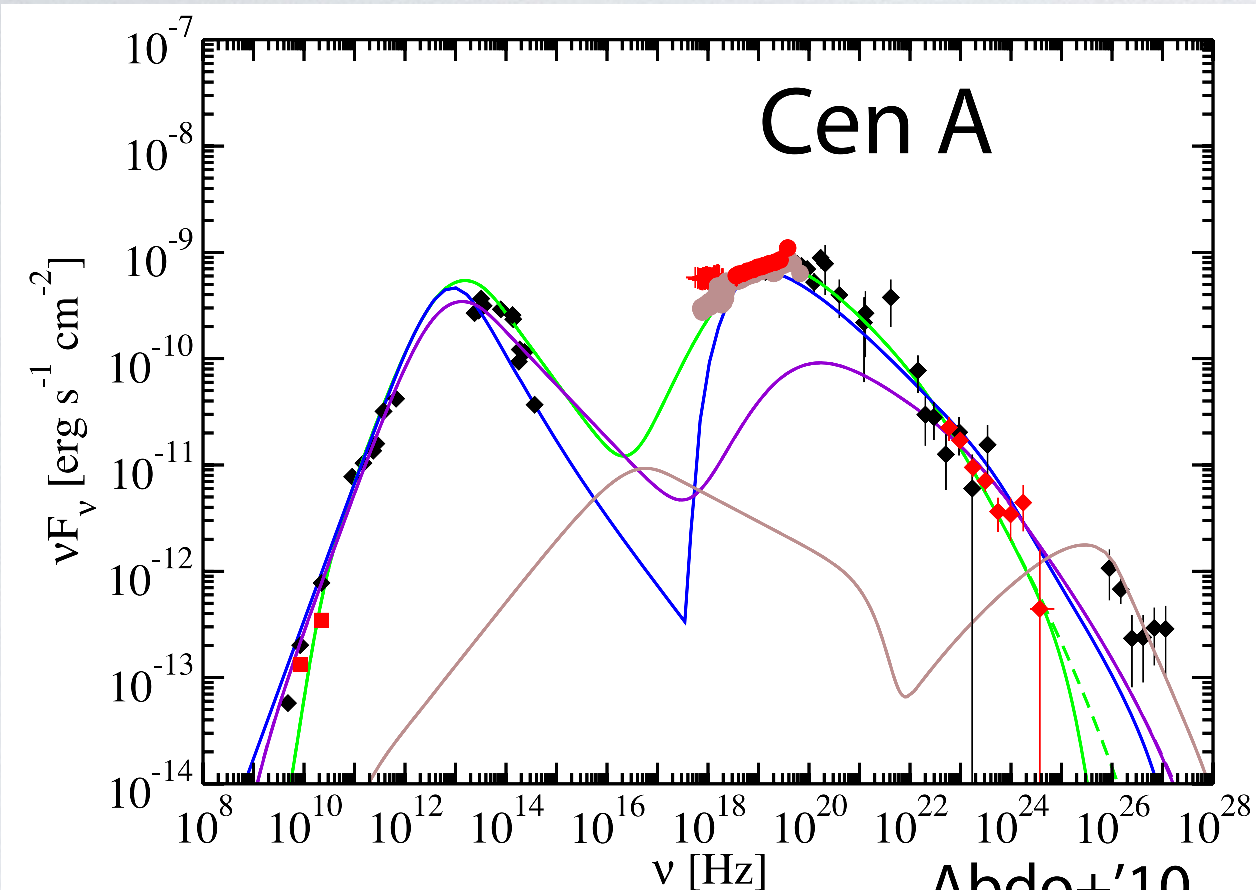
Secondary Gamma Rays? Stochastic Acceleration?



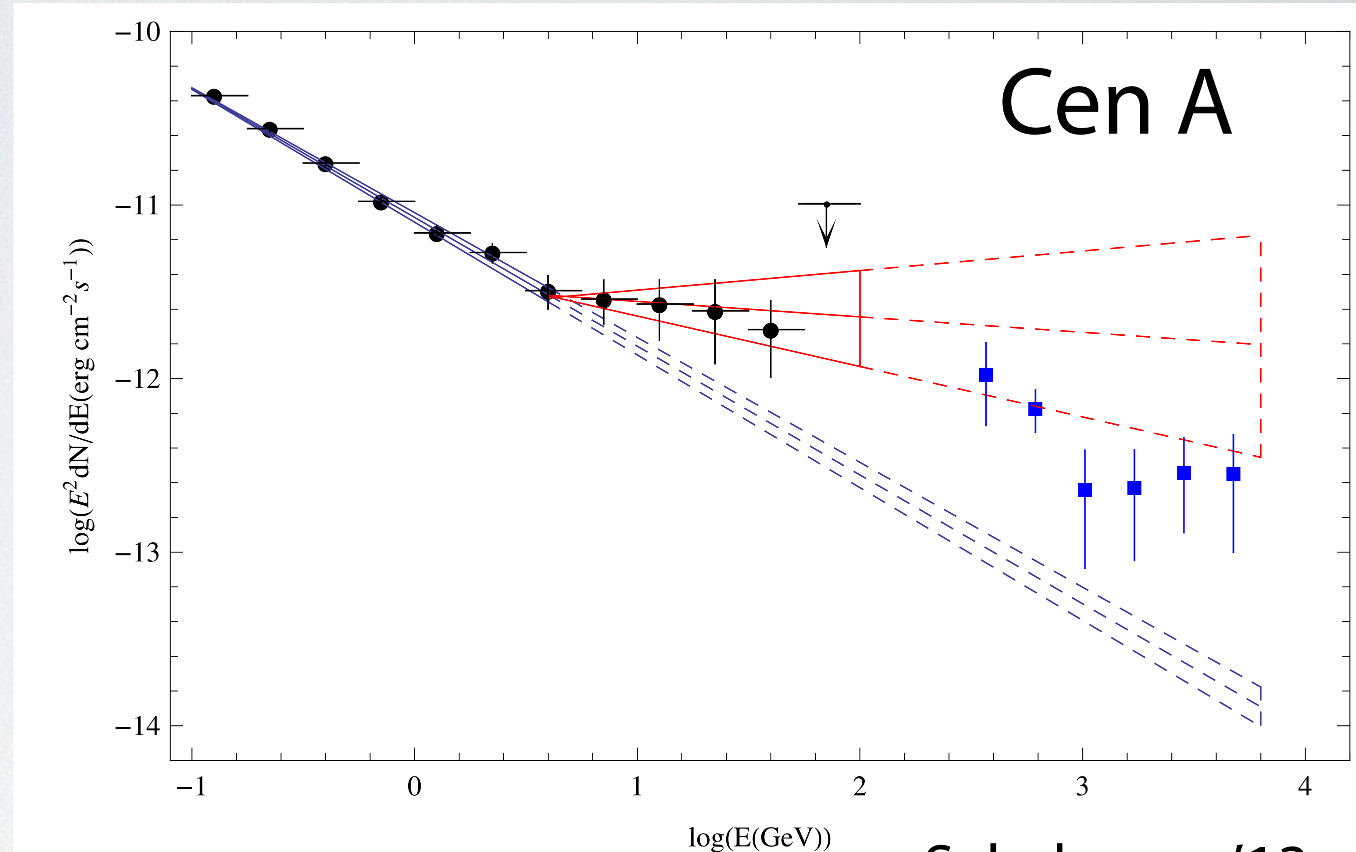


- Secondary gamma rays from cosmic rays along line of sight (Essey & Kusenko '10, Essey+'10, Essey+'11, Murase+'12, Takami+'13,YI+'14).
- Stochastic (2nd-order Fermi) acceleration (Stawarz & Petrosian '08, Lefa+'11).
- Lepto-hadronic emission (Cerruti+'14).

Another component in radio galaxies



Abdo+'10

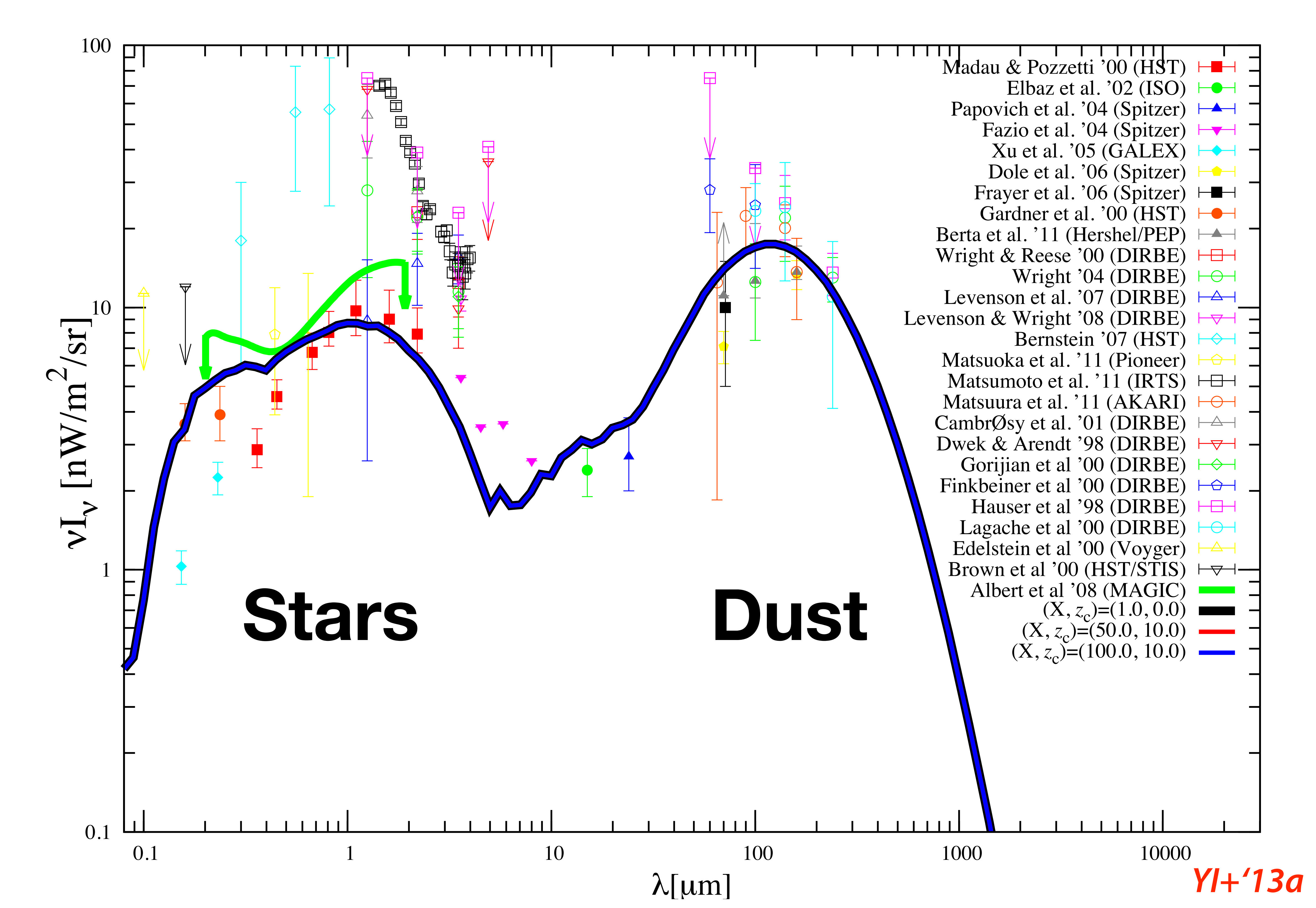


Sahakyan +'13

- Spectral hardening from ~4 GeV (Sahakyan+'13).
  - BH magnetosphere? multi components? hadronic? knots? cascade in torus? IC of host galaxy starlight?

COB/CIB from galaxies

Cosmic Optical & Infrared Background (COB & CIB)



Yl+'13a

Galaxy formation is complicating.

- Non-linear physics
- Many physical processes
  - gas cooling/heating, star formation, metal enrichment, mergers, dust formation, radiation transfer
- Different scales
  - Dark matter merger tree (cosmological scale) <-> star formation (galaxy scale)

Galaxy Formation Model

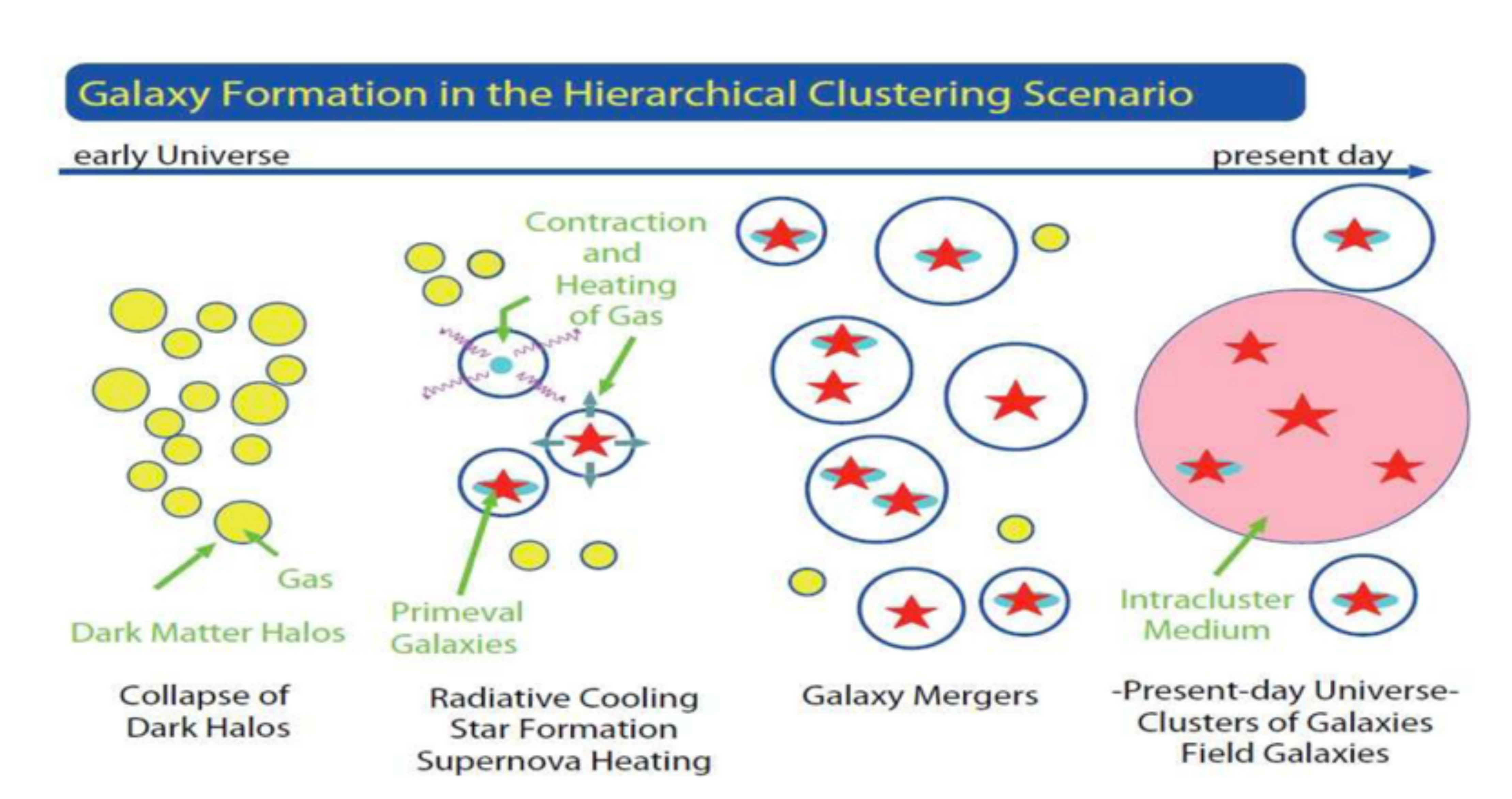
- Analytical Method
  - e.g. use DM halo function @ each z and Mass-luminosity relation -> galaxy luminosity function
- Semi-analytical Method
  - DM halo function based on the N-body simulation (or its fitting function)
  - Phenomenological models for baryon physics
- Numerical Simulation
  - Full-numerical calculation in given simulation boxes.
  - Number of particles is limited. -> particle mass is huge.

EBL models

Type of modeling and refs.	Galaxy number evolution	Galaxy emission
Type i, Forward evolution (Somerville+ 12; Gilmore+ 12; Inoue+ 13)	**Semi-analytical models**.	**Modeled**. Stars: Bruzual & Charlot 03 (BC03); Dust Absorption: Charlot & Fall, 00; Dust Re-emission: Rieke+ 09.
Type ii, Backward evolution (Franceschini+ 08)	**Observed** local-optical galaxy luminosity functions (starburst population) and near-IR galaxy luminosity functions up to z=1.4 (elliptical and spiral populations)	**Modeled**. Consider only a few galaxy types based on optical images.
Type iii, Inferred evolution (Finke+ 10; Kneiske & Dole 10)	**Parameterization** of the history of the star formation density of the universe. By construction, they do not include quiescent and AGN galaxies.	**Modeled**. Stars: Single bursts of solar metallicity from BC99 (Kneiske+)/BC03 (Finke+); Dust Absorption: General extinction law; Dust Re-emission: Modified black bodies.
Type iv, Observed evolution (Domínguez+ 11; Stecker+ 12; Helgason+ 12)	**Observed** near-IR galaxy luminosity functions up to z=4.	**Observed**. Multiwavelength photometry from the UV up to MIPS 24 for ~6000 galaxies up to z=1. Consider 25 different galaxy types.

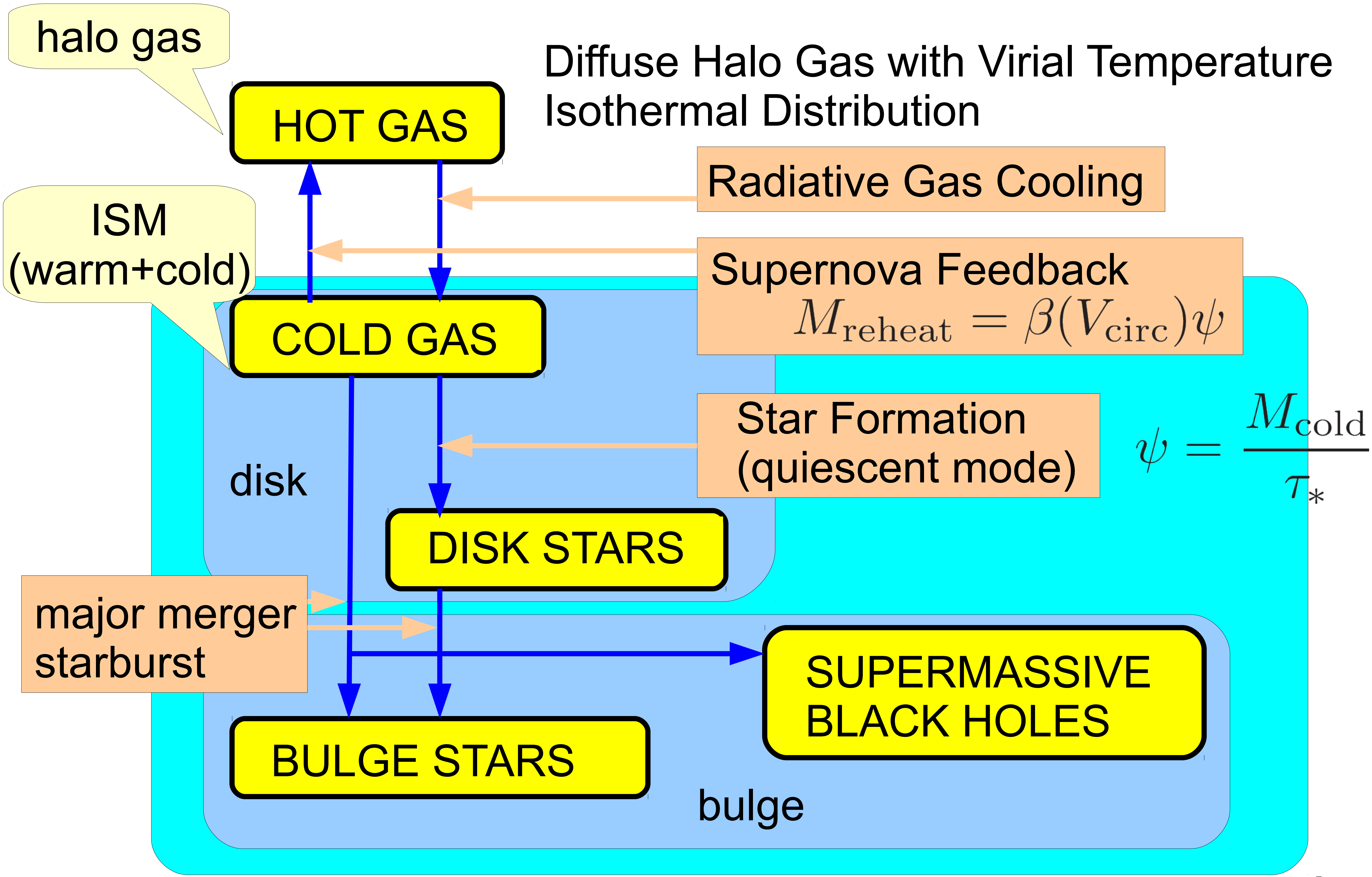
Hierarchical Galaxy Formation

- semi-analytical EBL models (e.g. Gilmore+'09, Younger & Hopkins '11, Gilmore +'12, Somerville+'12, ***YI+'13***)
  - artificially set parameters to reproduce observed data sets.

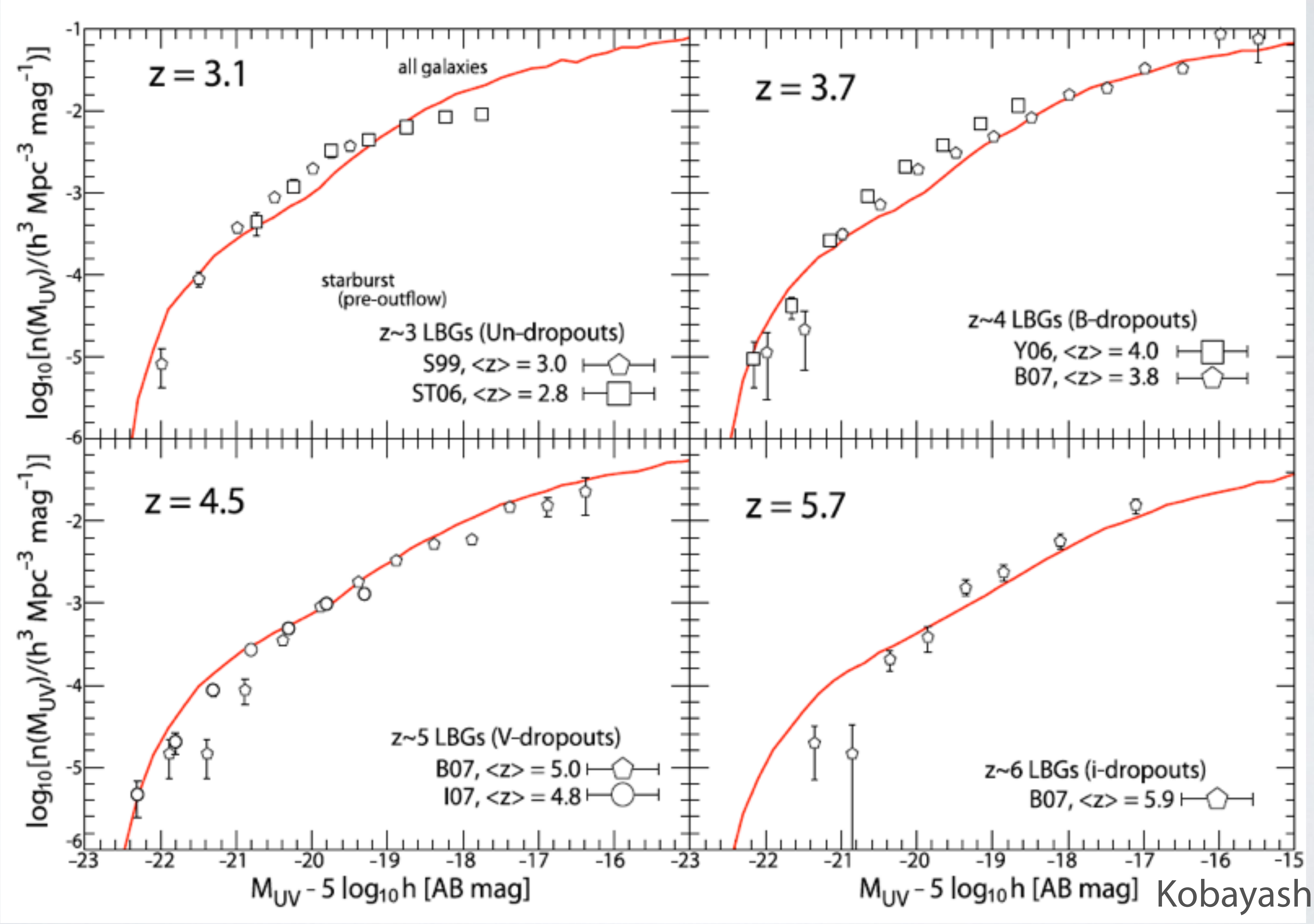


M. Nagashima

Evolutionary Cycle of Baryons

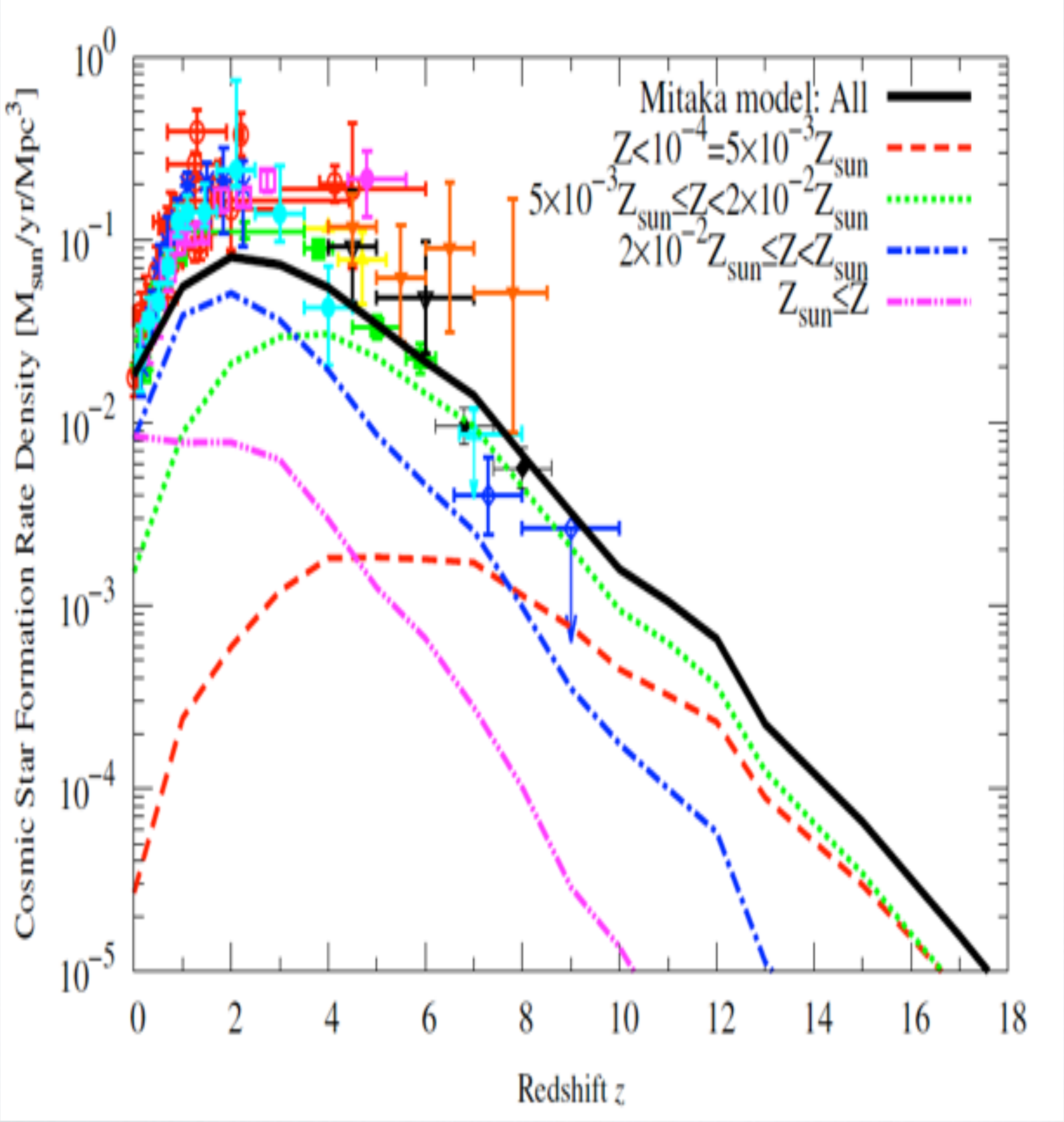


Comparison of a semi-analytical model with UV LF at z<6



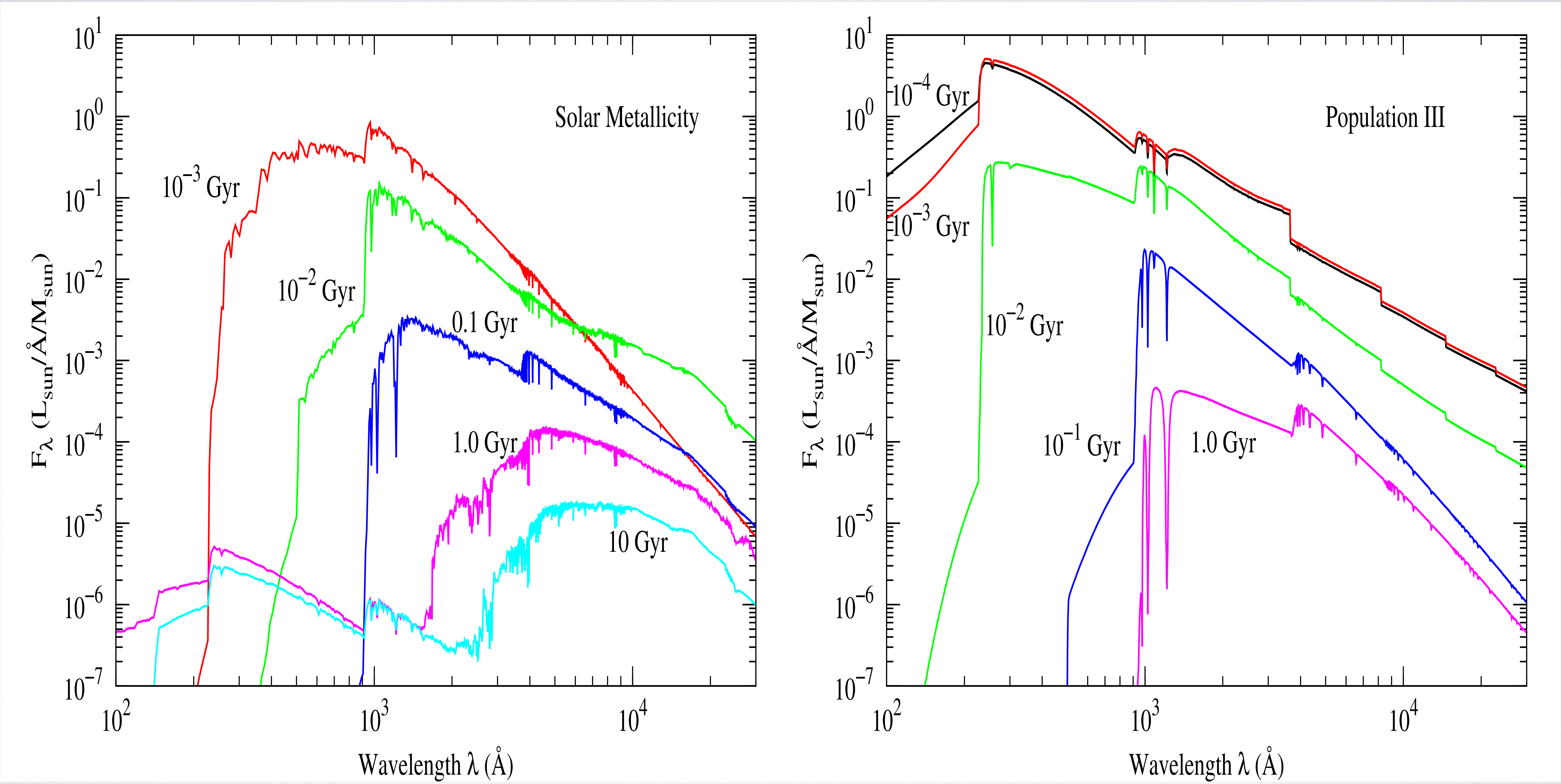
Kobayashi+'10

Cosmic Star Formation History



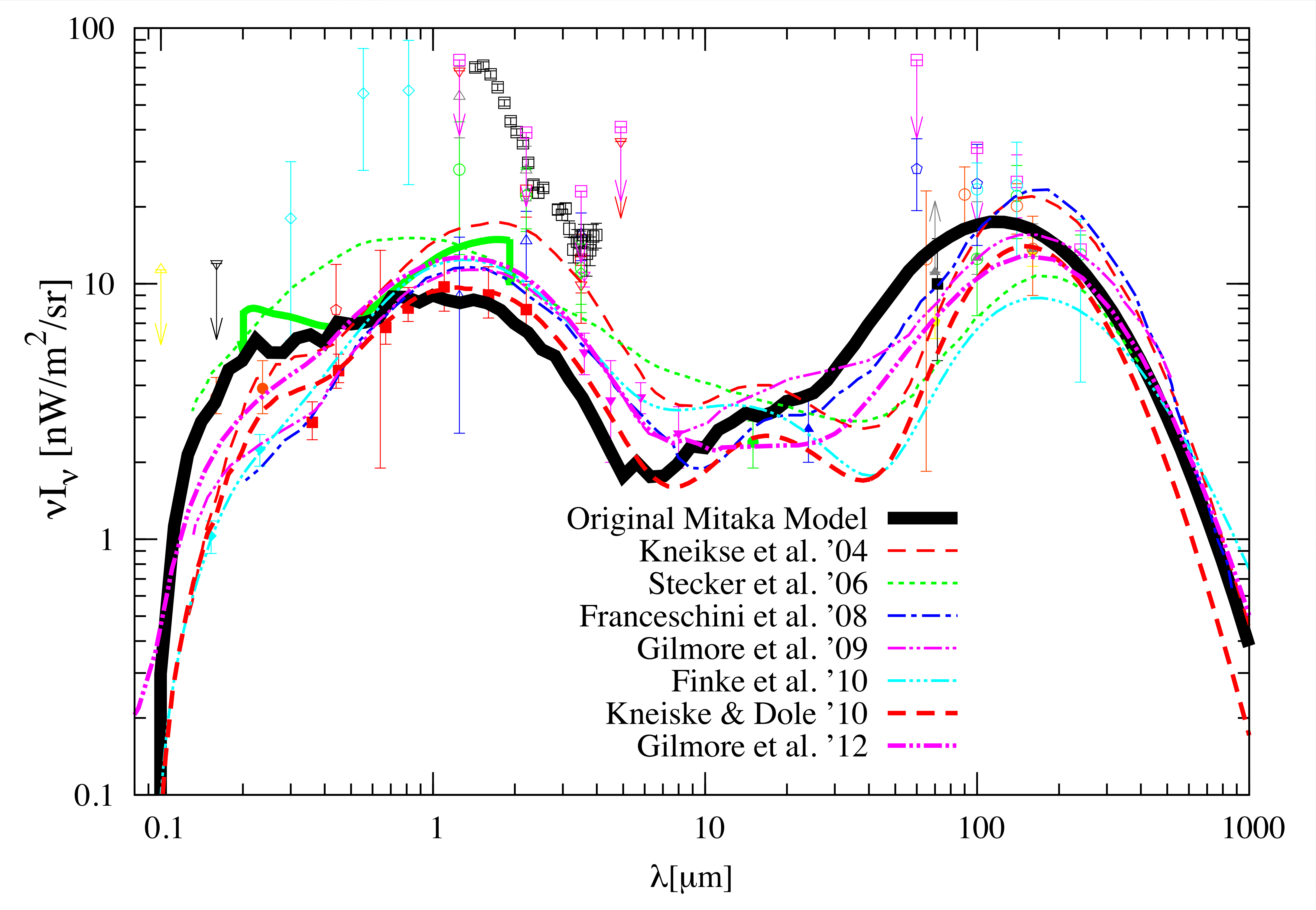
- Salpeter initial mass function for 0.1-60 $M_{\odot}$
- $Z<10^{-4}$ (Pop-III) are included.
- stellar population synthesis (SED) models:
    - Bruzual & Charlot '03 for Pop-I, II stars
    - Schaerer '03 for Pop-III stars

Stellar Population Synthesis Models



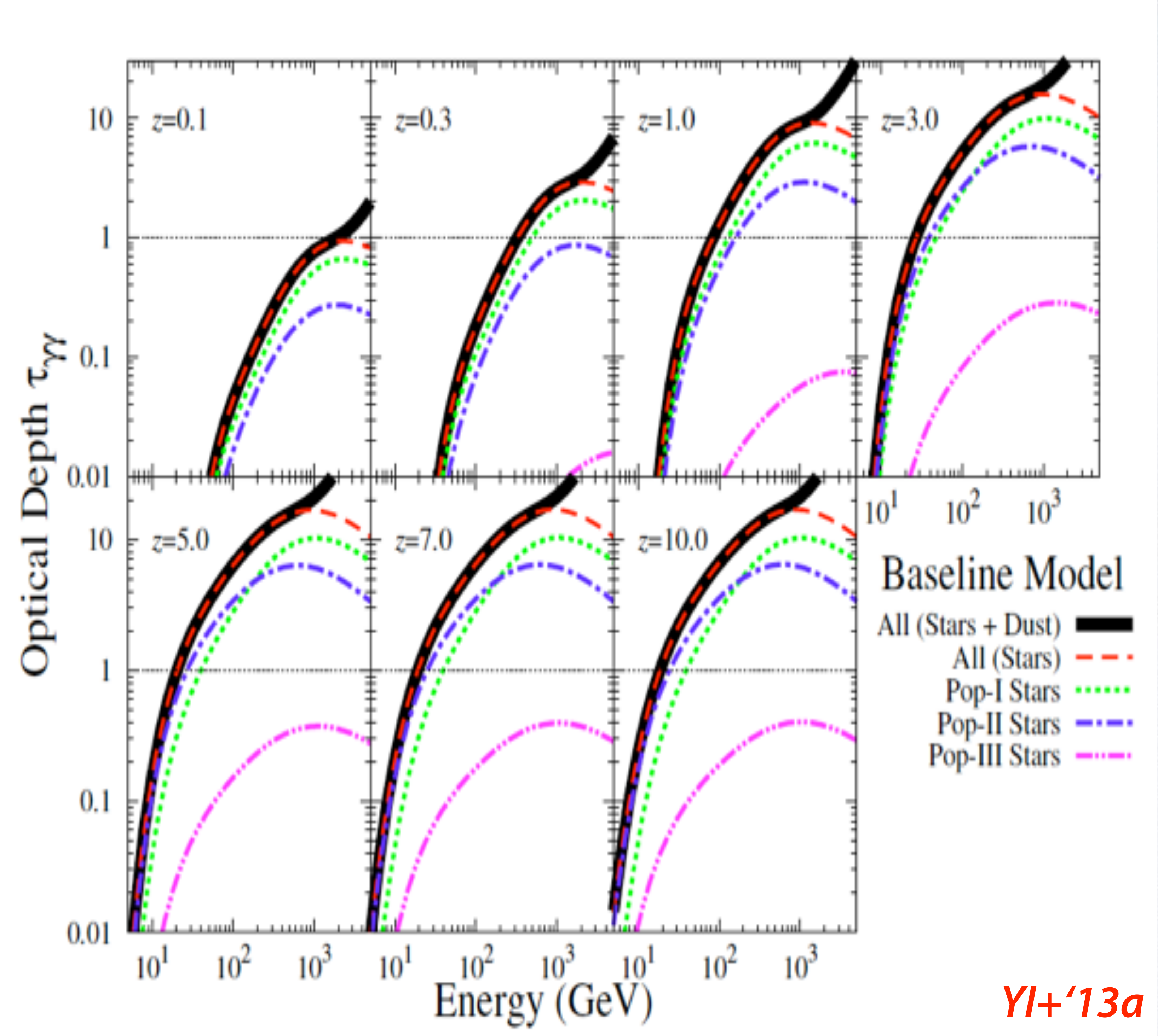
- Bruzual & Charlot ’03 ($Z > 10^{-4} = 0.005 \times Z_{sun}$)
- Schaerer ’03 ($Z < 10^{-4}$)

Cosmic Optical/Infrared Background @ z = 0



- Consistent with the available galaxy count data.

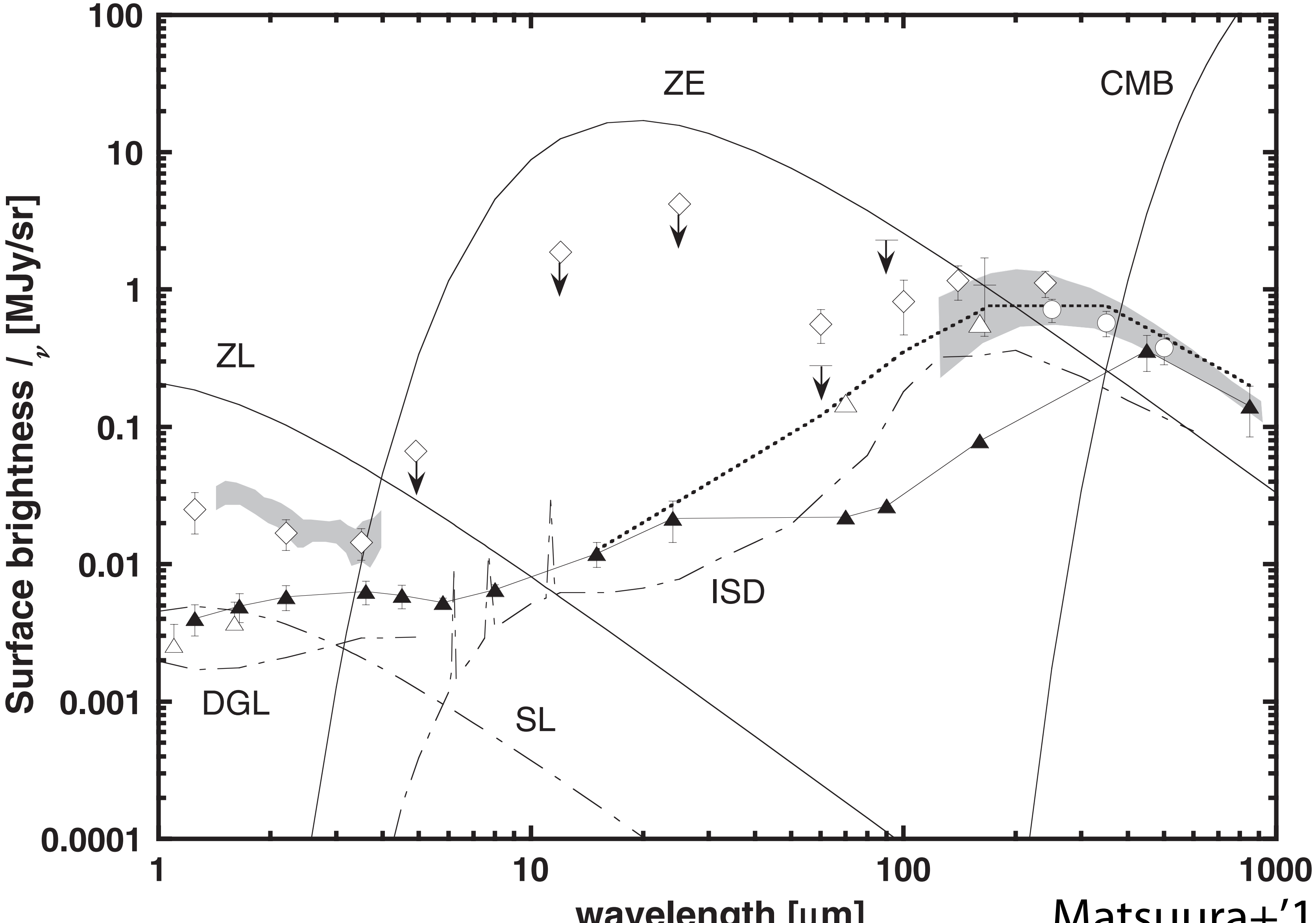
Gamma-ray Opacity



- Opacity is dominated by Pop-I & Pop-II stars.

Direct COB/CIB Measurement

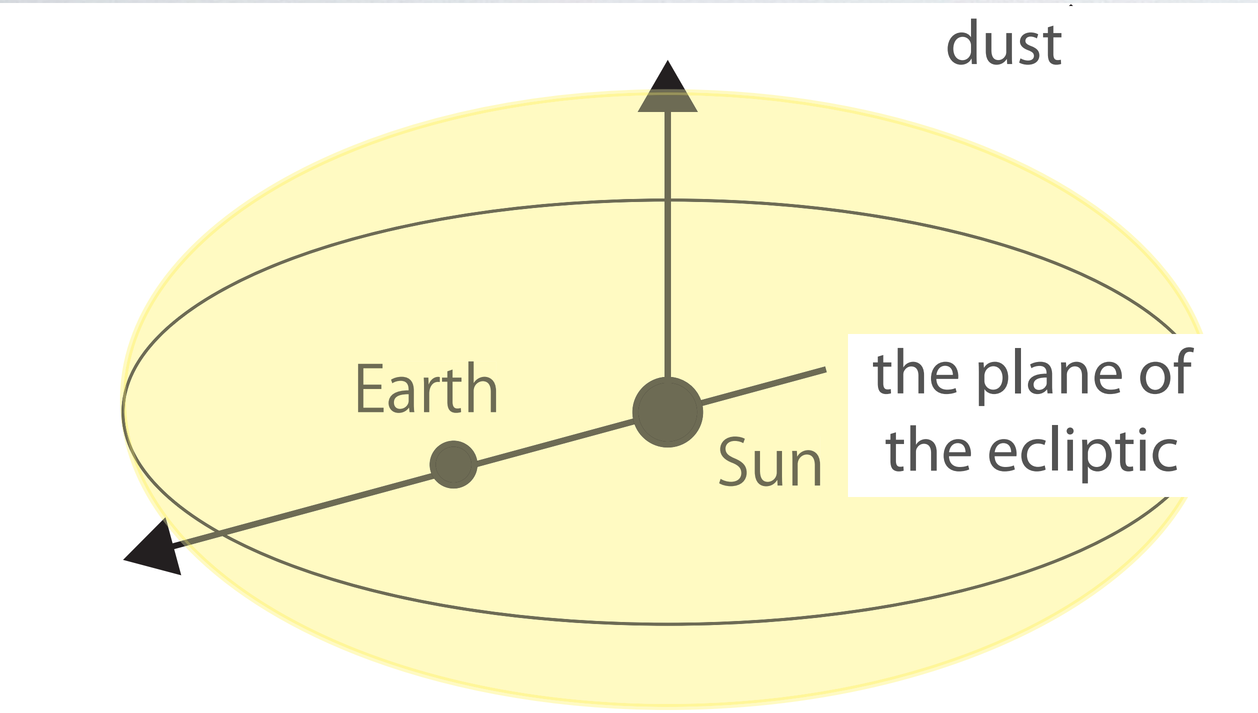
Direct Measurement of EBL

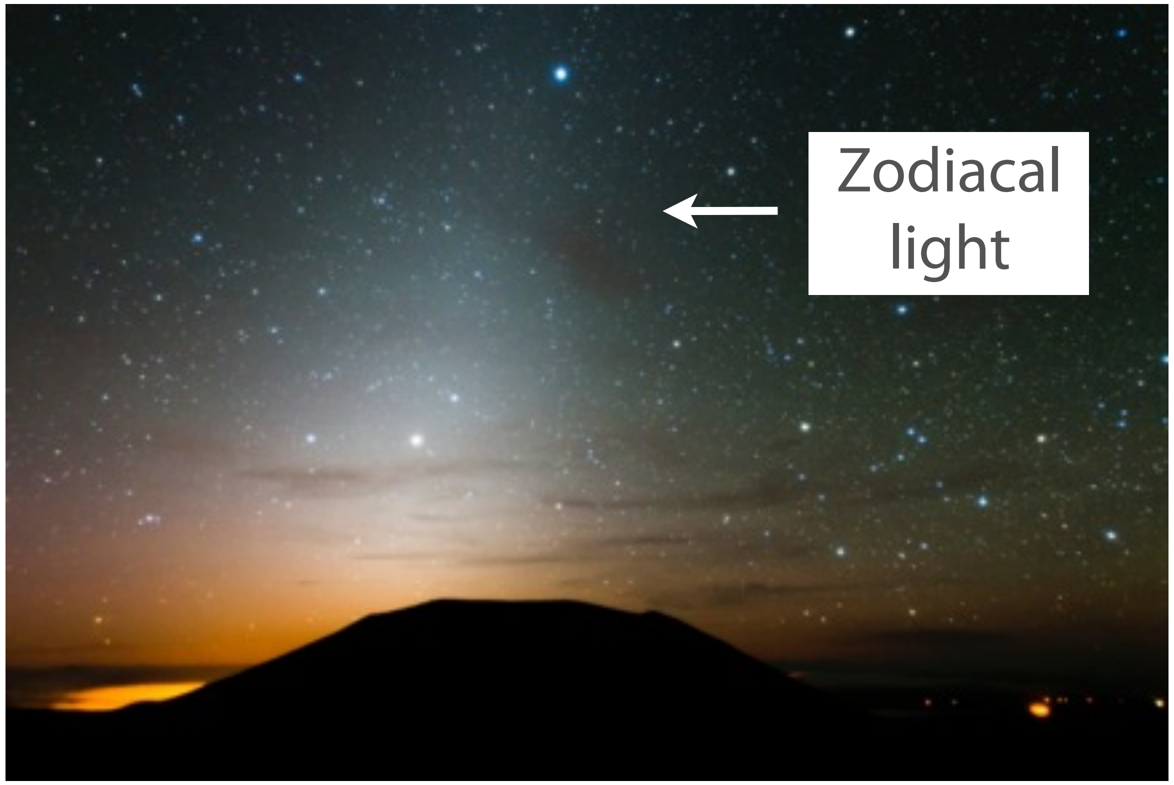


Matsuura+’11

- Foreground: Zodiacal light, Diffuse galactic light, Star light.

Zodiacal Light

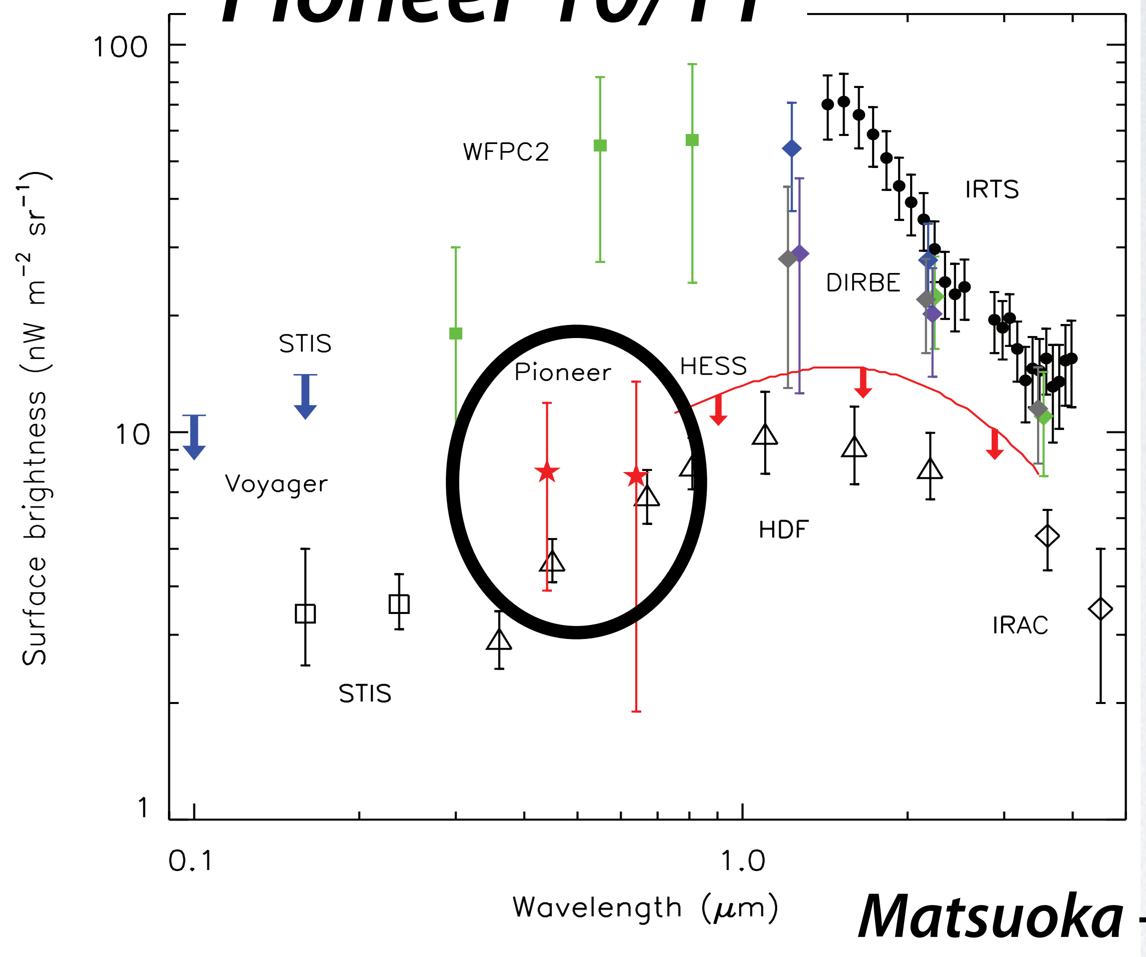




- Scattered solar emission by interplanetary dust (NIR)
  - polarized
- Interplanetary dust distribute around the plane of the ecliptic
- Brightest foreground emission for the COB/CIB measurement

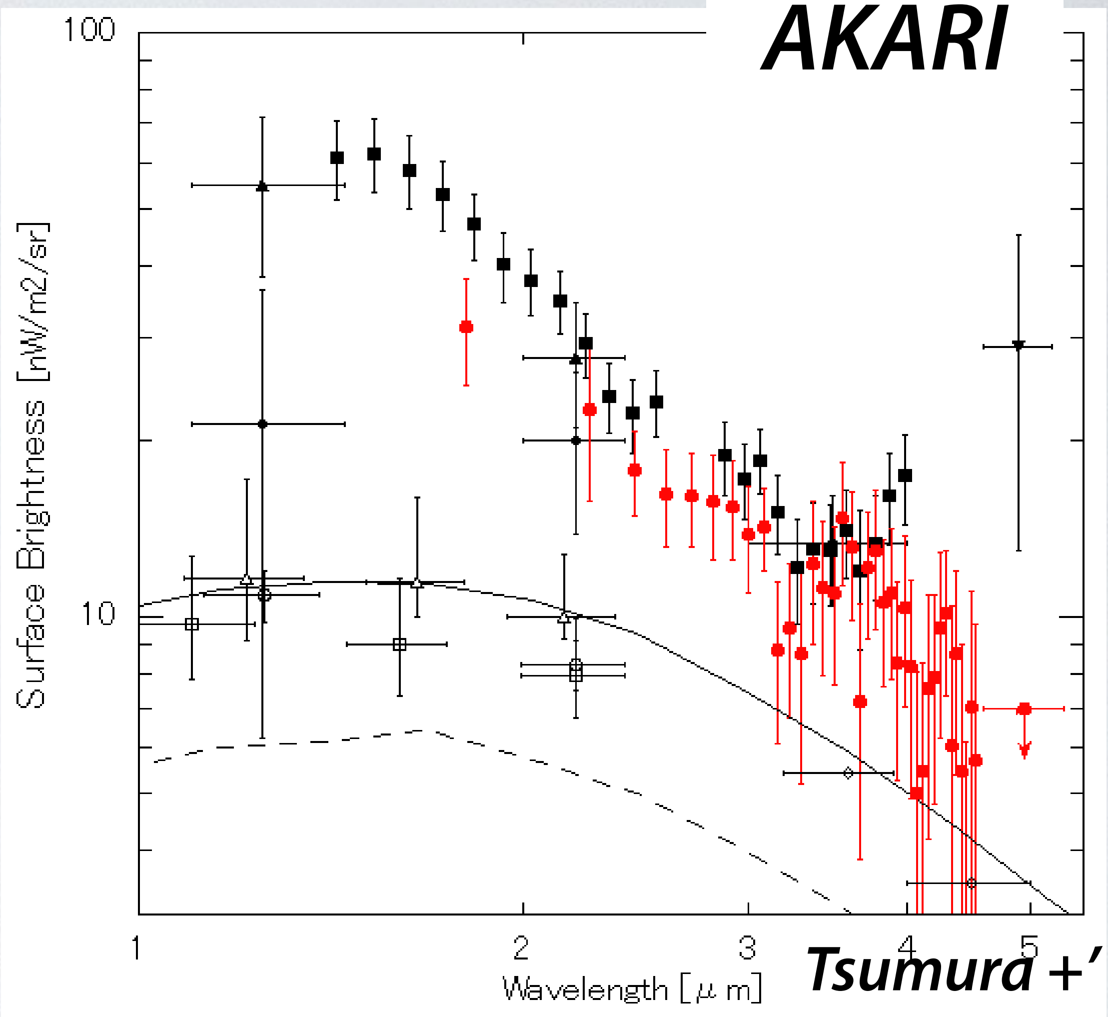
Direct Measurements of COB & CIB

Pioneer 10/11



Matsuoka +'11

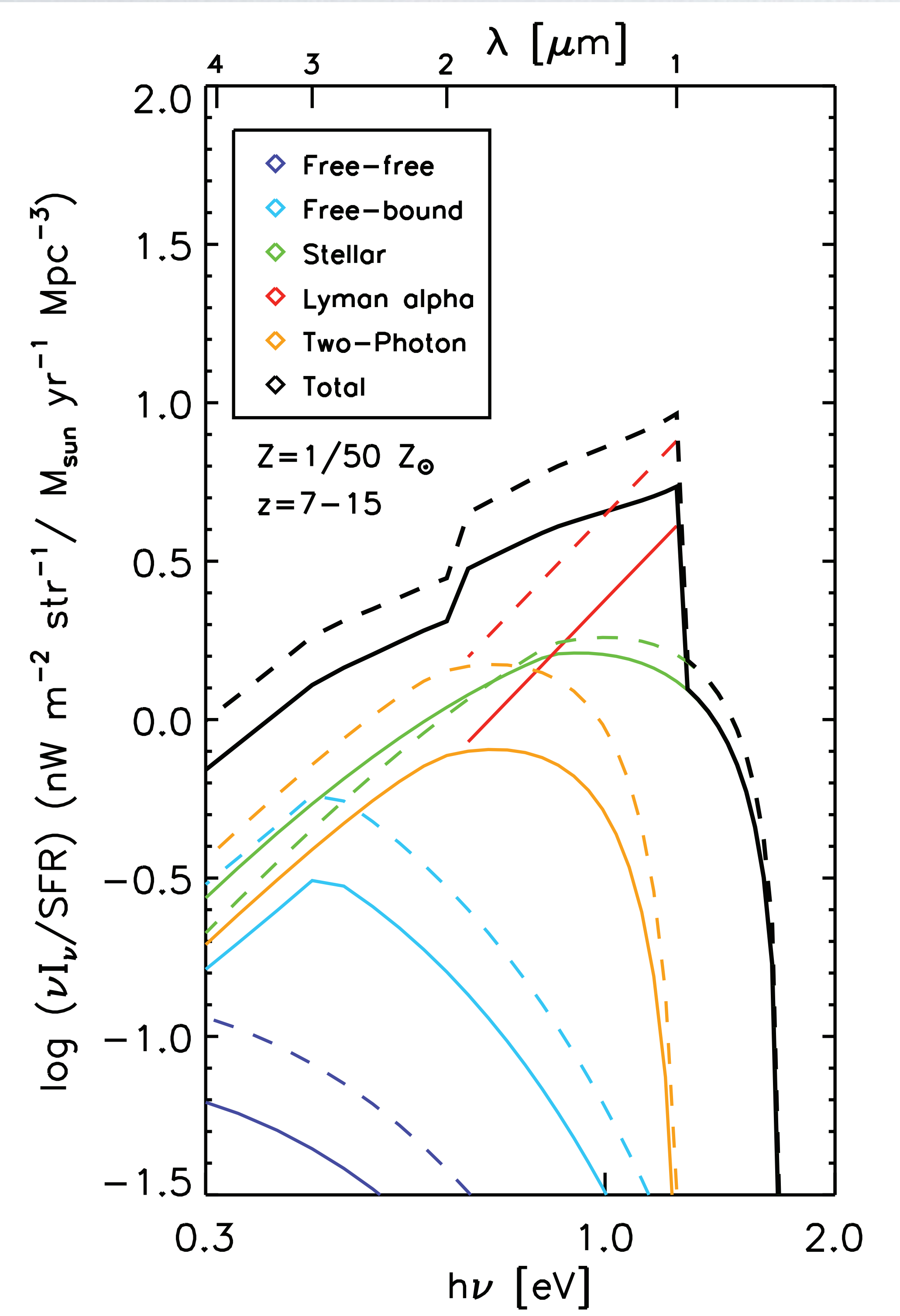
AKARI



Tsumura +'13

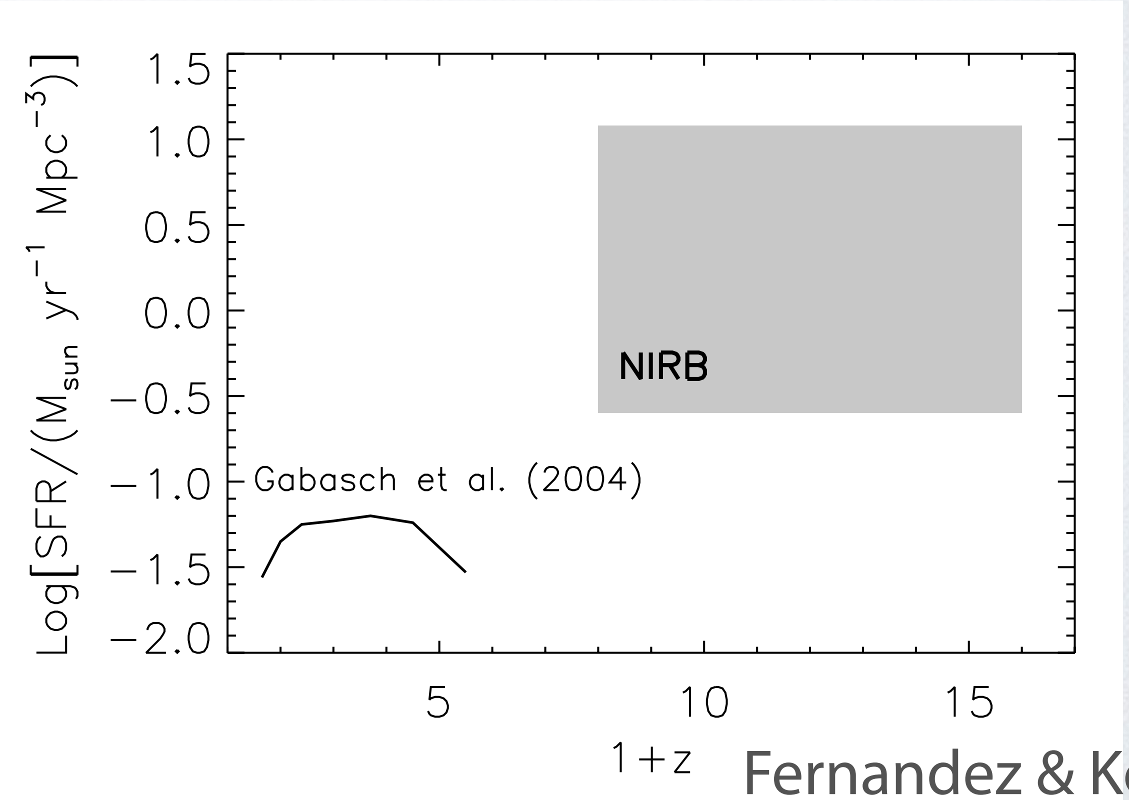
- Pioneer 10/11 measurements are consistent with the galaxy count lower limit.
- But, recent AKARI measurement is consistent with IRTS.
  - Peak at near infrared?

First stars ?



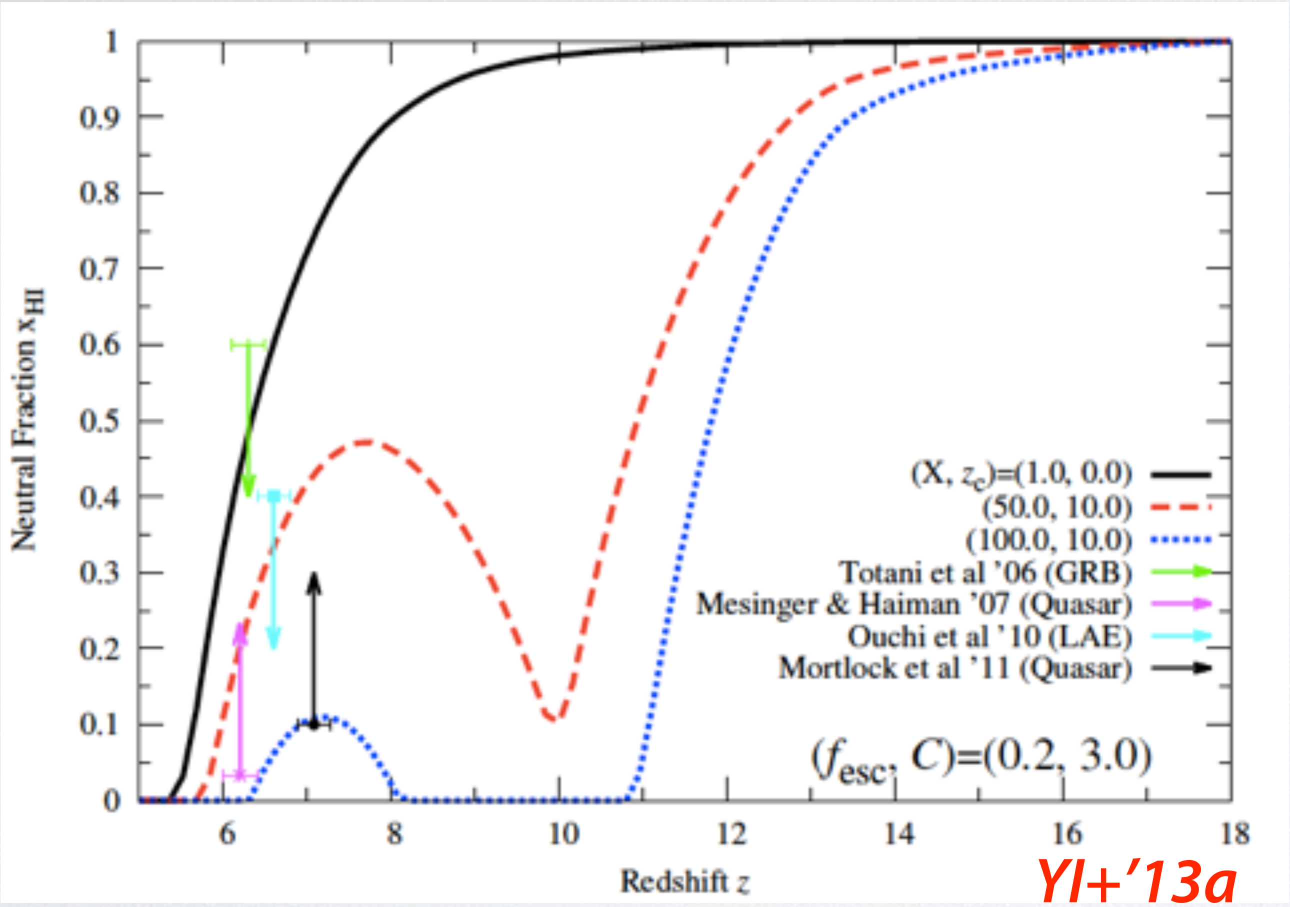
Fernandez & Komatsu '06

- Lyman alpha photons from z~10 will redshifted to ~1 um at z=0.
- We might see the light for first stars.
- But, we need very high first star formation rate density.

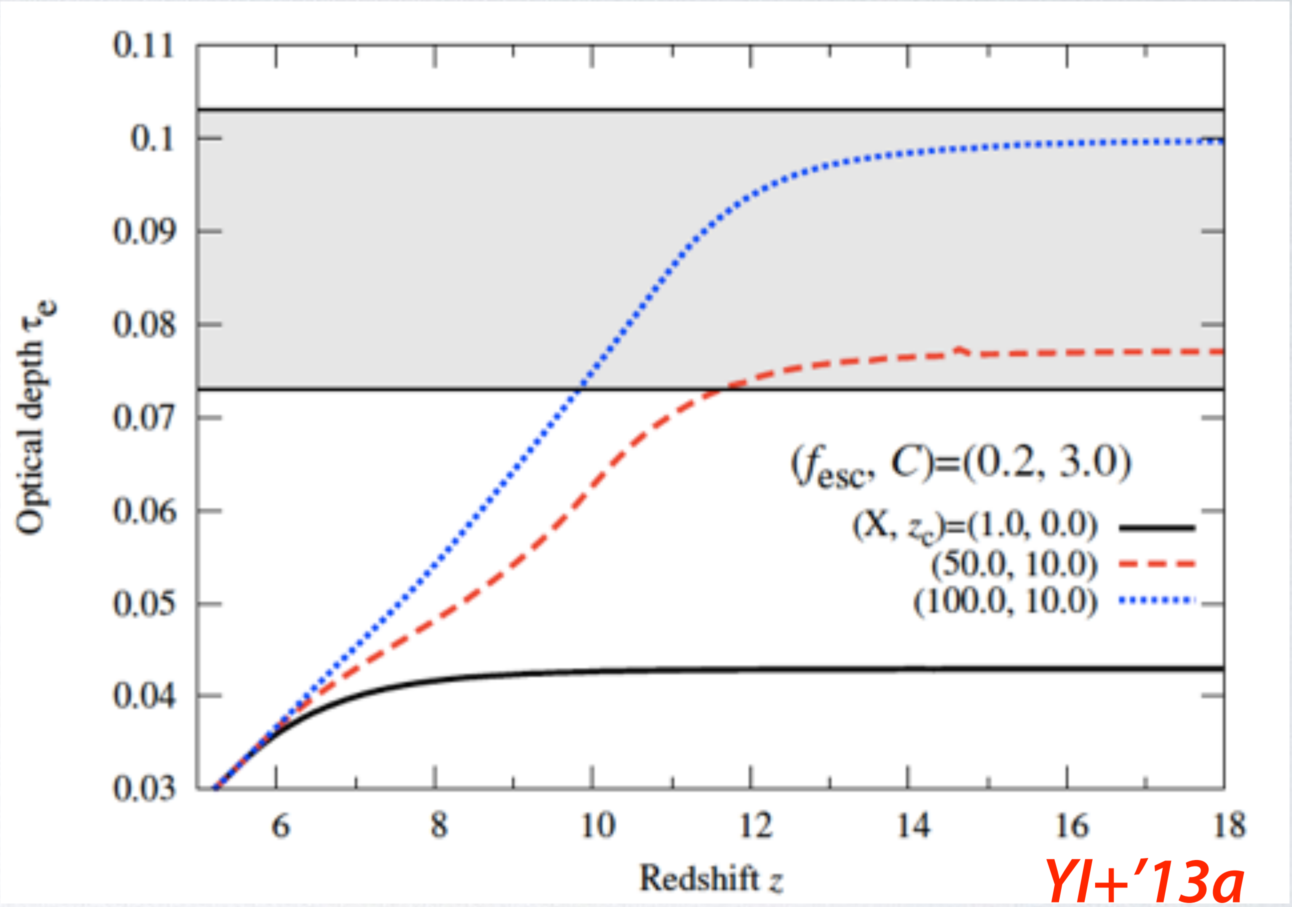


Fernandez & Komatsu '06

Reionization Constraints



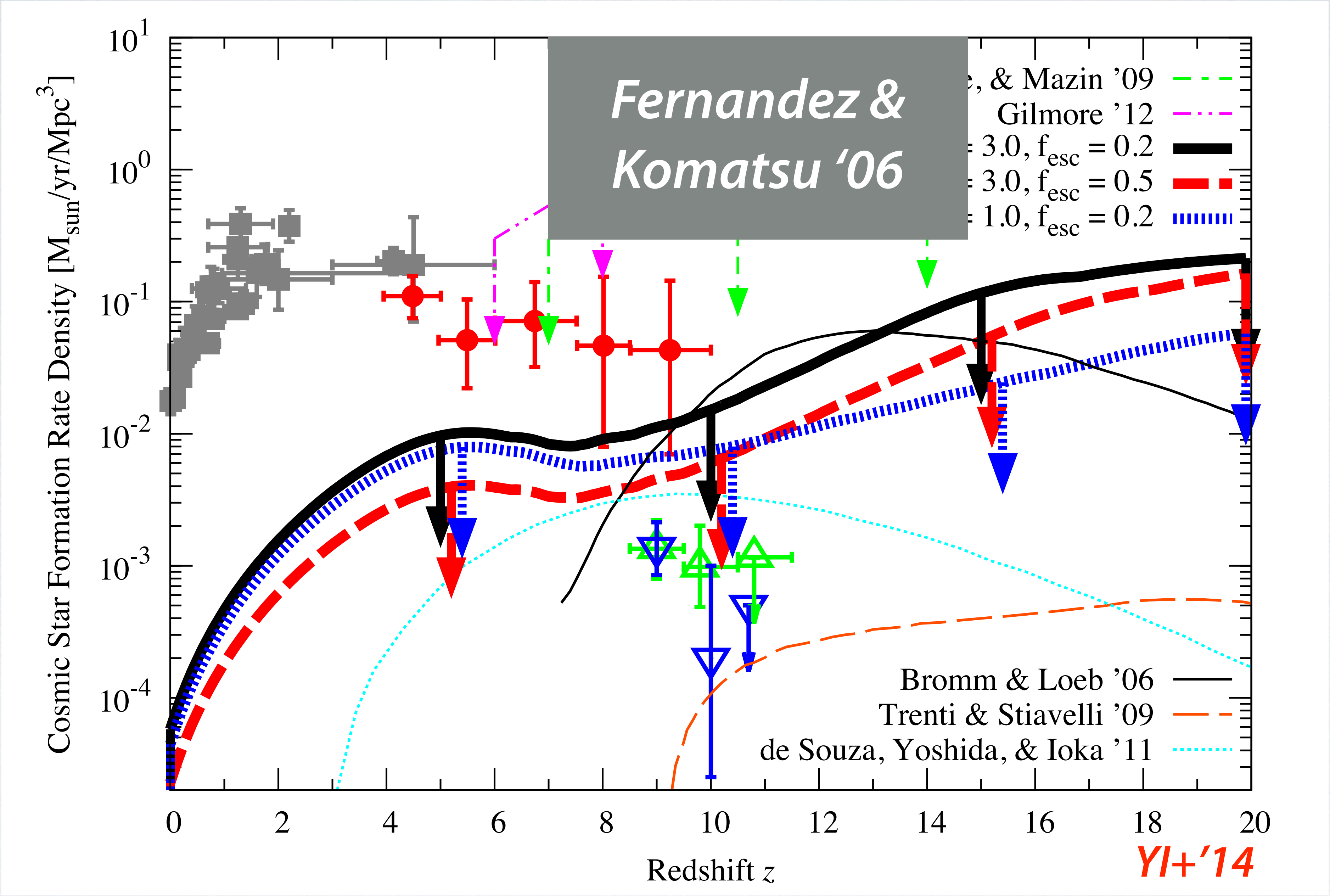
Neutral Hydrogen Fraction



Electron Thomson scattering opacity

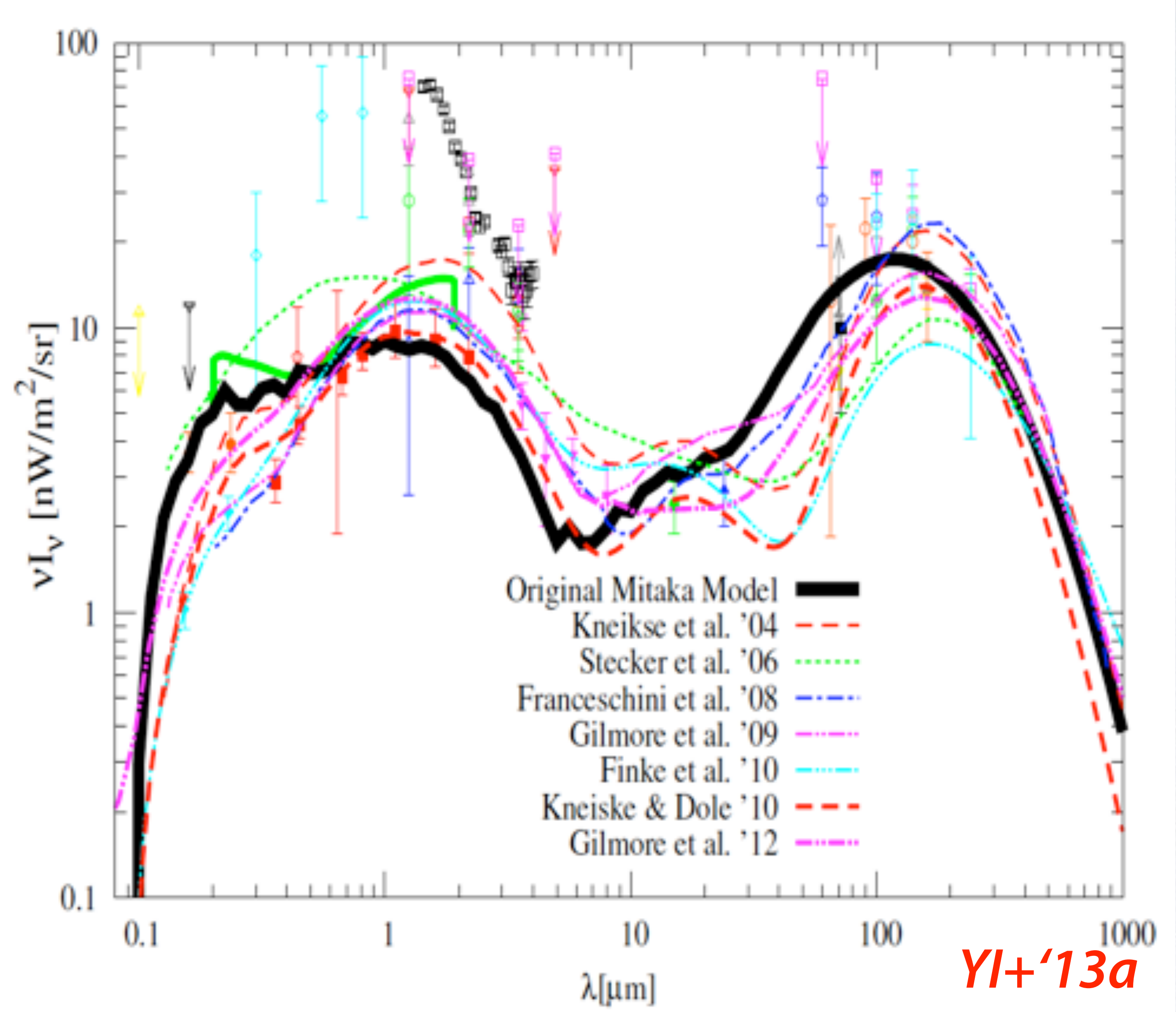
- Ionizing photon emissivity of first stars can not violate these observed reionization data.

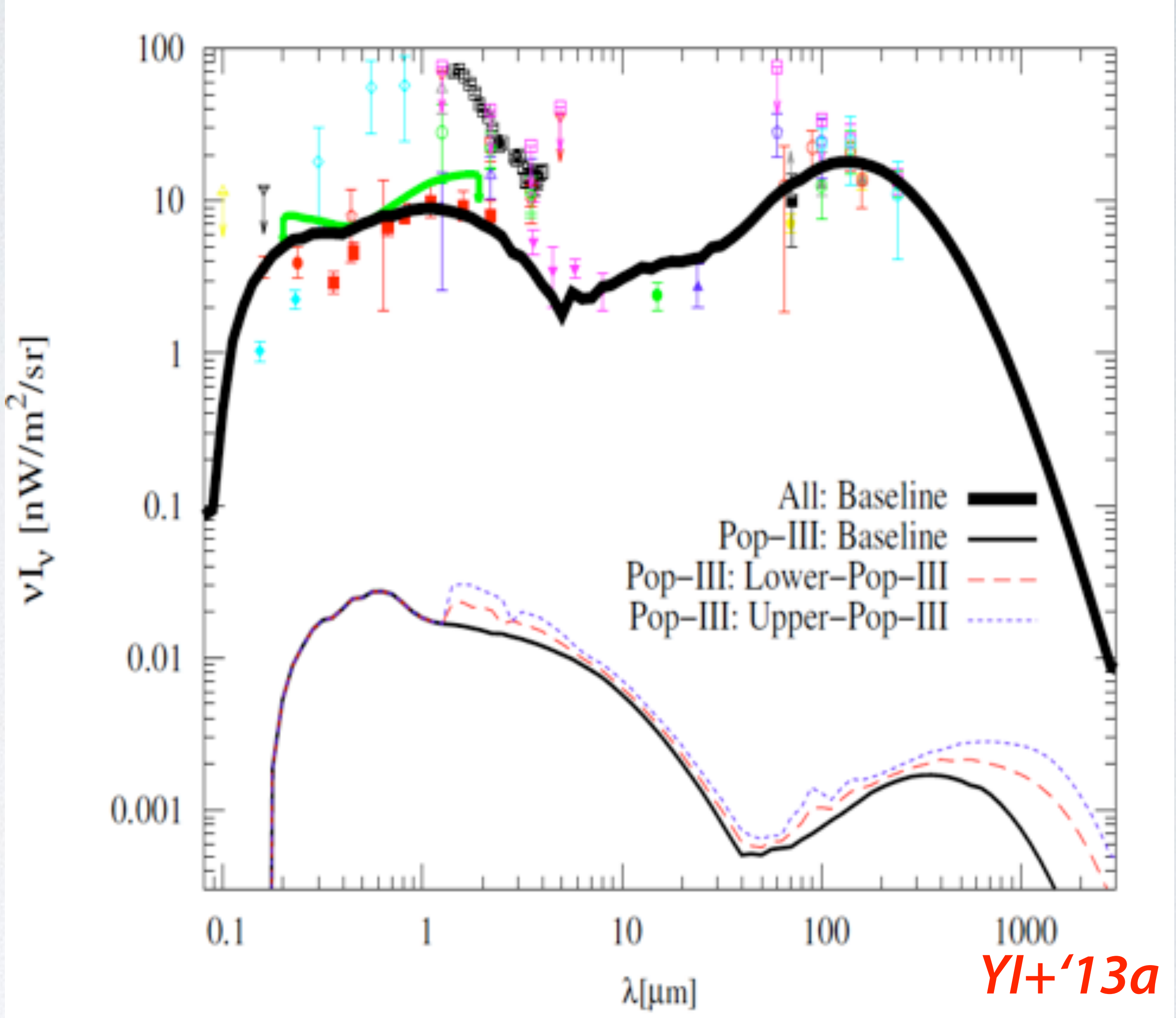
Constraints on First Stars



- Combining reionization and distant gamma-ray data (E<100 GeV).
- The required first star formation rate density is inconsistent with reionization data (e.g. Madau & Silk '05; YI+'14)

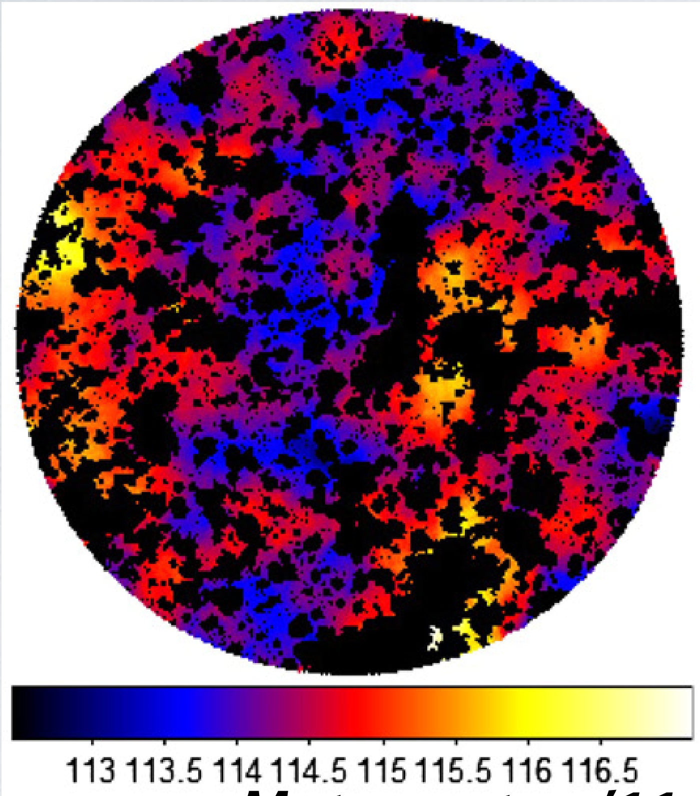
Semi-analytical Galaxy Formation Model with First Stars



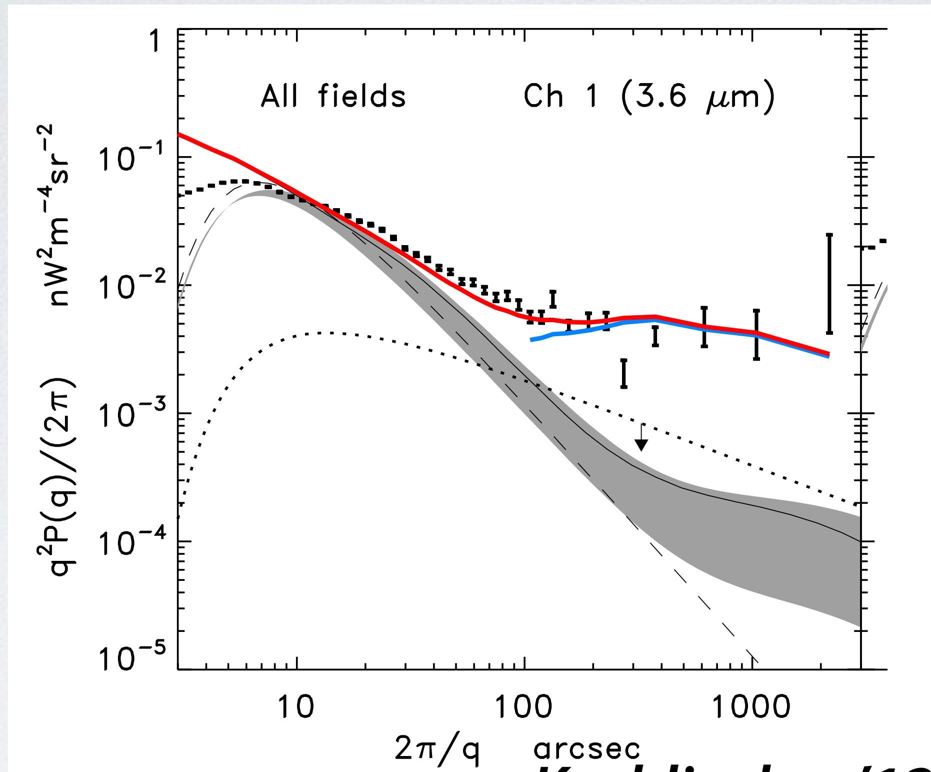


- A galaxy formation model including first stars which is consistent with reionization data.
- Pop-III contribution is <0.5% of total NIR EBL.

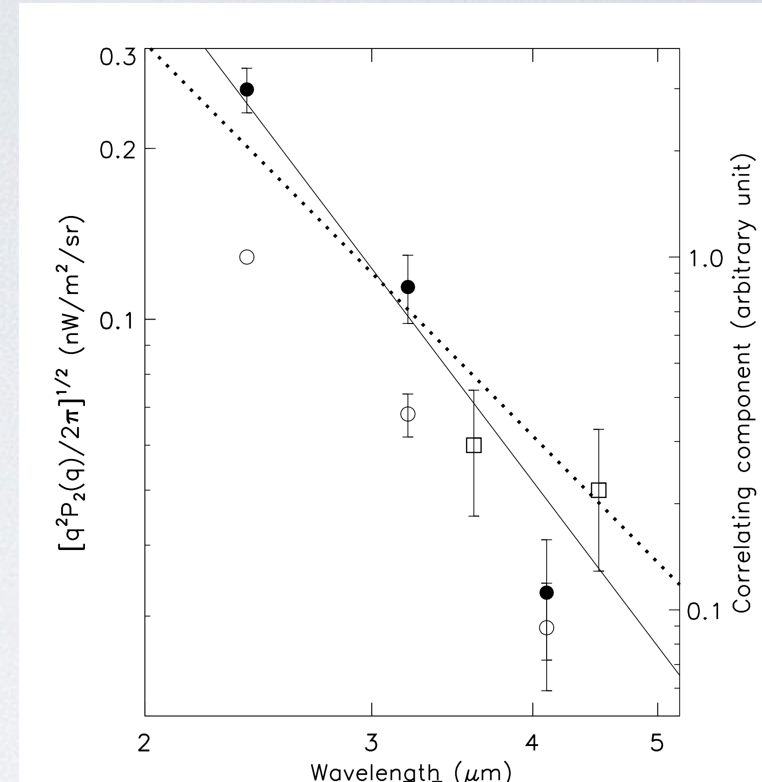
NIR Sky Fluctuation



Matsumoto +'11



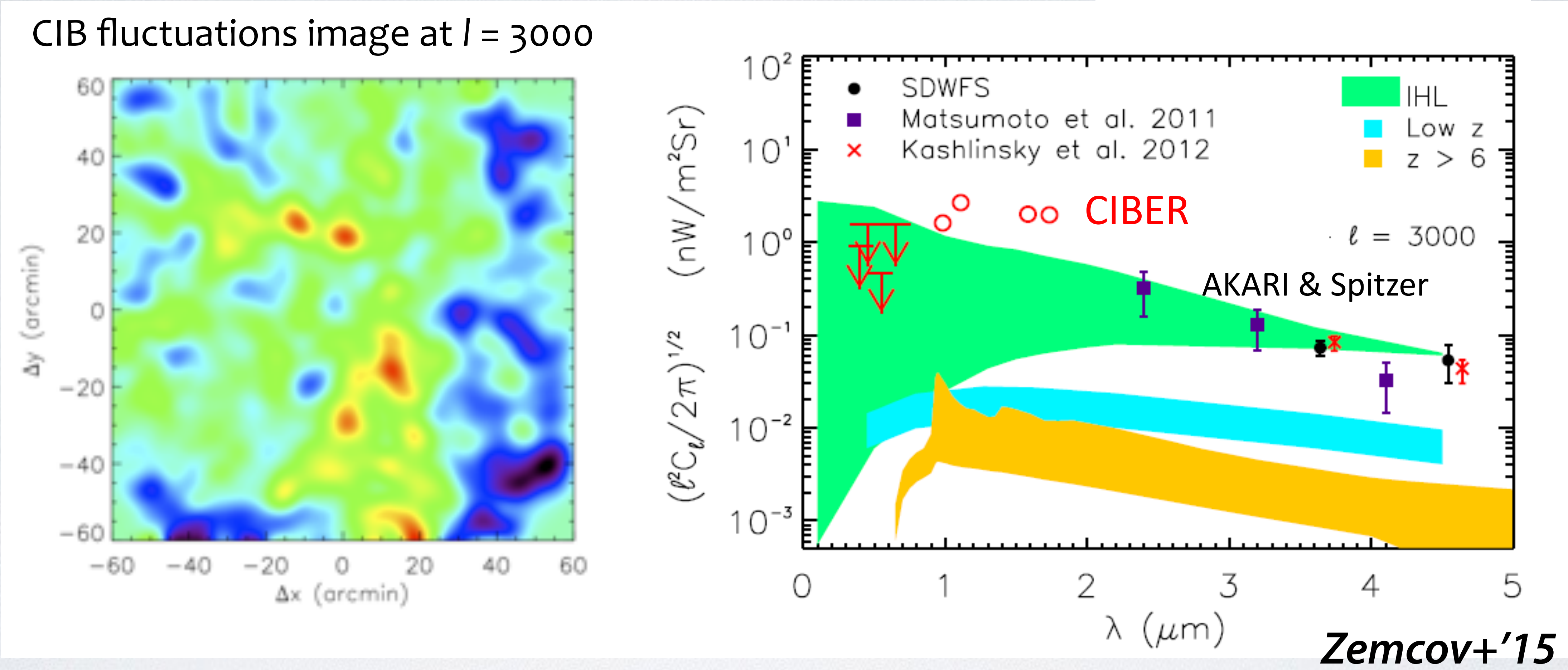
Kashlinsky+'12



Matsumoto +'11

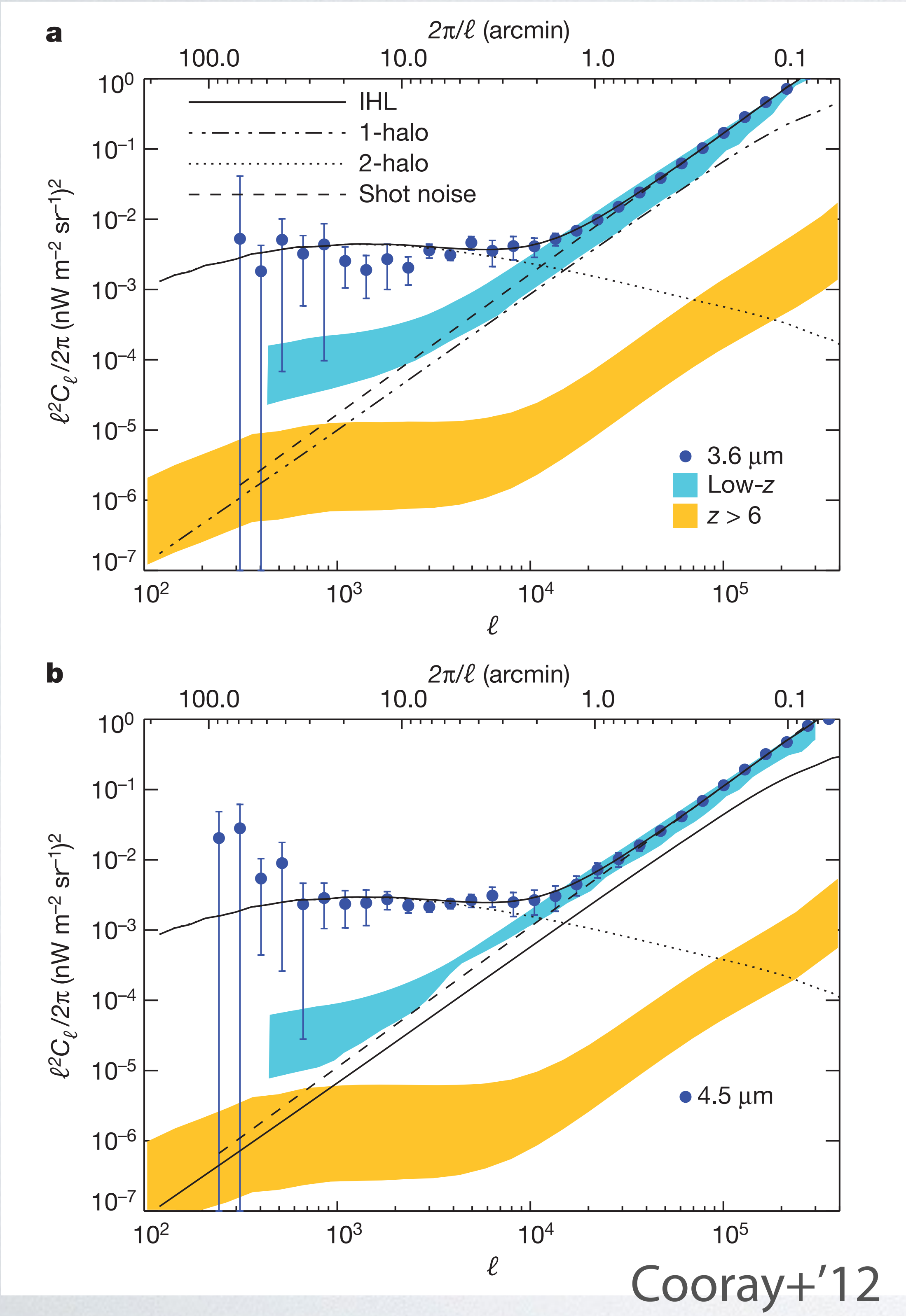
- AKARI & Spitzer reported NIR background fluctuation at 2.4, 3.2, 3.6, 4.1 and 4.5 um (Kashlinsky+'05, '07, '12, Matsumoto+'11, Cooray+'12).
    - 15-20% of CIB fluctuation is correlated with CXB (Cappelluti+'13).
- The angular power spectrum at large scales is close to the shape of a Rayleigh-Jeans spectrum, λ^{-3} (Matsumoto+'11, Cooray+'12)

CIBER Experiment at NIR region

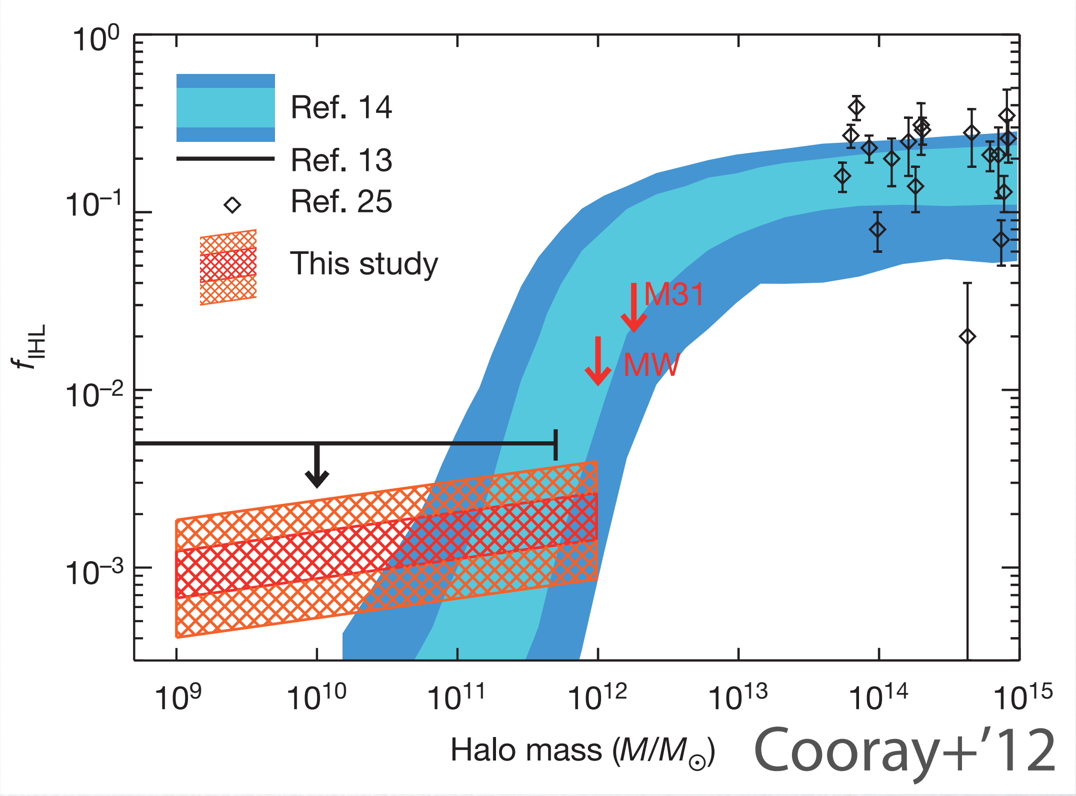


- CIBER confirmed a large scale fluctuation reported by Spitzer & AKARI, which can not be explained galaxies (Zecmov+'14 Science in press.).
- They will report the CIB intensity measurement soon.

Intracluster Halo Stars?



- Stars stripped from host galaxies by major mergers.
  - Intrahalo stars may create a fluctuation peak at l~1000.
- Is this population already taken into account in galaxy counts?



Summary

- Gamma-ray observation is useful tool to probe the COB/CIB indirectly.
  - It will be useful to constrain the intergalactic magnetic field through cascade emission.
- Galaxies' contribution is well studied through observation and theory
- Direct measurement indicate an excess in spectrum from galaxy component at NIR band.
  - But, spectrum measurements are hampered by the zodiacal light
  - An excess is also seen in the fluctuation.