Gamma-ray Attenuation Up to the Epoch of Cosmic Reionization and the First Stars

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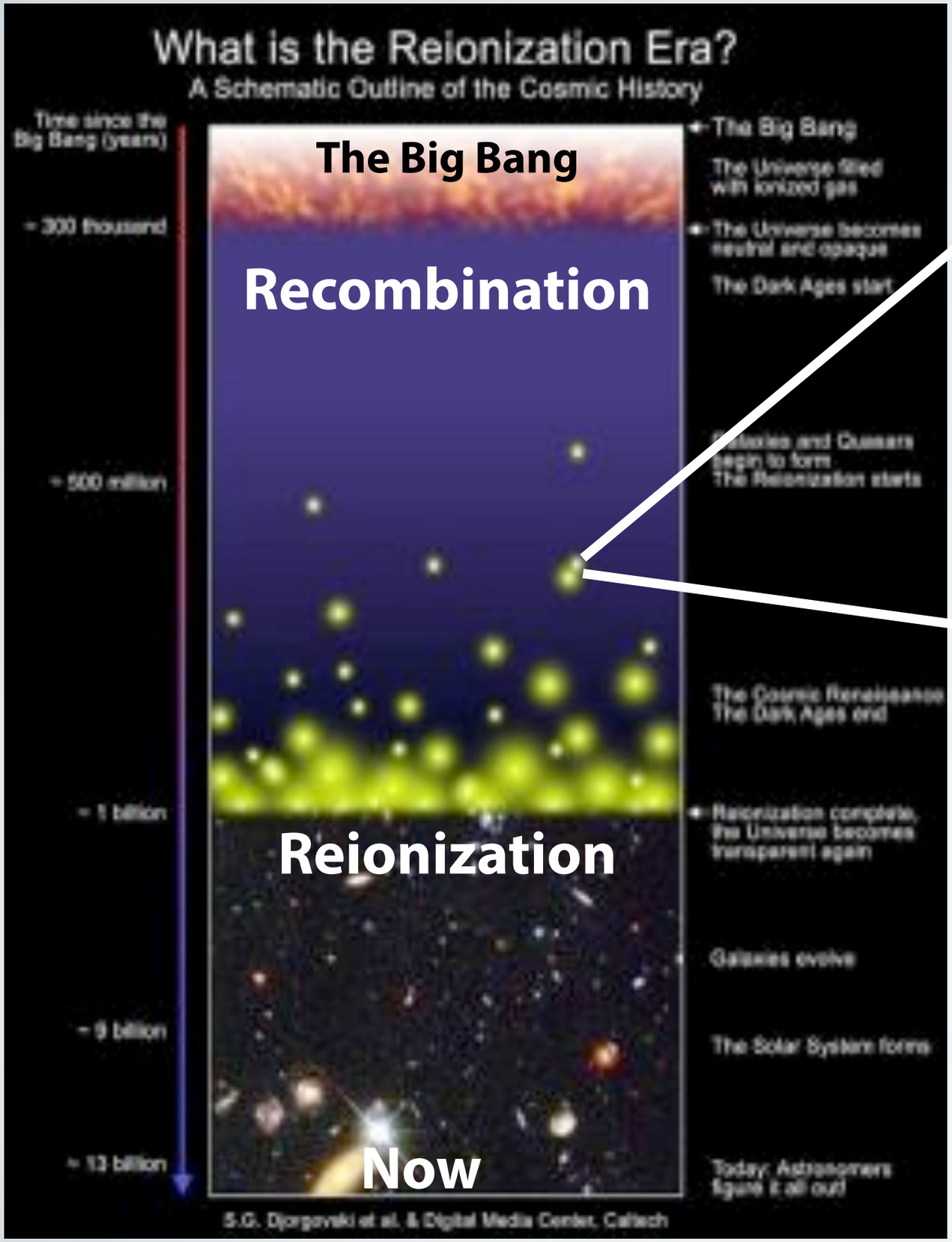
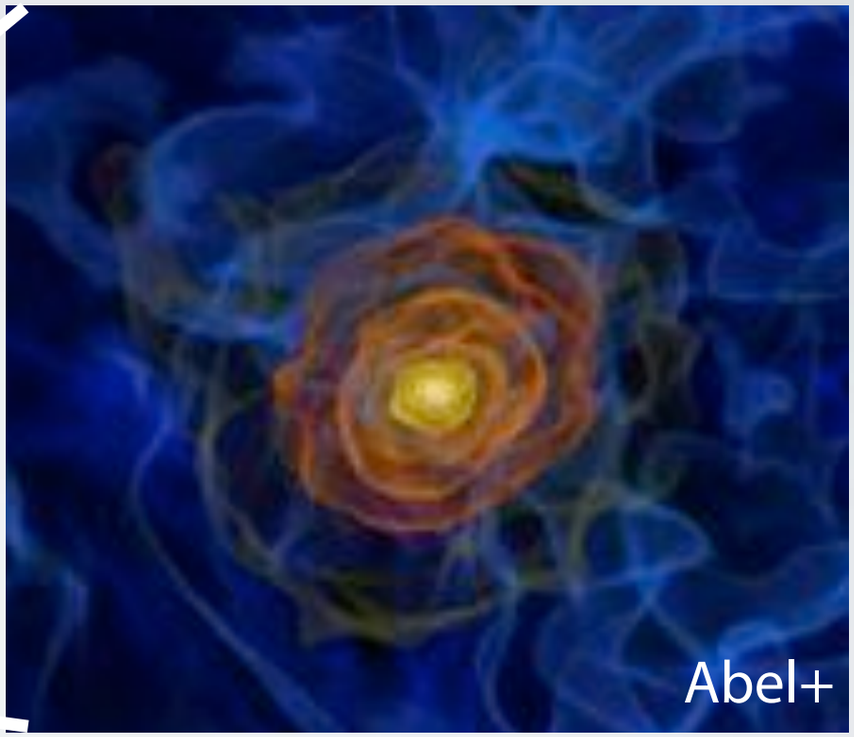
History of The Universe



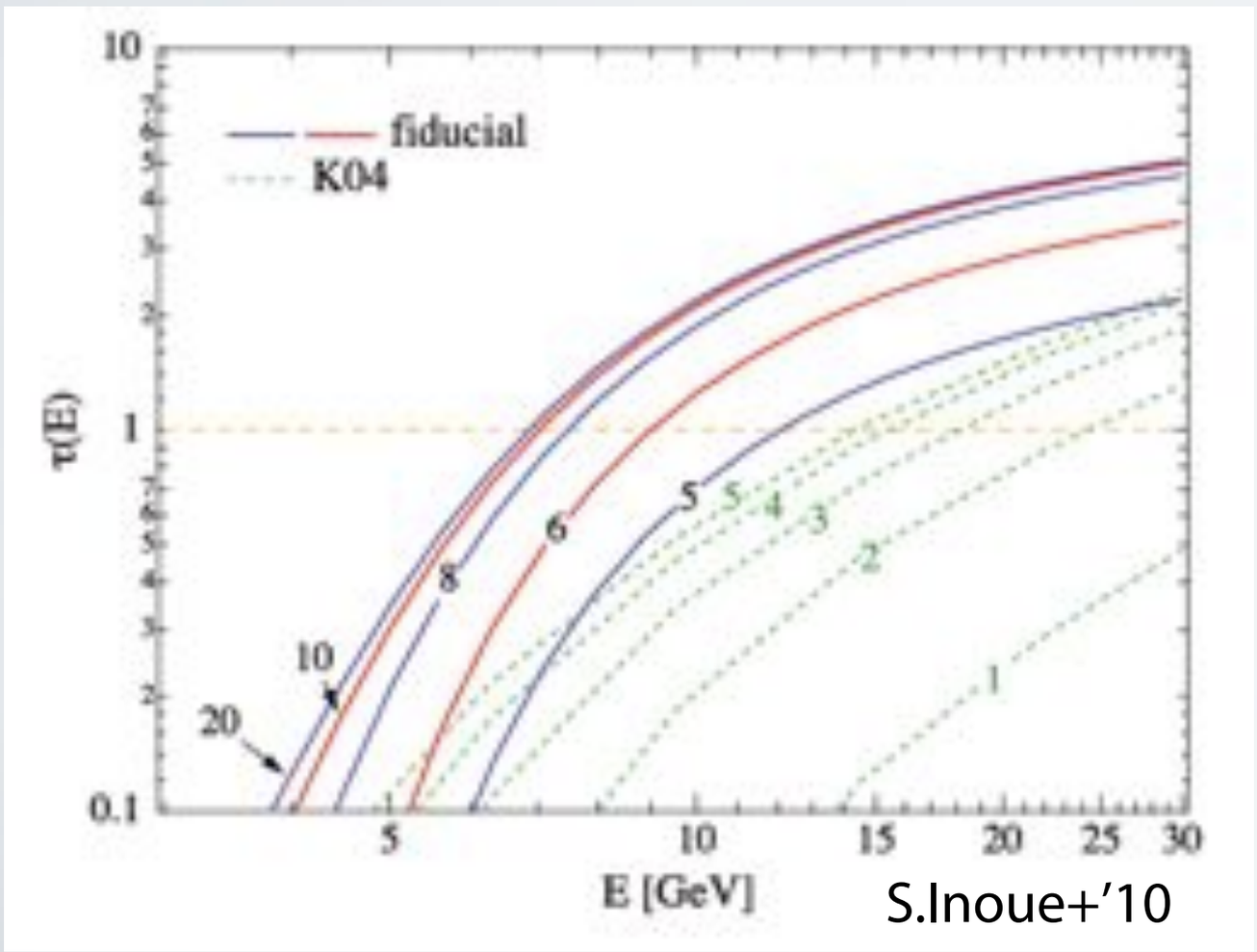


- ***How many First Stars (Pop-III Stars)?***

Can we see the signature of first stars through gamma-rays?

Yes, in principle.

Use $\gamma_{(>GeV)}+\gamma_{UV}\rightarrow e^{+}+e^{-}$.

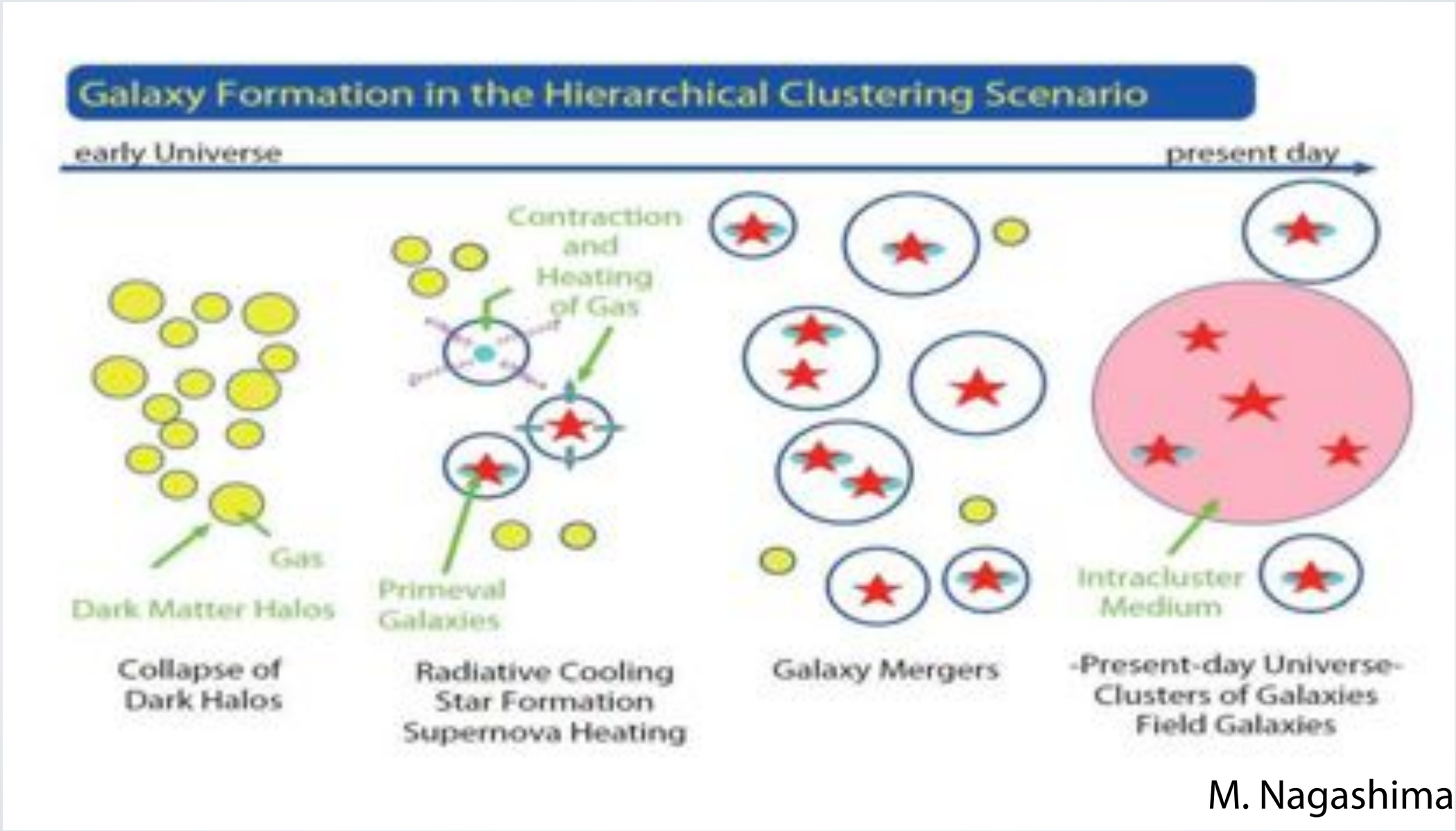


S.Inoue+'10

- Significant absorption
  (Oh '01, S.Inoue+'10).
  - Horizon is ~8 GeV at z=6.
- But, these studies are not compared with galaxy evolution at z<7.

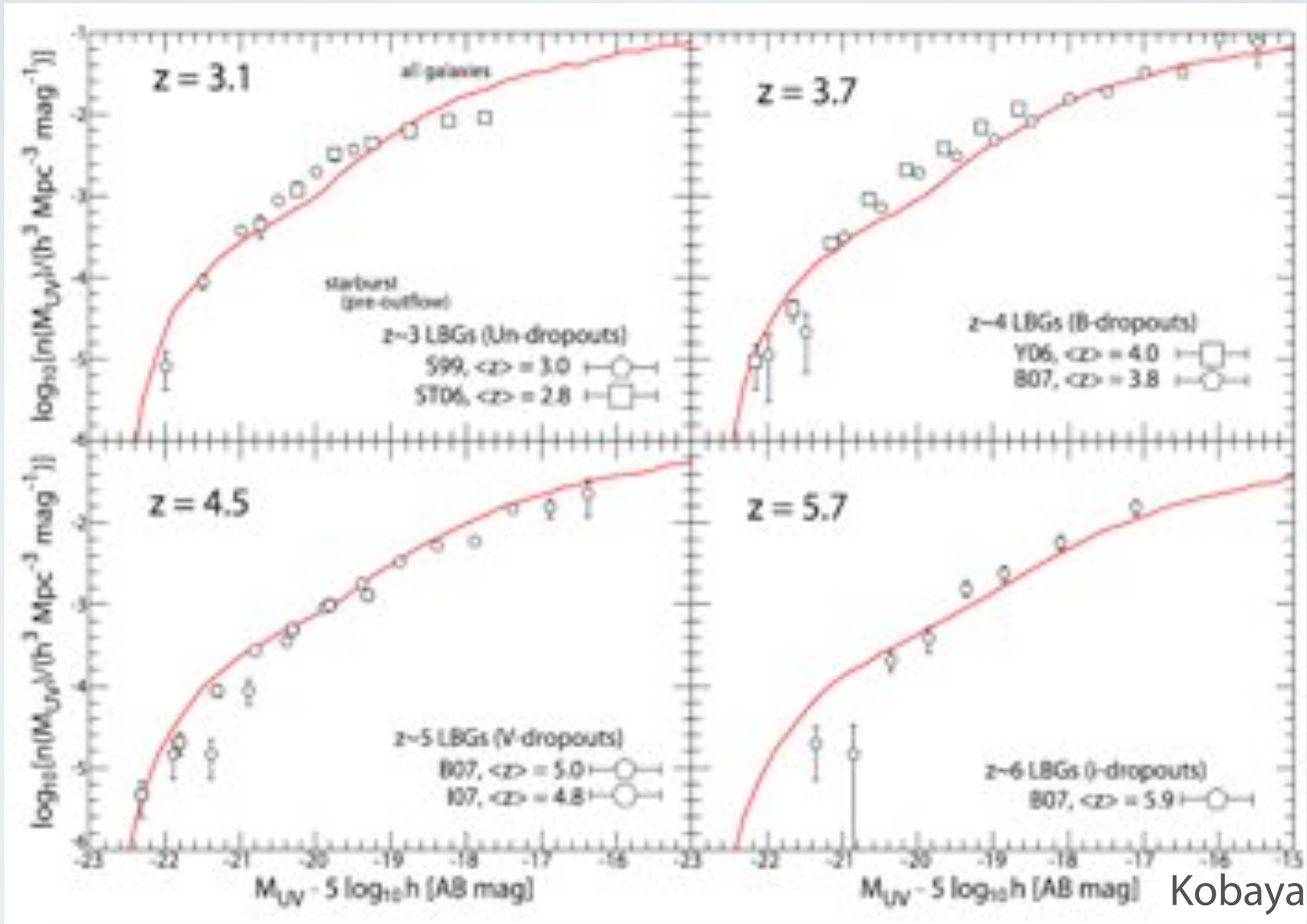
Hierarchical Galaxy Formation

- semi-analytical models (e.g. Mitaka model; Nagashima & Yoshii '04)
  - semi-analytical EBL models (e.g. Gilmore+'09, Younger & Hopkins '11, Gilmore+'12, Somerville+'12)



M. Nagashima

Comparison of the Mitaka model with UV LF at z<6

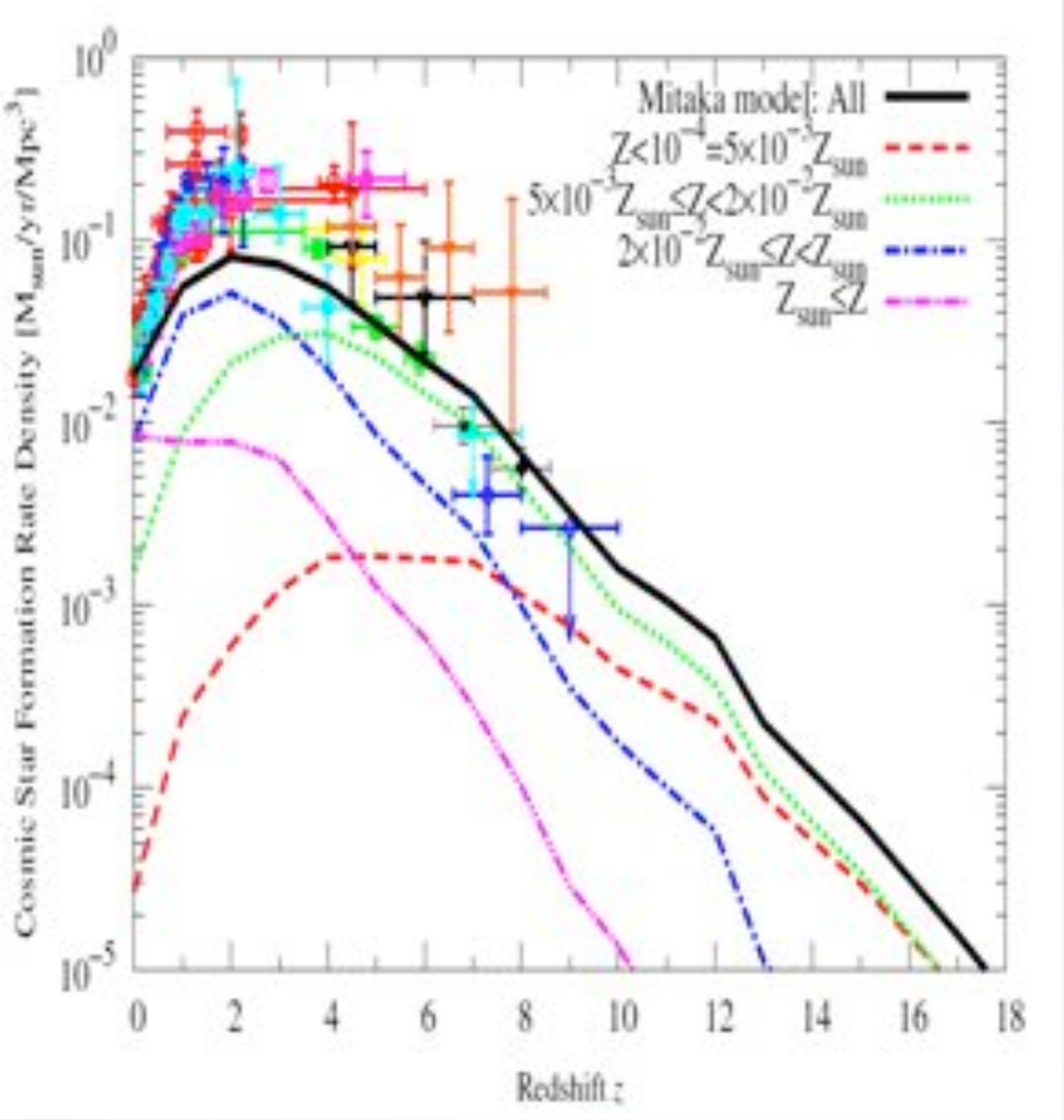


Kobayashi+'10

- Our model is consistent with various galaxy obs. data

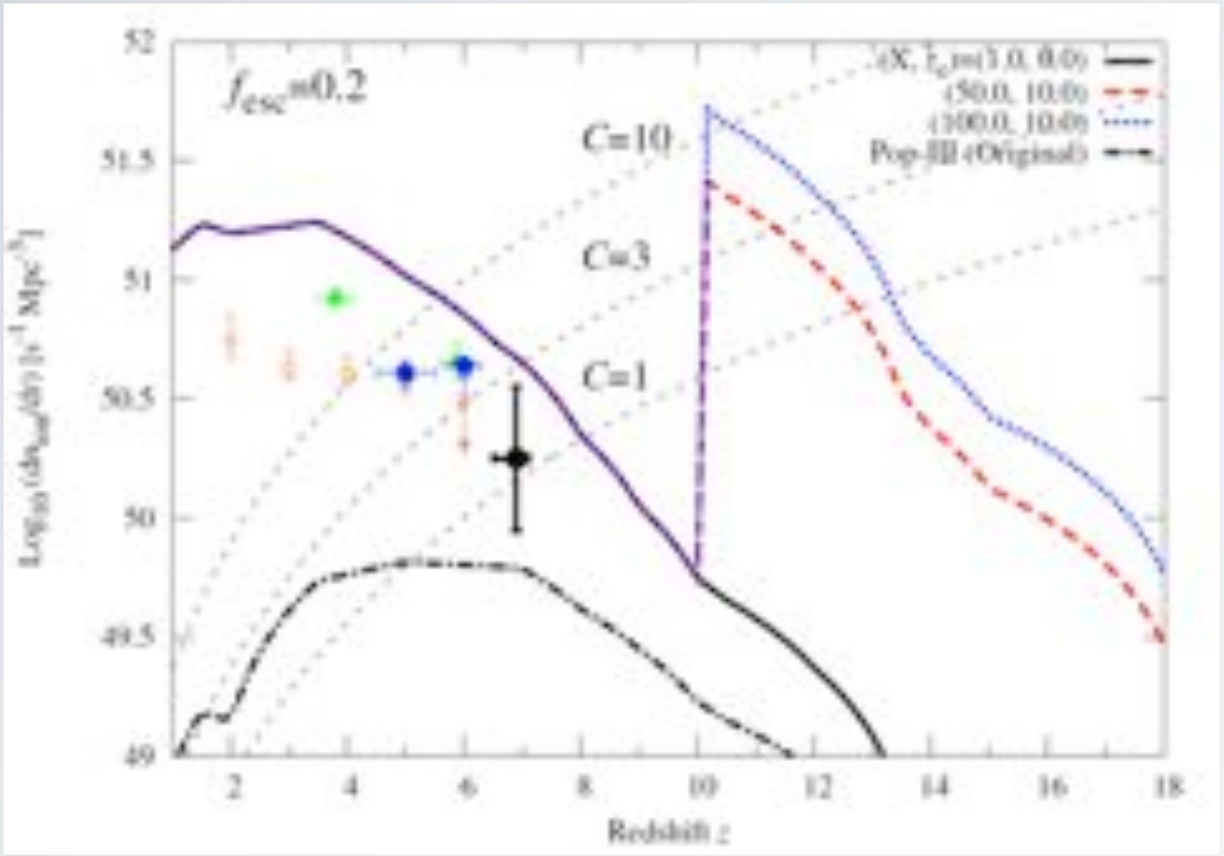
  (e.g. Nagashima & Yoshii '04, Kobayashi+'07, '10)

Cosmic Star Formation History

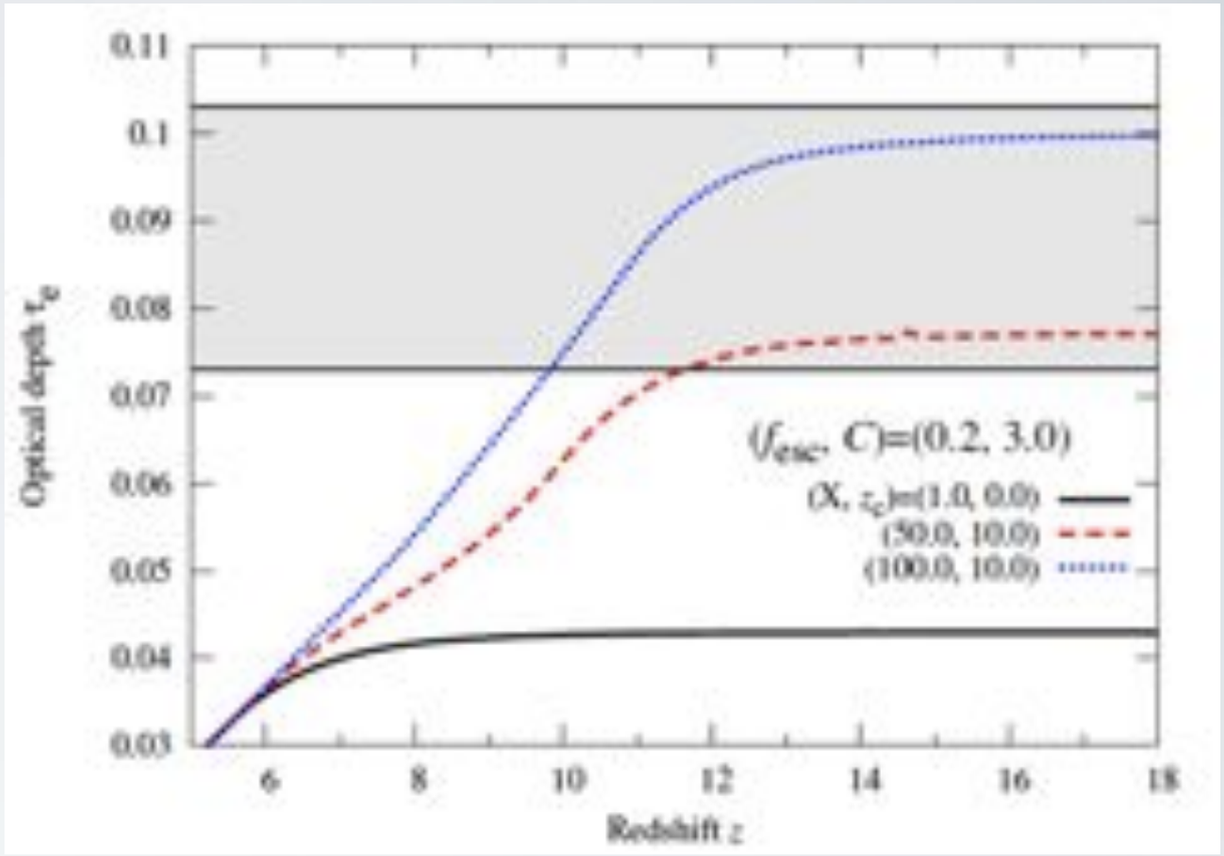


- Salpeter initial mass function for 0.1-60 $M_\odot$
- $Z<10^{-4}$ (Pop-III) are included.
- stellar population synthesis (SED) models:
  - Bruzual & Charlot ’03 for Pop-I, II stars
  - Schaerer ’03 for Pop-III stars

The History of Reionization



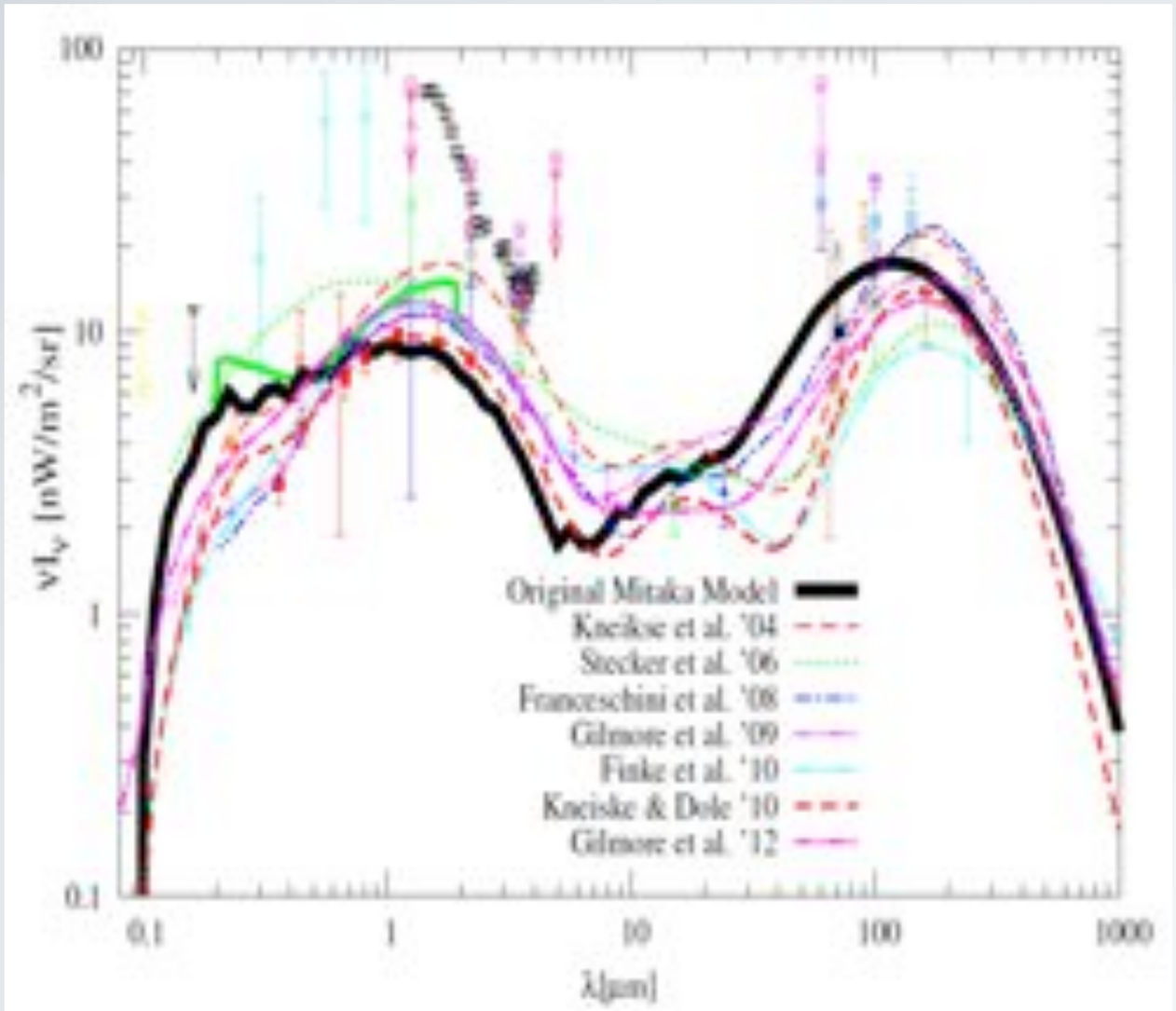
ionizing photon emissivity

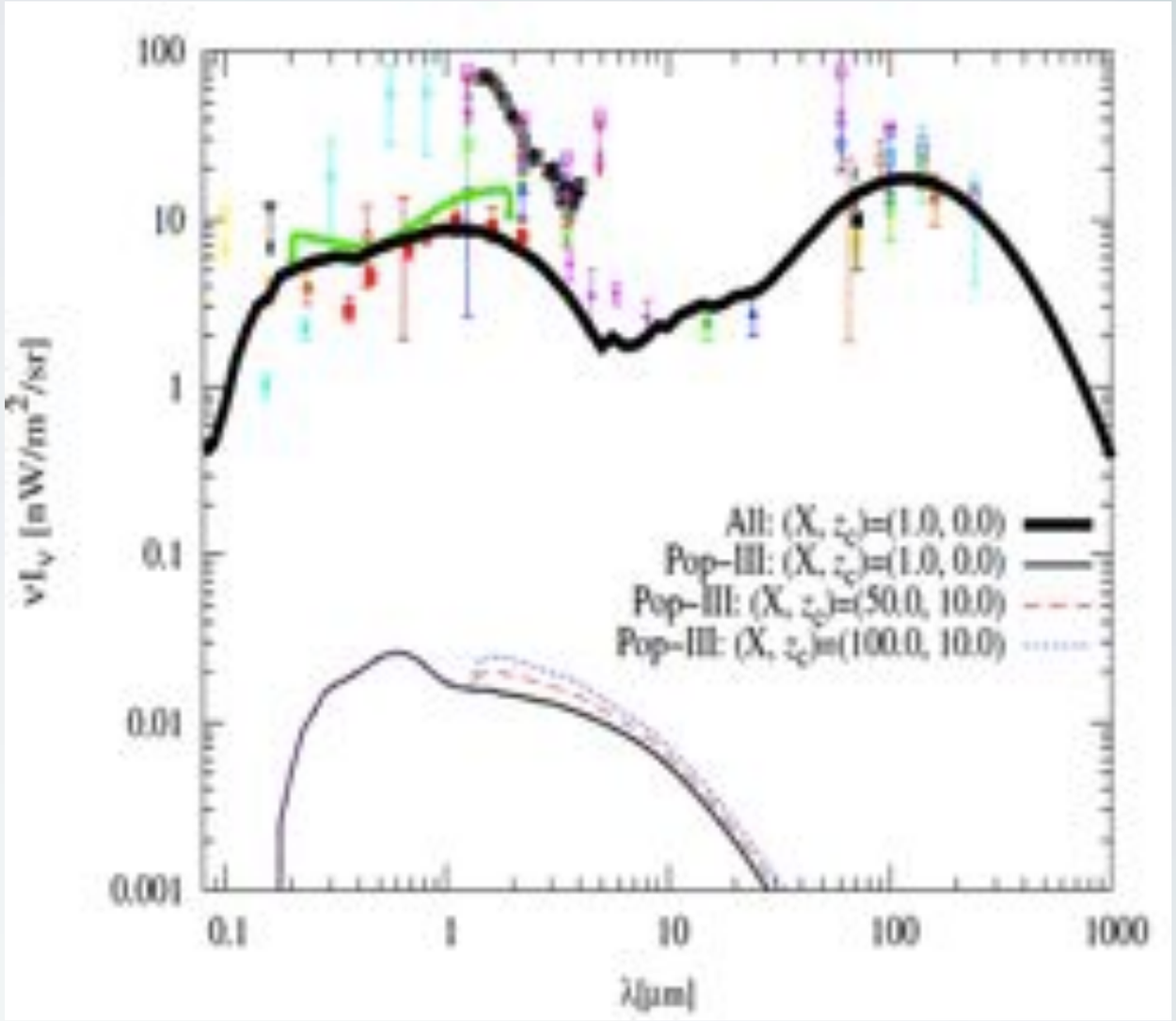


Thomson scattering opacity

- Our original model can reionize the Universe at z<8.
  - But it can not reproduce the WMAP Thomson scattering opacity.
- 50-100 times more ionizing photons are required at z>10.
  - IMF? escape fraction? clumpiness? BH accretion disk?

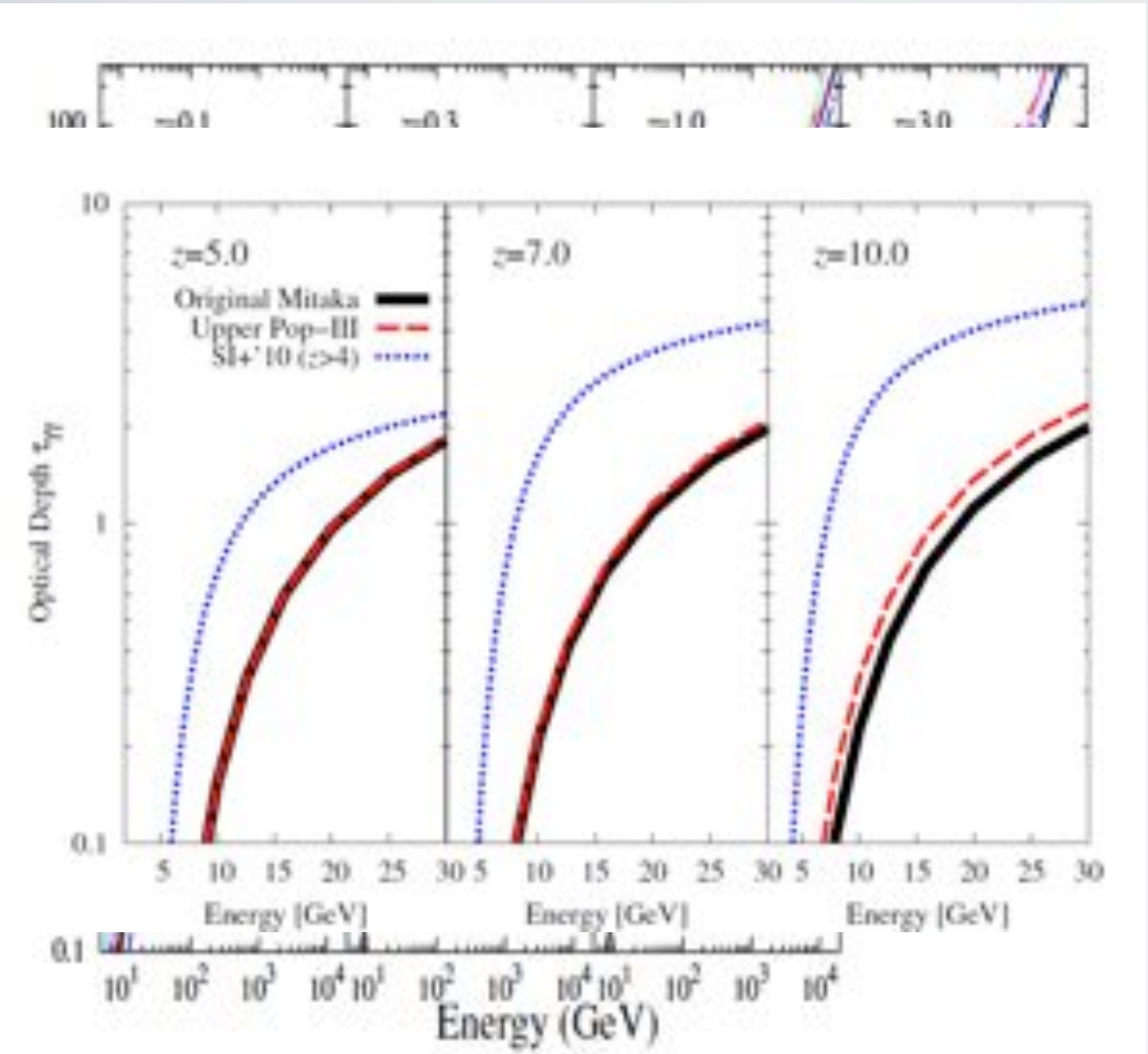
Extragalactic Background Light





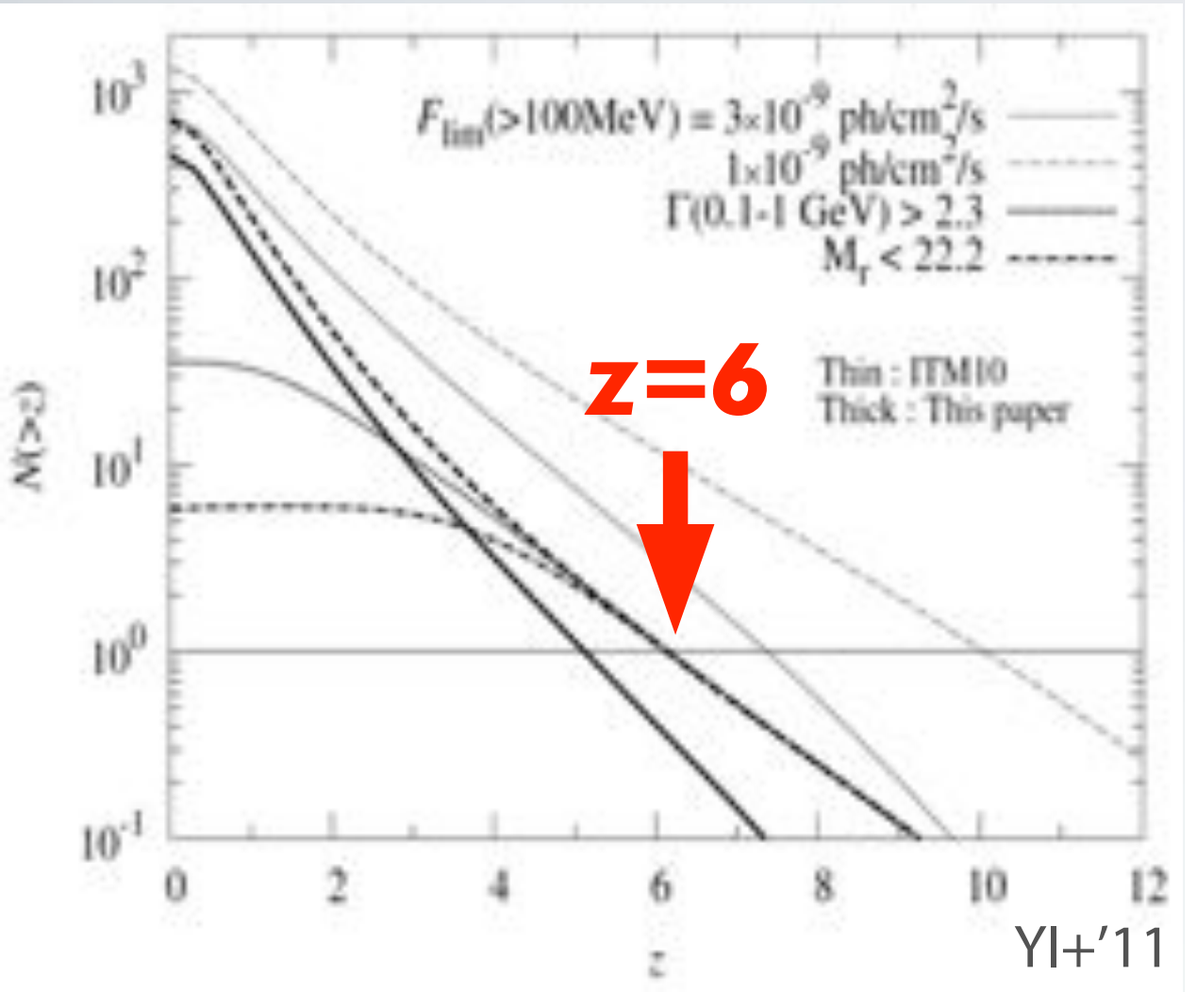
- Consistent with the available EBL data.
- Pop-III contribution is <0.5% of total NIR EBL.
  - Even if we add 100 times more Pop-III components at z>10, it does not change significantly.

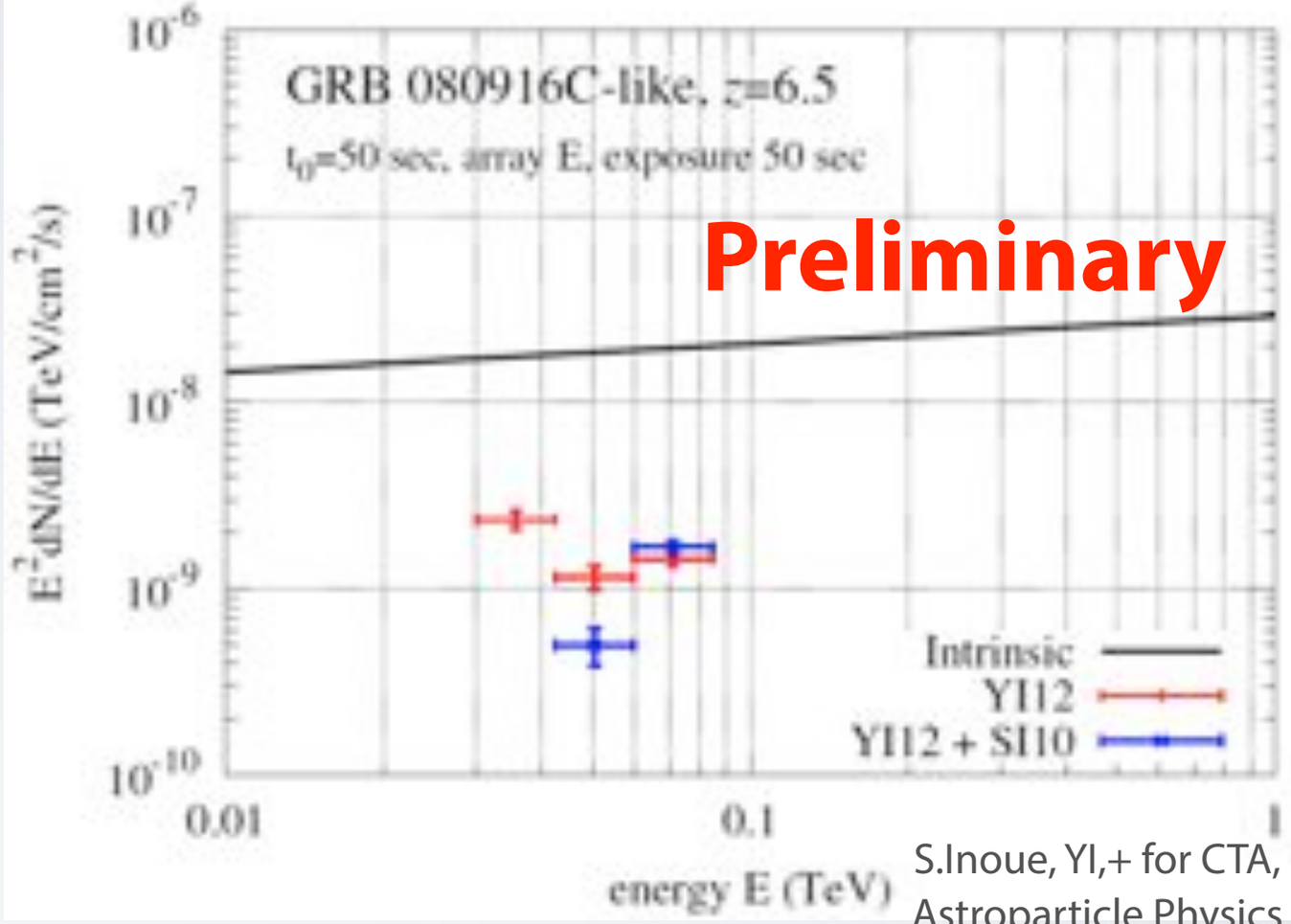
Gamma-ray Opacity



- The gamma-ray horizon at z>5 is ~20 GeV.
  - dominated by Pop-I, II stars.
- We can put an upper-limit on the Pop-III emissivity with high-z gamma-ray sources.
  - Complementary to Opt.-IR observation

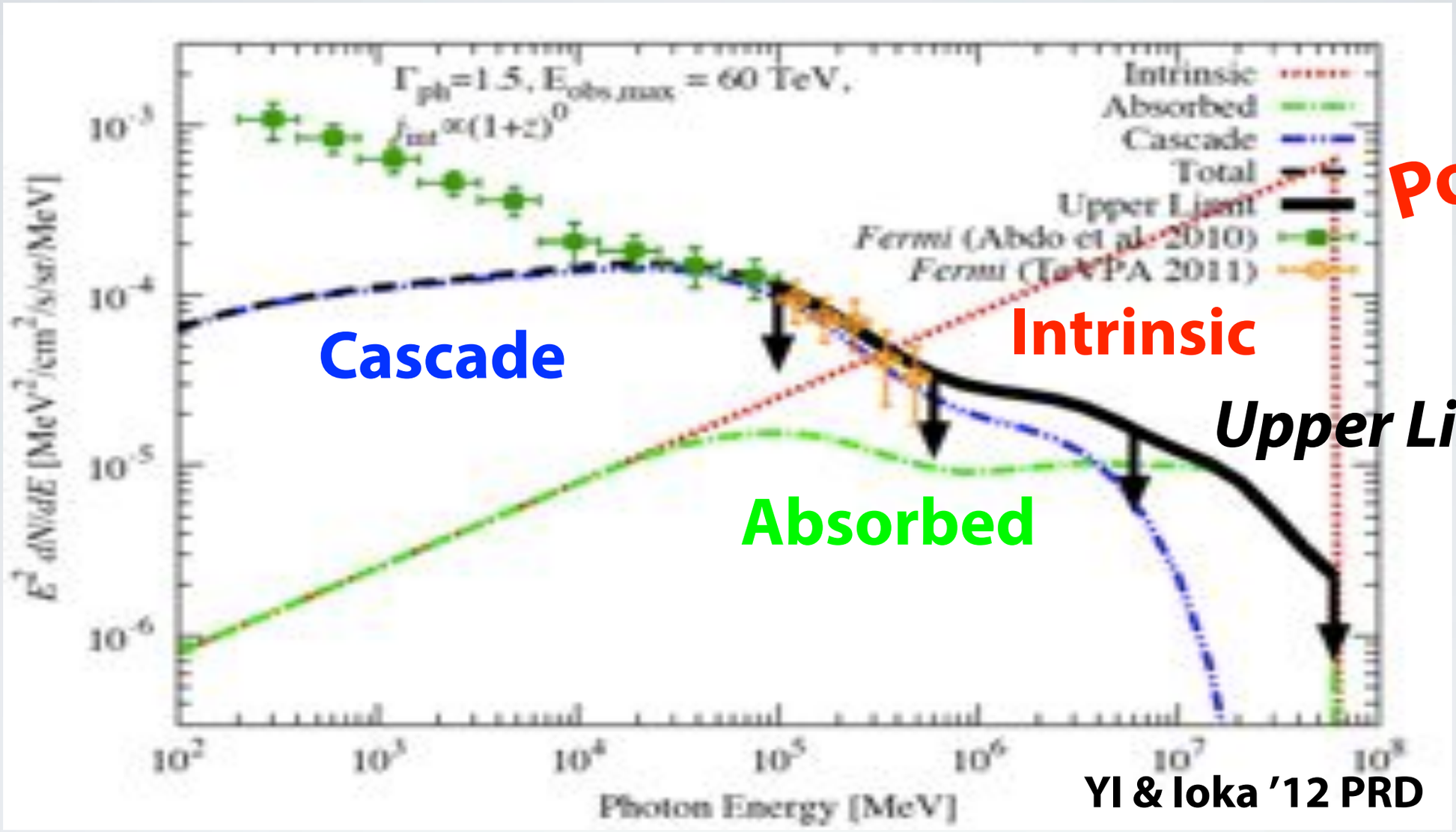
High-z Gamma-ray Blazar and GRB





- Fermi will detect a few blazars at z~6 with >5-yrs survey (YI+'11).
- CTA will be able to measure the spectrum of a GRB 080916C-like event even at z=6.5 (S.Inoue, YI+ for CTA, in. prep).

Extragalactic Gamma-ray Background



Poster 2.4

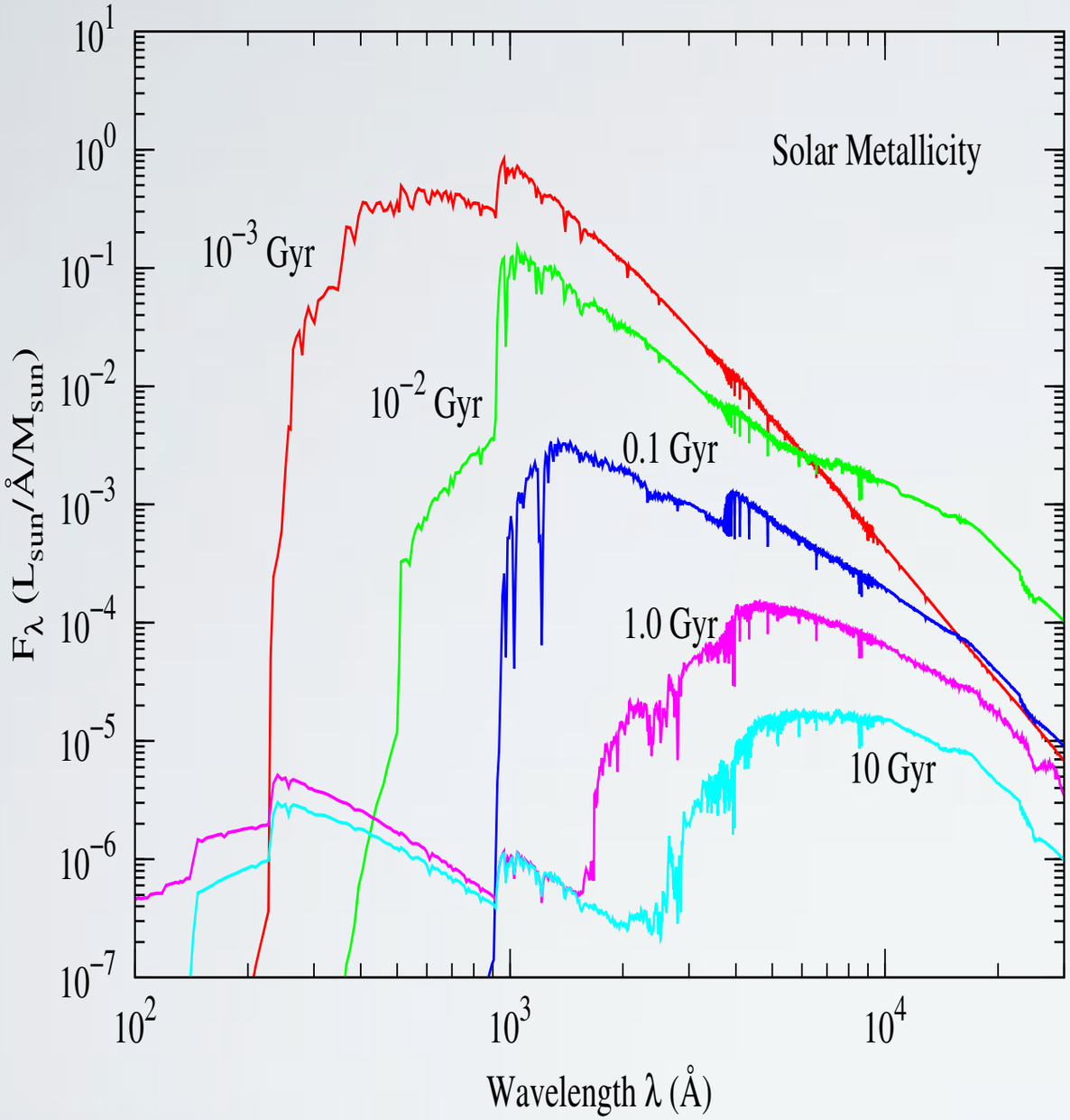
YI & Ioka '12 PRD

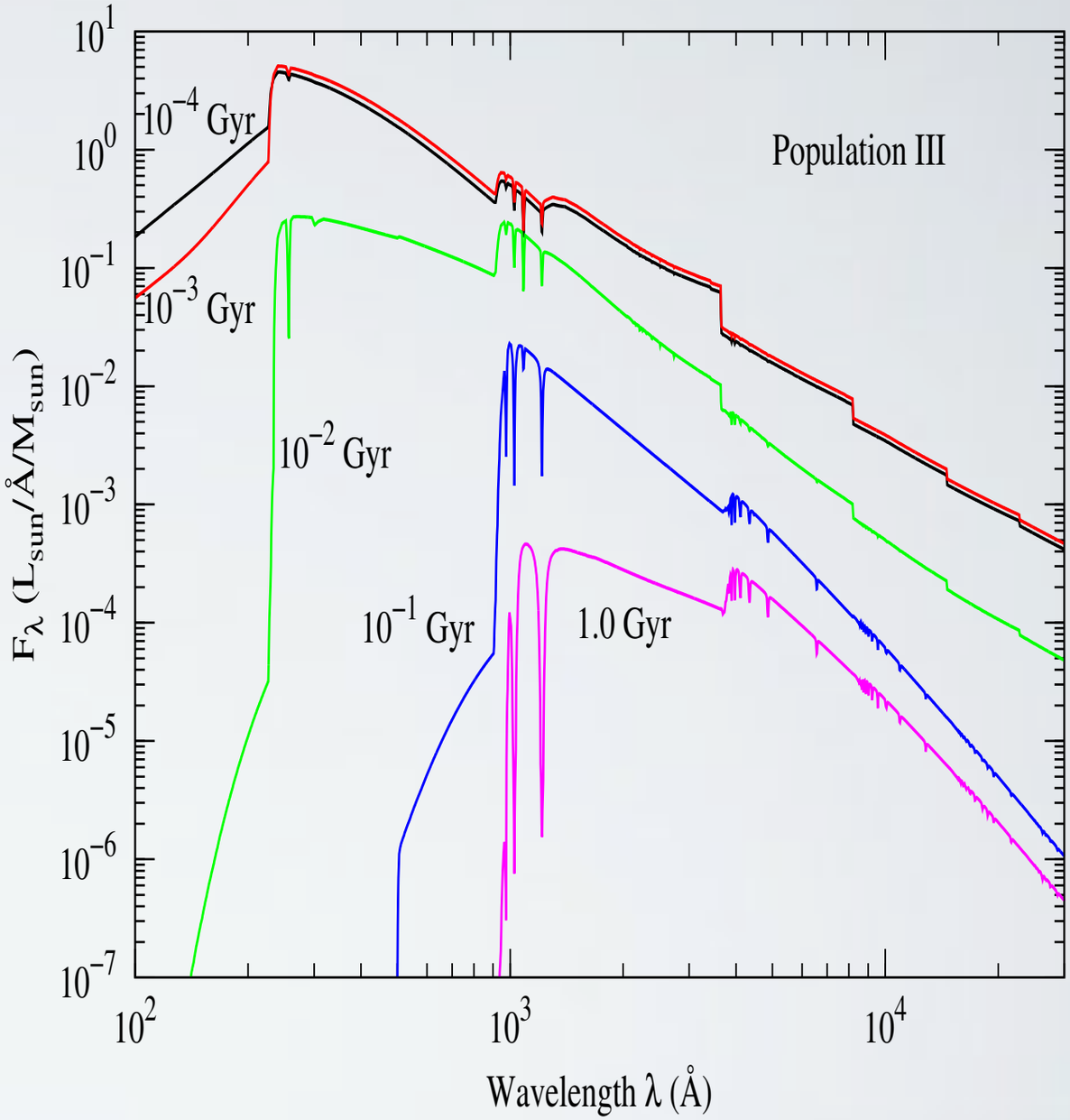
- Created e^+e^- scatter CMB to gamma-rays (cascade).
- EGB (>100 GeV) is limited not to make the cascade emission exceed cascade the EGB data.
  - Sensitive to the EBL model.

Summary

- We construct a new EBL model including first stars using a semi-analytical model.
  - The expected gamma-ray horizon at z>5 is ~20 GeV dominated by Pop-I, II stars.
- It is difficult to see the signature of first stars through gamma-ray obs.
  - But, we can put a strong constraints on the first star formation history.
- Future gamma-ray obs. will see sources at z>6.

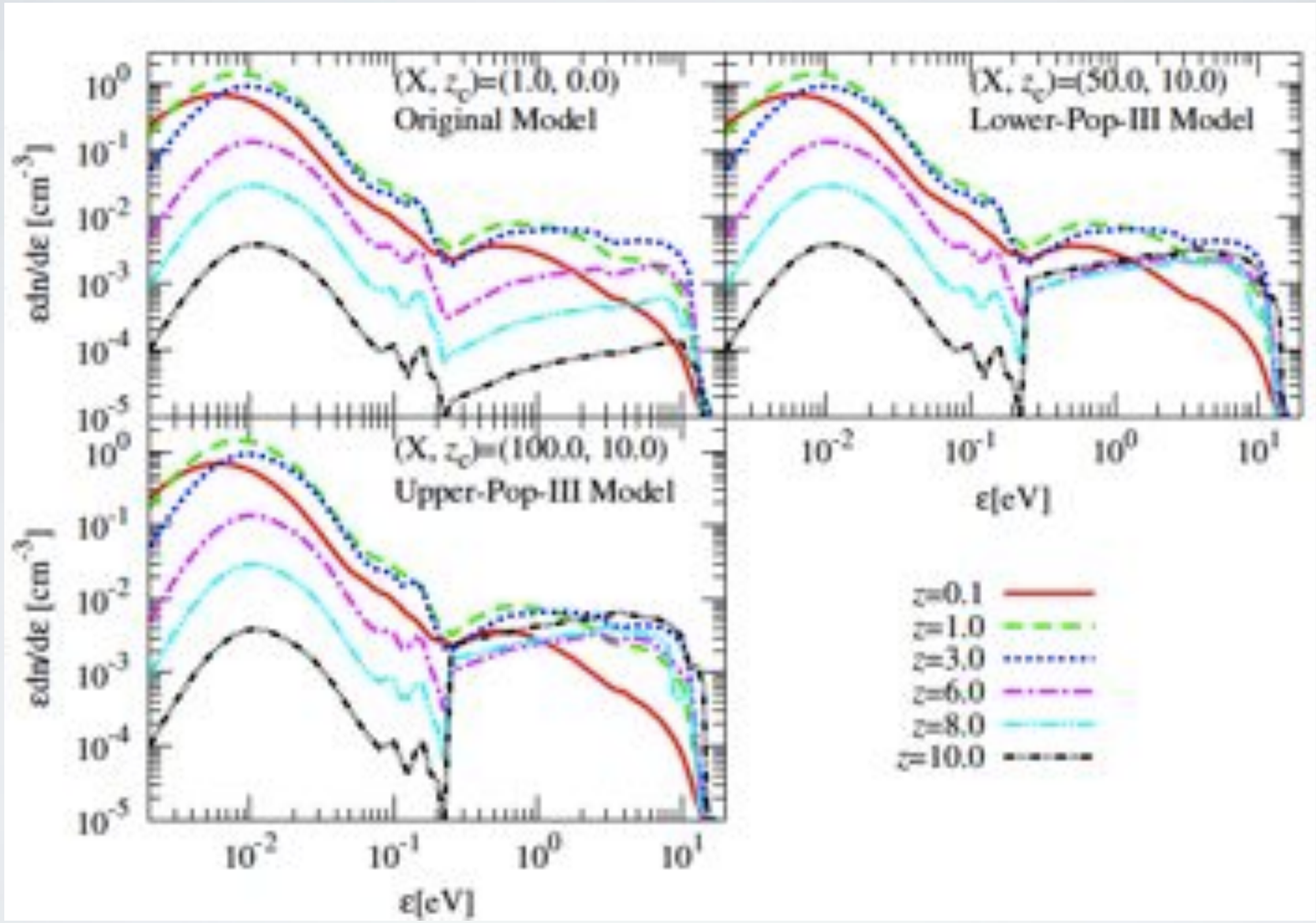
Stellar Population Synthesis Models



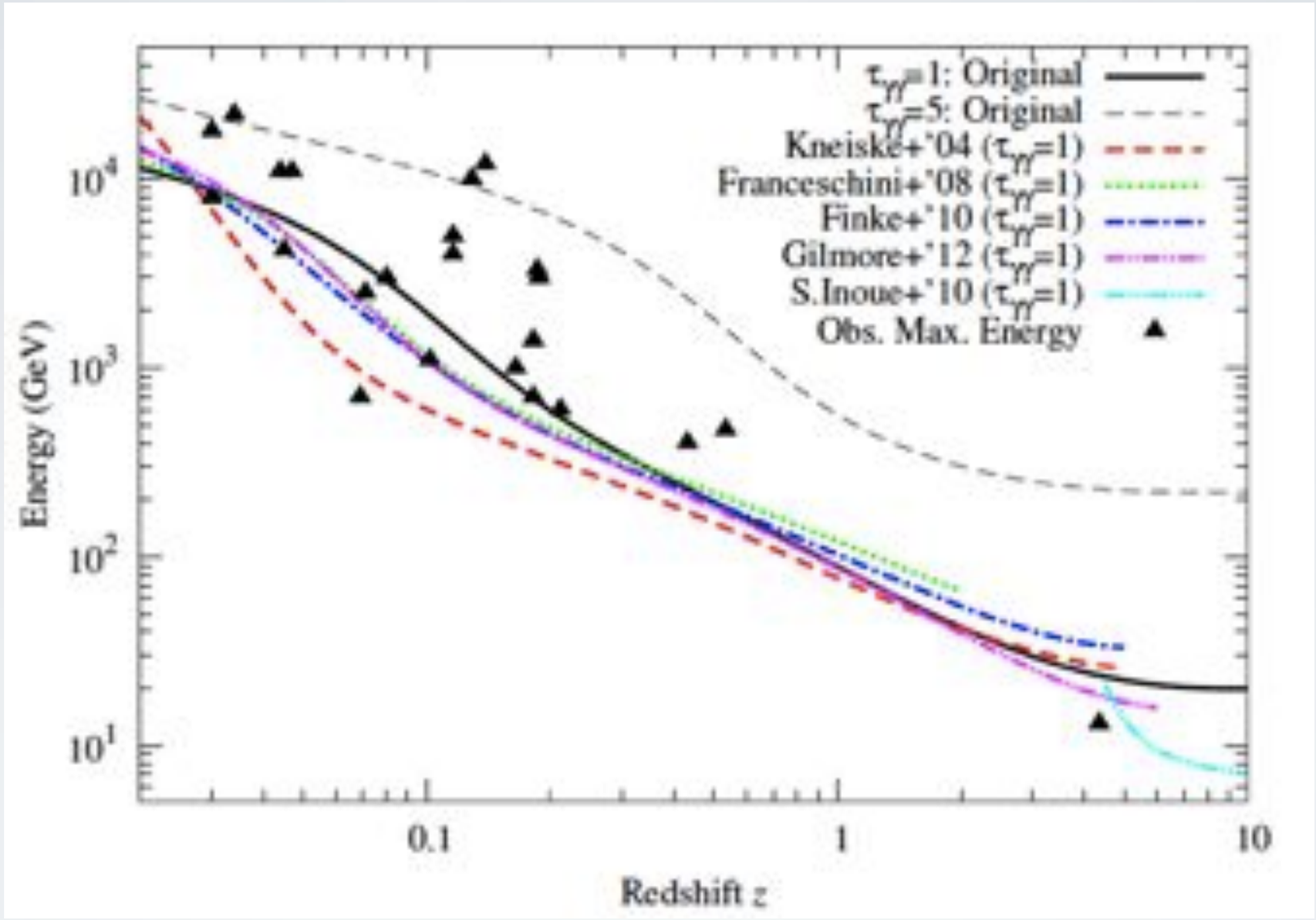


- Bruzual & Charlot ’03 ($Z > 10^{-4} = 0.005 \times Z_{sun}$)
- Schaerer ’03 ($Z<10^{-4}$)

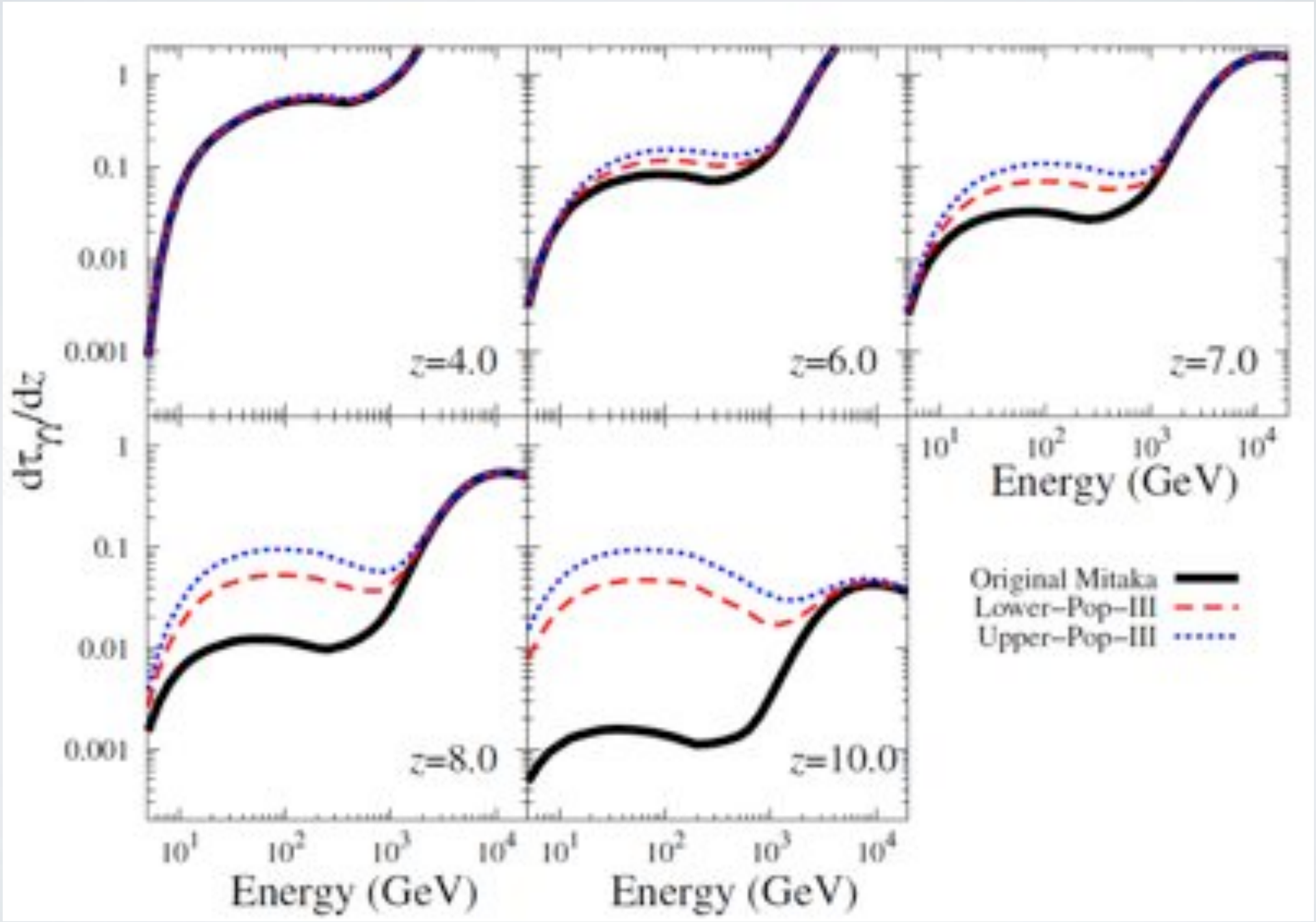
Proper Photon Density



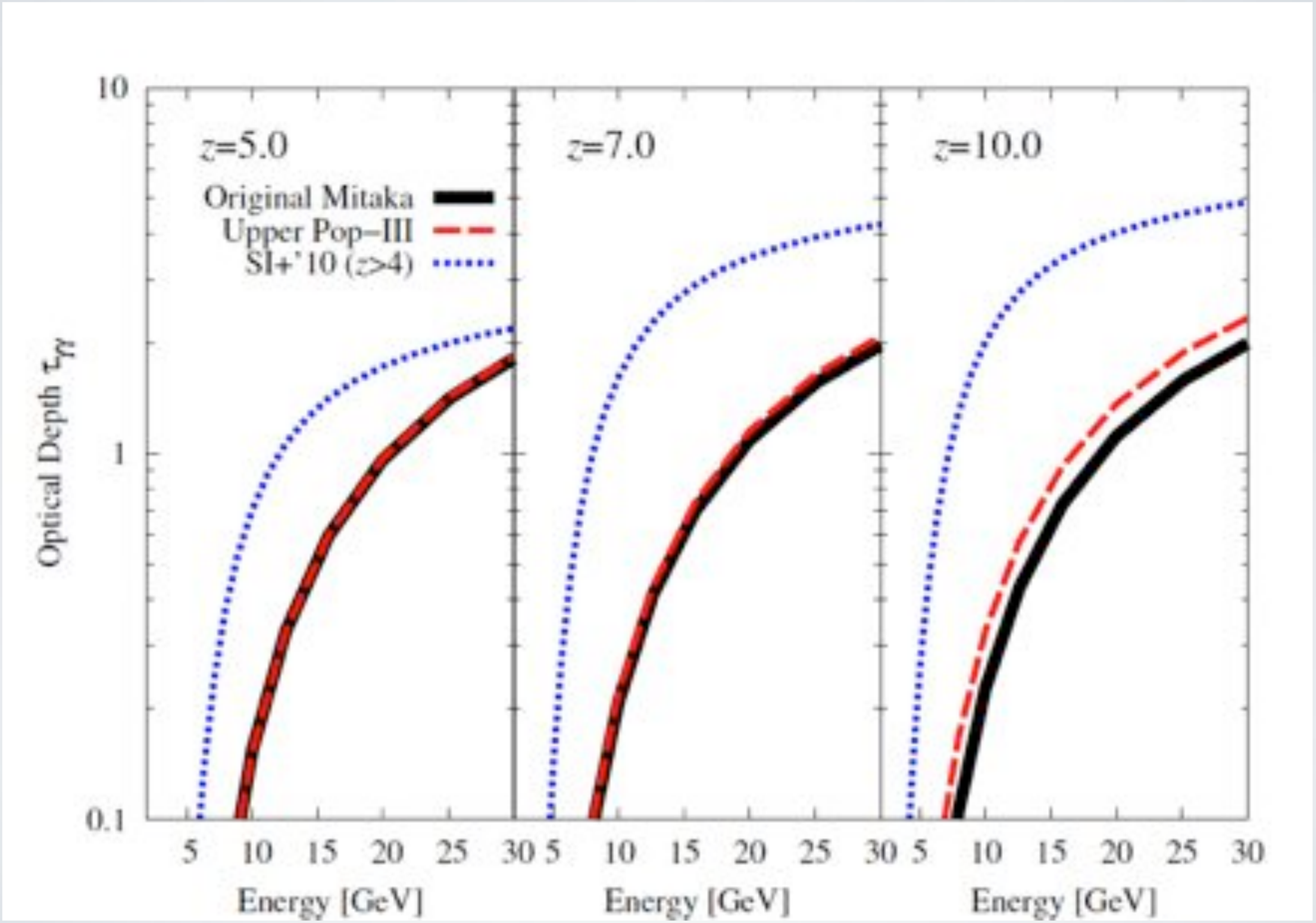
Gamma-ray Horizon



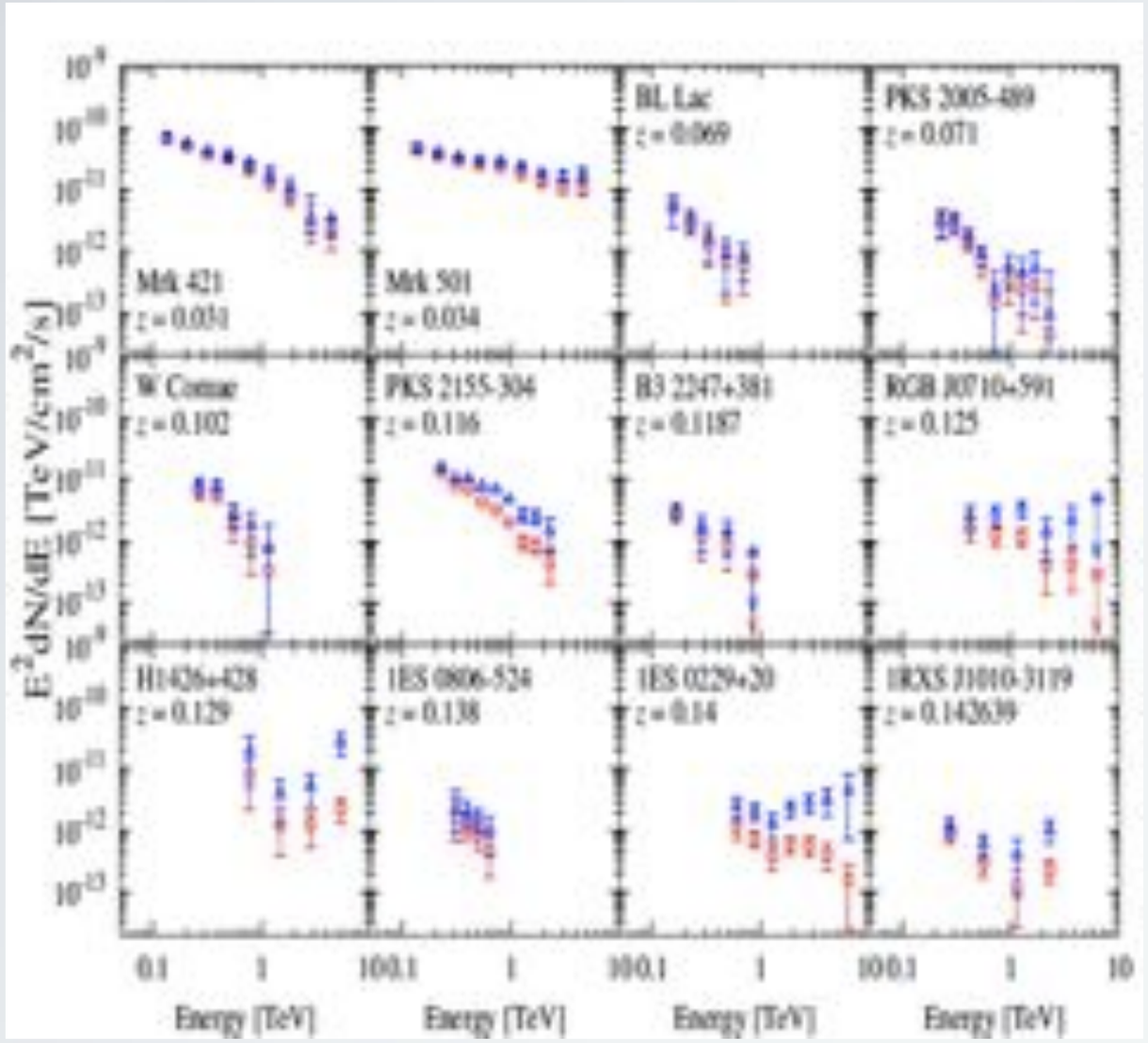
Opacity Evolution

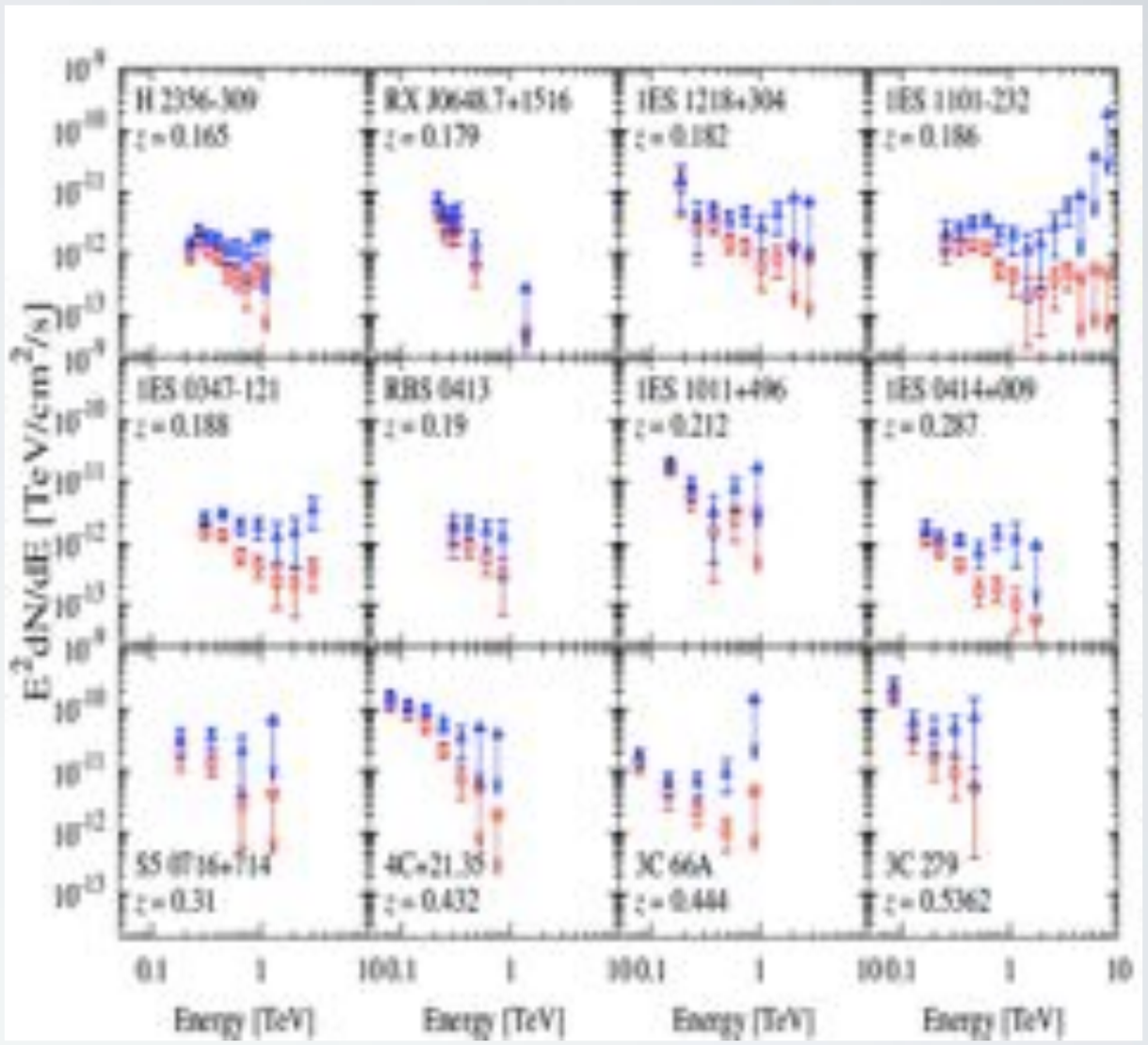


High-z Opacity



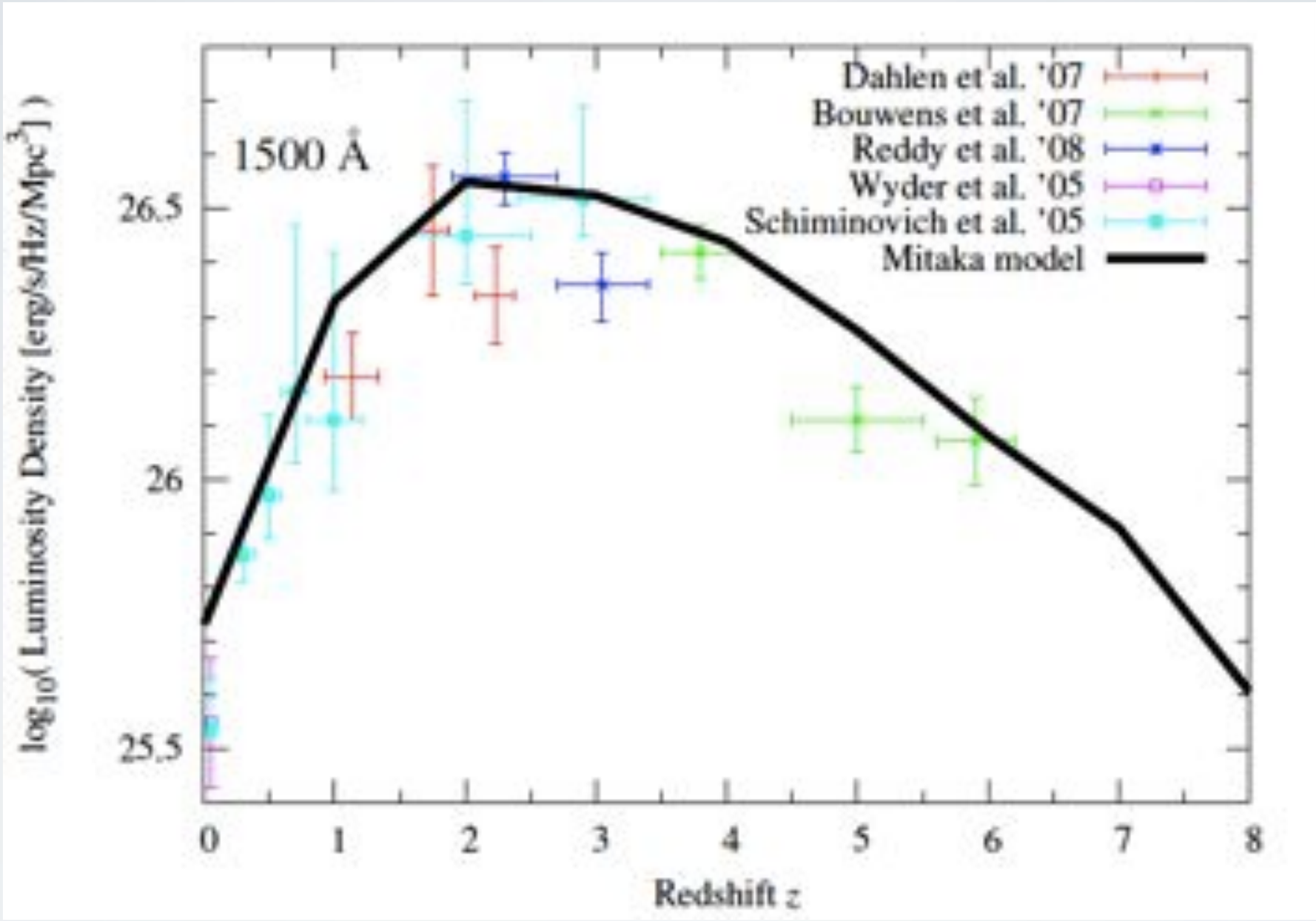
TeV Blazars



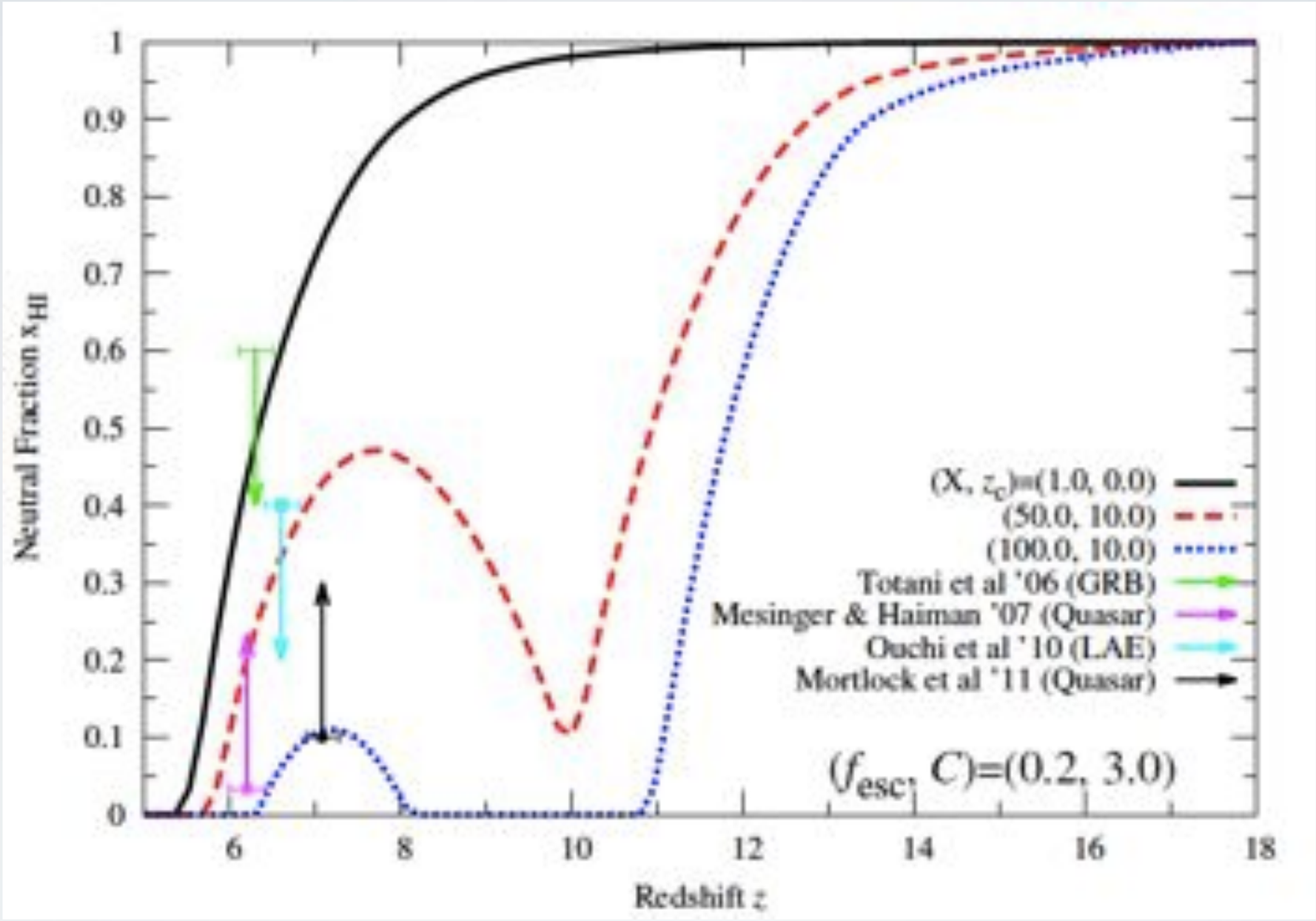


- Secondary Component around ~500 GeV?
  - Signature of VHE cascade emission? (e.g. Kusenko+'10)

UV Luminosity Density



Neutral Fraction

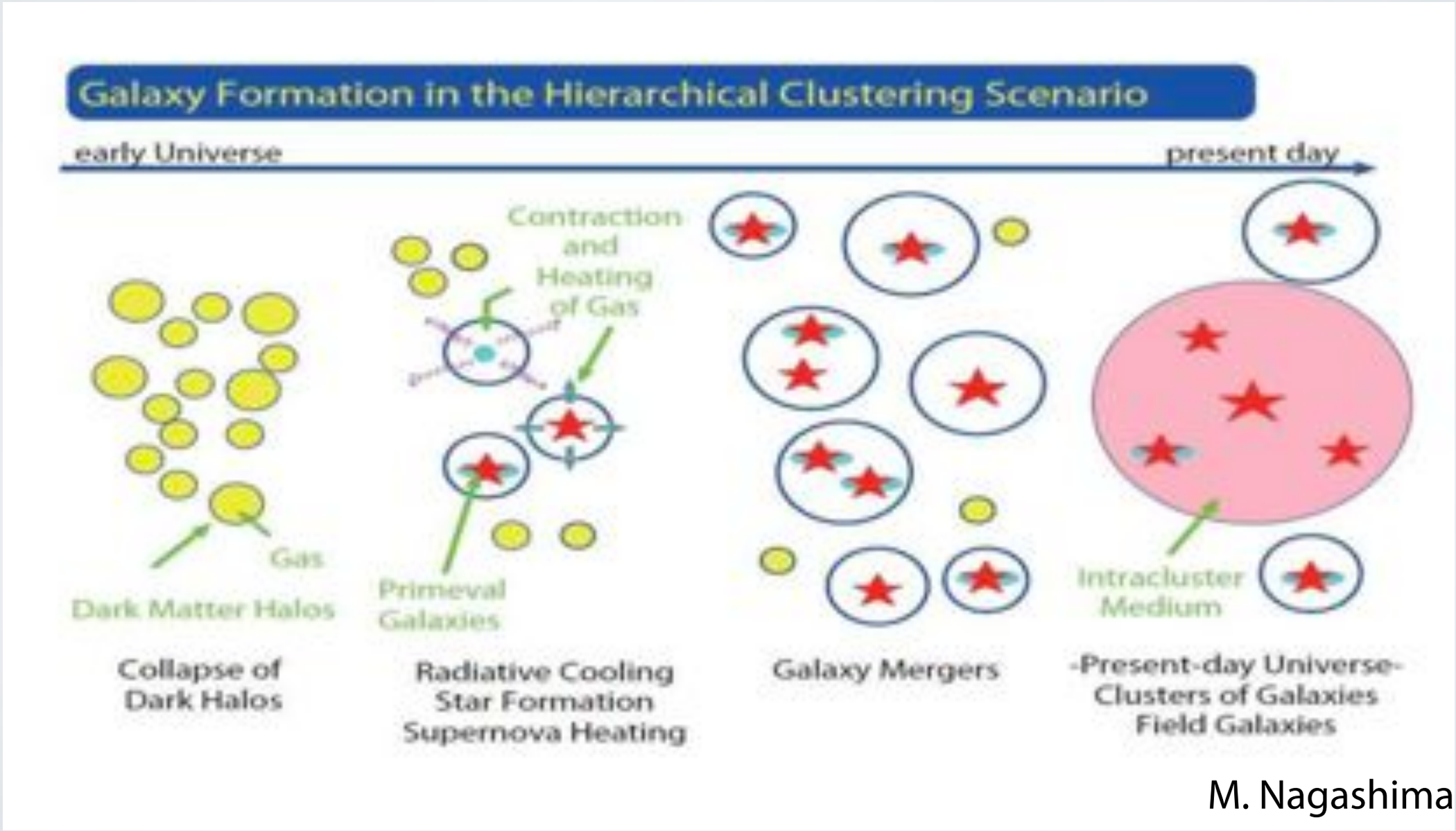


Extragalactic Background Light Models

- **Backward Evolution Model**
  (e.g. Malkan & Stecker '01, Totani & Takeuchi '02, Stecker+'06, Franceschini+'08, Dominguez +'11,Stecker+'12)
  - Extrapolate the observed galaxy luminosity function.
- **Forward Evolution Model**
  (e.g. Dwek+'98, Salamon & Stecker '98, Kneiske+'02, '10, Razzaque+'09, Finke+'10)
  - Integrate the observed cosmic star formation history.
- **Semi-analytical Model**
  (e.g. Gilmore+'09, Younger & Hopkins '11, Gilmore '12, Somerville+'12)
  - Follow the dark matter halo merger tree.
  - Semi-analytically solve the evolution of galaxies.

Hierarchical Galaxy Formation

- Has been modeled by
  - numerical simulations
  - semi-analytical models (e.g. Mitaka model; Nagashima & Yoshii '04)



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ADD BACKUP SLIDE

- Opacity for Each model
- dtau/dz model