The Infrared Glow of the First Galaxies

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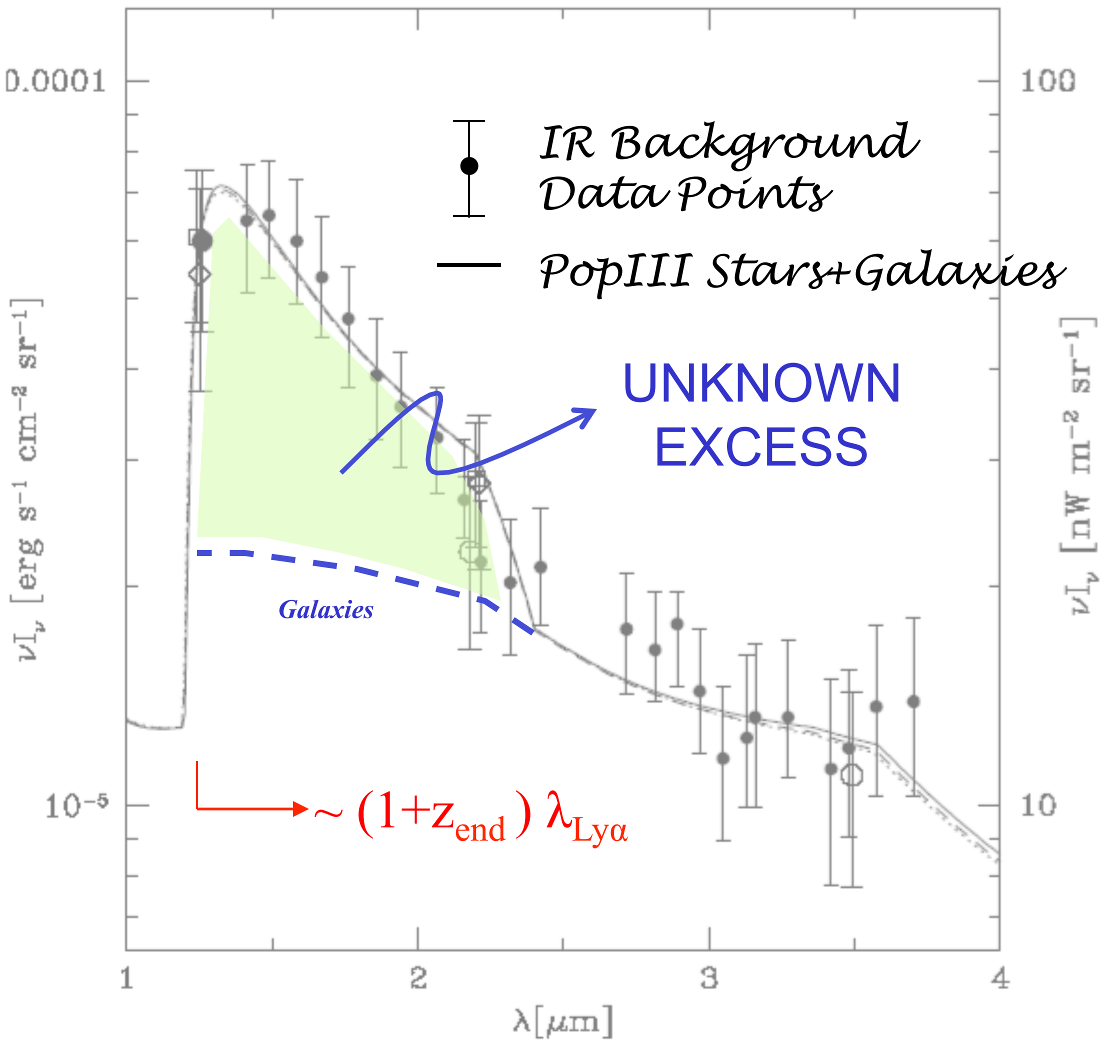
Salvaterra & AF 2002, Santos+02

A PUZZLING EXCESS



Best fit model to NIR data

$$z_{end} = 8.8$$

$$f_\star \approx 30\%$$

Massive Pop III stars can explain NIRB excess

BUT..

Salvaterra+05, Madau & Silk 2005

TOO MANY HIGH-Z GALAXY COUNTS

"Minimal" NIRB model:

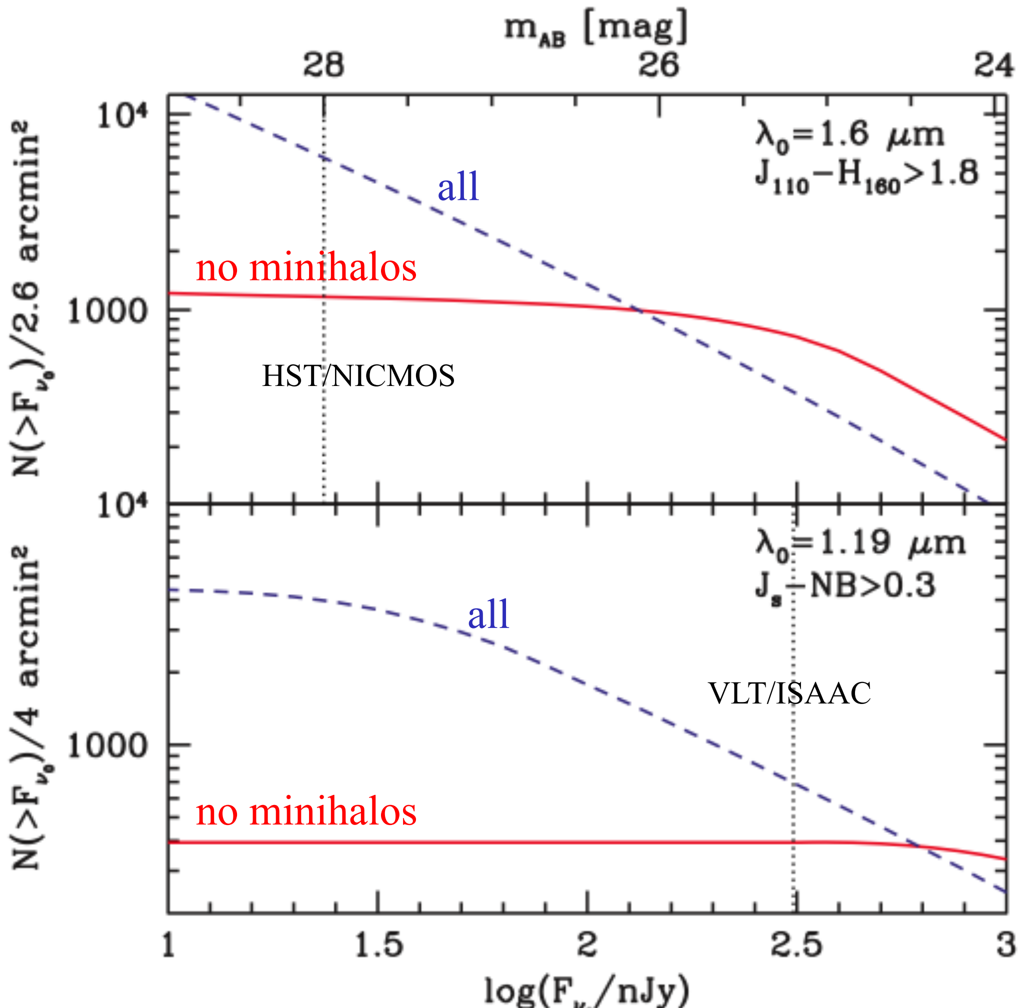
IRTS data + Wright ZL

PopIII stars with δ-fct IMF, M= 300 $M_\odot$

Expected galaxy counts

$$z \approx 10$$

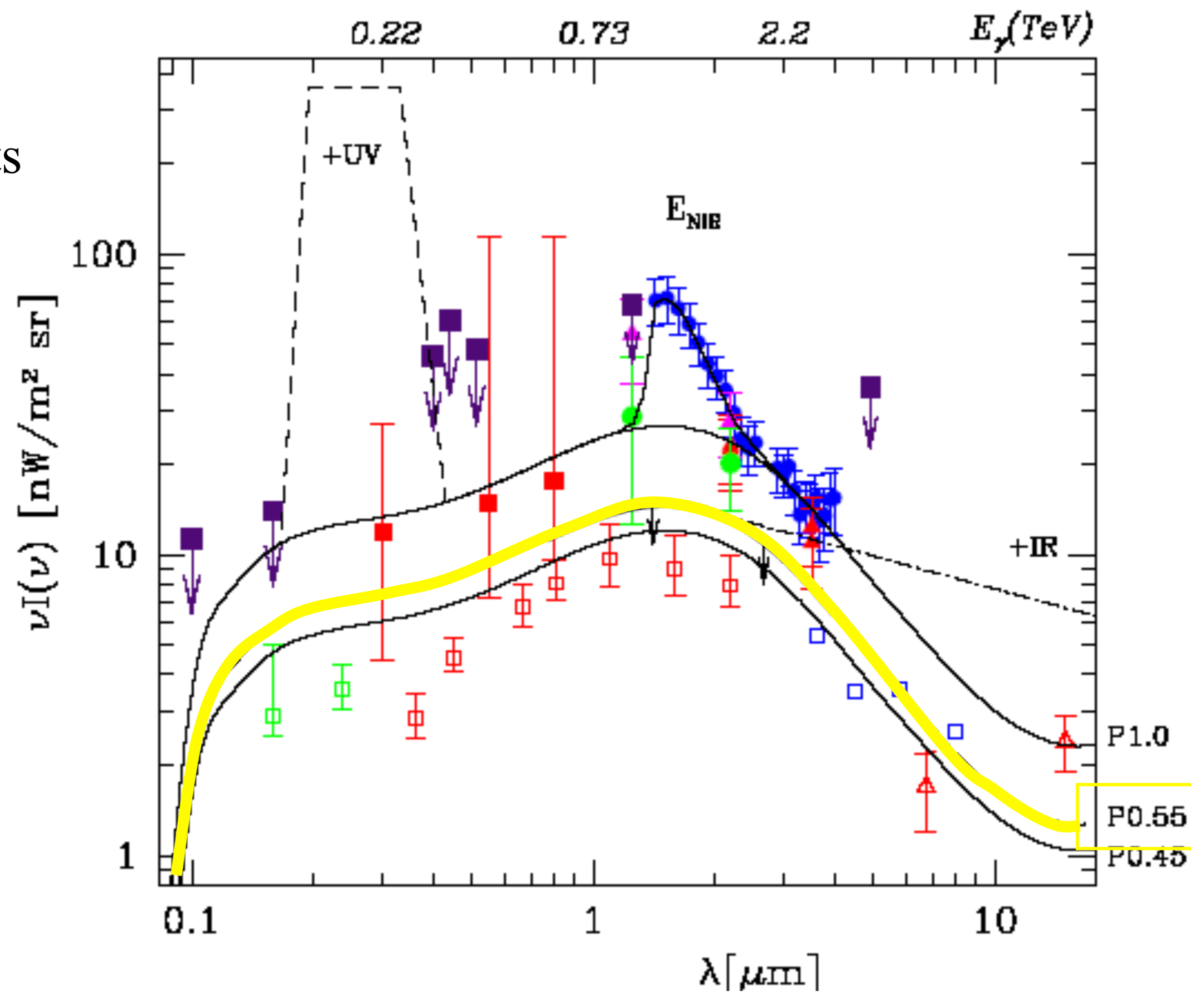
$$f_{\mathrm{NIRB}}(\mathrm{PopIII}) \leq 1\%$$



Aharonian+05, Dwek+05

GAMMA-RAY CONSTRAINTS

- Galaxy counts
- Direct measurements

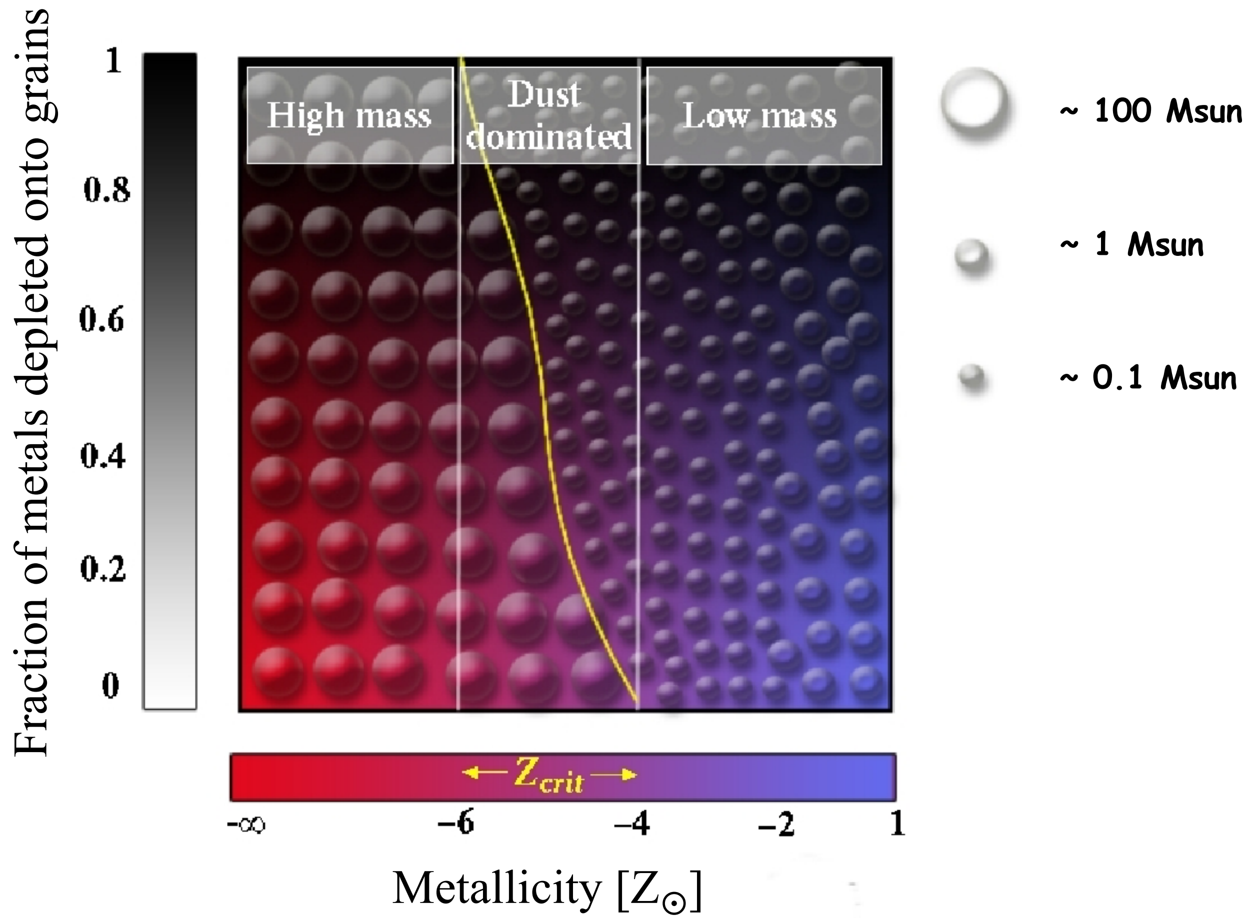


See also Mapelli+05

Modern Approaches

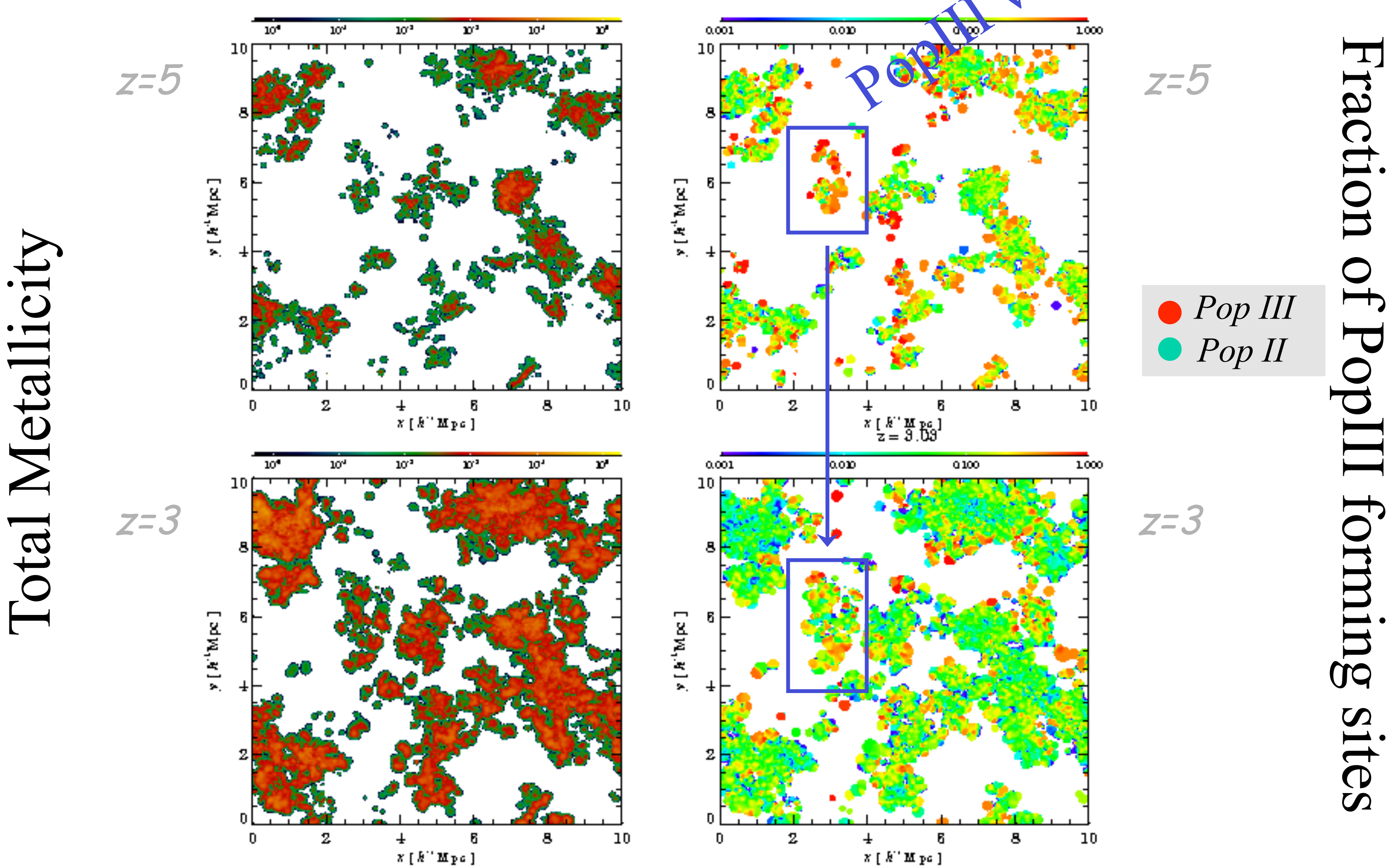
Schneider, AF+02, 06, 12

MASS OF EARLY STARS



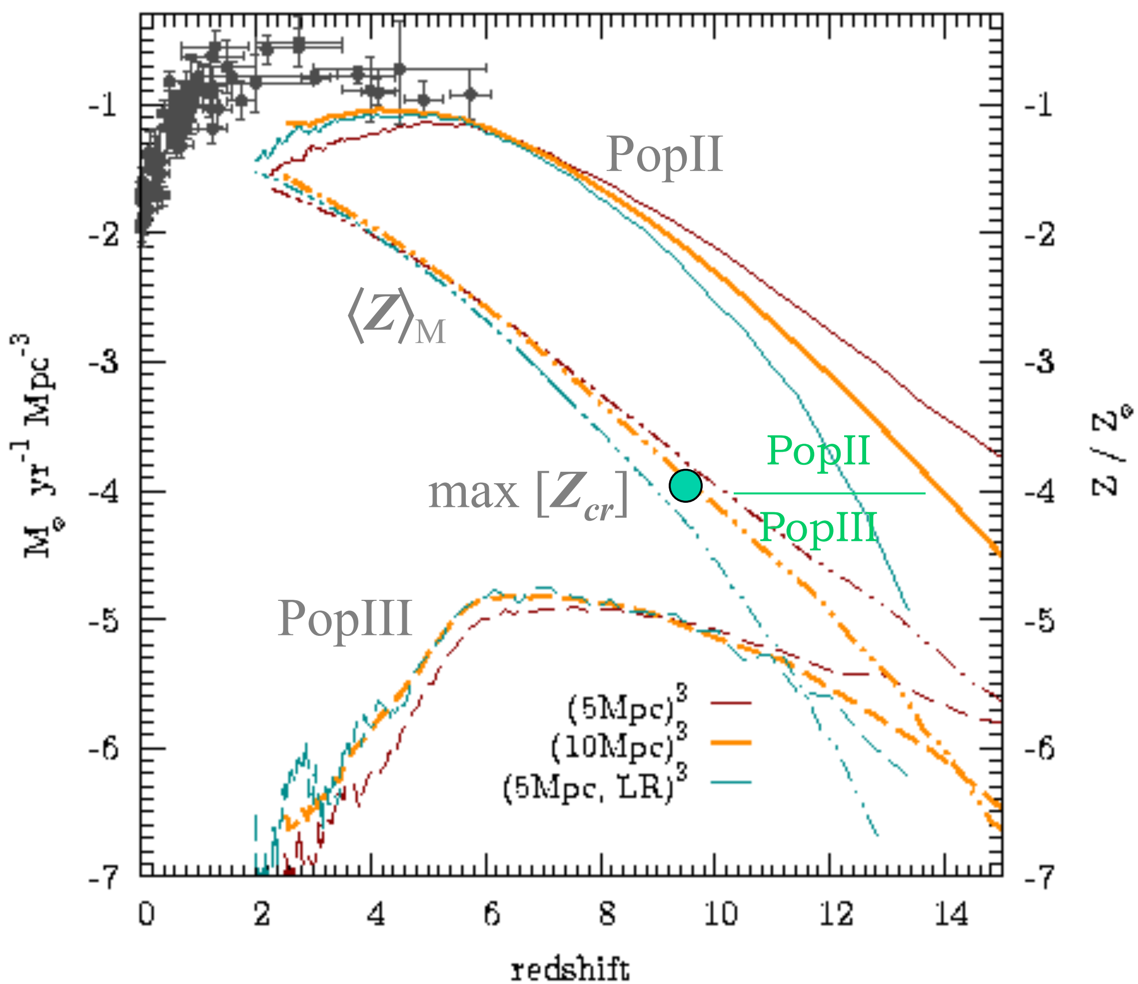
Tornatore, AF & Schneider 2007

COSMIC POPIII/POP II TRANSITION



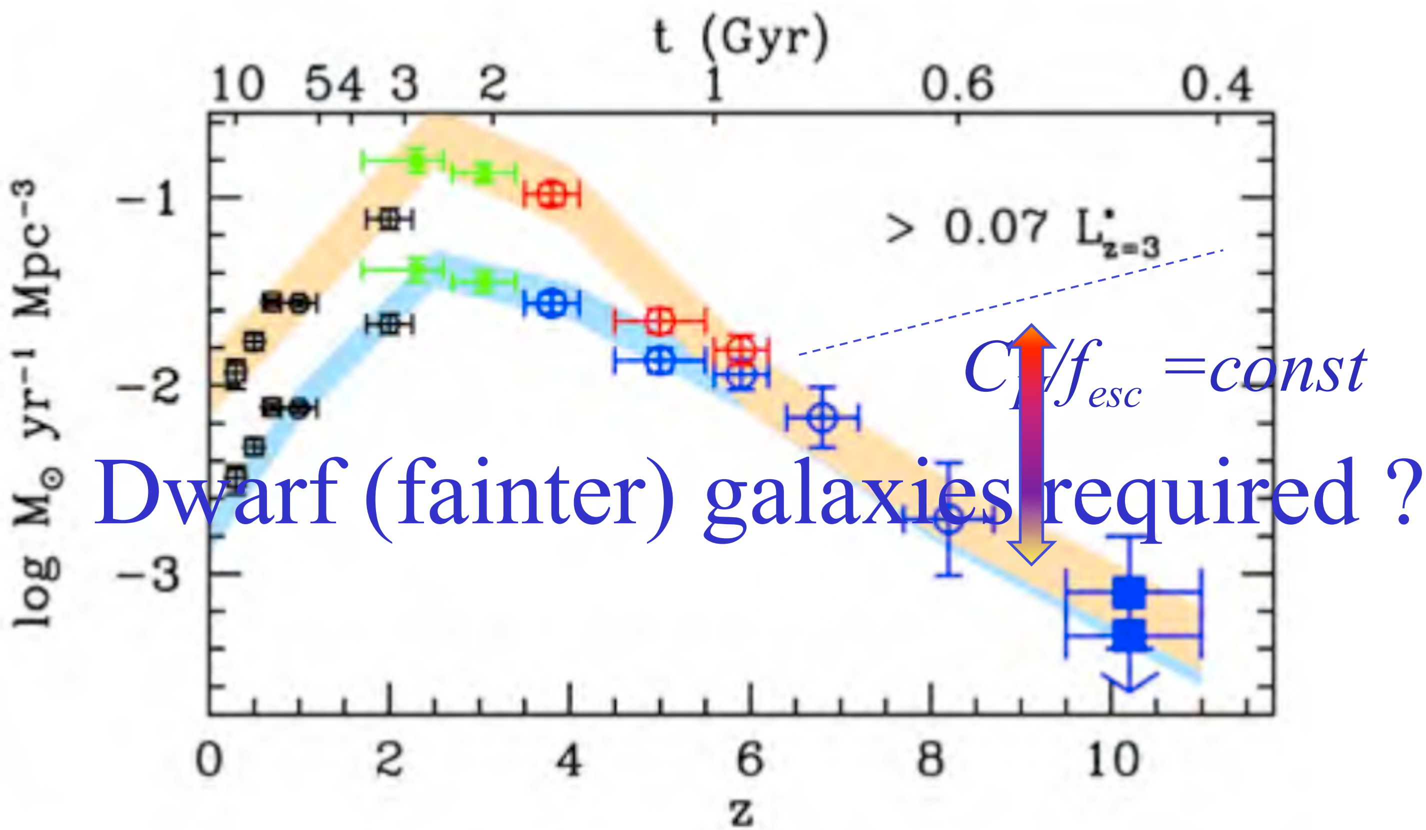
Tornatore, AF & Schneider 2007

STAR FORMATION RATES



DROPOUTS CONSTRAINTS

$$\dot{\rho}_{\rm crit} = (0.018\ M_\odot\ {\rm yr}^{-1}\ {\rm Mpc}^{-3}) \left[\frac{(1+z)}{8}\right]^3 \left[\frac{C_H/3}{f_{\rm esc}/0.2}\right] \left[\frac{0.004}{Q_{\rm LyC}}\right] T_4^{-0.845}$$



Choudhury & AF 2006, 2007

SMALL OR LARGE ?

Searching for the reionization sources

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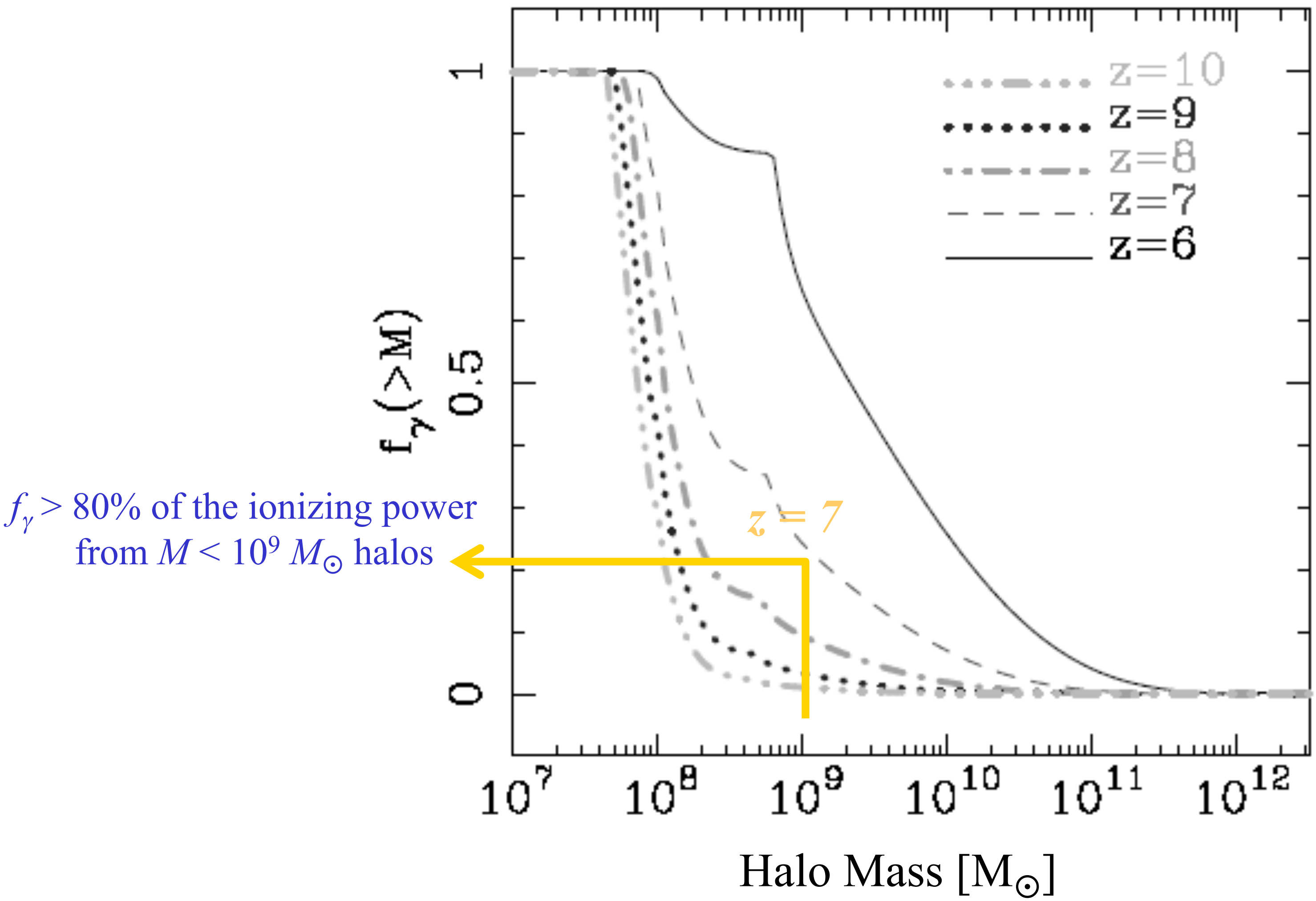
ABSTRACT
Using a reionization model simultaneously accounting for a number of experimental data sets, we investigate the nature and properties of reionization sources. Such model predicts that hydrogen reionization starts at $z \approx 15$, is initially driven by metal-free (PopIII) stars, and is 90% complete by $z \approx 8$. We find that a fraction $f_\gamma > 80\%$ of the ionizing power at $z \geq 7$ comes from haloes of mass $M < 10^9 M_\odot$ predominantly harboring PopIII stars; a turnover to a PopII-dominated phase occurs shortly after, with this population, residing in $M > 10^9 M_\odot$ haloes, yielding $f_\gamma \approx 60\%$ at $z = 6$. Using Lyman-break broadband dropout techniques, J-band detection of sources contributing to 50% (90%) of the ionizing power at $z \sim 7.5$ requires to reach a magnitude $J_{110,AB} = 31.2(31.7)$, where $\sim 15(30)$ (PopIII) sources/arcmin^2 are predicted. We conclude that $z > 7$ sources tentatively identified in broadband surveys are relatively massive ($M \approx 10^9 M_\odot$) and rare objects which are only marginally ($\approx 1\%$) adding to the reionization photon budget.

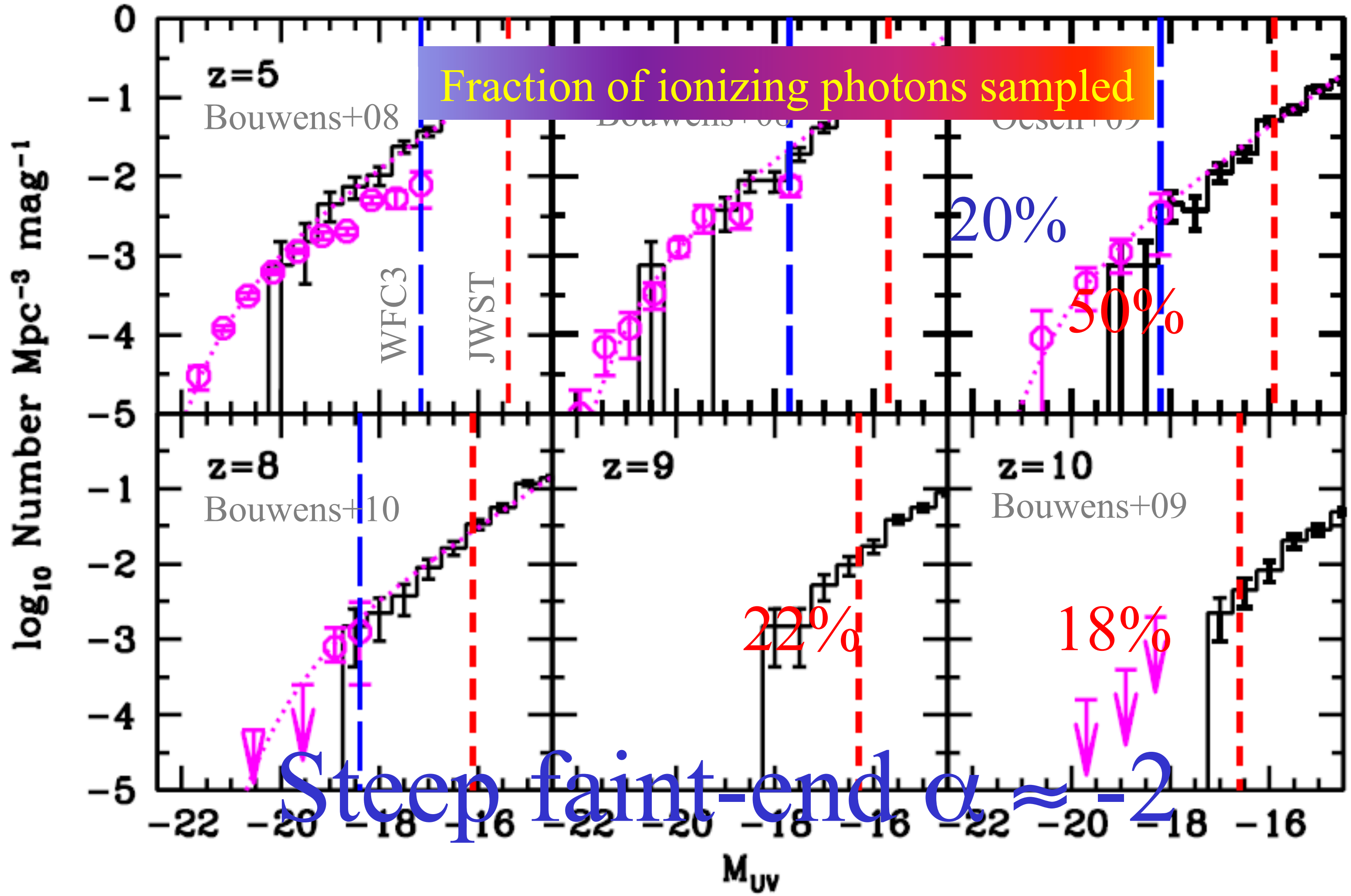
Choudhury & AF 2007

IONIZING PHOTON BUDGET



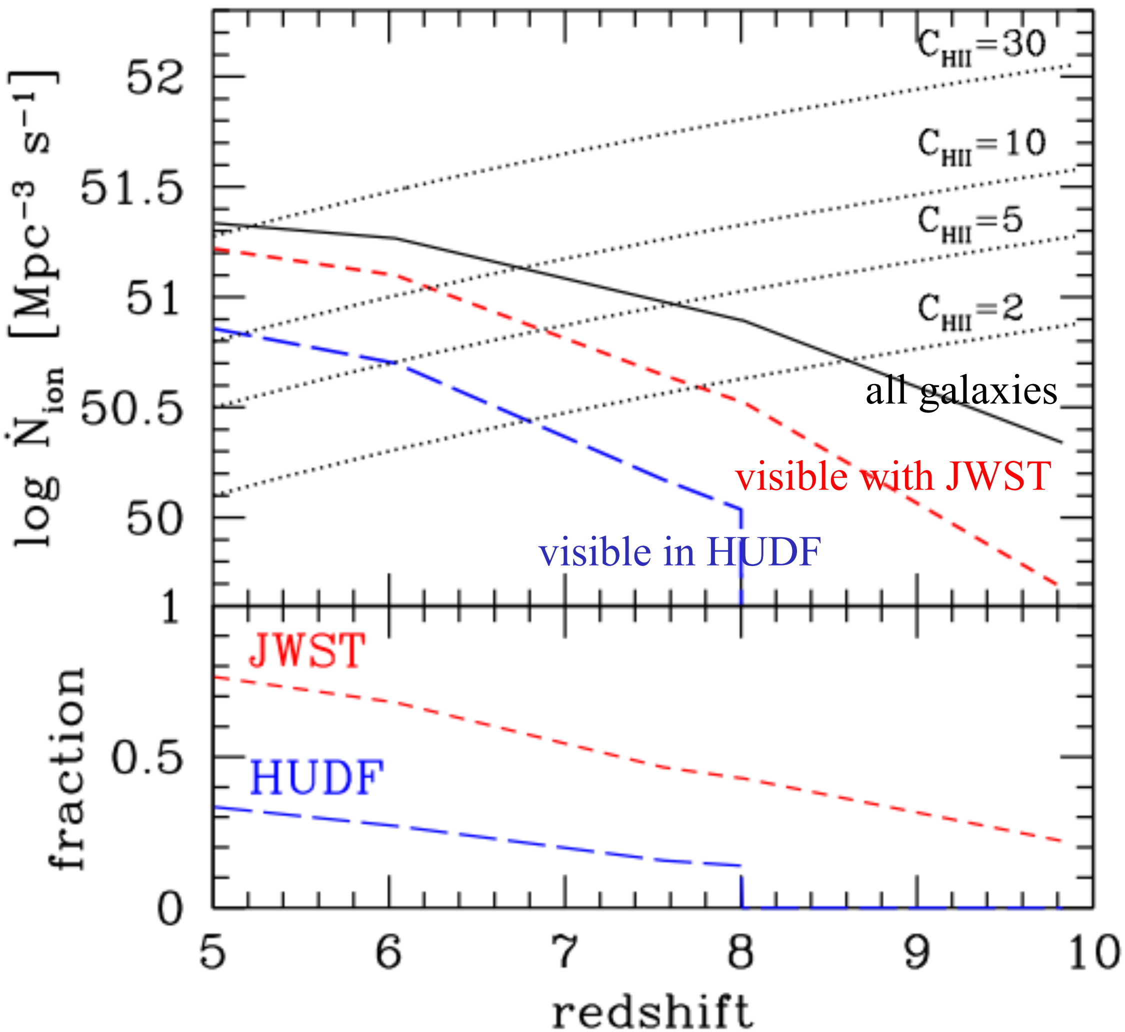
Salvaterra, AF, Dayal 2011

HIGH-Z LUMINOSITY FUNCTIONS



Salvaterra+11

IONIZING EMISSIVITY



Ionizing phot. emissivity

Fraction produced by visible galaxies

MODEL SUMMARY

(a) Chemical feedback regulated PopIII/Pop II transition
(b) Radiative feedback: H_2 minihalo suppression + photoevaporation
(c) Population spectral synthesis according to age, metallicity and (Salpeter) IMF for PopIII and PopII stars in each galaxy to get emissivity
(d) Reproduces high-z dropout galaxy LFs AND *reionization bounds (G-P and CMB)*
(e) Angular correlation of intensity fluctuations $C(\theta)$ from Peacock & Dodds formalism

From: simulations ($\epsilon_\nu^2(z)$), Lyα model ($e^{-2\tau_{eff}}$)

$$C(\theta) = \left(\frac{1}{4\pi}\right)^2 \int_{z_0}^{\infty} dz \, \frac{\epsilon_\nu^2(z)}{(1+z)^2} \, e^{-2\tau_{eff}} \left(\frac{dx}{dz}\right) \int_{-\infty}^{\infty} du \, \xi_g(r,z)$$

NON LINEAR GALAXY 2P C.F. $\xi_g(r,z) = \xi(r,z) b_{\rm eff}^2(z)$ MASS 2P C.F × (BIAS)^2

$$b_{\rm eff}(z) = \frac{\int_{M_{min}(z)}^{M_{max}(z)} dM_h \, b(M_h,z) \, \frac{dn}{dM_h}(M_h,z) \, f(M_h,z)}{\int_{M_{min}(z)}^{M_{max}(z)} dM_h \, \frac{dn}{dM_h}(M_h,z) \, f(M_h,z)},$$

Salvaterra+06, Cooray+06, Sullivan+06, Thompson+07, Fernandez+06,10,12

FLUCTUATIONS

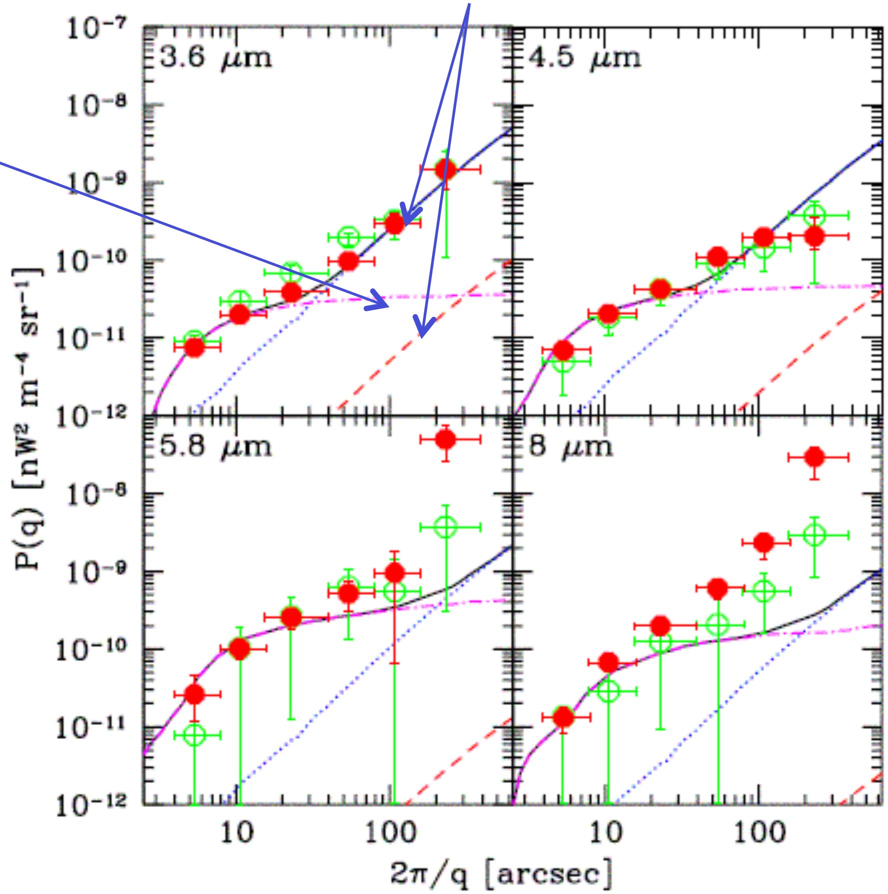
$$P(q) = 2\pi \int_0^\infty C(\theta) J_0(\theta, q)\theta d\theta$$

Clustering *z >5* galaxies

Shot noise
z <5 galaxies

POPII

POPIII



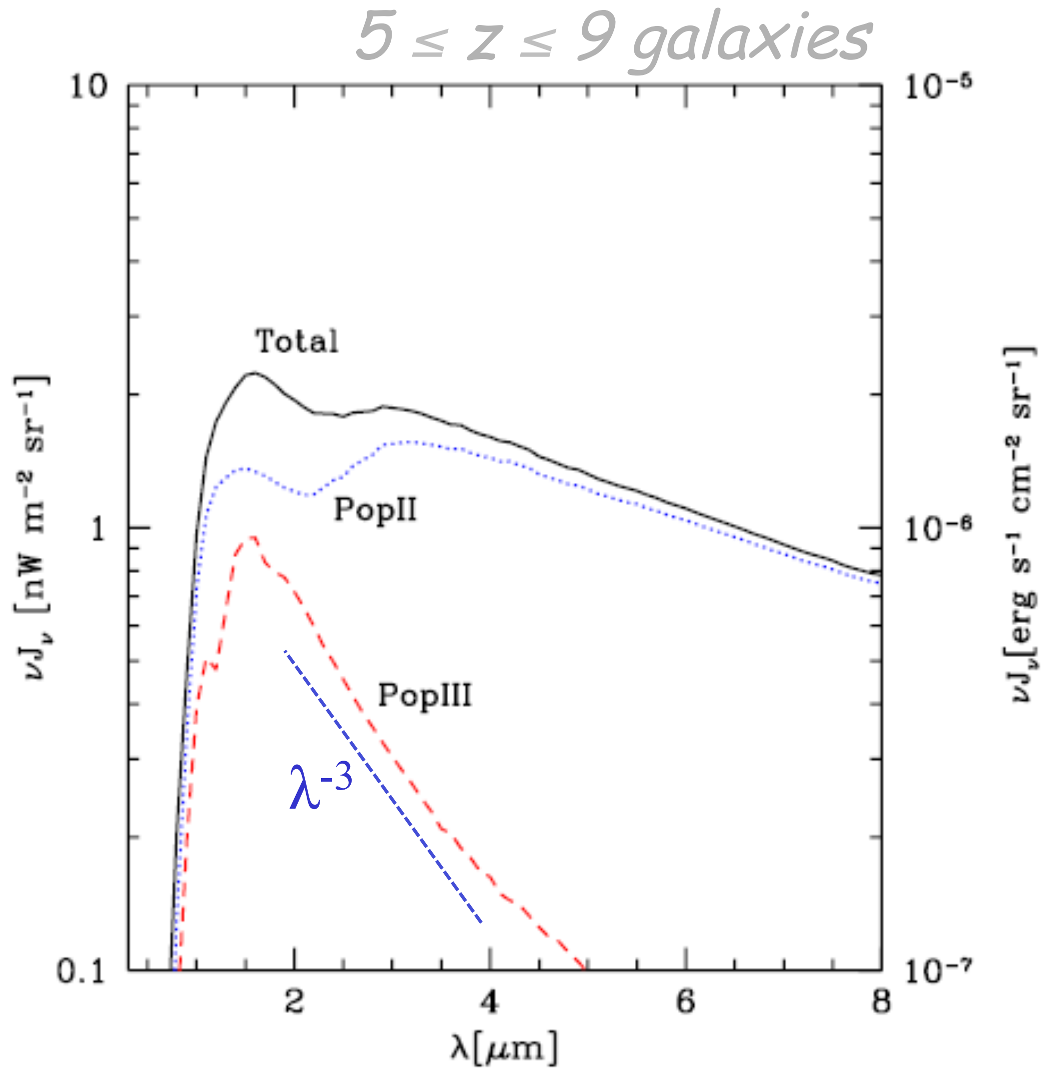
Spitzer/IRAC data

Kashlinsky+ 2005, 2007

Salvaterra+06

Salvaterra+06

INTENSITY



- Pop III stars disappear very rapidly: transition to normal stars at $Z_{crit} \approx 10^{-5\pm1} Z_{\odot}$
- Reionization sources populate the (steep) faint-end of LF ($M_{UV} > -18$)
- NIRB fluctuations at 3.6 and 4.5 μm consistent with clustering of reionization sources
- Pop III contribution always subdominant
- Expected intensity (1-2 nW m^{-2} sr^{-1}) consistent with γ-ray opacity studies
- Problem I: Predicted spectral colors are relatively red.
- Problem II: IRTS/AKARI intensity in J-band inconsistent with γ-ray experiments.