What Constraints Can we Get on the Reionization History from the Optical/Near-Infrared?

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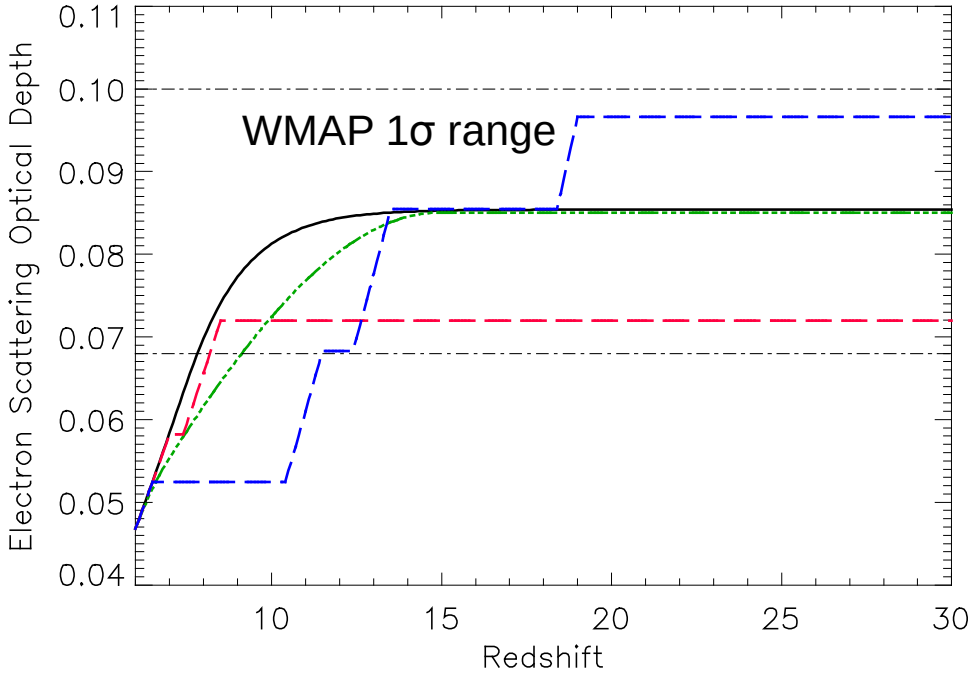
WMAP constrains large HI fractions…..weakly

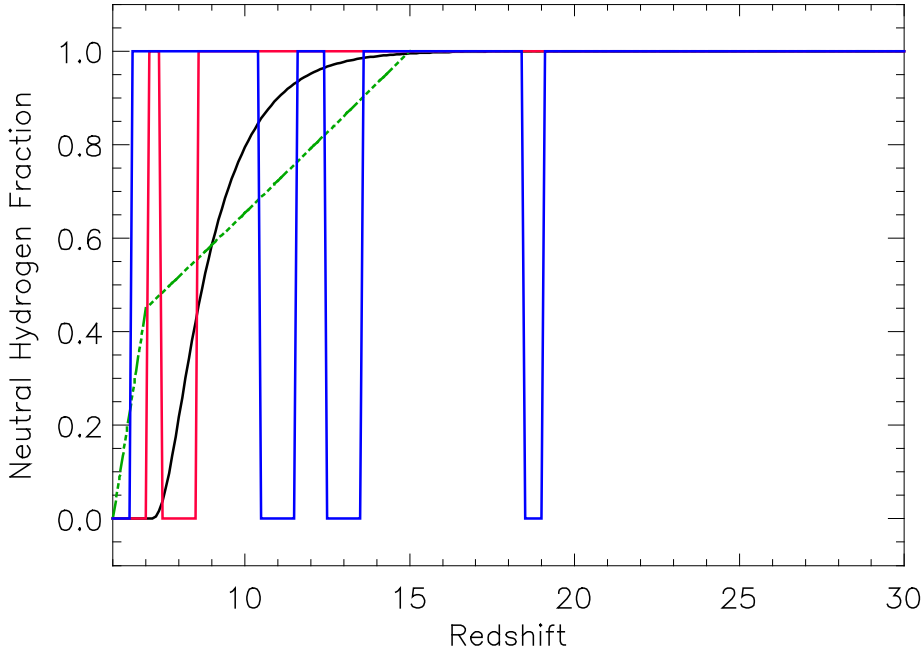
z<6 contributes ~0.04

So 0.044+/-0.016 measures reionization history.

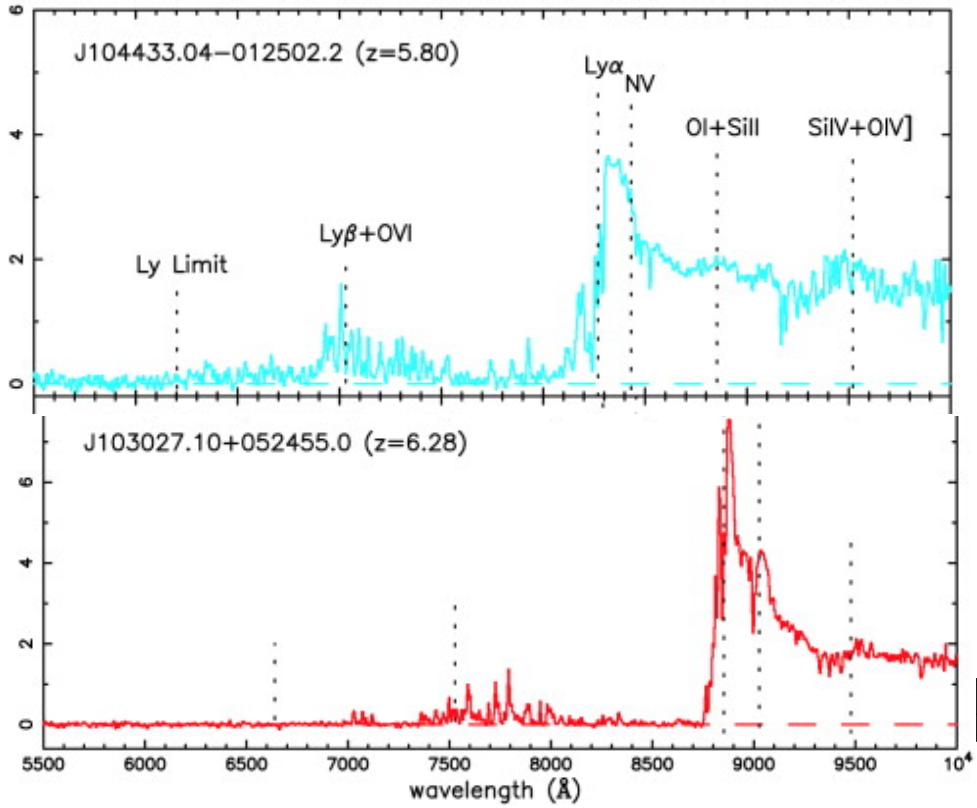
$$\tau = \int_0^{z_e} dz \sigma_T n_e(z) c \frac{dt}{dz}$$

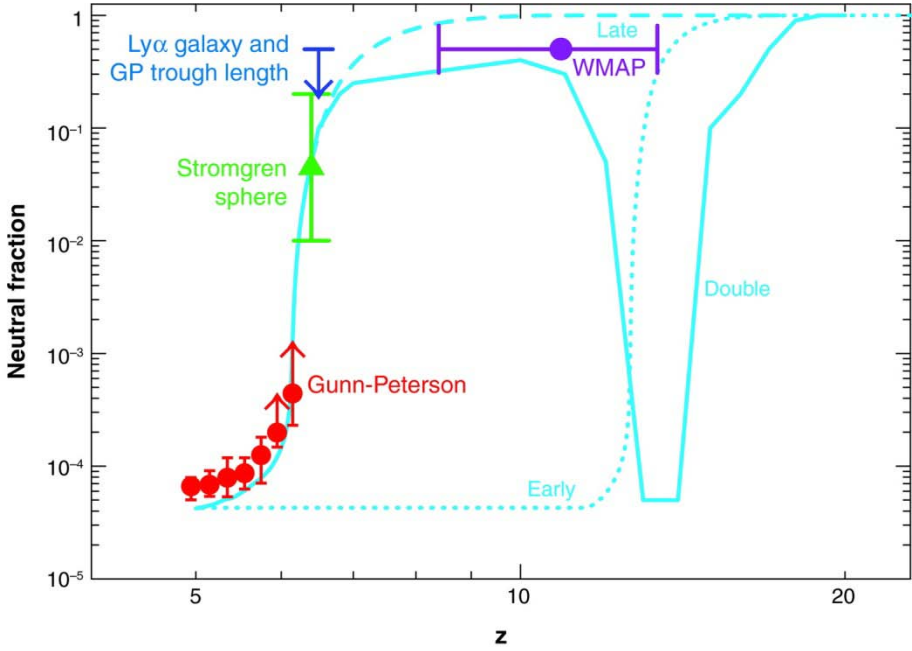
=0.084±0.016





End Stages of Reionization: Constrained by Sloan QSOs

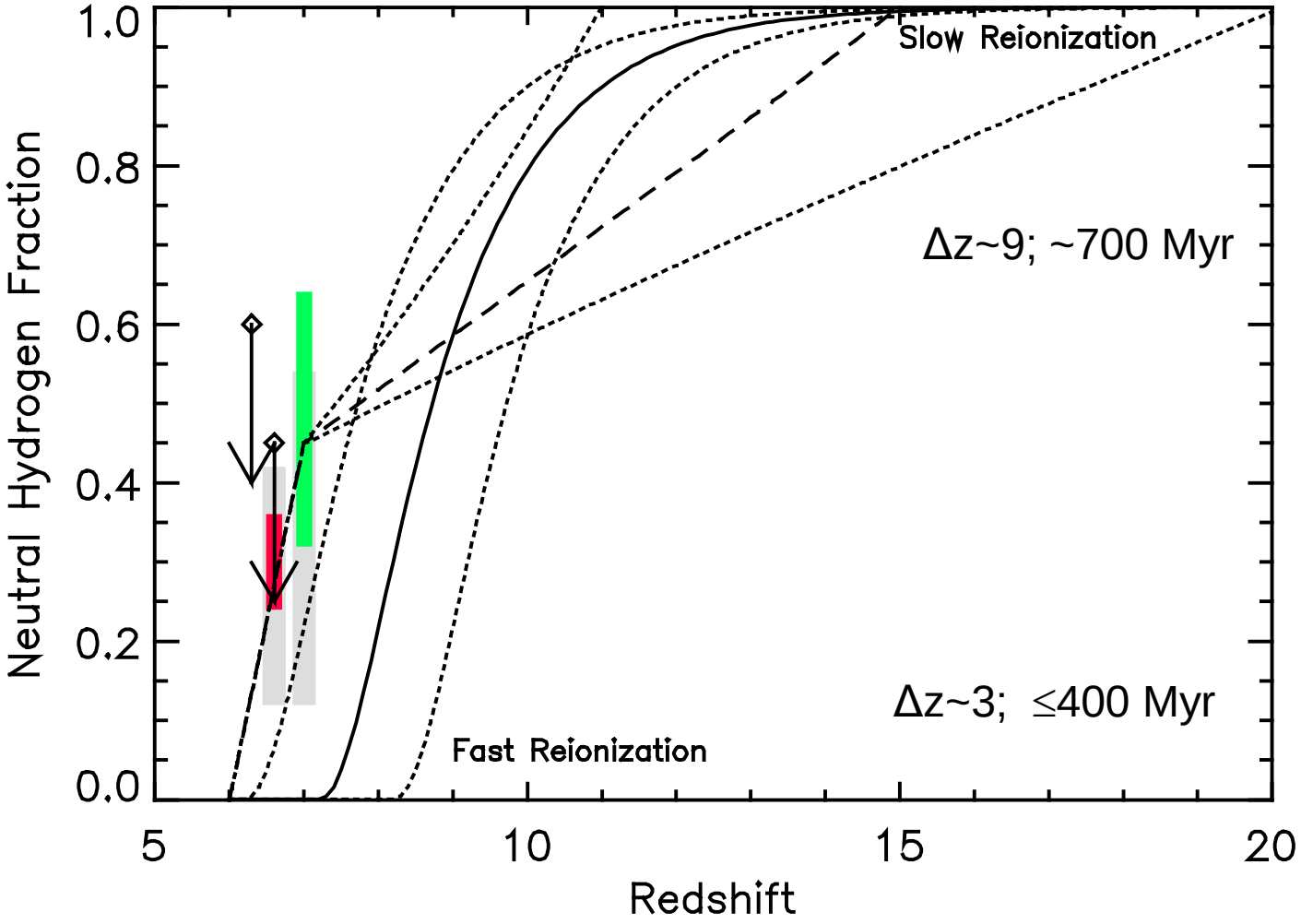




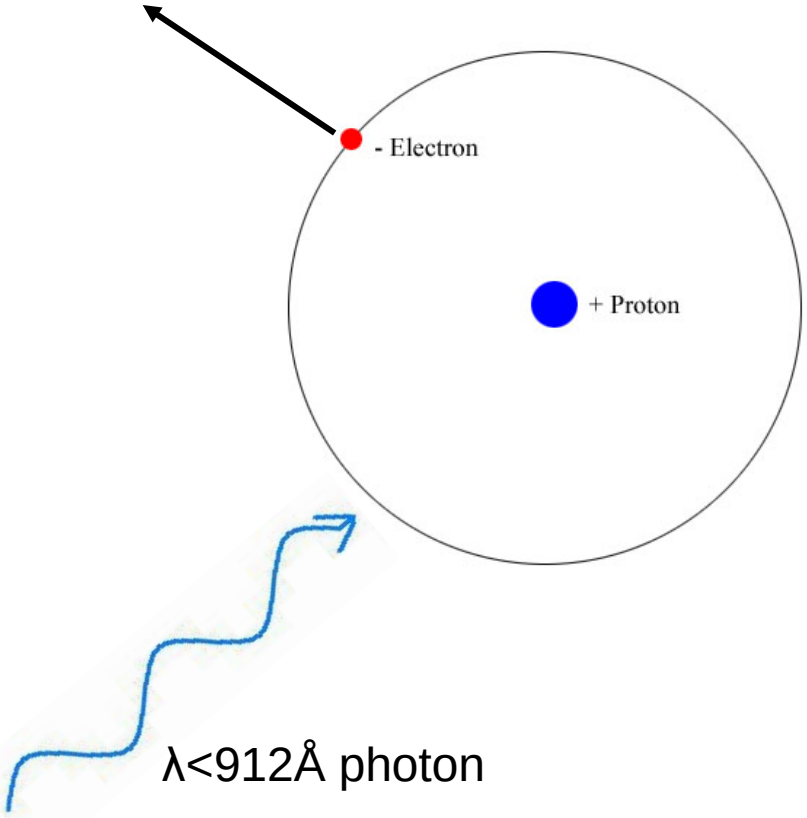
Fan X, et al. 2006.
Annu. Rev. Astron. Astrophys. 44:415–62

- Fan et al., Becker et al., Djorgovski et al. spectra of Sloan quasars showing the Gunn-Peterson trough
- Evidence for $N_H \sim < 10^{-3.5}$

We can measure the comoving rate density of ionizing photons i.e. the SFR



Need 1 photon/baryon to start reionization



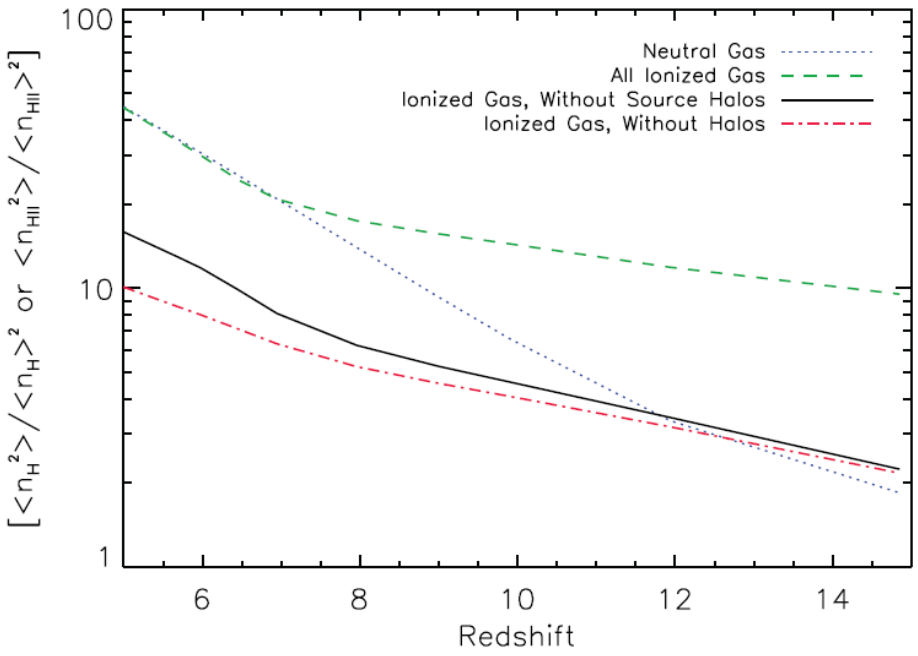
$$R = n_e n_{\mathrm{H\,II}} \alpha_{\mathrm{B}} C \ \mathrm{s}^{-1}\ \mathrm{Mpc},^{-3}$$

Sensitive to:

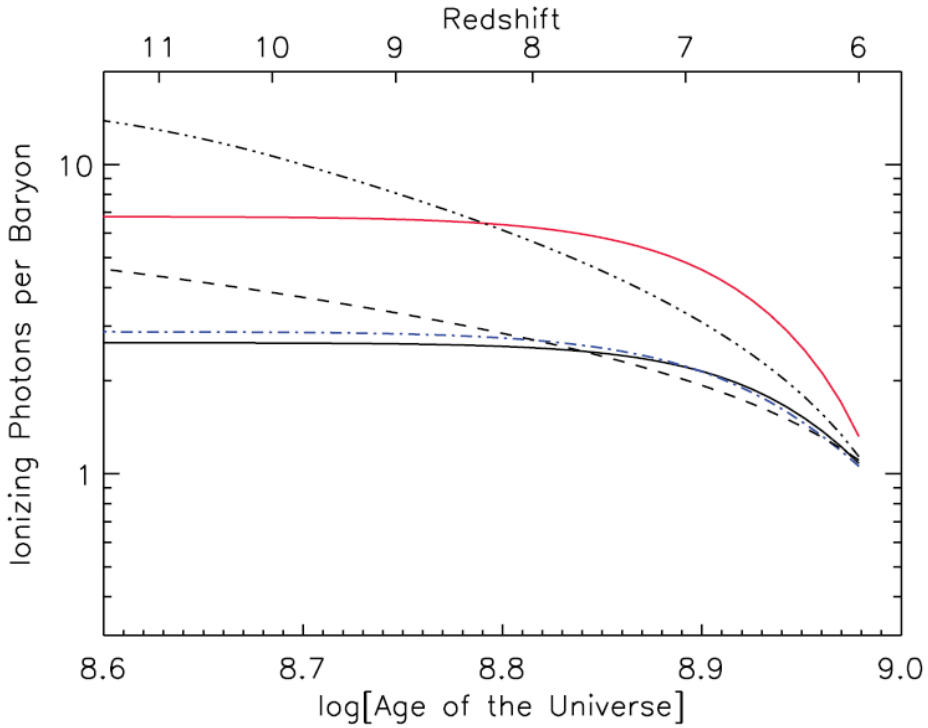
1. Clumpiness of the gas
2. Temperature of the gas
3. Co-moving electron density

Need ~3-10 photons/baryon to maintain ionized hydrogen due to recombinations

There are some nuisance parameters

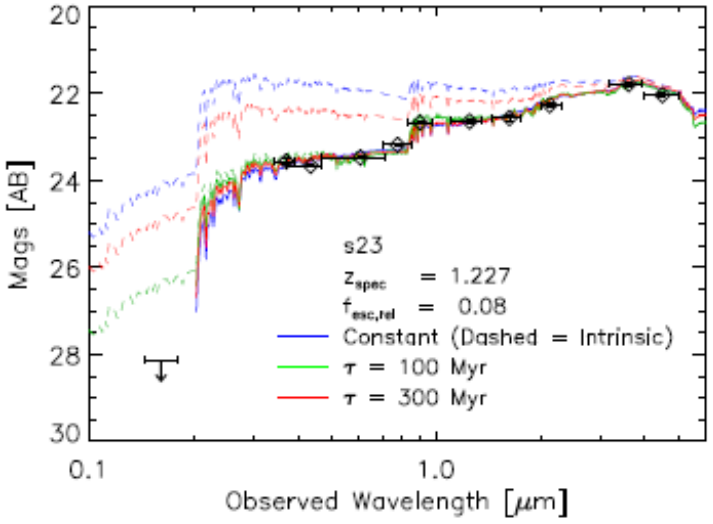


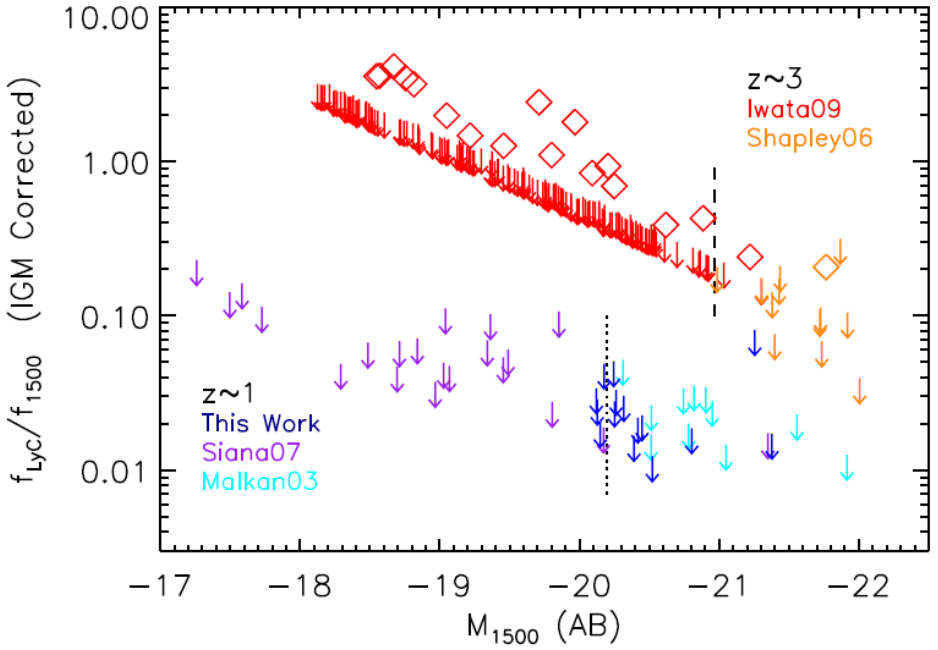
Clumping Factor of Gas
can only be estimated from simulations
e.g. Trac & Cen



Photon Production Rate =
Hydrogen Ionization + Recombination Rate

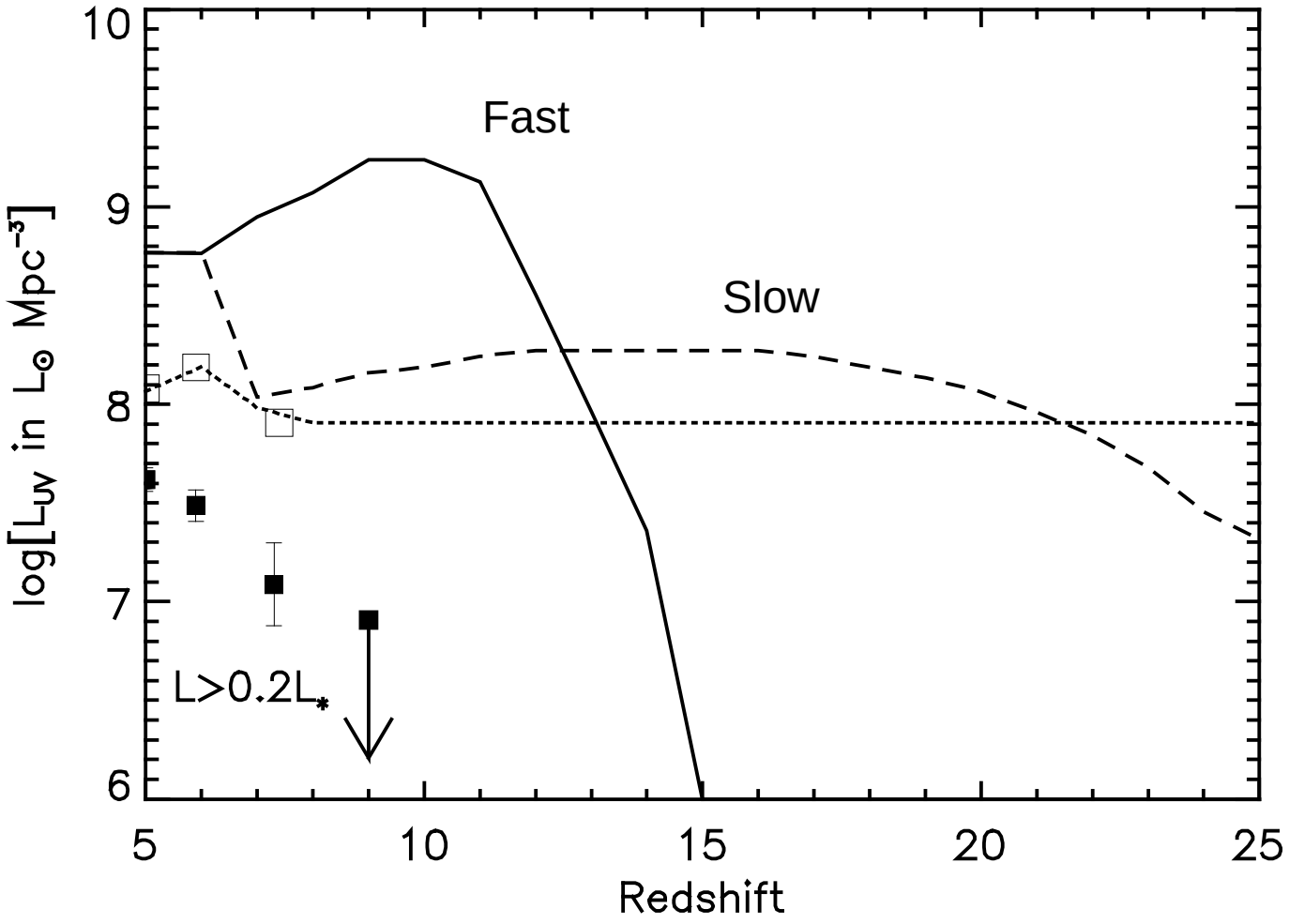
And the Escape Fraction is poorly known

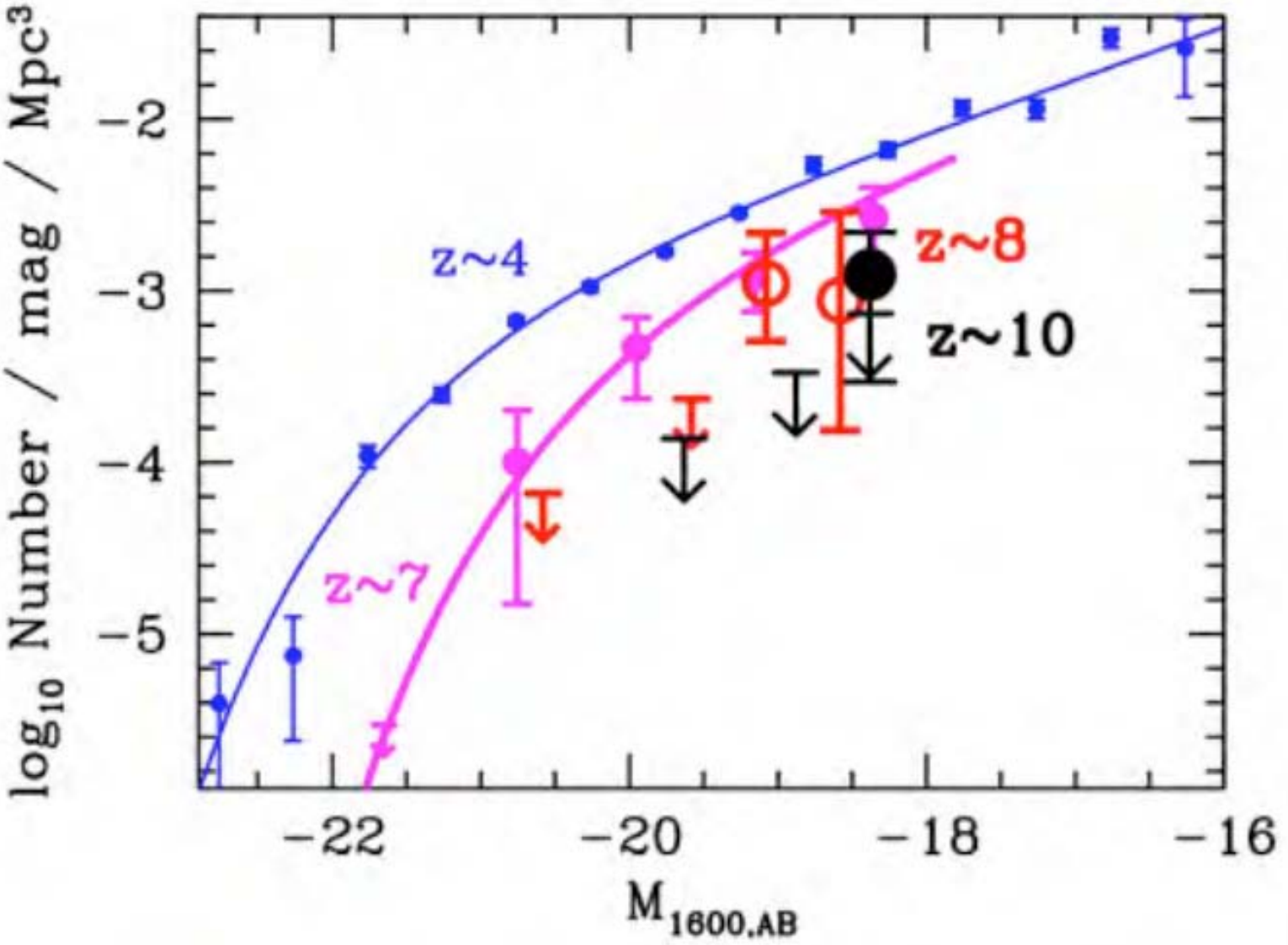




Siana et al. 2010

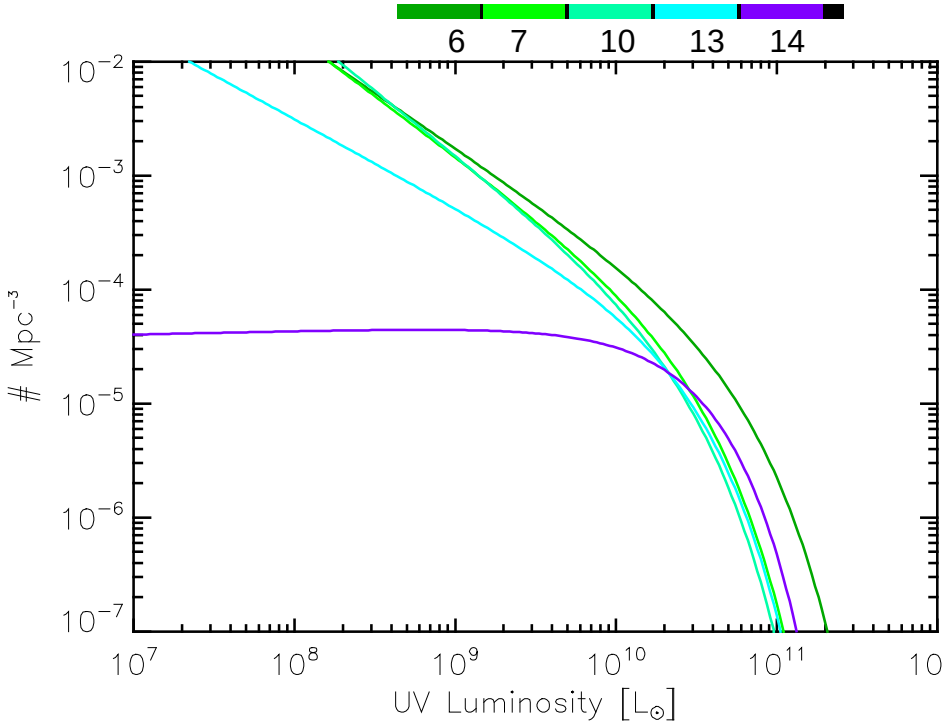
Minimum Required Evolution of UV Luminosity Density for Reionization





S '08
D '10

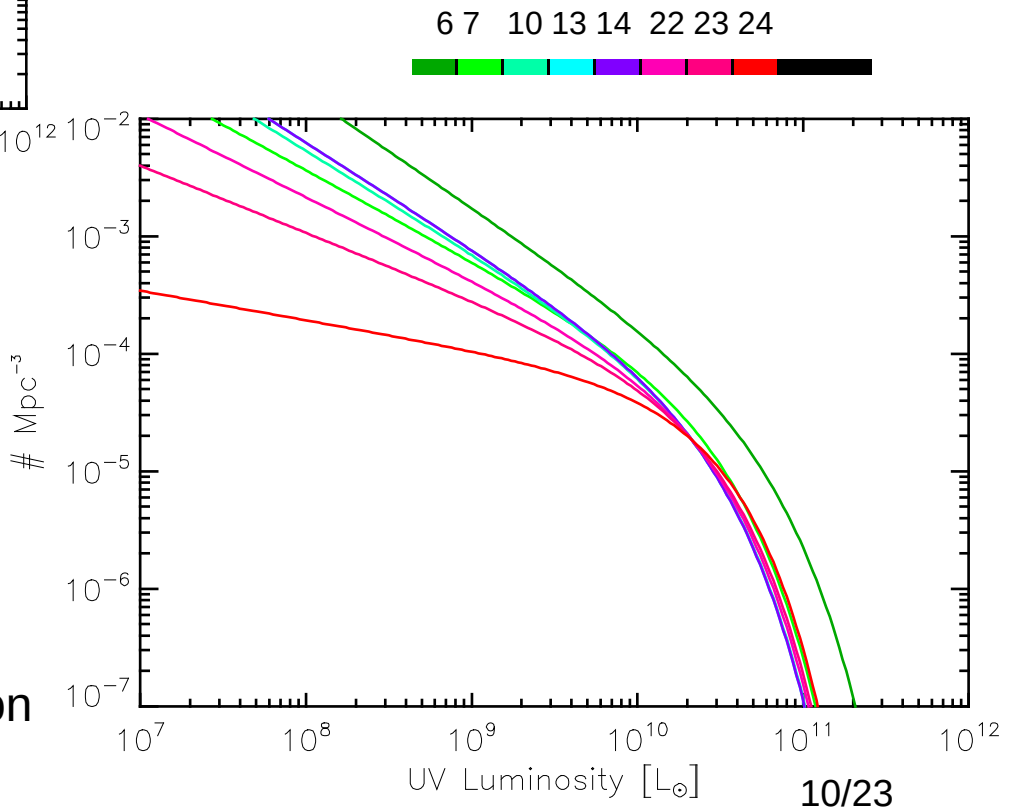
Some uncertainty in the faint end slope of the UVLF
But clear evolution in L* between 6 and 7



Fast Reionization

z	Age(Gyr)
6	0.95
7	0.78
10	0.48
13	0.34
14	0.30
22	0.16

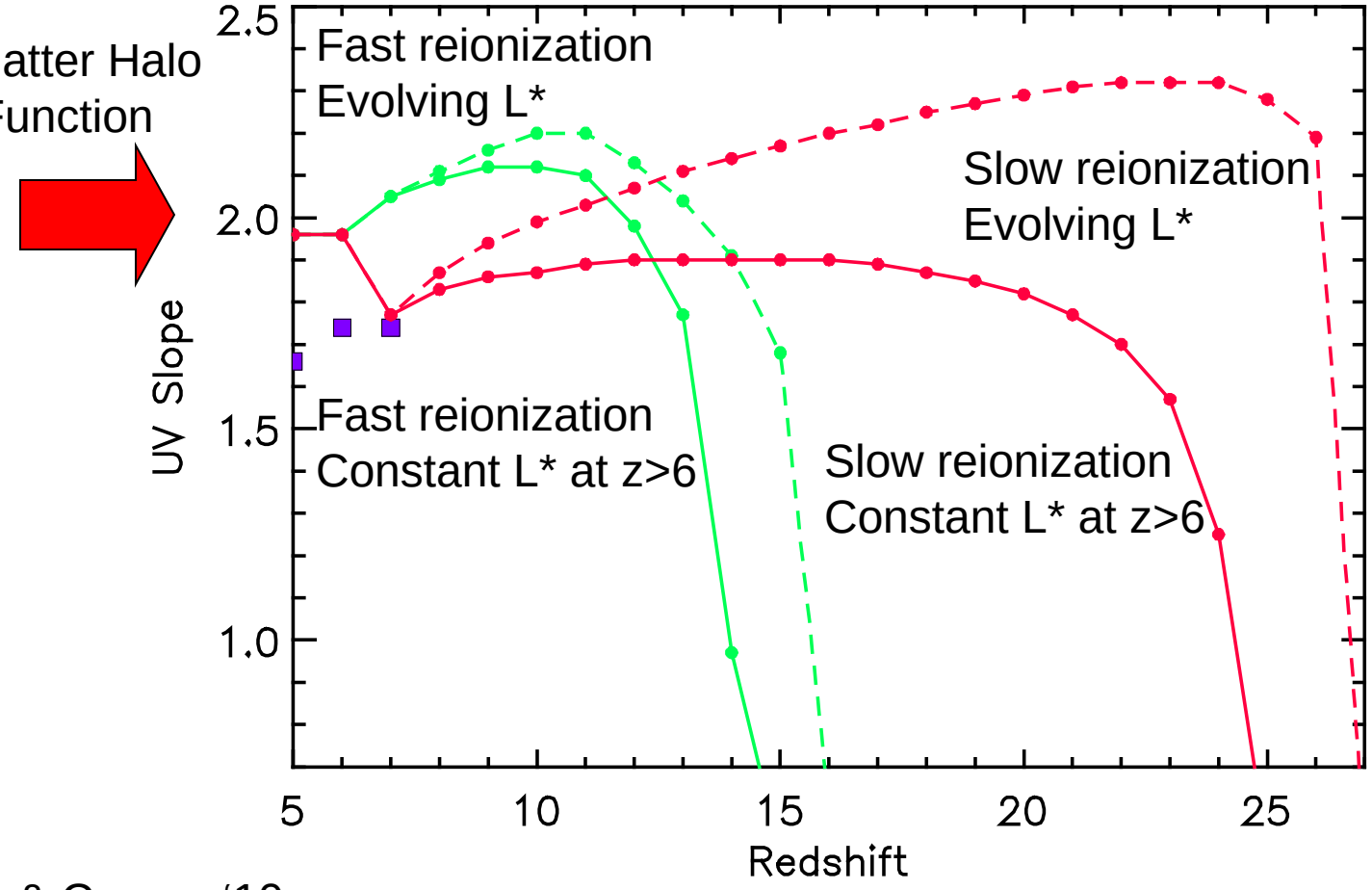
But L* has to be fixed at z>7!



Slow Reionization

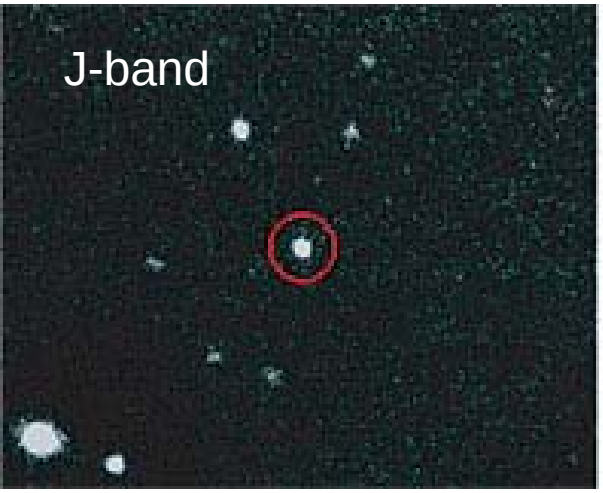
The Faint End of the Galaxy LF cannot be steeper than the Halo Mass Function

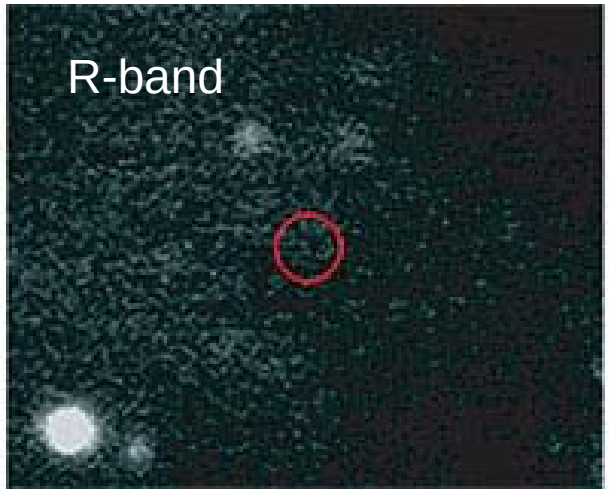
Dark Matter Halo Mass Function

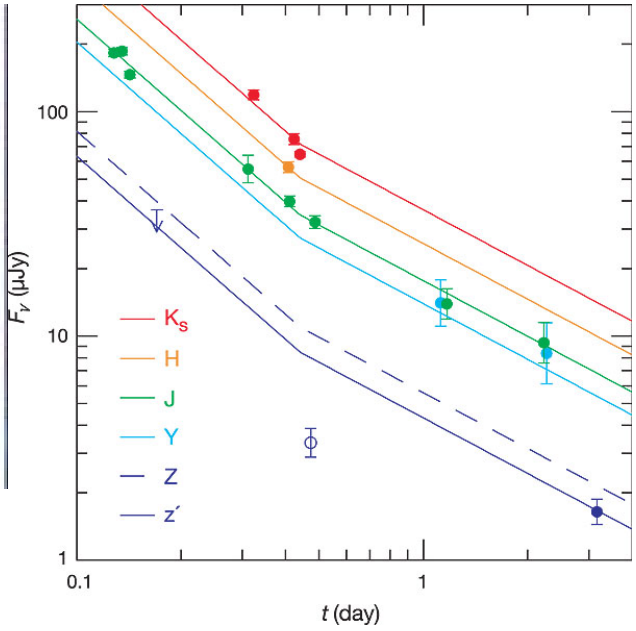


Chary & Cooray '10

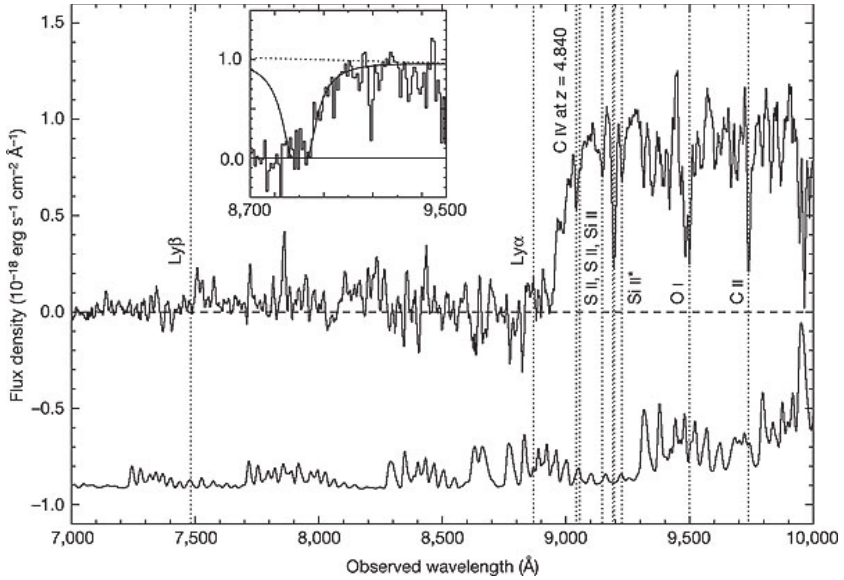
But to see the action, need the faint galaxies. And to see faint galaxies, need cosmic explosions which are x1000 brighter than the galaxy.





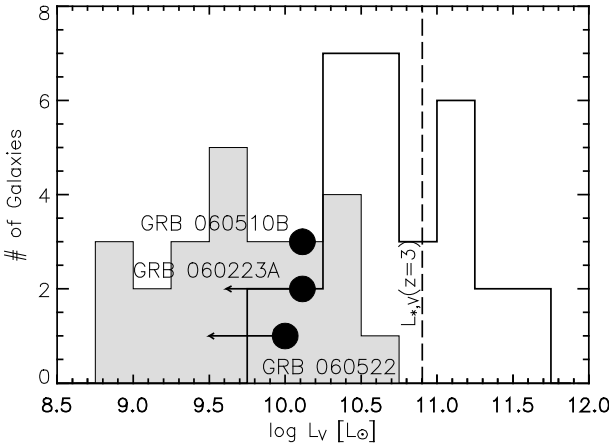


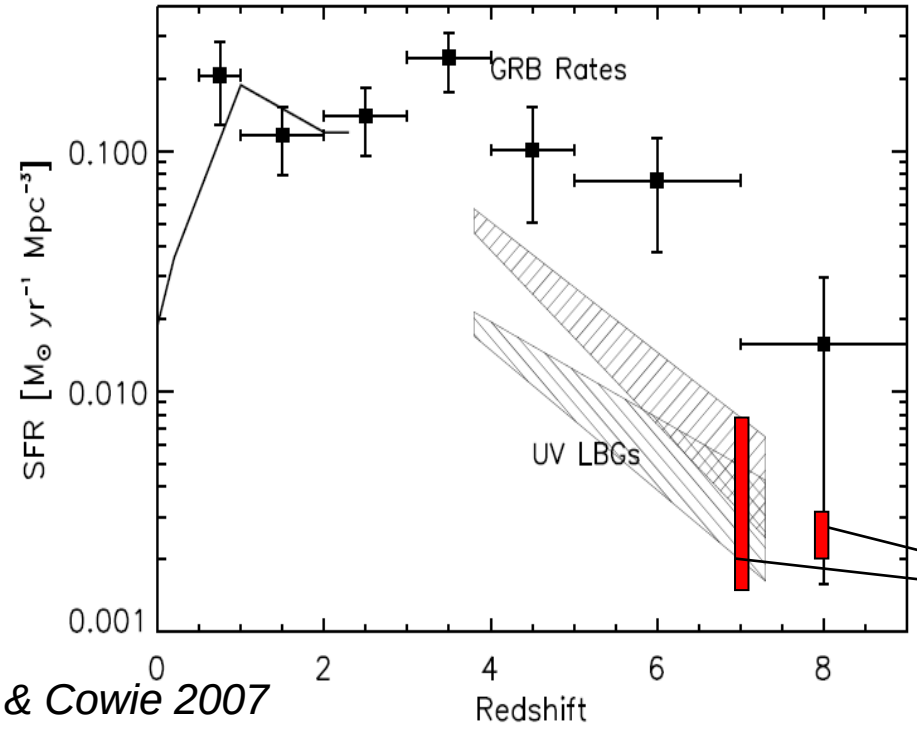
GRB 050904
z=6.295
Kawai et al.,
Haislip et al.



Can measure gas and metals in the galaxies.

Hint of a higher SFR at z~6 from GRB Hosts





WFC3 UDF (Bouwens)

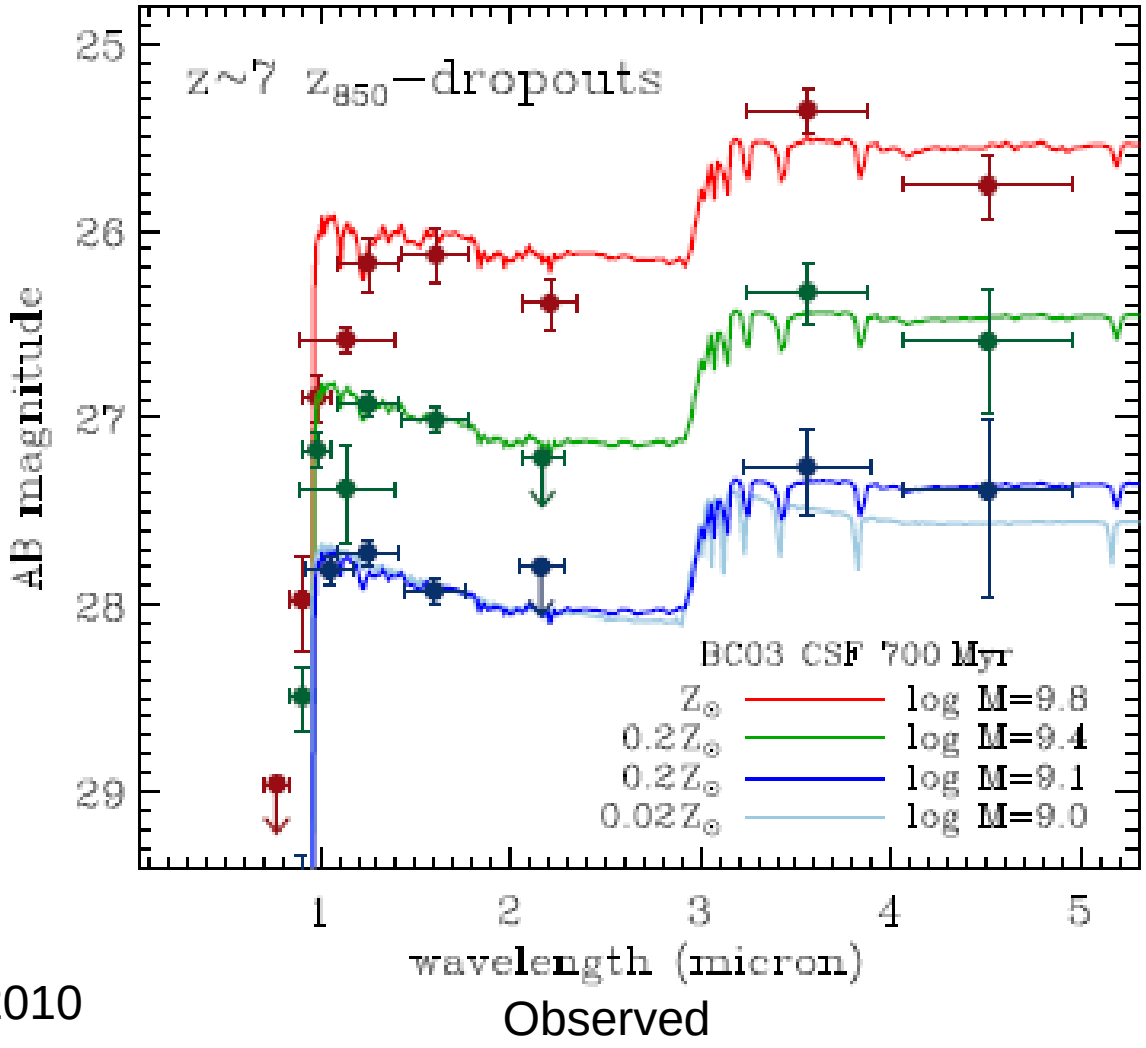
Chary, Berger & Cowie 2007

GRBs suggest a larger ionizing photon flux from faint galaxies

But we need at least two pieces of evidence….

The integral of the star-formation history is preserved in the stellar mass density of galaxies

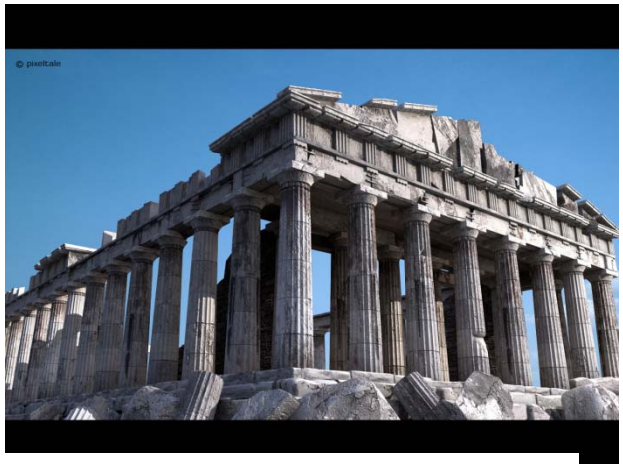
Constraints from the Spitzer Measured Stellar Mass

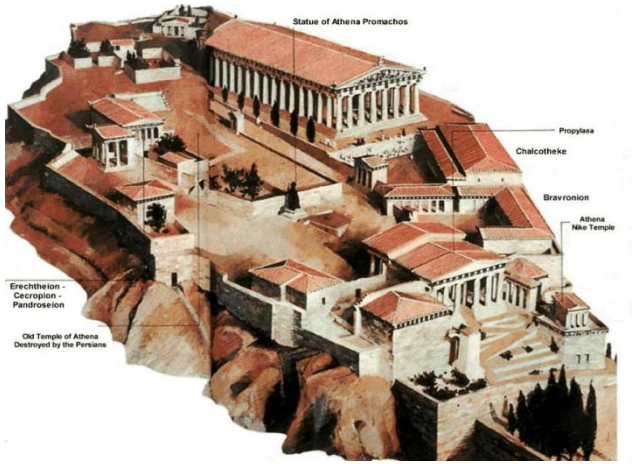


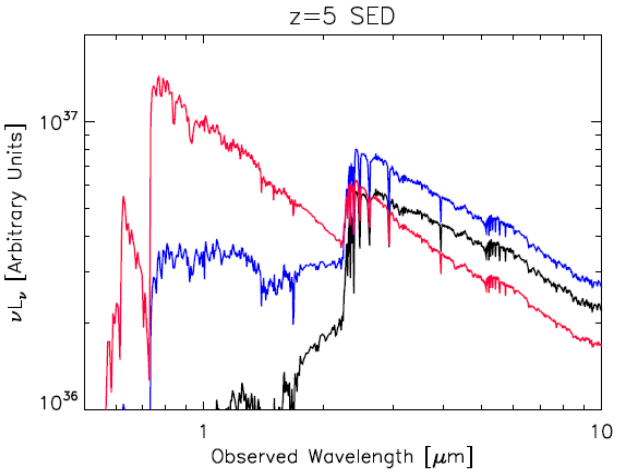
Labbe et al. 2010

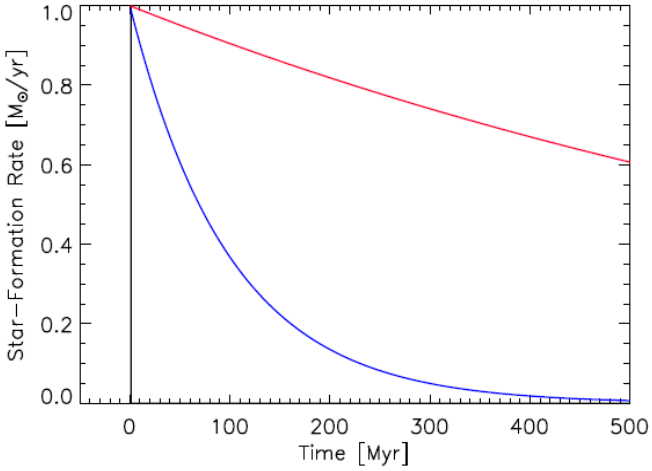
Observed

Astronomical Archaeology

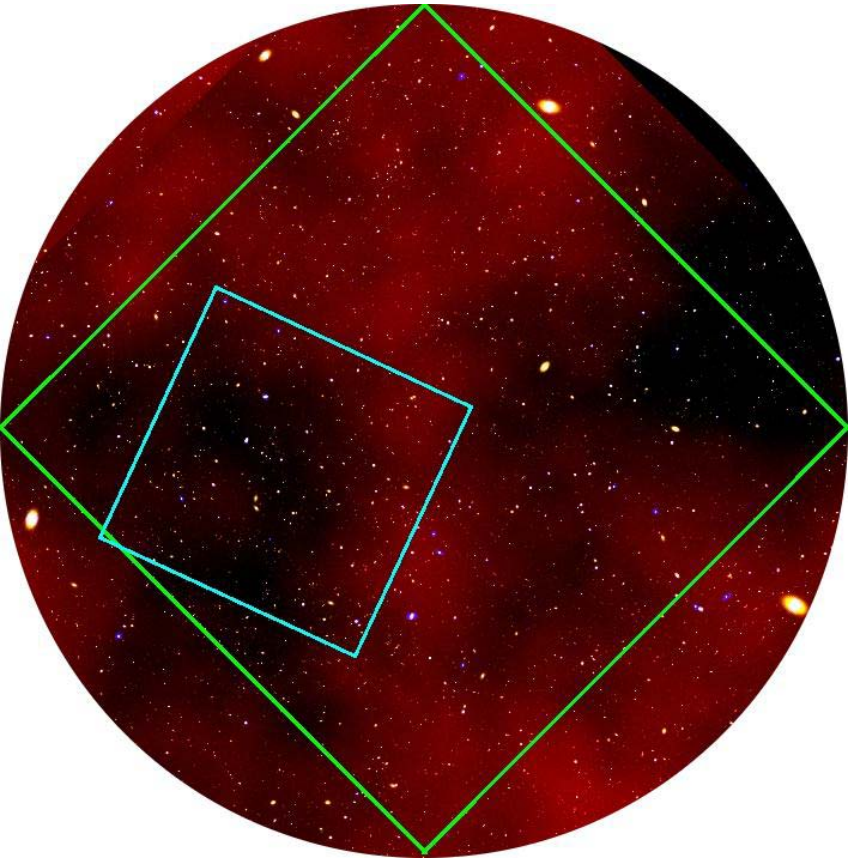


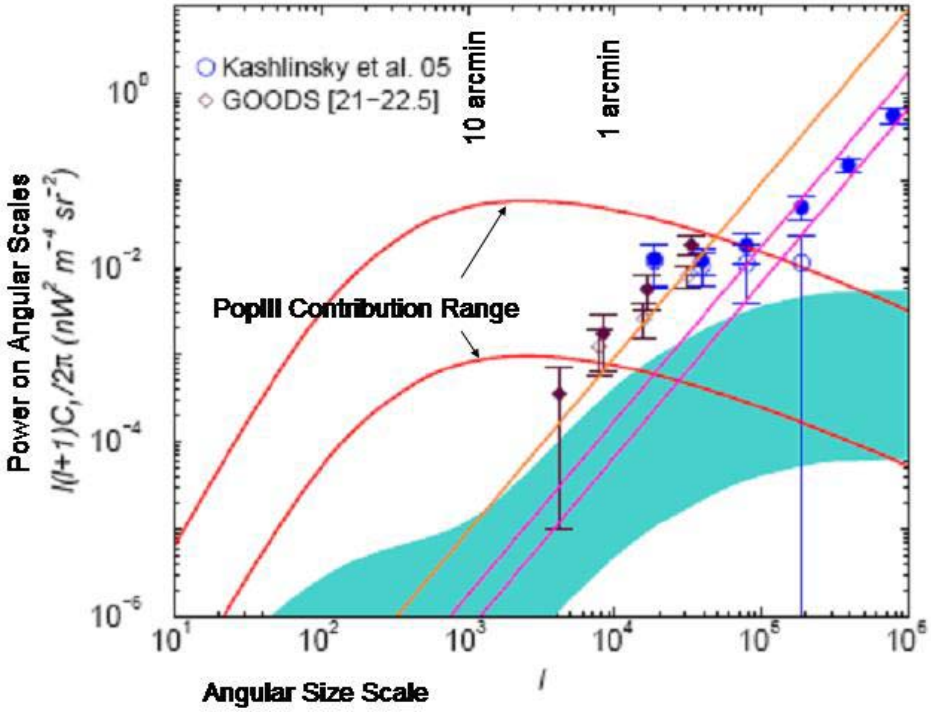






Population III Stars: Fluctuations in IR Background ?

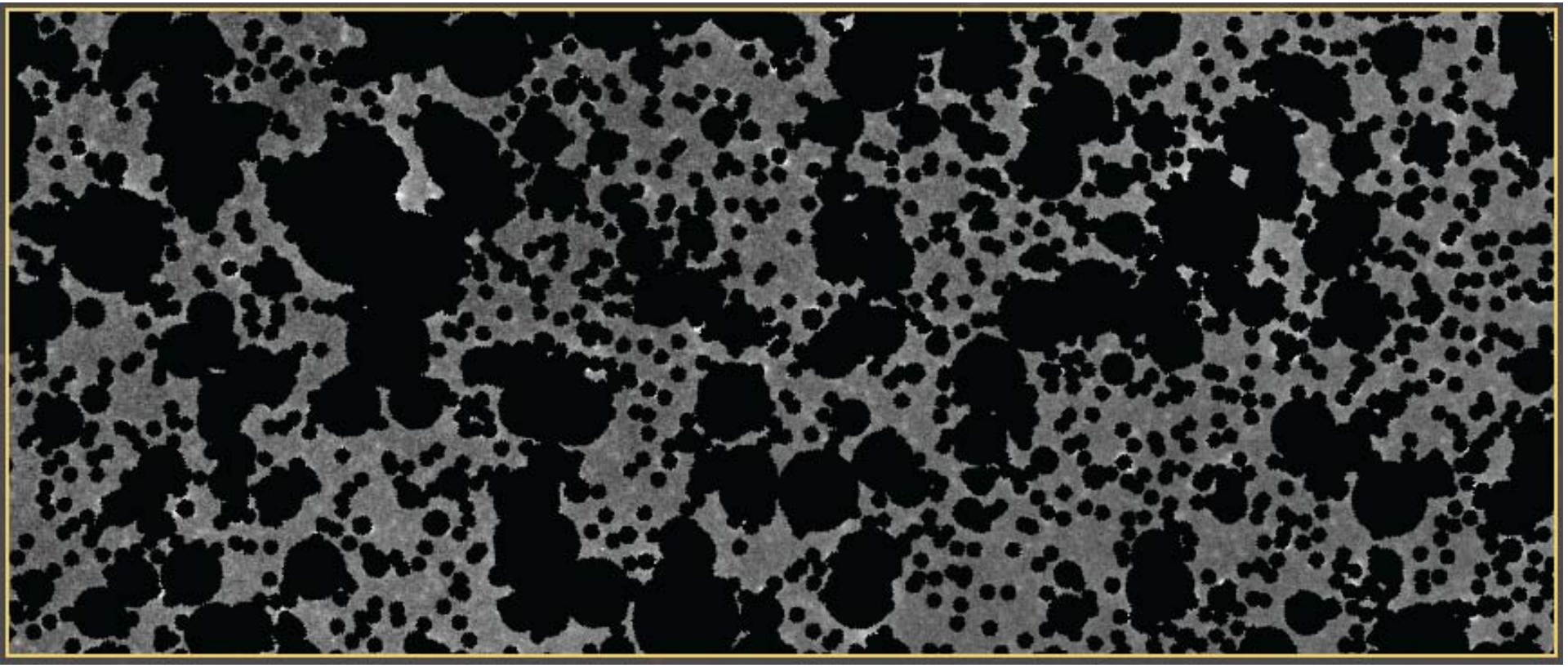




Power (C_l) peaks at l~1E2-3 corresponding to degree scales

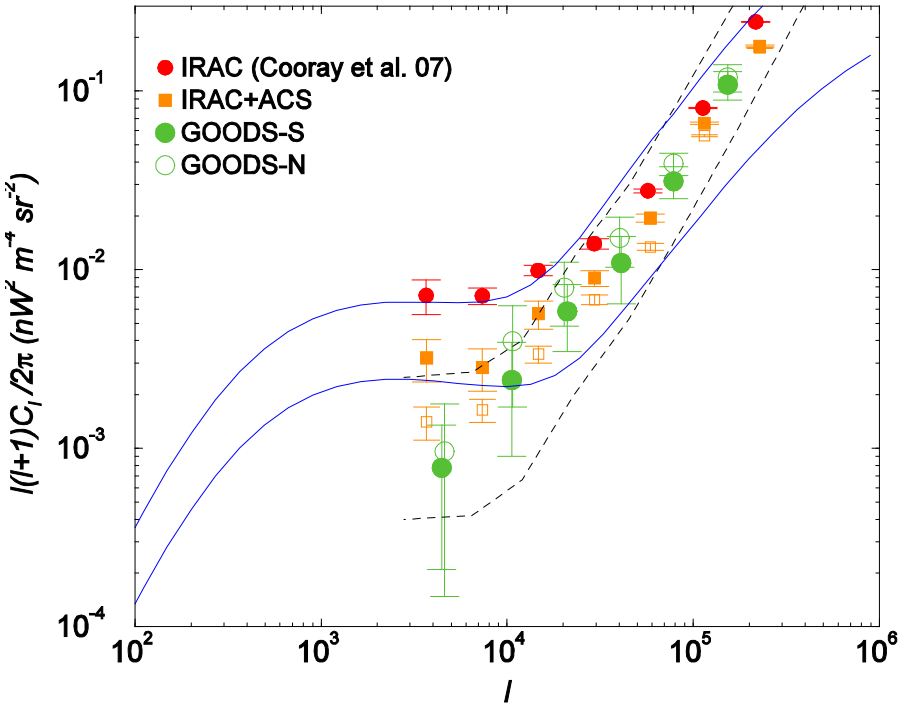
Cooray et al. ‘07, Sullivan et al.

Spitzer image with detected sources masked



Now also being done with shallower, Akari data

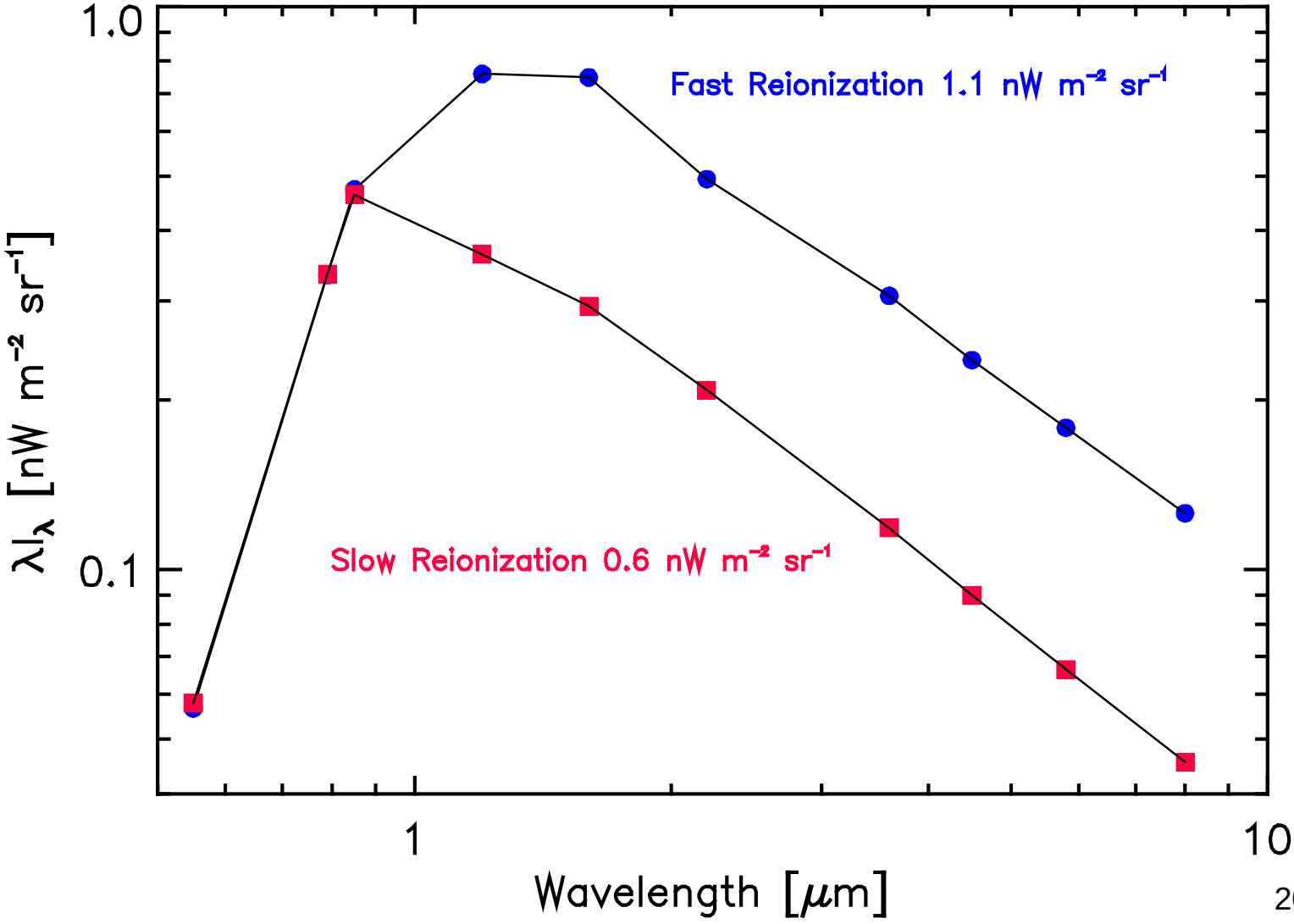
No evidence for a contribution from PopIII stars in IR Background Fluctuations



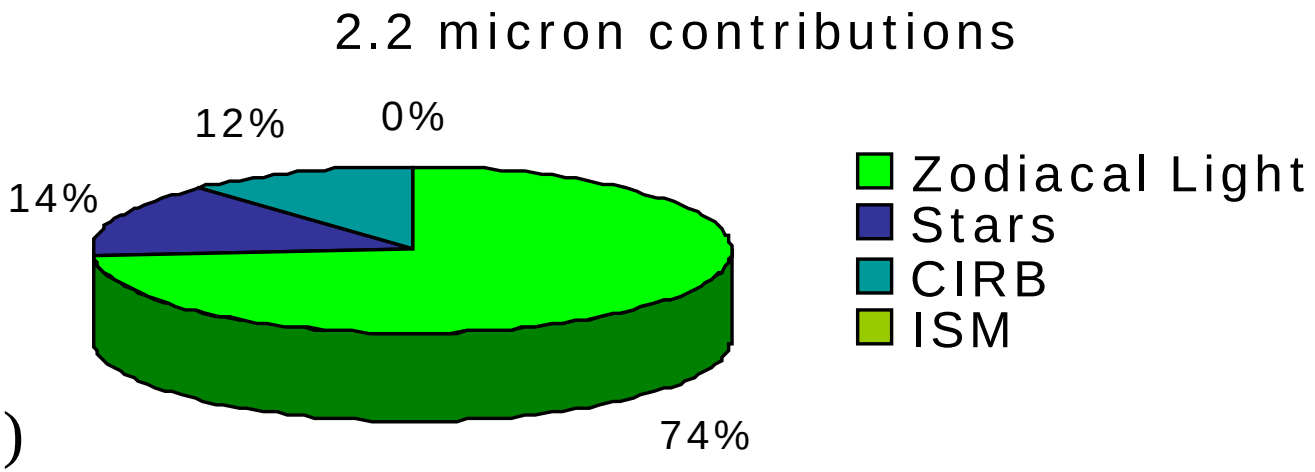
Chary, Cooray, Sullivan '08; Cooray et al 2007

Mostly 0<z<2 dwarf galaxies which contain ~20% of the stellar mass density at these redshifts.

In principle, absolute CIB measurements are more insightful

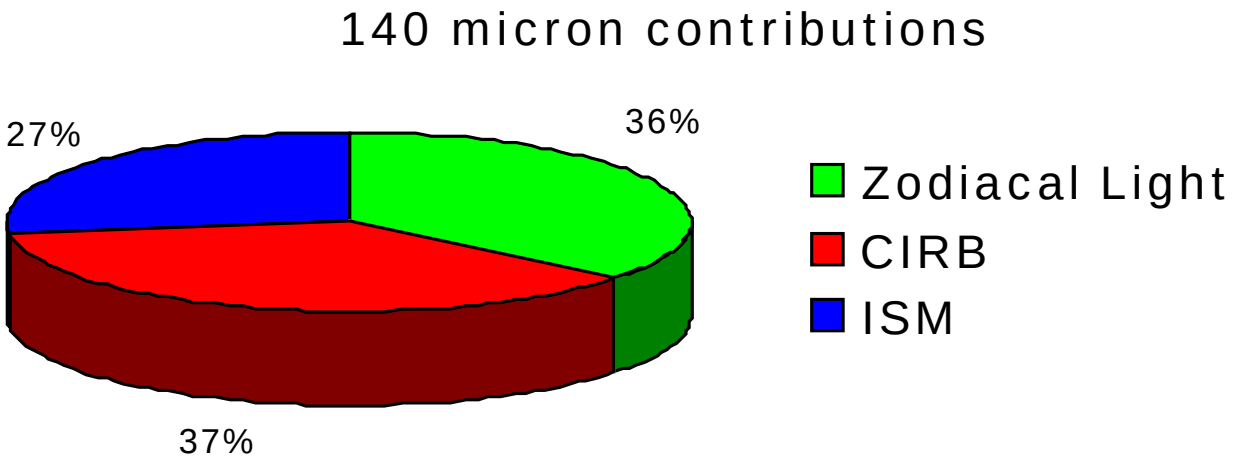


Unfortunately Sky Background at Infrared Wavelengths is Dominated By Zodiacal Light

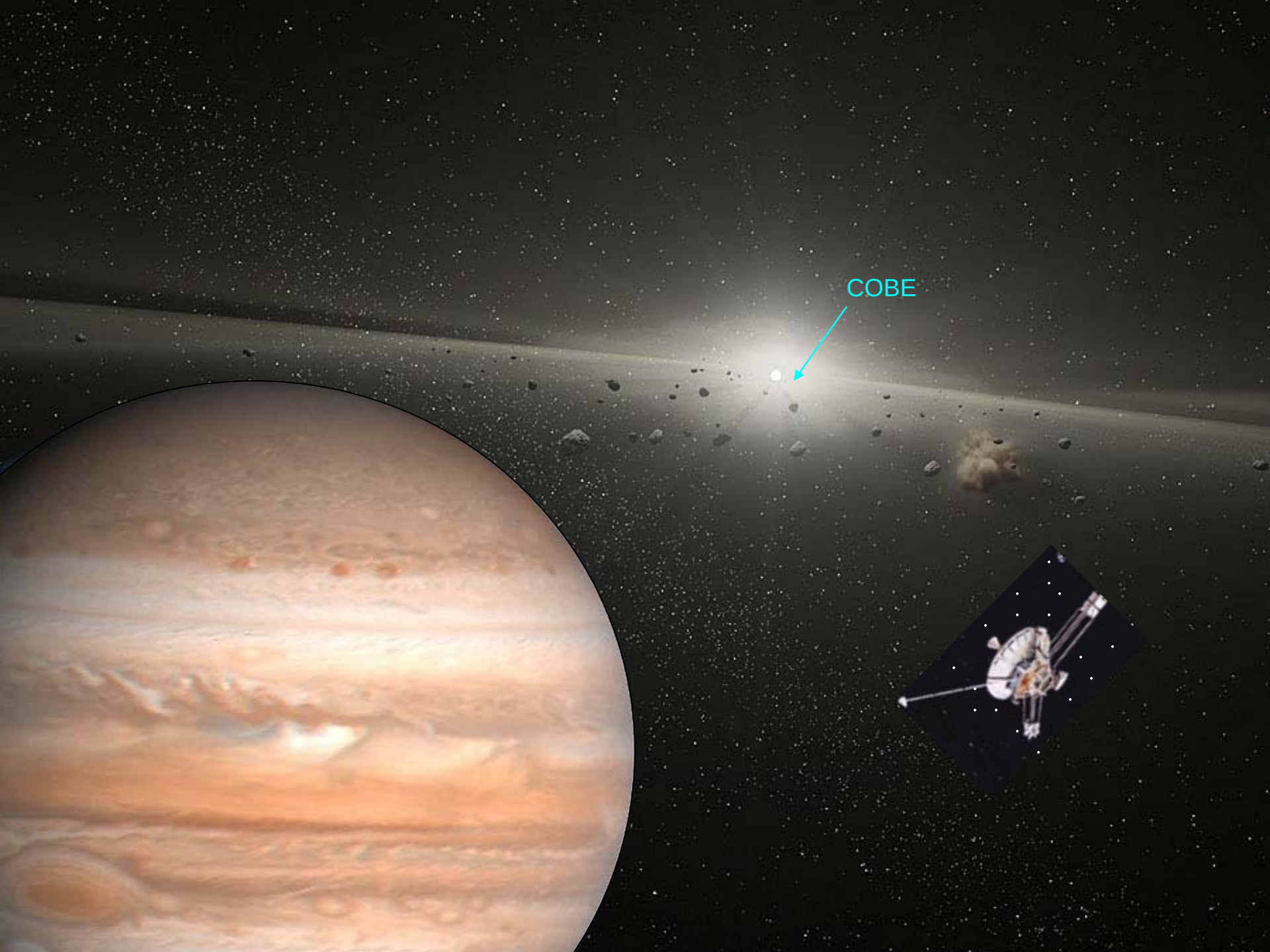


CIRB ($nW\ m^{-2}\ sr^{-1}$)

λ	νI_ν
2.2:	22.4±6.0
3.5:	11.0±3.3
140:	25±7
240:	14±3



We are literally searching for a needle in a haystack!


COBE

Options

- Gamma-ray Bursts: Prompt spectroscopy
  - luck & good IR Spectrograph on a 8-10m 'scope
- Measuring Cosmic Infrared Background at 1/100 level from outer zody
  - An outer planets mission, compact, high-performance absolute calibrated instrument (ZEBRA; PI: J. Bock; http://zebra.caltech.edu)
- Infrared Background Fluctuations
  - Mapping a 1-2 deg wide area and a moderately deep survey to mask out foreground galaxies
- Deeper, larger rest-frame UV surveys e.g. JWST
  - 6-7 Billion $

Increasing Cost