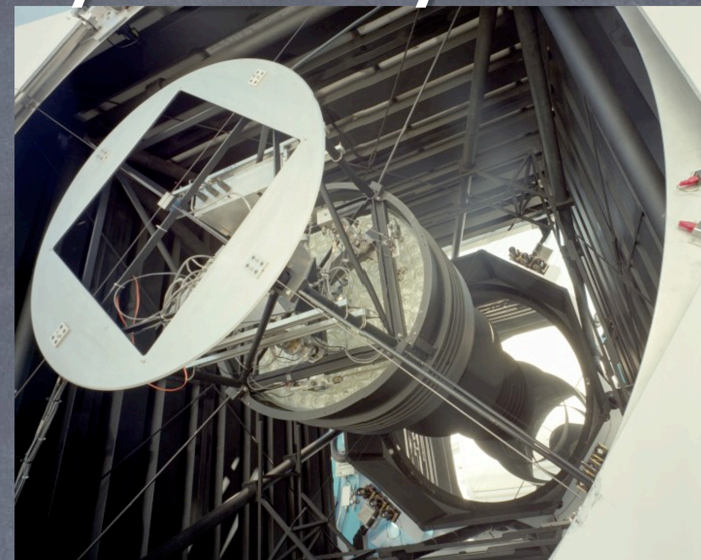
Star formation through cosmic time

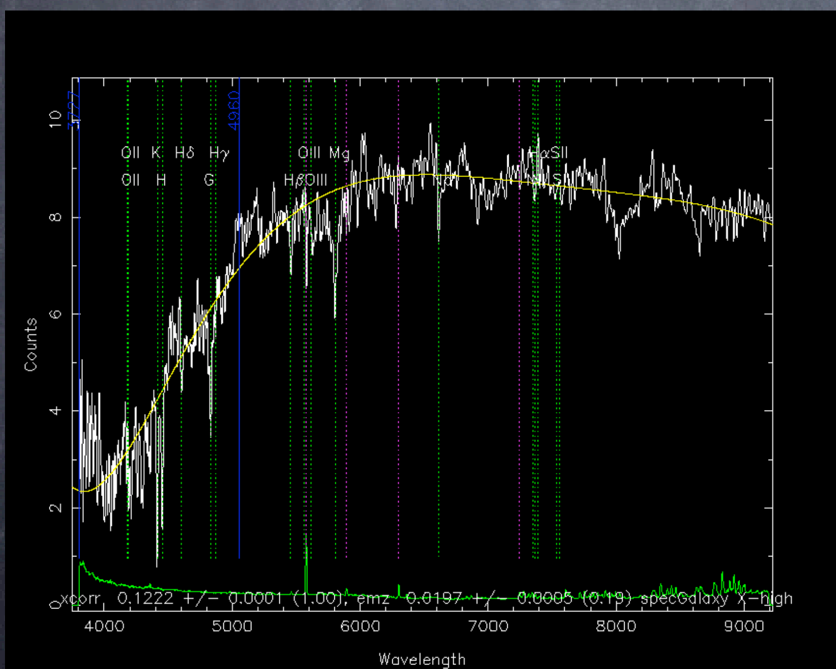
- Raul Jimenez   www.astro.princeton.edu/~raulj

  - The star formation history of galaxies from SDSS
  - Evidence for popIII formation at z~3-4
  - Finding the metals at re-ionization

Sloan Digital Sky Survey

~ 1,000,000 spectra public in SDSS Data Release 6 (DR6)



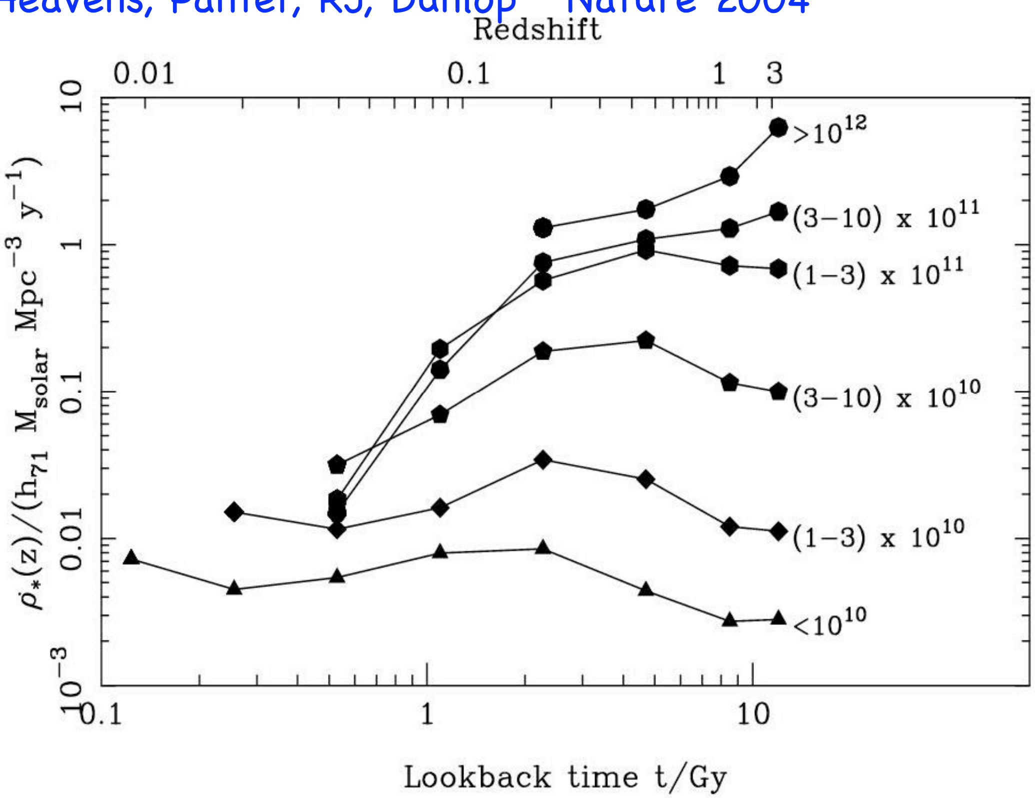


(Panter, Heavens & Jimenez (2003) analysed 37000 SDSS EDR galaxies)

SFR in galaxies of different stellar mass

Split by mass

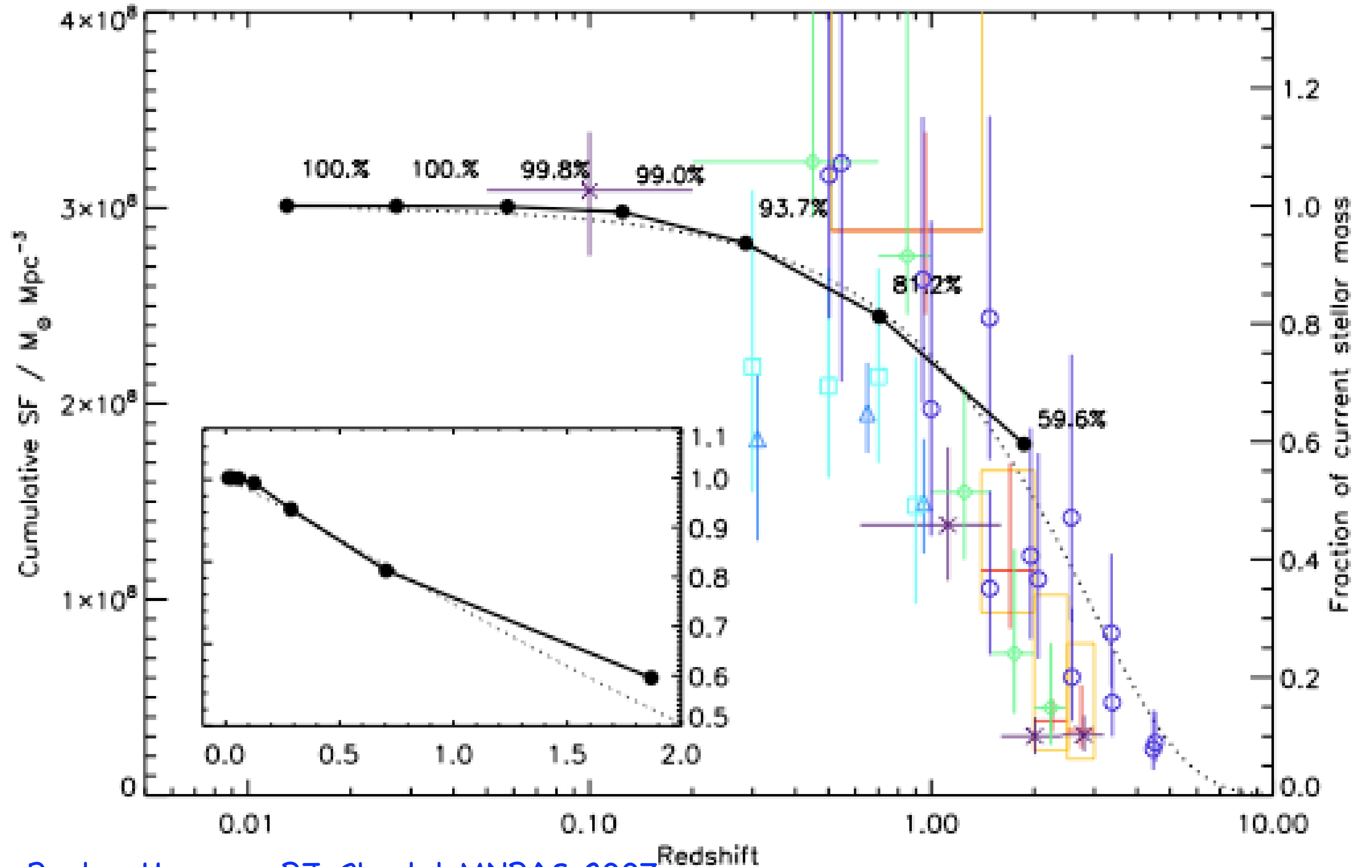
Heavens, Panter, RJ, Dunlop   Nature 2004



Galaxies with more stellar mass now formed their stars earlier

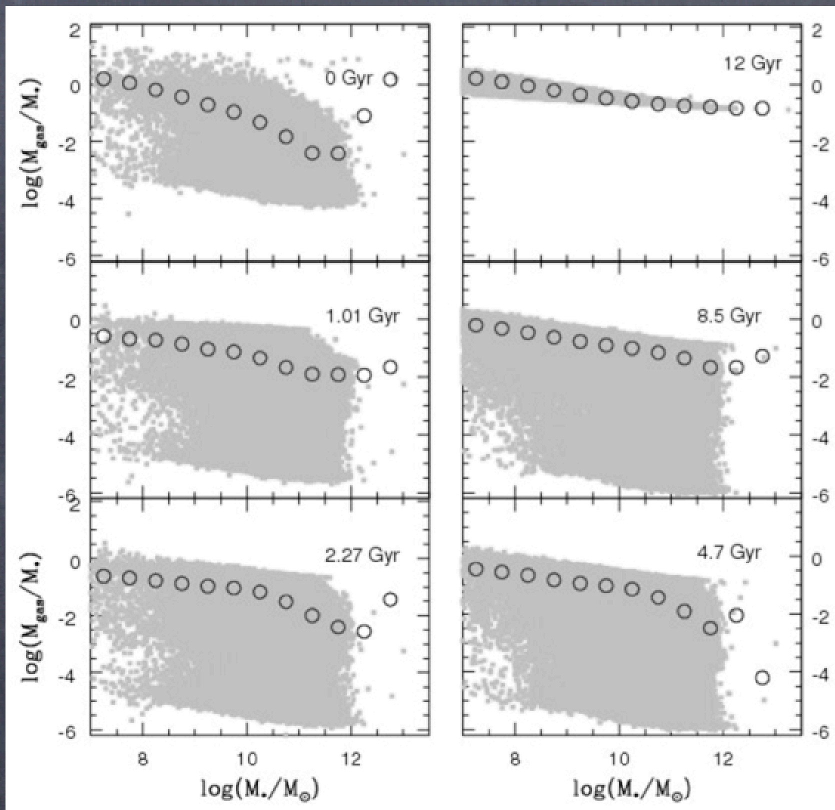
(Curves offset vertically for clarity)

Stellar build-up in the universe

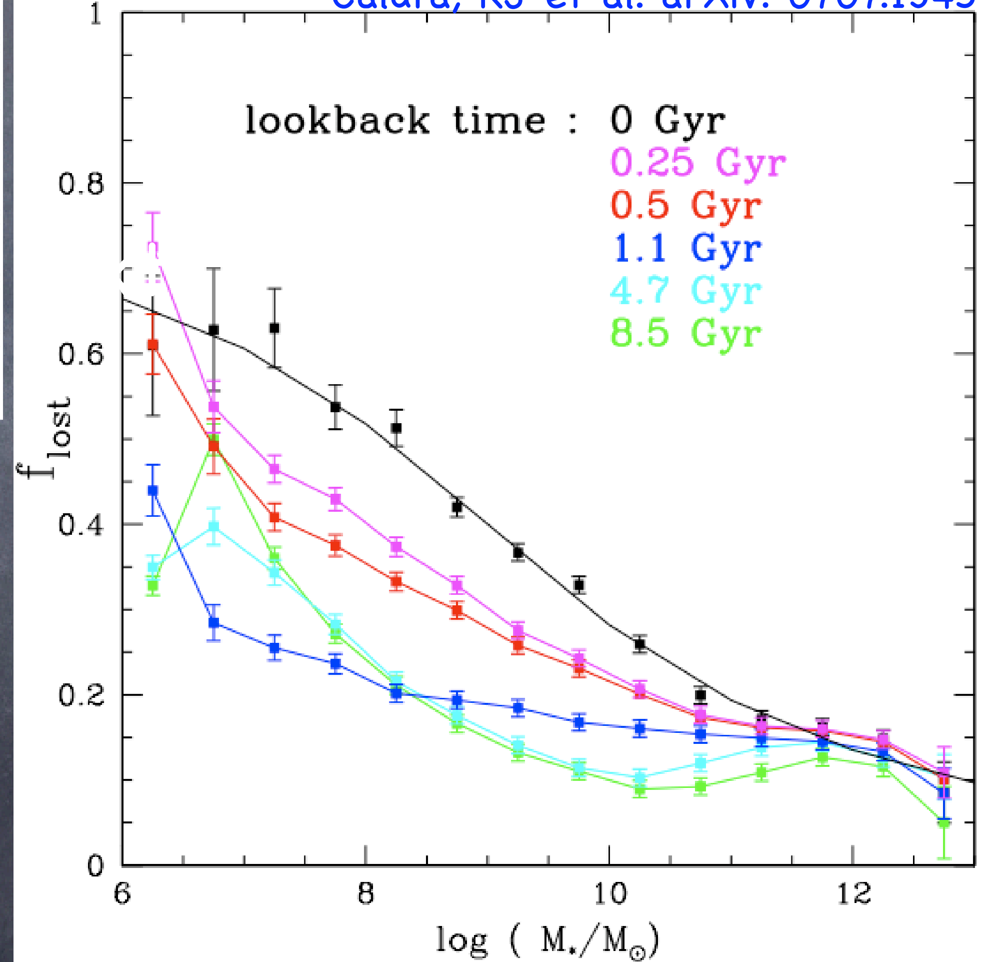


Panter, Heavens, RJ, Charlot MNRAS 2007

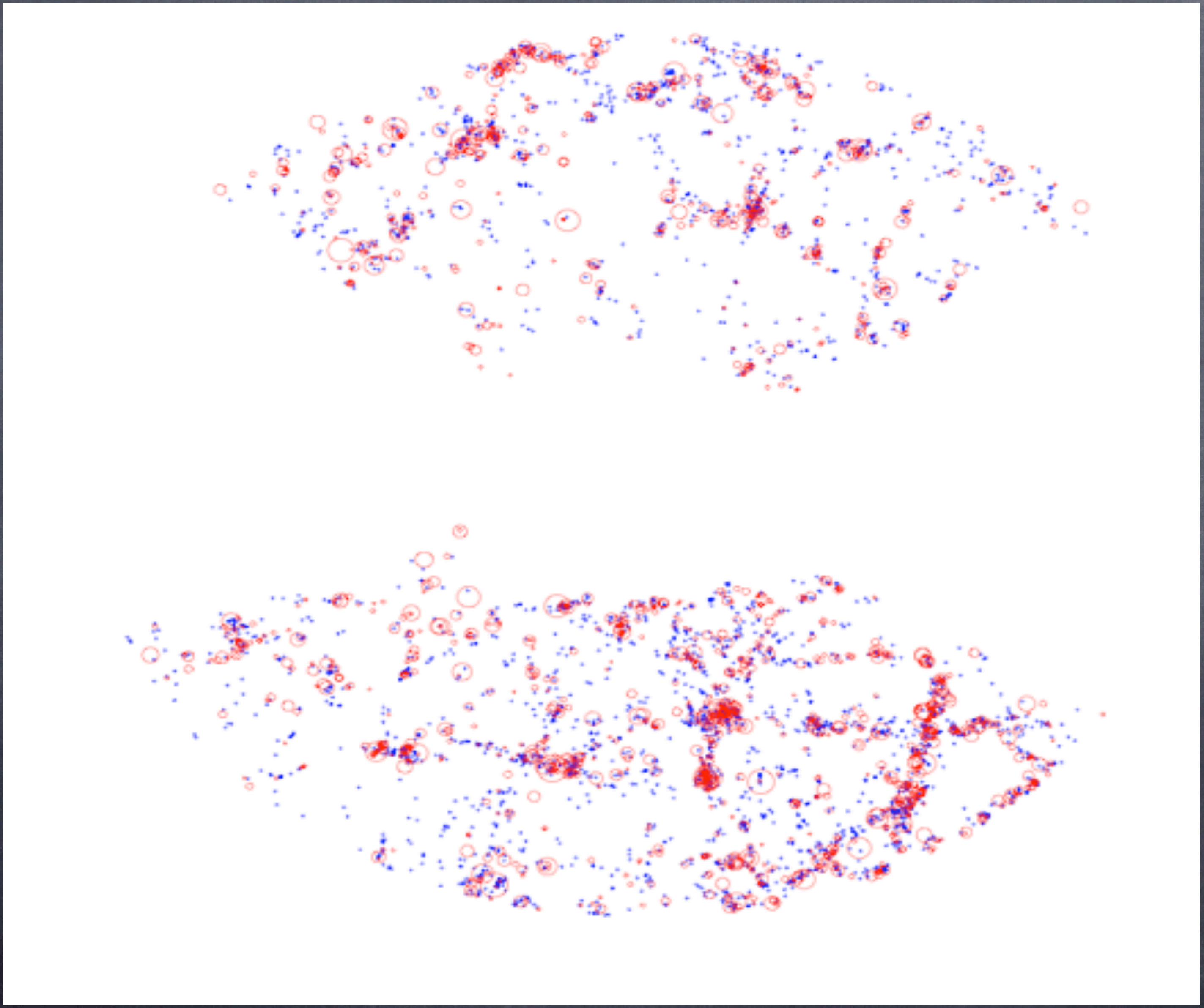
Amount of gas lost by galaxies as a function of stellar mass



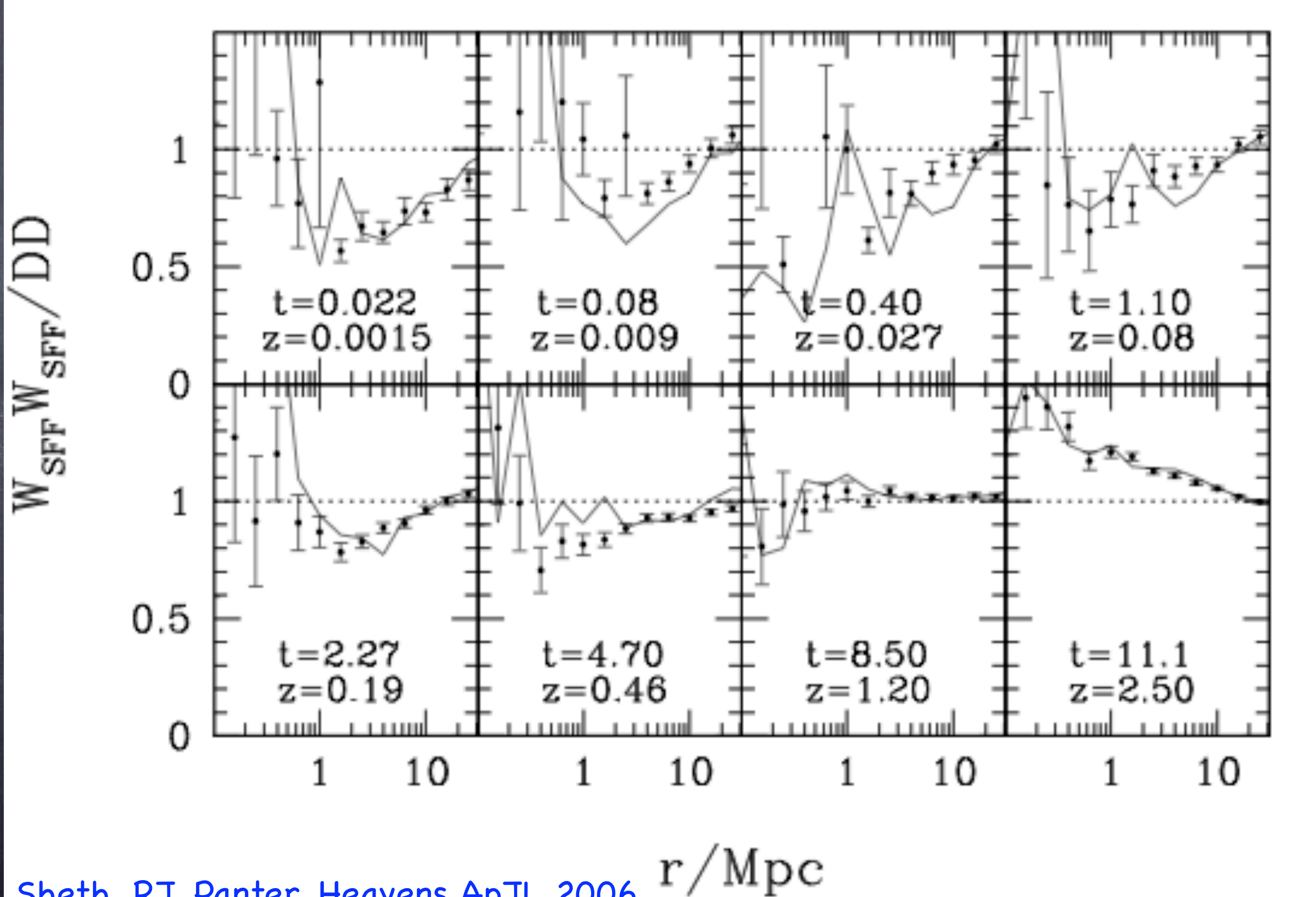
Calura, RJ et al. arXiv: 0707.1345



Where are the galaxies today that were red/blue in the past?

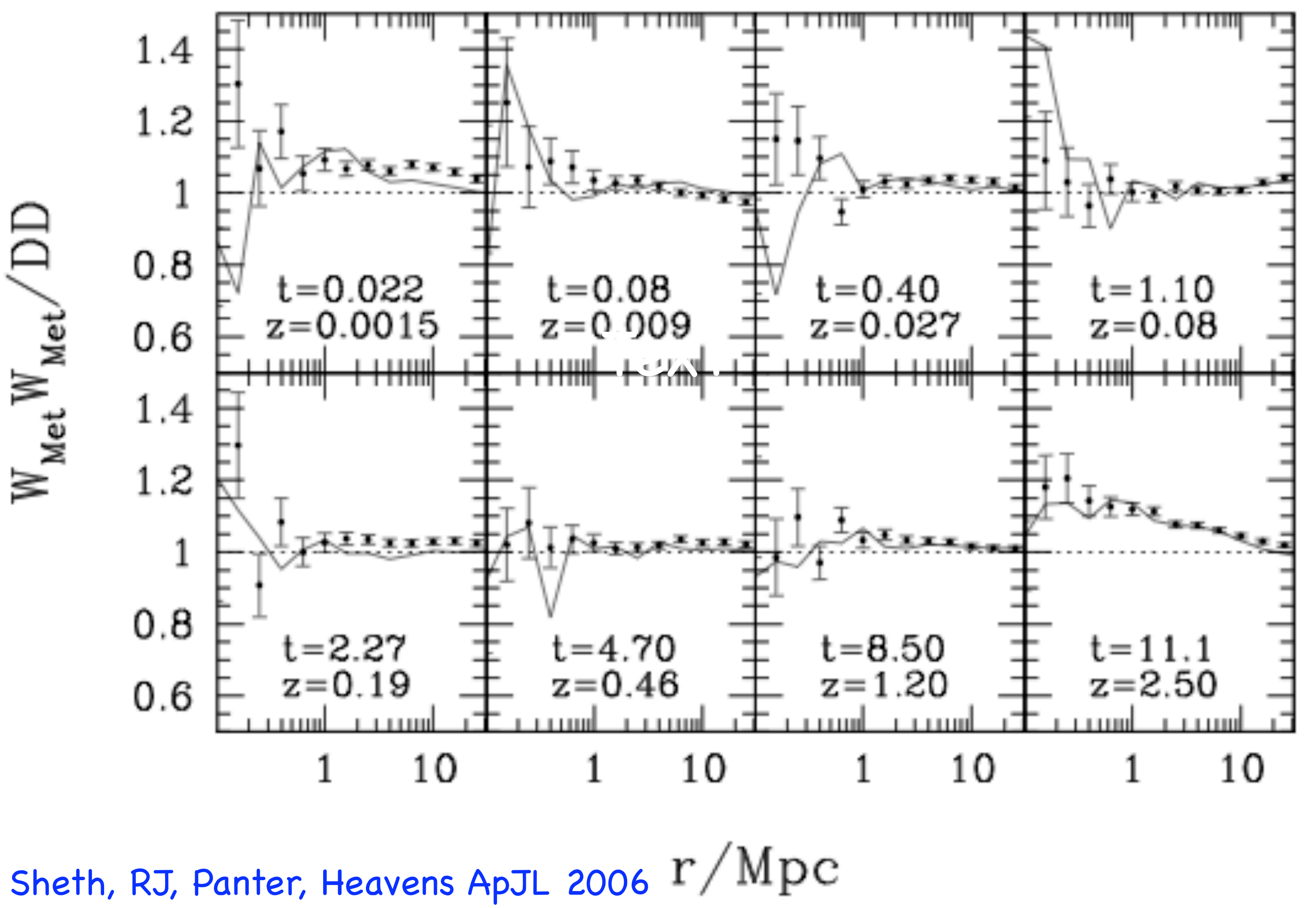


SF as a function of environment (mark correlations)



Sheth, RJ, Panter, Heavens ApJL 2006

Metallicity as a function of environment



Sheth, RJ, Panter, Heavens ApJL 2006

There are four puzzling observations of the high-redshift universe:

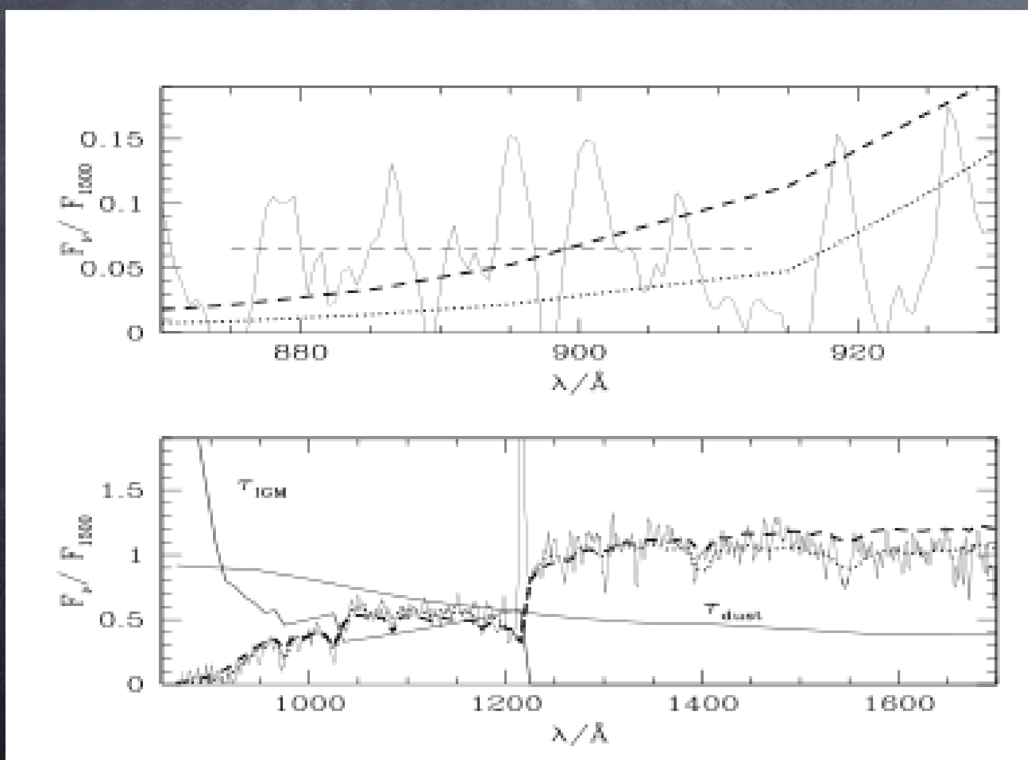
1. Significant UV emission from LBG at wavelengths < 912AA

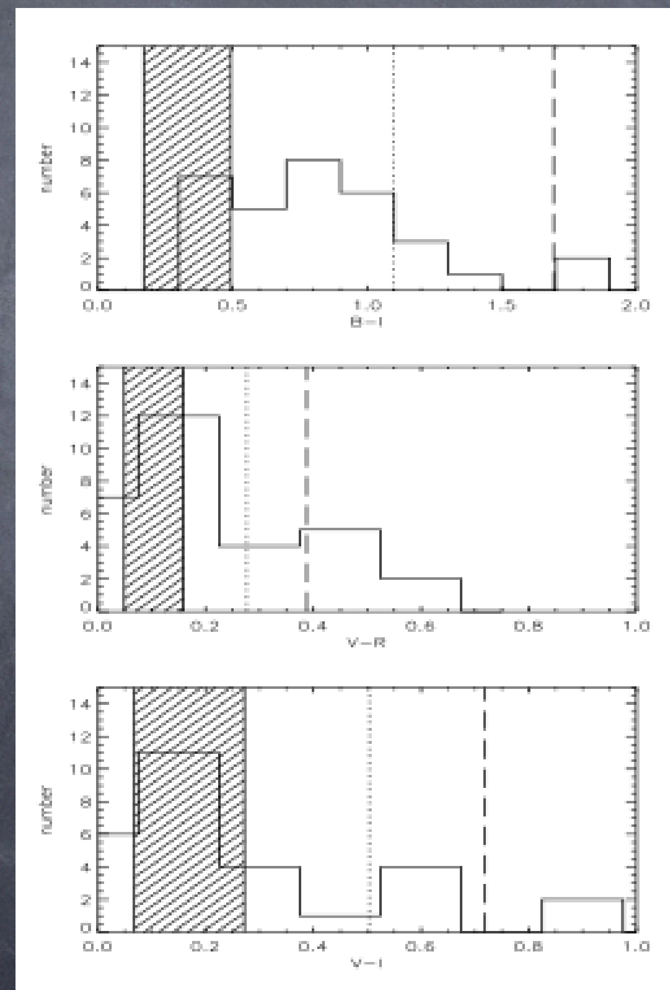
2. Strong Lyman-alpha emission from "blobs"

3. Lyman-alpha emission with large EW

4. Strong HeII (1640) AND weak CIV (1550)

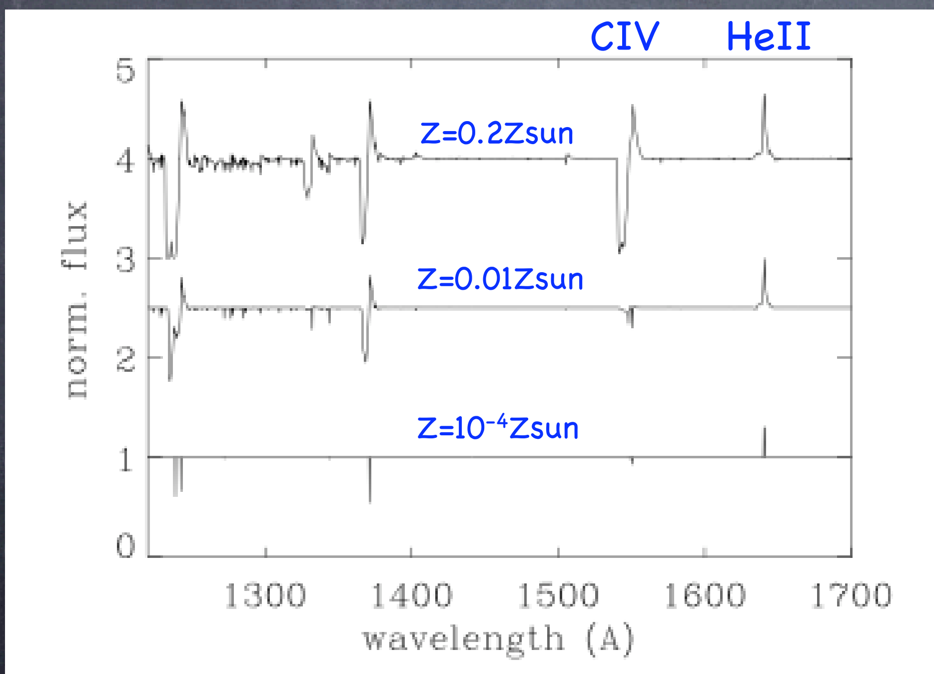
Jimenez & Haiman Nature (2006)

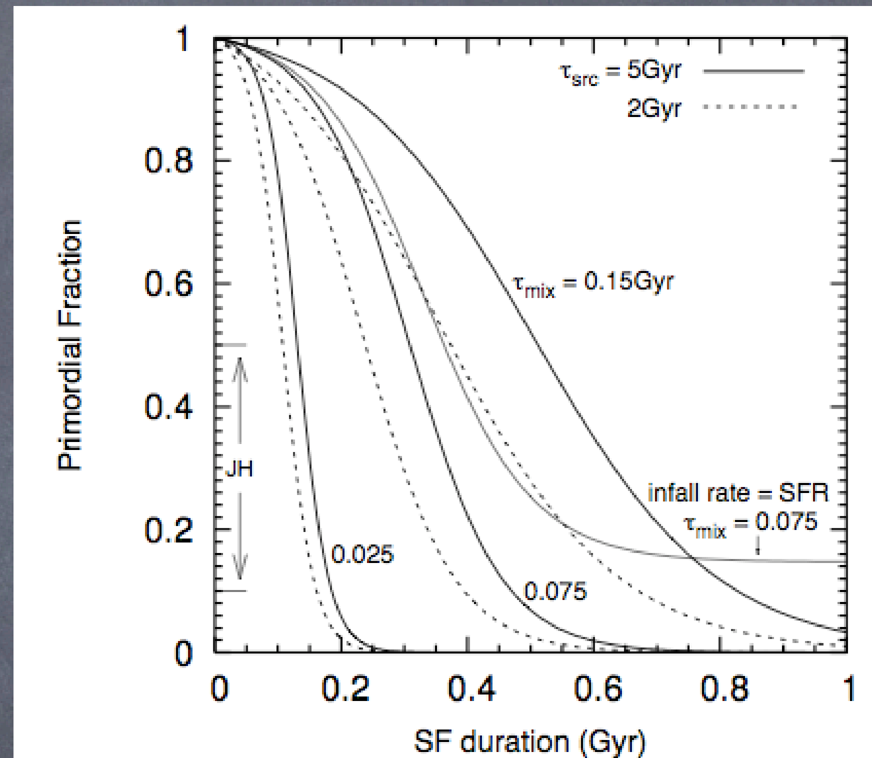




The ratio of the HeII to CIV lines is the clue

from Kudritzki 2002



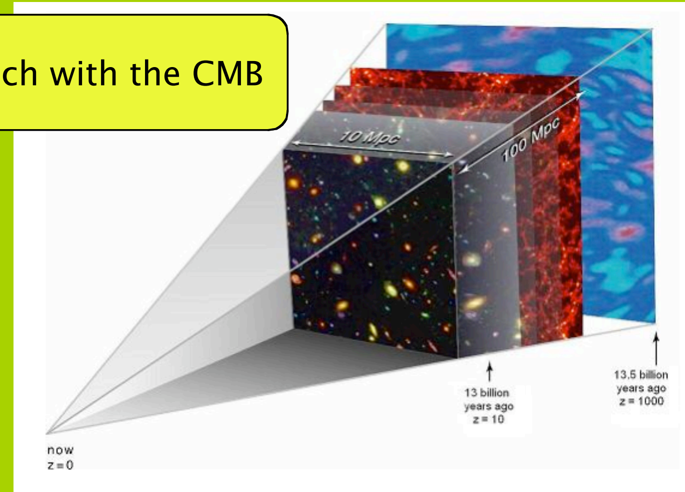


Time duration of mixing from Liubin & Scalo (2007)

Jimenez & Haiman Nature (2006) conclude from LBGs HeII/CIV ratio about 10% primordial SF at z ~ 4 (see also Liubin & Scalo ApJ 2007; Ferrara's talk)

Pumping oxygen

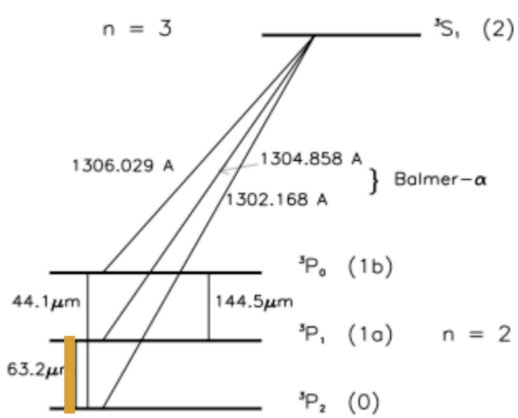
Mapping the Reionization Epoch with the CMB



$$T_b'(\nu) = T_{\rm ex}(1 - e^{-\tau_\nu}) + T_R'(\nu)e^{-\tau_\nu}$$

Normally $T_S = T_{CMB}$, but

Oxygen I



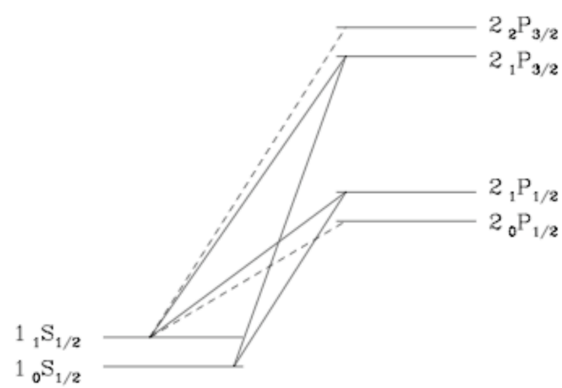
Fine structure

Balmer α pumping

Sounds familiar?

Wouthuysen-Field effect

HI 21 cm



Hyperfine structure

Lyman α pumping

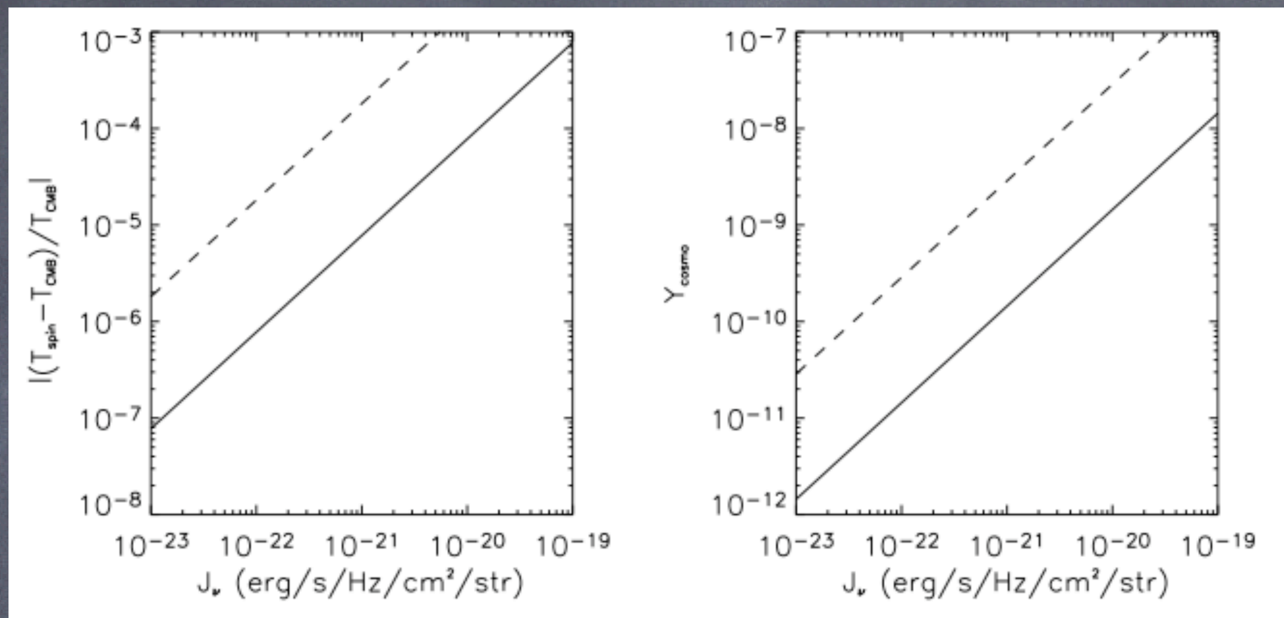
Hernandez-Monteagudo, Haiman, RJ, Verde ApJL 2007

$$\frac{T_{\star,ji}}{T_{S,ji}} = \log\left\{\frac{1+\frac{A_{ji}}{P_{ji}^{UV}}\left[1+\left(I_\nu c^2/2h\nu^3\right)_{\nu_{ji}}\right]}{\exp\left(-T_\star/T_{UV}\right)+\frac{A_{ji}}{P_{ji}^{UV}}\left(I_\nu c^2/2h\nu^3\right)_{\nu_{ji}}}\right\}$$

Since $I_\nu \simeq B_\nu[T_{CMB}]$, if $A_{ji} \gg P_{ji}^{UV}$ then $T_{S,ji} \rightarrow T_{CMB}$, if $A_{ji} \ll P_{ji}^{UV}$ then $T_{S,ji} \rightarrow T_{UV,ji}$ $\Rightarrow T_{S,ji}$ bracketed between T_{CMB} and $T_{UV,ji}$.

If $\partial \log[I_\nu/\nu^3]/\partial\nu\,|_{\nu_{2j}} < 0$, then $T_{S,ji} > T_{CMB}$ $\Rightarrow$ line seen in emission.

63.2m in emission

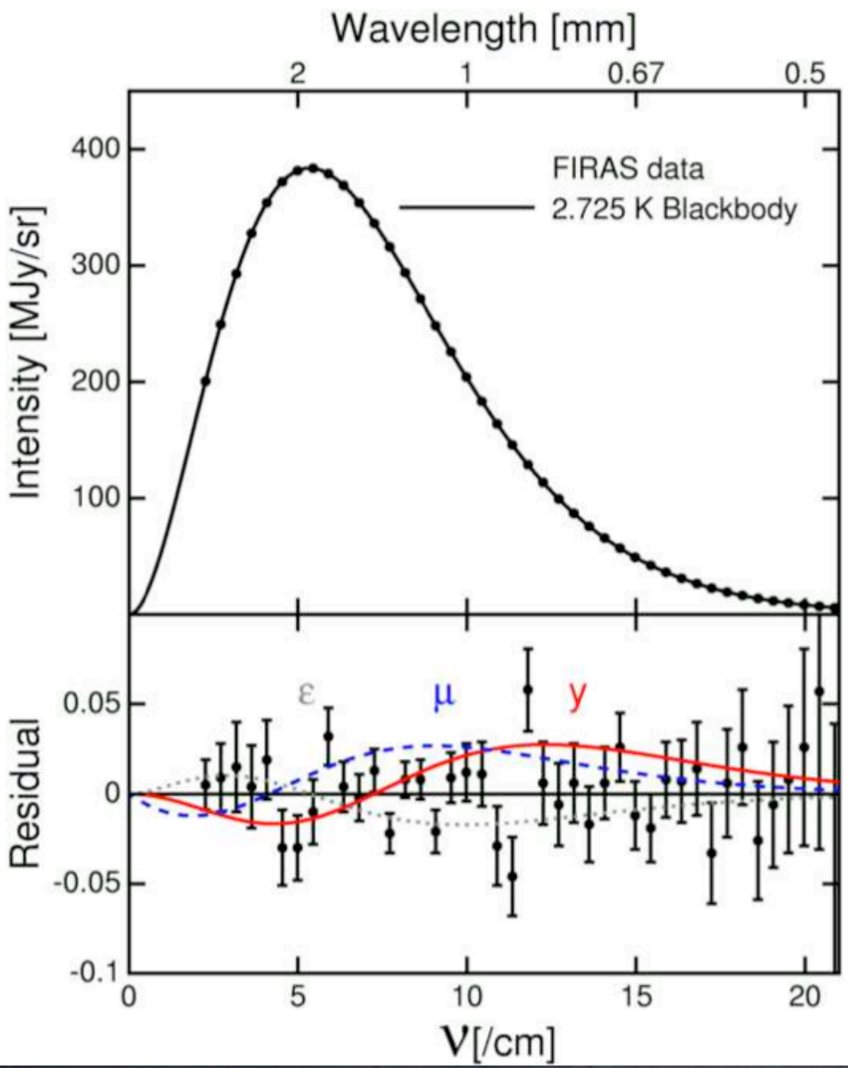


400 700GHz   z=10+7

y distortion is $10^{2or3}(Z/10^{-3}Z)^{-1}$ smaller than 21cm

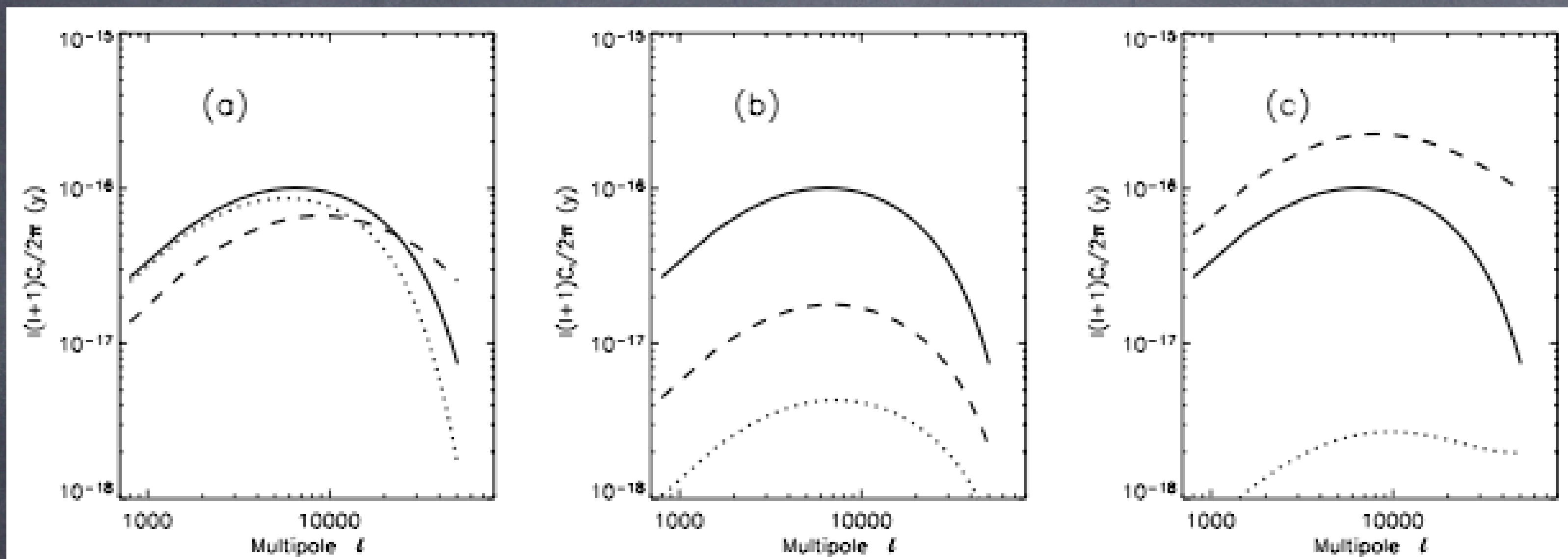
But foreground and systematics completely different

Could have used also 44.1m, effect ~5 larger, but worse foregrounds



- FIRAS data can already constrain OI abundance to be less than 5 – 40 $Z_\odot$ at $z > 10$ $\Rightarrow$ **first constraints on OI at reionization!**
- Future experiments (improved versions of FIRAS) should be able to set tight constraints on OI during the reionization epoch.

But... bubbles are rare objects, highly clustered... correlation properties?



Level of fluctuations for a metallicity 0.001 the solar value, could be detected with SCUBA2 or ALMA deep integrations

Hernandez-Monteagudo, Haiman, RJ, Verde 2007