Formazione dei primi quasar e loro proprieta'. Reionizzazione

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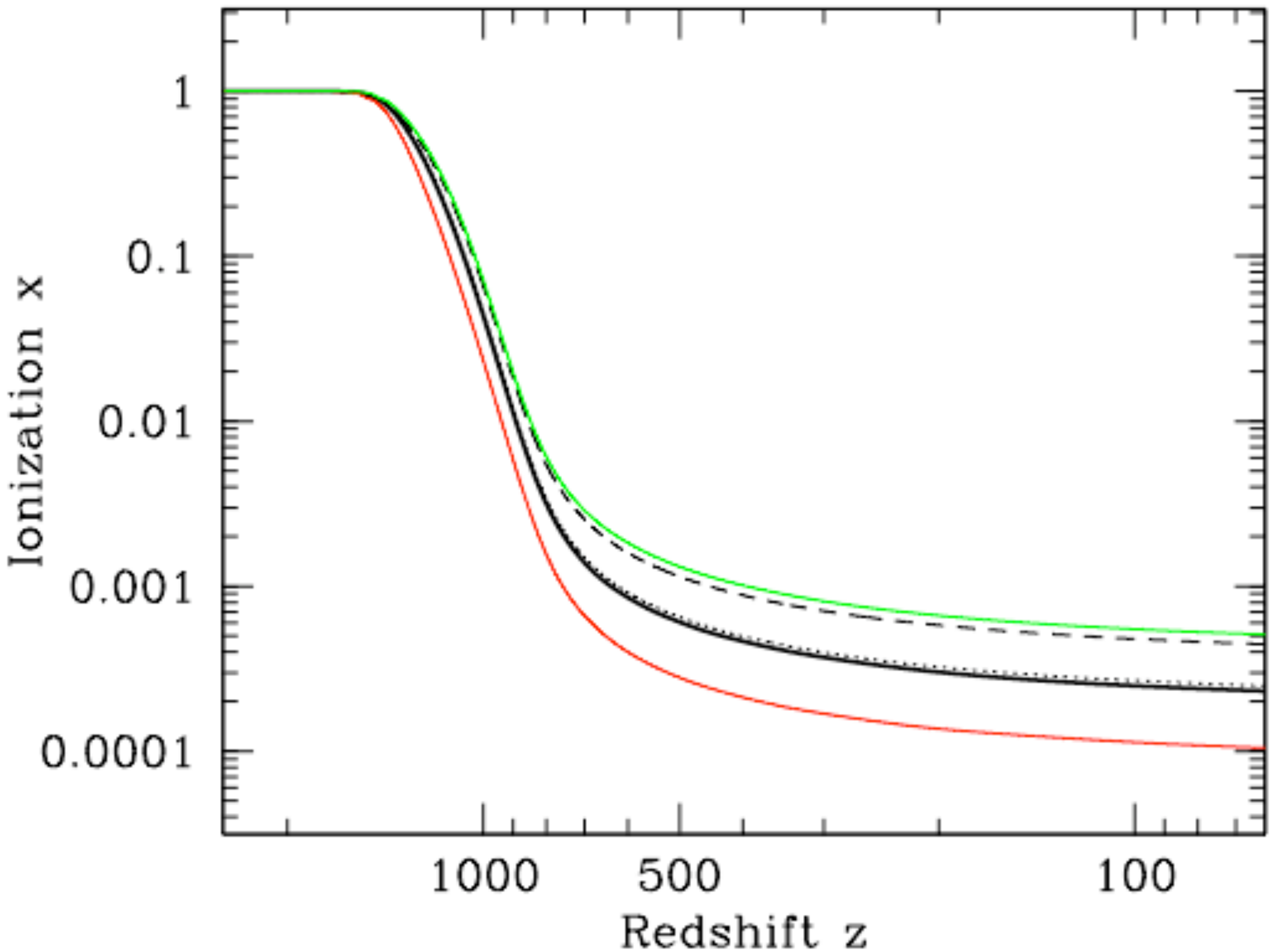
Discutero' le proprieta' dei quasar a redshift 6 scoperti dallo Sloan Digital Sky Survey e alcune idee sulla loro formazione. Passero' quindi a descrivere il processo di reionizzazione dell'idrogeno nell'Universo.

Universe is almost neutral following recombination

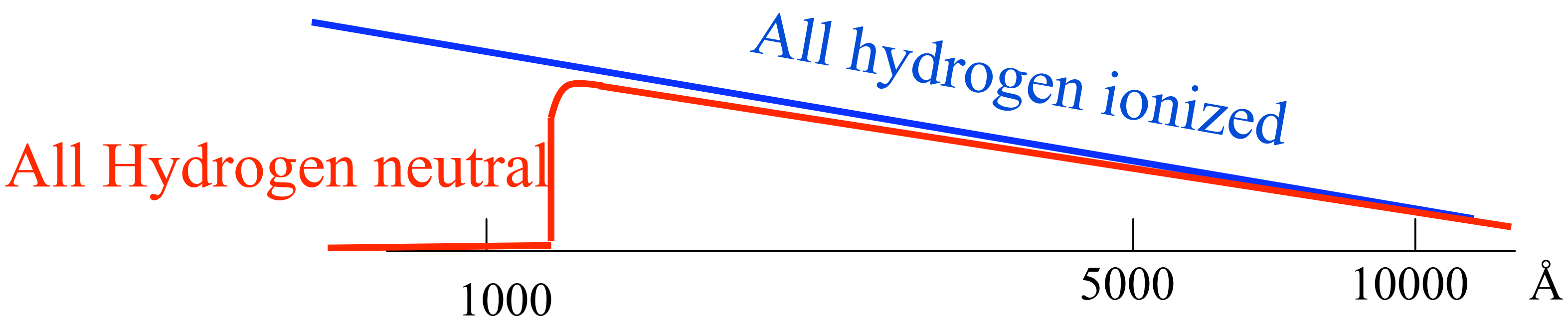
As we have seen yesterday as the Universe cools down, Hydrogen recombines except for a small residual fraction of a few 10^{-4} which remains ionized.



Ionization x
1
0.1
0.01
0.001
0.0001
1000
500
100
Redshift z

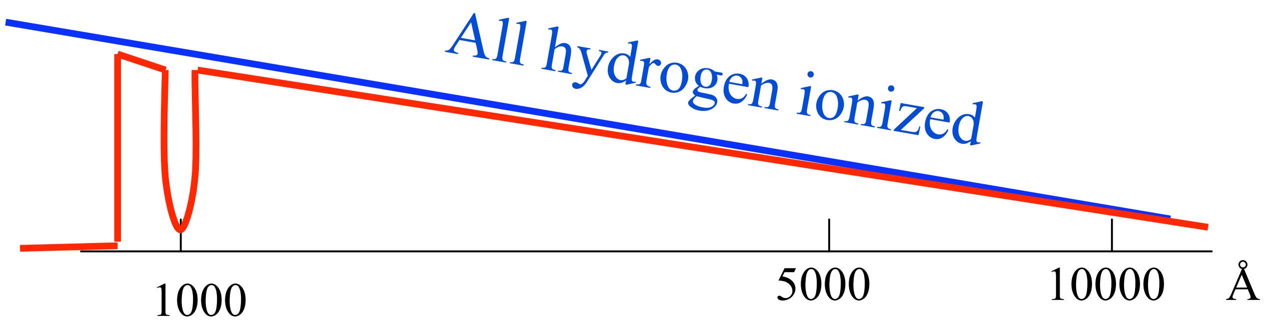
Transmission of UV photons

When computing the transmission to UV photons we can assume that Hydrogen is neutral. Even a small column density of Hydrogen in a diffuse IGM will completely absorb all ionizing UV shortwards than Lyman α (Gunn-Peterson trough) and possibly create a Lyman α damping wing.

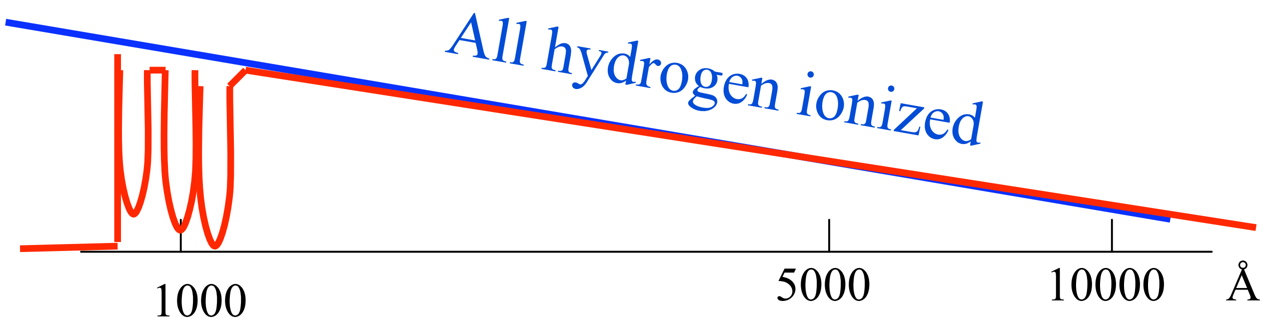


Local Hydrogen in the high-z under observation without a neutral IGM would produce only absorption shortwards of the Lyman continuum but no absorption between 912-1216Å.

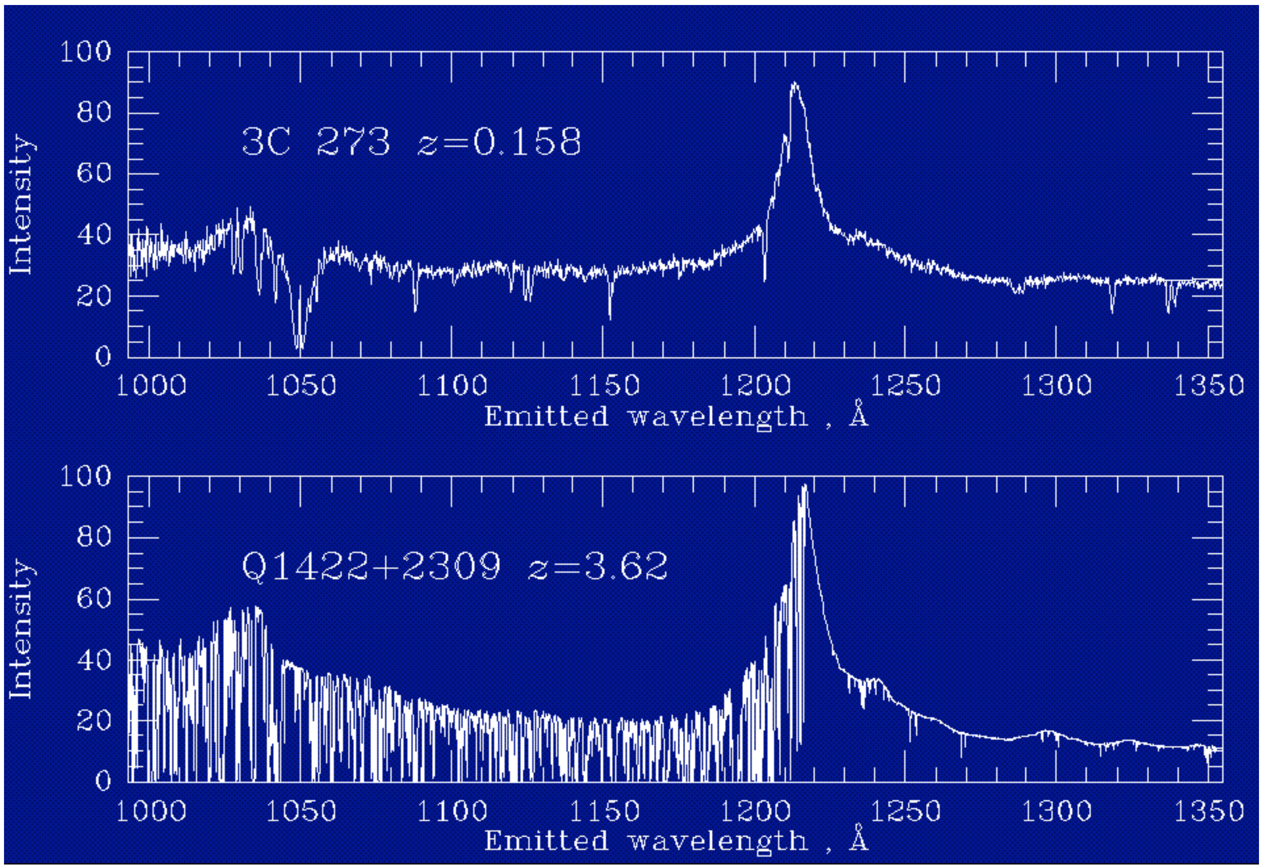
An intervening neutral Hydrogen cloud between us and the high-z object will produce a discrete Lyman a line which may end up in the wavelength range 912-1216Å.



A large number of absorbers will produce significant absorption between 912-1216Å. This phenomenon is known as the Lyman α forest and could mimic the effect of a neutral medium.

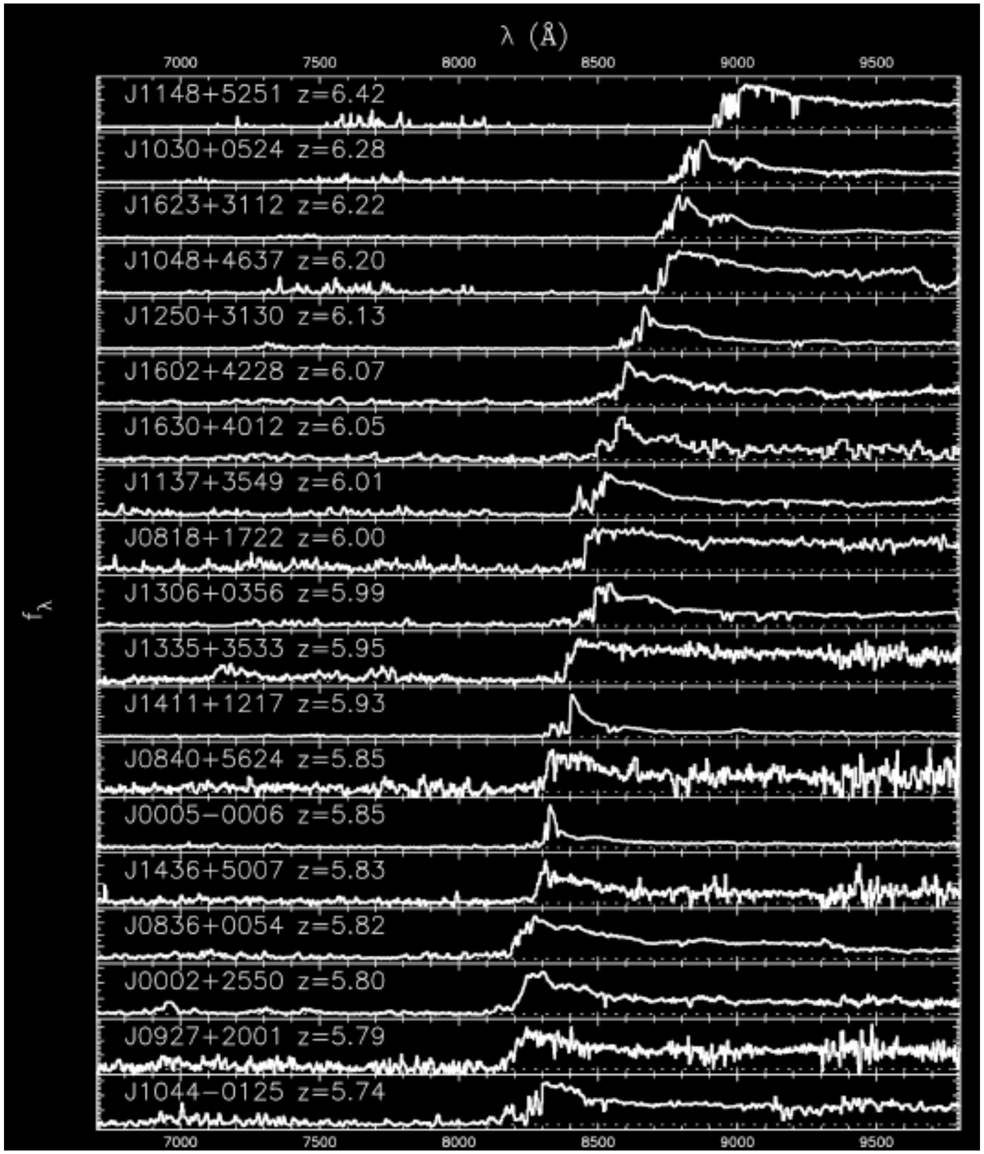


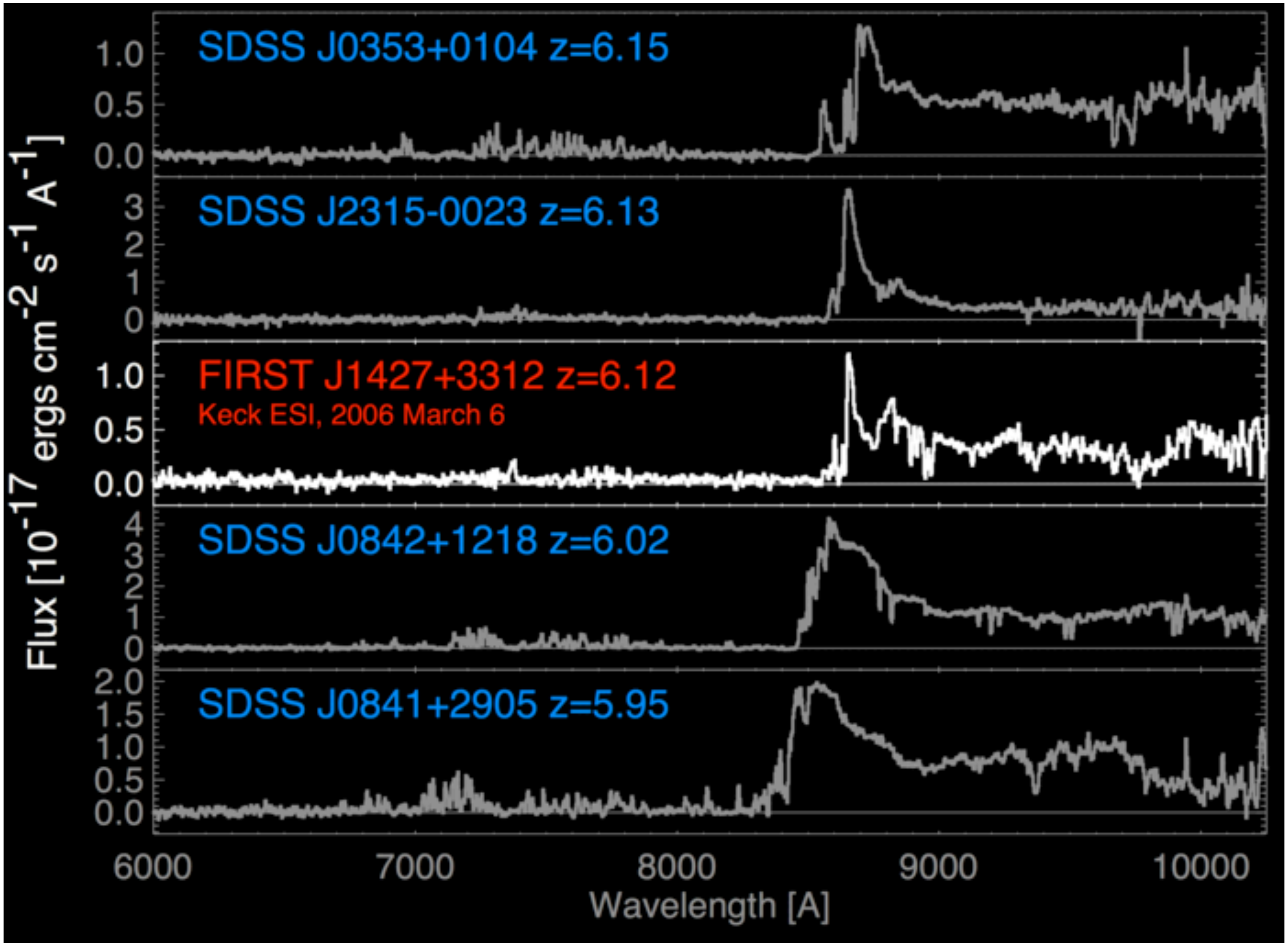
This is well illustrated by a comparison of the spectra of a very local QSO (z=0.16) and a more distant one (z=3.62).



The spectra of SDSS QSOs at z>5 show the spectral region below Lyman α becoming progressively darker.

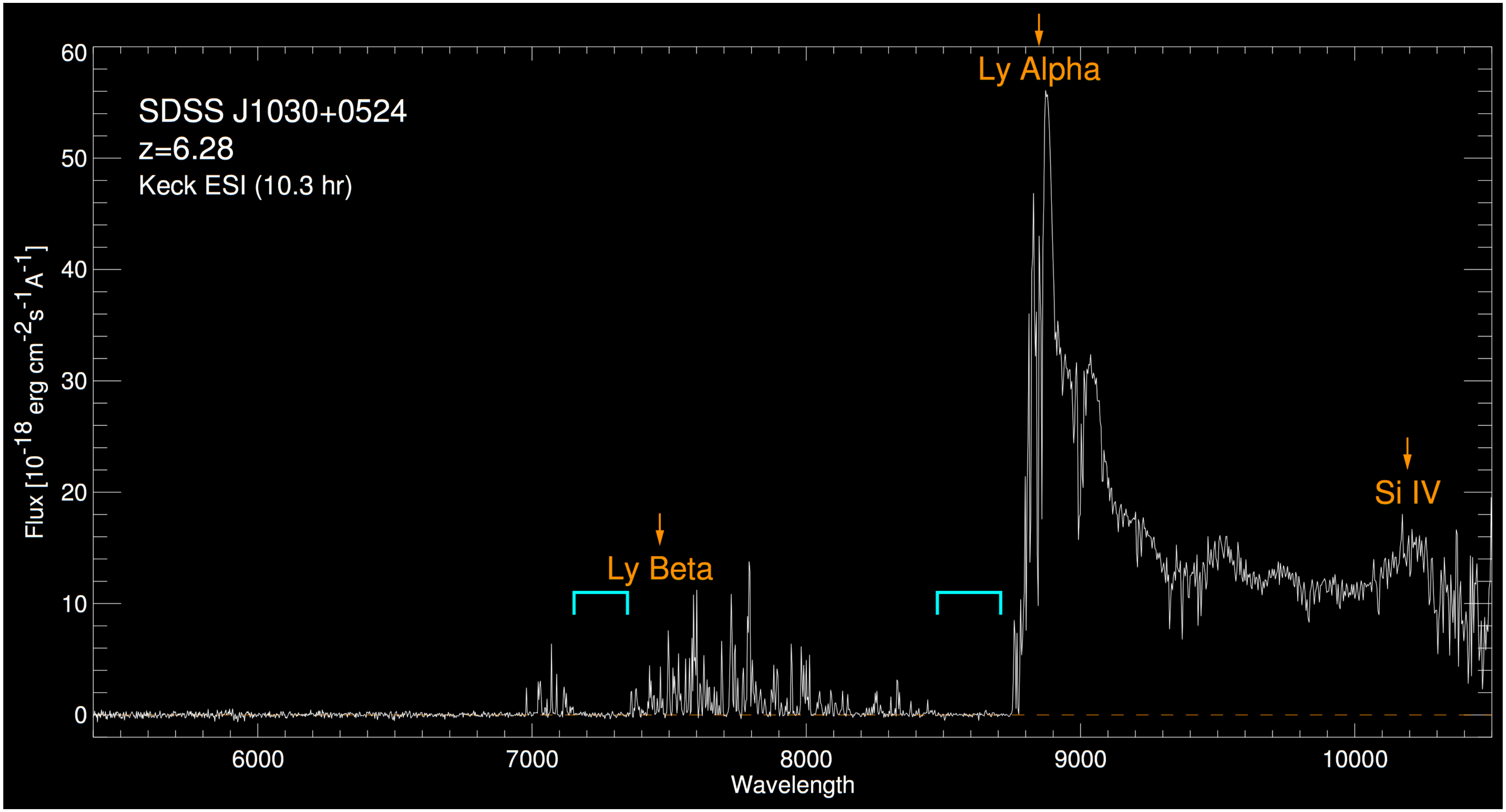
Is this evidence for a neutral medium or is it simply indication of a dense Lyman α forest?



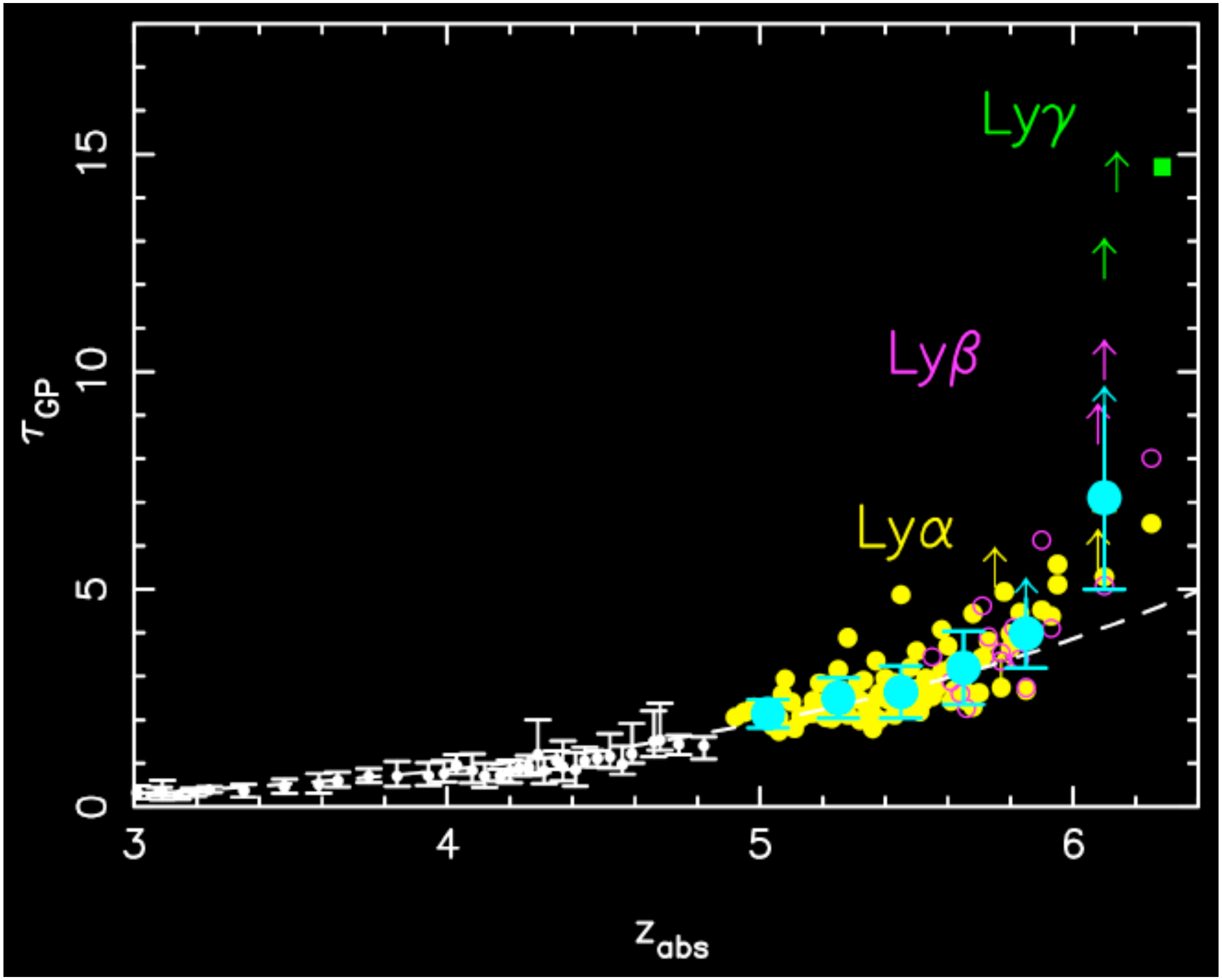


SDSS J0353+0104 z=6.15
SDSS J2315-0023 z=6.13
FIRST J1427+3312 z=6.12
Keck ESI, 2006 March 6
SDSS J0842+1218 z=6.02
SDSS J0841+2905 z=5.95
Flux [10^-17 ergs cm^-2 s^-1 A^-1]
Wavelength [A]

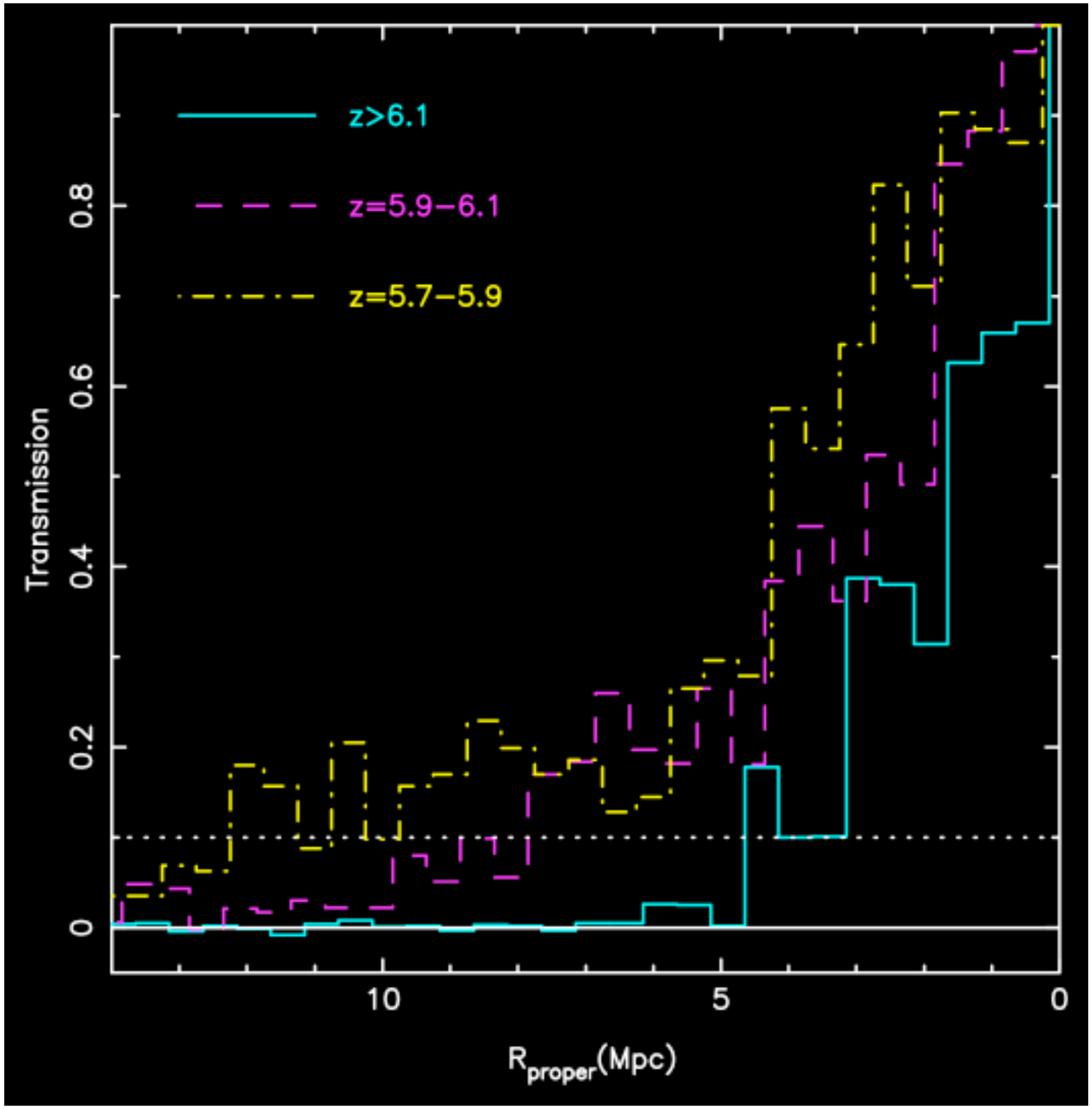
The darkest Gunn-Peterson trough



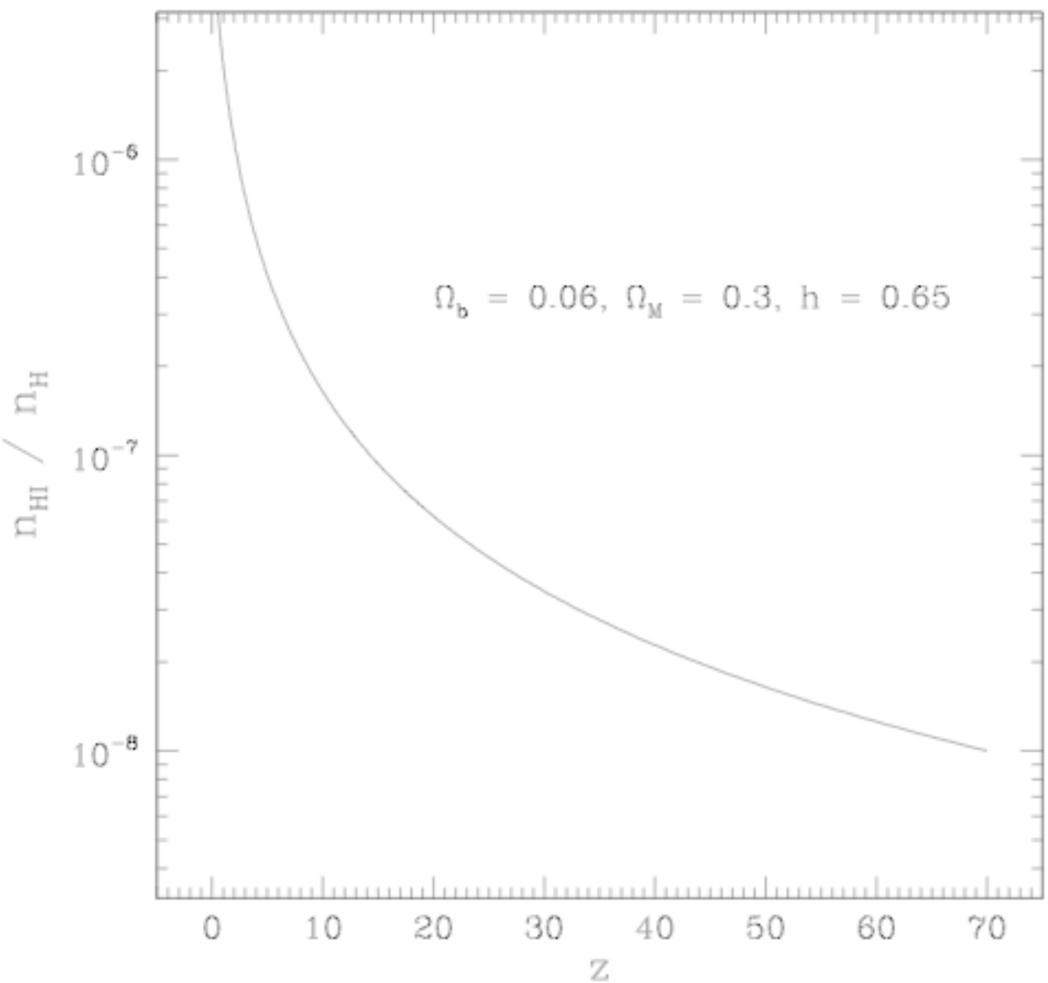
The optical depth in the Lyman lines seems to increase above the extrapolation of the Lyman forest.



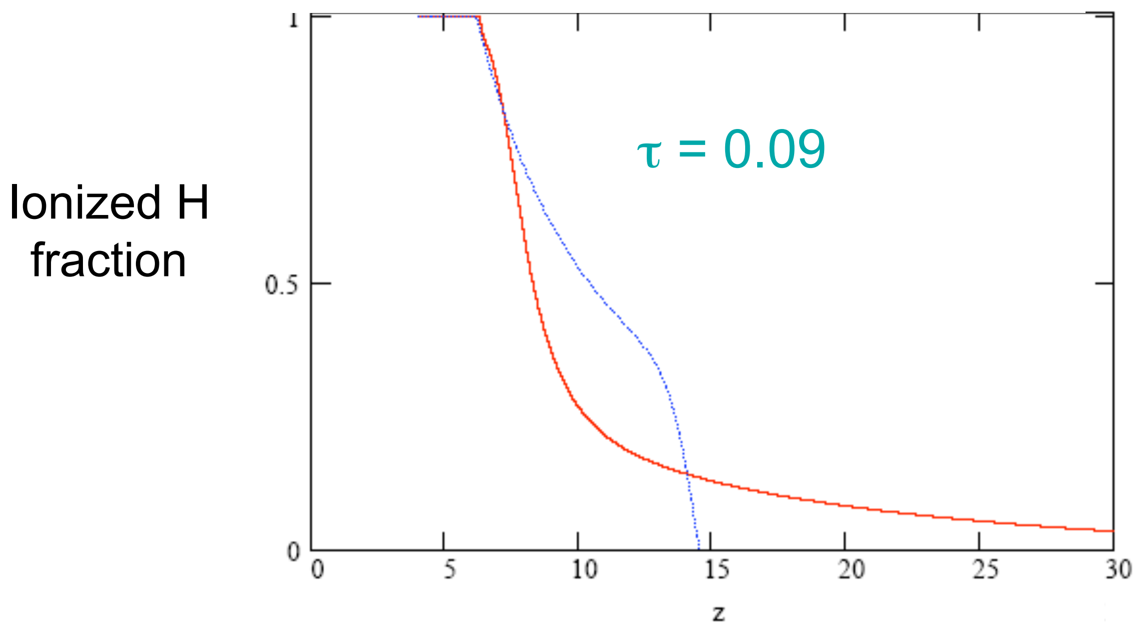
Transmission at the blue edge seems to change above z=6.1



A very modest neutral fraction is sufficient to produce $\tau = 1$.



WMAP provides another, indirect, measurement of the epoch of reionization from its signature in the CMB polarization.



Planck will do this a lot better!

Conditions for reionization

The surface brightness J_ν of a class of sources is related to their volume emissivity $E(\nu)$ = power radiated per unit frequency per unit comoving volume, by:

$$J_\nu = c/4\pi \int_{t1}^{t2} E\{[1+z(t)]\,\nu\}\,dt$$

Where we have assumed that our sources are "on" from time t_1 to t_2. The production rate of ionizing photons dn_c/dt is related to the volume emissivity $E(\nu)$:

$$dn_c/dt = \int_{\nu H}^{\infty} E(\nu)/h\nu\,d\nu$$

For a given spectral energy distribution (SED) there is a fixed relation between the production rate of ionizing photons and the flux density at a given reference frequency ν_0:

$$A(\nu_0) = E(\nu_0)/dn_c/dt$$

In practice A provides a normalization condition.

In order to reionize all Hydrogen the ratio B between the total number density of ionizing photons produced and the density of Hydrogen must be greater than 1.

$$B = \int_{t1}^{t2} dn_c/dt \, dt \; / \; n_H$$

We can now see that the surface brightness J_ν can be expressed simply in terms of a suitably averaged A and B:

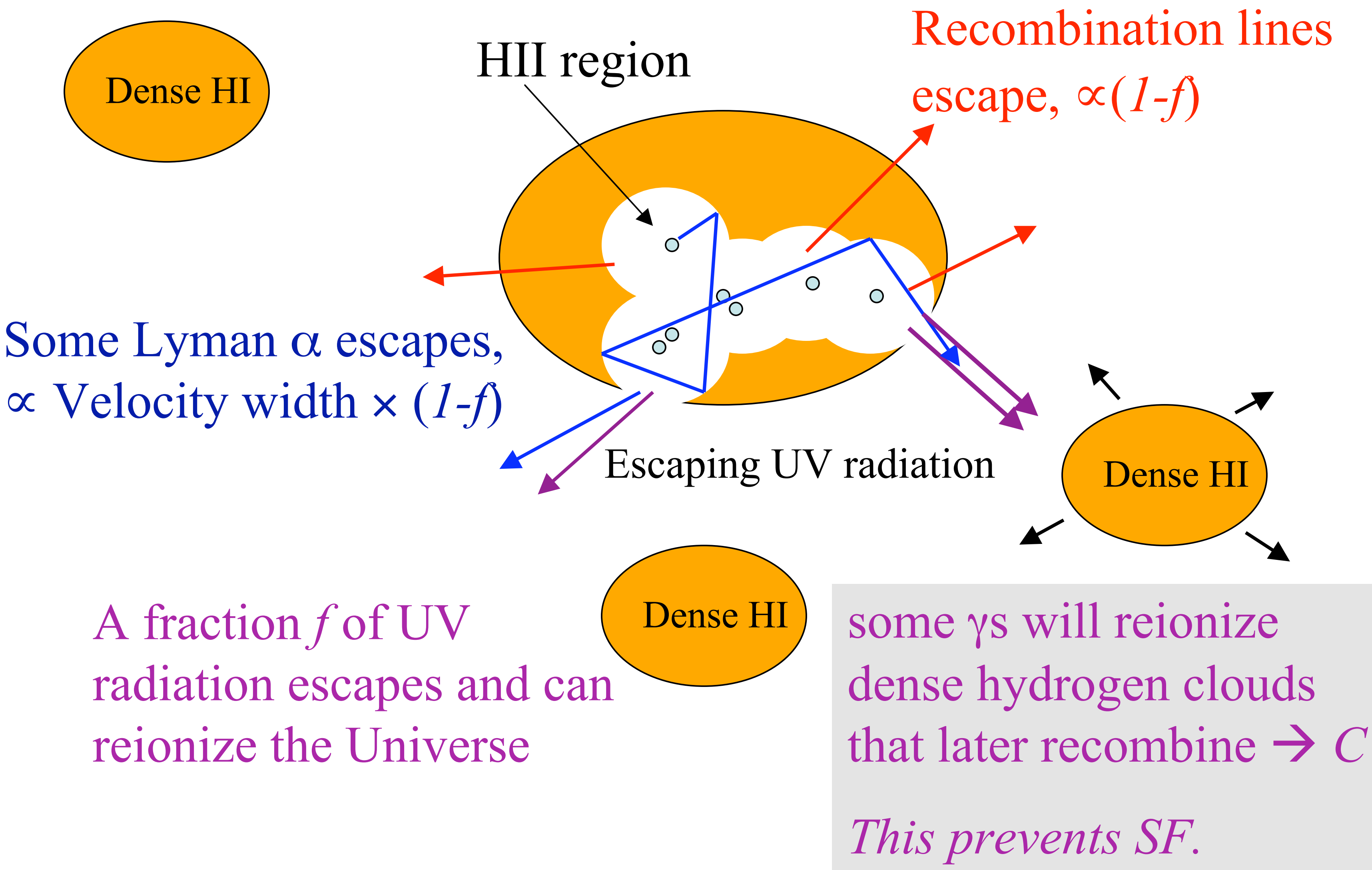
$$J_\nu = c \langle A \rangle B \, n_H / 4\pi$$

Where <A> is :

$$\langle A \rangle(\nu) = \int_{t1}^{t2} A\{[1+z(t)]\,\nu\}\,(dn_c/dt)\,dt \Big/ \int_{t1}^{t2} (dn_c/dt)\,dt$$

For a given star formation history <A> can be easily computed and the minimum surface brightness for reionization becomes a simply proportional to n_H.

Estimate luminosity of reionizing sources from first principles



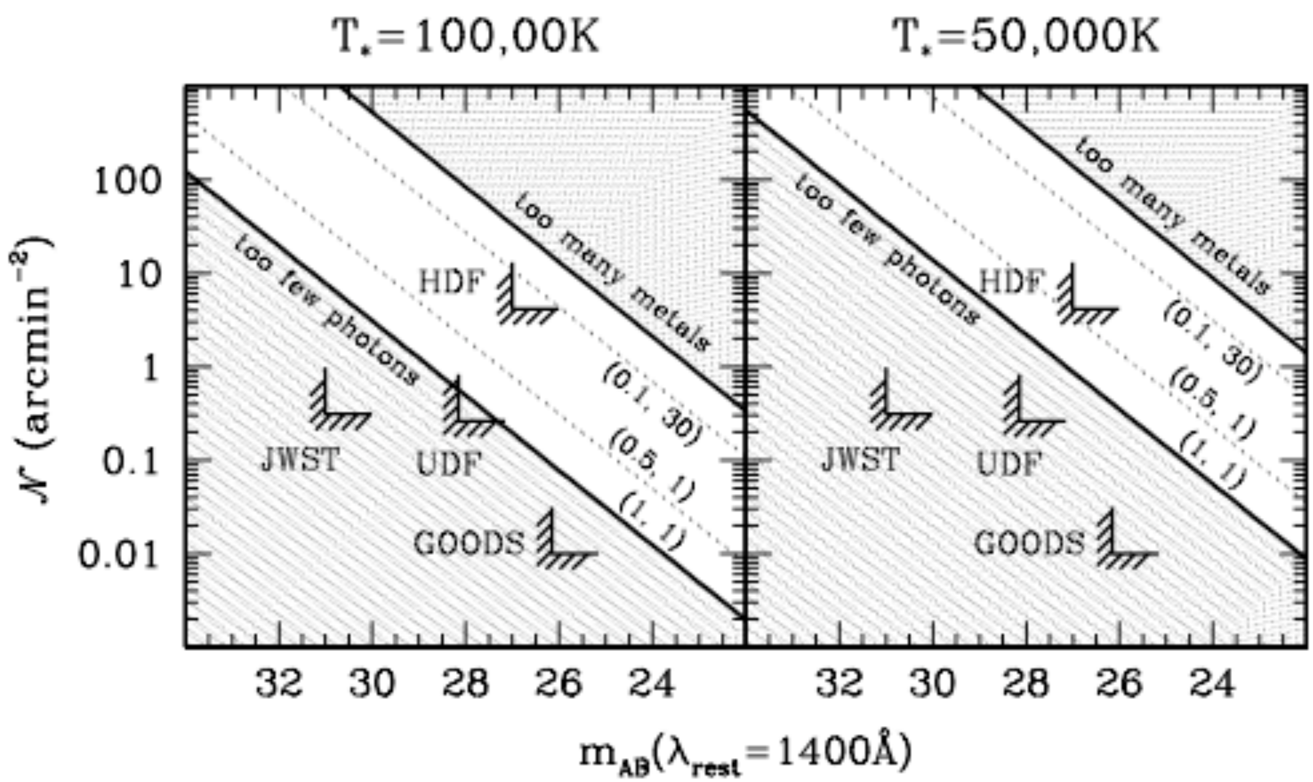
Factors pushing B above 1:

- presence of Helium, increasing B by about 8 per cent

- recombinations, increasing B by a factor dependent on C. The higher is C, the more recombinations.

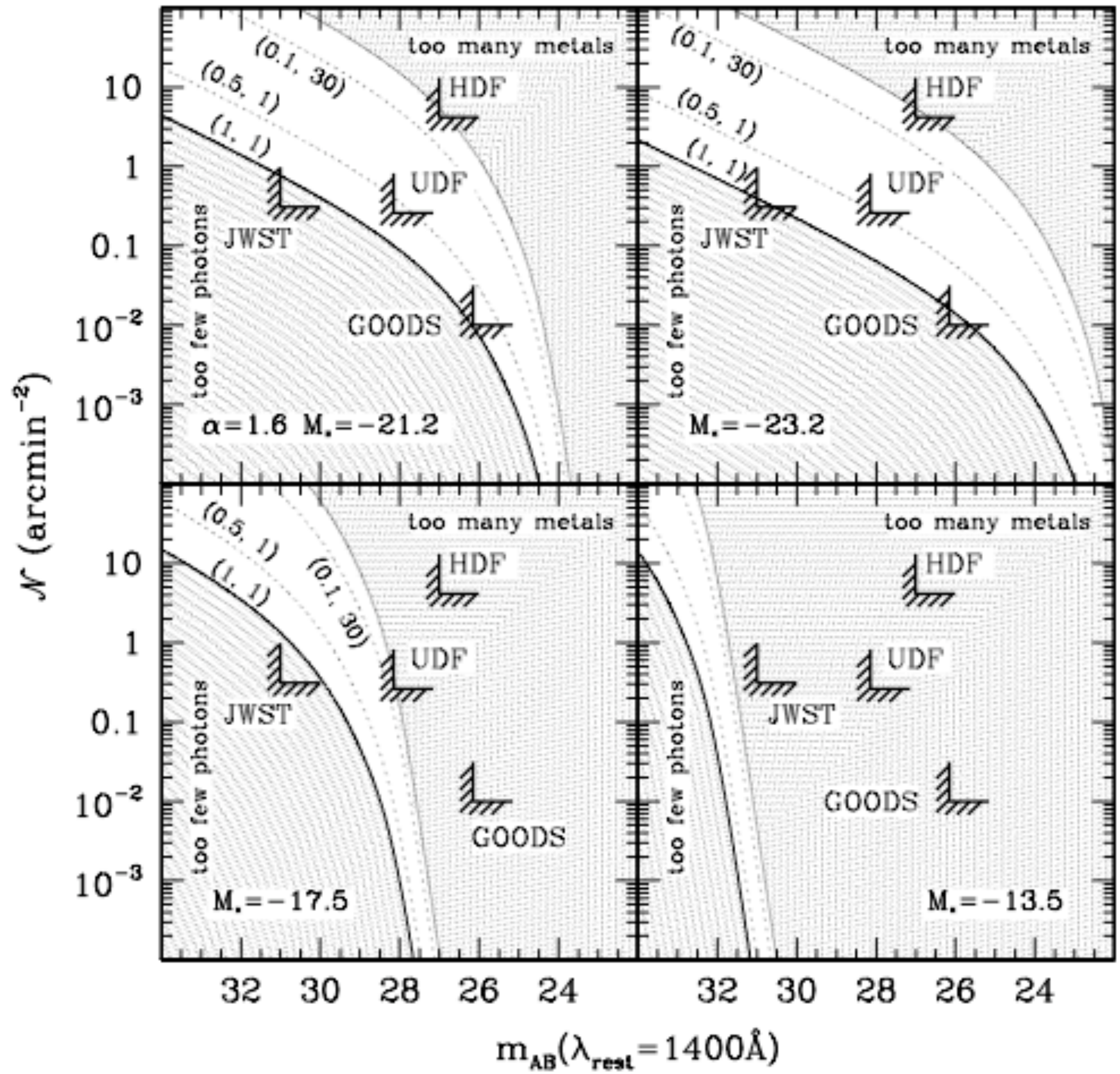
- escape fraction, increasing B as 1/f

Case of identical ionization sources

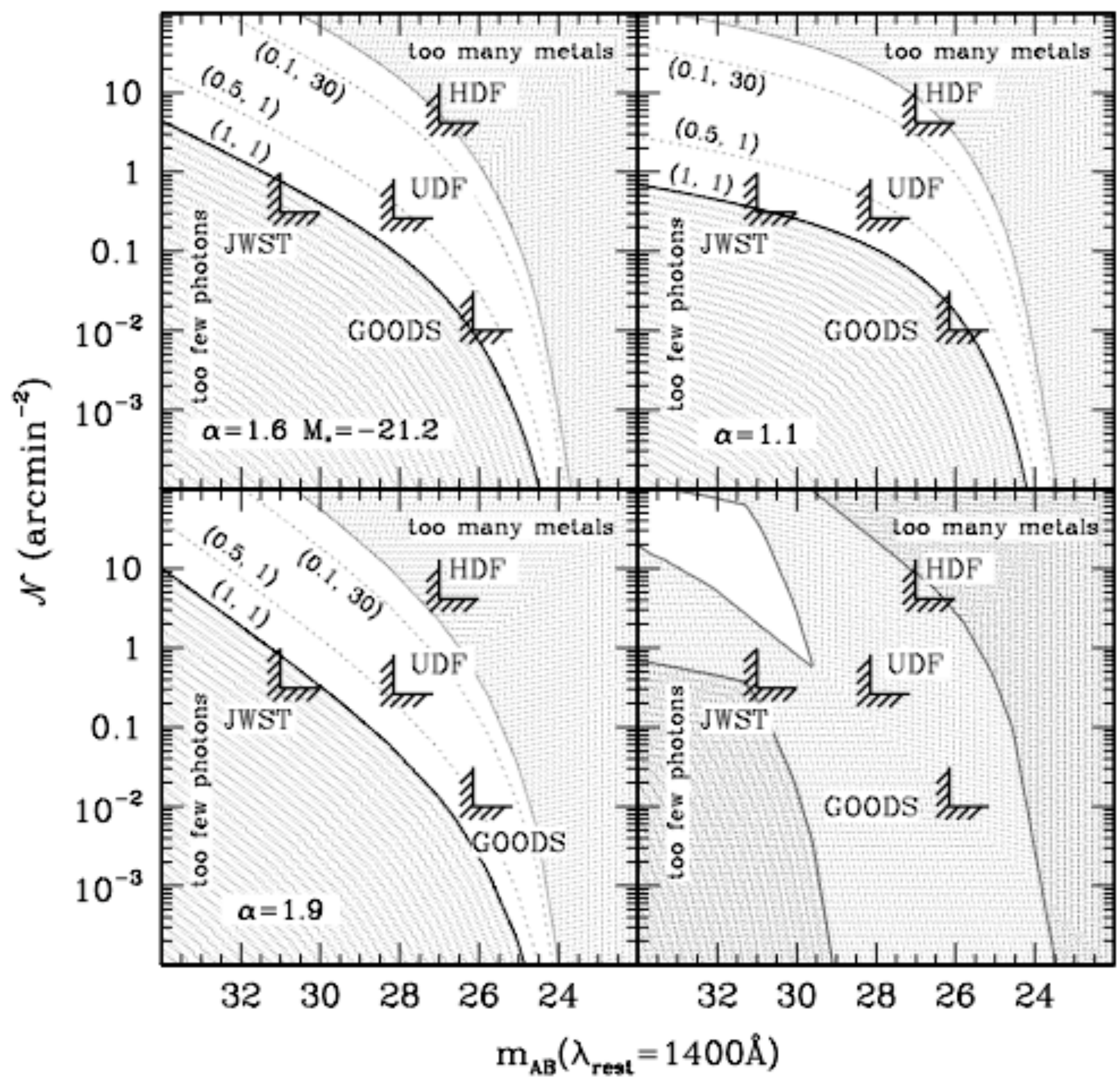


(f,C) : f is the escape fraction and C is the clumping factor

Let’s now assume that the sources are not identical but are described by some Schechter type luminosity function.



too many metals
(0.1, 30)
(0.5, 1)
(1, 1)
HDF
UDF
JWST
GOODS
too few photons
α=1.6 M.=−21.2
M.=−23.2
M.=−17.5
M.=−13.5
10
1
0.1
10^{-2}
10^{-3}
32
30
28
26
24
$\mathcal{N}$ (arcmin^{-2})
$m_{AB}(\lambda_{rest}=1400Å)$



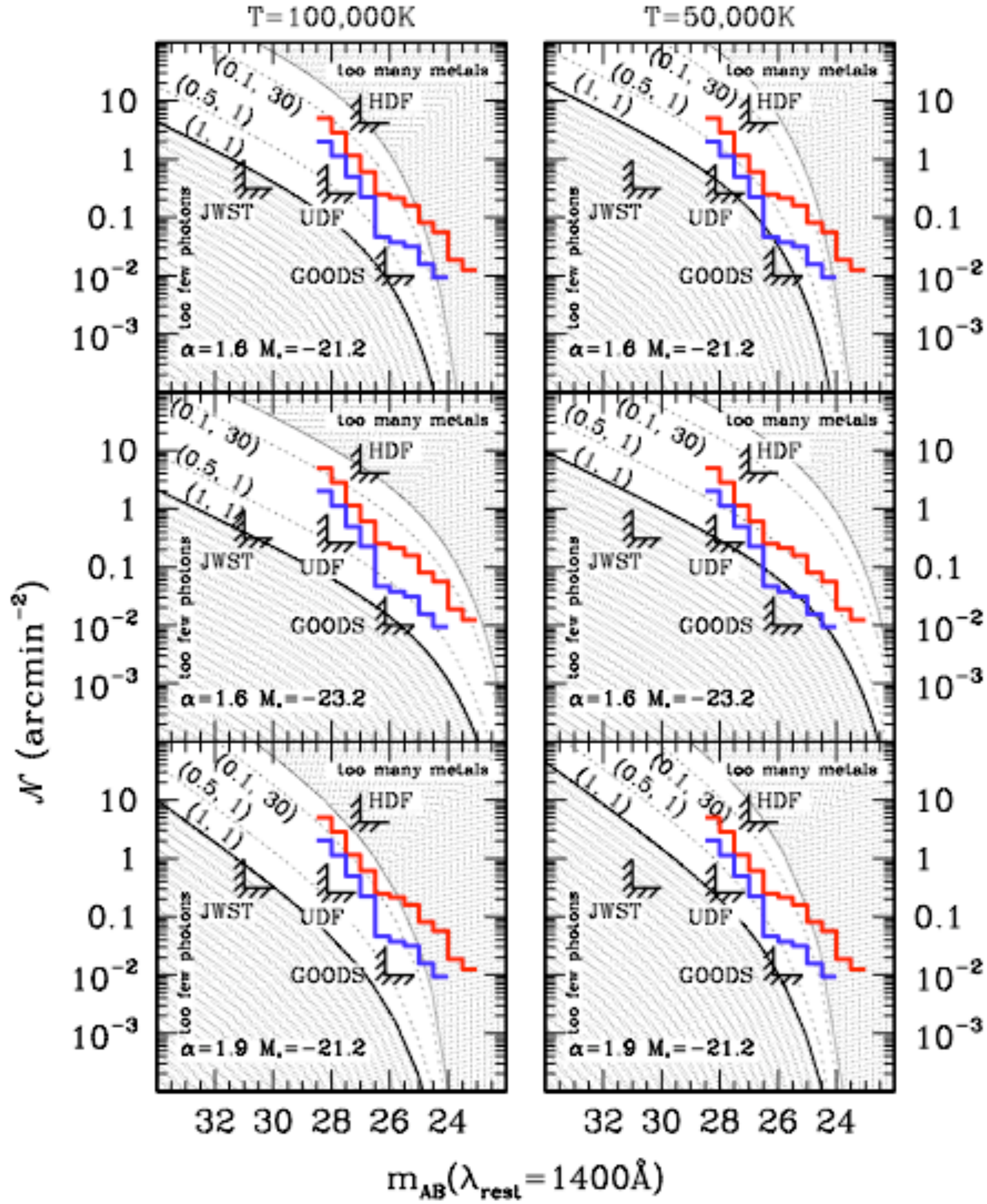
too many metals
too few photons
HDF
UDF
JWST
GOODS
(0.1, 30)
(0.5, 1)
(1, 1)
α=1.6 M*=−21.2
α=1.1
α=1.9
10
1
0.1
10^-2
10^-3
32
30
28
26
24
𝒩 (arcmin^-2)
m_AB(λ_rest=1400Å)

How do we use this in practice?

Two methods:

1. For a given sample of sources, e.g., I-dropout galaxies, compute the total cumulative surface brightness SB = $zp-2.5 \log_{10} \Sigma\ 10^{-0.4(m_{AB}-zp)}$, resulting value is then compared to minimum required.

2. Plot the observed counts in the luminosity function plot and compare with allowed area.


T=100,000K
T=50,000K
too many metals
HDF
UDF
JWST
GOODS
(0.1, 30)
(0.5, 1)
(1, 1)
too few photons
α=1.6 M.=−21.2
α=1.6 M.=−23.2
α=1.9 M.=−21.2
10
1
0.1
10^-2
10^-3
32 30 28 26 24
𝒩 (arcmin^-2)
m_AB(λ_rest=1400Å)

Can we observe Lyman α before reionization?

NO: any small amount of neutral Hydrogen will absorb Lyman α resonantly. The line will be re-emitted along some random direction only to be absorbed again, etc. The outcome is going to be either absorption by dust if present or scatter over a large area leading to very low surface brightness in Lyman α.

WAIT, YES! A bright source will generate its own Shapiro sphere (a Stroemgren sphere analogue in the expanding case) by ionizing all Hydrogen nearby. If the sphere is large enough Lyman α (or at least it's red wing) will be able to escape.

Can we tell the redshift of reionization from Lyman α?

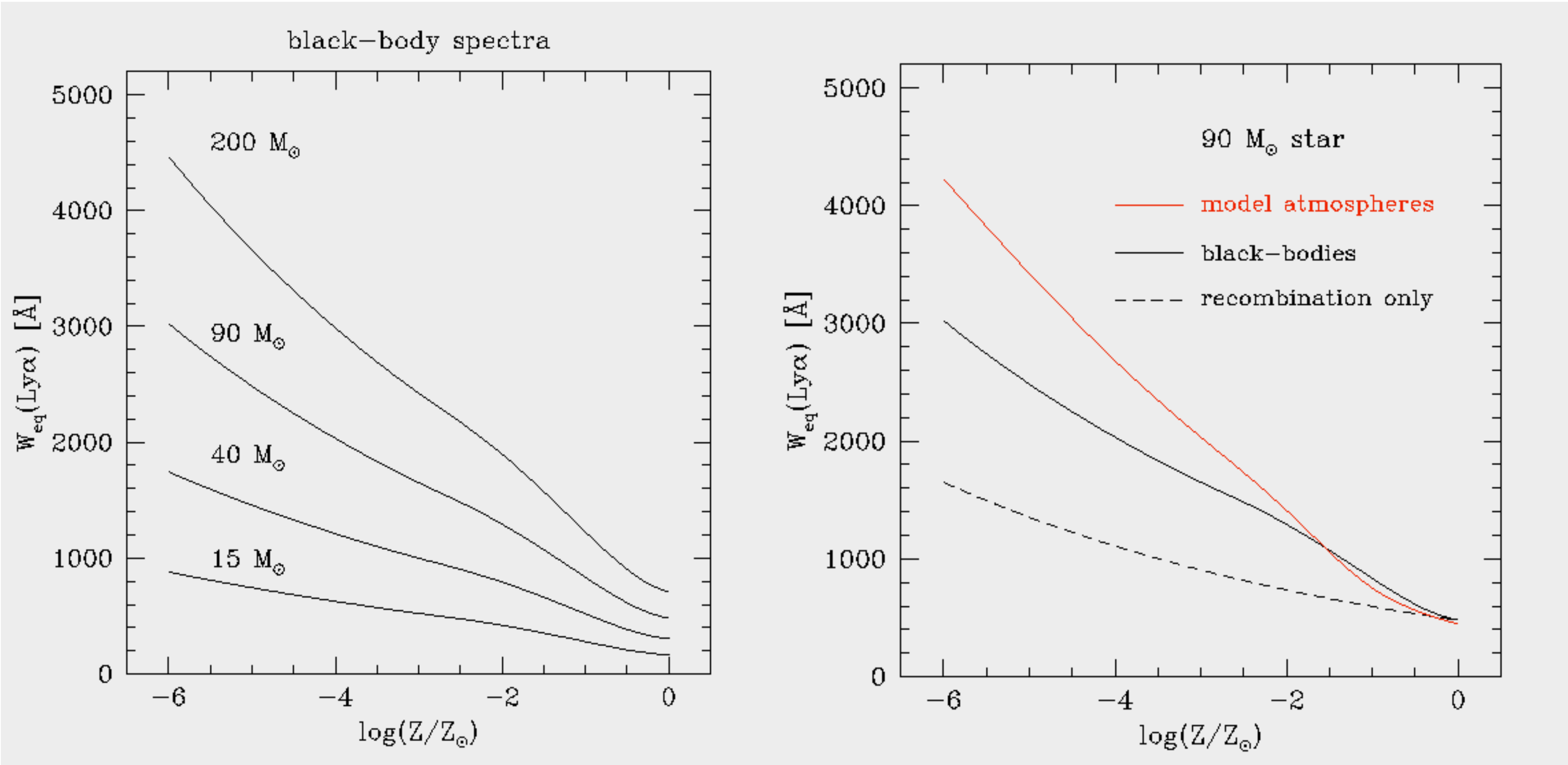
VERY HARD: for increasing redshift and increasing neutral fraction Lyman a will be attenuated more strongly, however, the intrinsic EW of Lyman alpha is higher when the metallicity is lower. This effect tends to counterbalance the cosmological attenuation by intervening neutral Hydrogen.

Ly-α Equivalent Width dependence on metallicity

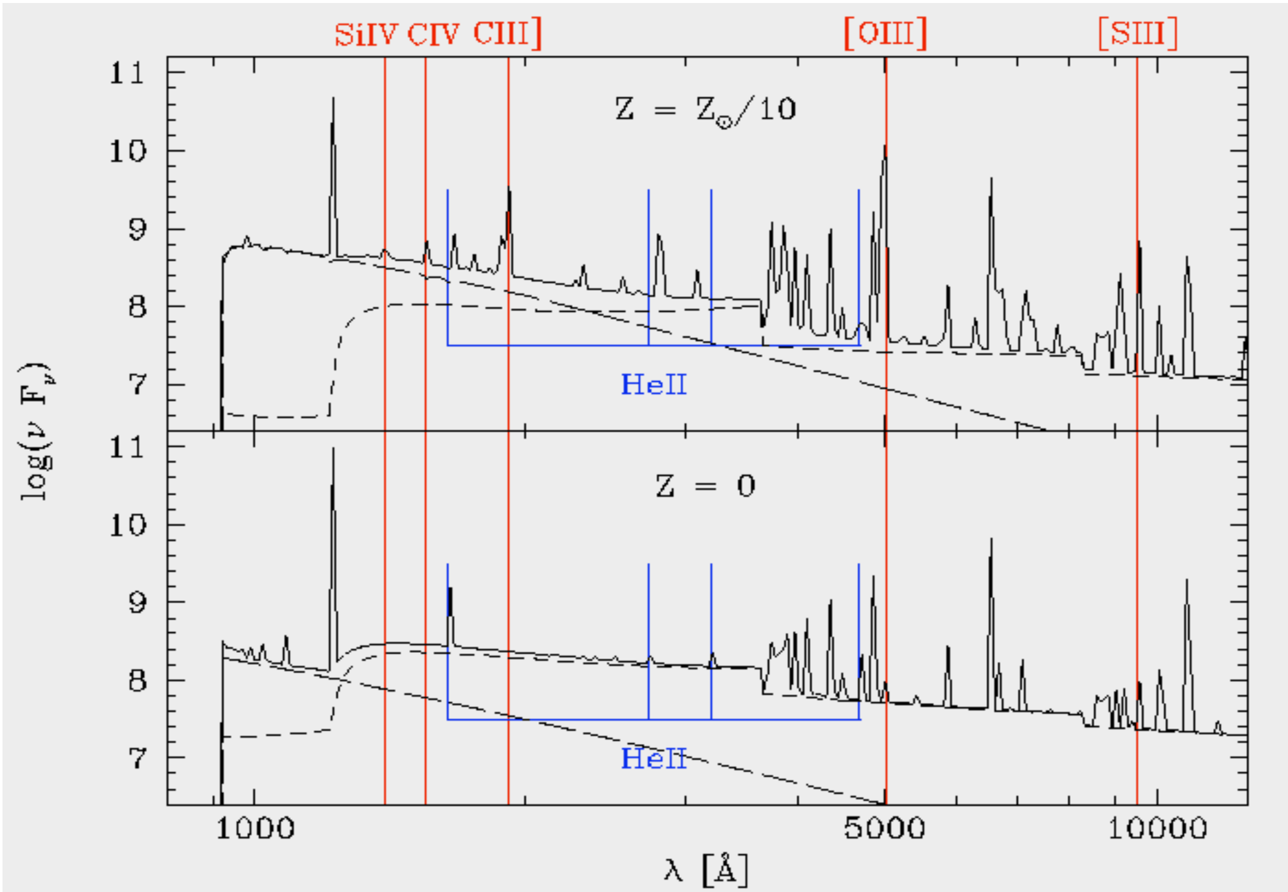
The Ly-α EW increases strongly at low Z because :

(a) the line intensity increases and

(b) the continuum flux decreases



A primordial HII region
(*f*=0)

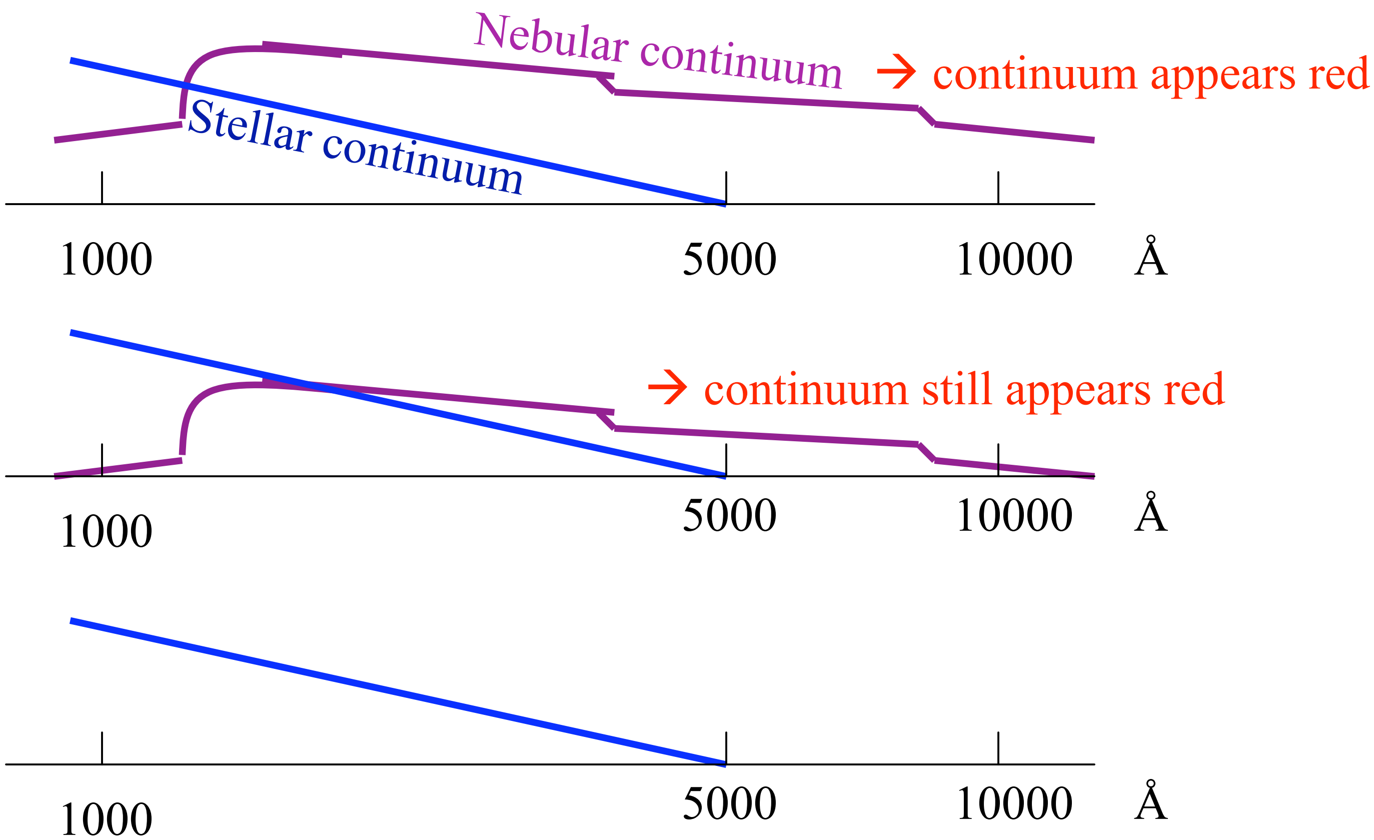


Spectra for zero-metallicity sources

f=0
No ionizing
γ escape

f=0.9
Most ionizing
γ escape

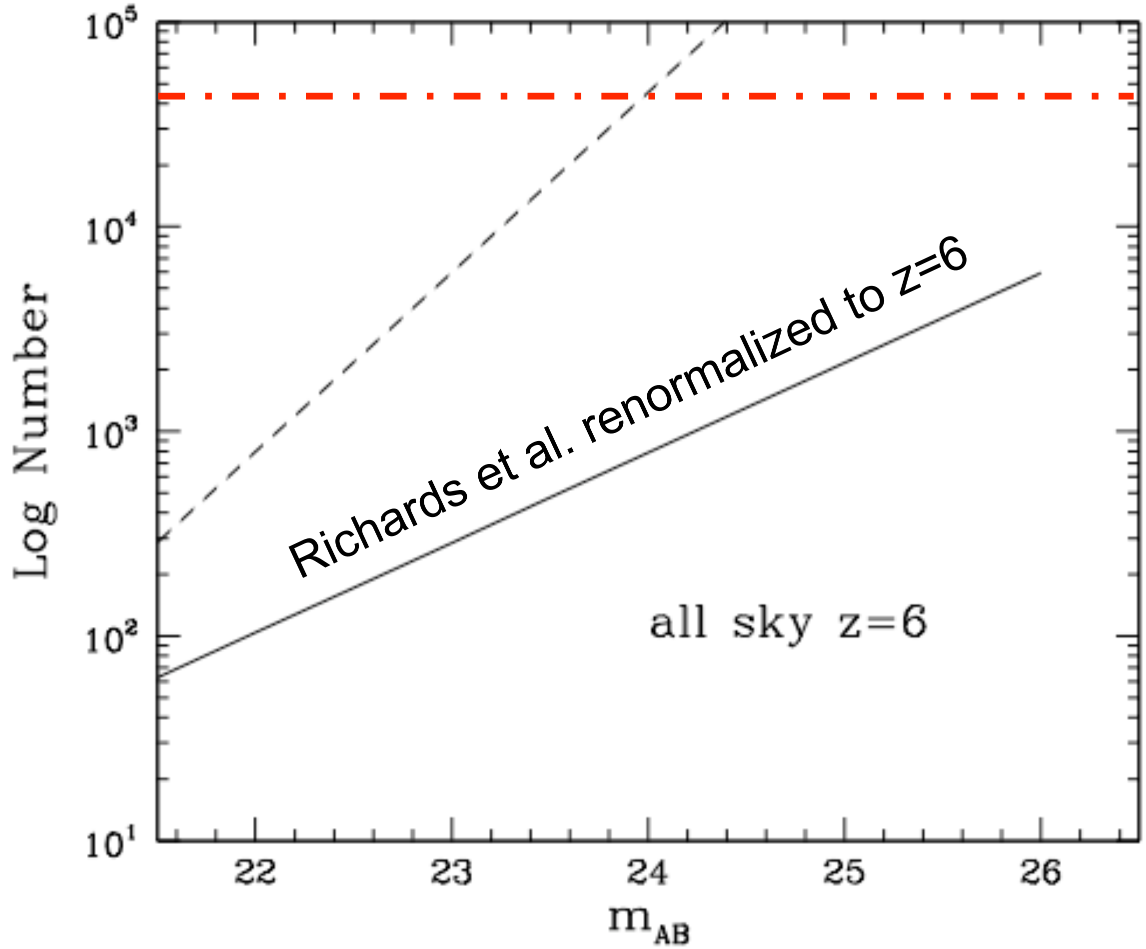
f=1
All ionizing
γ escape

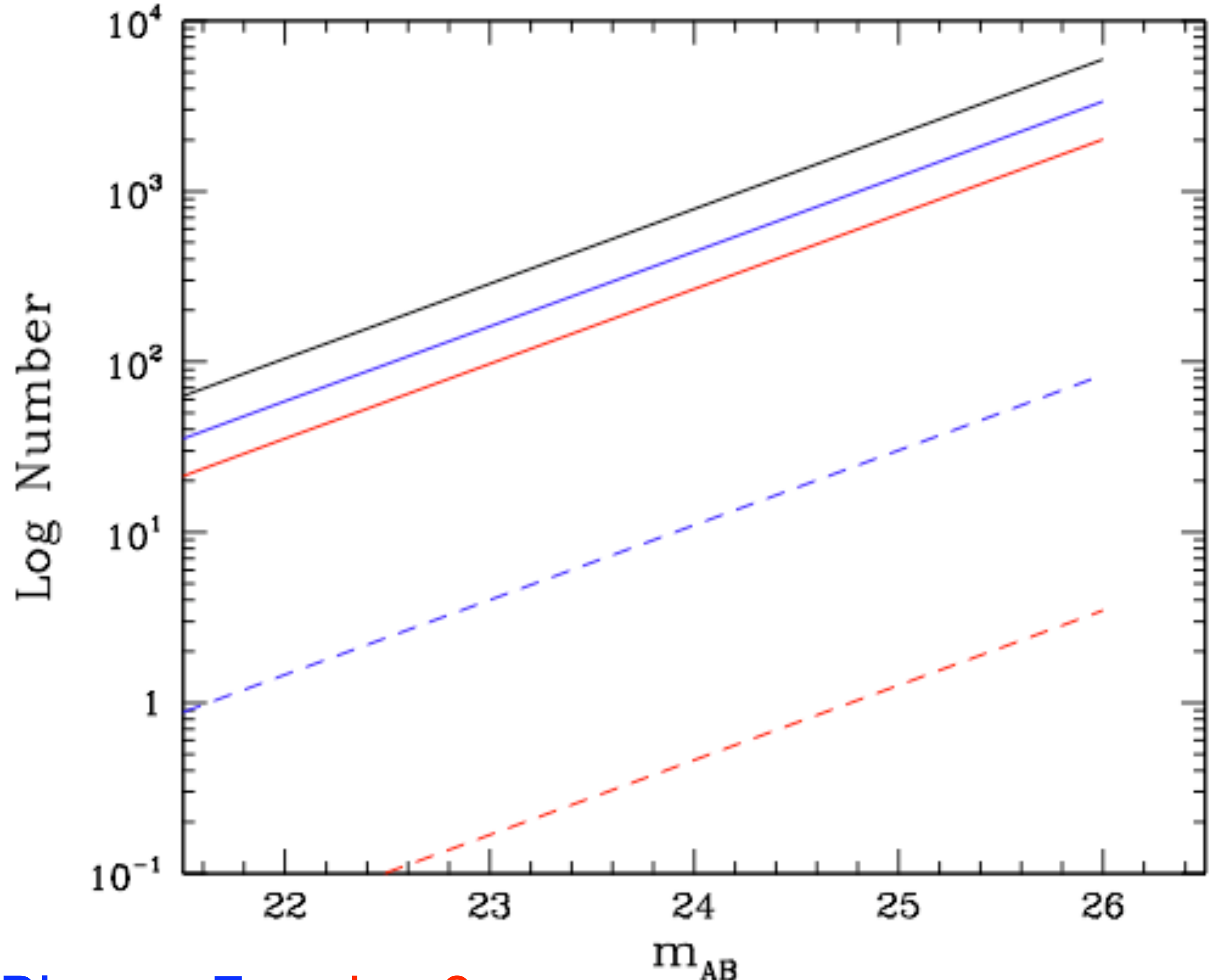


At higher metallicity the SED at 1400 Å is always dominated by stars.

Why QSOs aren't doing it?

They are very rare





Blue z=7, red z=8.

Solid linear evol. Dashed Eddington evol.

Summary and final remarks

-All existing data are compatible with reionization being completed at z=6 with a possibe start at high-z

- Reionization condition best described in surface brightness terms

- QSOs are probably not responsible for reionization because of their rarity and because their hard spectrum would reionize also Helium which instead reionizes much later.

References

- Reionization : Fan et al. 2006, ARAA, 44, 415; Madau et al. 1999, ApJ 524, 527.
- SB conditions for reionization: Stiavelli et al. 2004a, ApJ, 600, 508 (models), 2004b, ApJ, 610, L1 (appl. to UDF)