

# « Propriétés et évolution des galaxies »

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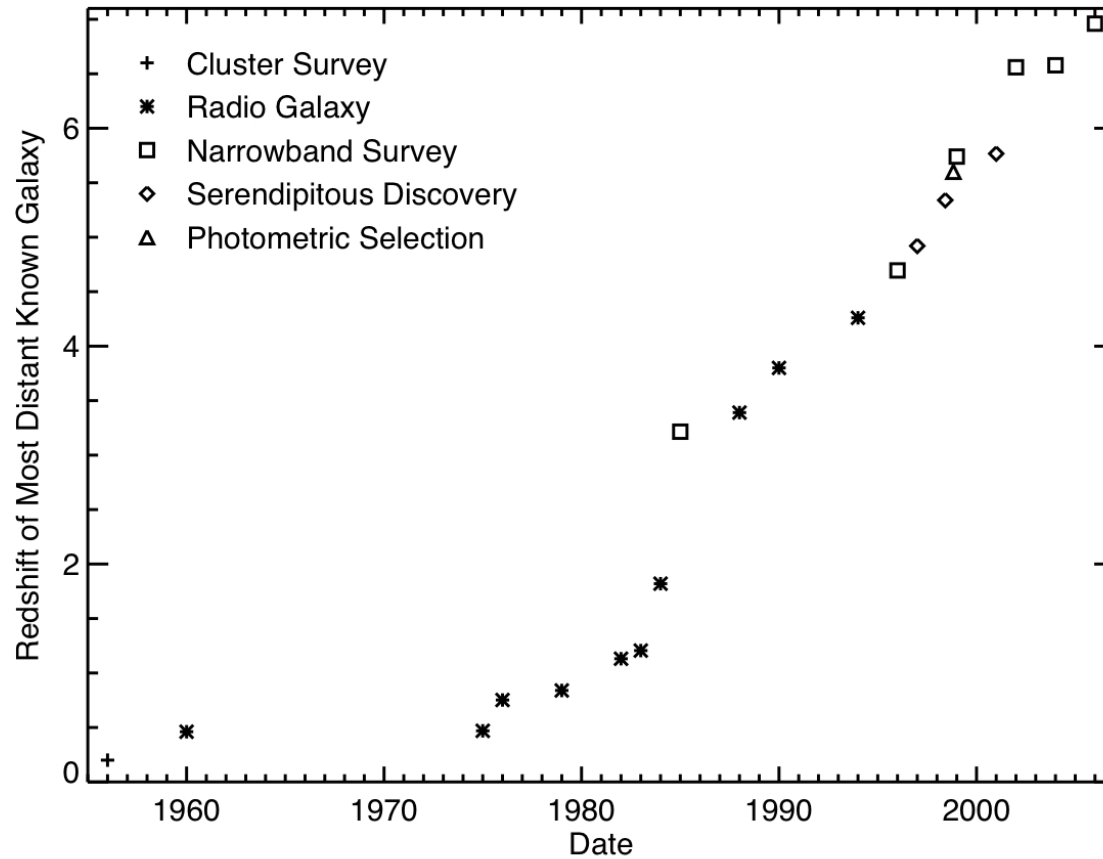
Tel: 01 69 08 54 39

À la recherche des galaxies les plus distantes

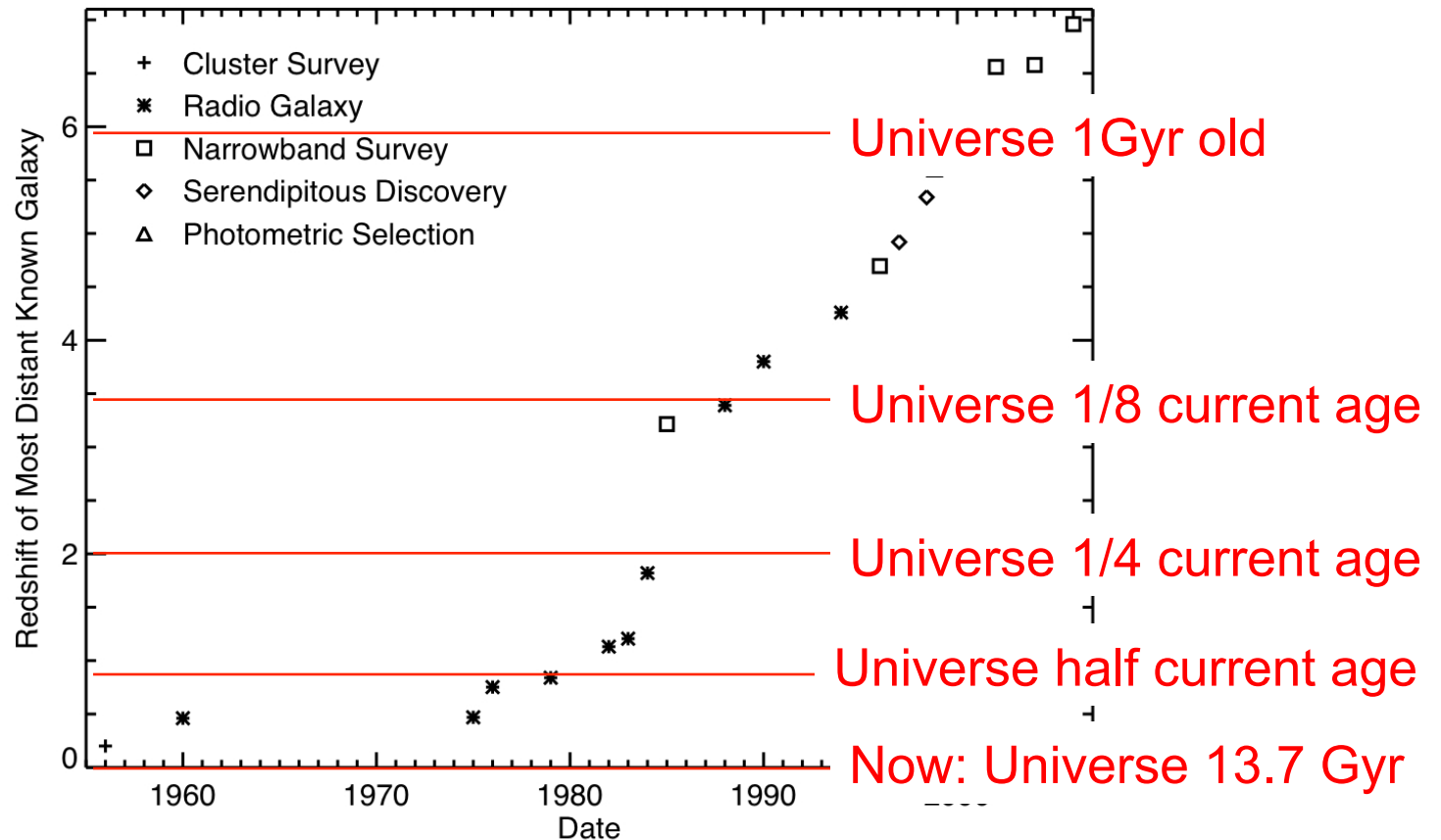
Master Recherche M2 Astronomie & Astrophysique  
Enseignement thématique des parcours M2 – Galaxies

[http://david.elbaz3.free.fr/master\\_m2](http://david.elbaz3.free.fr/master_m2)

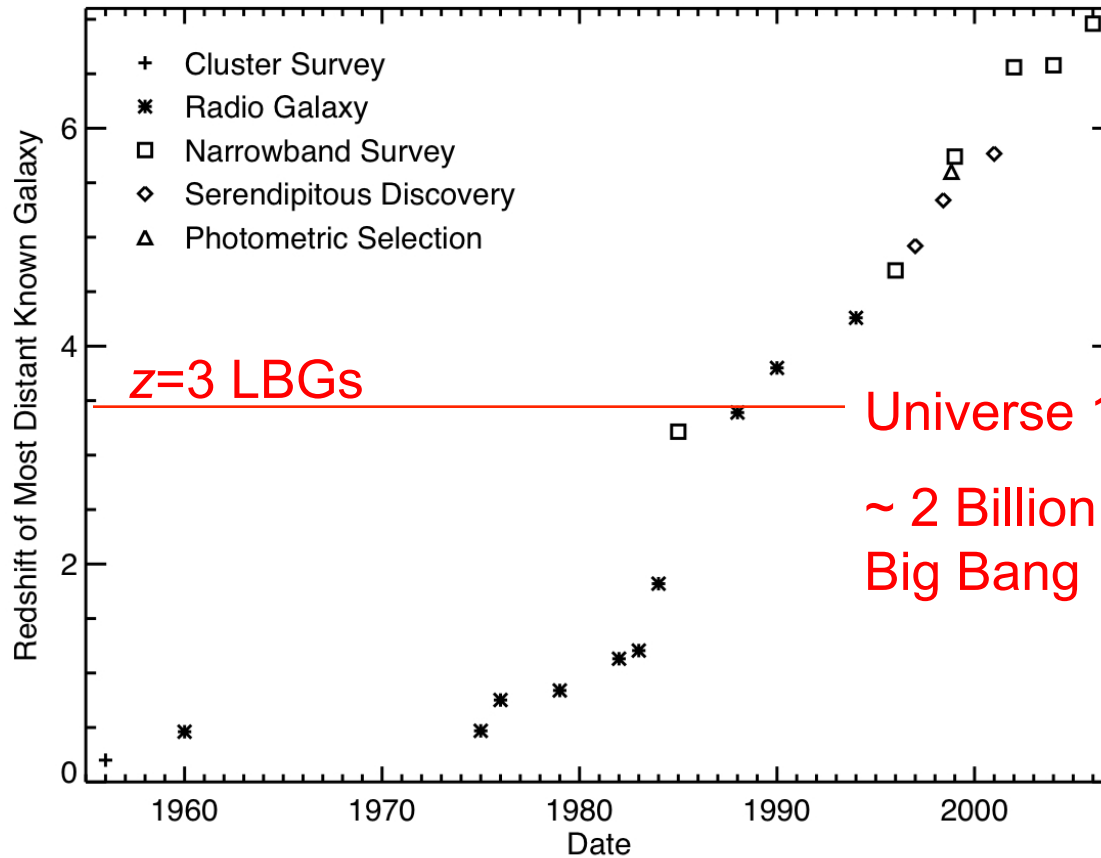
# À la recherche de la galaxie la plus distante



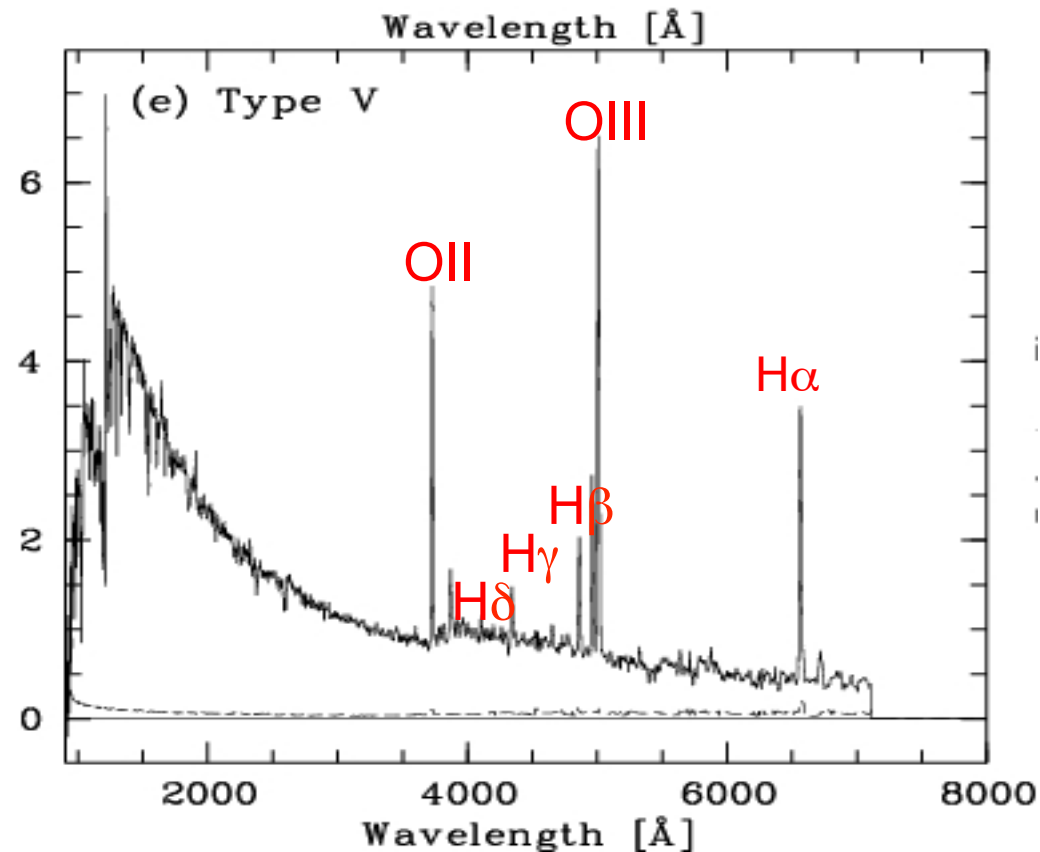
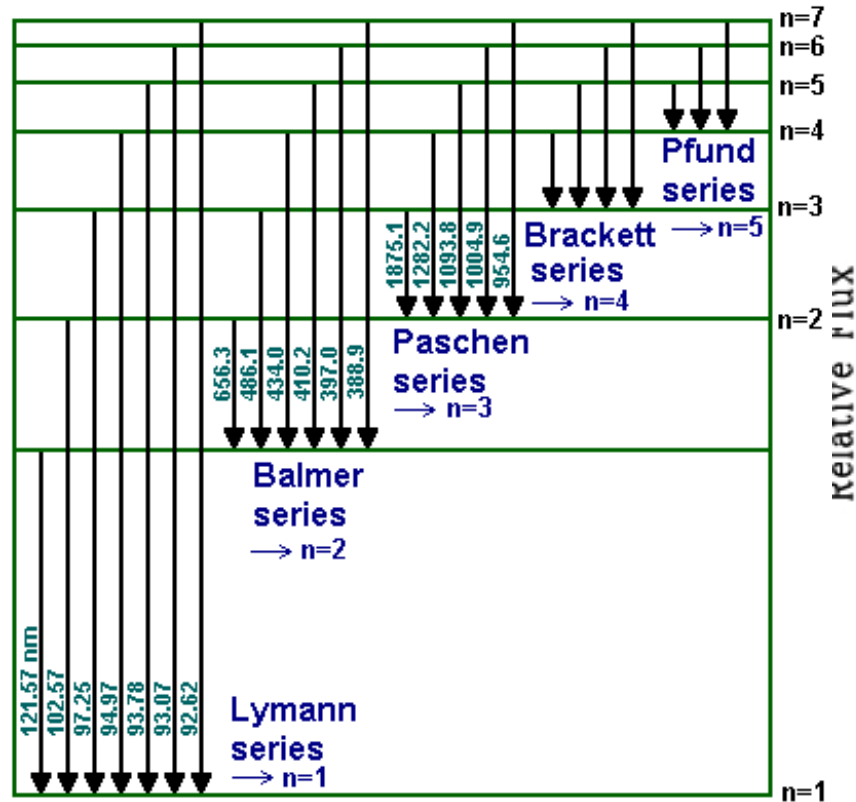
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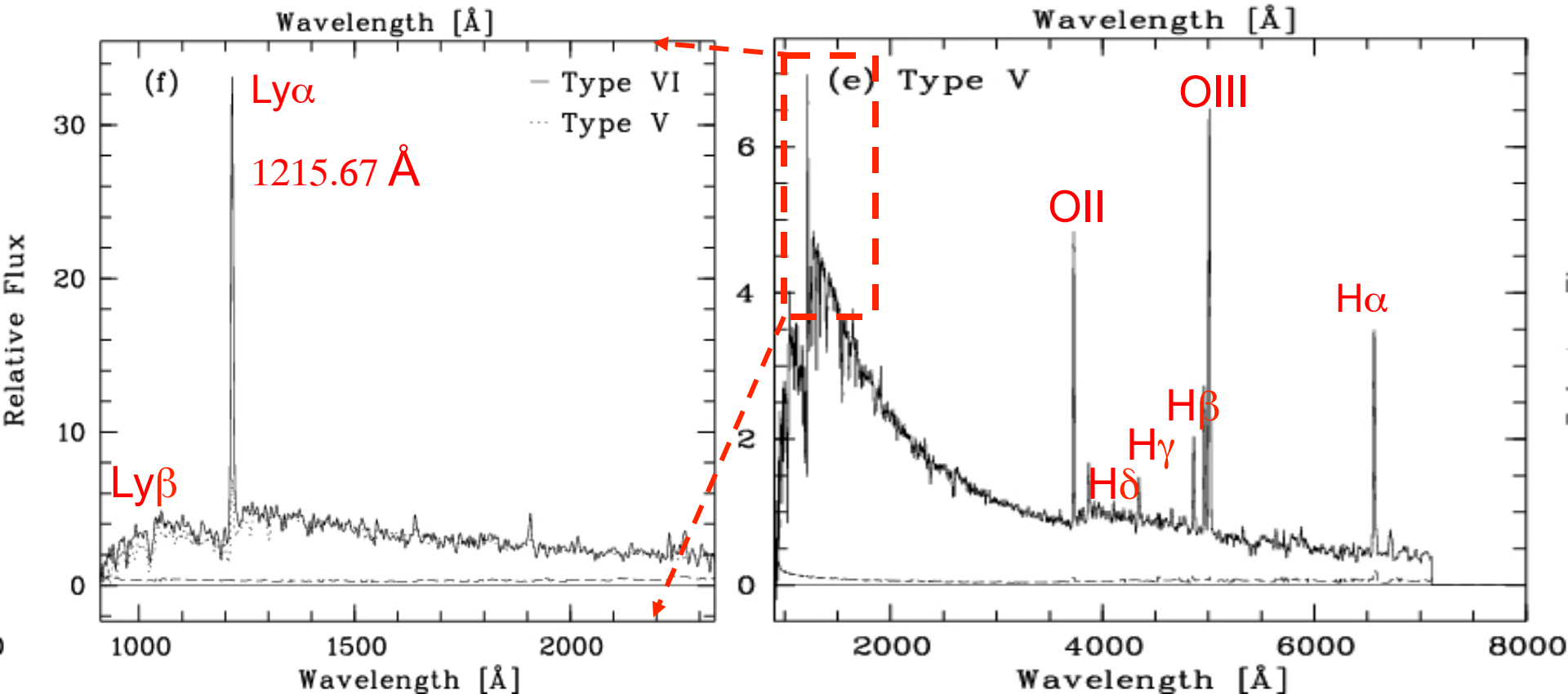
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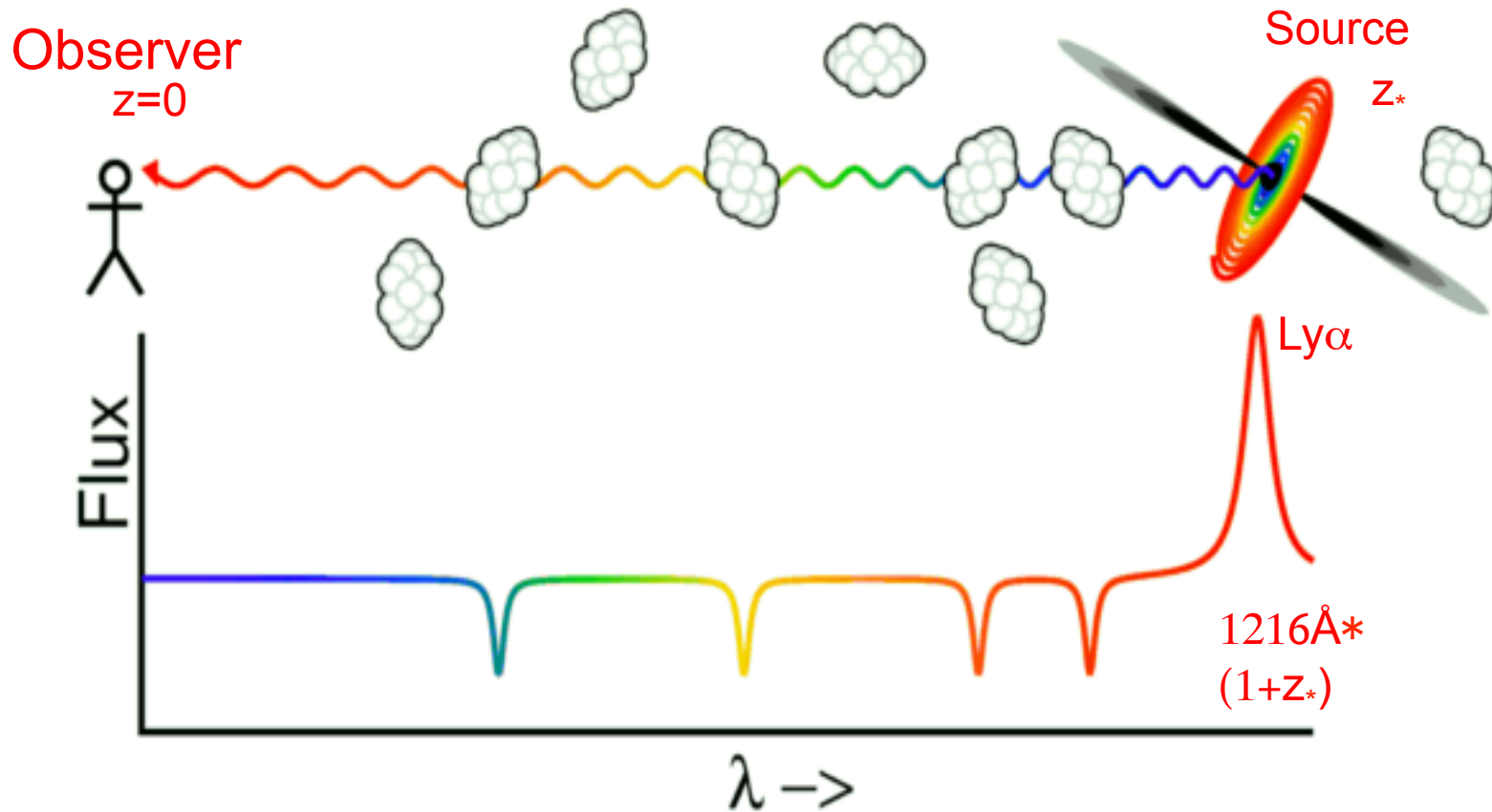
# Les raies de Balmer, de Lyman et de l'oxygène pour mesurer le redshift



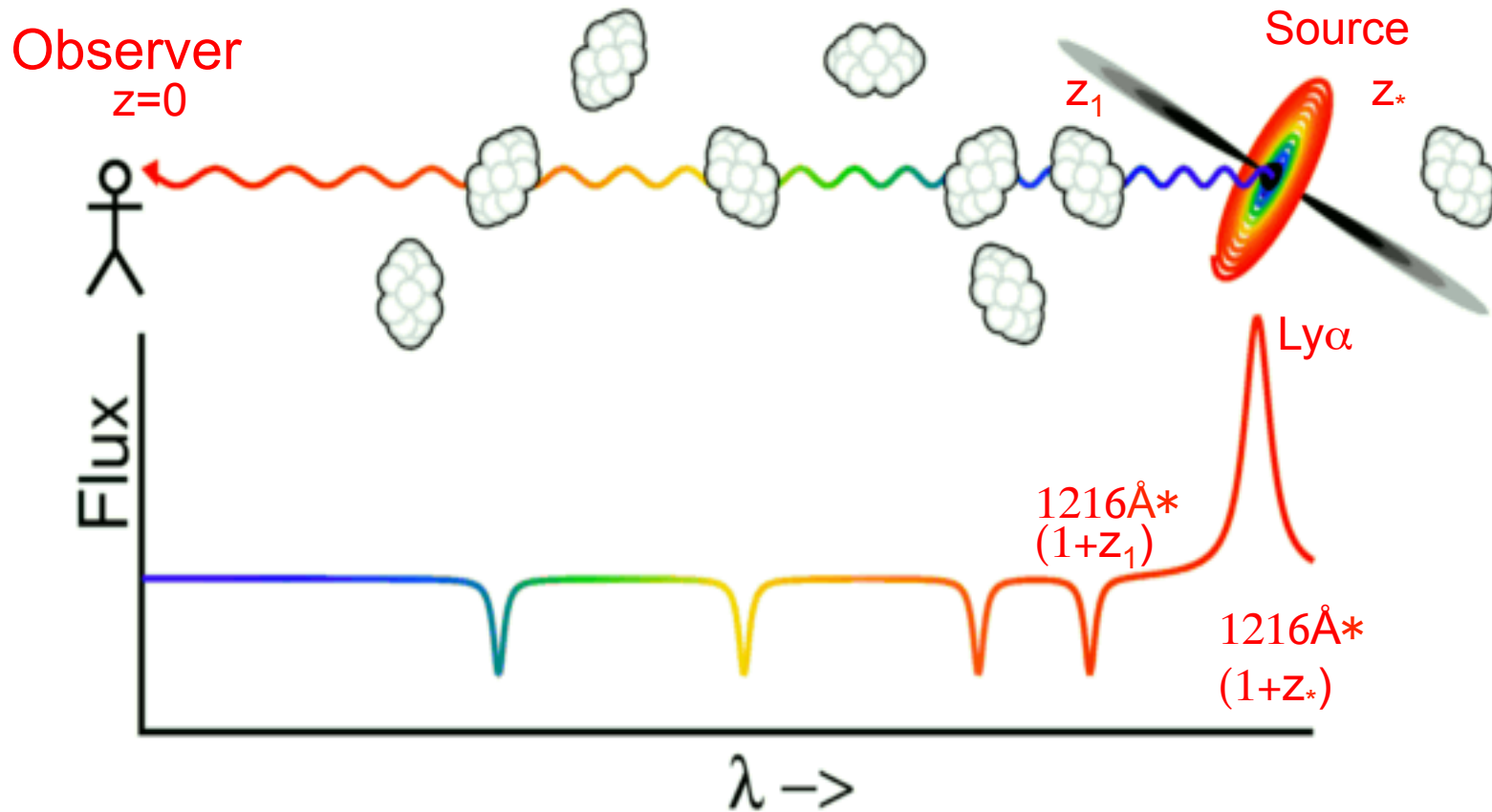
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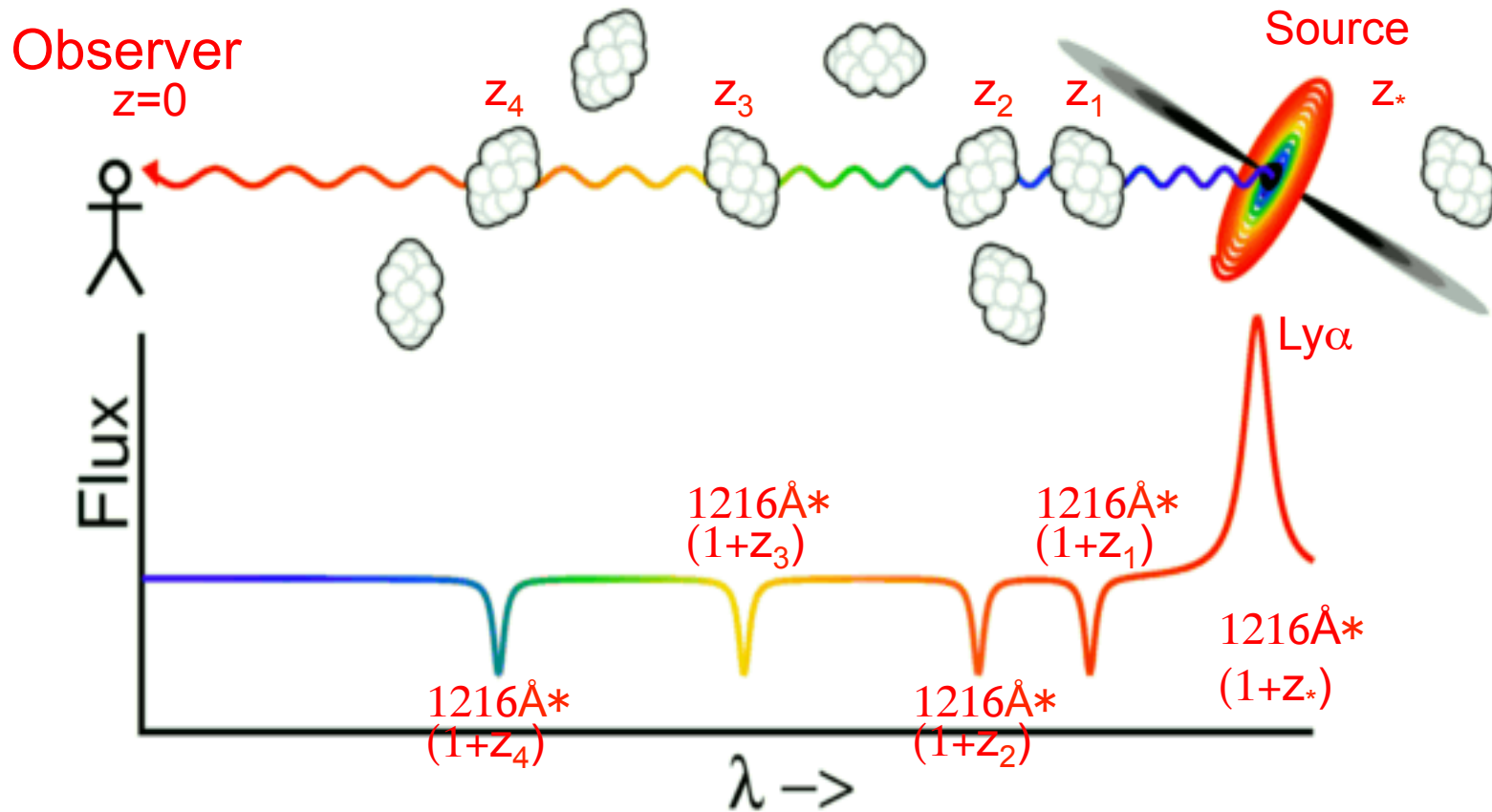
# La forêt Lyman $\alpha$



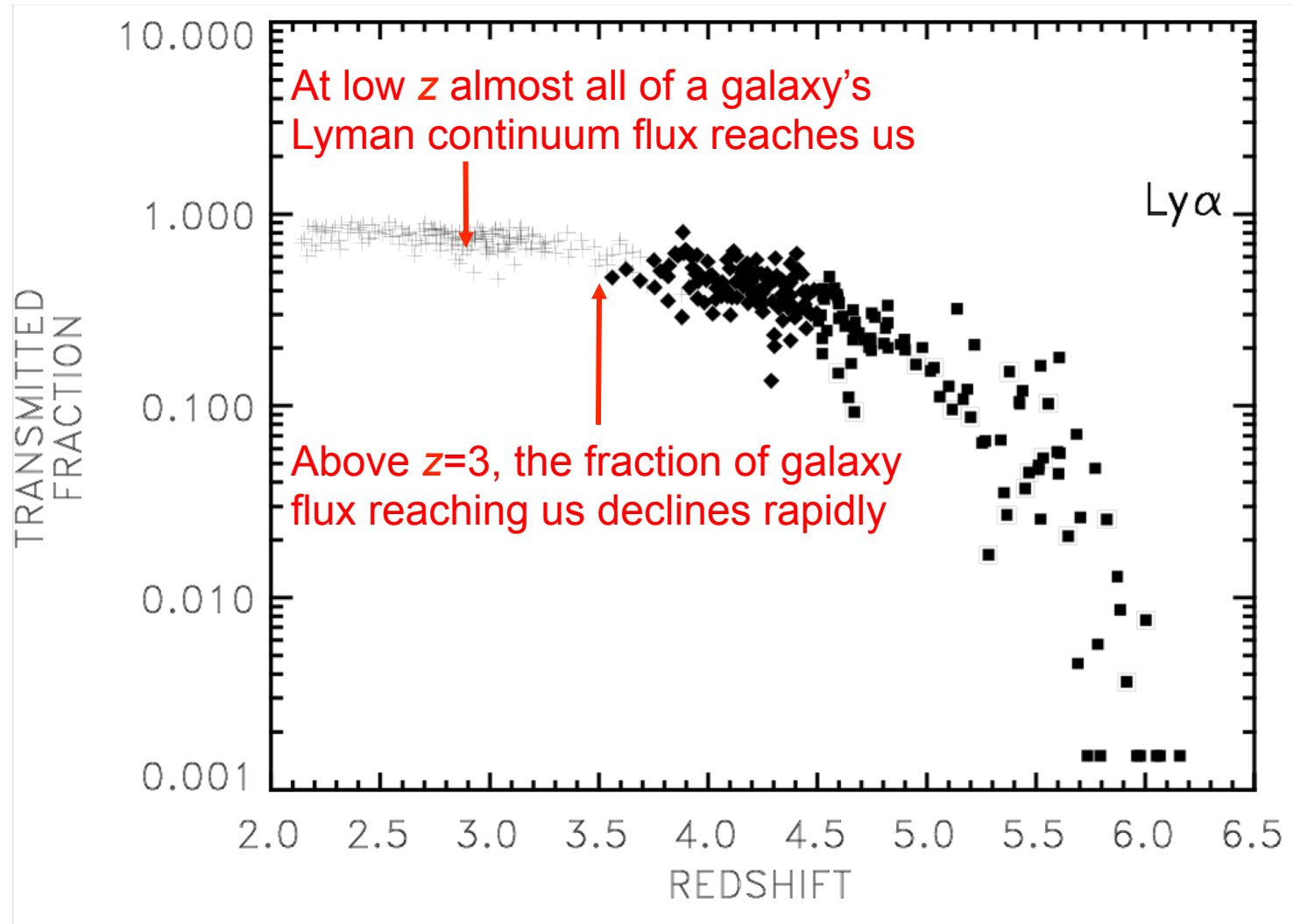
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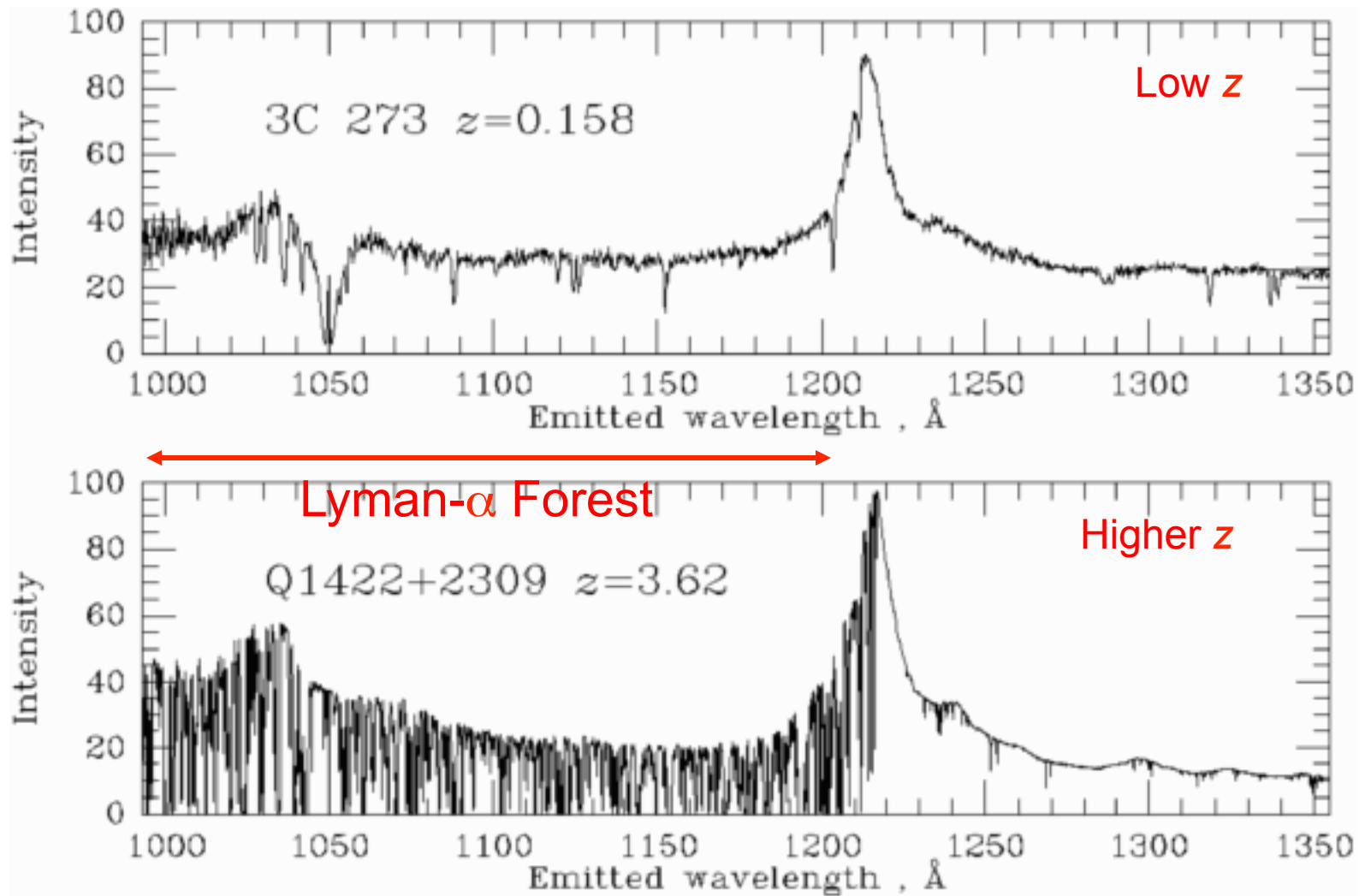
# La forêt Lyman $\alpha$



# The Lyman- $\alpha$ Forest

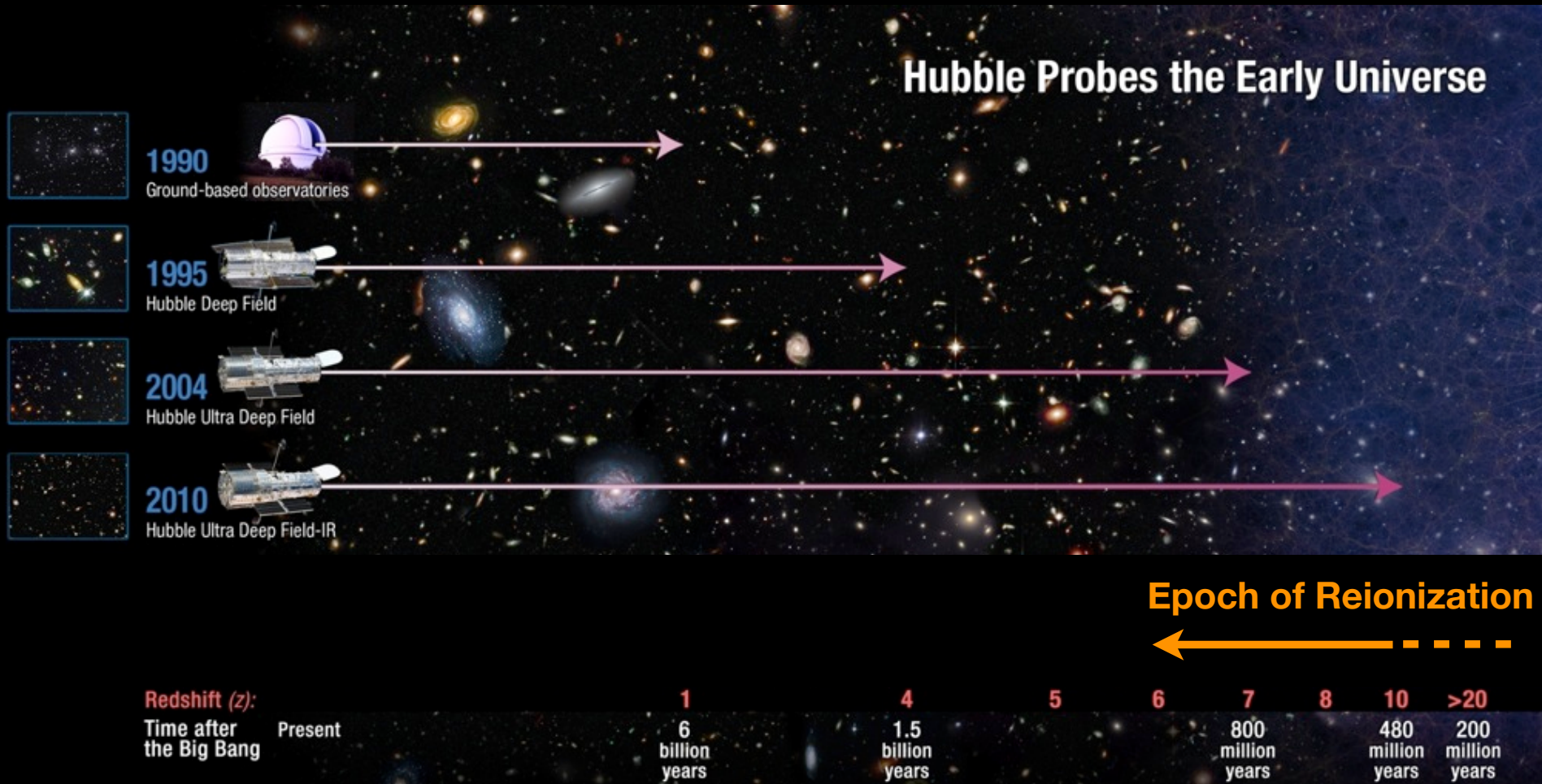


# The Lyman- $\alpha$ Forest



# The history of astronomy is a history of receding horizons.

E. P. Hubble



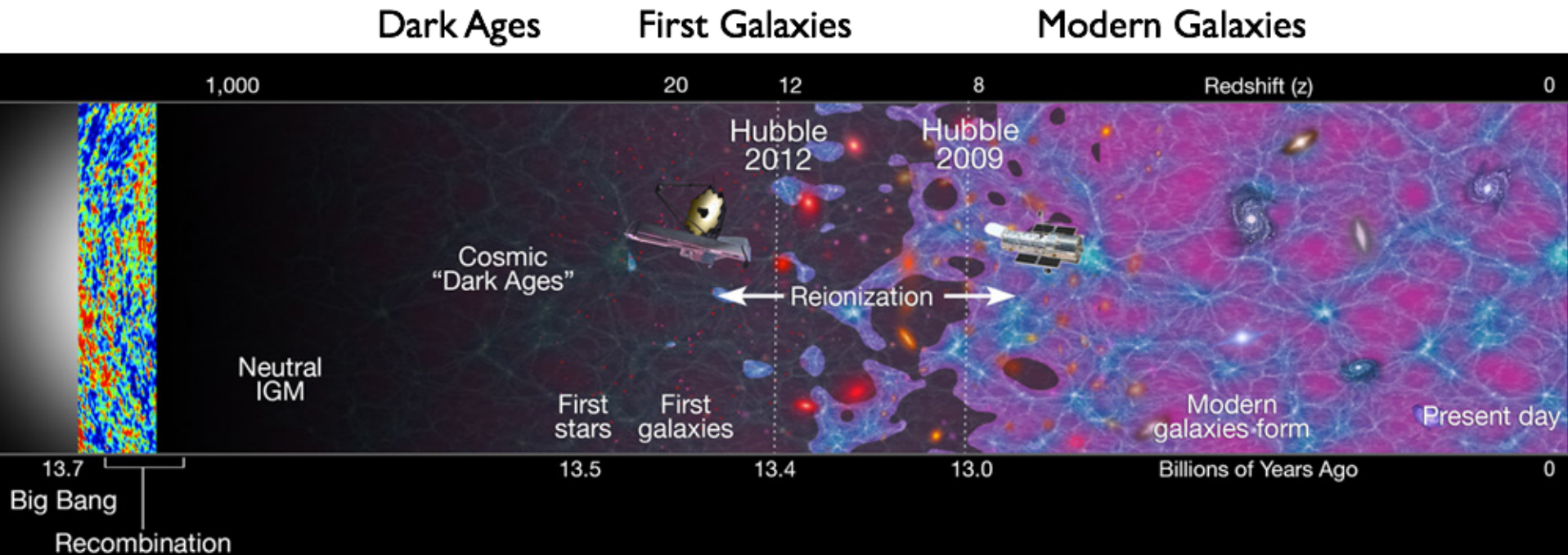
# Why are High-Redshift Galaxies Interesting?

Epoch where galaxies were born and rapidly grew...

Epoch where their dark matter halos were assembled

Epoch when the Universe was Reionized...

Did ionizing photons from galaxies drive cosmic reionization?

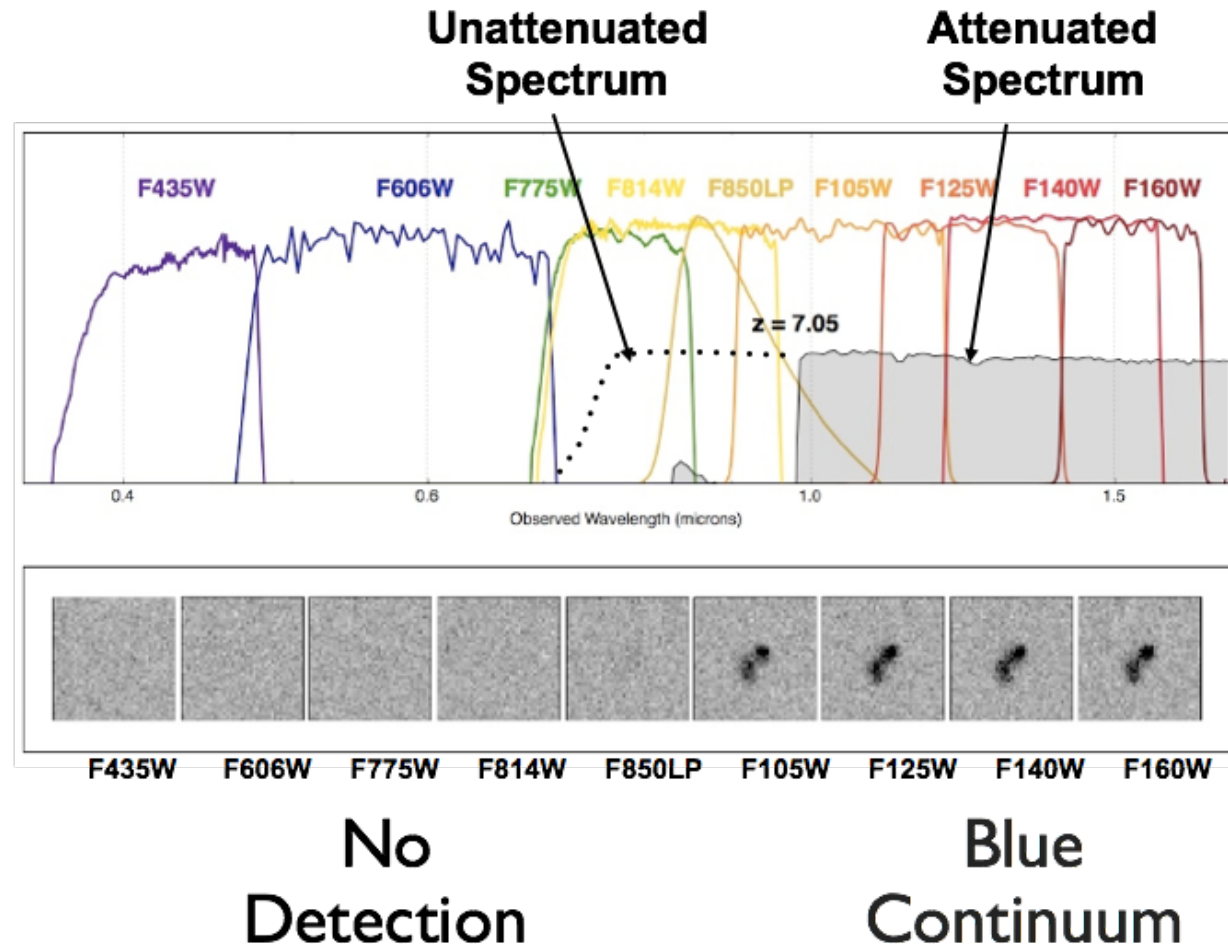


# How do we identify galaxies in the early universe?

## Lyman Break Technique

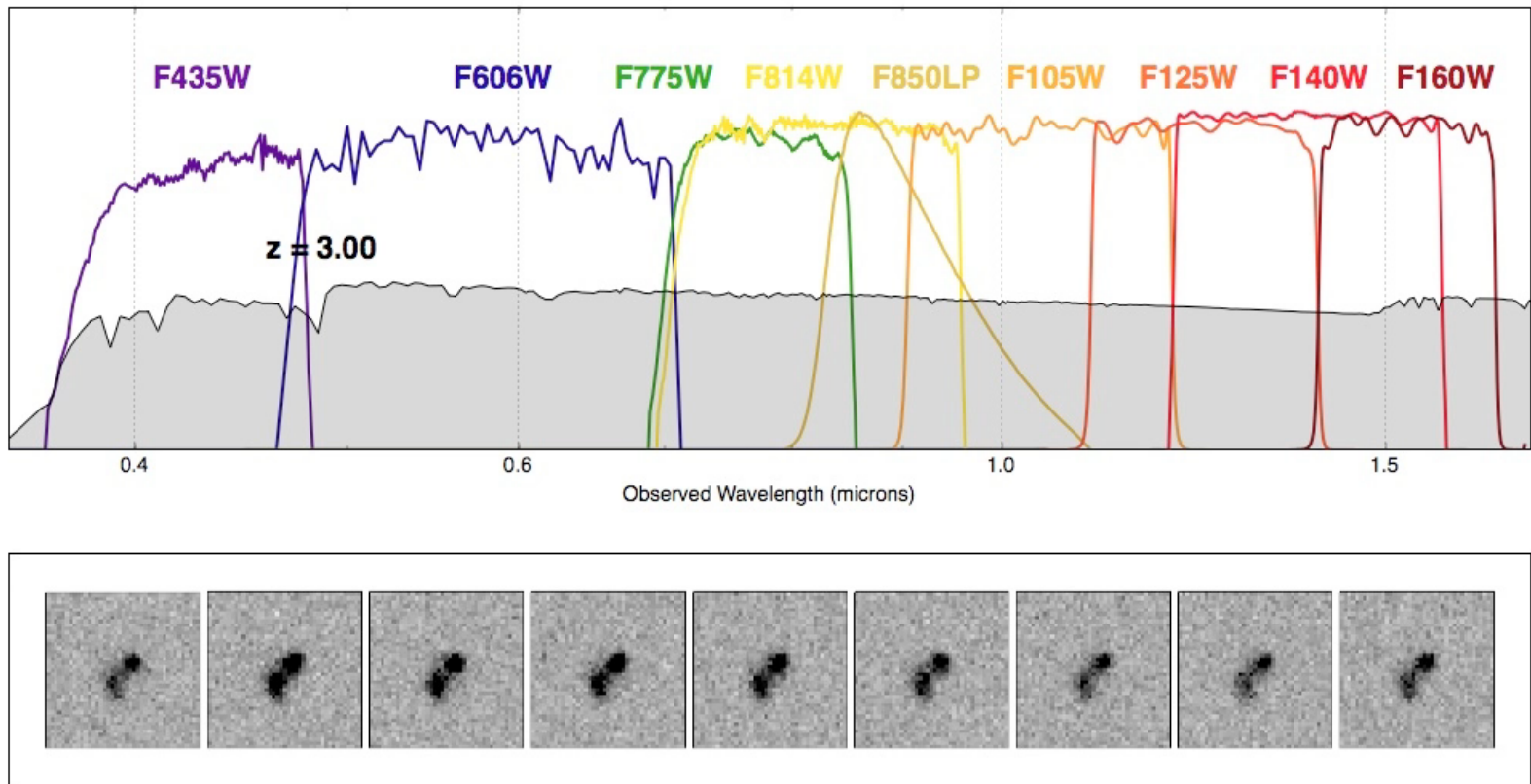
Position of break  
tells us the  
redshift

Example  
 $z=7$  galaxy



# How do we identify galaxies in the early universe?

Similar technique works in finding galaxies at  $z > 3$ :  
(strong Spectral Break in otherwise blue source)

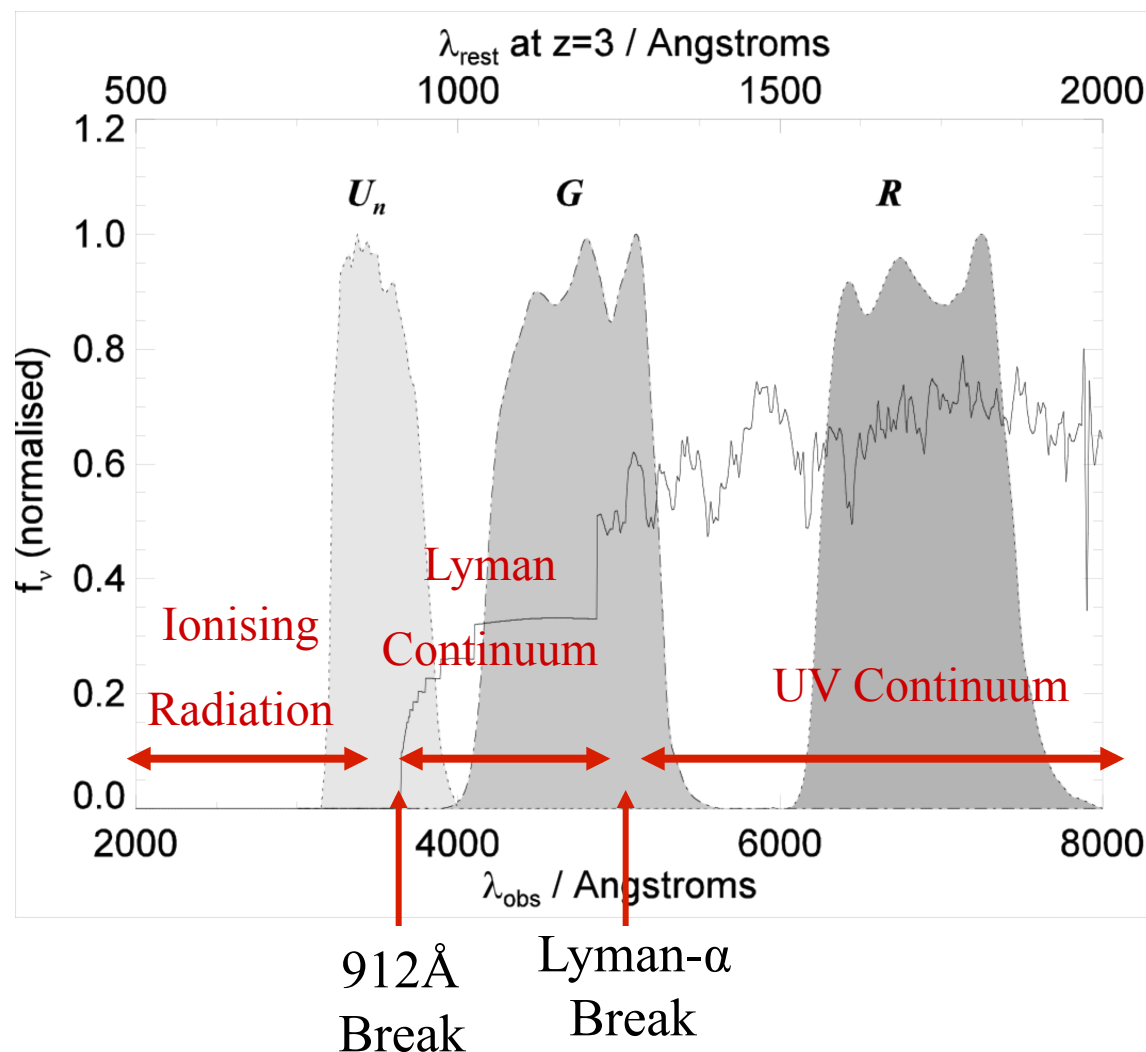


Animation available at <http://xdf.ucolick.org/>

# The Lyman Break Technique

The Steidel, Pettini & Hamilton (1995) Lyman Break Method

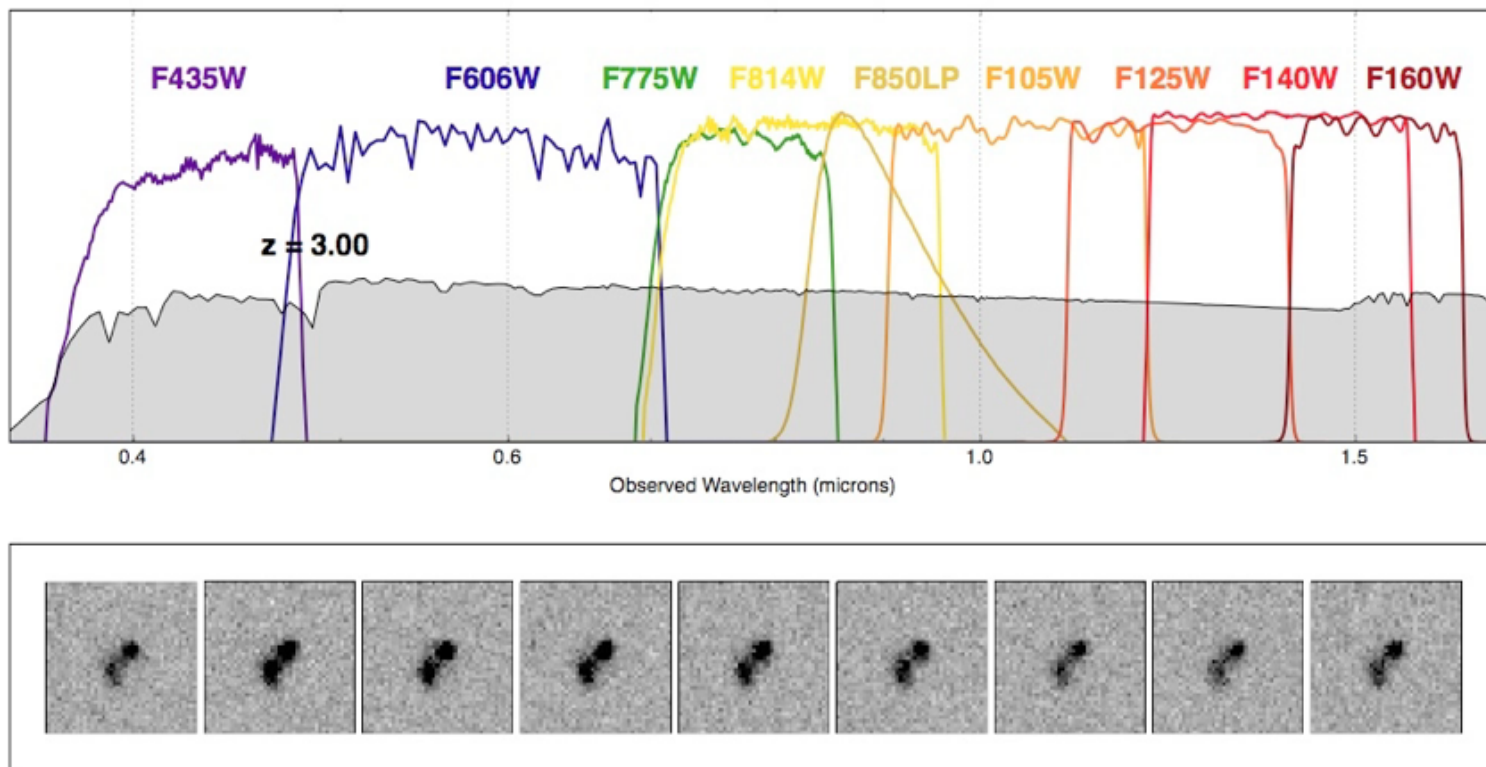
- At  $z=3$ , about 50% of the Lyman continuum is transmitted
- This leads to a 'break' in the spectrum



# How do we identify galaxies in the early universe?

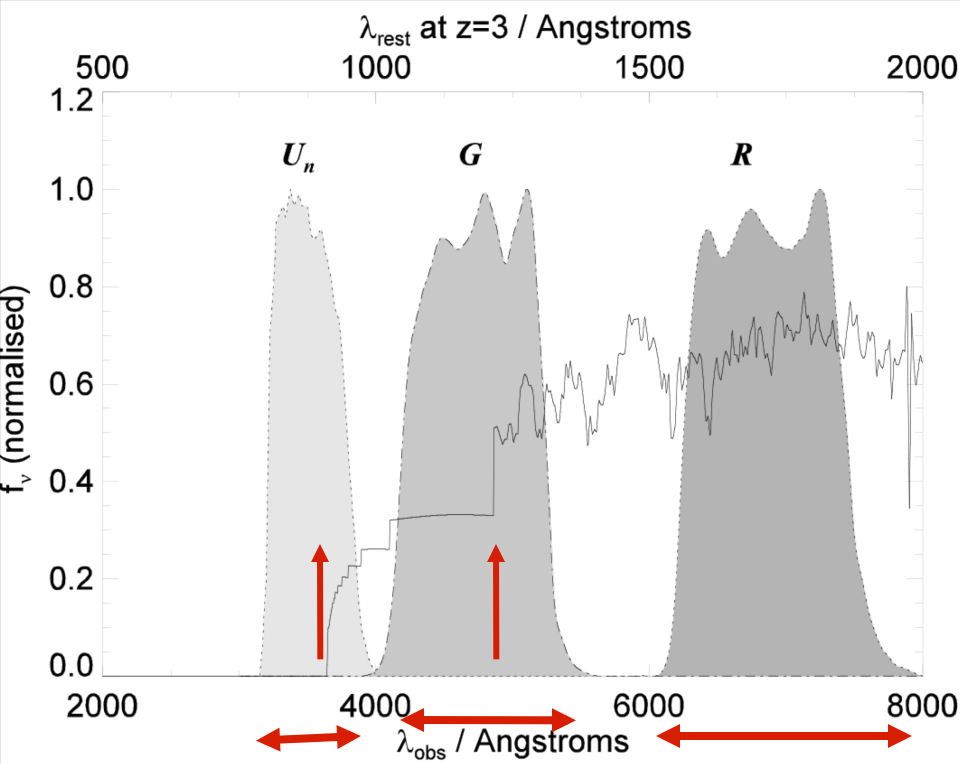
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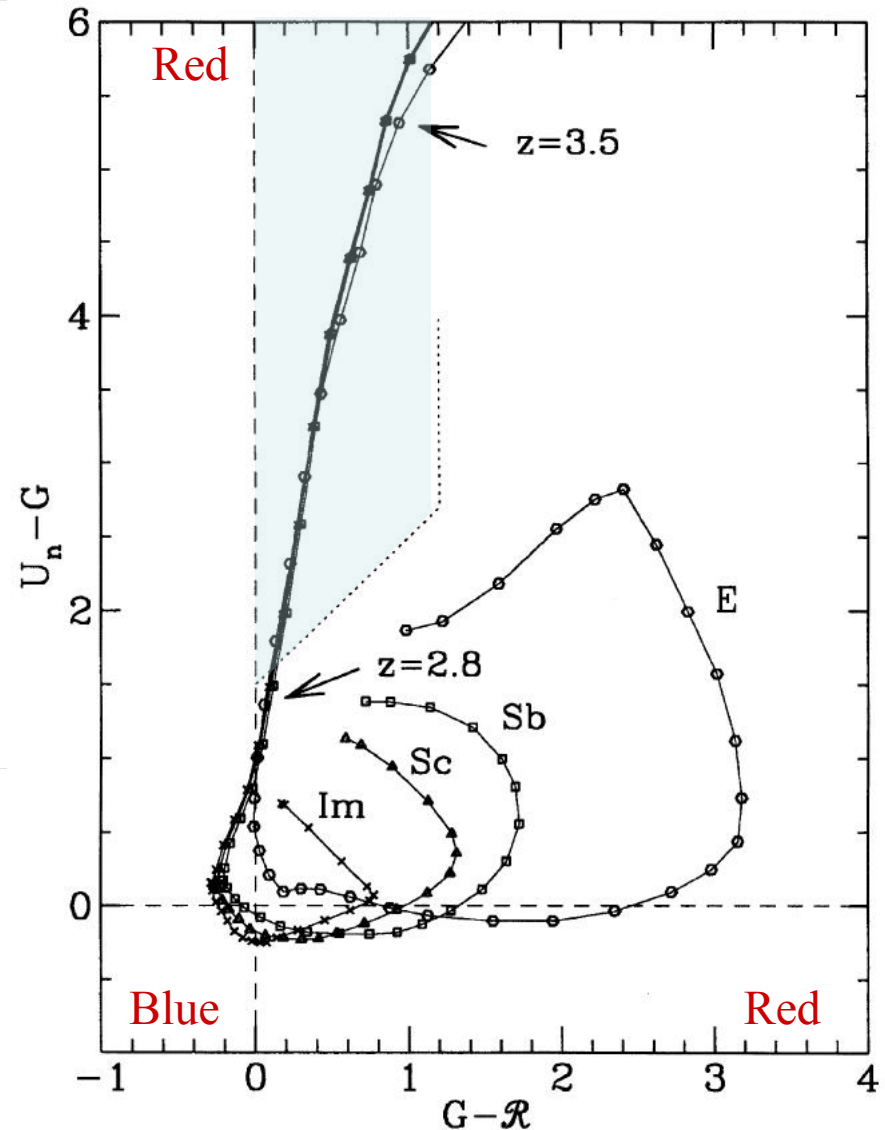


Animation available at <http://xdf.ucolick.org/>

# The Lyman Break Technique

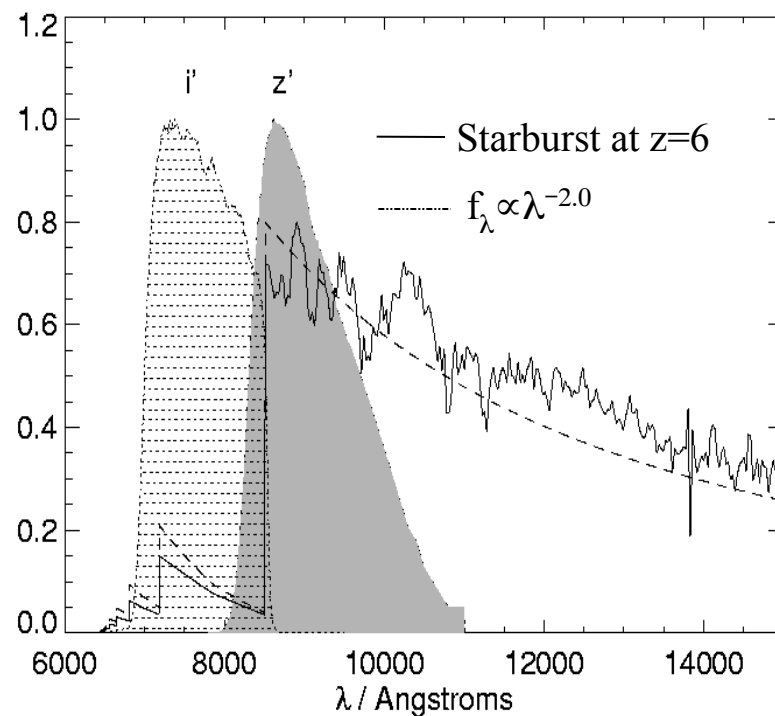


If the filters bracket the breaks, then the galaxies show extreme colours



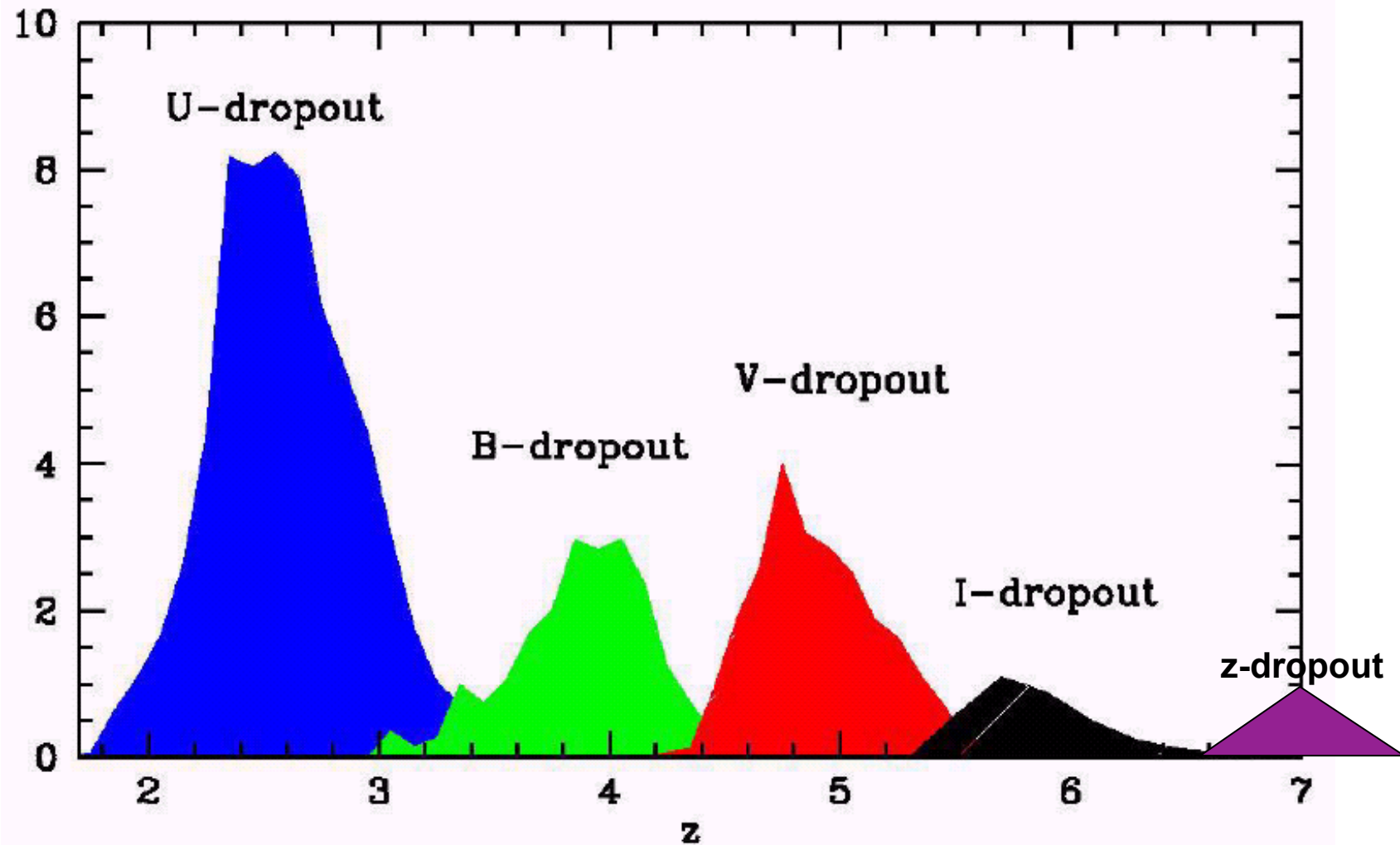
# The Dropout Technique

- At  $z > 4$ , the Lyman forest absorption reaches near 100%  $\Rightarrow$  only one break is detected
- A source will be detected in filters above the break but ‘drop-out’ of filters below it
- V-drops  $\Rightarrow z > 4.5$
- R-drops  $\Rightarrow z > 5$
- I-drops  $\Rightarrow z > 5.8$



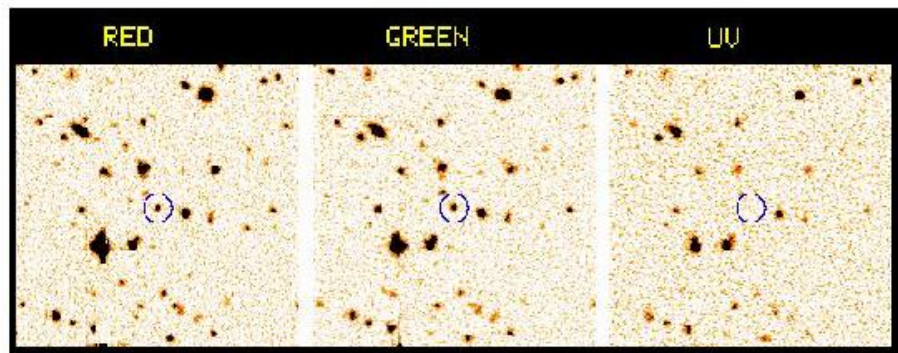
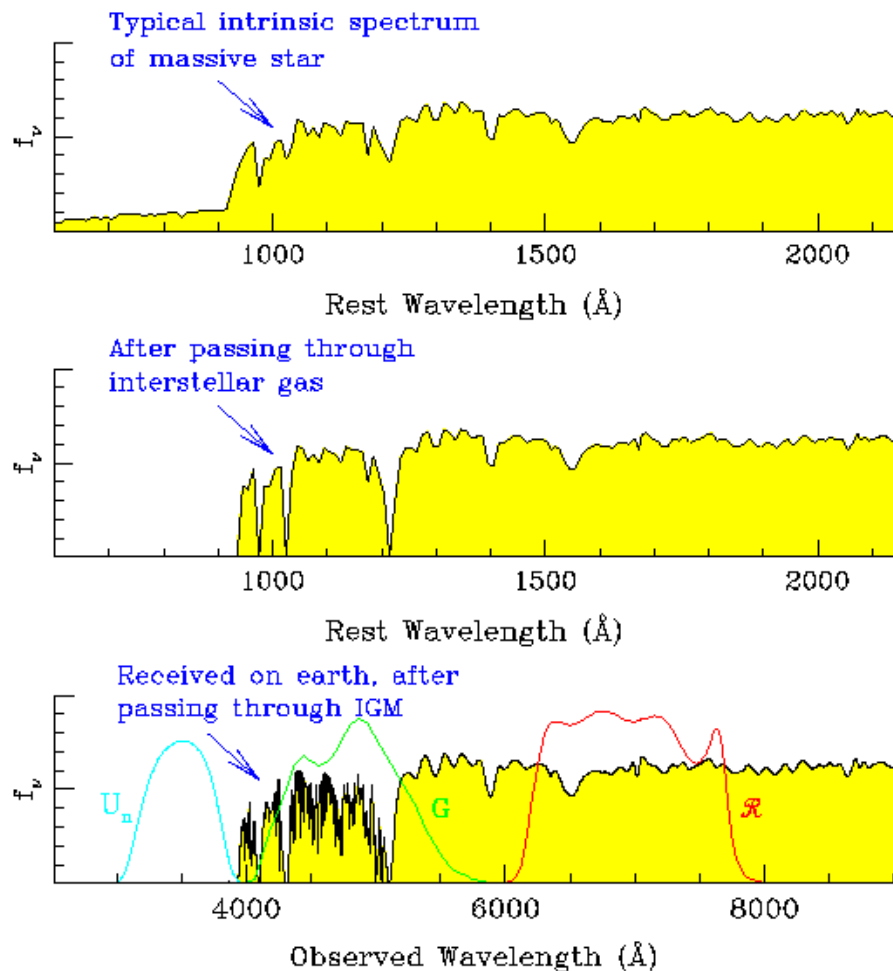
For galaxies at  $5.6 < z < 7.0$ ,  $i' - z' > 1.3$

# Lyman breaks or 'dropouts' at higher $z$



# Lyman Break Galaxies

## Effect of neutral hydrogen



The Lyman continuum discontinuity is particularly powerful for isolating star-forming high redshift galaxies.

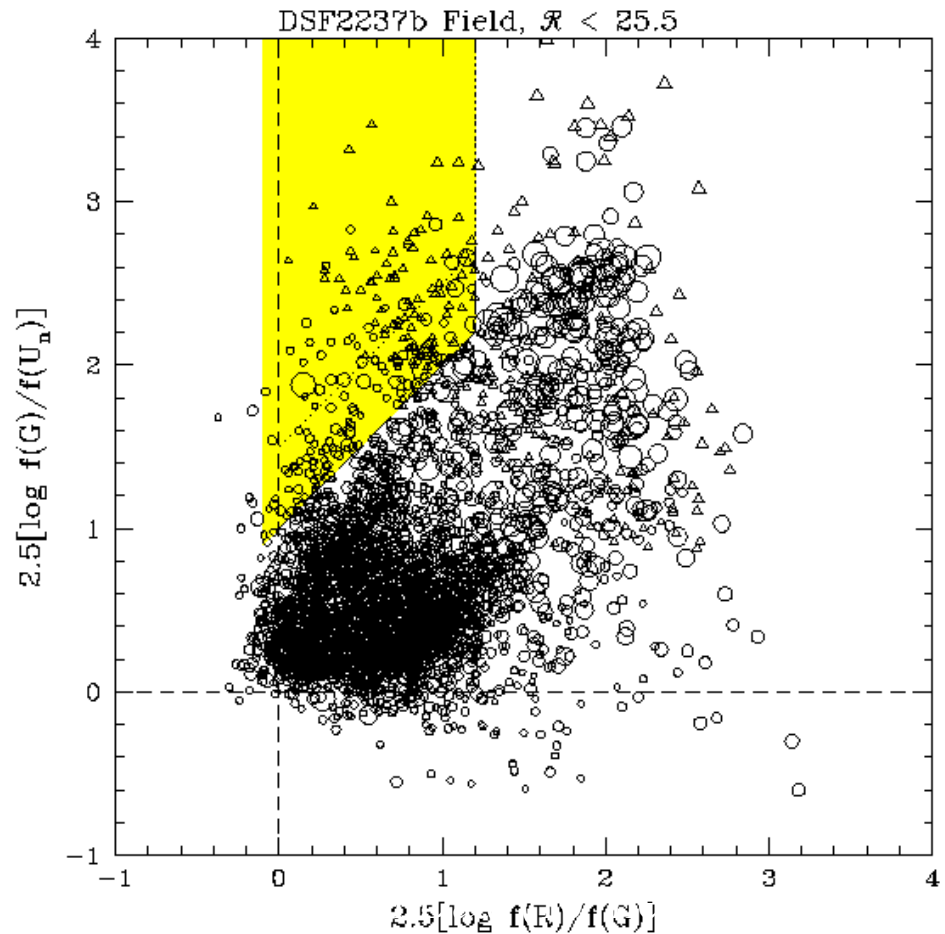
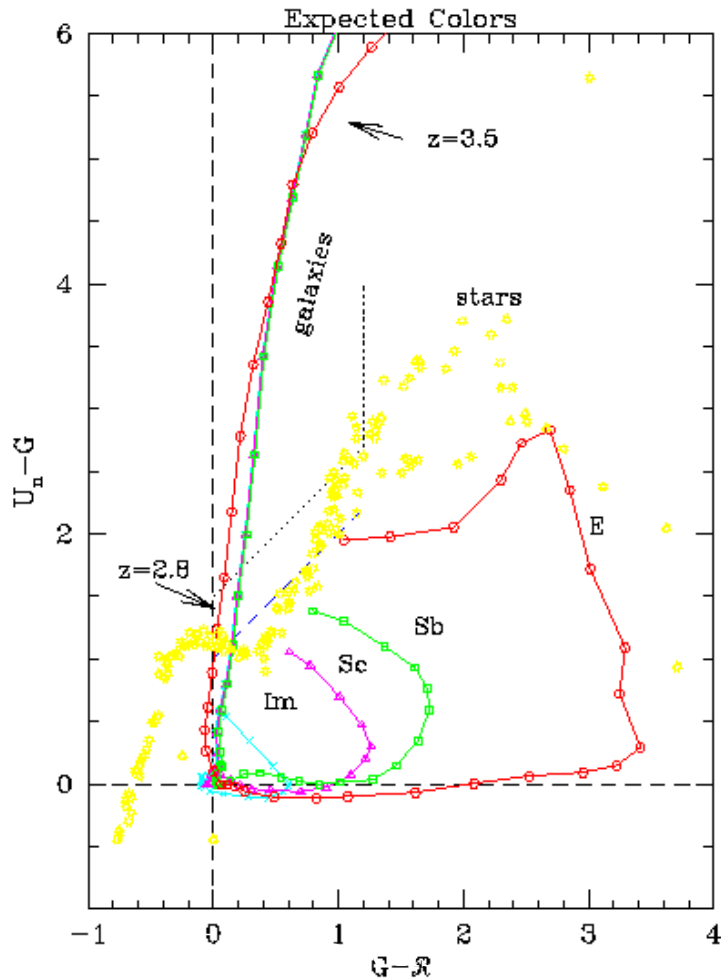
From the ground, we have access to the redshift range  $z=2.5-6$  in the 0.3-1 micron range.

Steidel et al 1999 Ap J 462, L17

Steidel et al 1999 Ap J 519, 1

Steidel et al 2003 Ap J 592 728

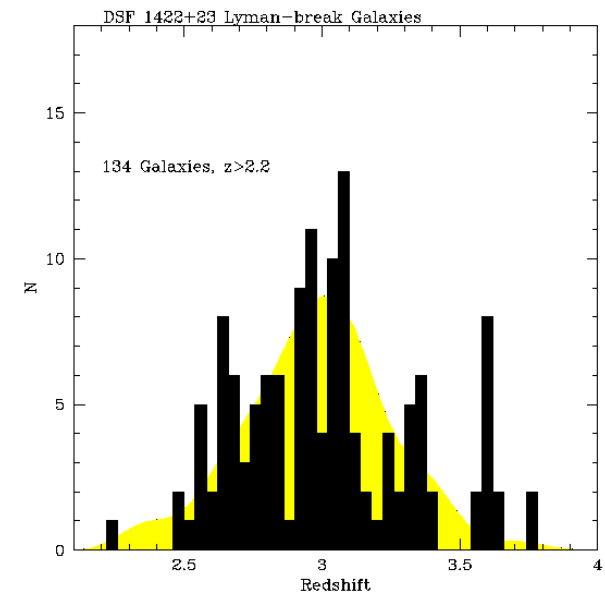
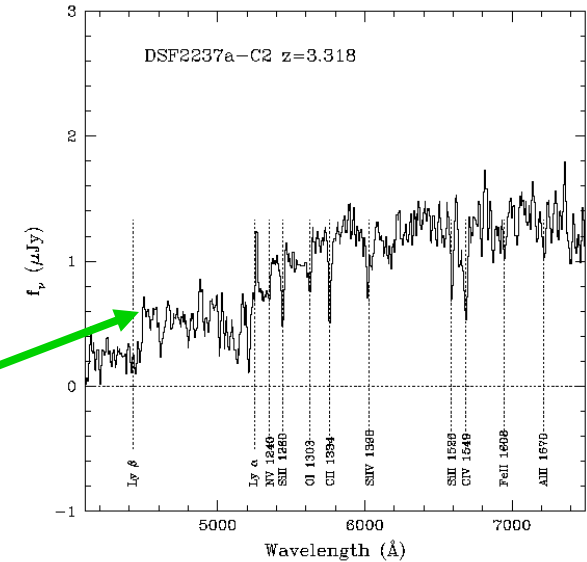
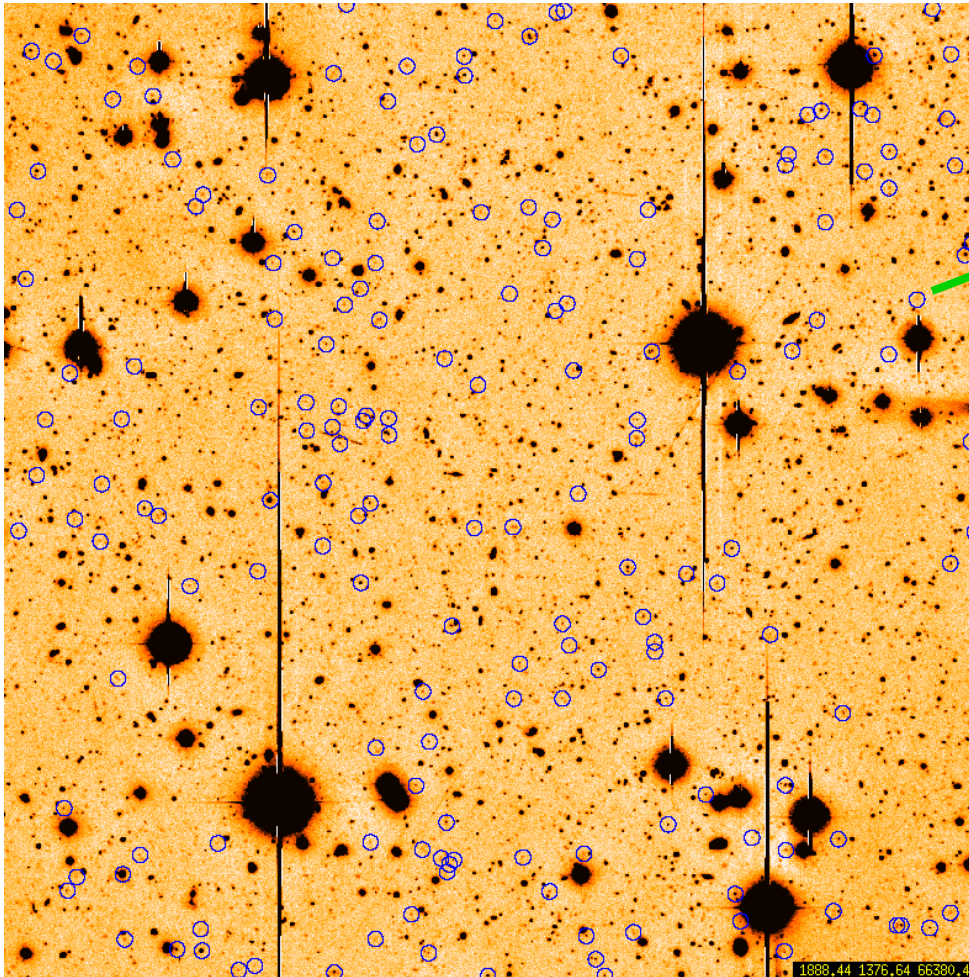
# Photometric Cuts: Predictions and Practice



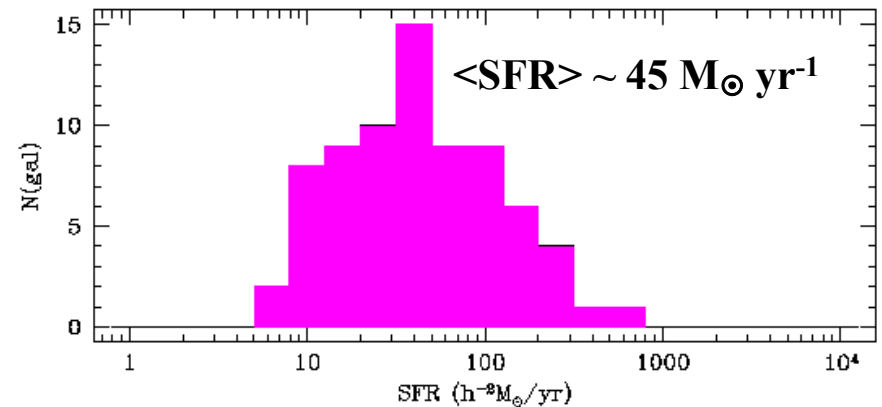
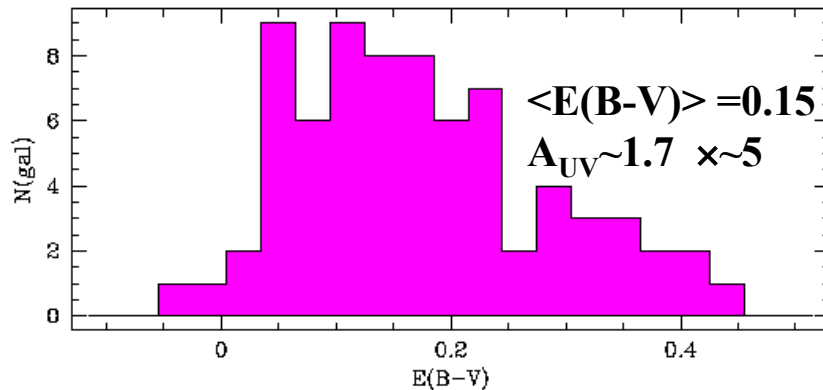
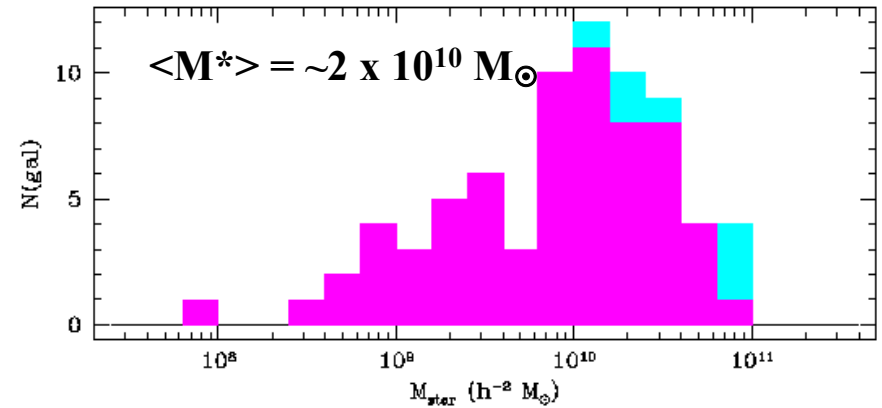
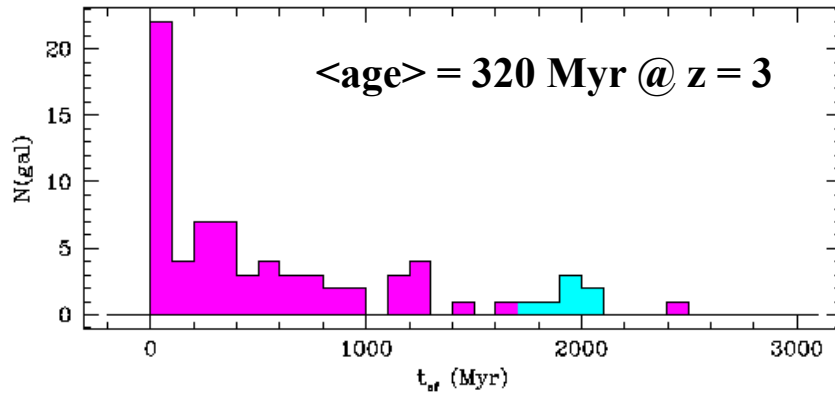
*Spectral energy distributions allow us to predict where distant SF galaxies lie in color-color diagrams such as (U-G vs G-R) (Steidel et al 1996)*



# Spectroscopic Confirmation at Keck



# Properties of Lyman Break Galaxies (z~3)



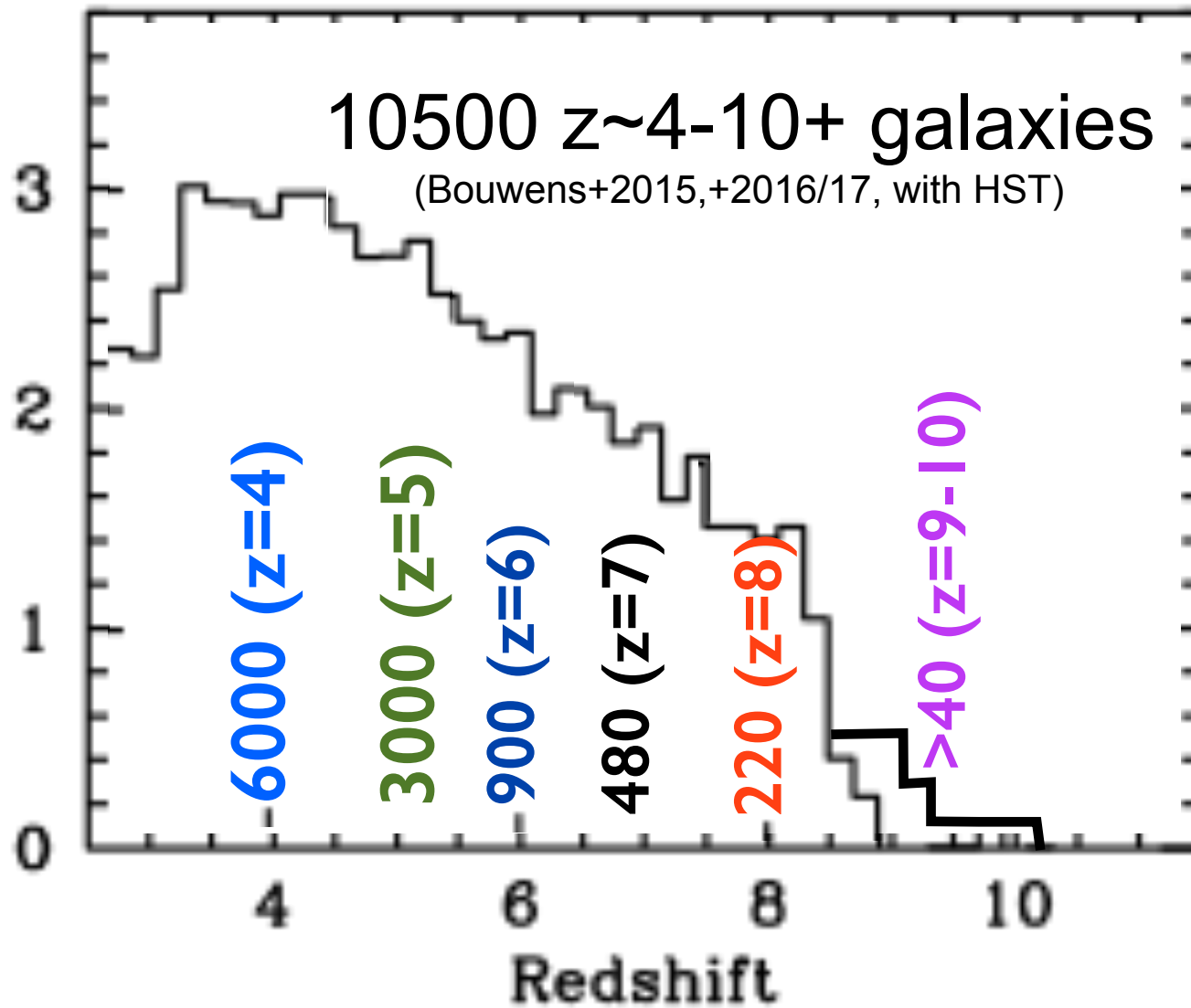
Extinction correlates with age— young galaxies are *much dustier*

SFR for youngest galaxies average  $275 M_{\odot} \text{ yr}^{-1}$  ; oldest average  $30 M_{\odot} \text{ yr}^{-1}$

Objects with the highest SFRs are the dustiest objects

**Shapley et al 2001 Ap J 562, 95**

# Etat des lieux

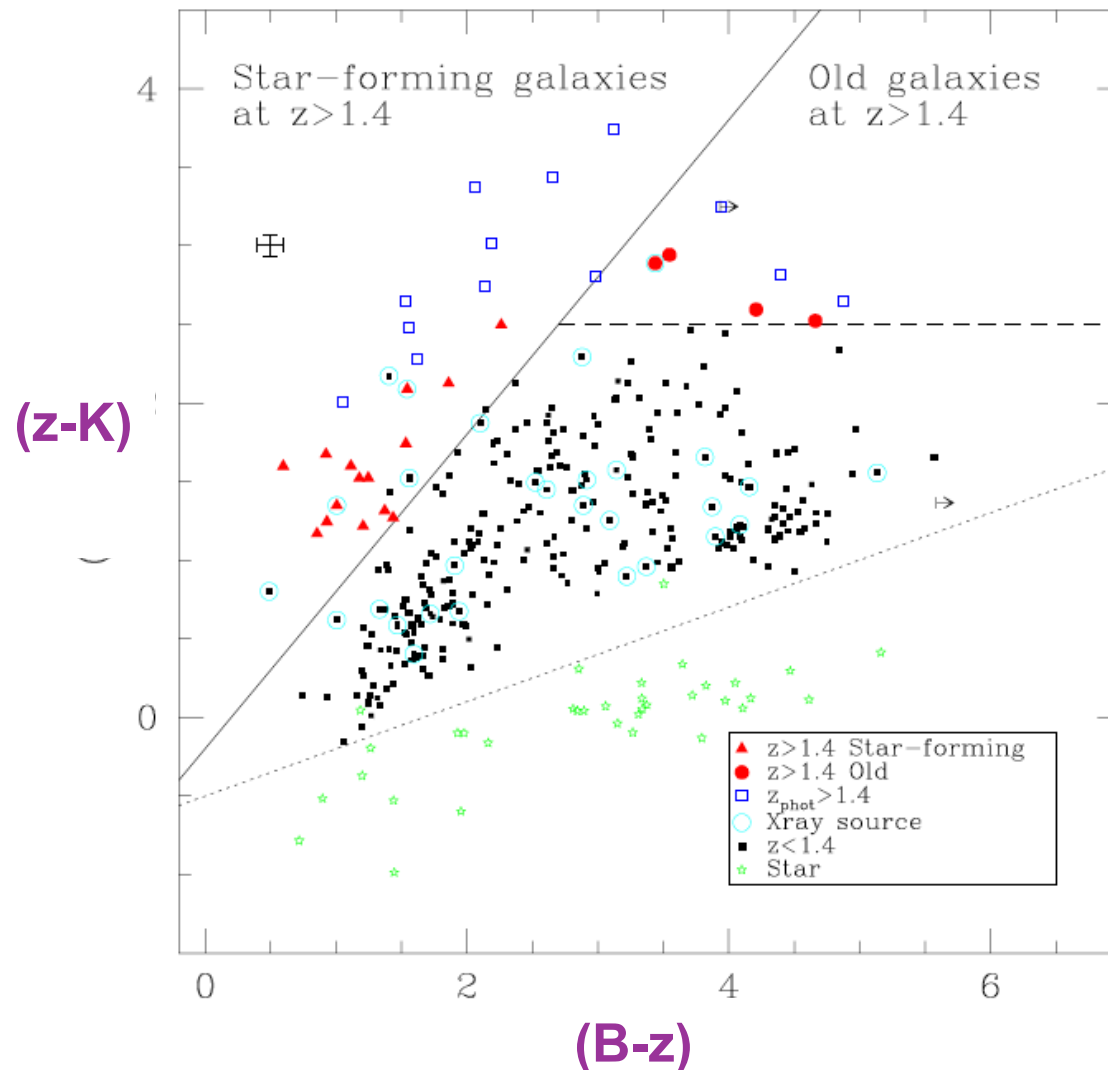


# 'BzK' selection of passive and SF $z > 1.4$ galaxies

New apparently  
less-biased  
technique for  
finding *all*  
galaxies  
 $1.4 < z < 2.5$

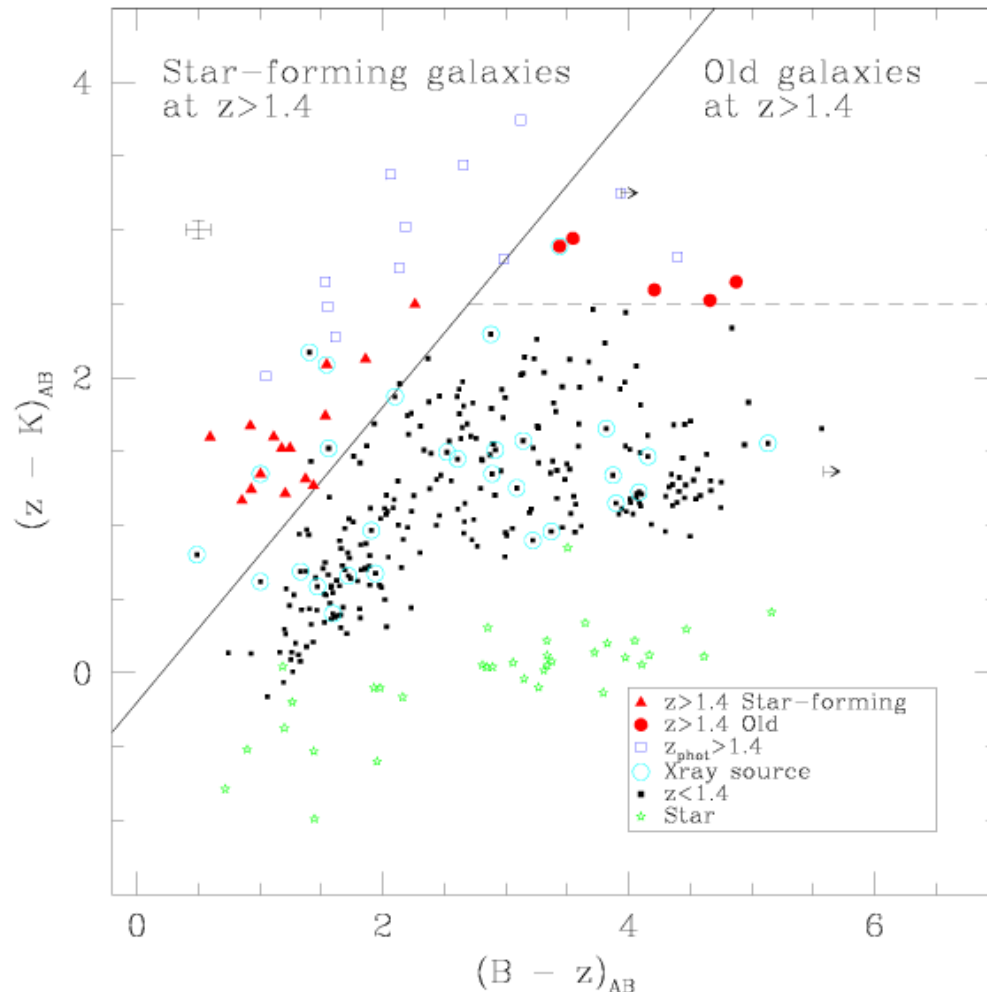
sBzK: star  
forming  
galaxies

pBzK: passive  
galaxies



**Daddi et al 2004 Ap J 617, 746**

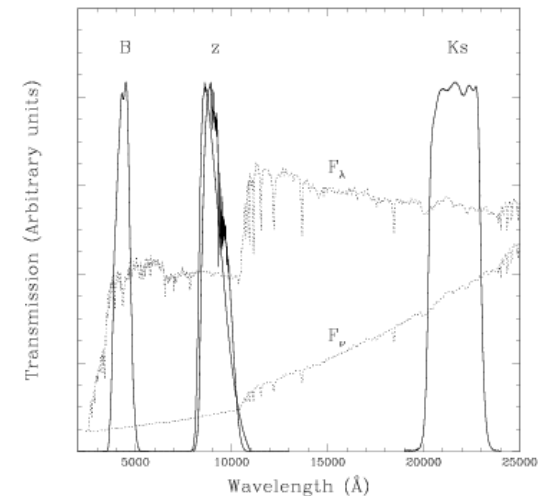
BzK selection technique:  
 selection of  $z \sim 2$  galaxies & separation of SF vs passive gals  
 4000Å break for old stars, slope of continuum for young stars



$$BzK = (z - K) - (B - z) \quad (\text{AB mags})$$

$BzK > -0.2 \rightarrow \text{SF at } z > 1.4$

$BzK < -0.2 \text{ \& } z - K > 2.5 \rightarrow \text{Old}$



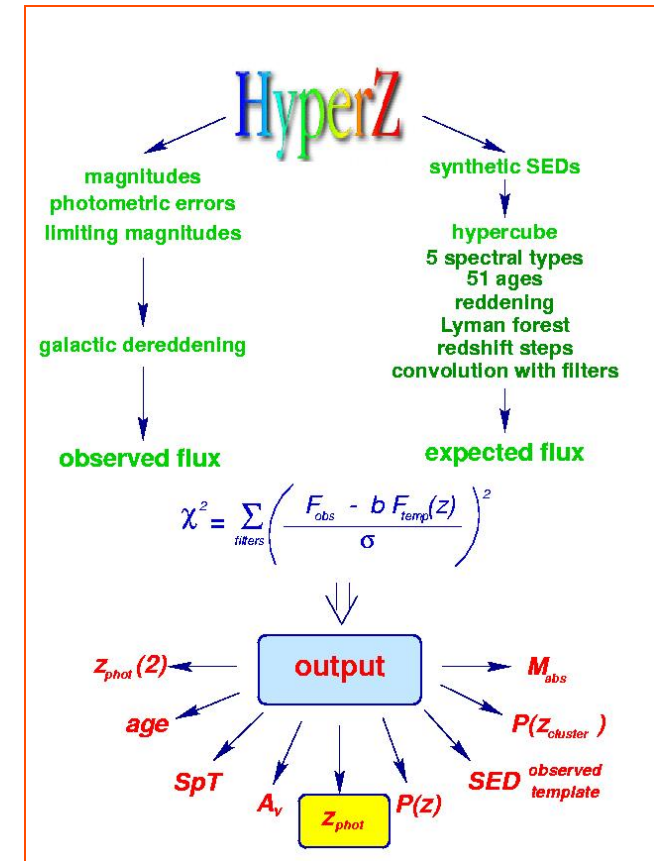
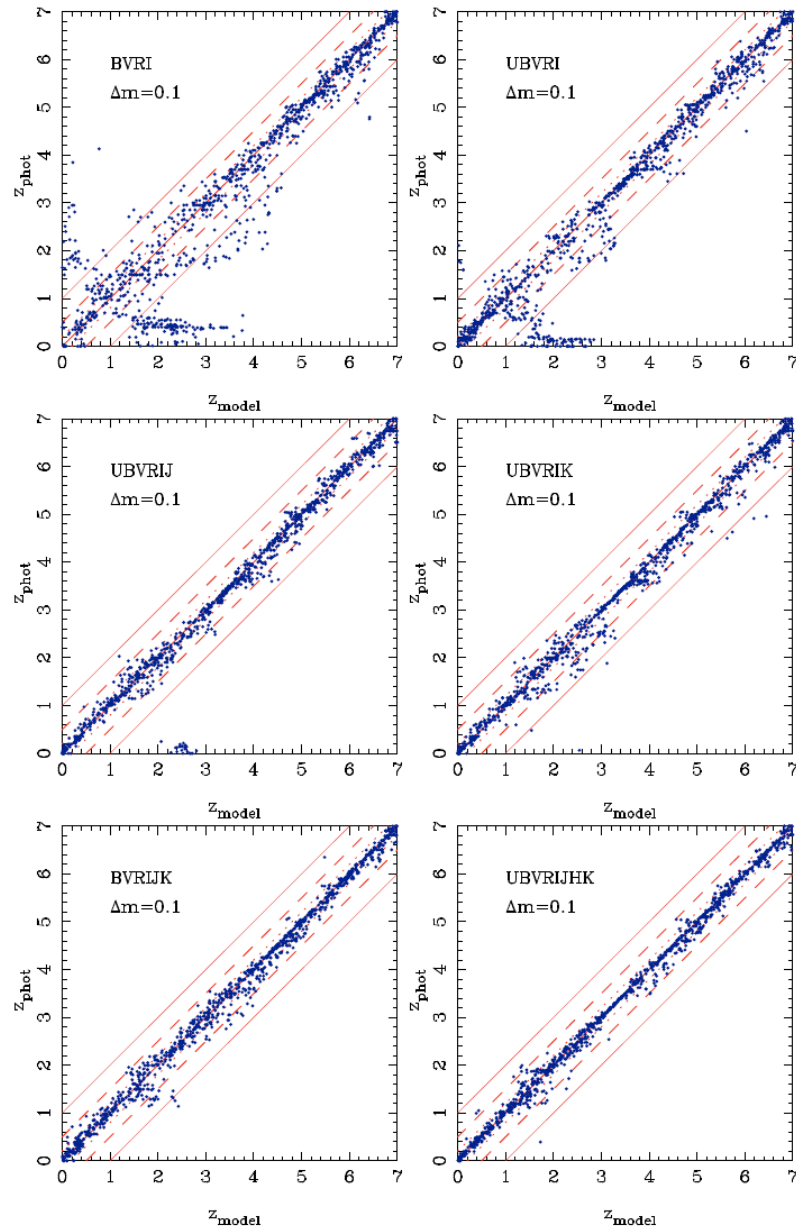
Daddi et al. 2005

94% of spec redshifts; K20 survey

Technique calibrated with  $\sim 50$   $z > 1.4$  redshifts

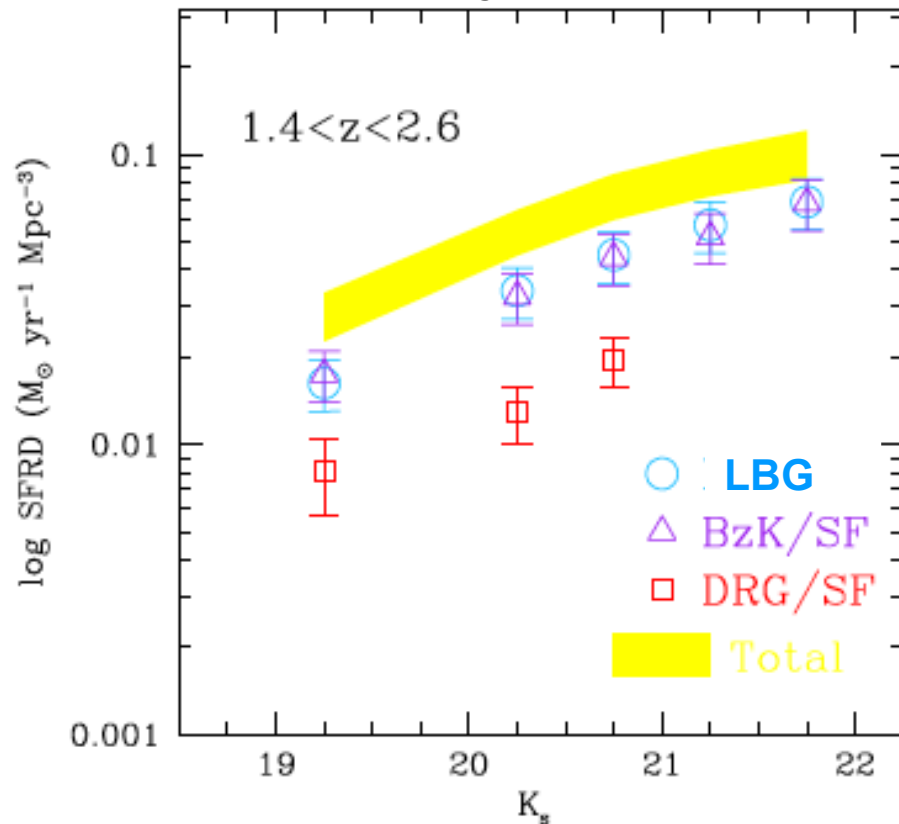
# Les redshifts photométriques

D'une manière plus générale, on utilise les discontinuités de Balmer et de Lyman pour obtenir une estimation du redshift des galaxies faibles, et donc difficiles d'accès en spectroscopie, à l'aide des leurs magnitudes en bandes larges. Plusieurs programmes sont accessibles pour réaliser ces calculs, dont HyperZ (Bolzonella, Miralles, Perro, 2000, <http://webast.ast.obs-mip.fr/hyperz>)



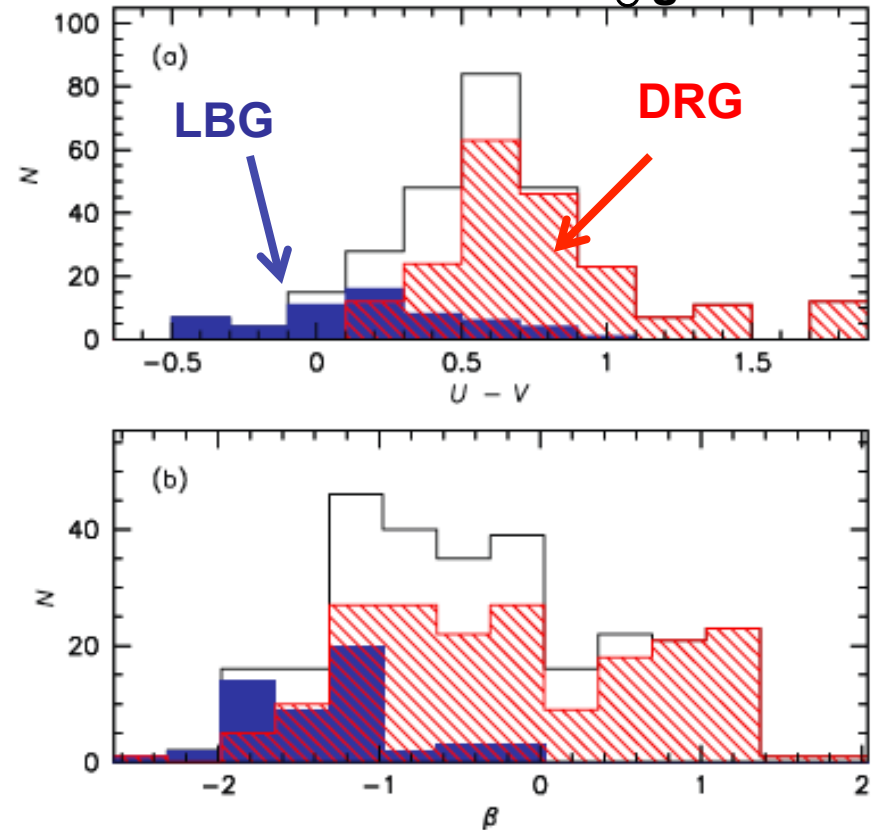
# Connecting the BzK, LBG and DRG Populations

## SF Density Contributions



Reddy et al 2005 Ap J 633, 248

## Distribution of $M > 10^{11} M_{\odot}$ galaxies



van Dokkum et al 2006 Ap J 638, L59

van Dokkum et al (2006) - LBGs constitute only 17% of massive galaxies!

# High-redshift galaxies in the *Hubble Deep Field*: colour selection and star formation history to $z \sim 4$

Piero Madau,<sup>1★</sup> Henry C. Ferguson,<sup>1★</sup> Mark E. Dickinson,<sup>1★</sup> Mauro Giavalisco,<sup>2★†</sup>  
Charles C. Steidel<sup>3★‡§</sup> and Andrew Fruchter<sup>1★</sup>

## Absorption intergalactique

### 2 INTERGALACTIC ATTENUATION

In this section we will briefly review the theory of the propagation of UV radiation through a clumpy universe, following Madau (1995).

#### 2.1 Basic equations

Let  $L(\nu_{\text{em}})$  be the specific power emitted with frequency  $\nu_{\text{em}}$  by a source at redshift  $z_{\text{em}}$ . The mean specific flux observed at Earth is

$$\langle f(\nu_{\text{obs}}) \rangle = \frac{(1 + z_{\text{em}}) L(\nu_{\text{em}})}{4\pi d_L^2} \langle e^{-\tau} \rangle, \quad (1)$$

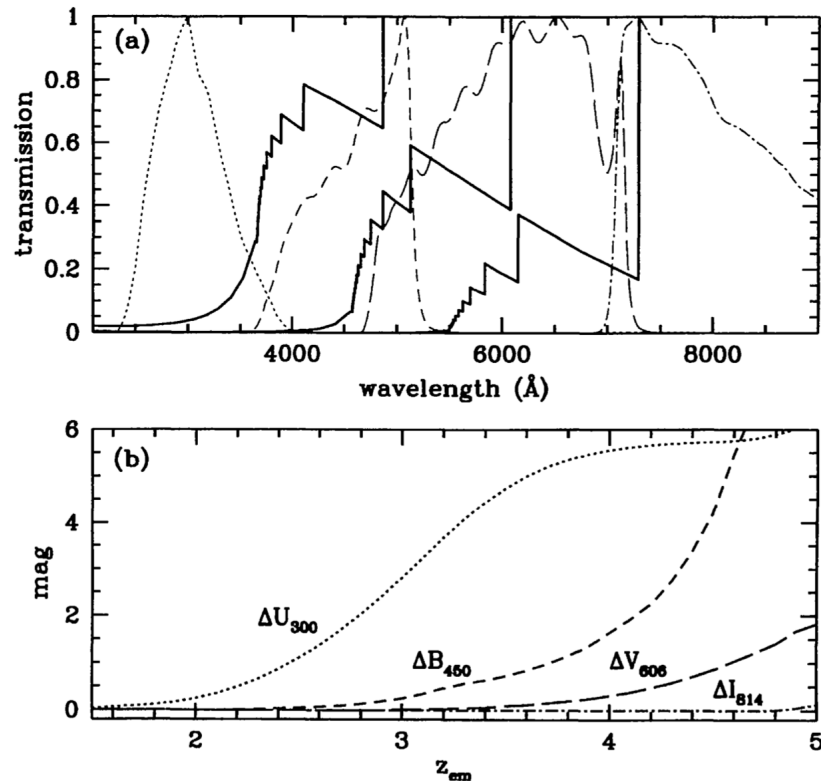
where  $\nu_{\text{obs}} = \nu_{\text{em}}/(1 + z_{\text{em}})$ ,  $d_L$  is the luminosity distance to  $z_{\text{em}}$  and the average transmission over all lines of sight is, assuming Poisson-distributed clouds,

$$\langle e^{-\tau} \rangle = \exp \left\{ \int_0^{z_{\text{em}}} \int \frac{\partial^2 N}{\partial N_{\text{H I}} \partial z} [1 - e^{-\tau_c}] dN_{\text{H I}} dz \right\}. \quad (2)$$

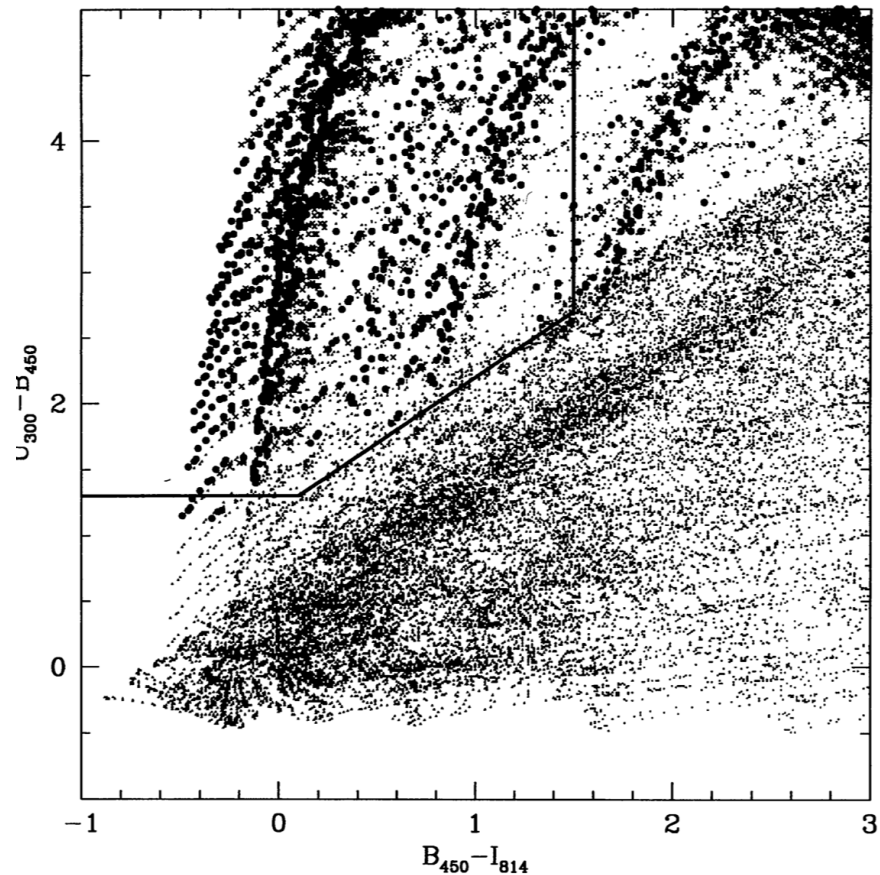
Here,  $\tau_c$  is the optical depth through an individual cloud at frequency  $\nu = \nu_{\text{obs}}(1 + z)$ , and  $(\partial^2 N / \partial N_{\text{H I}} \partial z)$  is the redshift and column density distribution of absorbers along the path. An ‘effective’ optical depth of a clumpy medium can be defined as  $\tau_{\text{eff}} = -\ln(\langle e^{-\tau} \rangle)$ .

Along with resonant line scattering from  $\text{Ly}\alpha$ ,  $\beta$ ,  $\gamma$  and higher order members, we include photoelectric absorption from H I in the  $\text{Ly}\alpha$  forest clouds and Lyman limit systems along the line of sight. Since the bluest filter used for the *HDF* observations is centred at  $3000 \text{ \AA}$  and has FWHM  $\sim 800 \text{ \AA}$ , galaxies will only be subject to H I cosmological attenuation from material located at  $z \gtrsim (2600/1216) - 1 = 1.1$ .

# Lyman break selection



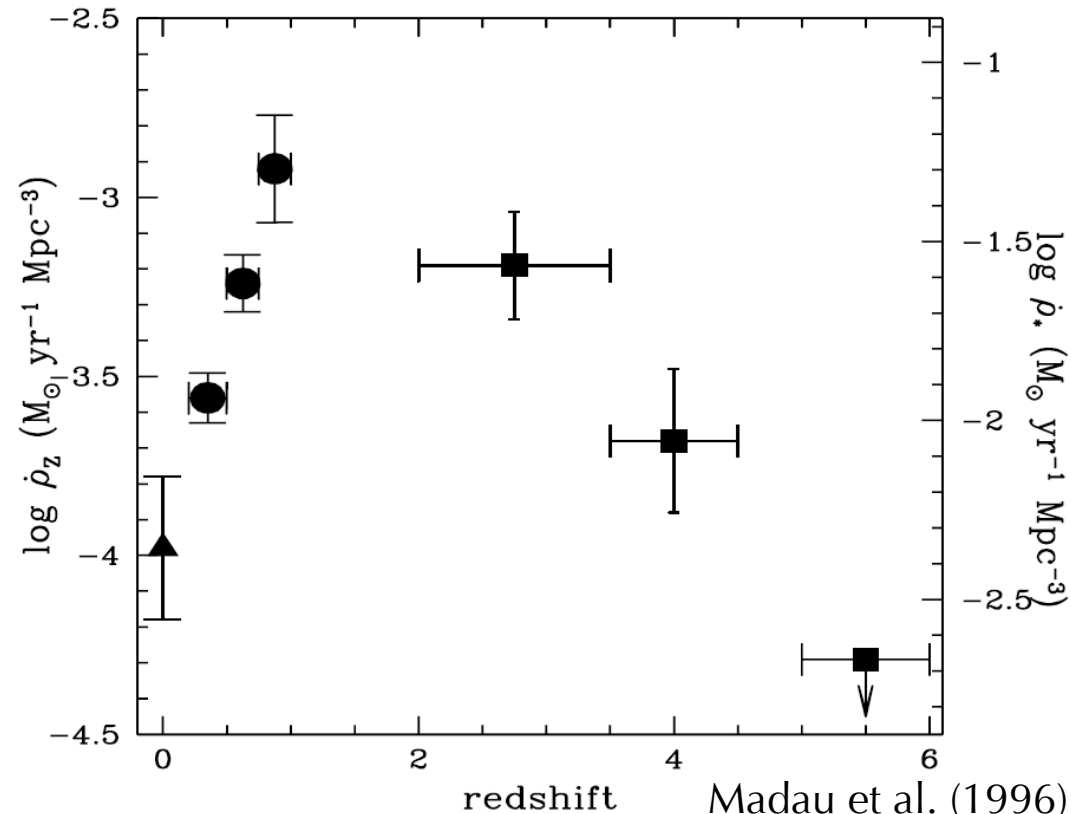
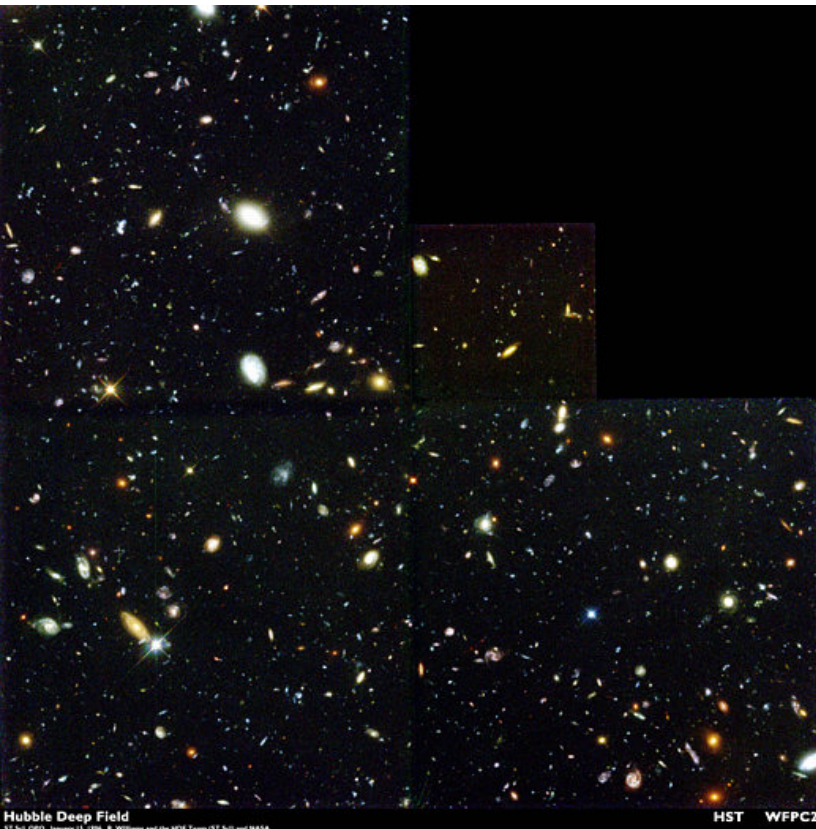
**Figure 1.** (a) Mean cosmic transmission for a source at  $z_{em} = 3, 4$  and 5 (solid lines), as a function of observed wavelength. The characteristic staircase profile is due to continuum blanketing from the Lyman series. Also plotted are the response functions of the four broad passbands, F300W (dotted line), F450W (short-dashed line), F606W (long-dashed line) and F814W (dash-dotted line) used for the *Hubble Deep Field*. (b) Magnitude increments  $\Delta U_{300}$  (dotted line),  $\Delta B_{450}$  (short-dashed lines),  $\Delta V_{606}$  (long-dashed line) and  $\Delta I_{814}$  (dash-dotted line), derived by integrating the mean cosmic transmission over the corresponding bandpass, as a function of the emission redshift.



$B_{450} - I_{814}$  for model galaxies. A total of 103 879 synthetic spectra of galaxies representing a wide range of metallicities, dust contents and redshifts were folded through the *HDF* bandpasses. The galaxies shown as solid circles are those in the redshift range  $2 < z < 3.5$  and extinctions  $A_B < 1$ .  $\times$ s are galaxies in the same redshift range that have ages greater than  $10^8$  yr or extinctions  $A_B > 1$ . Galaxies within the polygon in the *HDF* observations are selected as  $z < 3.5$  objects. The selection criteria are  $U_{300} - B_{450} > 1.3$ ,  $U_{300} - B_{450} > B_{450} - I_{814} + 1.2$ , and  $B_{450} - I_{814} < 1.5$ .

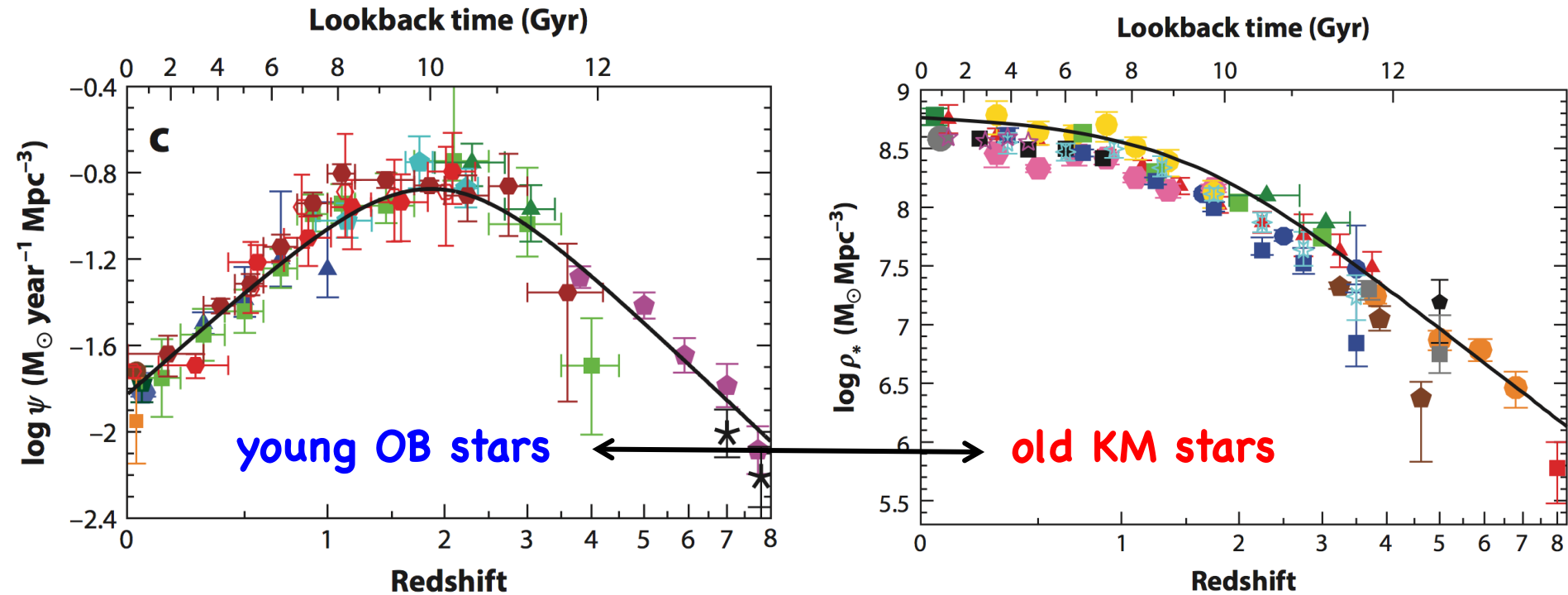
# Histoire cosmologique de la formation d'étoiles

La densité de luminosité UV se mesure en  $L_{\odot}\text{Mpc}^{-3}$ , elle peut être traduite en terme de densité de formation d'étoiles en  $M_{\odot}\text{yr}^{-1}\text{Mpc}^{-3}$ , en utilisant le coefficient de conversion  $L(\text{UV}) \rightarrow \text{SFR}$  de Kennicutt (1998). Mais il ne s'agit que d'une limite inférieure pour deux raisons: (i) on ne détecte que les galaxies les plus lumineuses, (ii) une fraction importante de la luminosité UV intrinsèque des étoiles d'une galaxie est absorbée par la poussière et réémise dans l'IR. En utilisant les LBG du HDFN (Hubble Deep Field Nord, image la plus profonde du ciel, jusqu'à une magnitude de 29), Madau et al. (1996) ont dérivé la première histoire cosmique de la formation d'étoiles, appelée "Madau plot", d'après une étude de la densité de  $L(\text{UV})$  par Lilly et al. (1996).



# cosmic SFR & $M^*$ density vs time

Une fois ces effets pris en compte, les données observationnelles deviennent plus cohérentes.



Madau & Dickinson 2014

# Constraints on models

- Stellar mass function
- Baryonic mass function
- HI mass function
- Luminosity function (in  $\neq$  bands)
- Cosmic SFR density
- Gas fractions
- Gas metallicities
- Stellar ages and metallicities
- SFR -  $M^*$  relation
- $M_*/M_{\text{halo}}$  (from lensing)
- Black hole - bulge mass relation
- Tully - Fisher relation (L-v)
- Galaxy sizes
- Galaxy morphology
- Clusters: Hot gas (X-ray) vs total mass
- AGN bolometric luminosity function
- AGN mechanical luminosity function