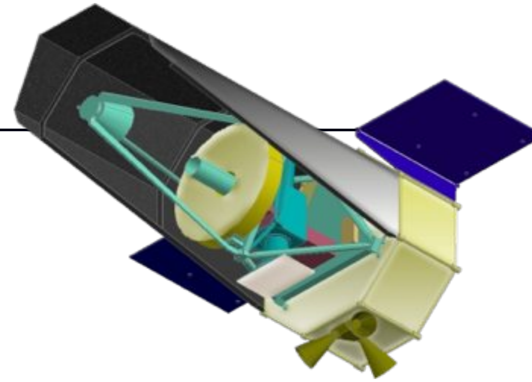
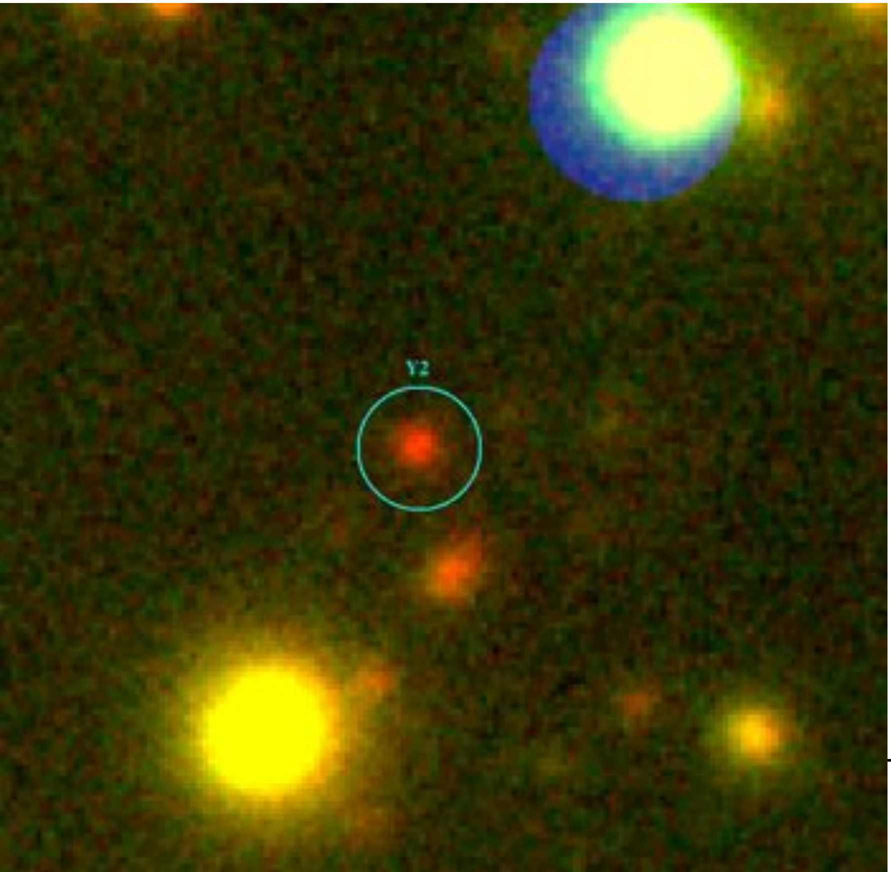


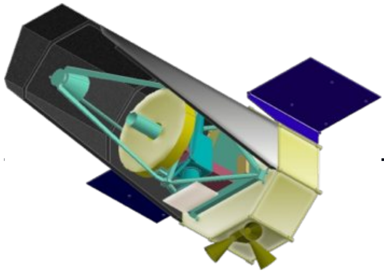


Studying the first galaxies with WISH

R. Pello

GAHEC Group

(IRAP, Toulouse)



WISH : a unique design

Science goal : Investigate the birth of the first objects out from the dark ages as well as structure assembly in the universe.

The formation of the first bounded objects marks the transition from simplicity to complexity …

- WISH design :

➔ a ***1.5m telescope***

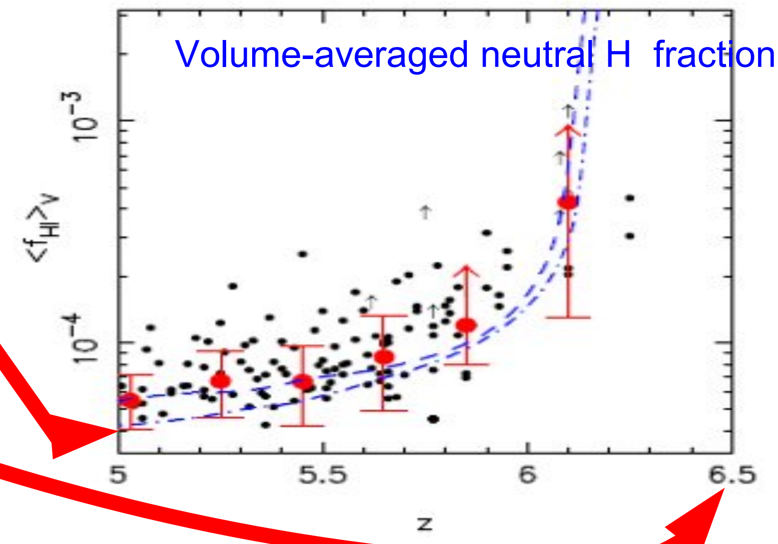
➔ ***wide-field camera :*** *1000 arcmin2 , pixel scale 0.155 arcsec*

➔ ***Wavelength domain : 1-5 µm***

➔ ***<~ 1 arcmin2 IFU / slitless spectroscopy (R~1000)***

Unique deep and wide-area sky surveys

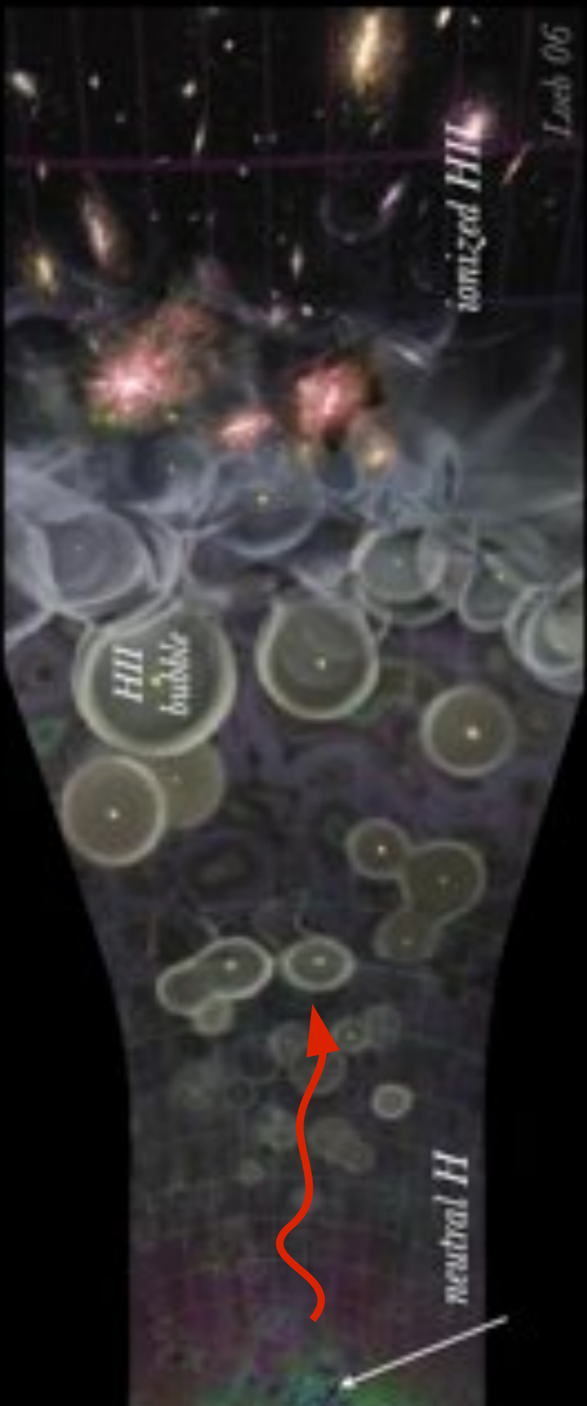
The end of the reionization



Fan et al 2006

- Complete absorption even for a tiny neutral fraction (~10^{-4}, whereas the present value is ~10^{-5}) ==> this test is only sensitive when the IGM is “almost” ionized, and saturates for higher neutral fractions. Large line of sight variance is also observed!

The beginning of the reionization probed by WMAP/PLANK



- z(reionization)=11+/-1.2 (Komatsu et al. 2011). Large uncertainties remain. The actual value depends on the reionization process (instantaneous or more complex scenarios). **==> more with Planck**

Some important questions remain:

- What were the **sources responsible for the reionization?** Galaxies & AGNs? GRB contribution?

- When and how reionization occurred? A gradual process? Multiple phases?

Current observational constraints

Extremely deep Surveys combining optical+near-IR data : HUDF09, UKIDSS Ultra Deep Survey, GOODS, CANDELS, Extended Groth Strip, Chandra Deep Field, …

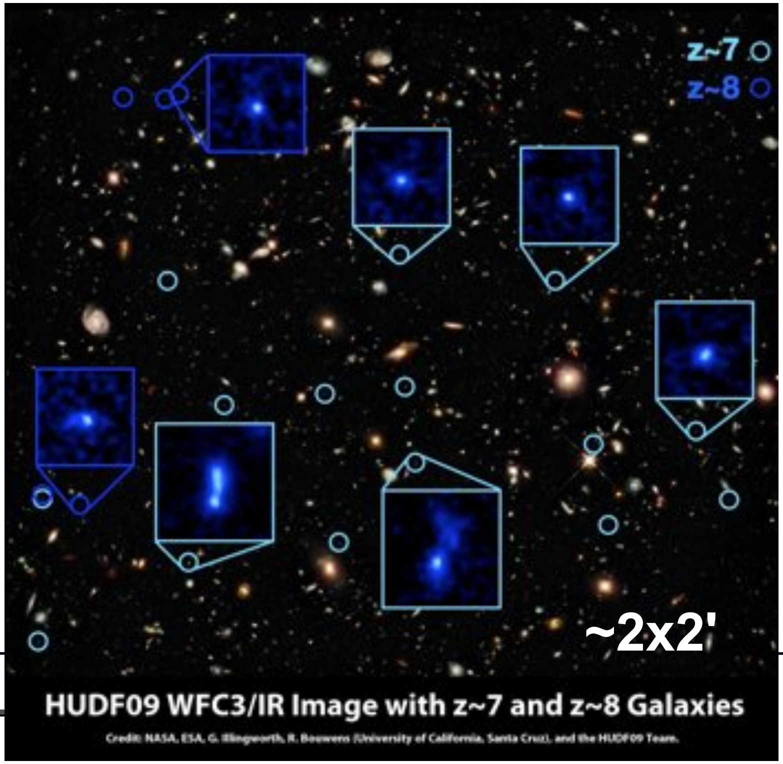
e.g. Bouwens et al. 2010, 14+,
See also HUDF09 web site

Multi-wavelength data (HST, Spitzer,...)

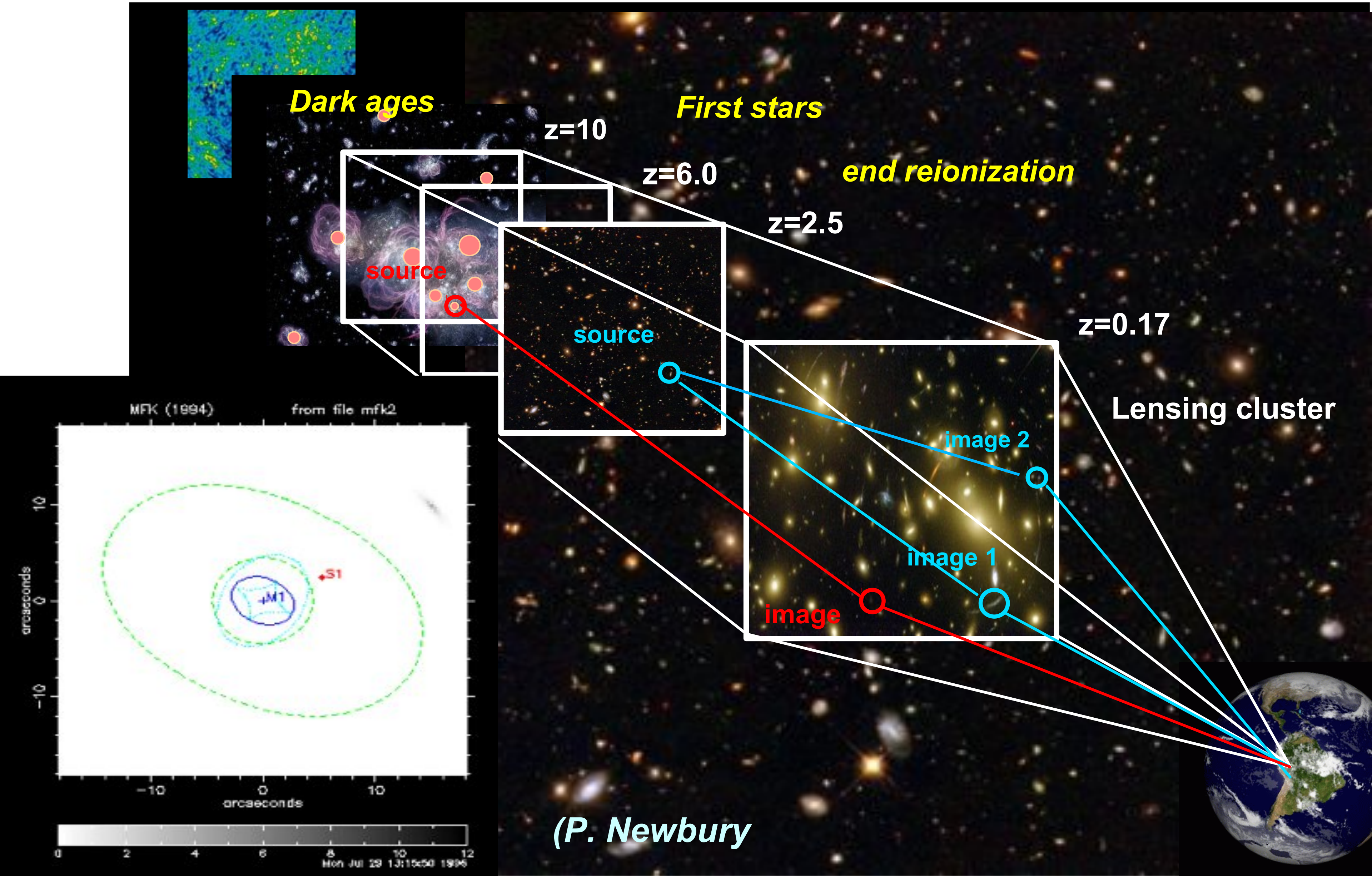
High-z samples are "faint", typically m~28-29 at z~7-8

+ lensed sources (e.g. CLASH SURVEY, or HFF)

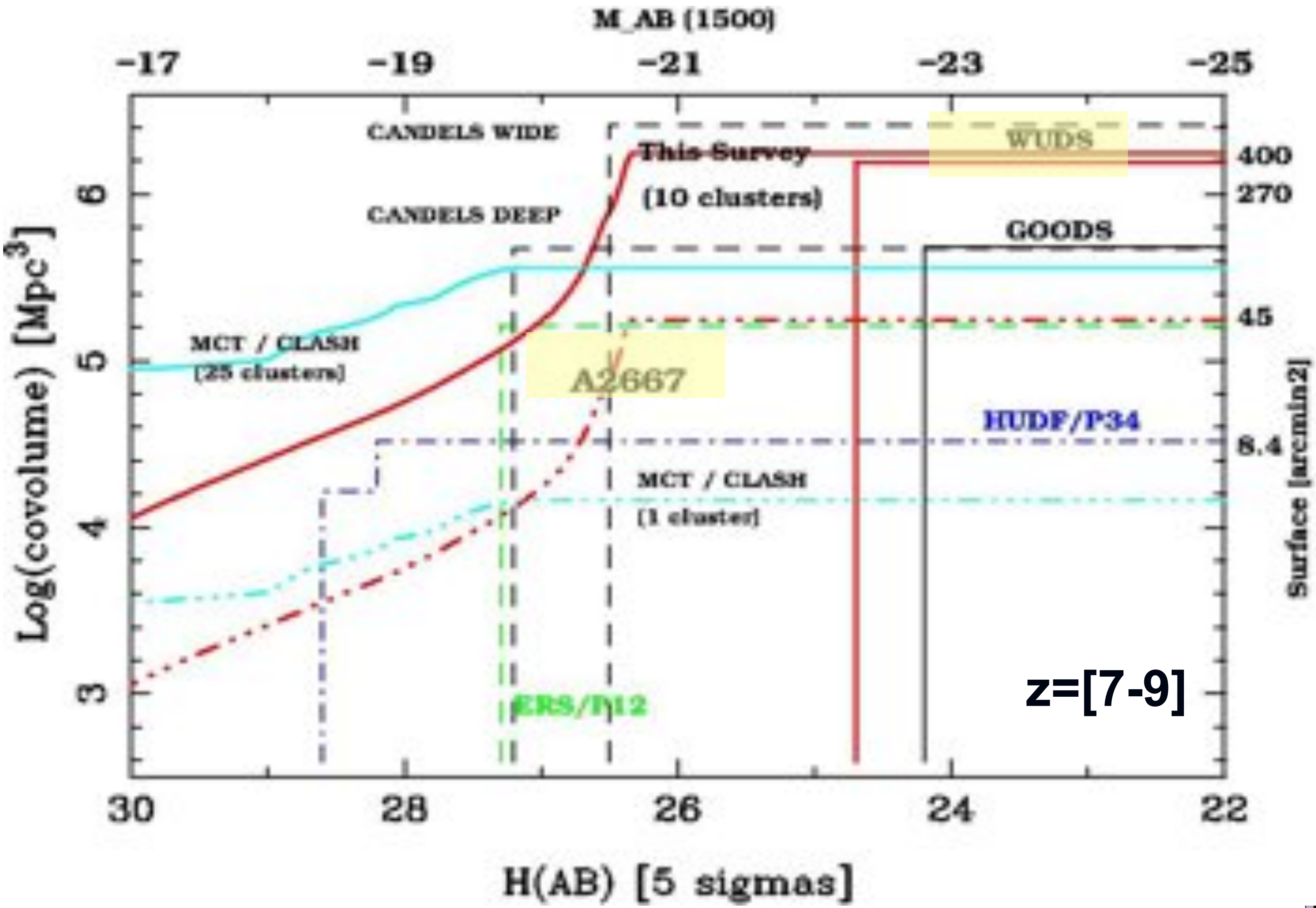
Spectroscopic follow up is difficult with 8-10m class telescopes! The situation is rapidly evolving with the arrival of multi-object NIR facilities (e.g. KMOS/VLT or EMIR/GTC) … for the brightest candidates !



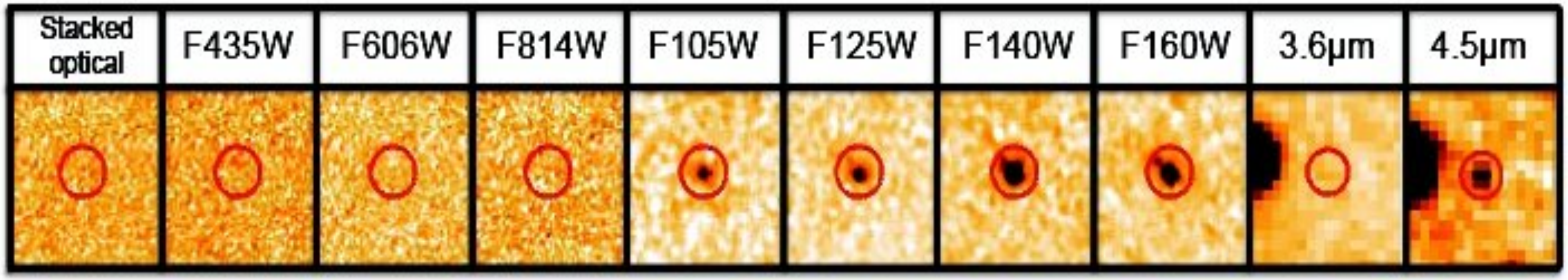
Lensing clusters used as gravitational telescopes



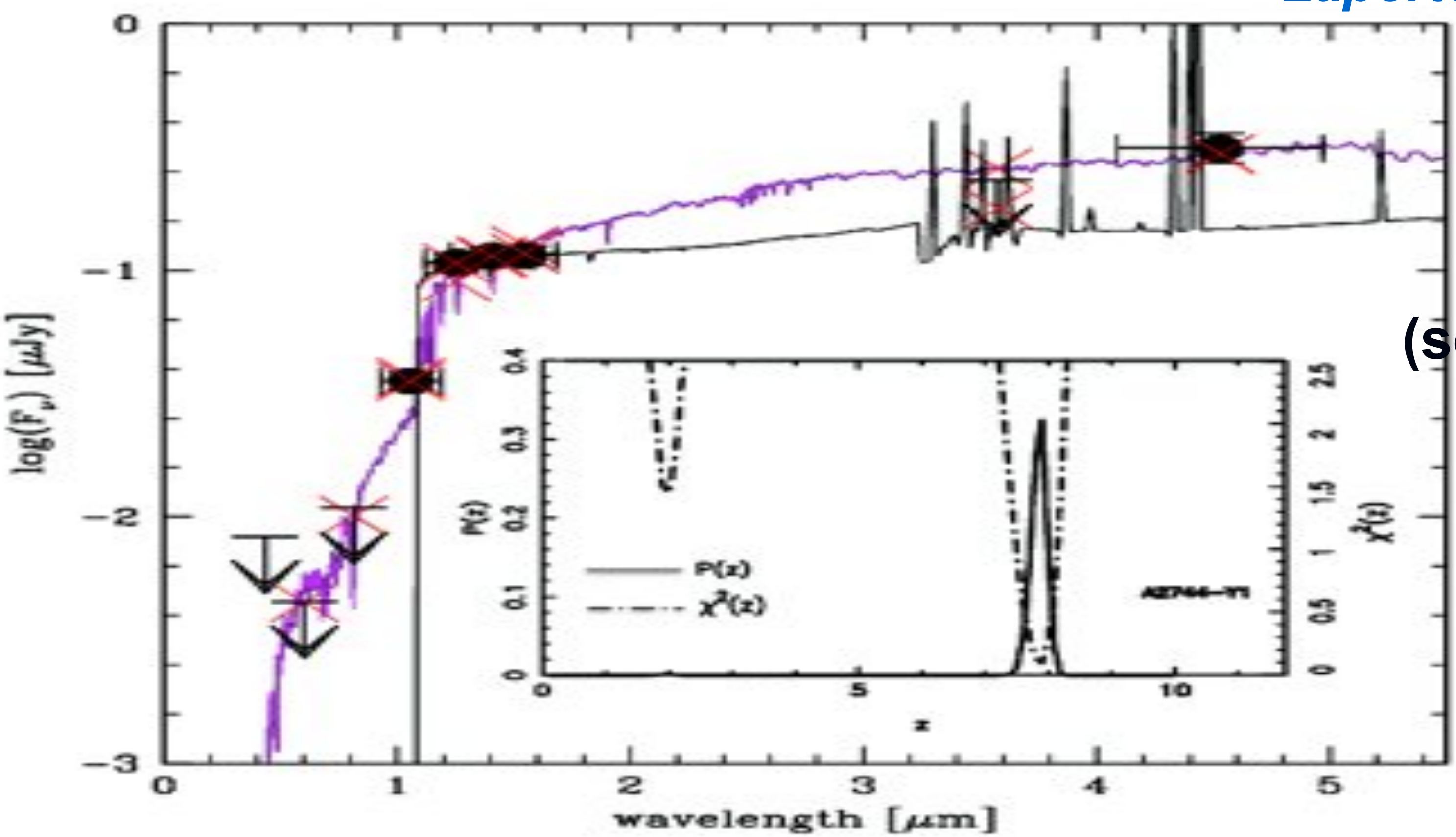
Lensing Clusters & Blank Fields



Z~8 candidate behind A2744 (Hubble Frontier Fields)

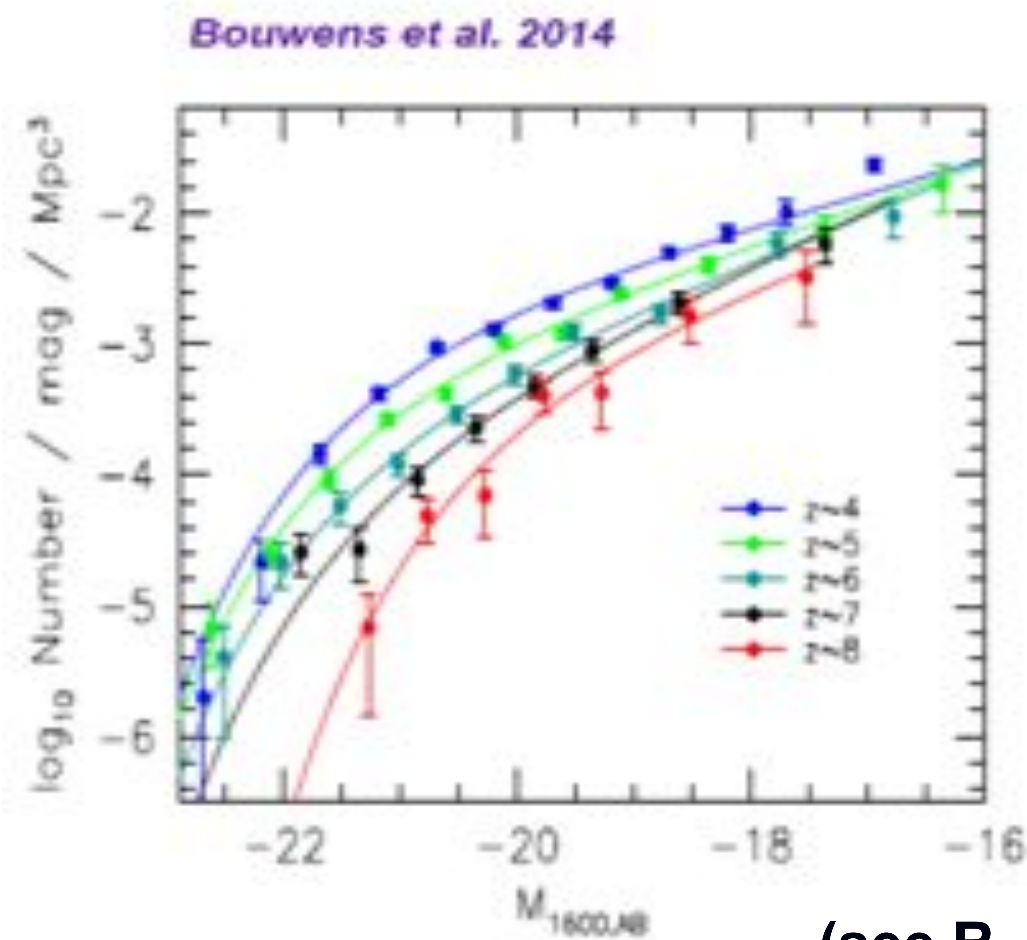


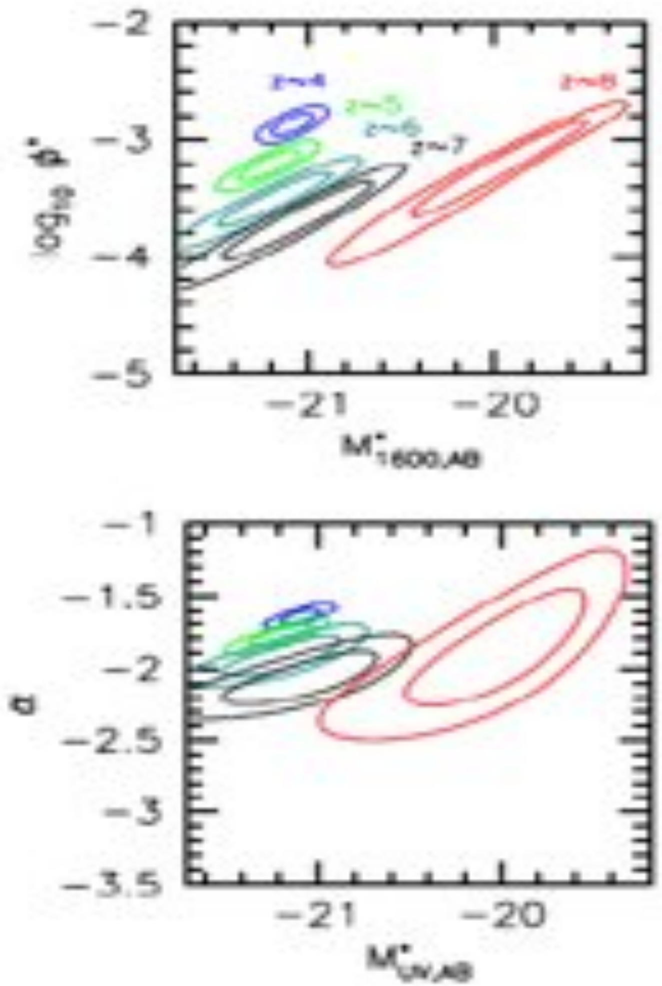
Laporte et al. 2014



(see H. Ateck talk)

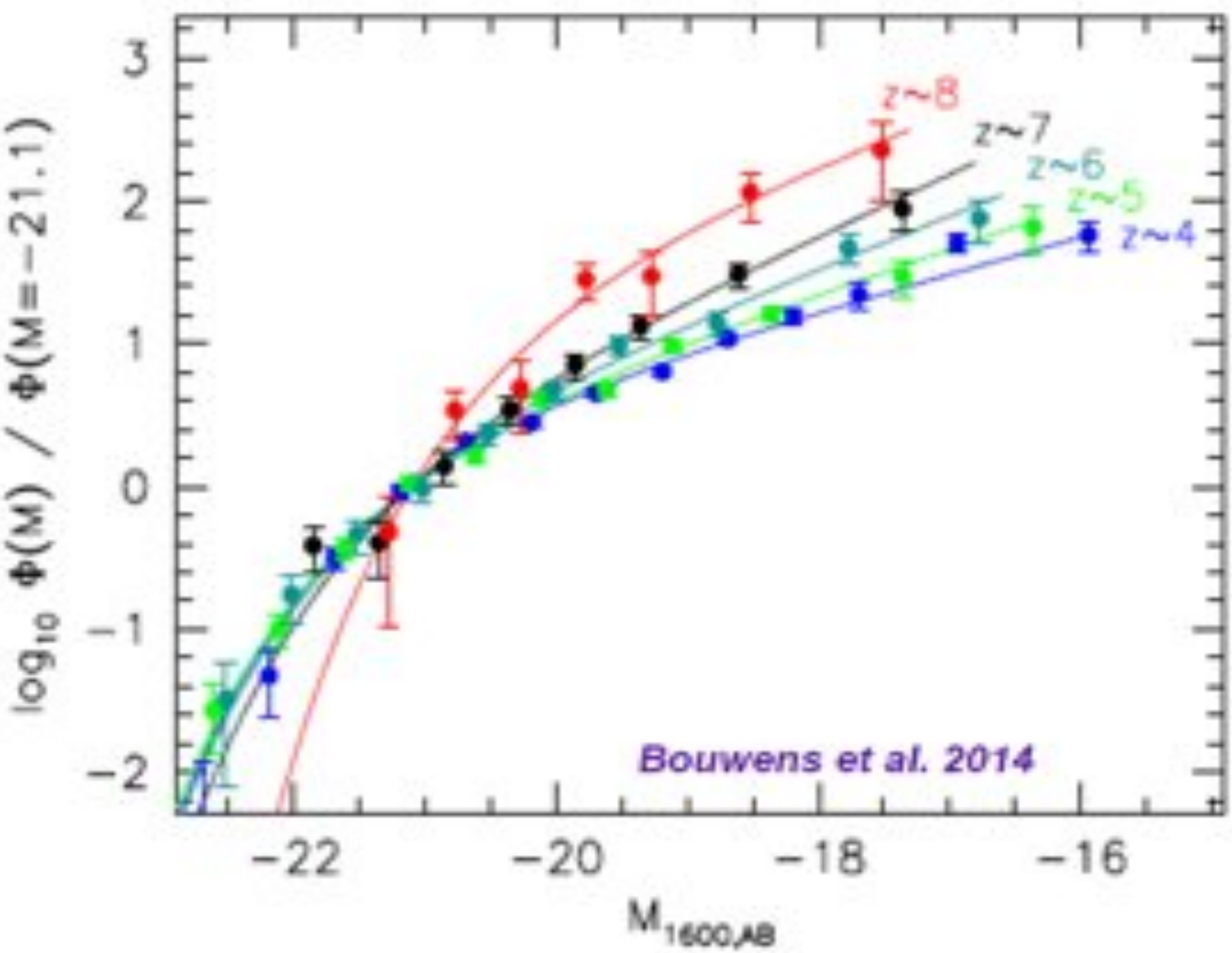
Present constraints : LBG Surveys





(see R. Bouwens talk)

Present constraints : LBG Surveys



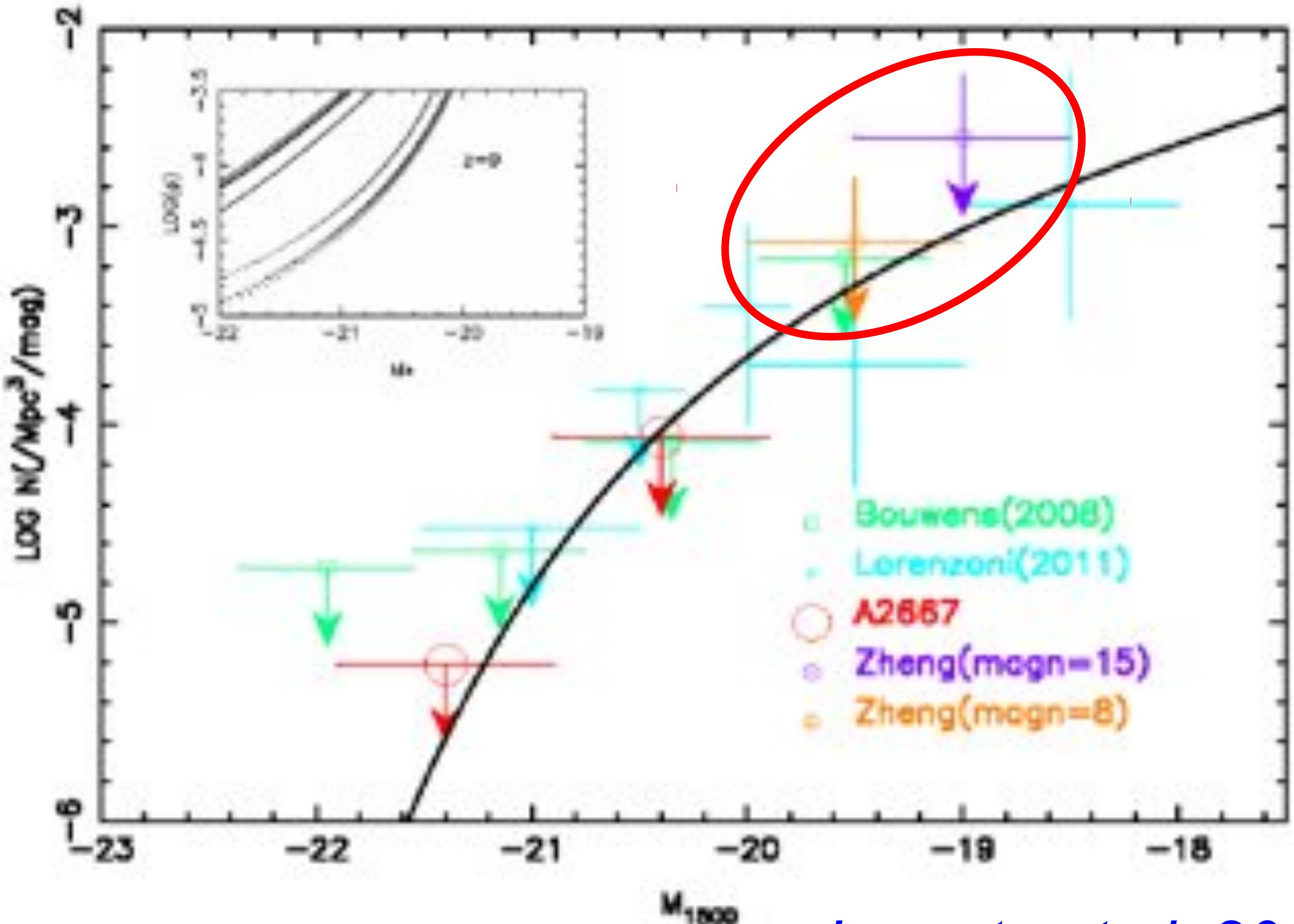
The slope of the LF becomes steeper

(see R. Bouwens talk)

Present constraints : LBG Surveys

Z=9 LF(UV) constraints

Lensing LBG Surveys

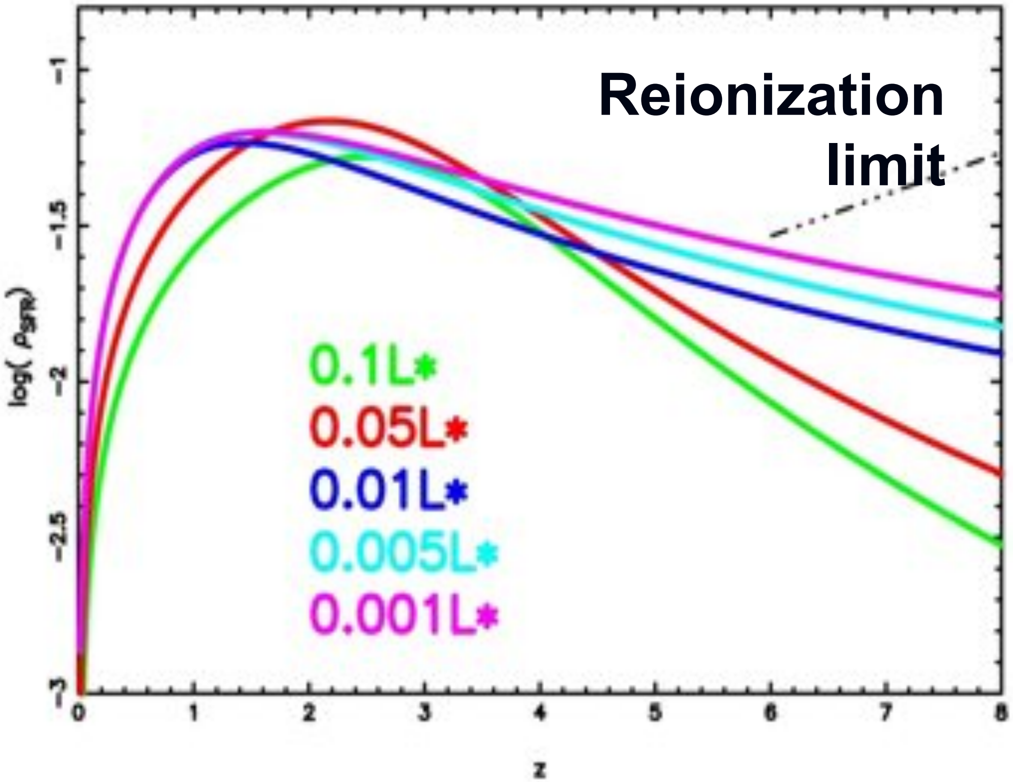


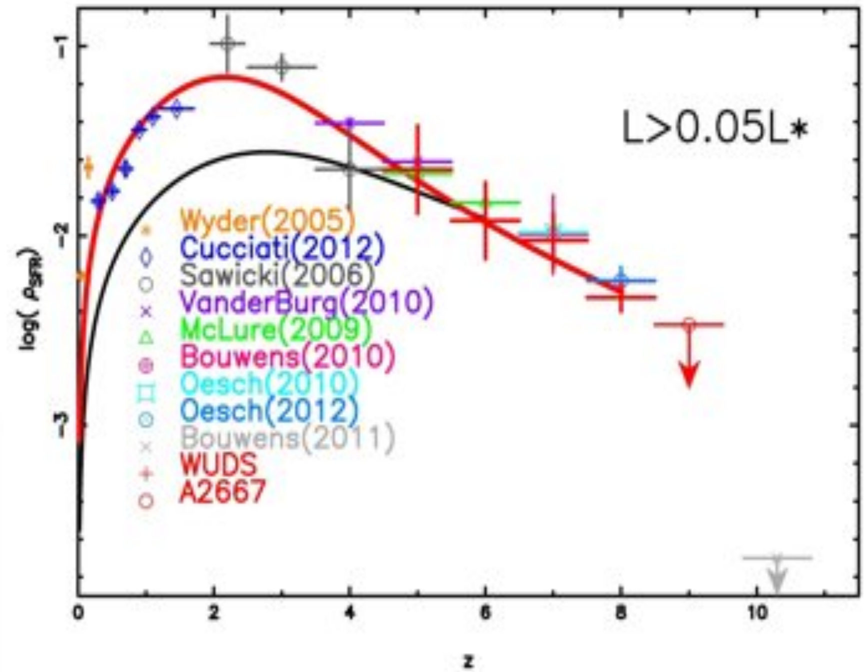
Laporte et al. 2012

Cosmic SF History

See also Filkenstein et al. 2012

$$\dot{\rho}_{UV} = \frac{6.43\times10^{25}\, erg.s^{-1}.Mpc^{-3}}{f_{esc}}\left(\frac{1+z}{9}\right)^{3}\frac{\Omega_b h_{70}^2}{0.0458}\frac{C}{5}$$





$$\rho_{UV} = \int_{0.05L^{\star}_{z=3}}^{\mathrm{inf}} L_{1500}\Phi(L_{1500})dL_{1500}$$

from Laporte 2012

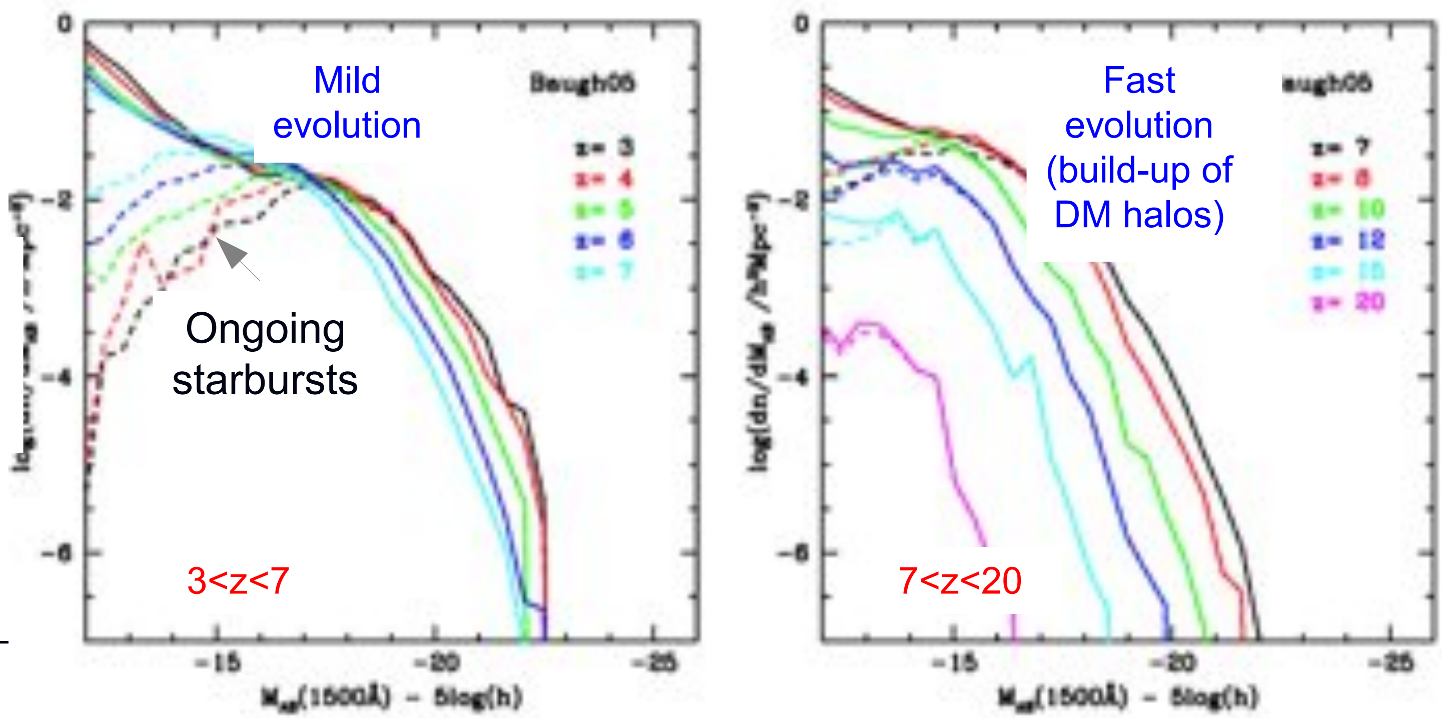
Observations vs simulations

Evolution of LBGs in the ΛCDM model

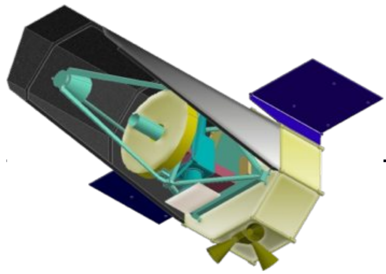
Evolution of the LBG Luminosity Function (LF) based on semi-analytical models (tuned to fit z~0 to z~2-3 observed properties at all wavelength…).

- Starbursts dominate the bright end and at high-z
- Quiescent galaxies dominate the faint end
- **Detailed predictions depend on (technical) modeling details & physical parameters (dust / photoionization & sn feedback/ IMF/ Burst time-scale,…)**

LF Including Dust extinction



GALFORM Lacey et al. 2011



WISH LIST / SCIENCE DRIVERS

- Formation and evolution of galaxies : characterization of the **first galaxies (z~7-15)** :

➔ Efficient & robust (photometric) selection of LBGs

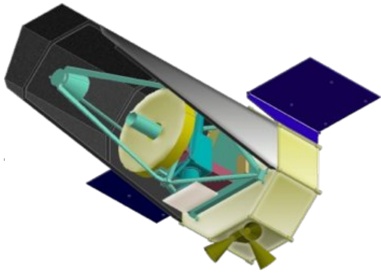
➔ **Redshift** mesurements (based on Ly alpha + other strong e-lines)

➔ Determination of the **nature** of high-z galaxies

➔ ***Spectroscopy : Use of well-known indicators to determine the physical parameters surch as***

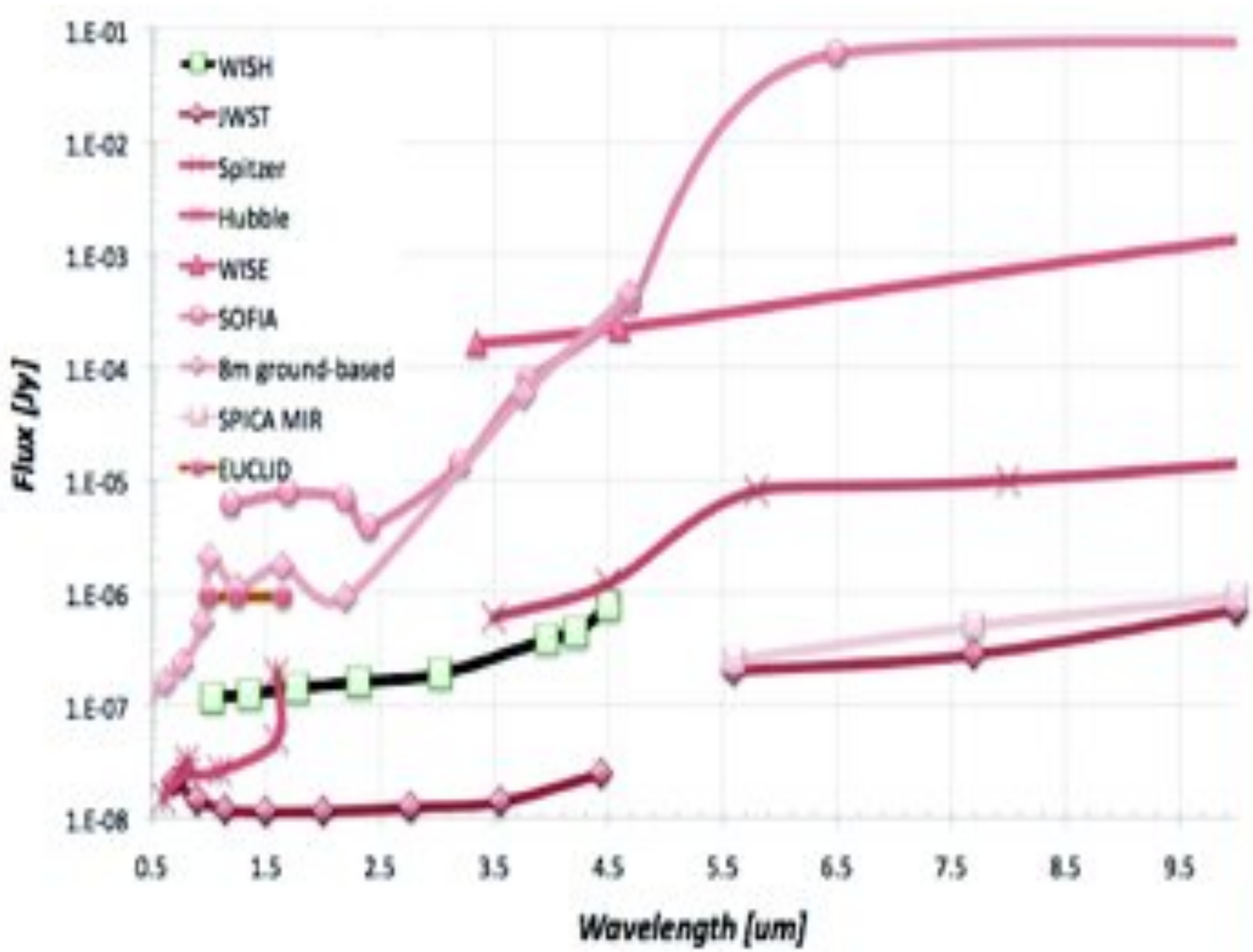
- ✗ SFR (H alpha, H beta, …)
- ✗ Dust attenuation
- ✗ Metallicity (R23, …)
- ✗ AGN, …

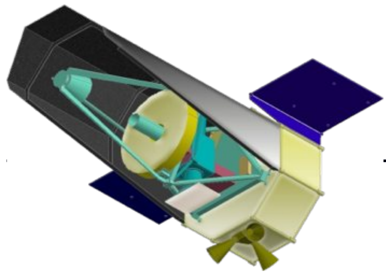
- **Others :** High-z supernovae, solar system objects, …



WISH : Filters System

Name	λ center µm	FWHM µm
Filter 0	1.040	0.280
Filter 1	1.360	0.360
Filter 2	1.775	0.470
Filter 3	2.320	0.620
Filter 4	3.030	0.800
Filter 5	3.965	1.070
Filter 5e	4.215	1.570
Filter 6	4.500	1.000

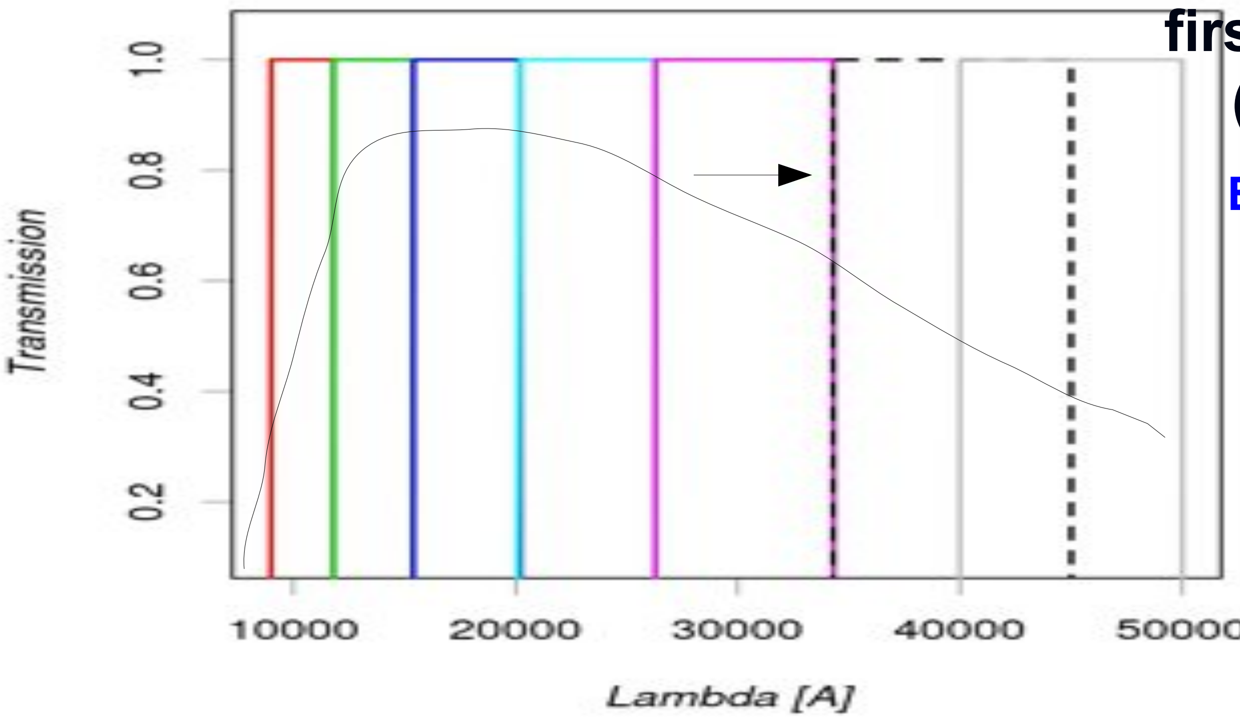




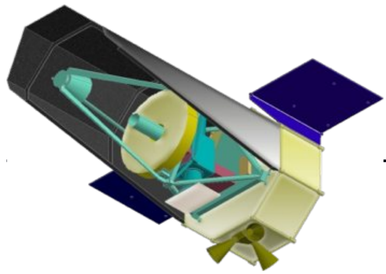
WISH : Survey Strategy

- **<u>Ultra Deep Survey</u>** (UDS): m(AB) = ~28 - 100 deg2
- **<u>Ultra Wide Survey</u>** (UWS): m(AB) = 24-25 - 1000 deg2
- **<u>Extreme Survey</u>** (ES): m(AB) = 29-30 over 0.25 deg2

1216 A z~7 → z~20 first (proto)galaxies



Evolution of the UV-continuum slope β : **correlated with SF history, metallicity, dust content, IMF, age of the stellar population, ...**



WISH : Survey Strategy

Evolution of LBGs properties in the ΛCDM model

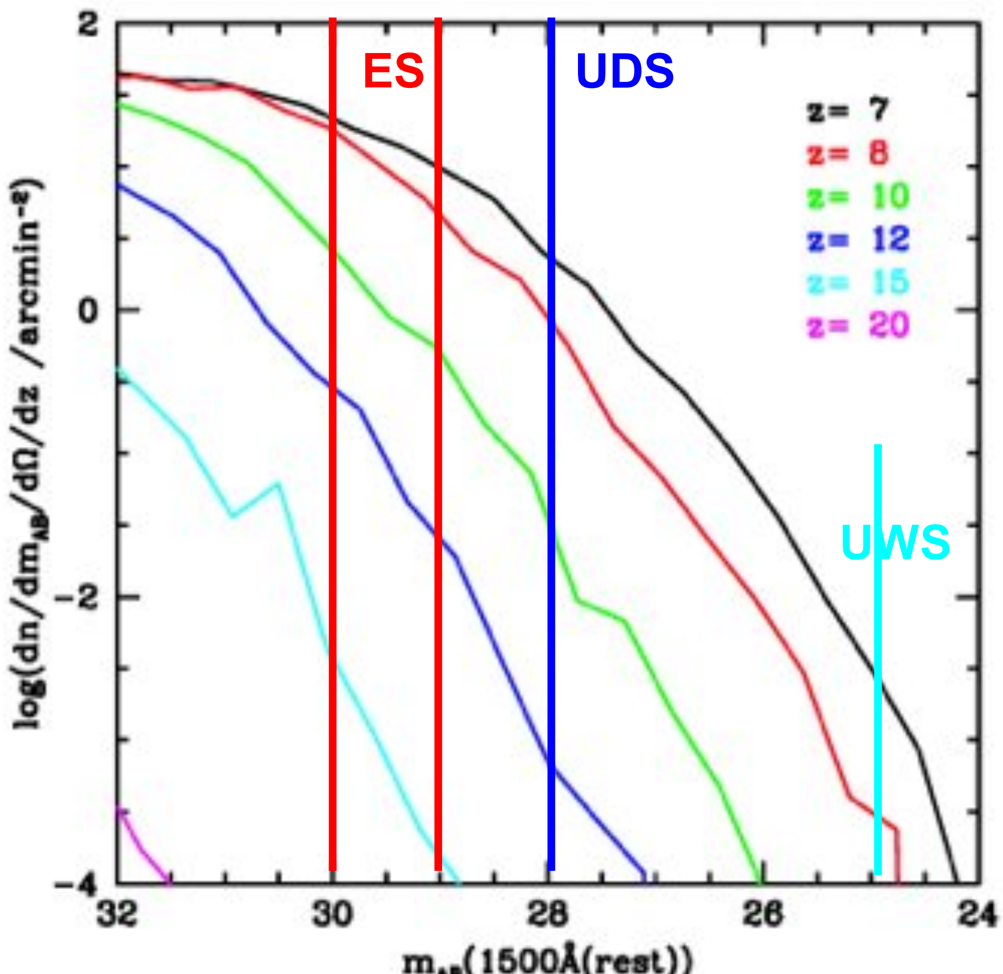
Surface density :

- a few z>15 LBGs expected with m~29 in the WISH/ES (~1000 arcmin2)

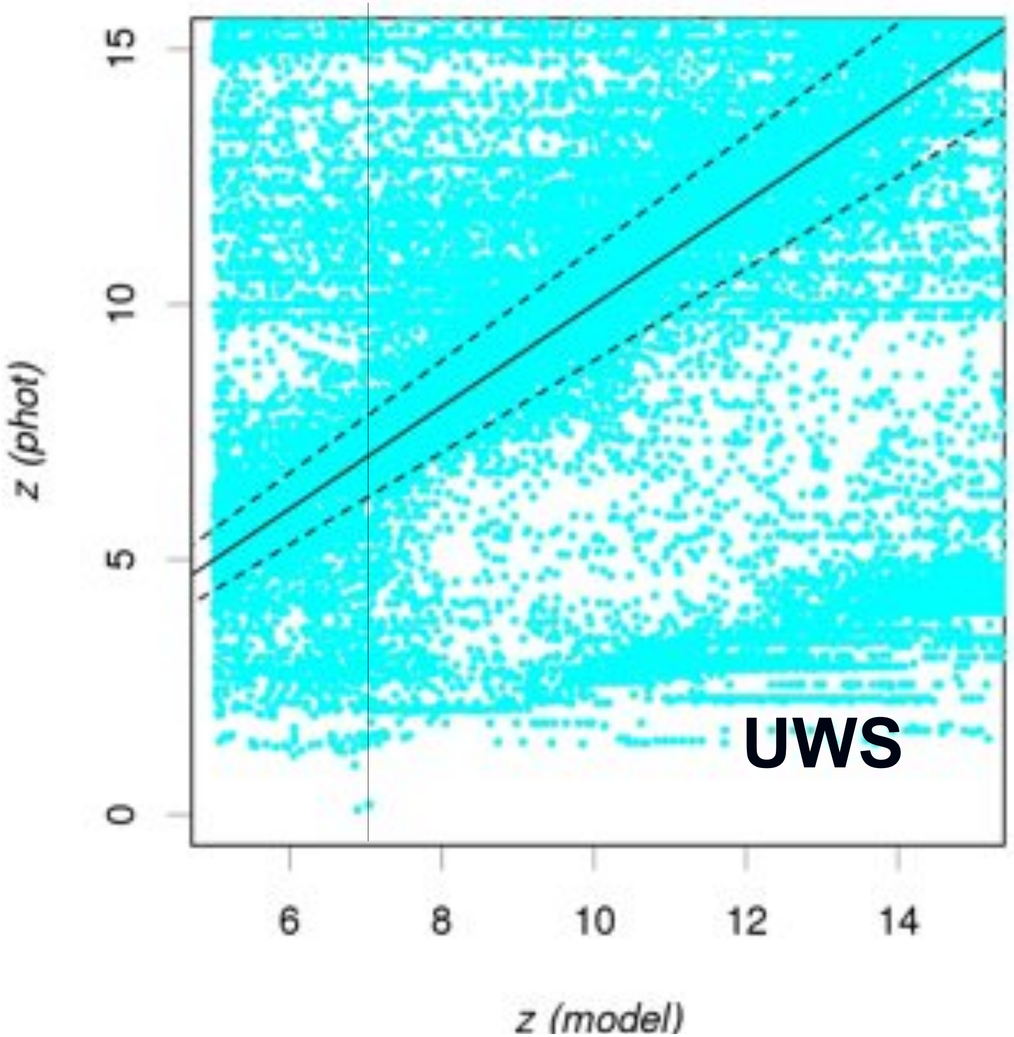
- ~100 z~15 and ~1000 z~12 LBGs in the UDS+ES

Surface densities in blank fields

GALFORM Lacey et al. 2011



WISH : Photometric identification



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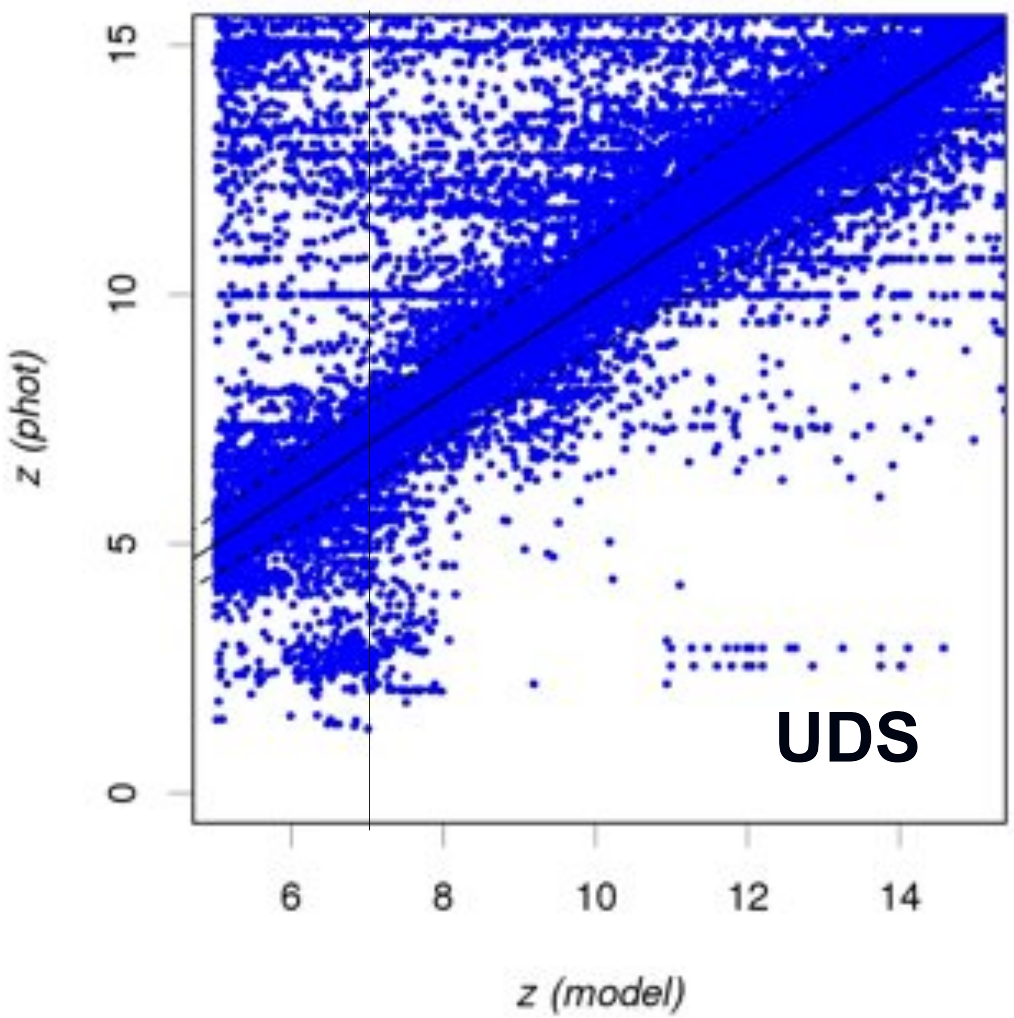
- **Ultra Wide Survey** (UWS): m(AB) = 24-25 - 1000 deg2
- **Extreme Survey** (ES): m(AB) = 29-30 over 0.25 deg2

M(1500) < - 20
55% dz<0.1(1+z)
59% at z>7

WISH : Photometric identification



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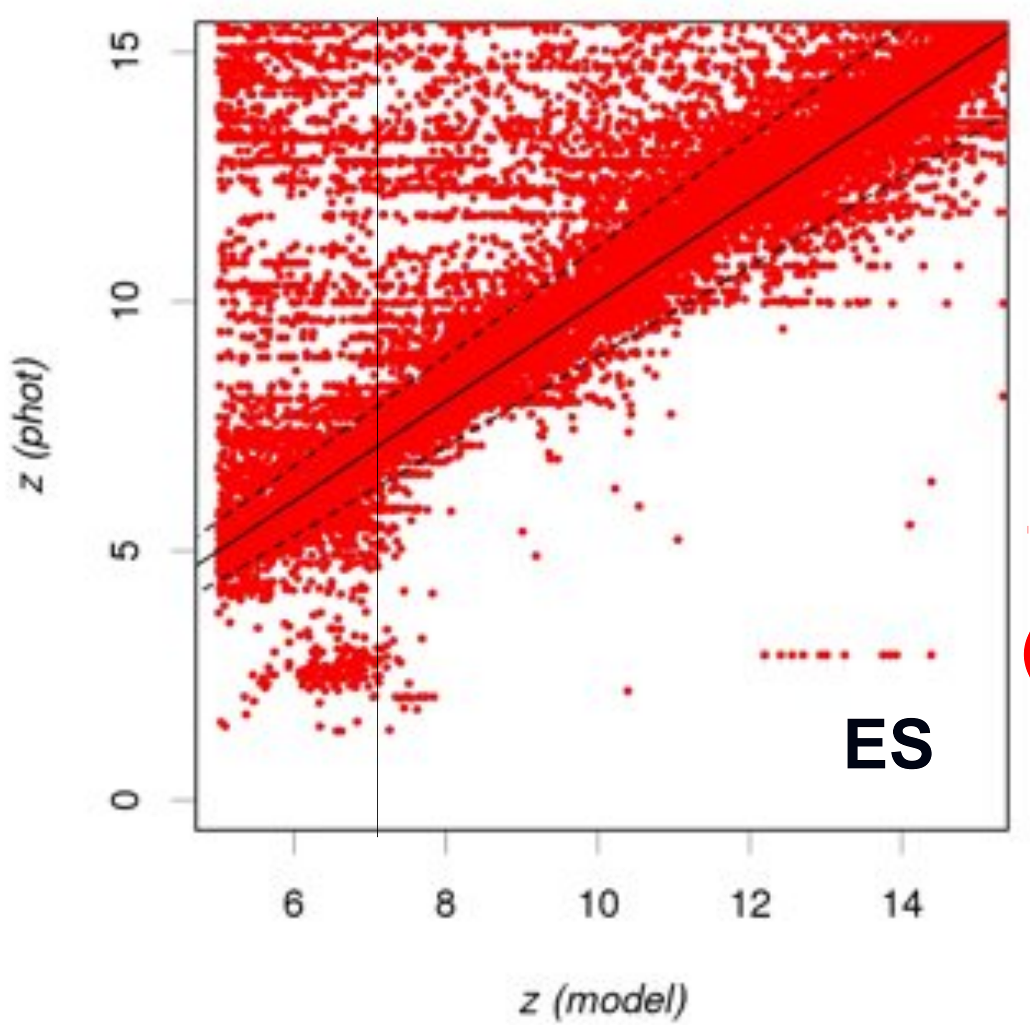
- **<u>Extreme Survey</u>** (ES): m(AB) = 29-30 over 0.25 deg2

M(1500) < - 20
85% dz<0.1(1+z)
87% at z>7

WISH : Photometric identification



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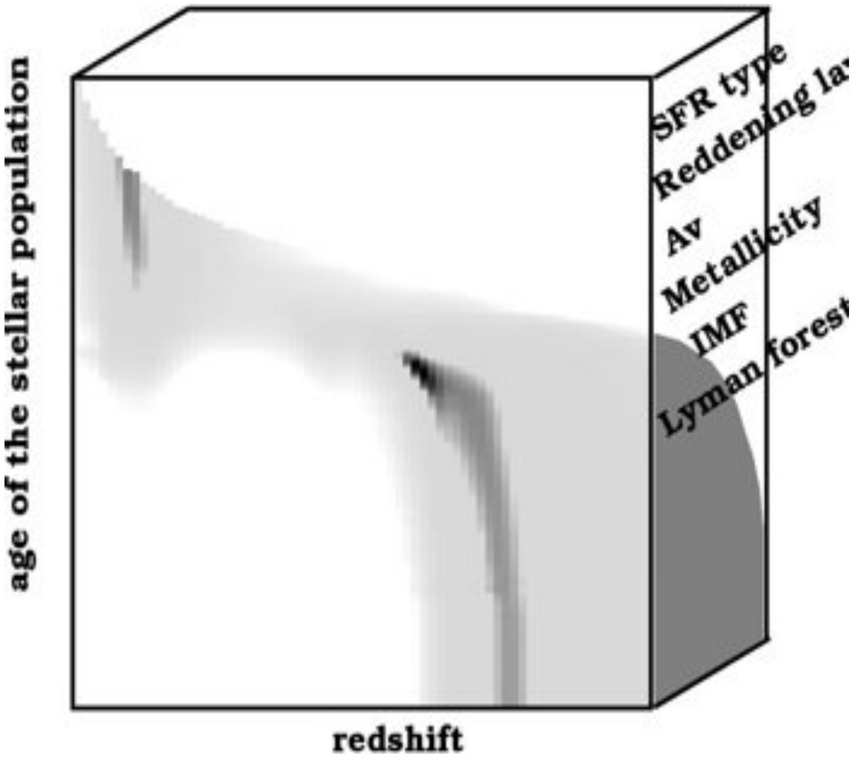
- **Extreme Survey** (ES): m(AB) = 29-30 over 0.25 deg2

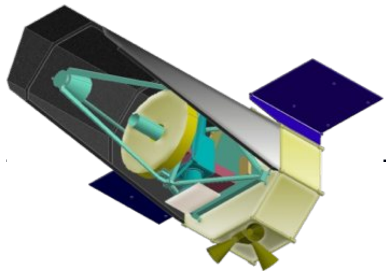
M(1500) < - 20
87% dz<0.1(1+z)

Properties from Photo-z and SED-fitting

- **Galaxy types / classification /sample selection**
- **SFR, SFHs and SFRD**
- **Stellar masses**
- **Dust properties**
- **Properties of (extremely)-high redshift galaxies**
- **Global properties of the galaxy population :**
  - Luminosity/mass functions
  - Environment effects
  - LSS/ Clustering properties
  - ...



PDZ



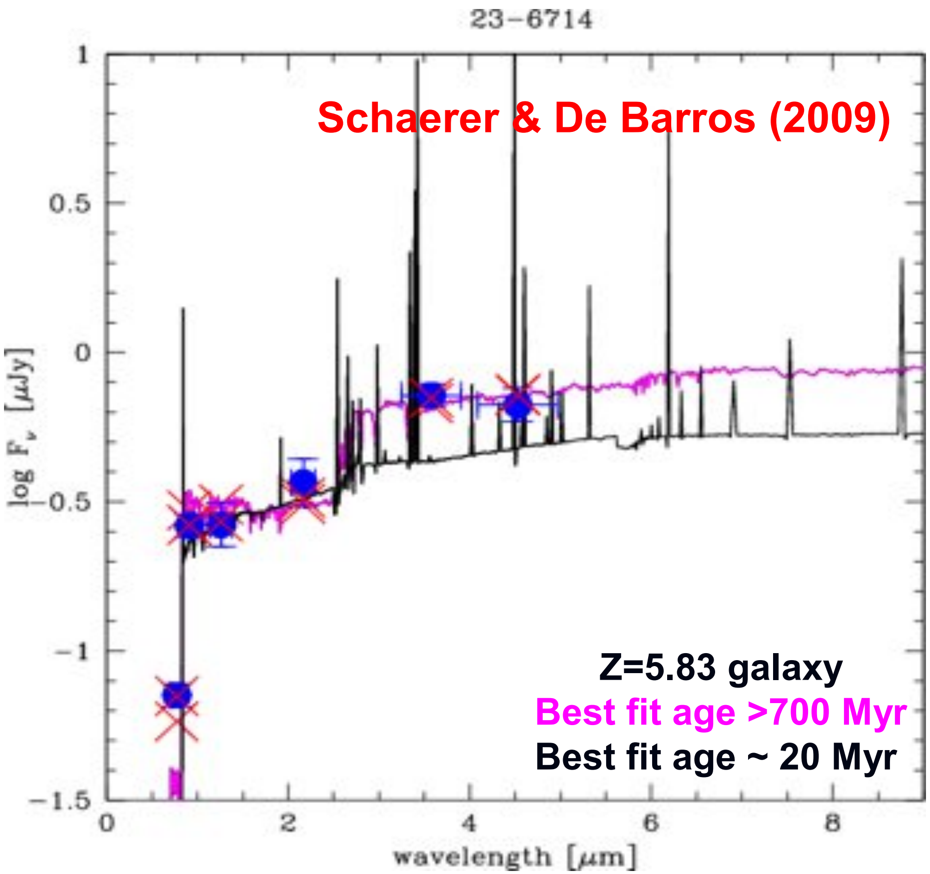
Why spectroscopy ?

- **SED fitting procedures**. Rely on "template" libraries, dependence on the parameter space and effective wavelength coverage.
- Degenerate solutions.
  - **Current Spectroscopy** : poor S/N for high-z sources. Limited wavelength coverage.
  - A combination of SED fitting + spectroscopy...

JWST / ALMA / WISH / ELTs

See D. Schaerer's talk

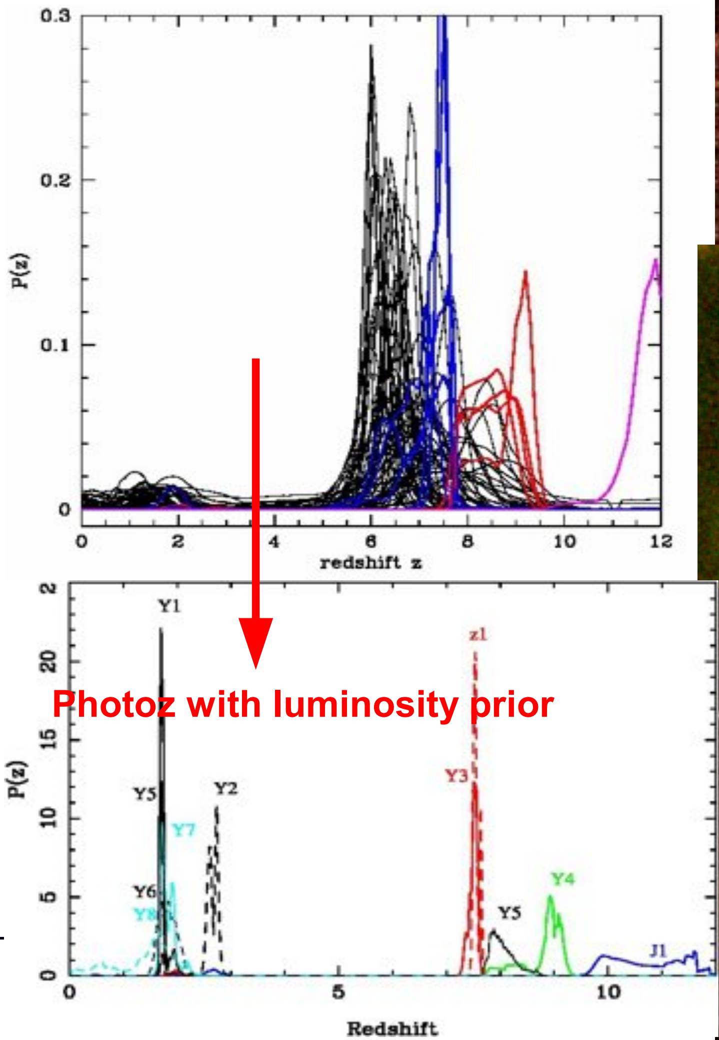
Nebular e-lines are susceptible to contribute to broad-band integrated flux ==> errors in redshift for LBGs & SED-fitting degeneracies (see e.g. Schaerer+ 2011, De Barros et al. 2012)

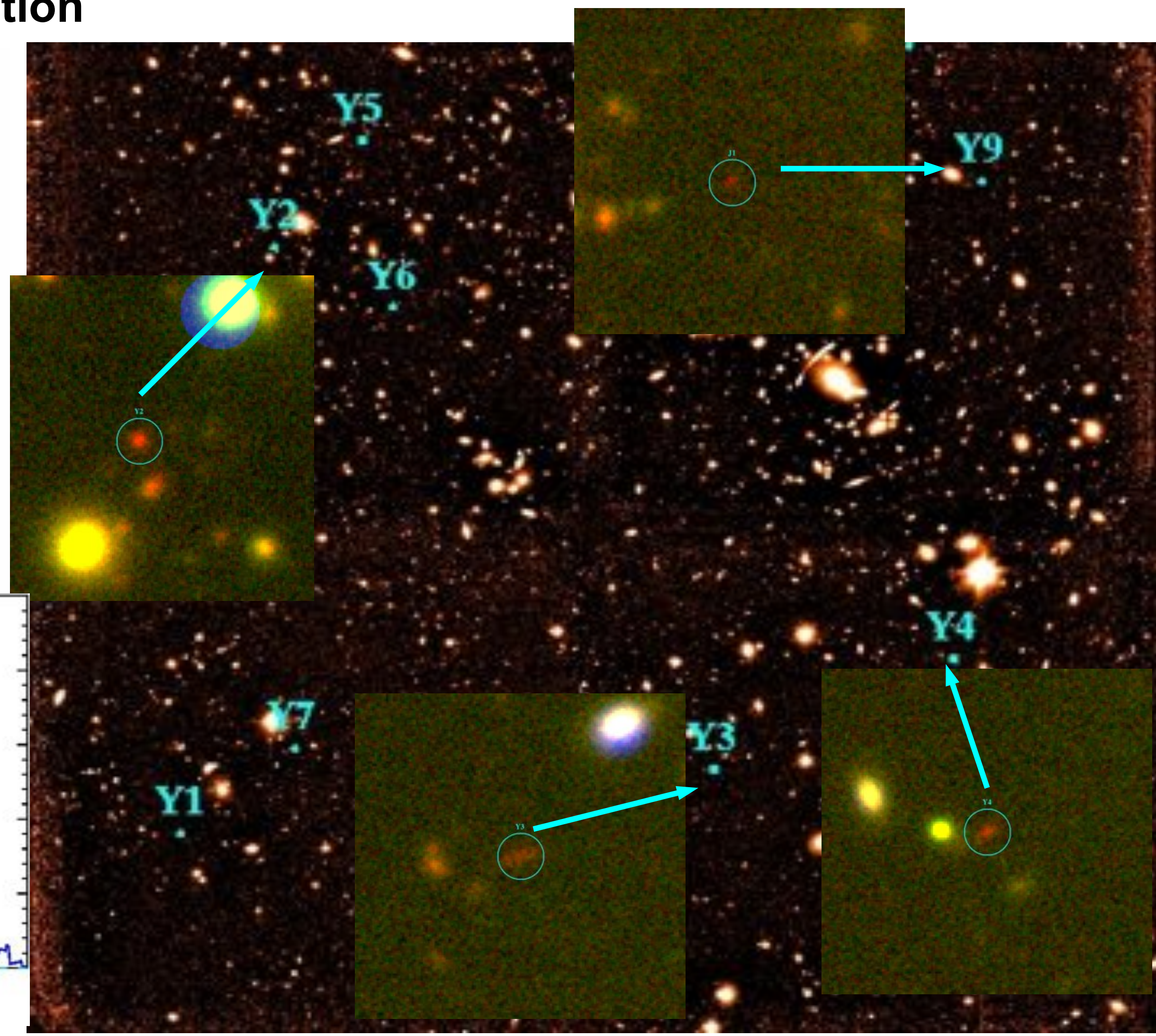


An example ….

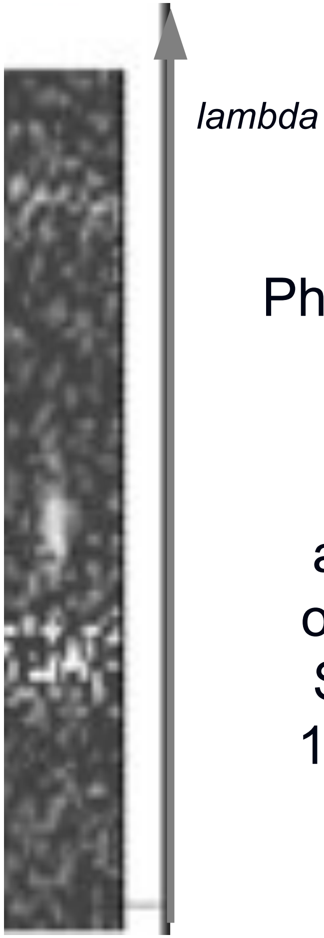
Laporte et al. 2011:

Several "bright" z~>7 candidates behind the lensing cluster A2667. Photometric redshifts. Strong contamination



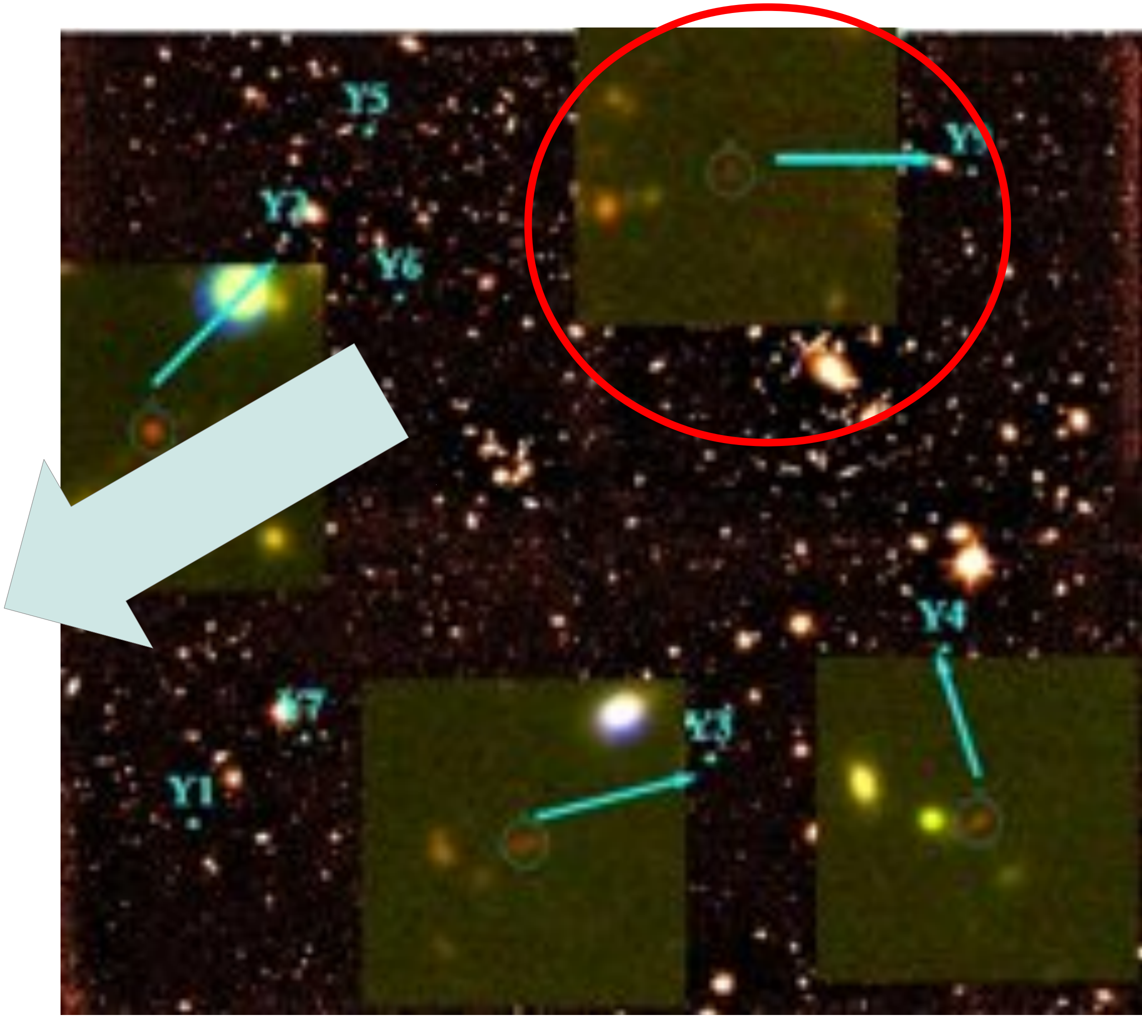


Issue #1 : Photometric candidates = contamination



Photometric redshift
z~12 ...
+
Bright and asymetric e-line observed with X-Shooter /VLT at 1.529 microns …
z~12 ?!!!!

… this is NOT Lyman alpha, but [OIII]5007 !



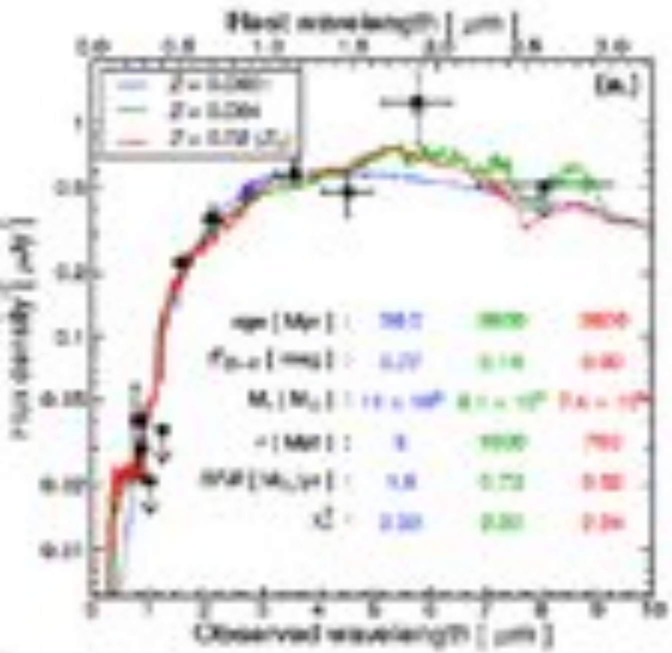
Hayes et al. 2012
Laporte et al. 2012

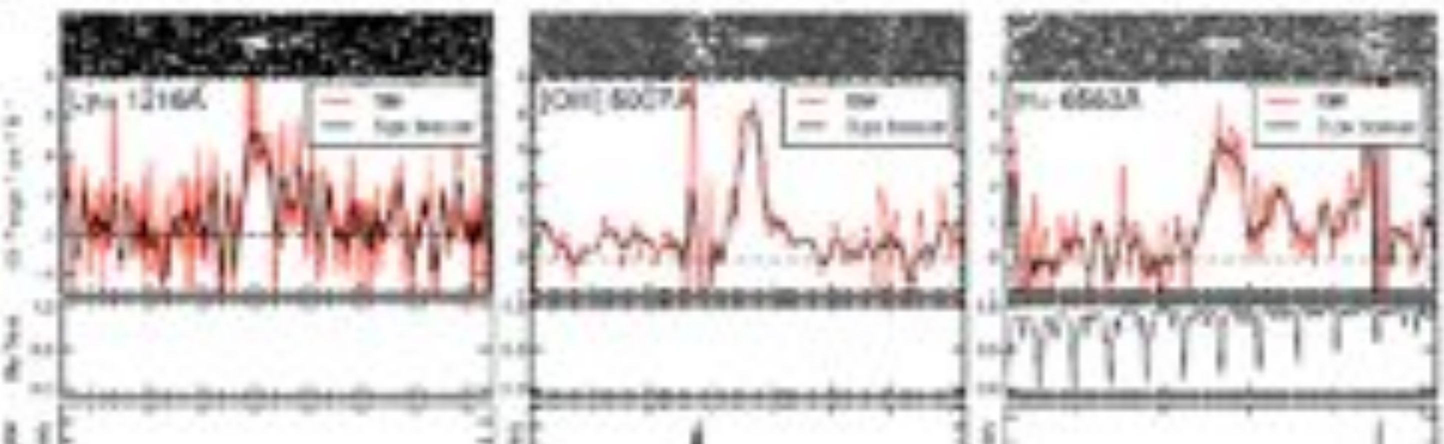
Issue # 1 : Photometric candidates = contami

Hayes et al. 2012

Table 1. A2667-J1 fluxes in emission lines

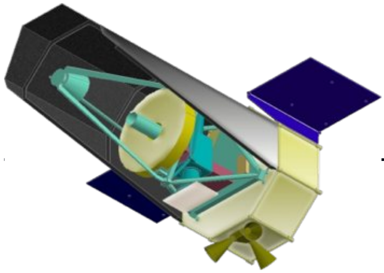
Species	λ_{rest} Å	λ_{obs} Å	z	Flux 10^{-17} erg s^{-1} cm^{-2}
H I Lyα	1215.67	3743.0	2.079	9.41 ± 2.25
He II	1640.42	...	...	< 4.87
[O II]	3727.09	...	...	< 2.72
[O II]	3728.79	...	...	< 2.72
H I Hβ	4862.72	14968.2	2.084	7.77 ± 4.22
[O III]	4960.30	15288.2	2.082	7.66 ± 2.72
[O III]	5008.24	15436.6	2.082	18.8 ± 0.96
H I Hα	6564.61	20231.6	2.082	22.7 ± 4.06
[N II]	6585.46	20290.2	...	< 3.62





Spectrosco
observation
A2667-J1 wi
Shooter

"Bright" m(H)
candidat
~1h exposure
A promine
asymetric, e
Several addi
emission-li
detected a
further inspec
z=2.08 interl
2 stellar popu
: old domina
young S



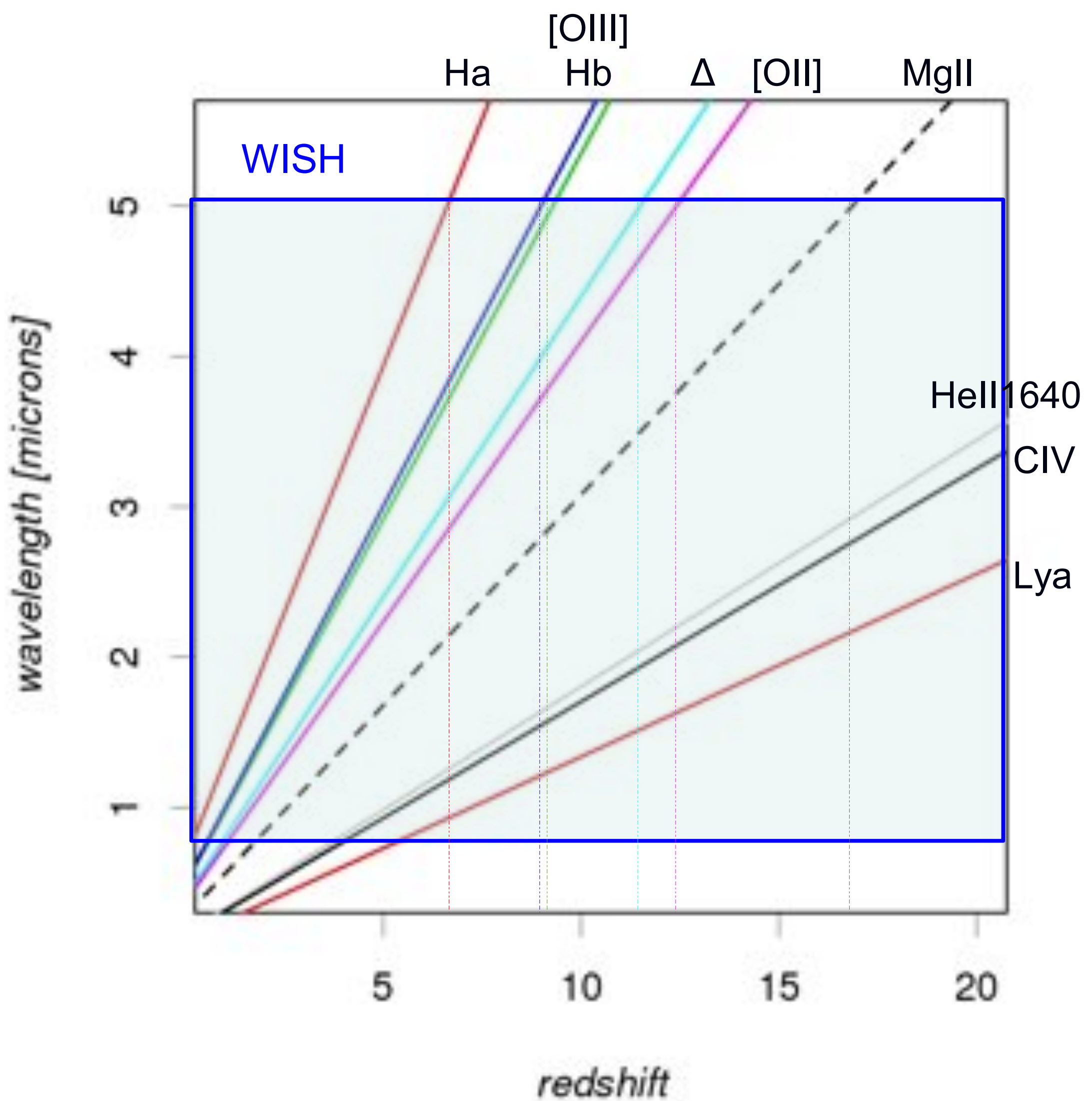
WISH LIST / SCIENCE DRIVERS

➔ **Redshift** mesurements (based on Ly alpha + other strong e-lines)

➔ Determination of the **nature** of high-z galaxies

➔ ***Spectroscopy : Use of well-known indicators to determine the physical parameters surch as***

- ✗ SFR (Ha, Hb, …)
- ✗ Dust attenuation
- ✗ Metallicity (R23, …)
- ✗ AGN, …



- Comparison of several (spectroscopic) facilities to perform galaxy physics (**at least 5 lines in the optical range:** *[OII]λ3727, [OIII]λ4959, 5007, Hβ, [NII]λ6584* and *Hα* ratio) and to measure redshifts (at least 2 lines) as a function of the redshift. Note that we do not take UV lines and NIR lines and PAH into account.

- As expected from the usable wavelength ranges of each of the telescopes, WISHSpec and JWST/NIRSpec are much more adapted to the very high redshift (i.e. $z > 3$).

- On the spectroscopic side, assuming ~ 1 x 1 arcmin^2 field of view, WISHSpec **should observe more spectra than NIRSpec**. JWST would collect 10^5 galaxies down to AB=25 (R=100) to calibrate the photometric redshifts. NIRSpec would collect 10^4 galaxies (Franx 2011) over JWST lifetime (100 simultaneously, at all redshifts and part (how many?) at low R.

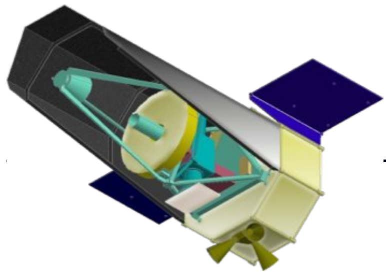
Redshift	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
WISH/Spec	4	7	7	7	7	7	5	5	4	2	2	2	1	1	1
JWST/NIRSpec	4	7	7	7	7	7	5	5	4	2	2	2	1	1	1
EUCLID/NISP	6	7	3	1	0	0	1	1	1	1	1	1	1	1	0
HST/WFC3IR	6	4	1	0	0	0	1	1	1	1	1	1	0	0	0
WFIRST	6	7	3	1	0	0	0	0	0	0	0	0	0	0	0
SPICA/MCS	0	0	0	0	0	0	3	3	4	6	6	6	7	7	7
JWST/MIRI	0	0	0	0	0	0	3	3	4	6	6	6	7	7	7

Table valid for the optical lines ***[OII]λ3727, [OIII]λ4959, 5007, Hβ, [NII]λ6584*** and ***Hα***

Physics OK

Redshift OK

BAD



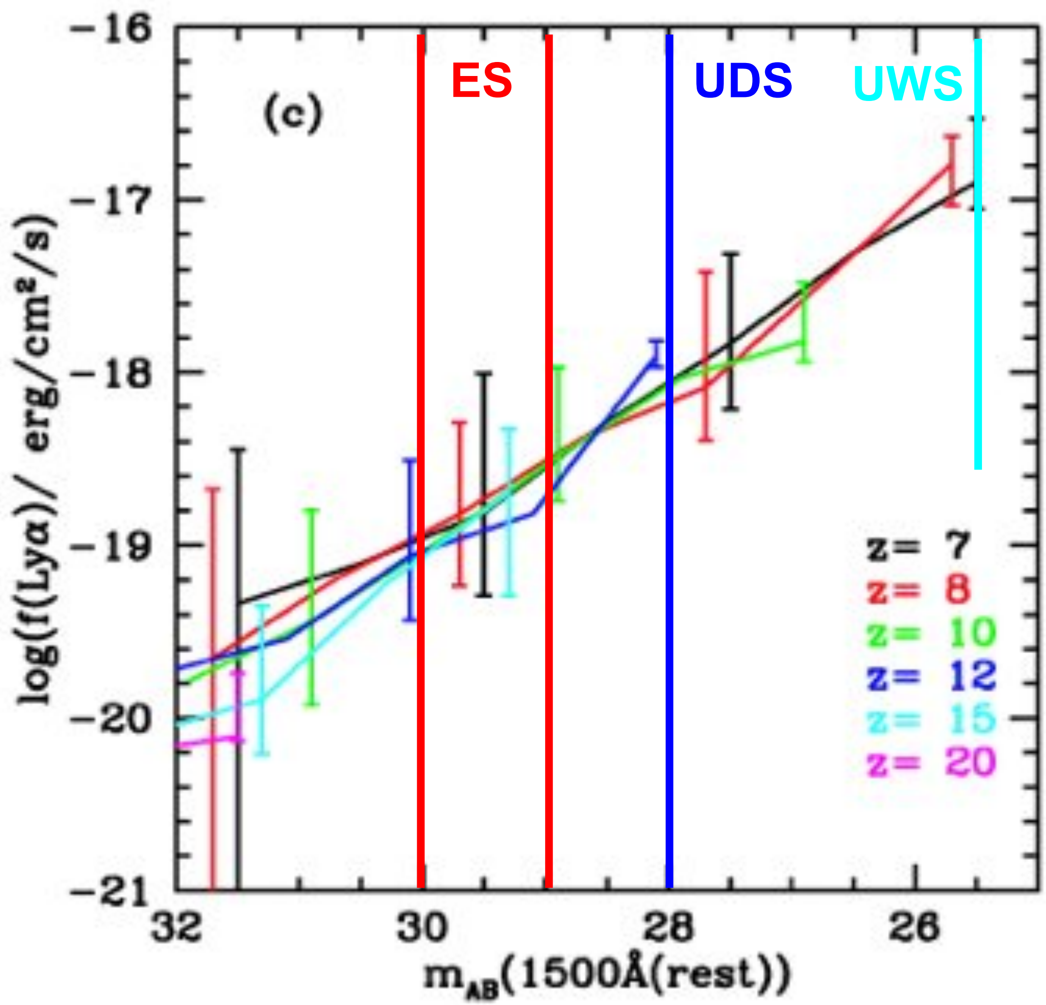
WISH : Survey Strategy

Lyman alpha flux

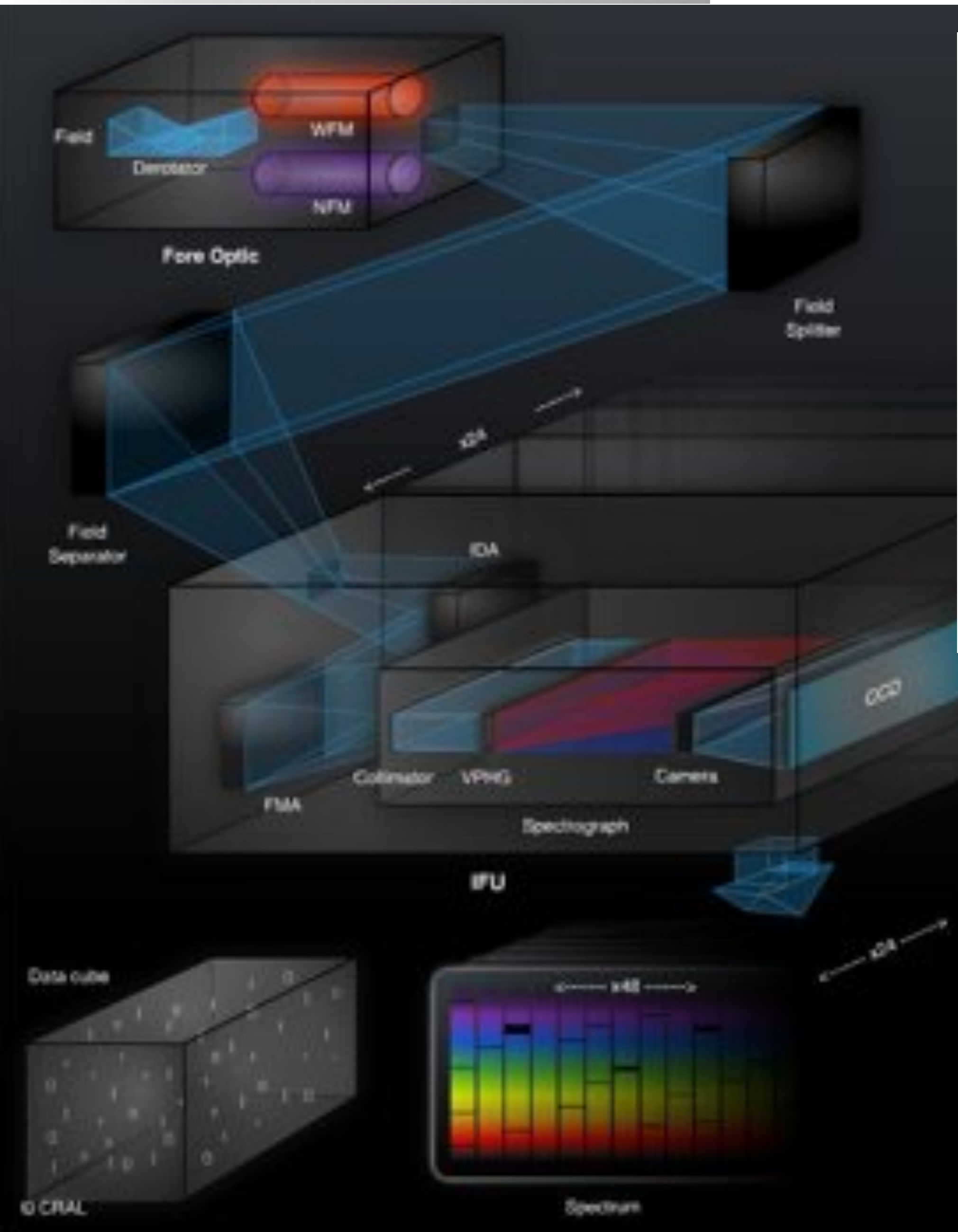
GALFORM
Lacey et al. 2011

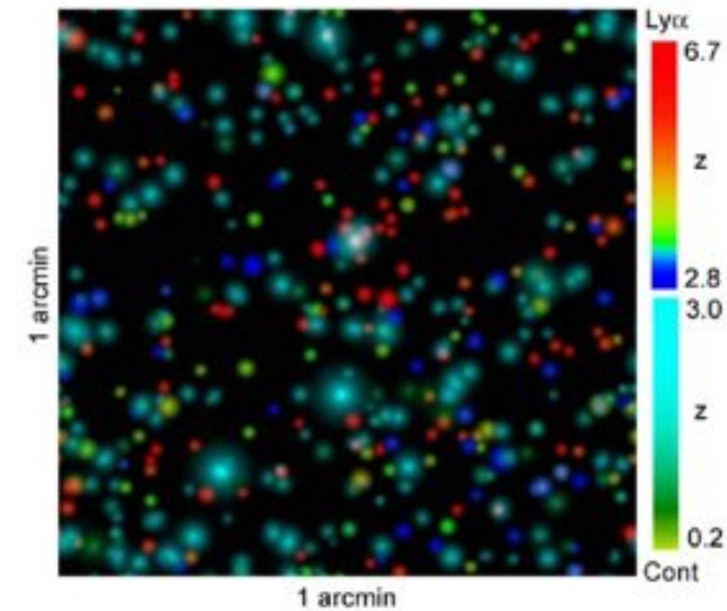
Evolution of LBGs properties in the ΛCDM model

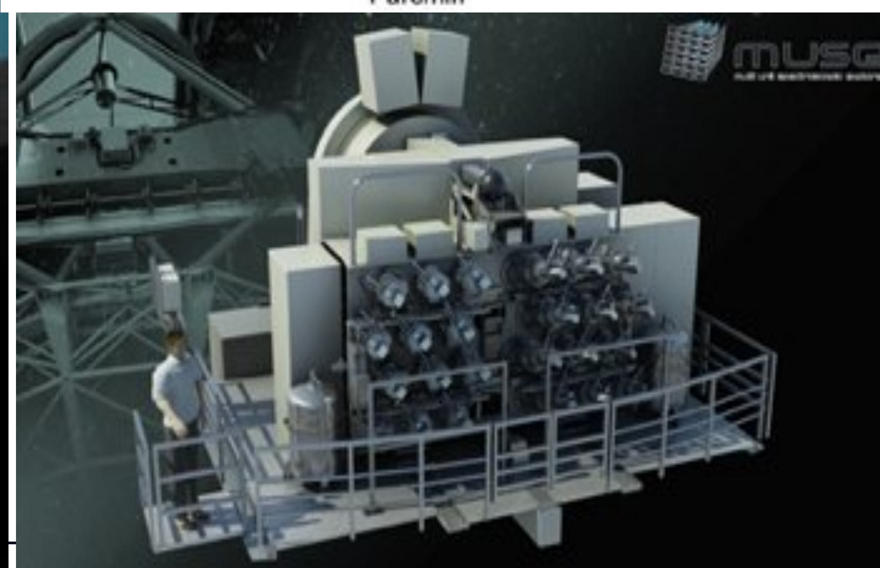
Ly alpha flux (assuming escape fraction 2%) ~ a few 10^{-18}- 10^{-19} erg/cm2/sec for LBGs with m~28-30 (within the reach of E-ELT)



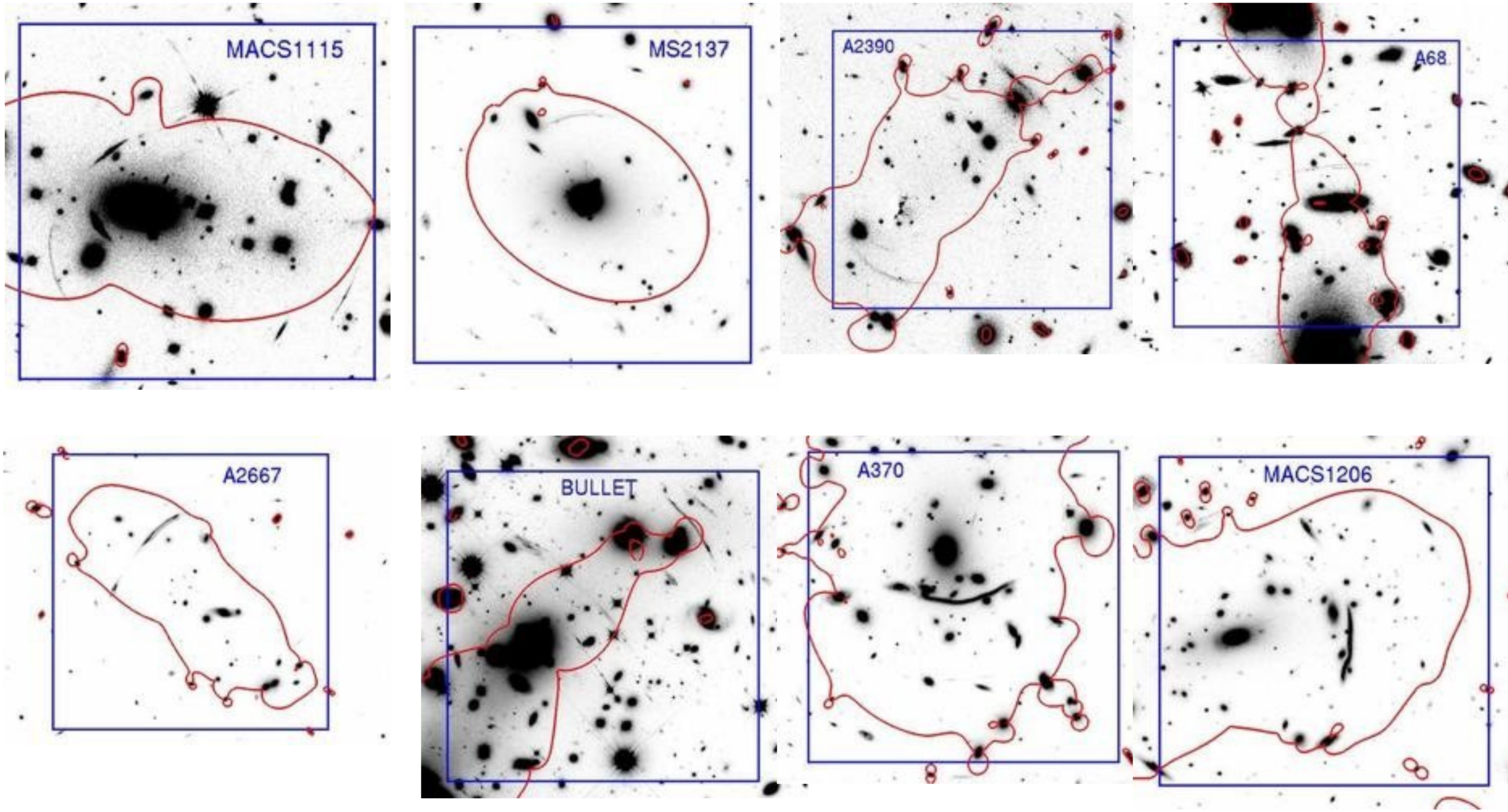
MUSE / VLT


Field
WFM
Derotator
NFM
Fore Optic
Field Splitter
x24
Field Separator
IDA
CCD
FMA
Collimator
VPHG
Camera
Spectrograph
IFU
x24
Data cube
x48
Spectrum
© CRAL

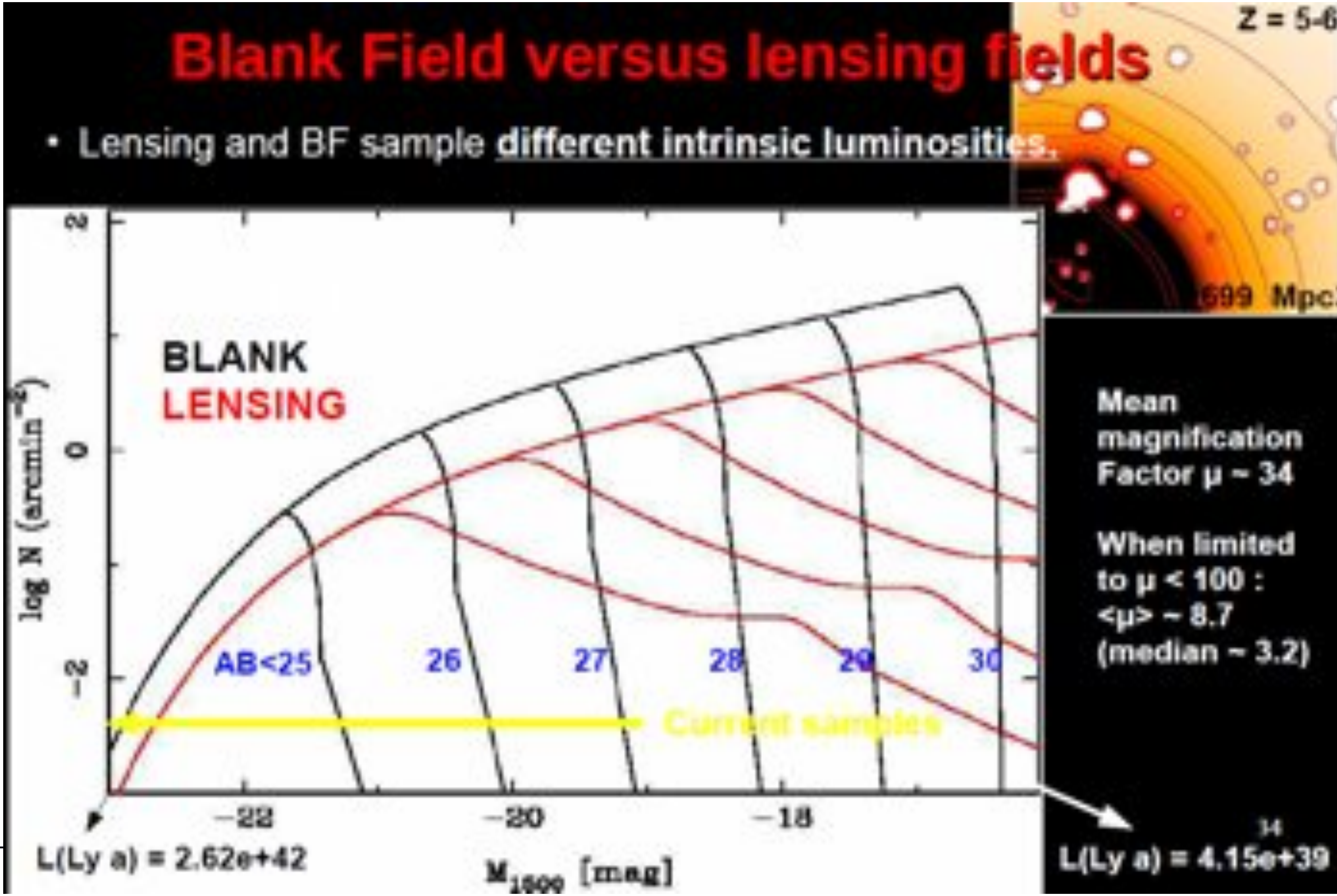

Lyα
6.7
z
2.8
3.0
z
0.2
Cont
1 arcmin
1 arcmin



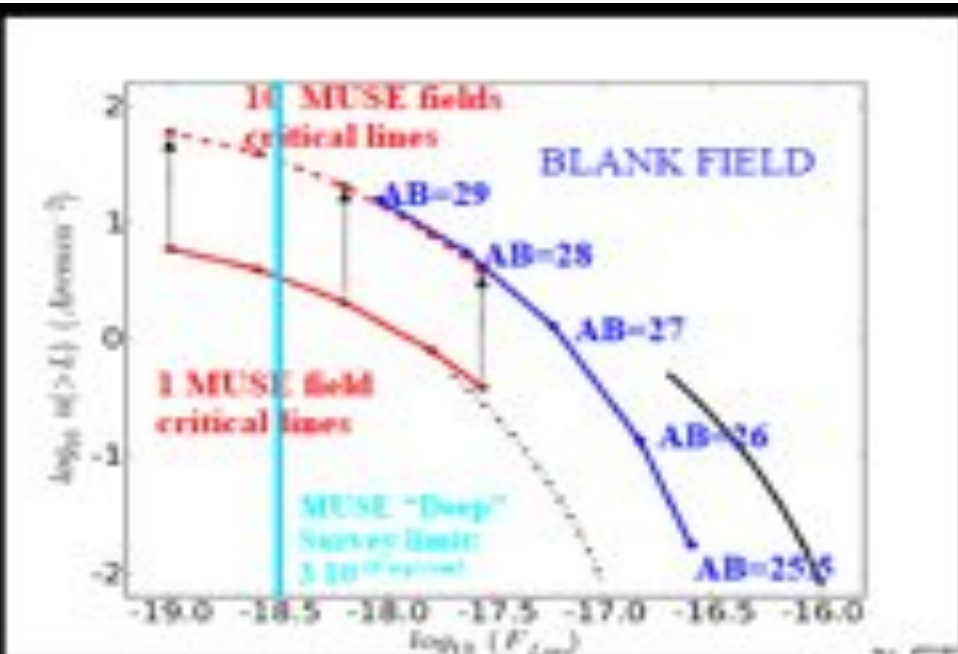
MUSE GTO



MUSE FOV simulation



MUSE FOV simulation

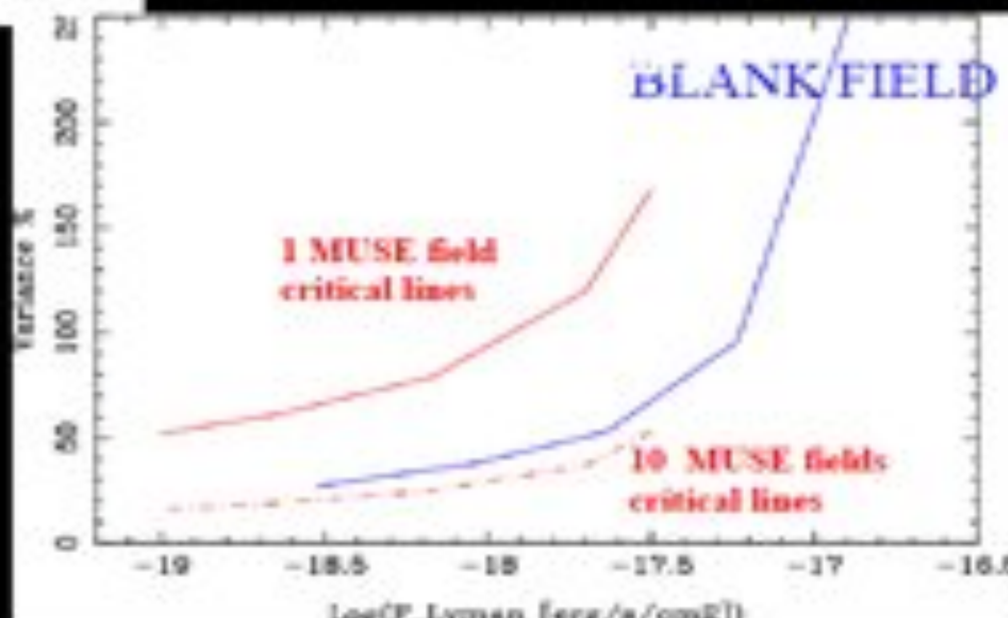


Errors in Lensing models:

m_AB=25.5 => 23%
m_AB=26.0 => 17%
m_AB=27.0 => 11%
m_AB=28.0 => 7%
m_AB=29.0 => 5%

$$\sigma_v^2 = \frac{\int_V \int_V d^3x_1 d^3x_2 \xi(|x_1 - x_2|)}{\int_V \int_V d^3x_1 d^3x_2}$$

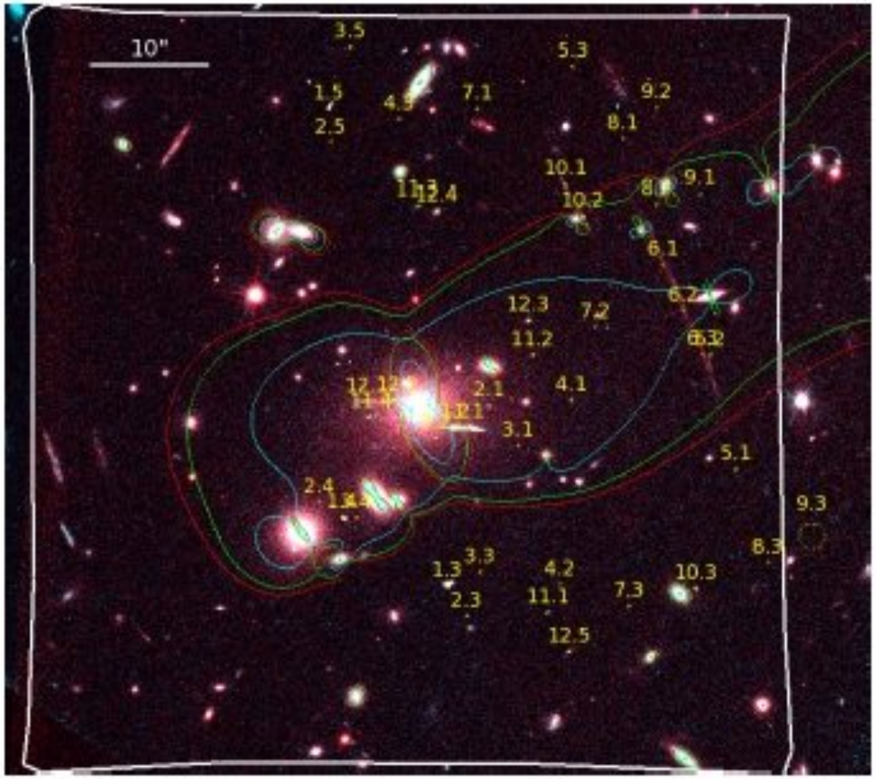
Trenti & Stiavelly (2008)



SMACSJ2031.8-4036

ID	α (hrs) 20:31:	δ (deg) −40:37:	z_{spec}	μ	line	flux 10^{-18} erg/s/cm^2
1.1	52.90	32.5	3.508	19.9 ± 1.9	Lyα	185 ± 5
1.2	52.99	32.5	3.508	11.7 ± 1.2	Lyα	169 ± 4
1.3	53.05	45.8	3.508	6.8 ± 0.2	Lyα	270 ± 3
1.4	53.83	40.1	3.508	2.5 ± 0.1	Lyα	42 ± 0.6
1.5	53.93	06.0	3.508	3.5 ± 0.1	Lyα	110 ± 2
2.1	52.74	30.7	3.508	4.7 ± 0.2	Lyα	22.4 ± 0.6
2.2	[53.12]	[31.1]				
2.3	52.91	48.4	3.508	4.7 ± 0.1	Lyα	21.1 ± 0.8
2.4	53.99	38.8	3.508	2.7 ± 0.1	Lyα	10.4 ± 0.6
2.5	53.90	08.9	3.508	3.9 ± 0.1	Lyα	16.4 ± 0.7
3.1	52.53	34.1	5.623	5.3 ± 0.2	Lyα	37.6 ± 1.4
3.2	53.14	33.5	5.623	2.6 ± 0.1	Lyα	17.7 ± 1.1
3.3	52.81	44.6	5.623	8.2 ± 0.3	Lyα	56.6 ± 1.8
3.4	53.72	40.1	5.623	2.2 ± 0.1	Lyα	11.6 ± 0.9
3.5	53.76	00.9	5.623	3.3 ± 0.1	Lyα	24.8 ± 1.4
4.1	52.14	30.3	3.340	4.1 ± 0.1	Lyα	8.3 ± 0.7
4.2	52.22	45.7	3.340	5.0 ± 0.1	Lyα	12.6 ± 1.0
4.3	53.40	06.9	3.340	5.2 ± 0.1	Lyα	9.9 ± 0.8
5.1	50.92	36.1	3.723	9.1 ± 0.2	Lyα	14.3 ± 1.0
5.2	51.11	26.5	3.723	18.1 ± 0.8	Lyα	6.8 ± 0.7
5.3	52.12	02.5	3.723	5.1 ± 0.1	Lyα	6.5 ± 0.7
6.1	51.46	18.9	1.425	19.5 ± 1.0	[OII]	582 ± 13
6.2	51.31	22.8	1.425	11.8 ± 0.5	[OII]	578 ± 12
6.3	51.17	26.4	1.425	18.2 ± 0.6	[OII]	553 ± 11
7.1	52.83	06.1	5.240	4.9 ± 0.1	Lyα	14.5 ± 0.8
7.2	51.96	24.2	5.240	4.2 ± 0.1	Lyα	8.1 ± 0.6
7.3	51.71	47.6	5.240	4.1 ± 0.1	Lyα	6.7 ± 0.5
8.1	51.75	08.6	5.613	15.0 ± 0.5	Lyα	3.4 ± 0.4
8.2	51.51	13.9	5.613	14.0 ± 0.6	Lyα	2.7 ± 0.3
8.3	50.69	43.9	5.613	4.1 ± 0.1	Lyα	0.4 ± 0.1
9.1	51.19	13.1	6.408	14.8 ± 0.9	Lyα	10.3 ± 0.8
9.2	51.51	06.0	6.408	13.8 ± 0.6	Lyα	5.5 ± 0.7
9.3	[50.36]	[41.7]				
10.1	52.18	12.4	3.856	14.1 ± 0.4	Lyα	4.0 ± 0.8
10.2	52.05	14.9	3.856	4.1 ± 0.1	Lyα	9.6 ± 1.3
10.3	51.22	46.1	3.856	6.1 ± 0.2	Lyα	8.9 ± 1.3
11.1	52.31	48.1	2.256	3.7 ± 0.1	CIII]	2.5 ± 0.8
11.2	52.42	26.5	2.256	3.4 ± 0.1	CIII]	1.4 ± 0.6
11.3	53.27	14.0	2.256	5.6 ± 0.1	CIII]	9.6 ± 2.6
11.4	53.62	31.6	2.256	4.9 ± 0.3	CIII]	6.3 ± 1.4
11.5	[53.27]	[30.8]				
12.1	53.64	30.3	3.414	5.6 ± 0.4	Lyαb	
12.2	53.42	30.2	3.414	4.3 ± 0.3	Lyαb	
12.3	52.45	23.6	3.414	4.4 ± 0.1	Lyαb	
12.4	53.13	14.4	3.414	7.3 ± 0.2	Lyαb	
12.5	52.15	51.4	3.414	3.2 ± 0.1	Lyαb	

Richard et al. 2014



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3.2	53.14	33.5	5.623	2.6 ± 0.1	Lyα	17.7 ± 1.1
3.3	52.81	44.6	5.623	8.2 ± 0.3	Lyα	56.6 ± 1.8
3.4	53.72	40.1	5.623	2.2 ± 0.1	Lyα	11.6 ± 0.9
3.5	53.76	00.9	5.623	3.3 ± 0.1	Lyα	24.8 ± 1.4
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7.3	51.71	47.6	5.240	4.1 ± 0.1	Lyα	6.7 ± 0.5
8.1	51.75	08.6	5.613	15.0 ± 0.5	Lyα	3.4 ± 0.4
8.2	51.51	13.9	5.613	14.0 ± 0.6	Lyα	2.7 ± 0.3
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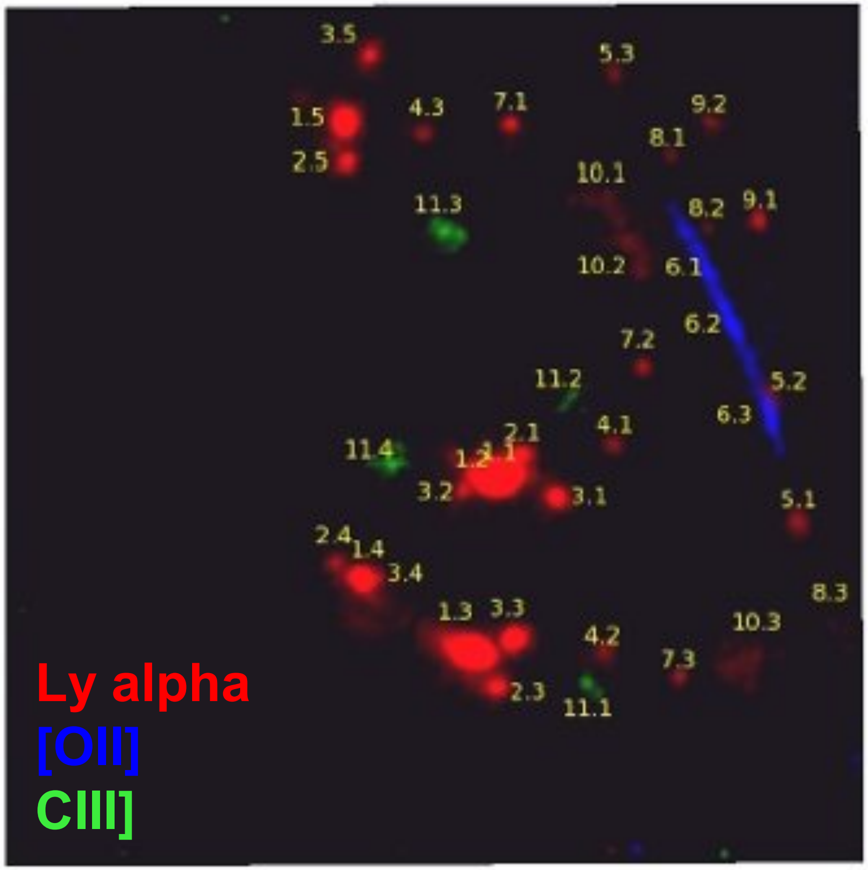
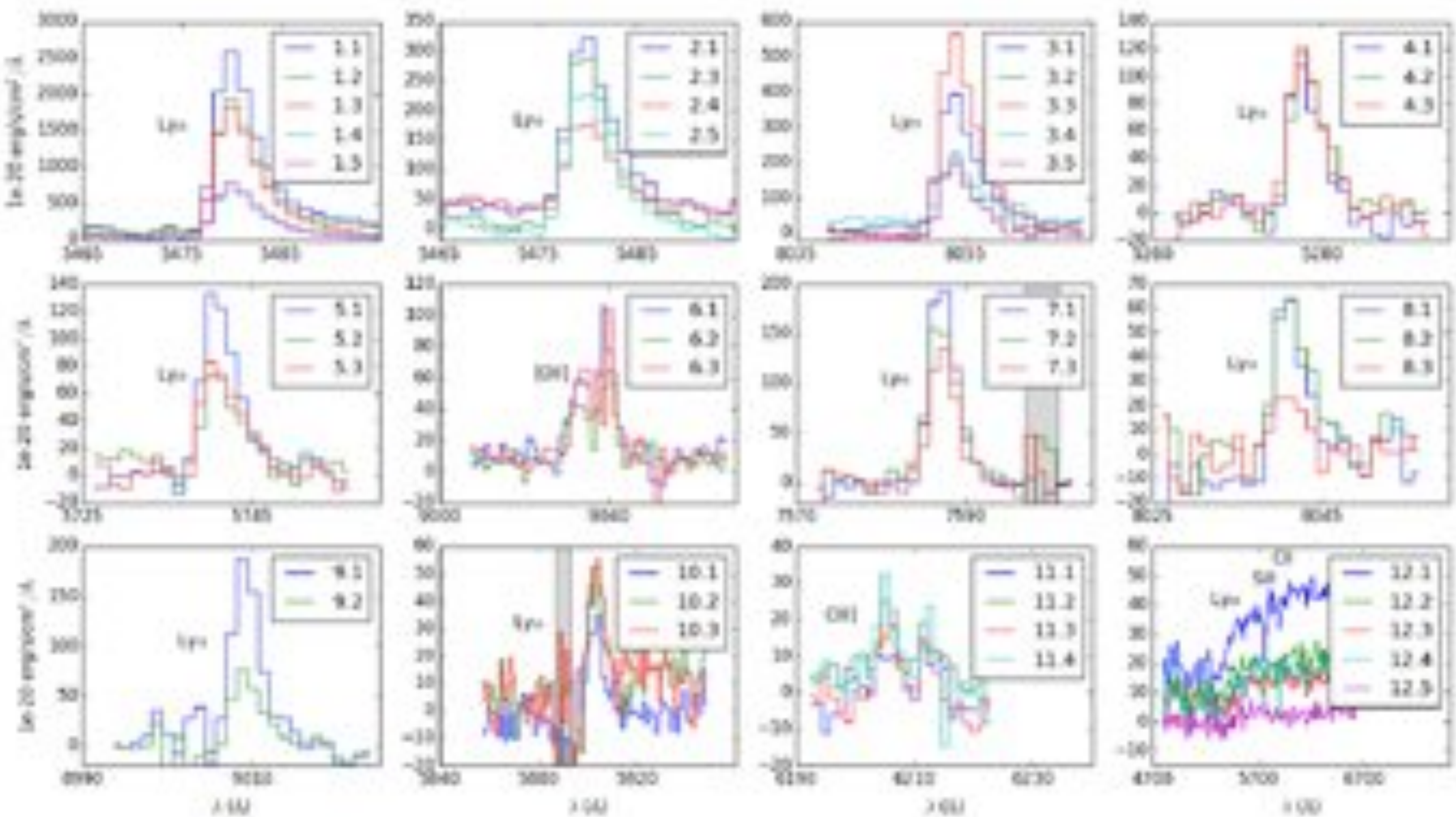
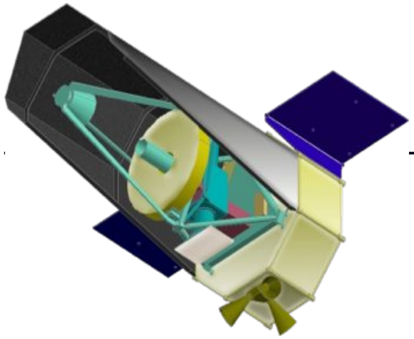
Richard et al. 2014



SMACSJ2031.8-4036

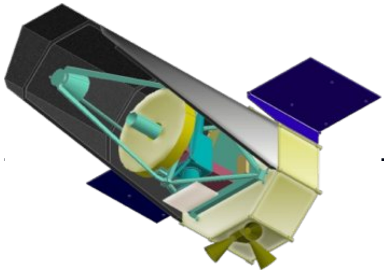
Richard et al. 2014



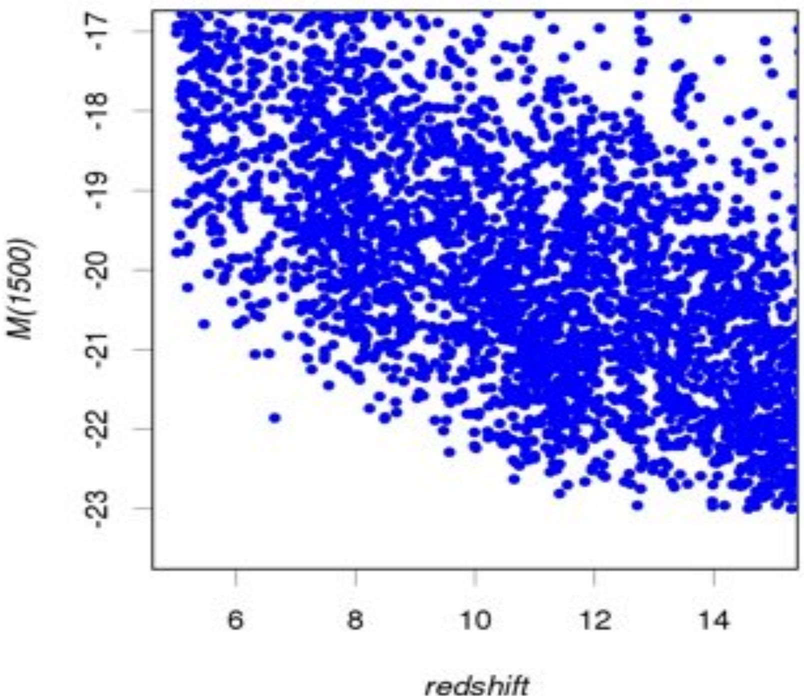


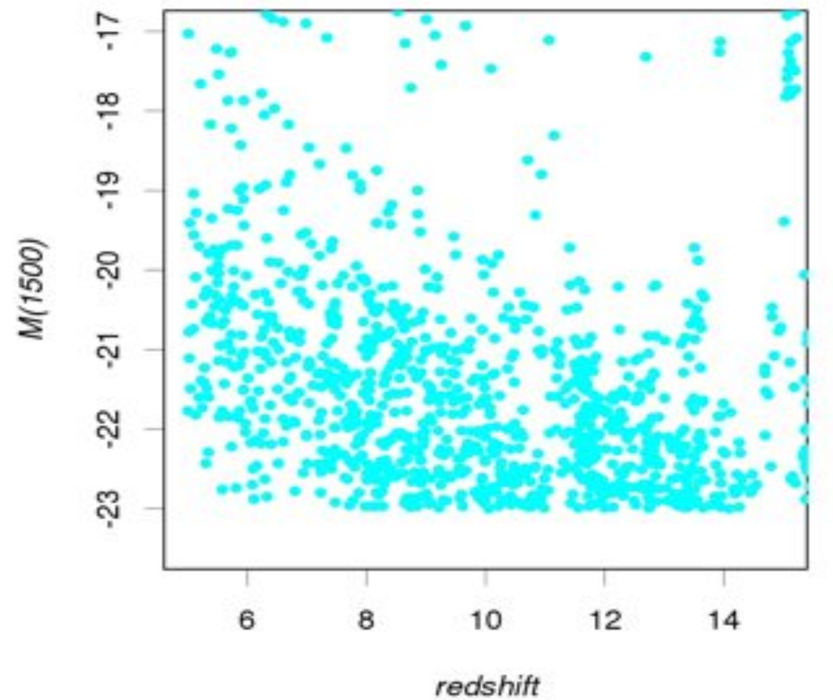
Conclusions

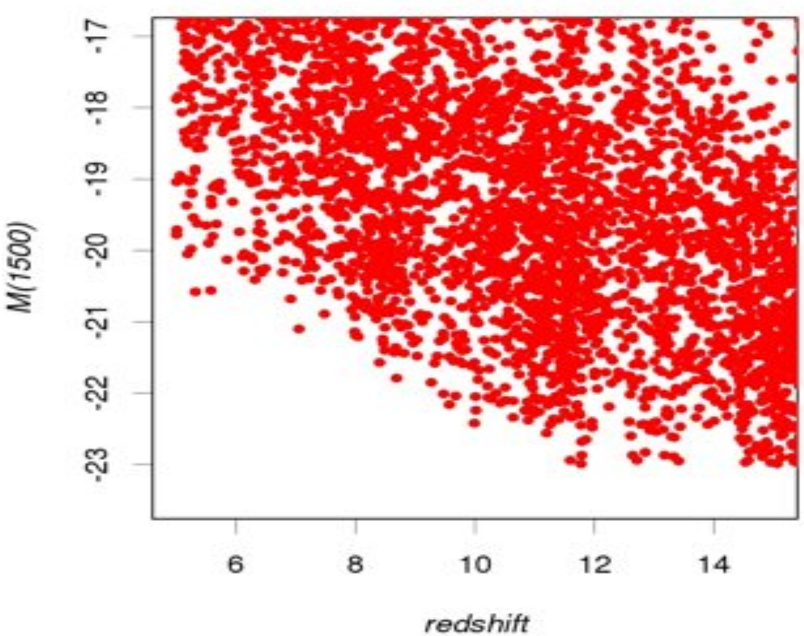
- WISH : well suited to study the galaxy assembly at z~7 – 15 (reionization era)
- Excellent synergy with other existing or coming facilities (EUCLID, JWST, ELT, …)
- WISH photometric system allows to identify z~5-15 LBGs galaxies. Statistically significant samples of z~10-15 galaxies in the UDS/ES. Bright and rare objects on the UWS.
- Spectroscopic mode is essential to address the physical properties of galaxies in the reionization era.



WISH : ANNEXES







- **Ultra Deep Survey** (UDS): m(AB) = ~28 - 100 deg2
- **Ultra Wide Survey** (UWS): m(AB) = 24-25 - 1000 deg2
- **Extreme Survey** (ES): m(AB) = 29-30 over 0.25 deg2