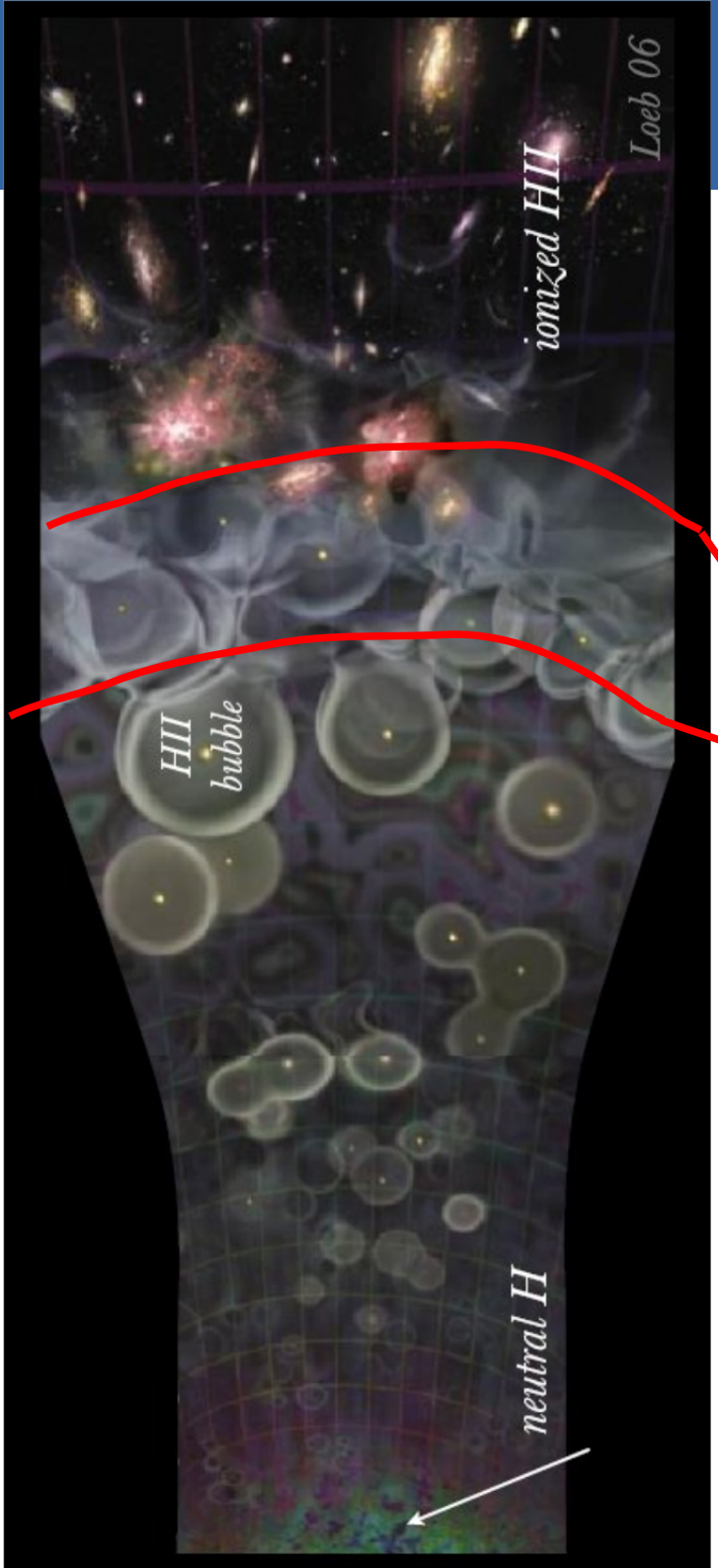


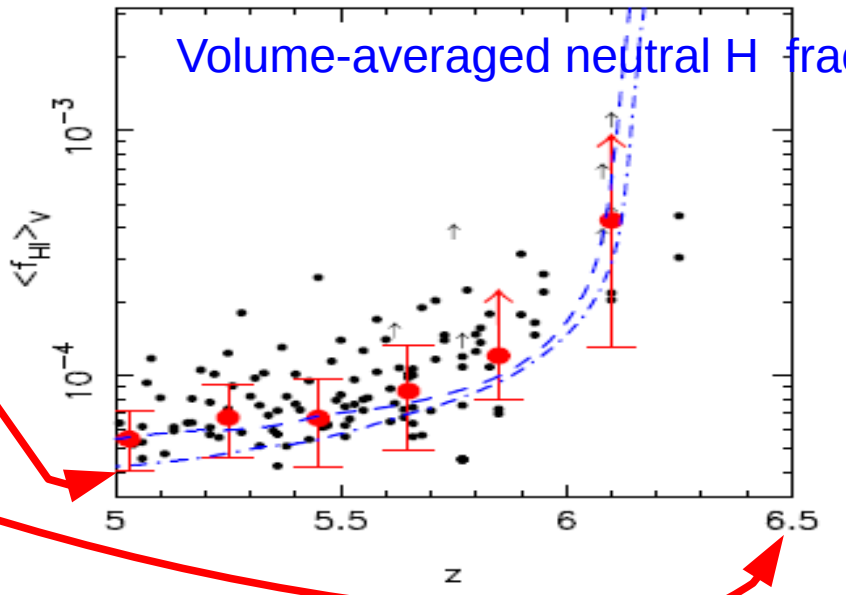


# The First Galaxies seen by EMIR


- IRAP/OMP : R. Pelló, N. Laporte (+UCL), T. Contini, D. Schaerer (+ U. Genève), G. de la Vieuville, F. Boone, N. Laporte (UCL)
- IAC : P. Garzon, M. Balcells, M. Prieto, J.M. Rodriguez-Espinosa, I. Trujillo, ...
- LAM/Marseille : S. Arnouts, O. Ilbert, ...
- CRAL/Lyon : J. Richard, L. Tresse
- UCM Team : J. Gallego, …
- U. Florida : R. Guzman, ...

# The end of the reionization

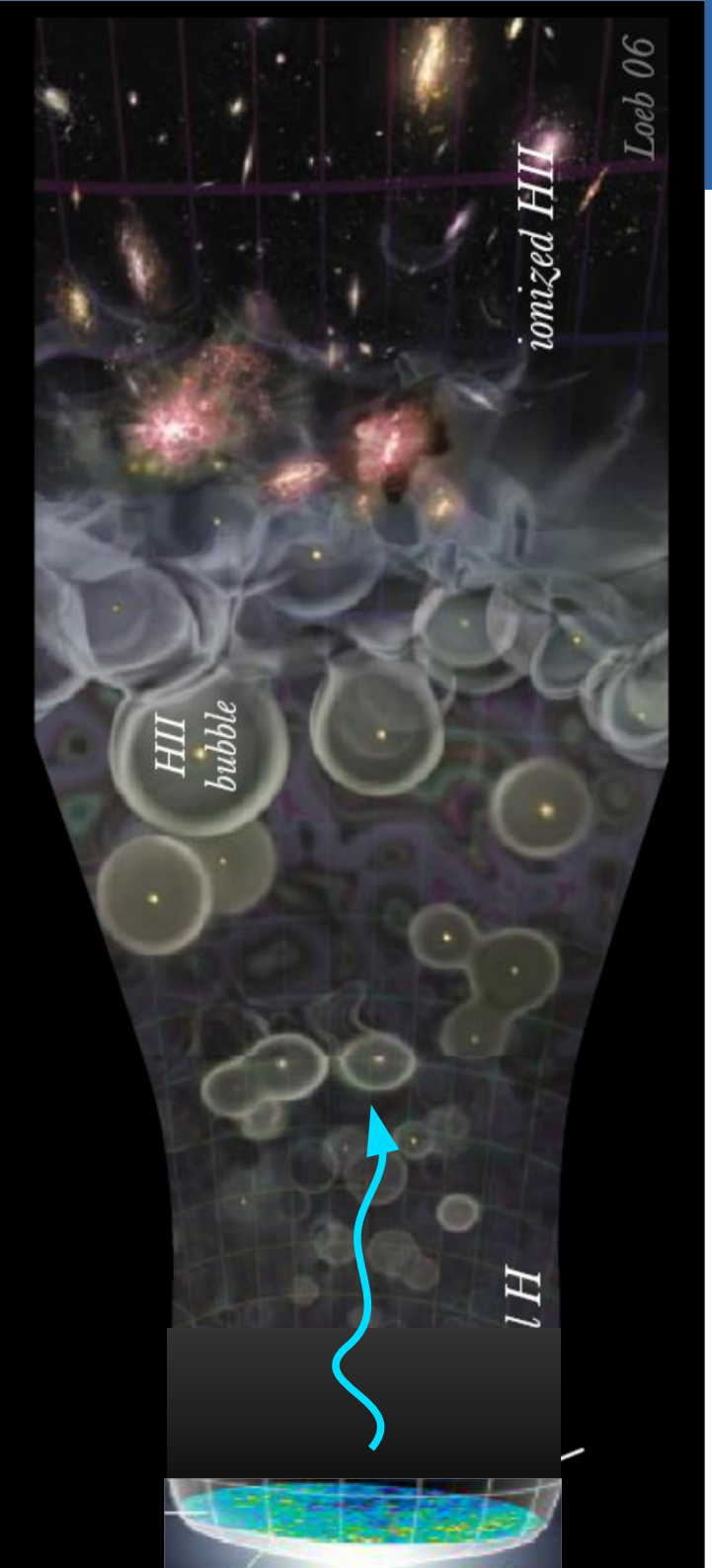



**Fan et al 2006**

$$\tau_{\rm GP}(z) = 4.9 \times 10^5 \left(\frac{\Omega_m h^2}{0.13}\right)^{-1/2} \left(\frac{\Omega_b h^2}{0.02}\right) \left(\frac{1+z}{7}\right)^{3/2} \left(\frac{n_{\rm HI}}{n_{\rm H}}\right)$$

- Evolution of **optical depth of Lya photons.** GP effect
- Complete absorption even for a tiny neutral H fraction (~$10^{-4}$) >> present value (~$10^{-5}$) ==> this test is only sensitive when the IGM is "almost" ionized, and saturates for higher neutral fractions.

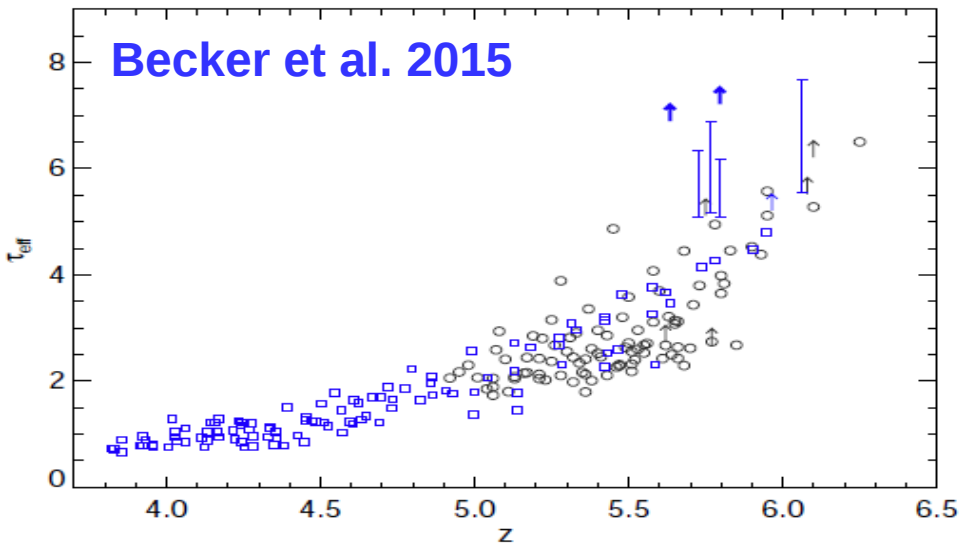



# The beginning of the reionization

- Foreground **electron scattering of CMB photons** with an optical depth corresponding to z(reionization). Observed since WMAP year-1 (2003) at 4 sigma level.
- **z(reionization)**=
  - 11+/-1.2 (Komatsu et al. 2011) WMAP
  - 11.4 [+4.0/-2.8] (Planck col. 2014) PLANCK
  - 7.8 – 8.8 (model dependent) PLANCK 2016

    < 10% ionization at z > 10
- Uncertainties remain... The actual value depends on the reionization process (“instantaneous” versus more complex scenarios).

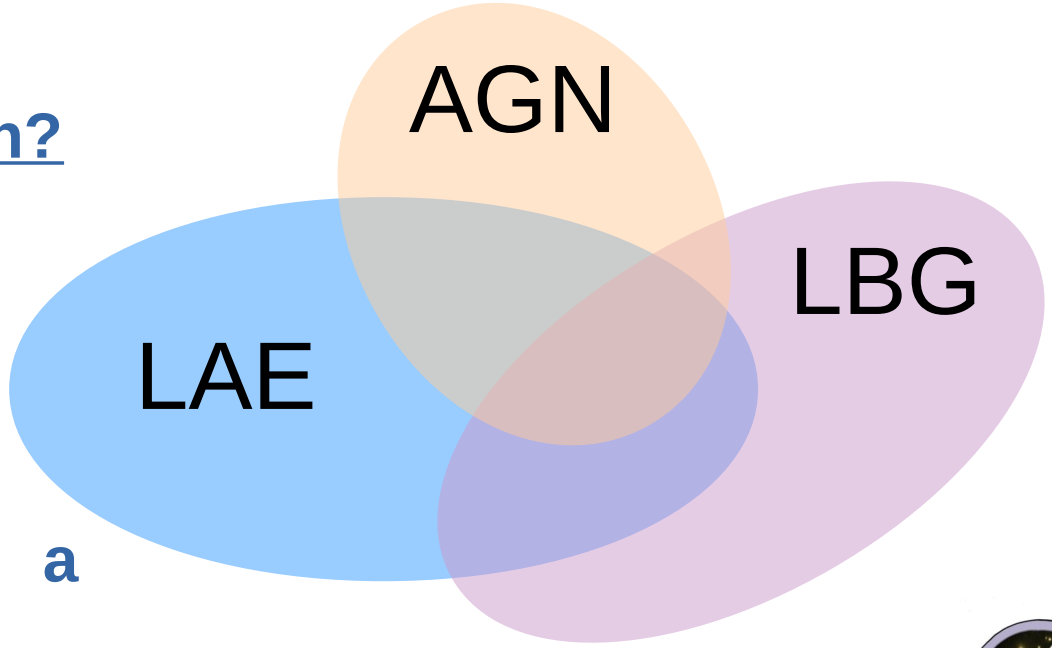
# Sources of the reionization and actual process




- Large line of sight variance is also observed!
- Evidences for a “patchy” H reionization (inhomogeneous at ~100 Mpc scale; see Becker et al. 2015)
- A gradual process? Multiple phases?

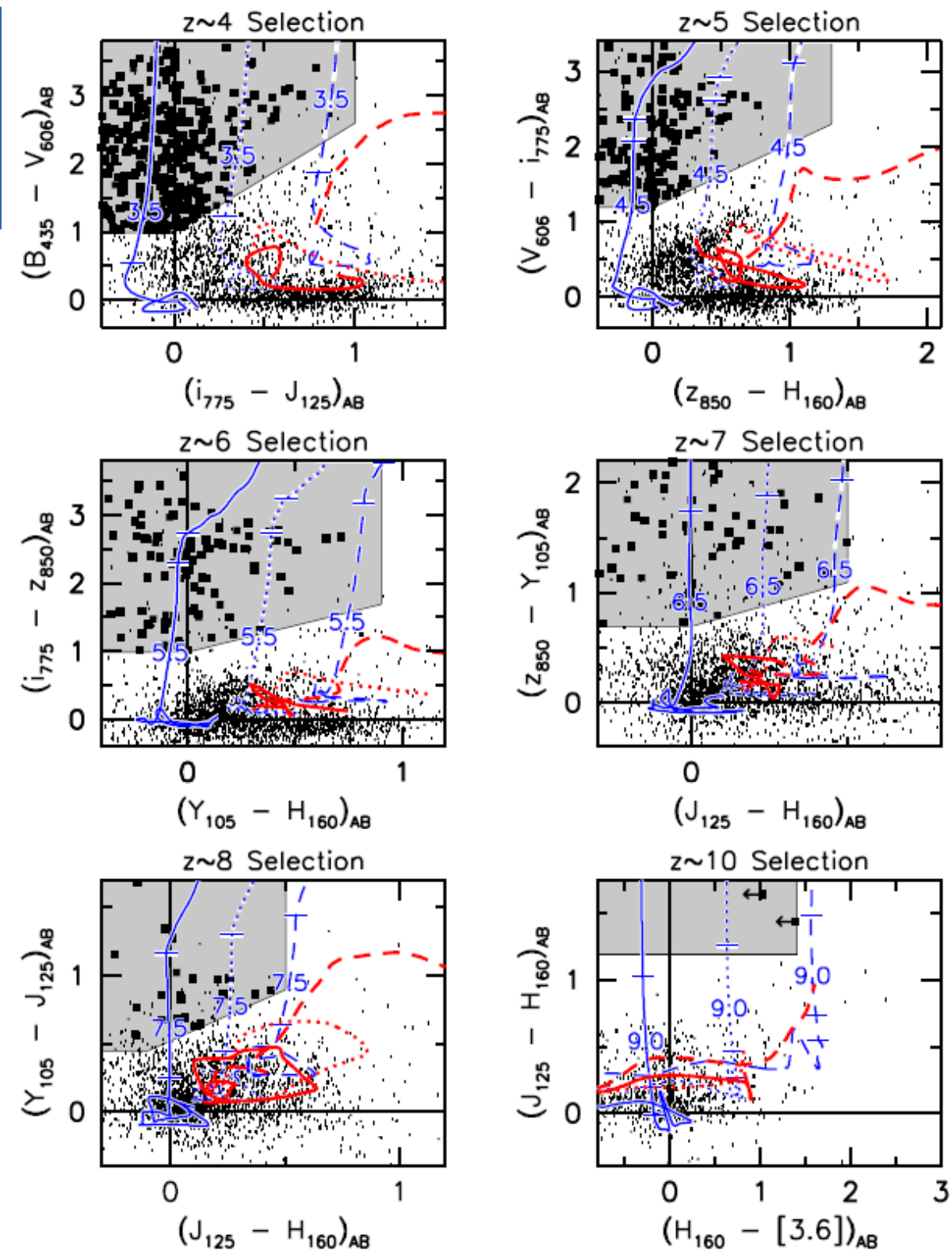
What were the **sources responsible for the reionization?**

- Galaxies
- AGNs
- GRB contribution?




**Observational selection has a huge impact !**

# LBG Surveys : UV Luminosity Function




- HST Legacy surveys :
  - CANDELS,
  - HUDF09,
  - HUDF12,
  - ERS
  - BORG/HIPPIES

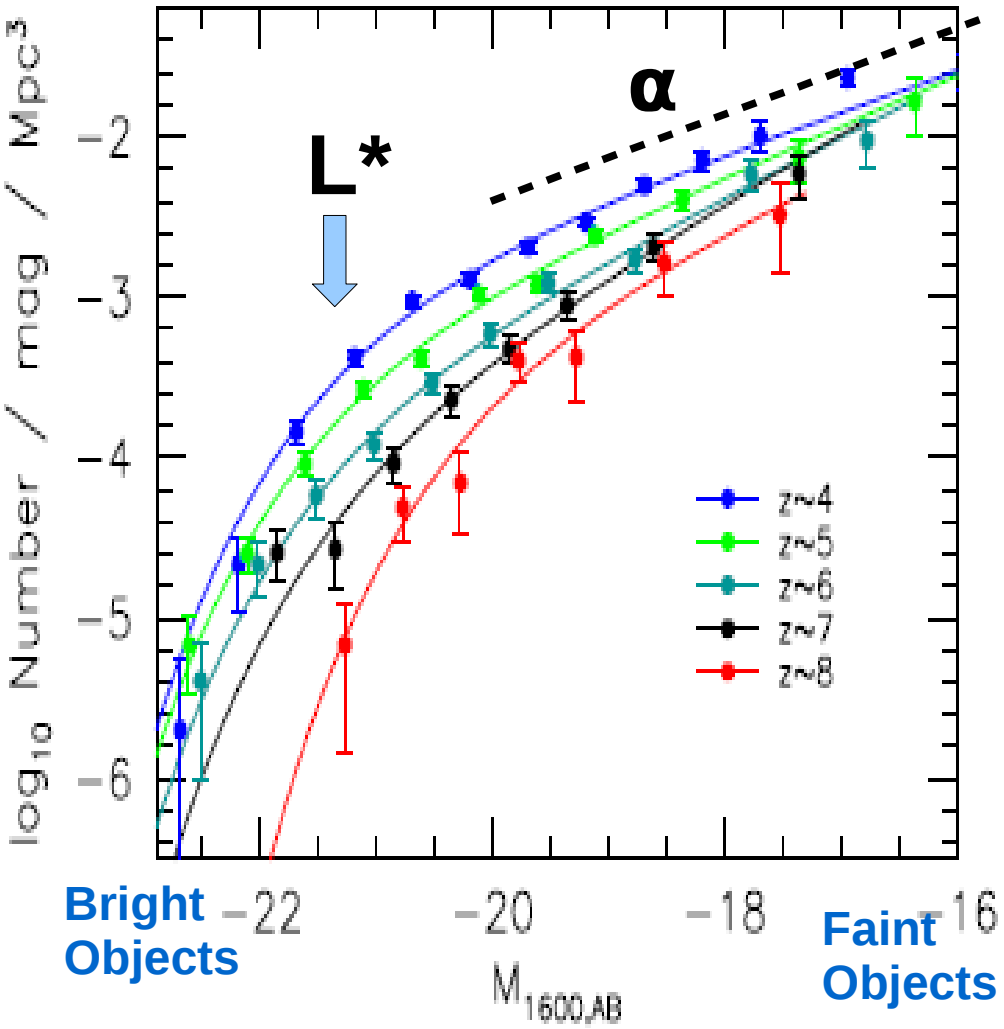
Total FOV: ~1000 arcmin$^2$

***Bouwens et al. 2015***

# LBG Surveys: Luminosity Function

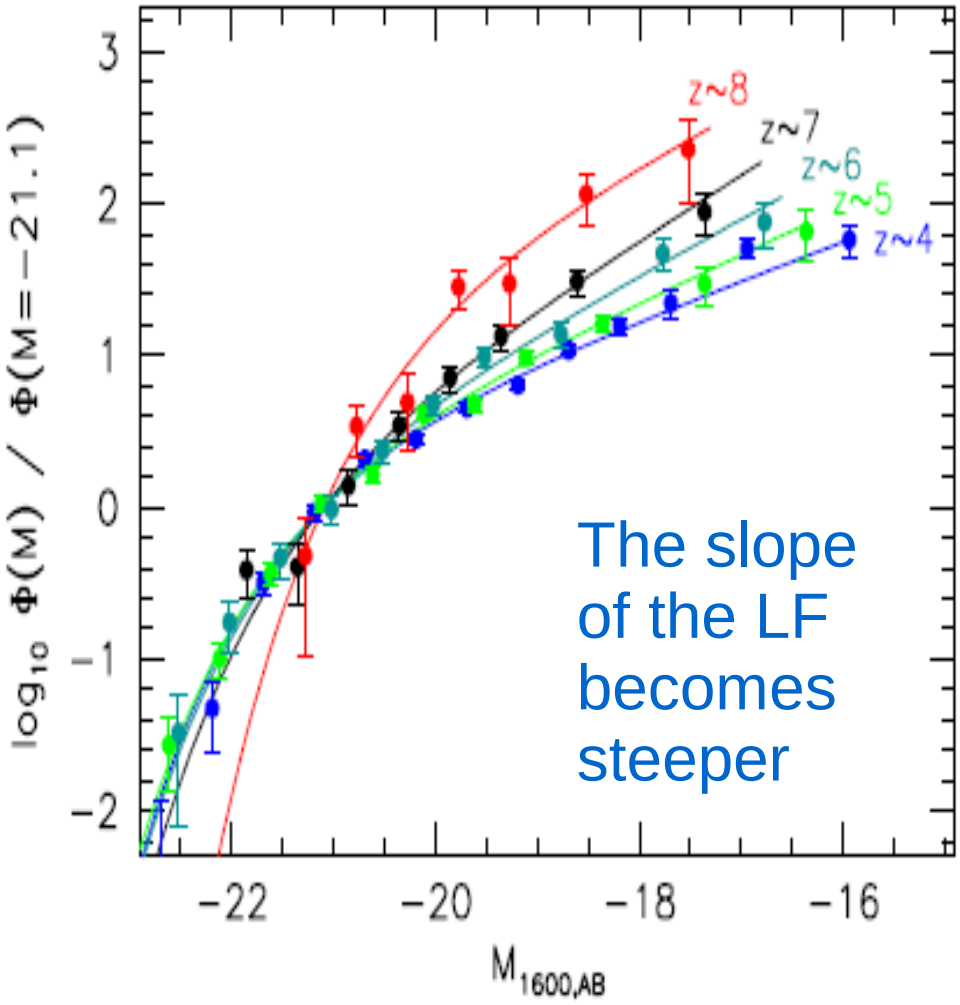
$$\Phi(L)\,dL = n_* \left(\frac{L}{L_*}\right)^{\alpha} exp\left(-\frac{L}{L_*}\right) d\left(\frac{L}{L_*}\right)$$

***Bouwens et al. 2015***

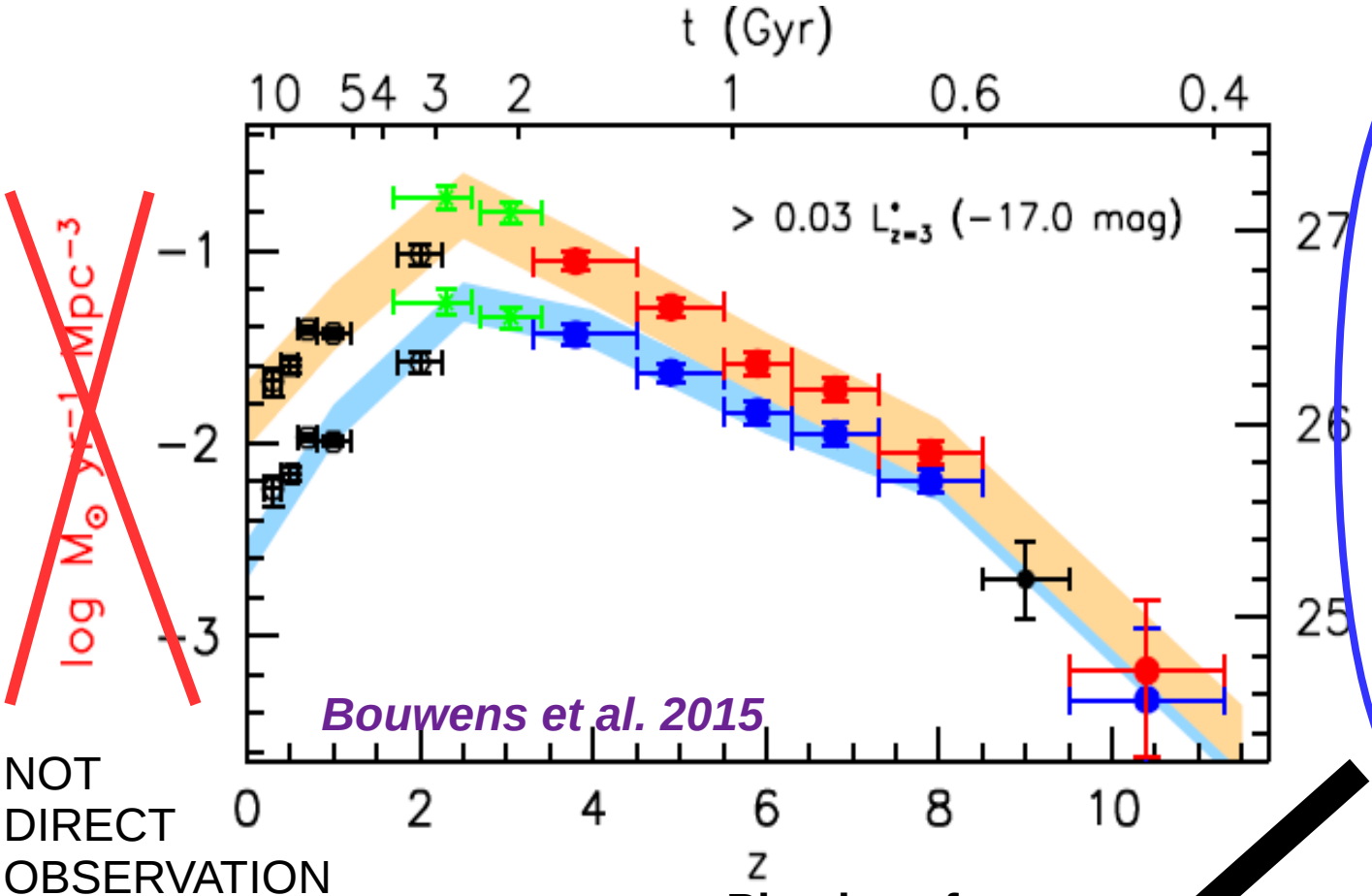



**Bright Objects**

**Faint Objects**



# Cosmic SF History




NOT DIRECT OBSERVATION

**Physics of Star-forming galaxies**

**Evolution on the density of UV photons**

$$\rho_{UV} = \int_{L_{lim}}^{\infty} \Phi(L_{1500}) dL_{1500}$$

**EVOLUTION OF THE COSMIC IONIZING EMISSIVITY**

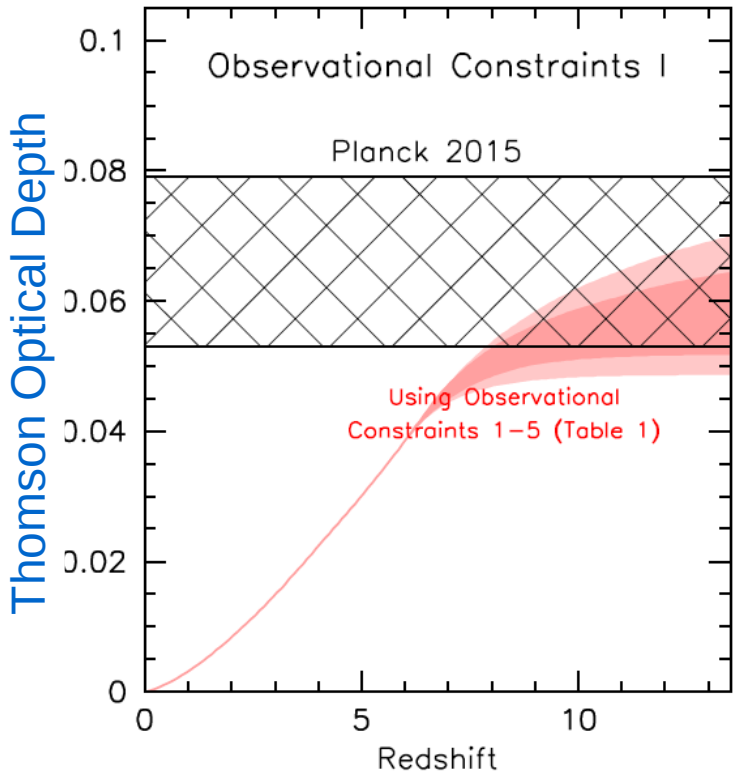




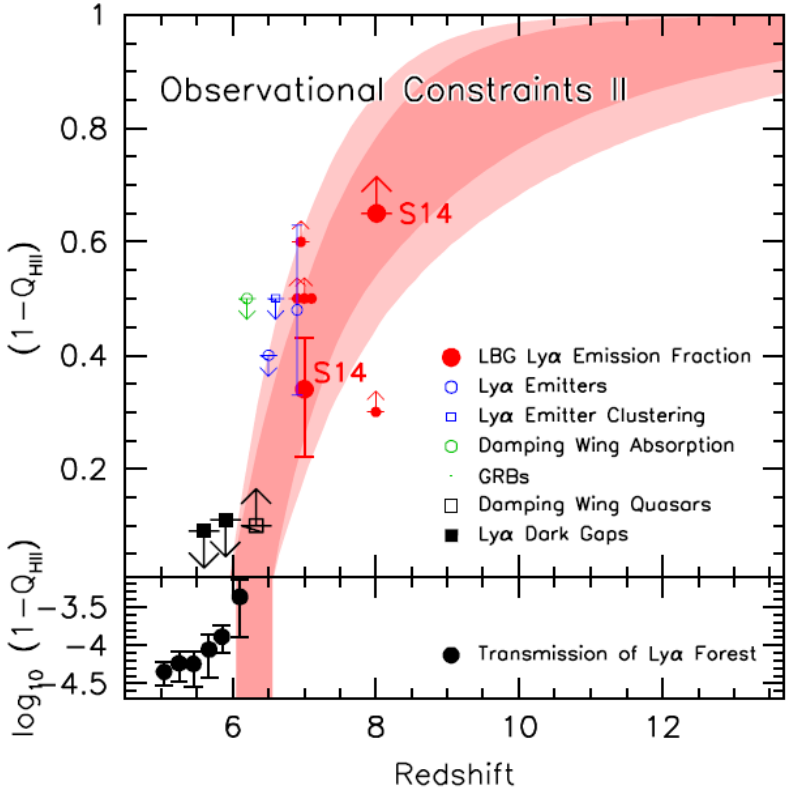
# Empirical evolution of the cosmic ionizing emissivity

Bouwens et al. 2015

- Conversion UV luminosity density ⬌ ionizing emissivity is consistent with plausible values of f(esc) and clumping factor C(HII)... provided that the LF is extended up to the faintest limits M(inf)~ -13




Q(HII) : filling factor of ionized H

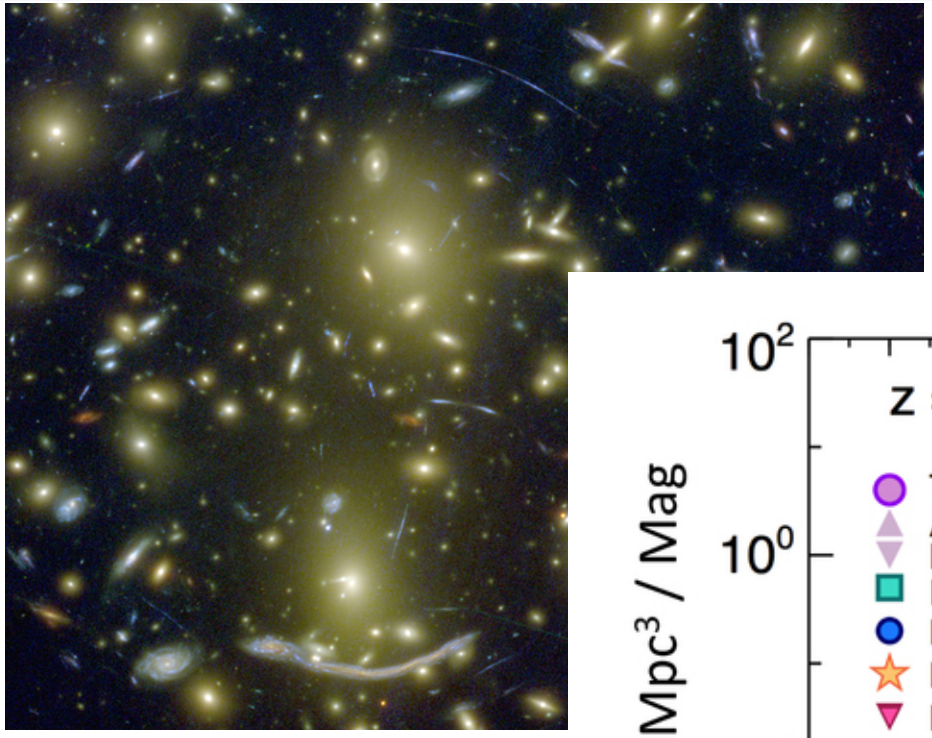



- The UV luminosity density at z~7 seem sufficient to keep the universe reionized assuming “standard” conditions (see also Atek+2015).
- Uncertainties at z>~8 : The faint end of the UV LF is not constrained enough. LAE studies seem to show that the reionization is in progress at z~8 (see Tilvi+2015).
- The reionization seems to be dominated by faint star-forming galaxies, presently beyond the reach of current facilities … in blank fields!

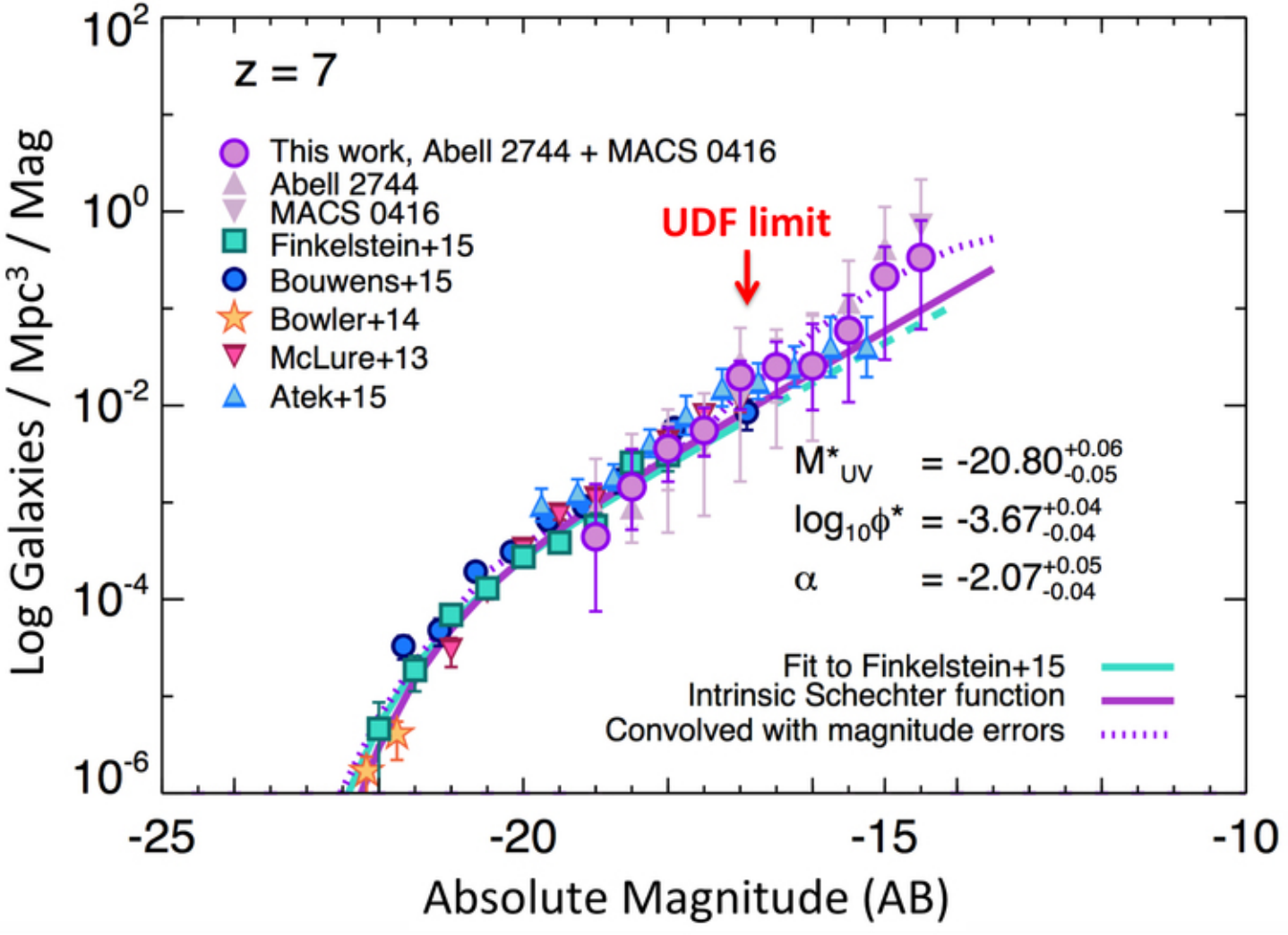




# LBG Surveys (Lensing fields)

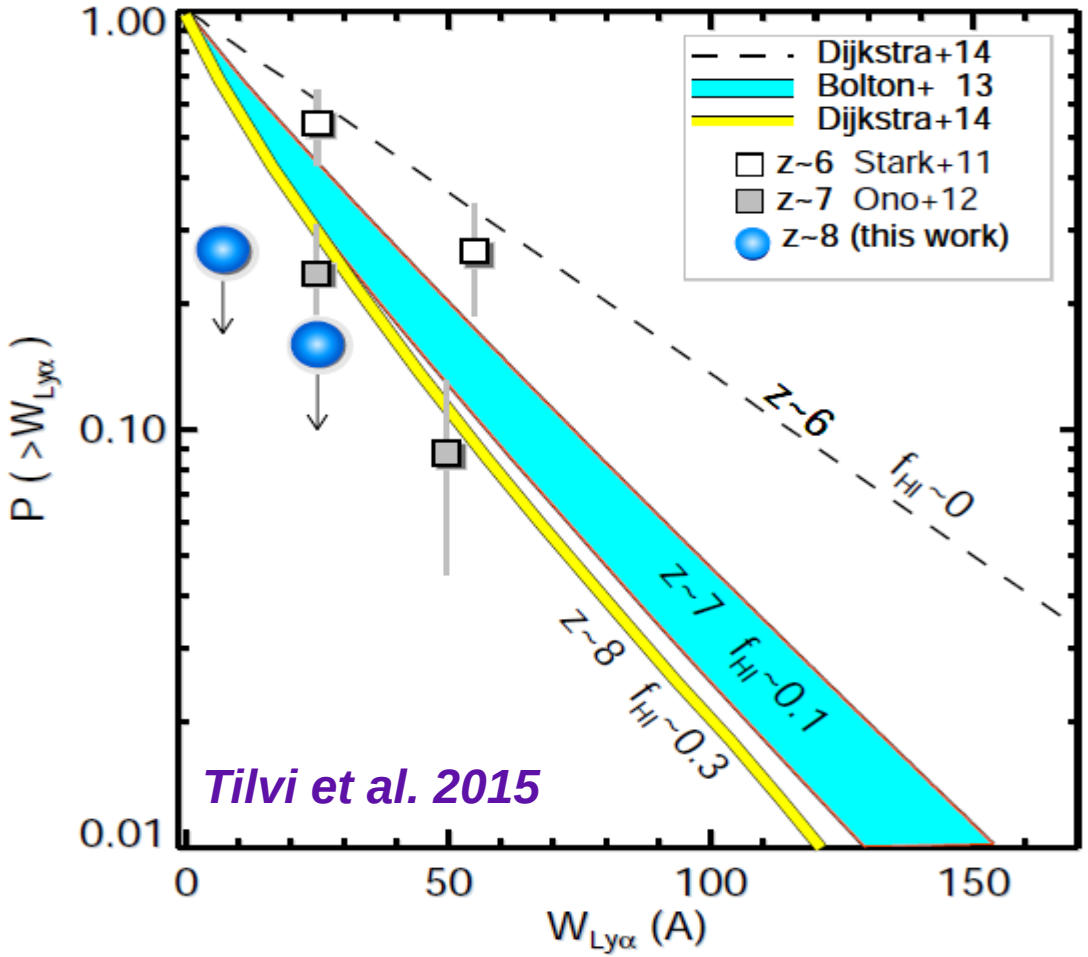


*Coe+ 2016*
*Hubble FF*




See also
*Laporte+ 2014,*
*Atek+ 2015,*
*Infante+ 2015,*
*Laporte+ 2016*

# LAE and HI fraction




- Example from Tilvi+2015 : Cumulative Lyman-α probability distribution for their faint sample (M(UV) > −20.25 mag), compared to model predictions.

- Usual assumption: On average, the prevalence of Lya emission in galaxies beyond the reionization is a simple extrapolation of observations below the reionization (z<6). Departures from this general trend are interpreted as an increasing fraction of neutral H.
- Based on this approach, the “filling factor" of ionized hydrogen is supposed to evolve from 66% at z~7 to <35% at z~8, with large uncertainties (Pentericci et al. 2014; Tilvi et al. 2014; Schenker et al. 2014).

=> reionization in progress at z~8

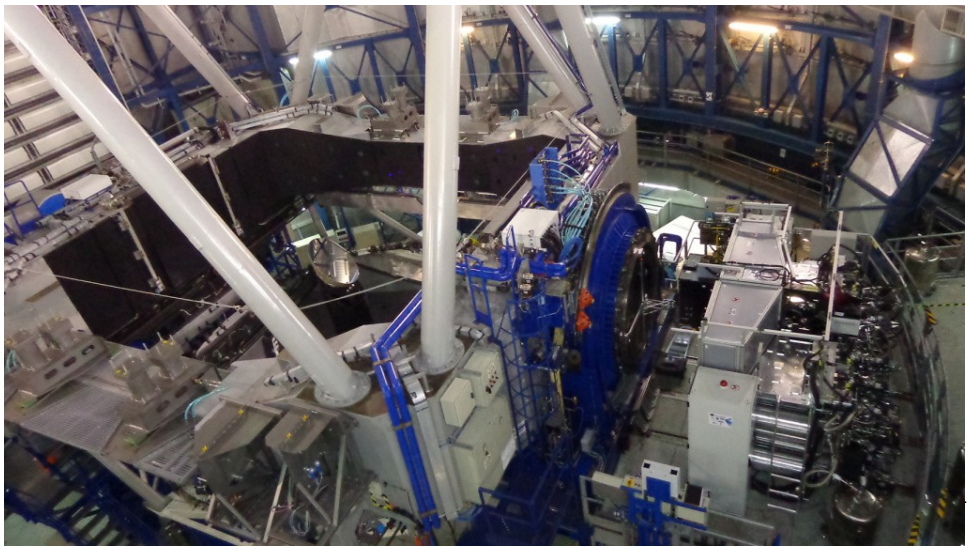
muse multi unit spectroscopic explorer & EMIR

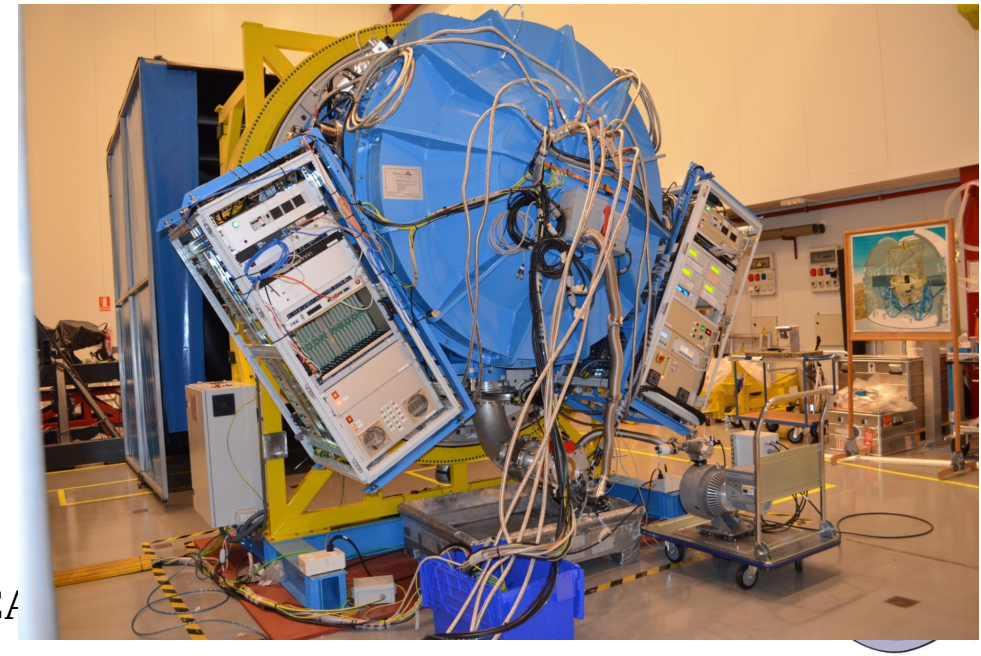
AIP CRA Lyon ESO ETH Institut für Astrophysik Göttingen irap NOVA




- IFU
- 1 arcmmin$^2$
- Visible domain: 465-930 nm



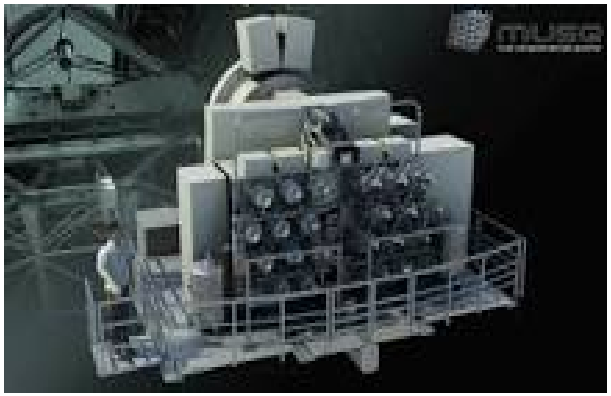





# Combined Survey MUSE / VLT & EMIR/GTC :

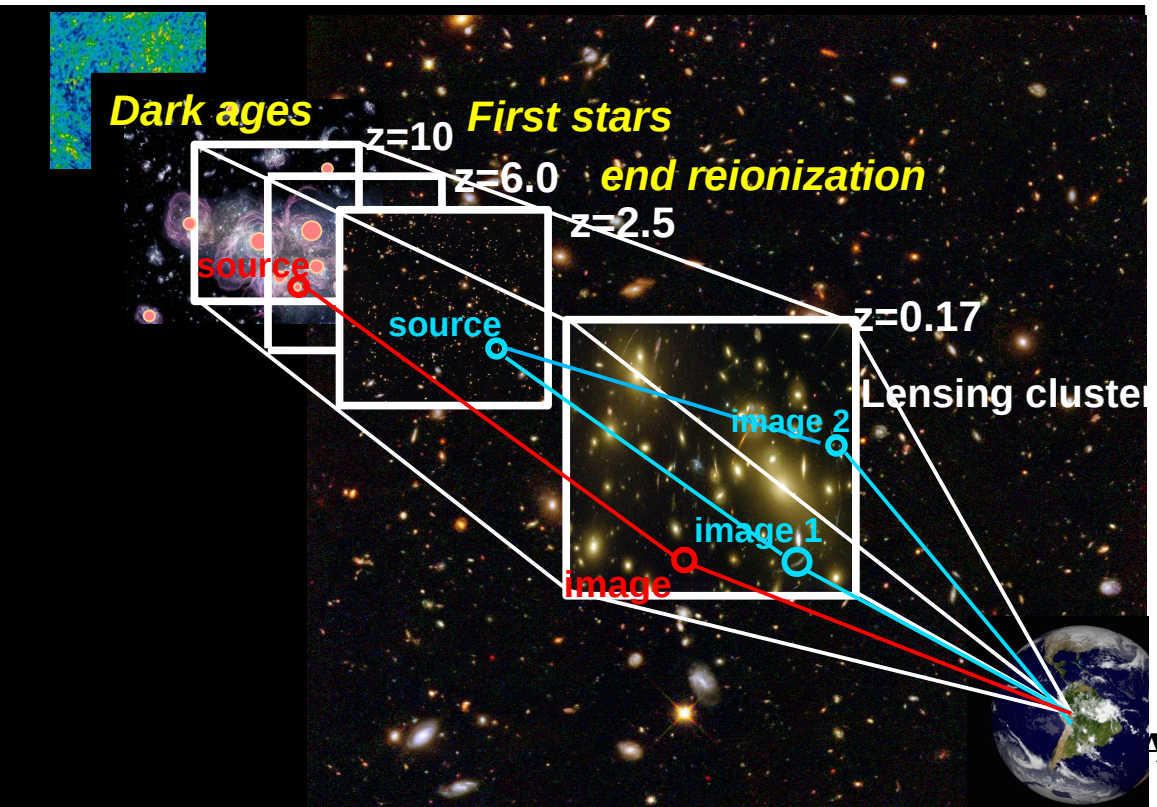
- The identification of galaxies at 6<z< 12 requires an homogeneous and deep coverage of the near-IR domain in combination with (ultra-deep) optical data.
- Lensing clusters are more efficient to conduct detailed (spectroscopic) studies in the sensitive redshift domain, and also to explore the faint-end of the LF, whereas observations in wide blank fields are needed and fully complementary to set reliable constraints on the "bright" end of the LF
- All photometrically-selected samples, either LBG or LAE, need a spectroscopic follow up to confirm both the redshift and the nature of these candidates.
- 2 complementary approaches for a combined survey targeting the sources of cosmic reionization:
  - **"Blind" survey** looking for serendipitous detections of LAEs behind clusters (MUSE, z< 6.7)
  - **"Pointed" survey** up to H~25 (as deep as possible! ) LBGs, selected in BF + lensing clusters (EMIR)

# Blind census of LAE behind lensing clusters with MUSE



**MUSE**

- GTO project (work in progress)
- **Final Goal:** A first complete census of star-forming galaxies/ ionizing sources. Determining the contribution of (faint) LAEs to the re-ionization
- **Why MUSE?** MUSE is ideally suited in terms of FOV. No preselection of sources.
- **Why lensing fields?** (See e.g. Maizy et al. 2010): Magnification => reducing the bias towards the brightest sources.




Results on LAE Lensing Program :

A1689 (z=0.18),

A2390 (z=0.23),

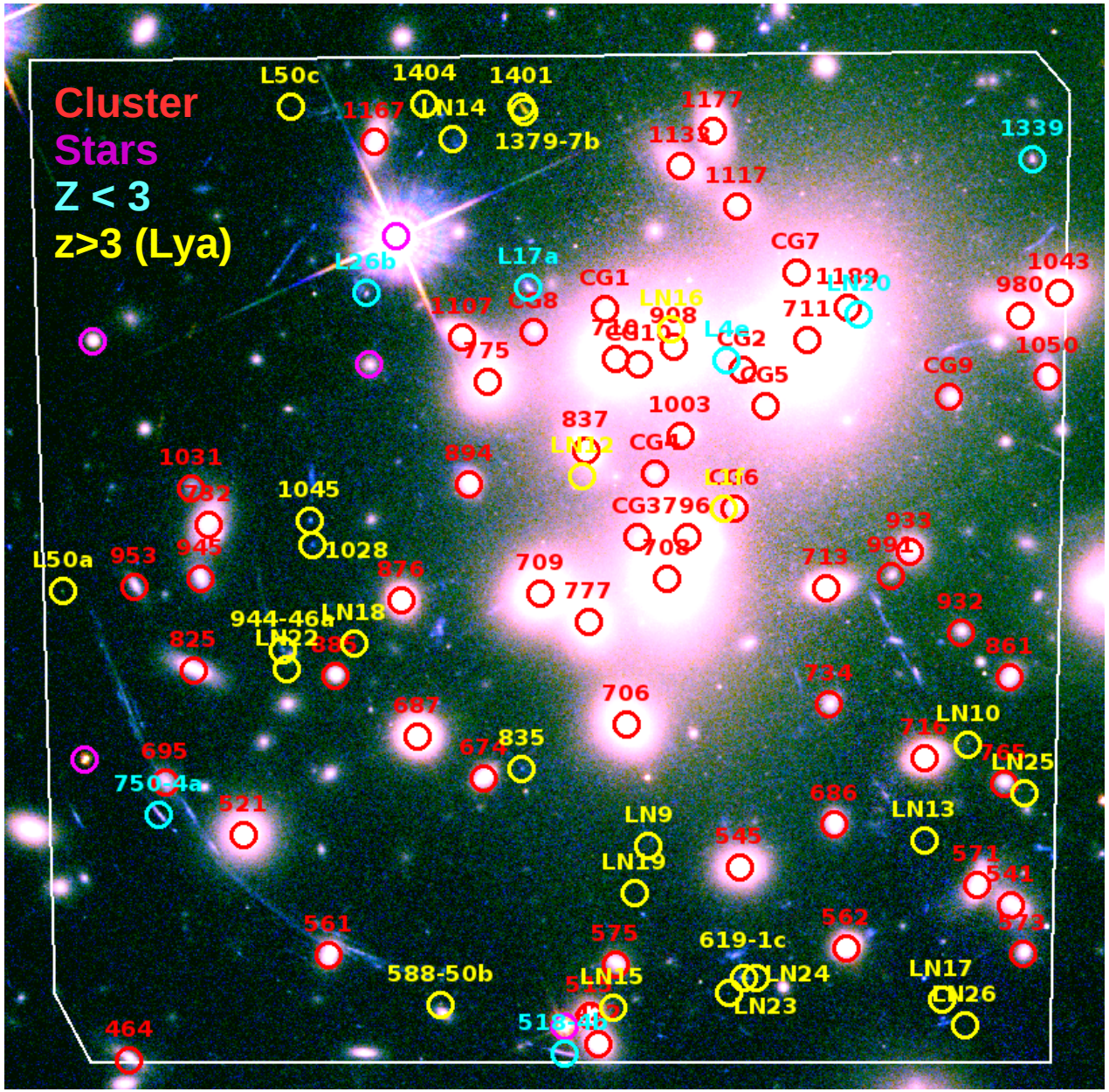
A2667 (z=0.23),

A2744 (z=0.308)

…

**==> D. BINA's thesis !**

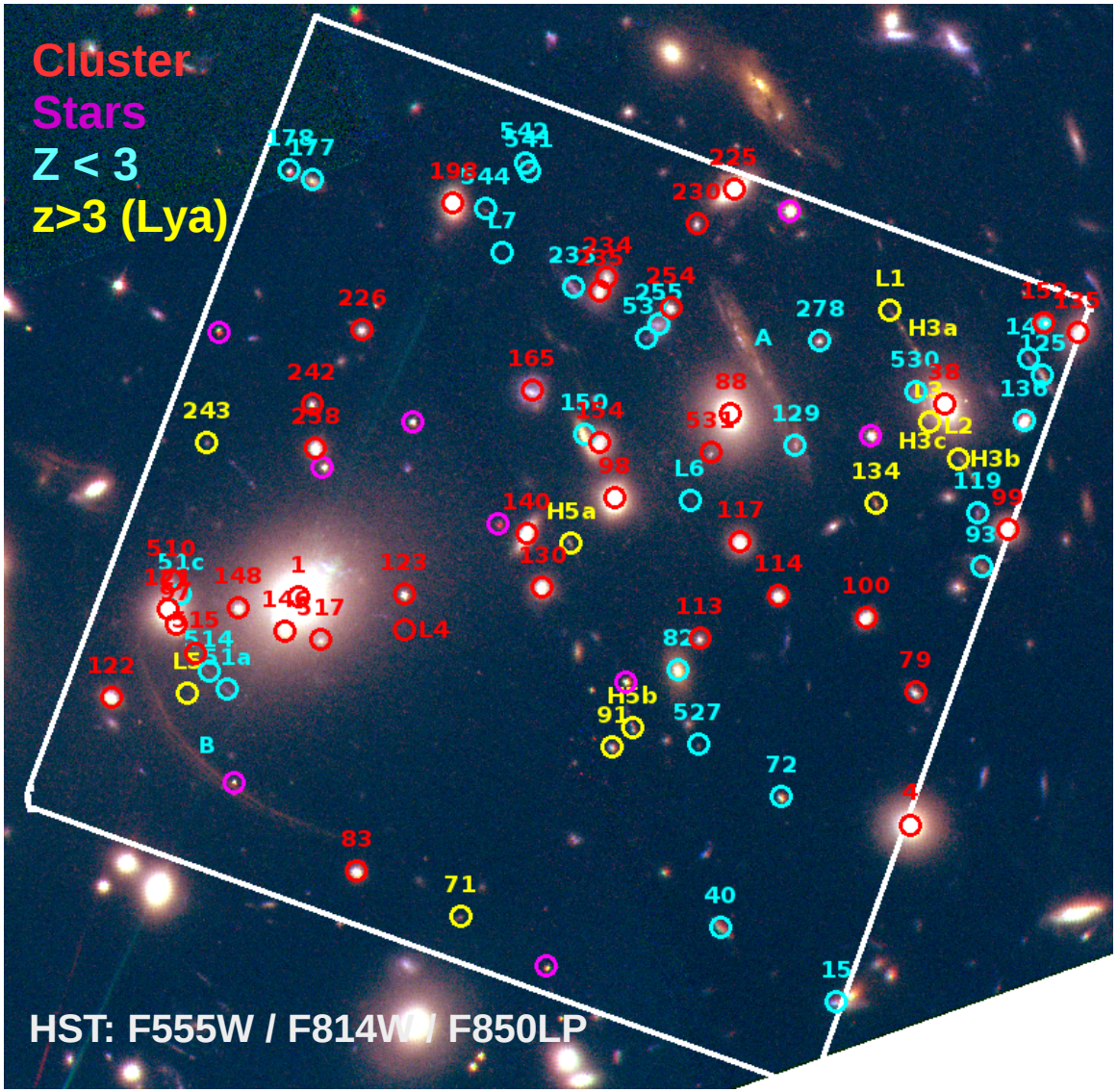
# A1689




- A1689 (z=0.1847, Teague et al. 1990)
- FOV : ~185x185 kpc
- MUSE observation : ~1.8h = 1100 sec x 6 exposures
- Seeing ~0.6” at 7300A
- Source Extraction + z measurements :
  ➔Manual/guided
  ➔**LSD-CAT, MUSELET & CubEx**
- 21 e-line background galaxies: 7 known + 14 new galaxies
- 17 LAE at z>3
- All these sources are multiple-image systems

***Bina, RP et al. 2016***

# A2390

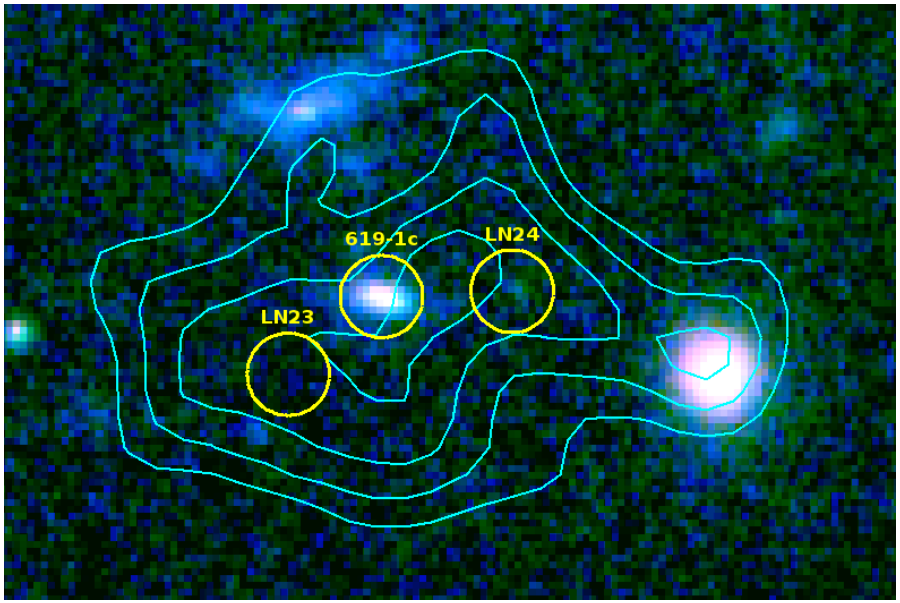


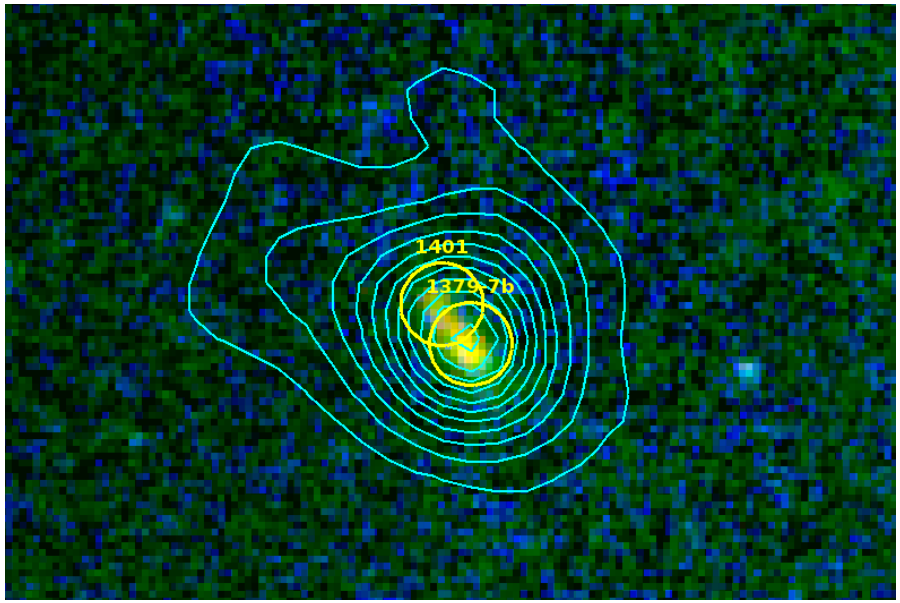

- **A2390** (z=0.23, Le Borgne et al. 1991; Yee et al. 1996)
- 3.698 kpc/", FOV ~220x220 kpc
- MUSE observations: 2h (4x1800 sec)
- Seeing ~ 0.75" (FWHM, white light)
- Same procedure as for A1689 (Bina+16):
  - Guided extraction of sources detected on HST/F814W image (continuum selected)
  - Automated extraction of line-emitters with MUSELET
- Source extraction + z measurement:
  - 38 cluster galaxies / 9 stars
  - **42** images of **31 background sources**
  - **9 multiple images / 5 are NEW**
  - **5 sources at z≳4**

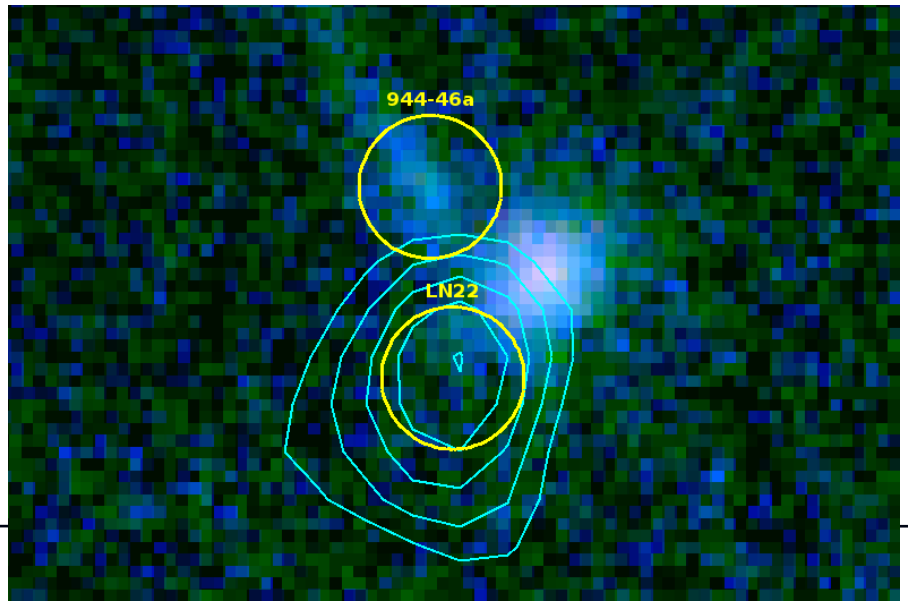
# A1689: extended Lya emission

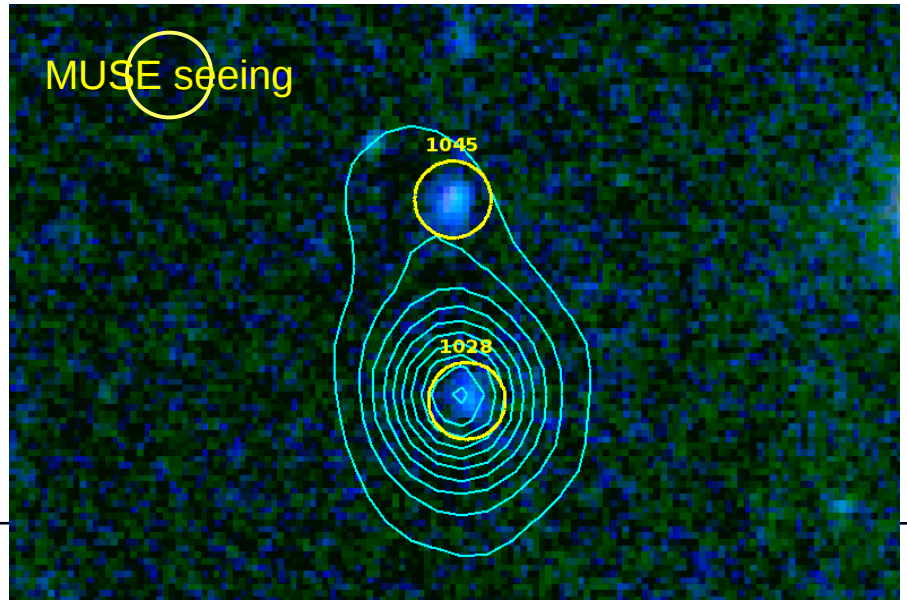
- Extended Lya emission seen in 4 cases :

***Bina, RP et al., 2016***



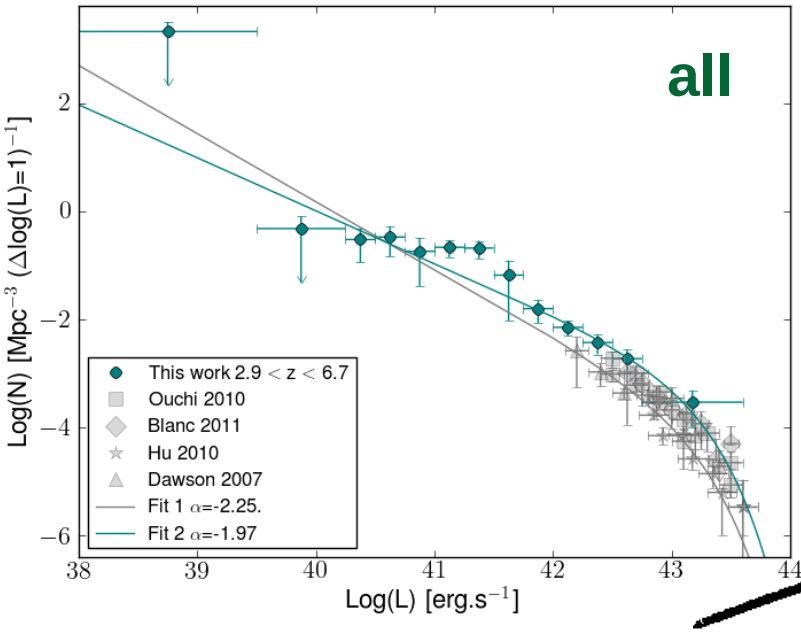



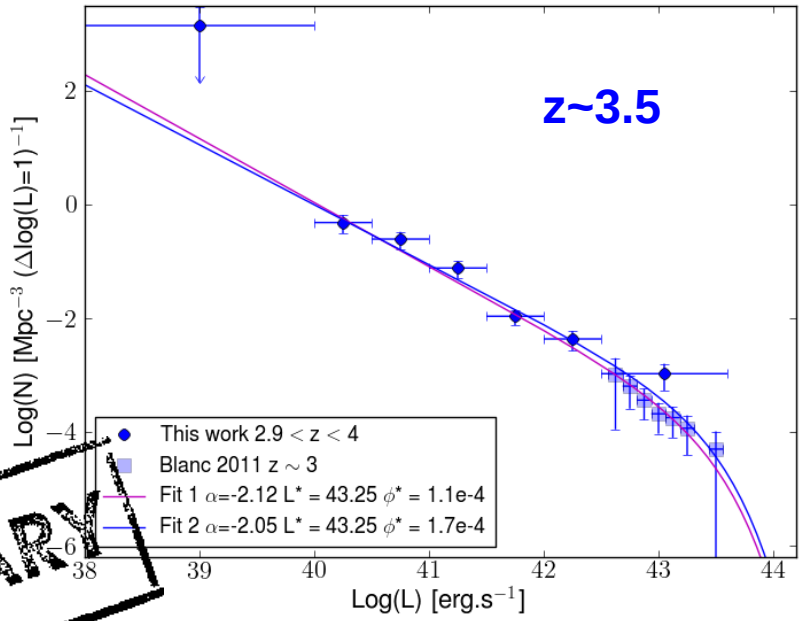



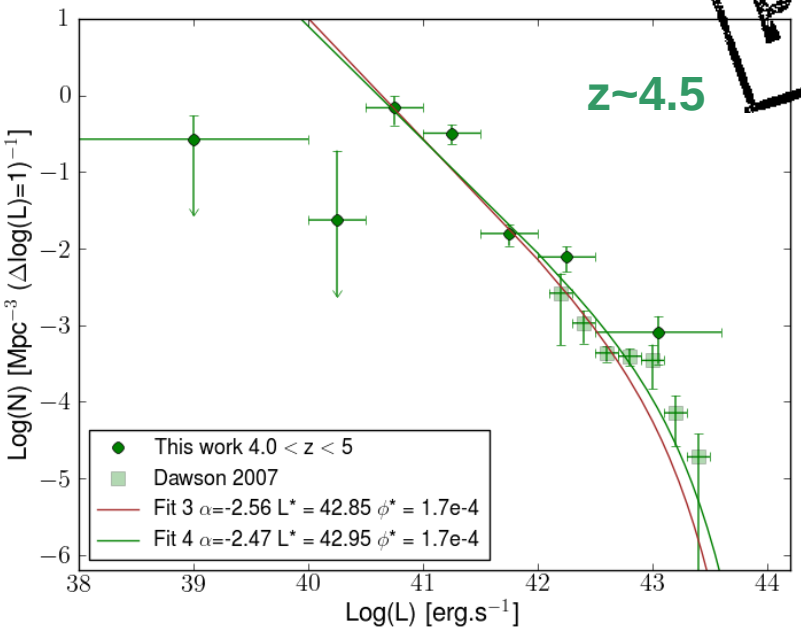
# LAE in A1689 + 2390 + A2667 + 2744

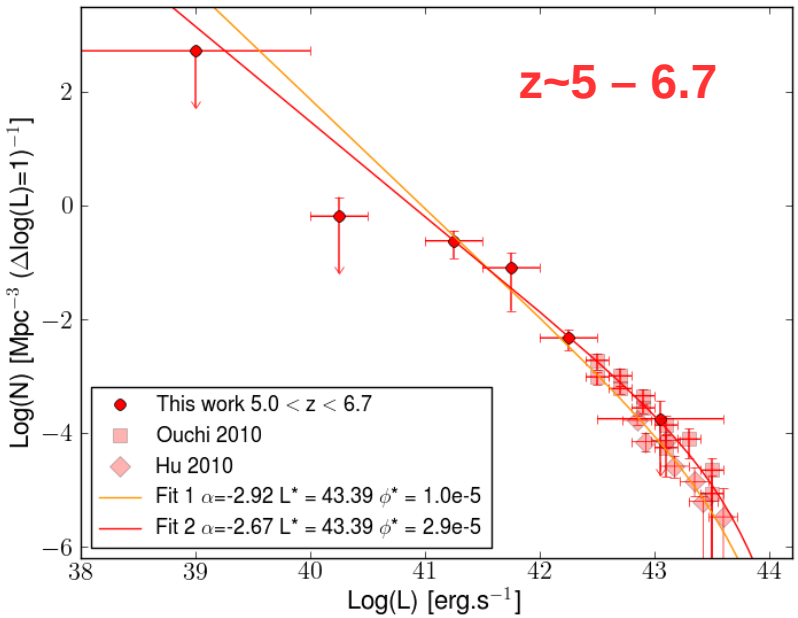
*Bina, GdV, RP+17, in preparation*



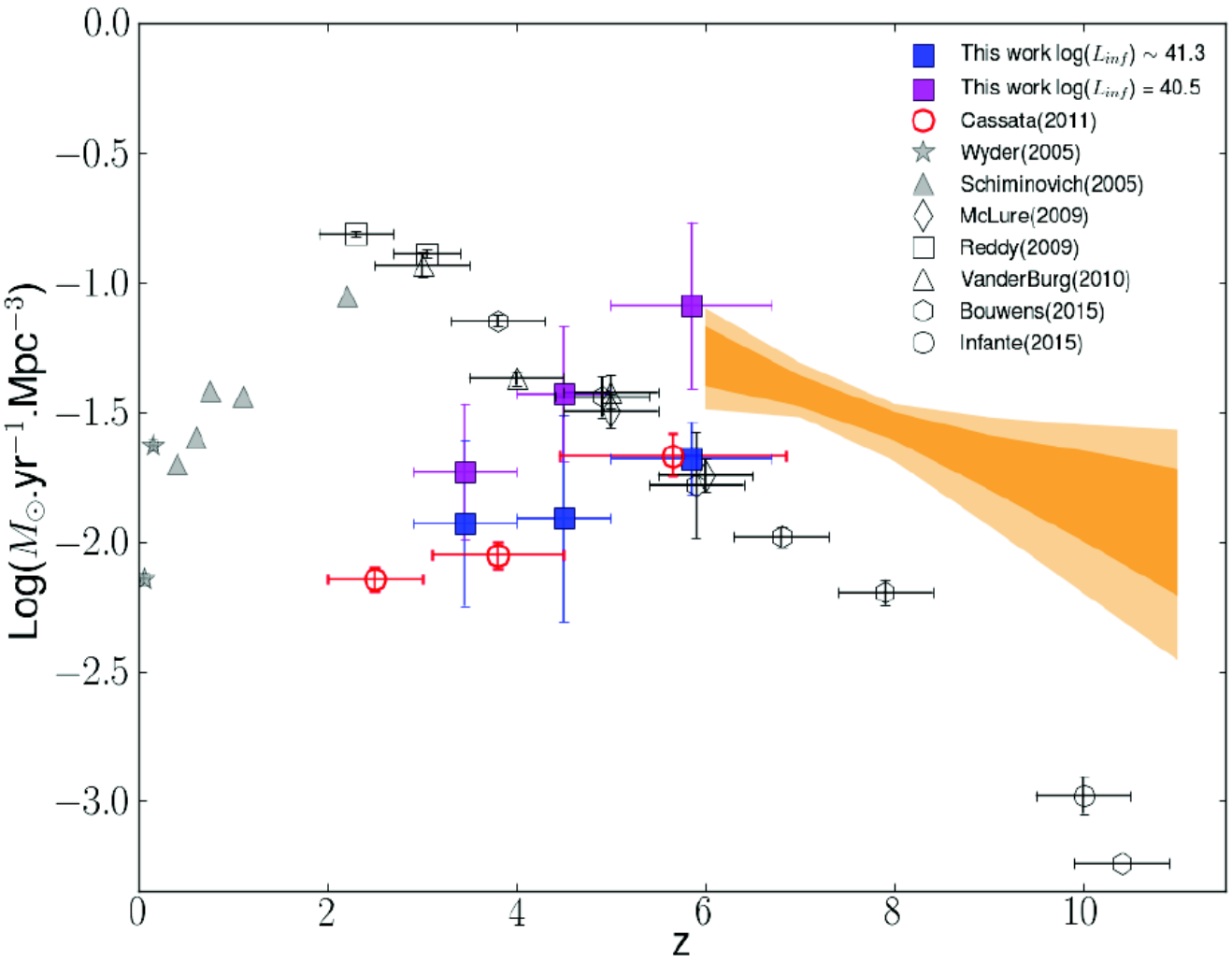




PRELIMINARY



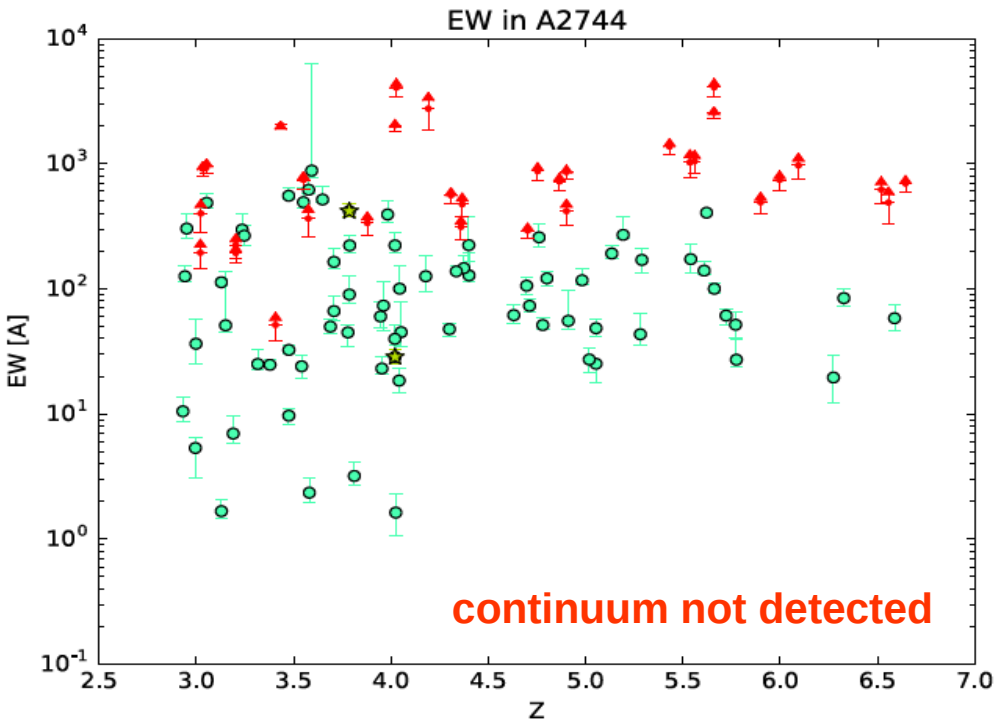
# LAE in A1689 + A2390 + A2667 + A2744

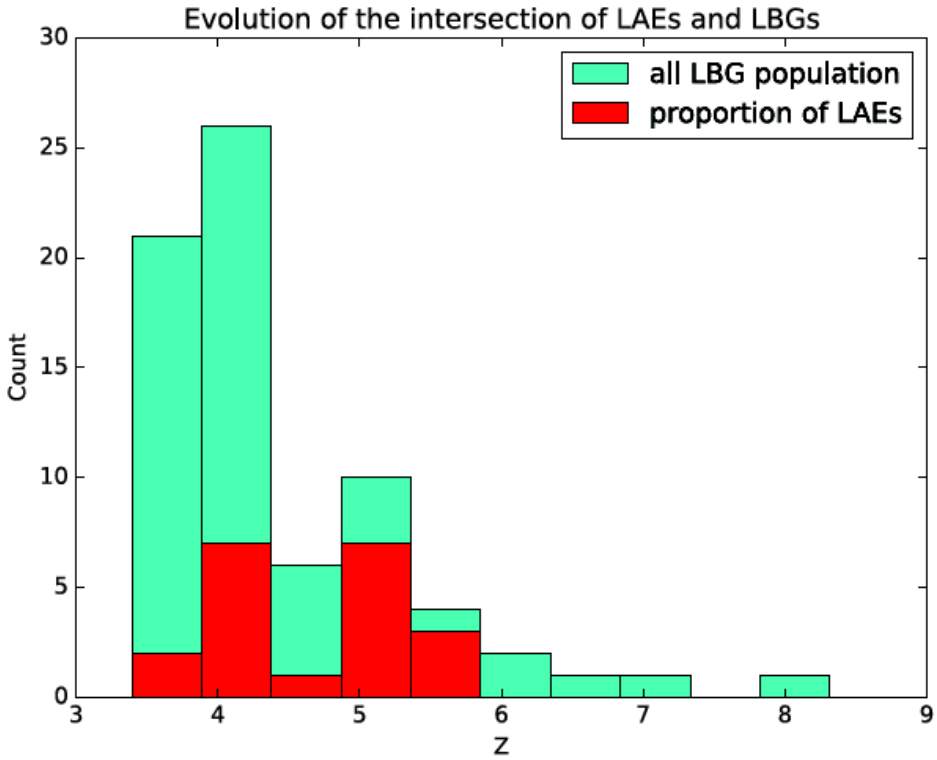



***Bina, GdV, RP+17, in preparation***

- Given the intrinsically-low luminosities, this sample is particularly sensitive to the slope of the LF towards the faintest-end.
- The density of sources obtained in this survey is roughly consistent with a steep value of $\alpha \leqq -2.0$ (evolving towards $\alpha \leqq -2.7$ between z~3 and 7) (see also Drake+17).
- LAEs represent a major contribution to ionizing flux at z~6

# LAEs / LBGs in HFF A2744



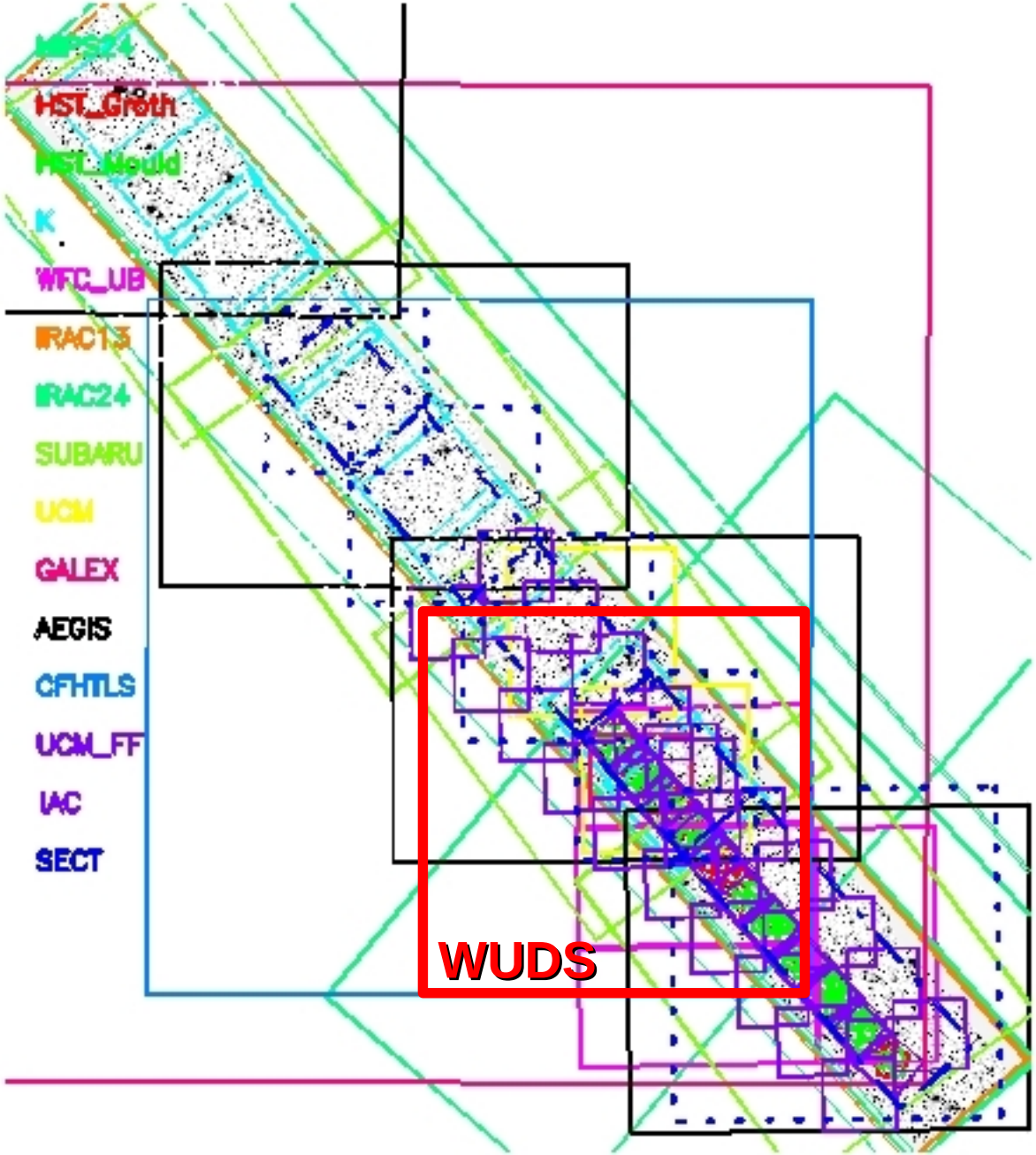

- The continuum is not detected for 34 / 132 LAEs (~26%)
- ~30% of the LBGs selected in this field are also LAEs (to be confirmed).

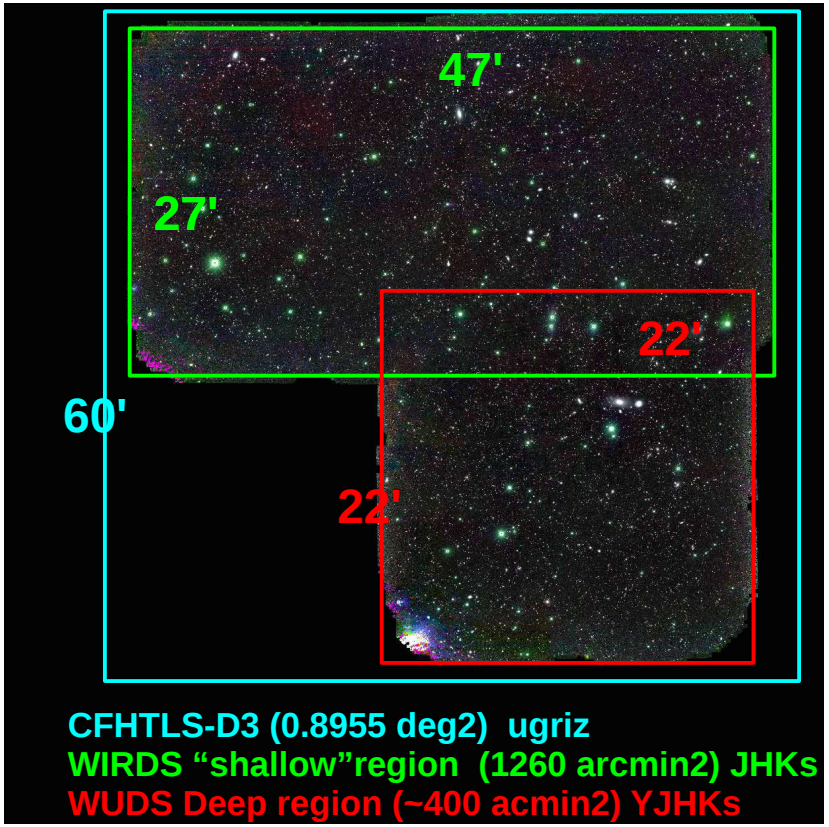
***De La Vieuville+, in prep.***

# Some lessons learned from lensed MUSE LAEs...

- Our survey of LAEs at $3 \lesssim z \lesssim 6.7$ behind lensing clusters with MUSE is sensitive to luminosities ranging between $39.0 < \log(L) < 42.5$ after correction for magnification. These are typical targets for MOSAIC...
- Some of these systems display extended and/or ex-centered Lya emission wrt the continuum emission.
- Accounting for this, between ~25 and 30% LAE are not detected in the continuum up to $m \gtrsim 28$. Also ~30% LBG-selected targets are also LAEs.
- Given the intrinsically-low luminosities, this sample is particularly sensitive to the slope of the LF towards the faintest-end. The density of sources obtained in this survey is roughly consistent with a steep value of $\alpha \lesssim -2.0$ (evolving towards $\alpha \lesssim -2.7$ between z~3 and 7) (see also Drake+17 based on MUSE data, Bina+17 in preparation).
- LAEs represent a major contribution to ionizing flux at z~6 ...

# EMIR/GOYA Fields ...



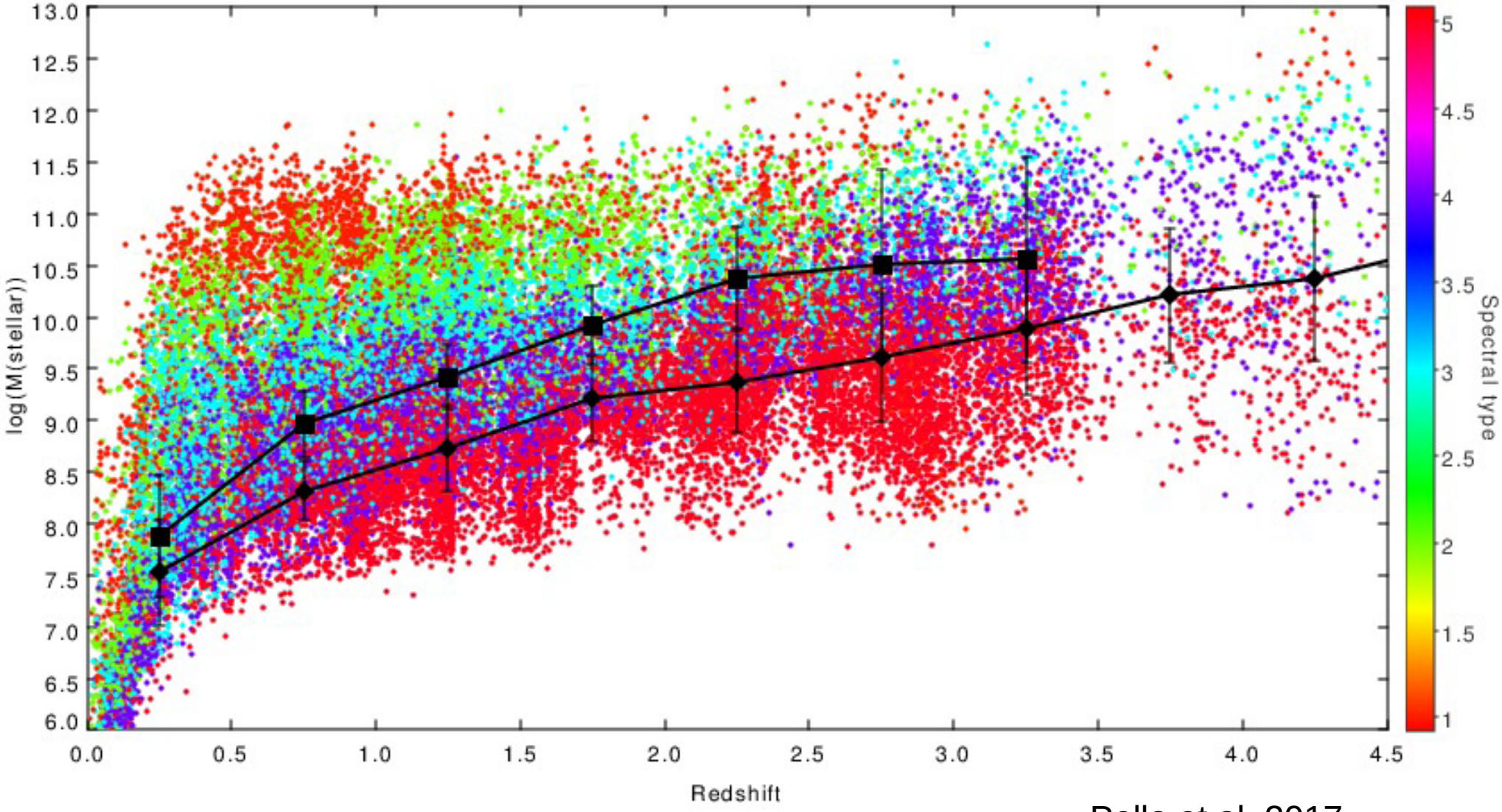

## GTO Fields (first epoch)

**GOODS-N** 12 36 49 / +62 12 58

**EGS / WUDS** 14 16 35 / +52 16 25

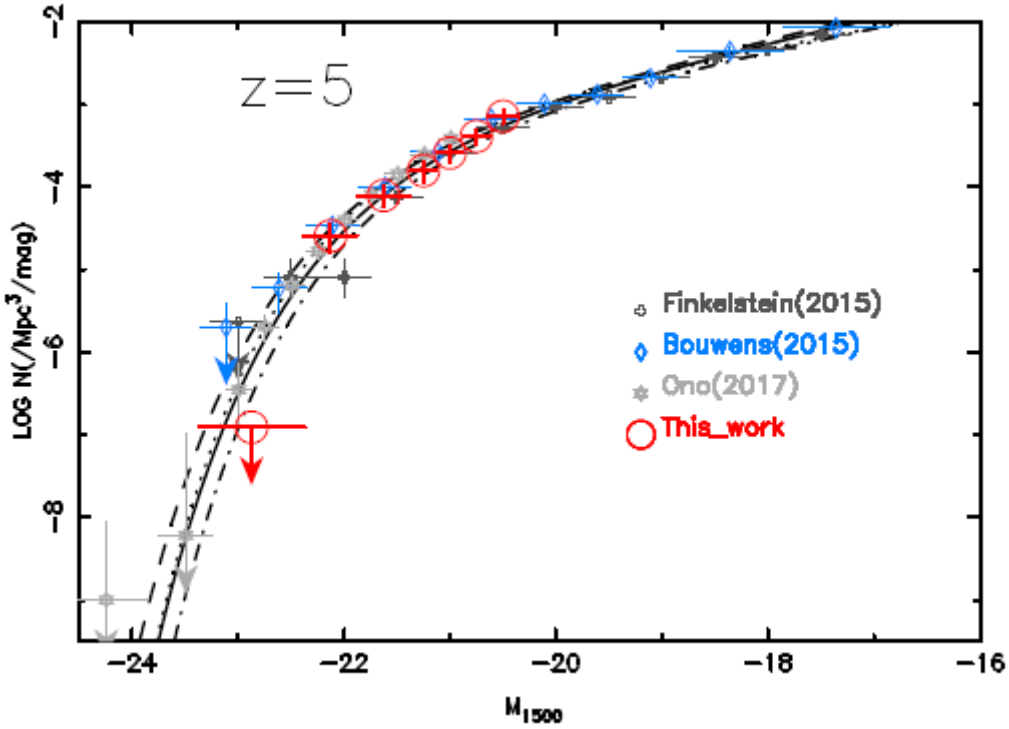
**SXDS (Subaru/XMMNewton deep survey)**
02 18 00 / -05 00 00

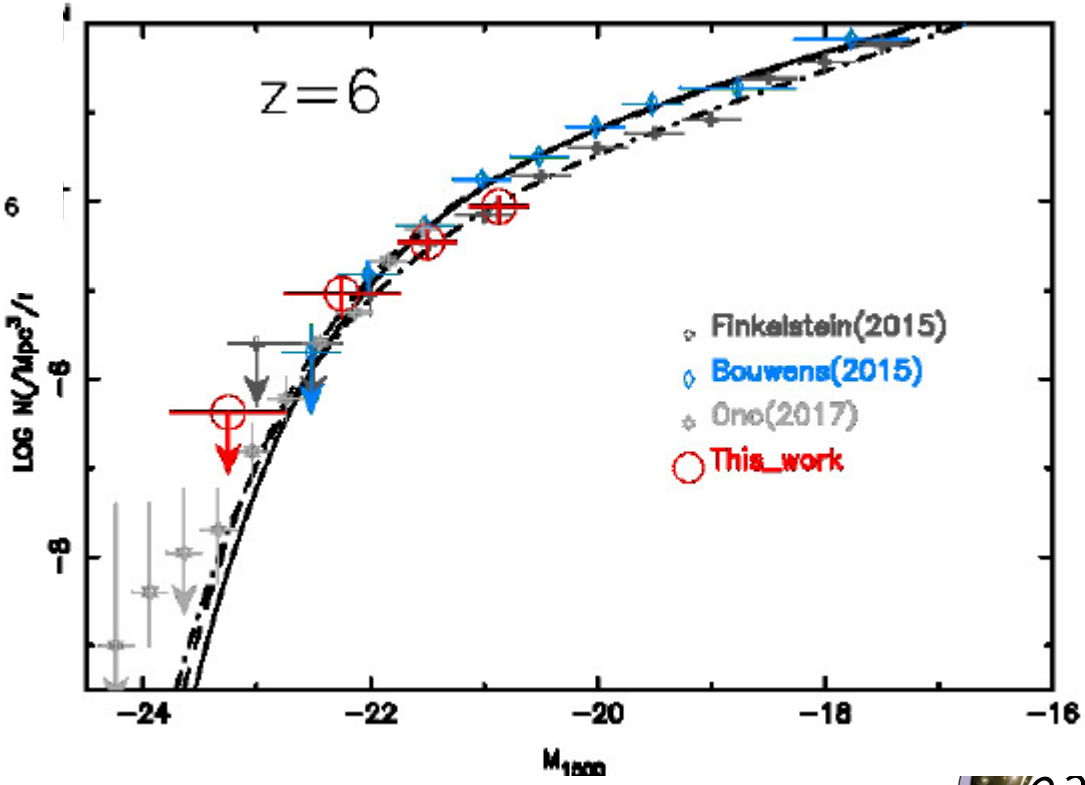
# EMIR/GOYA Fields : WUDS




Pello et al. 2017

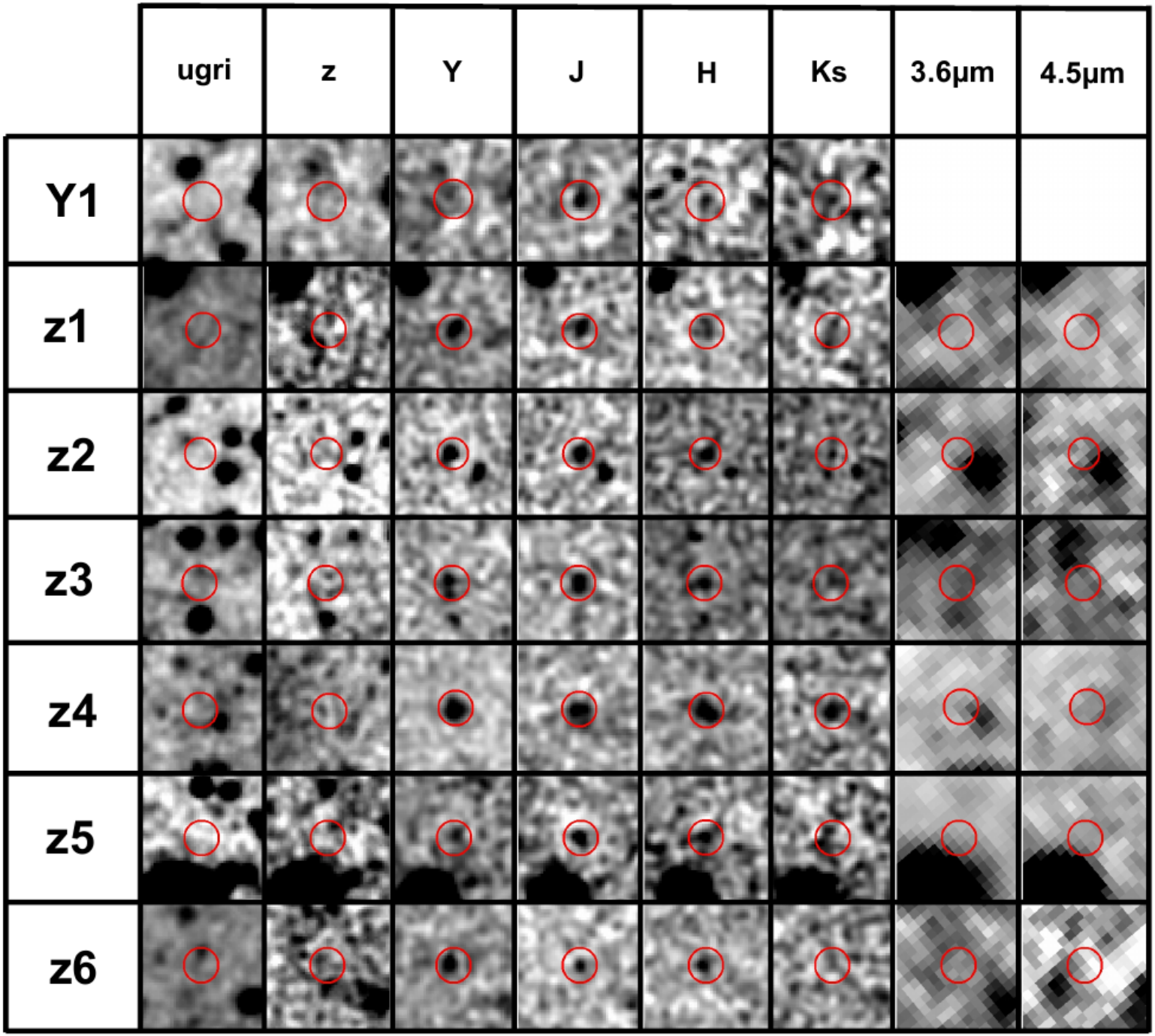
# EMIR/GOYA Fields : WUDS




Pello et al. 2017

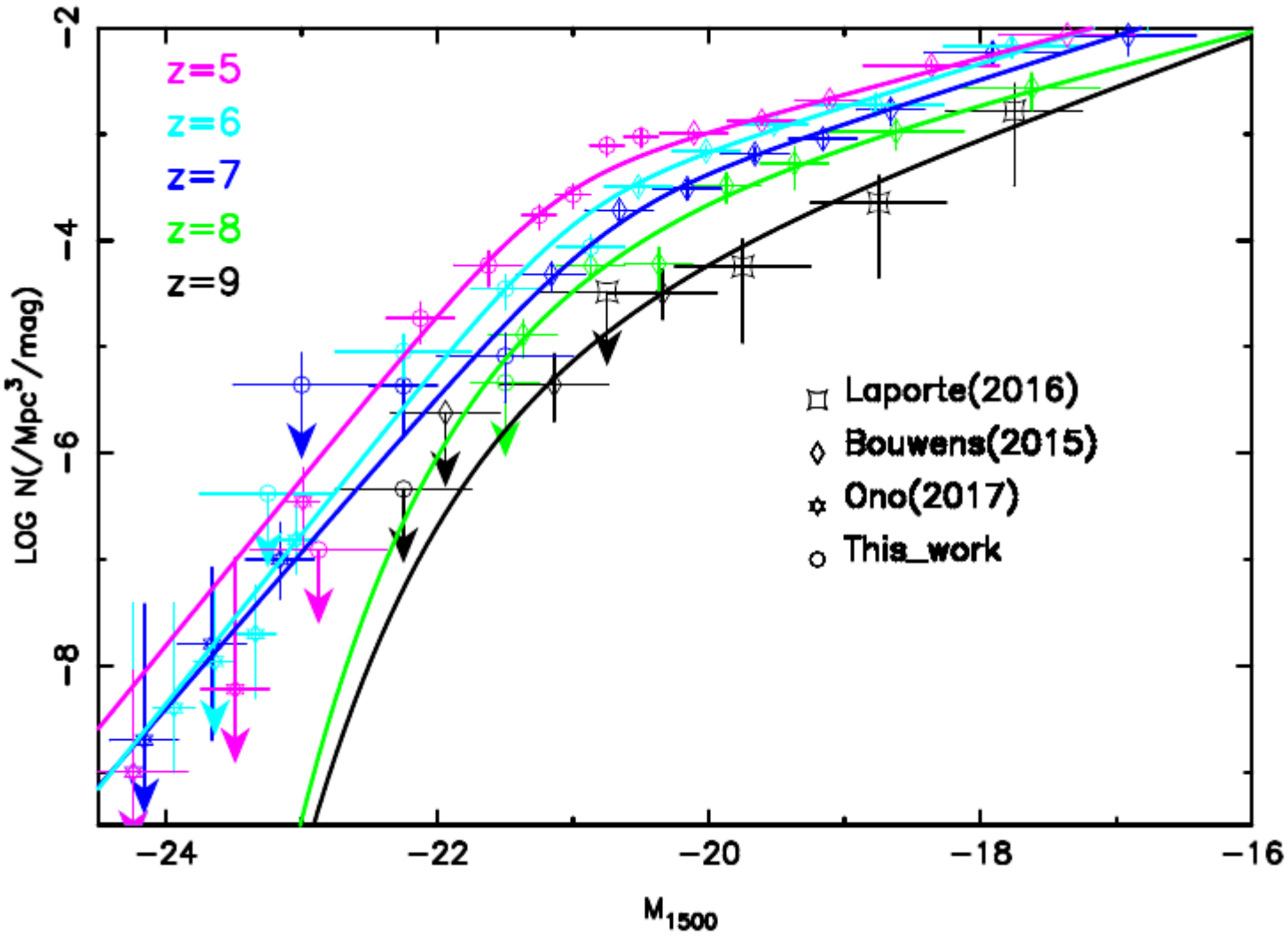
# EMIR/GOYA Fields : WUDS




Laporte et al. 2017

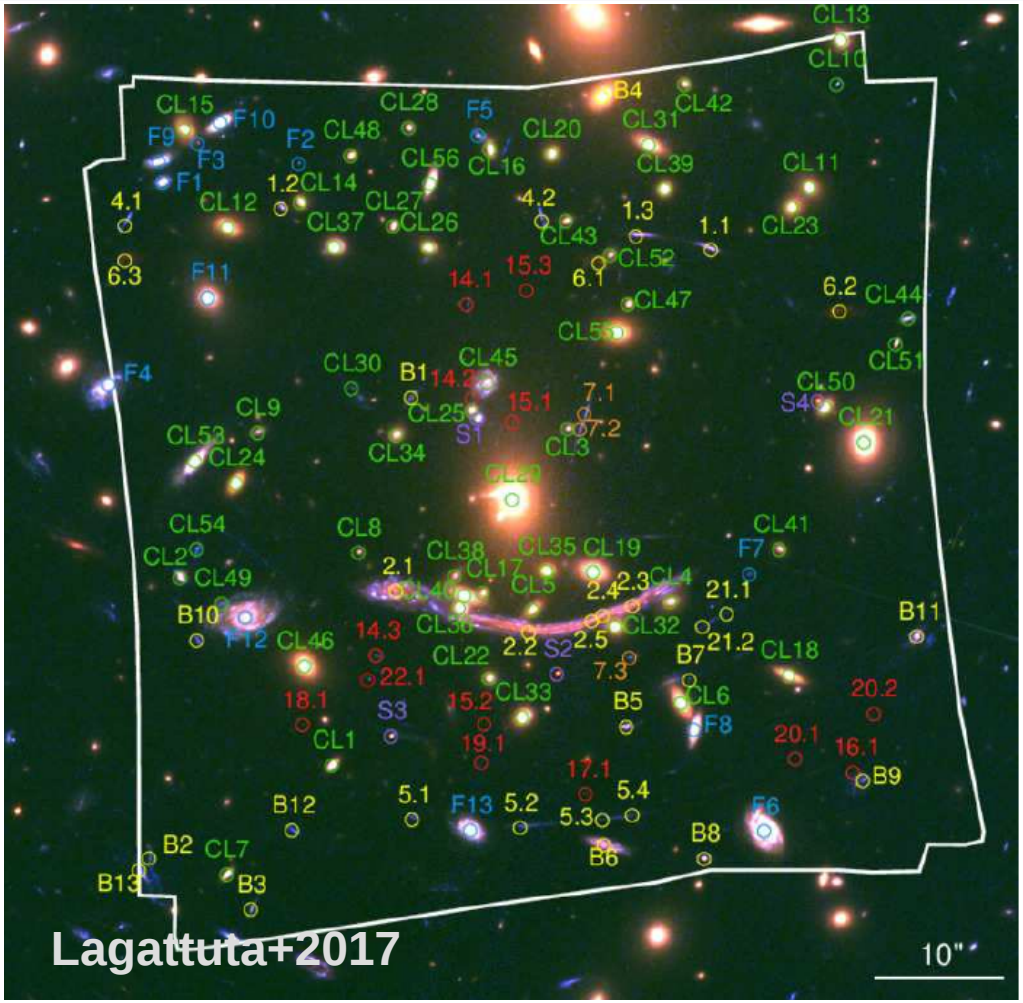
| Source | $z_{phot}$ | $1\sigma$ |
|---|---|---|
| WUDS_Y1 | 7.72 | 7.25 - 9.19 |
| WUDS_z1 | 7.03 | 6.81 - 7.21 |
| WUDS_z2 | 7.03 | 6.81 - 7.21 |
| WUDS_z3 | 7.03 | 6.76 - 7.22 |
| WUDS_z4 | 6.99 | 6.72 - 7.23 |
| WUDS_z5 | 7.00 | 6.66 - 7.22 |
| WUDS_z6 | 6.91 | 6.44 - 7.27 |

# EMIR/GOYA Fields : WUDS




Laporte et al. 2017

# EMIR/GOYA Lensing Fields ?







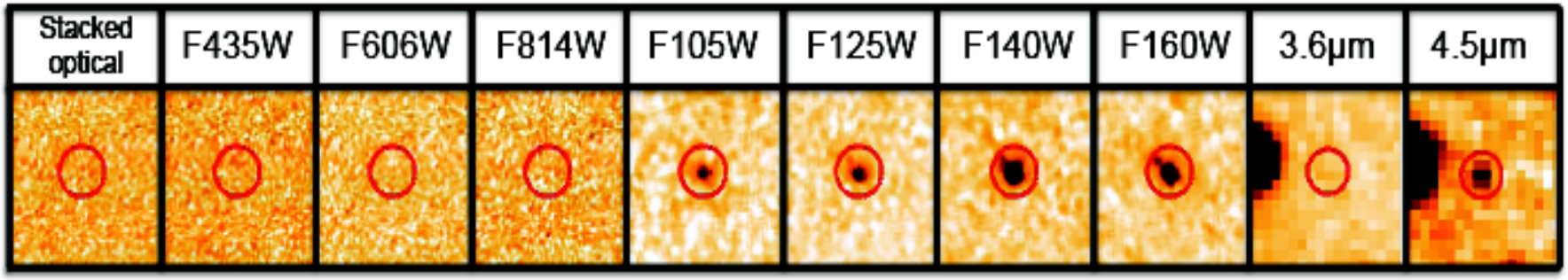
## GTO Fields / Hubble FF (First Epoch)

**Abell 370** **02:39:52.9 / -01:34:36.5**

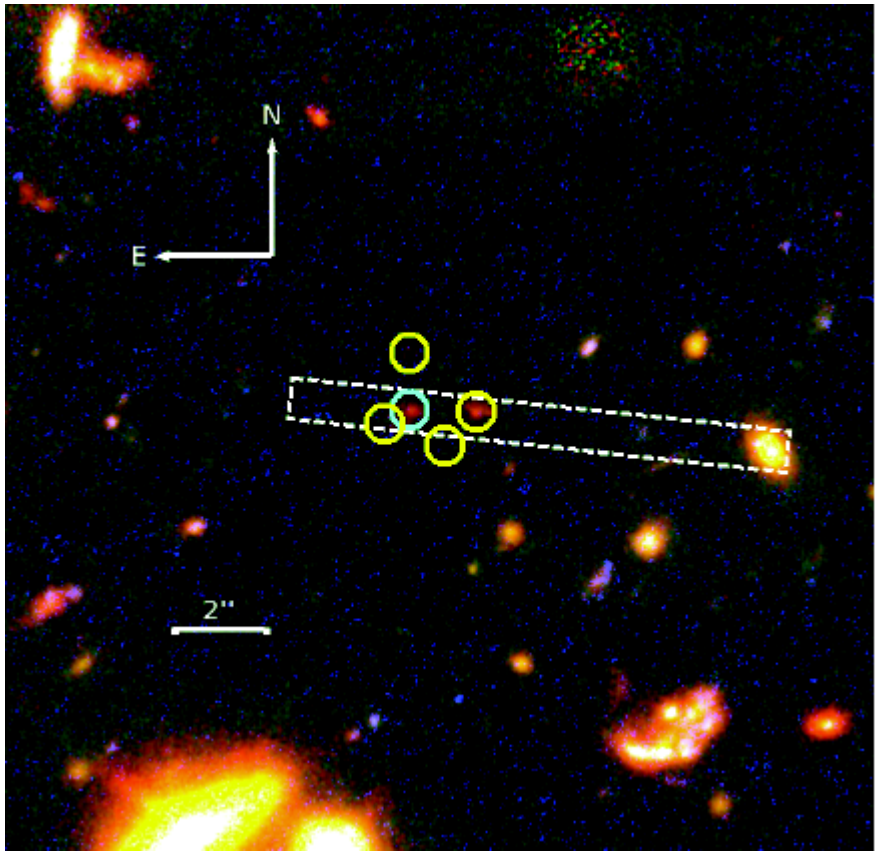
**(also explored by MUSE GTO ...)**

**MACSJ0717.5+3745** **07:17:34.0 / +37:44:49.0**

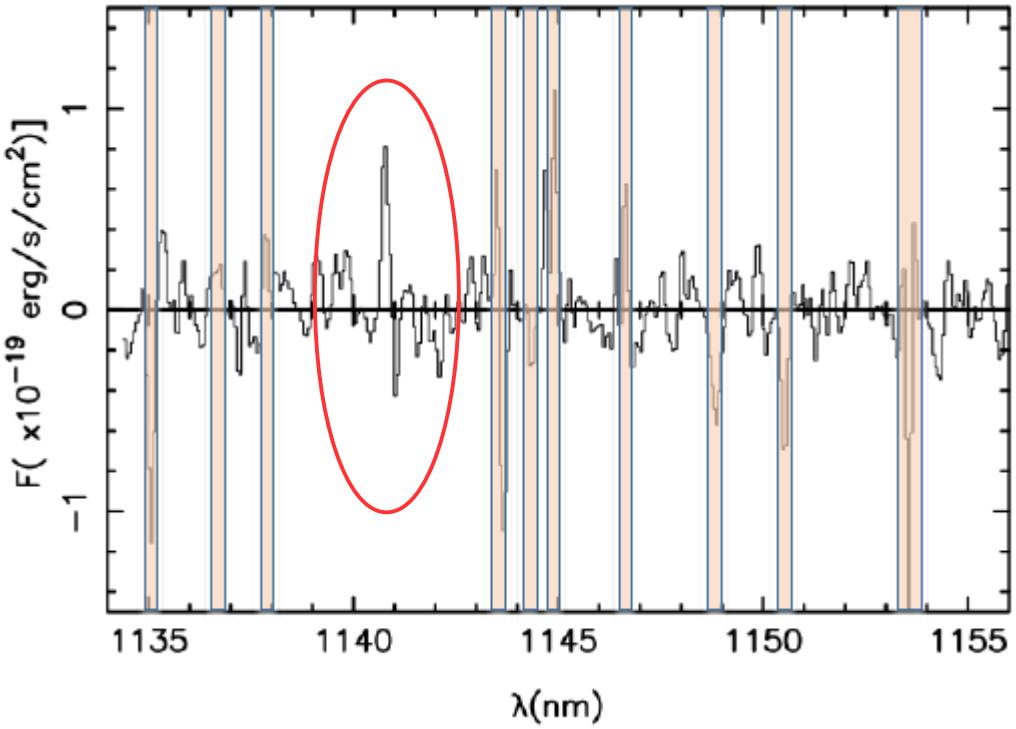
# Candidate at z~8 behind A2744



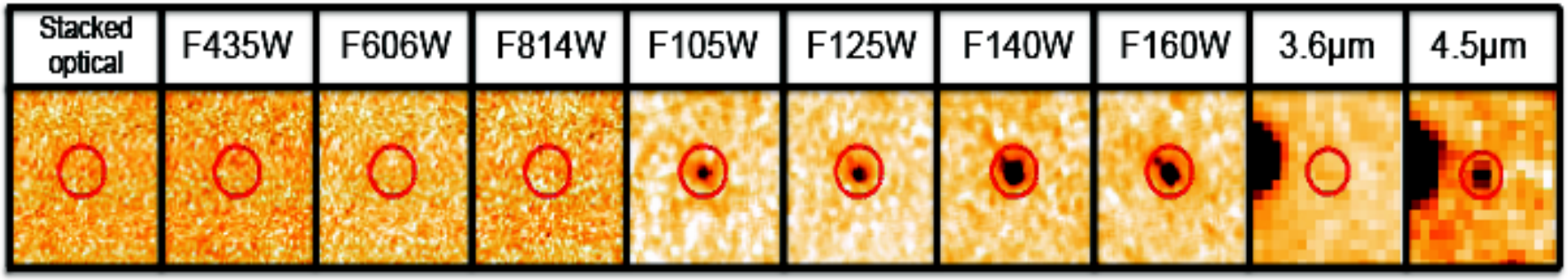

***Laporte et al. 2014, 2017***



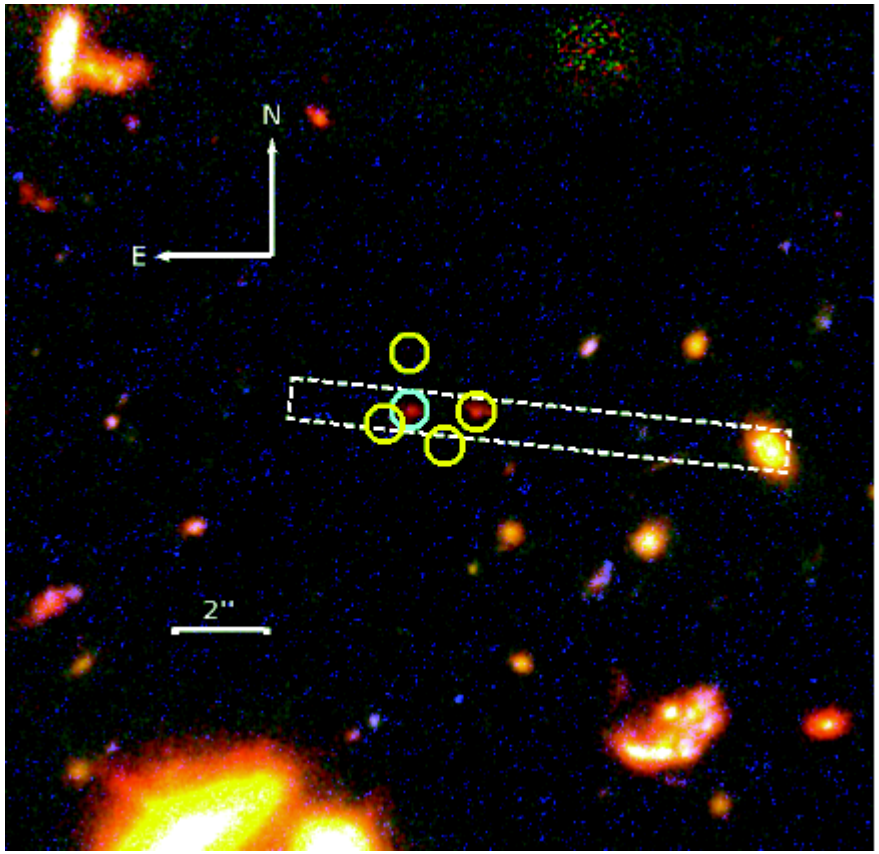

- Spectroscopic confirmation at z=8.38 avec X-Shooter/VLT et ALMA



# Candidate at z~8 behind A2744




***Laporte et al. 2014, 2017***




- Spectroscopic confirmation at z=8.38 avec X-Shooter/VLT et ALMA

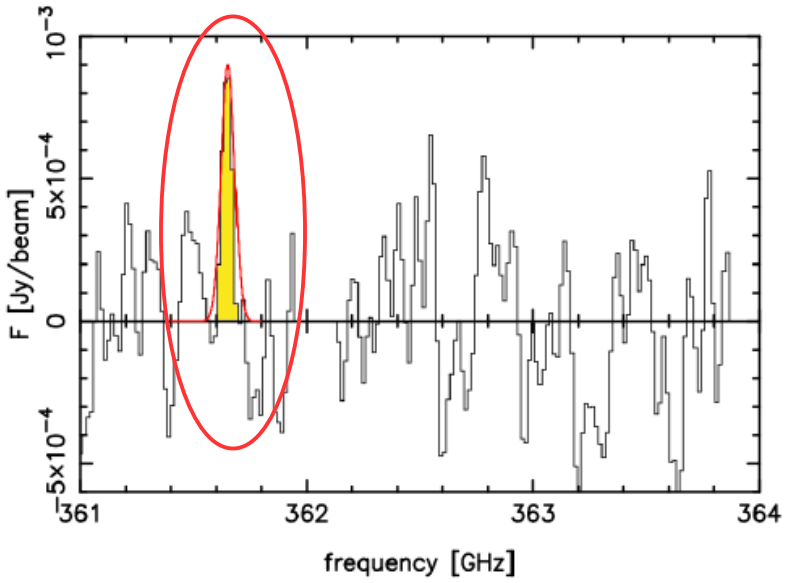



FIG. 5.— The ALMA [OIII]88$\mu$m spectrum with a resolution of 25km s$^{-1}$. The best Gaussian profile is over-plotted in red at the central frequency corresponding to a redshift of $z$=8.382. The derived line width is ≈43km s$^{-1}$.

# LBGs with EMIT/GTC

- The main goals and the results expected from GOYA for z>6 LBGs can be summarized as follows:
  - I) The **Lyman alpha luminosity** and equivalent widths (estimated using the broad-band fluxes) and SED-fitting will provide a measurement of the **SFR**, and a **combined constraint on the maximum age / Initial Mass Function / metallicity of the objects based on models**. If metal lines (e.g. CIV 1550...) are detected/measured, these will provide direct constraints on the metallicity through photoionisation models.
  - ii) The detection of **HeII 1640** emission (together with the detection or non-detection of metal lines) would be a unique indication of extremely metal-poor stellar populations or AGN activity, when combined with other lines.
  - iii) **Lyman alpha profiles** and estimates of the IGM transmission will be used to place constraints on the contribution of these objects to cosmic re-ionization.

# Thanks!

