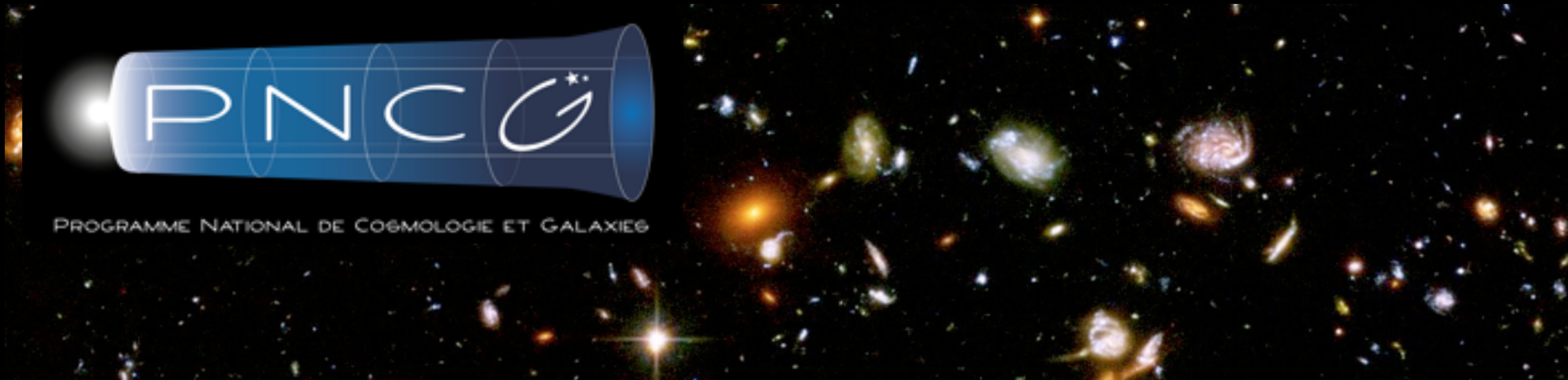


JOHAN RICHARD (CRAL)
SÉBASTIEN PEIRANI (IAP)

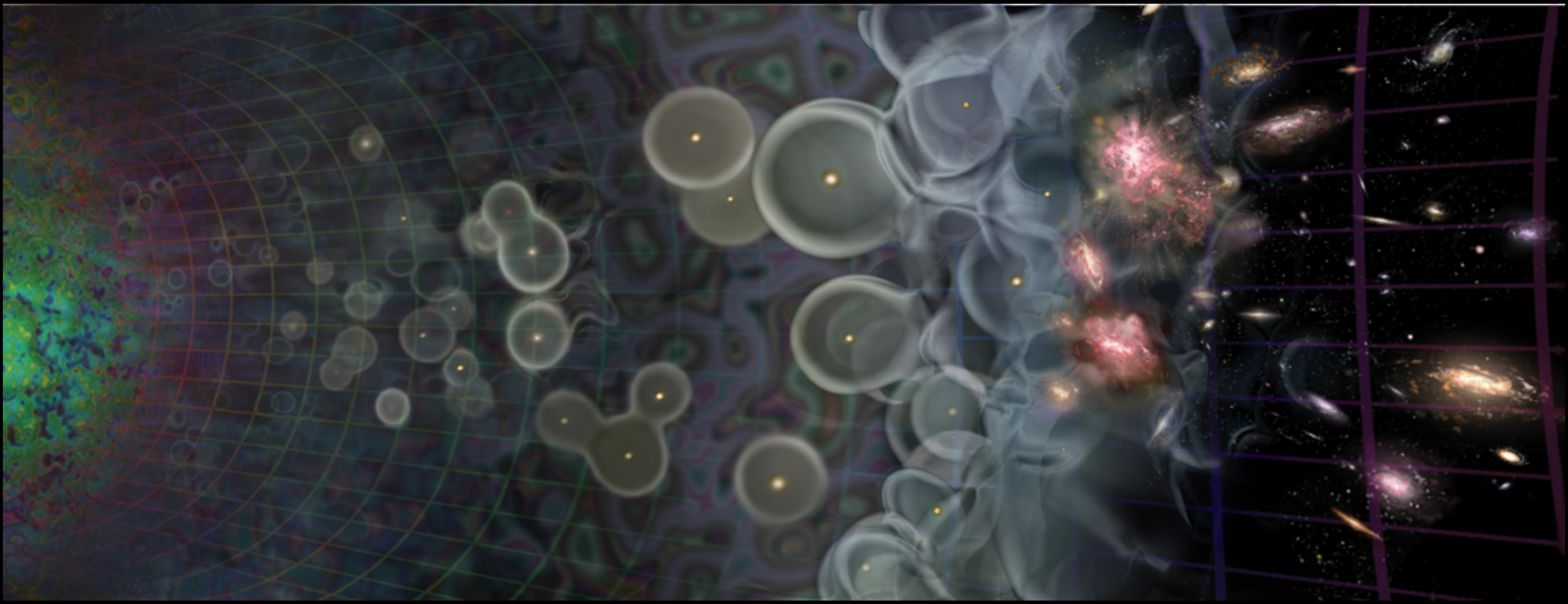
- **Formation des galaxies**
- **Univers Lointain**

Journées du PNCG, 23-24 novembre 2016

FIRST LIGHT

- What are the **first galaxies**?
- What sources caused **reionisation** ?
- How did these first galaxies assemble ?

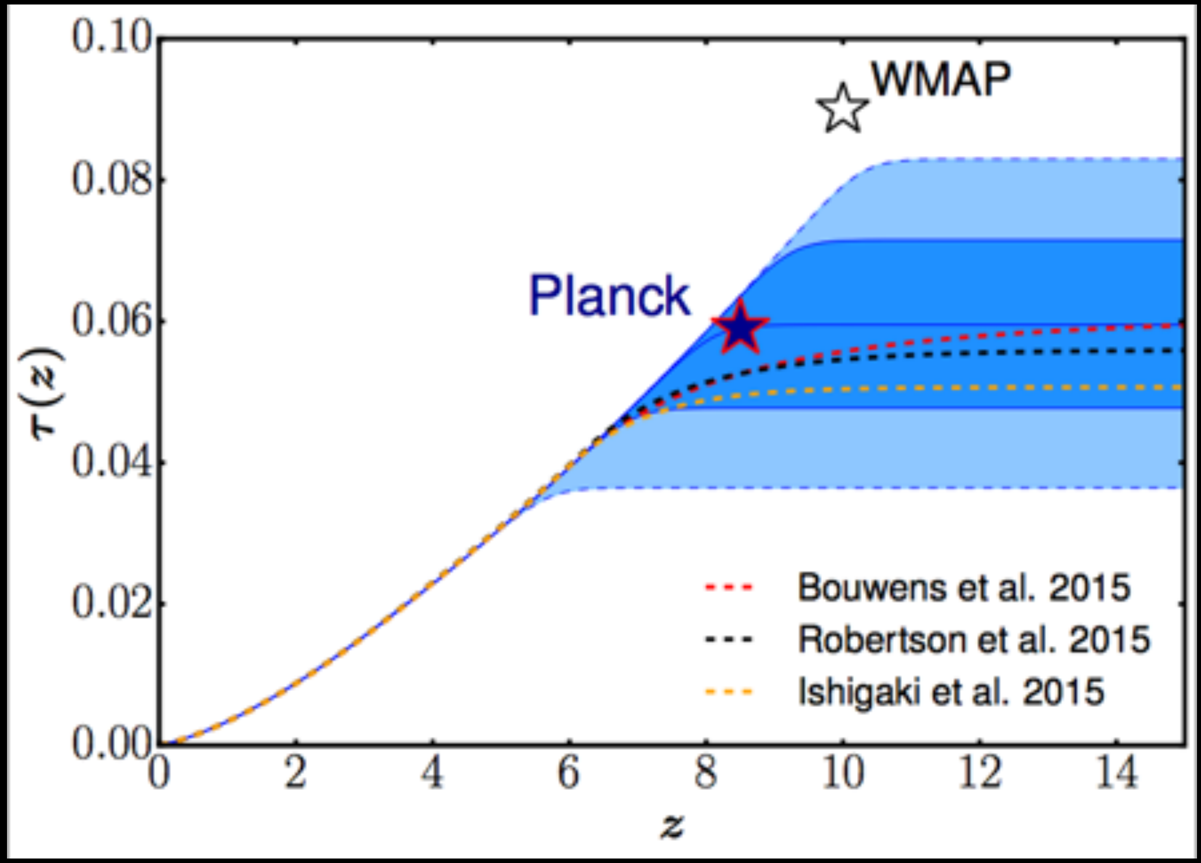
Observations: z>3
Lyman-α
Dust
Simulations
Future instruments



REIONISATION

Low value for τ suggested by Planck data:

- consistent with reionized Universe at z ~ 6
- Later reionisation: enough low luminosity galaxies at z < 9 ?

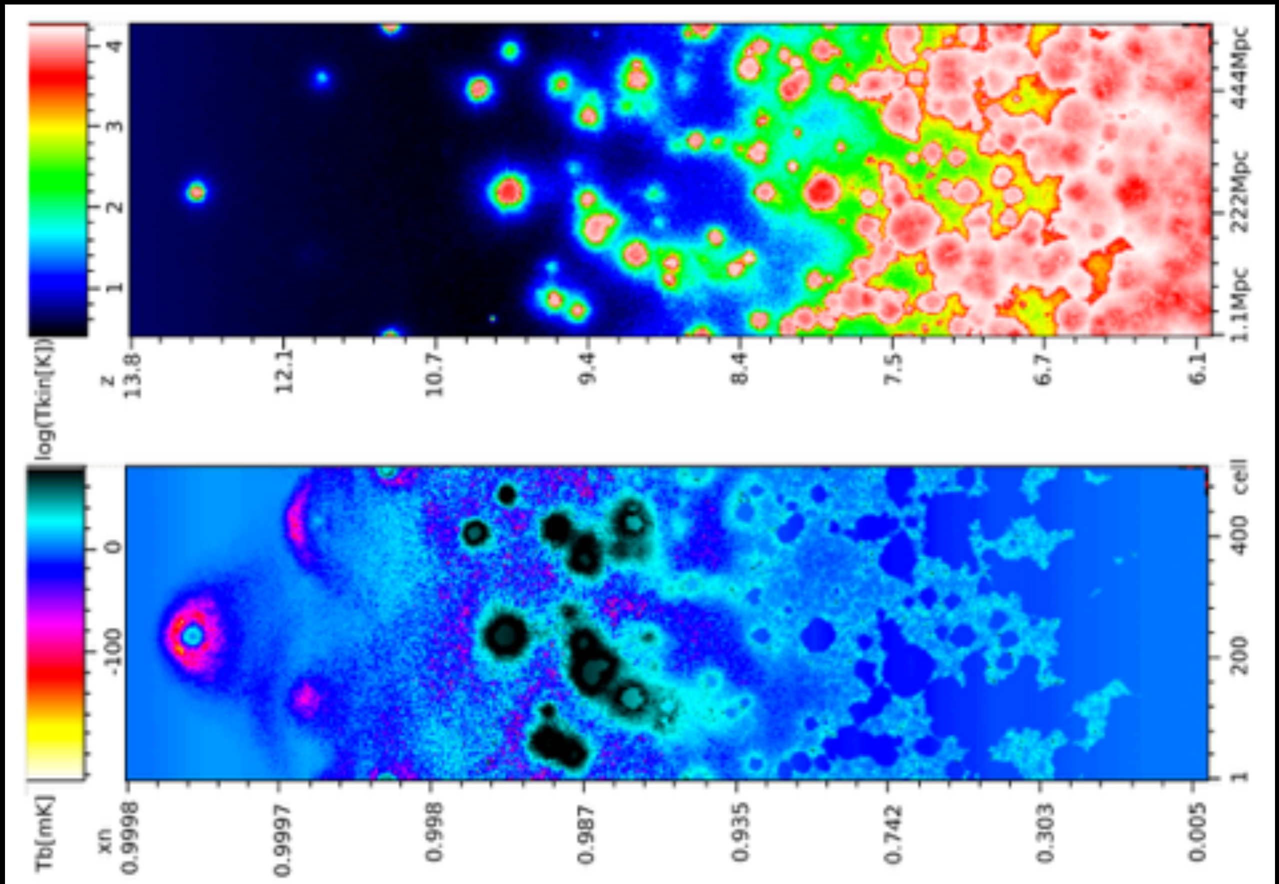


XLVII. Planck constraints on reionization history

- Simulating 21 cm signal:

e.g. anisotropies from differential brightness temperatures

Zawada et al. 2014, predictions for SKA over 20x20 degrees



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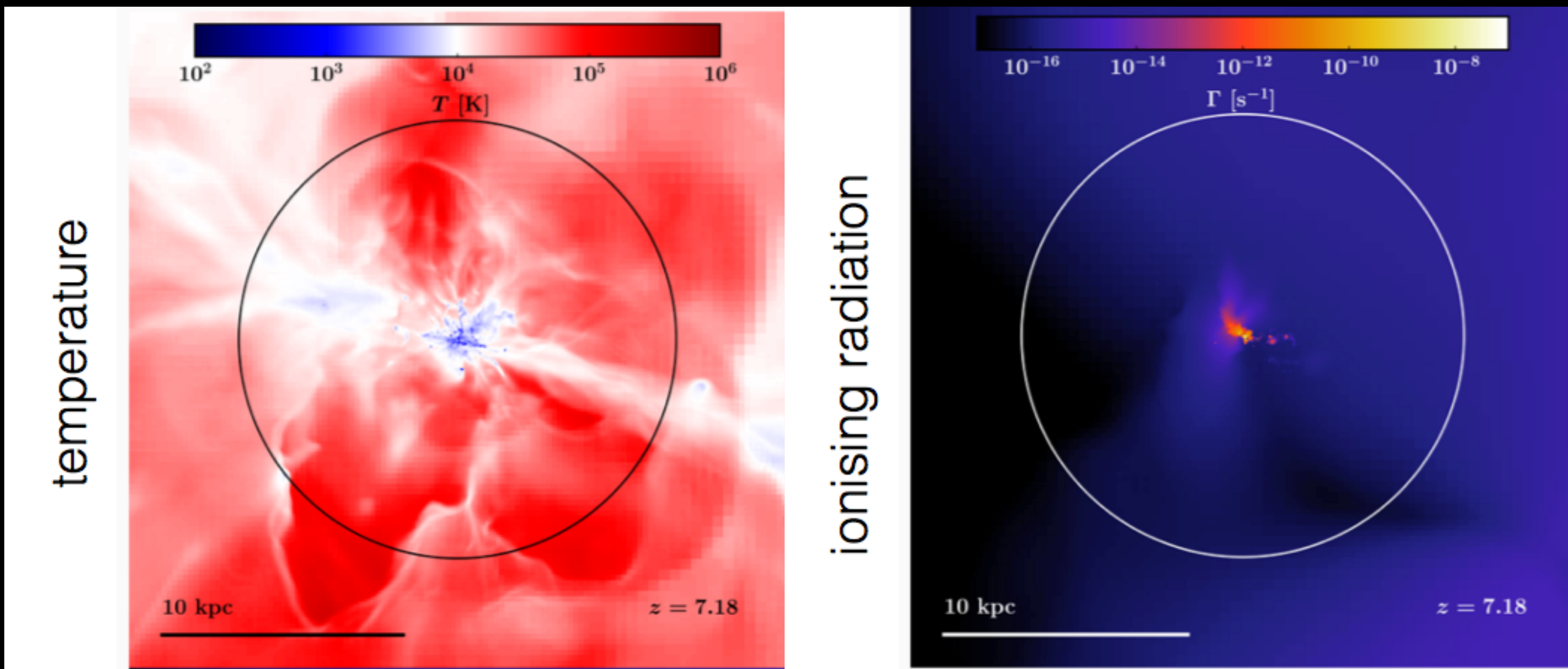
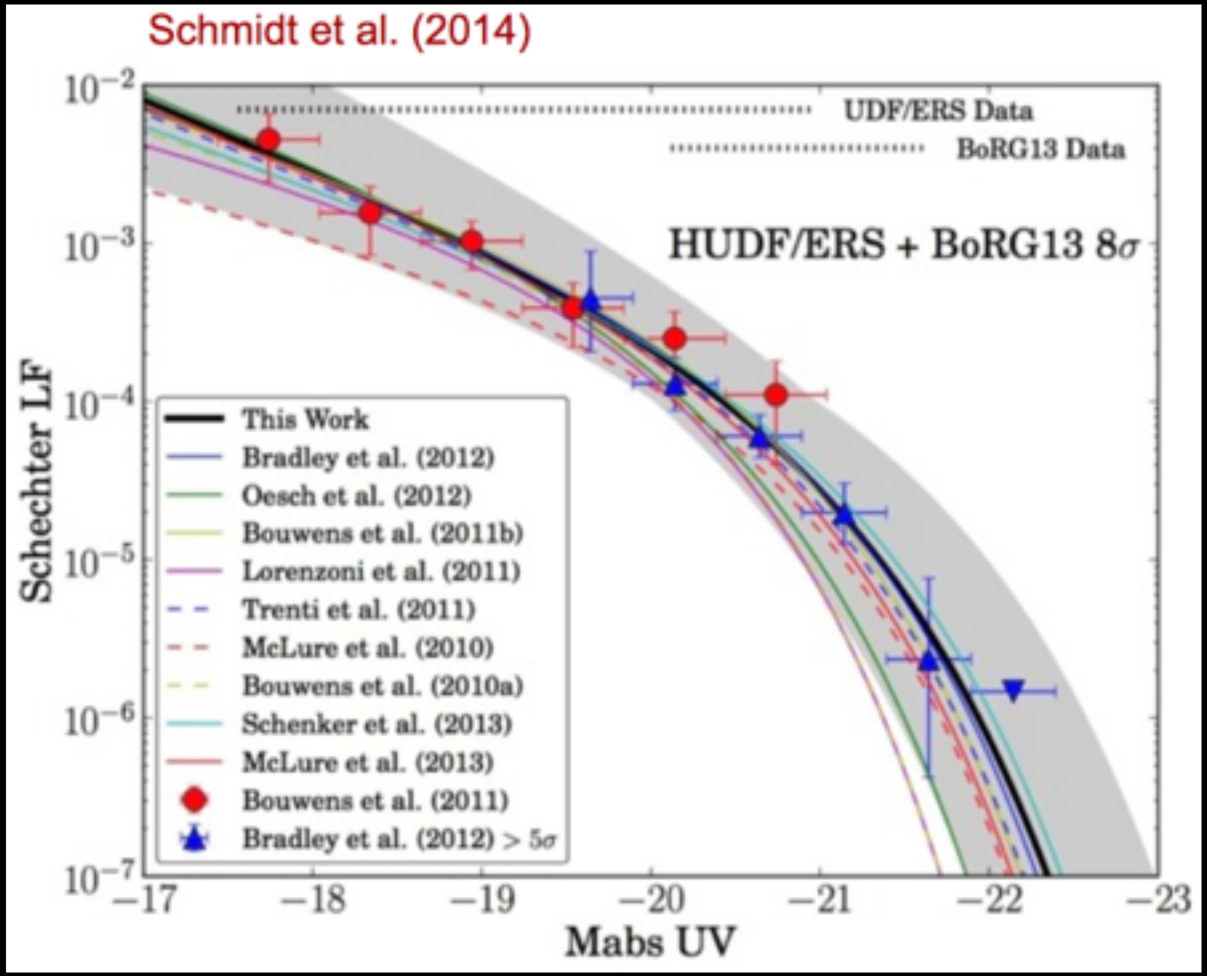
PREDICTIONS FROM SIMULATIONS

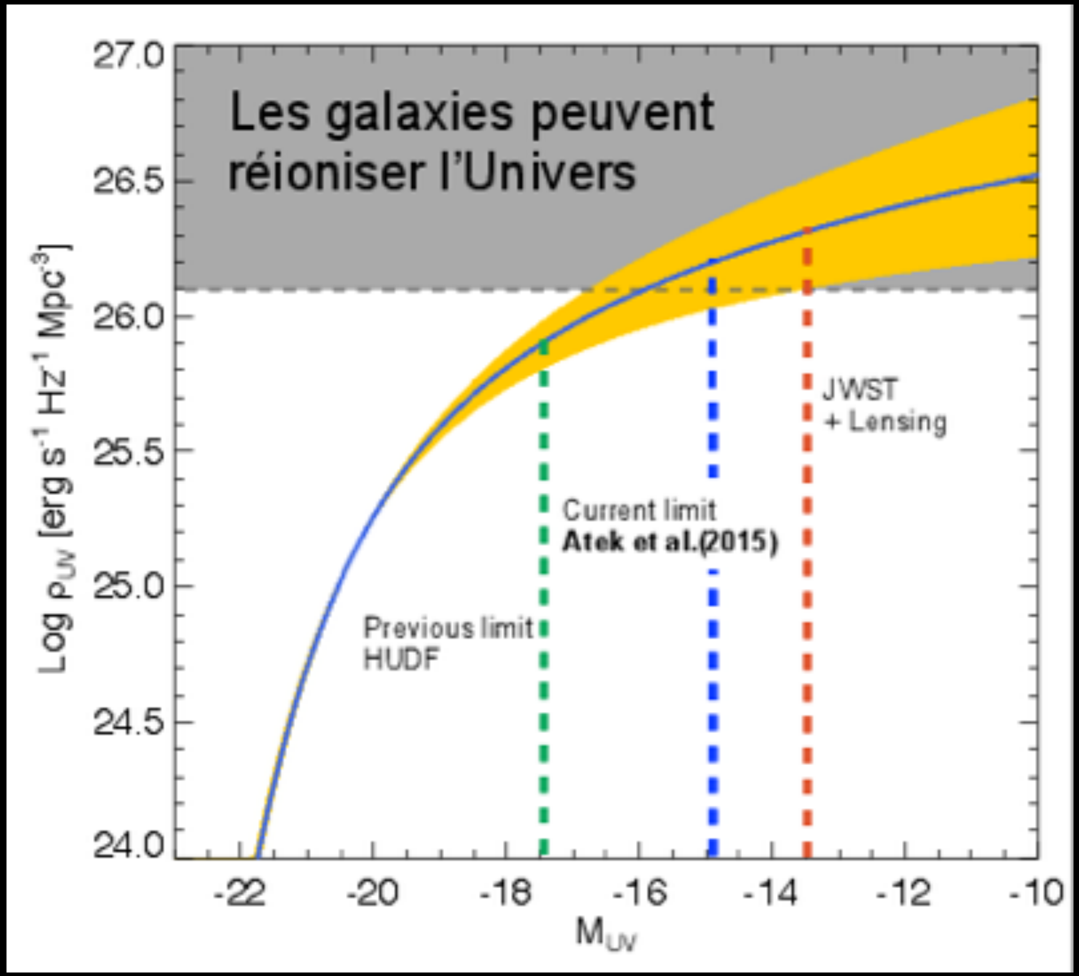


Trebitsch+16

- Numerical simulations help understanding the detailed properties of the sources of reionisation. New methods implemented in RAMSES (Rosdahl+13, +15)
- Recent PRACE application (J. Rosdahl): enough resolution to resolve the Lyman Continuum and Lyman alpha escape

LUMINOSITY FUNCTION FROM DEEP FIELDS



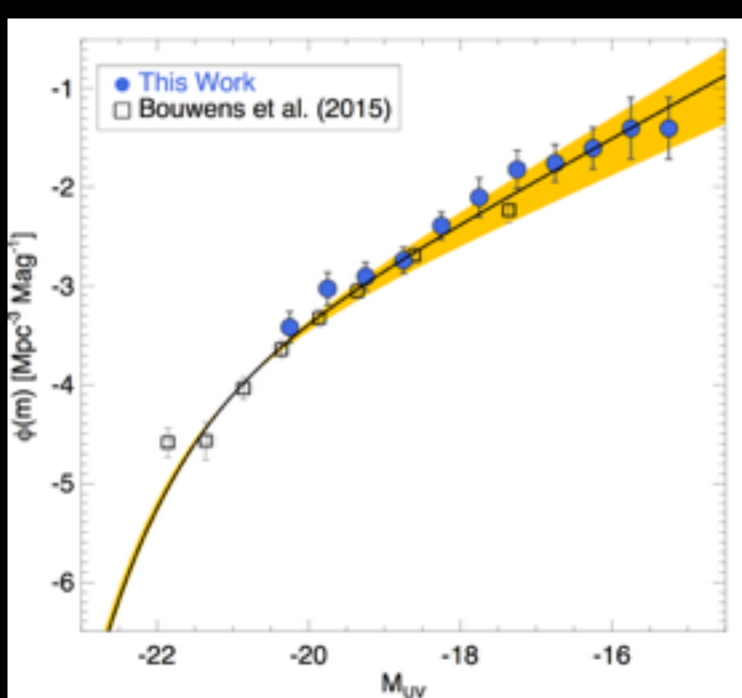


Current limits on the luminosity function:

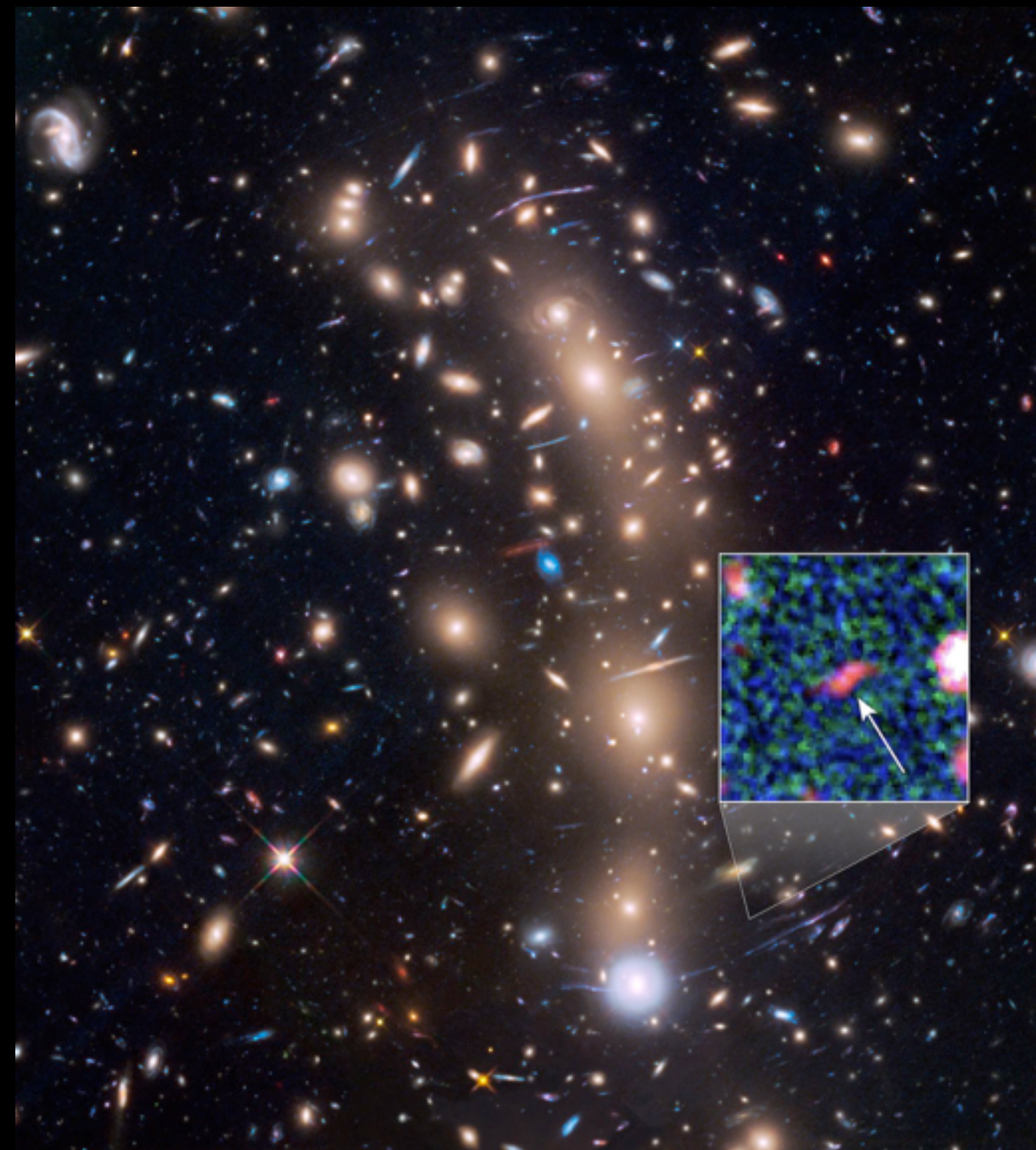
- knowledge of the redshift evolution at $z > 7$, limited by statistics
- extrapolation to the faint end (sources dominating reionisation)

FRONTIER FIELDS(1)

- Very deep Hubble observations of 6 massive lensing clusters
- ~ 29 AB in the image plane: up to ~ 32 AB intrinsically! => typical JWST sources

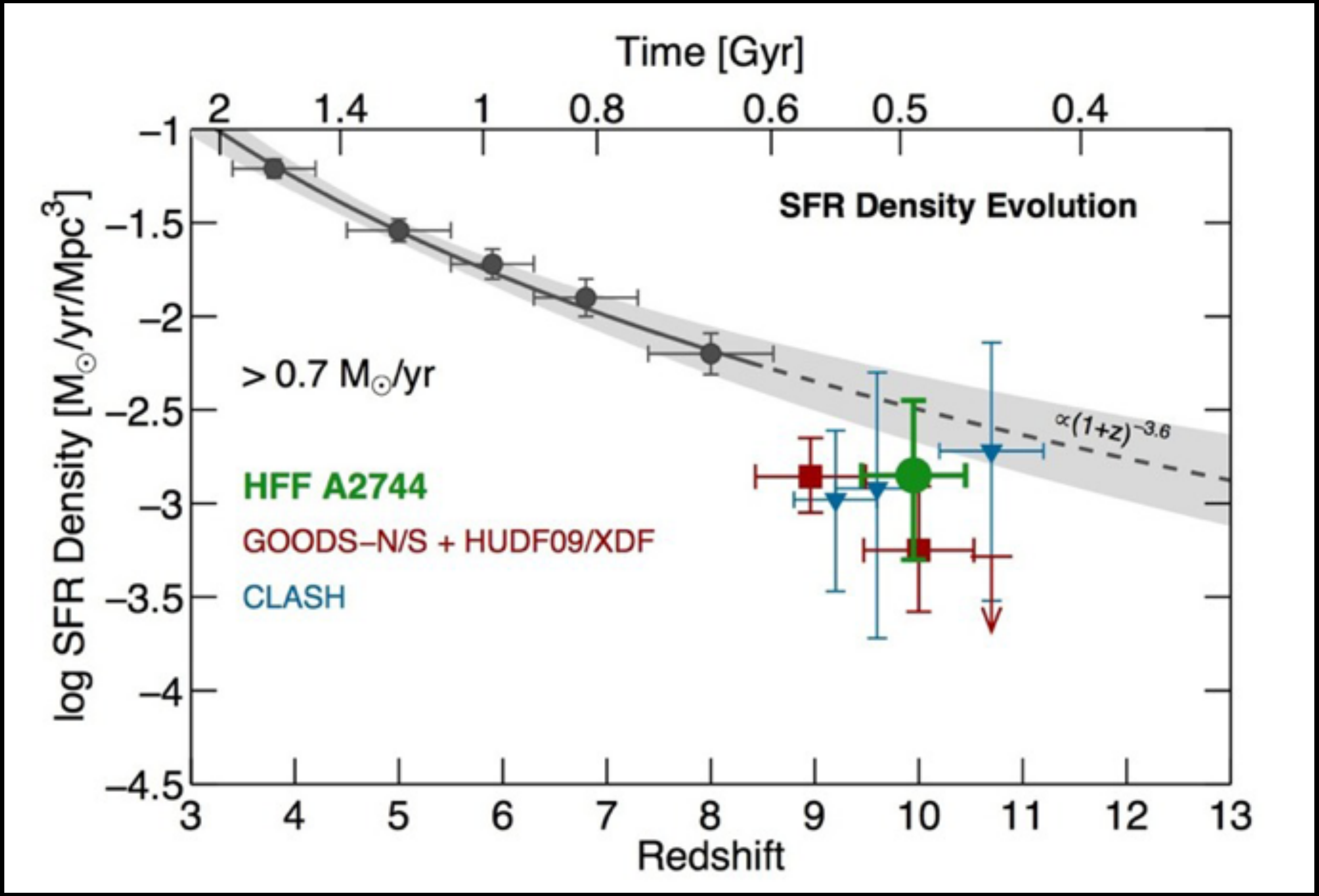


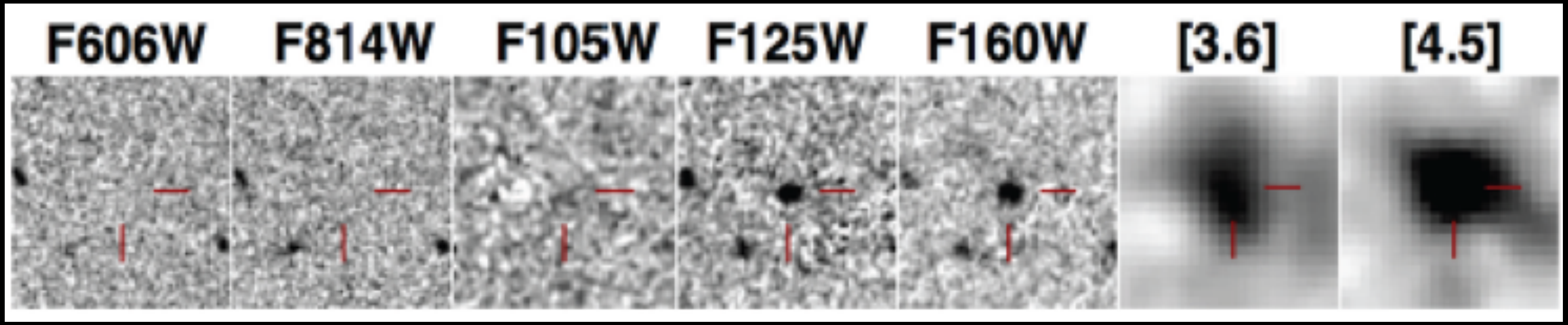
Atek et al. 2014, 2015, 2016



Infante, Zheng, Laporte et al. 2015 (z>9)

FRONTIER FIELDS (2)

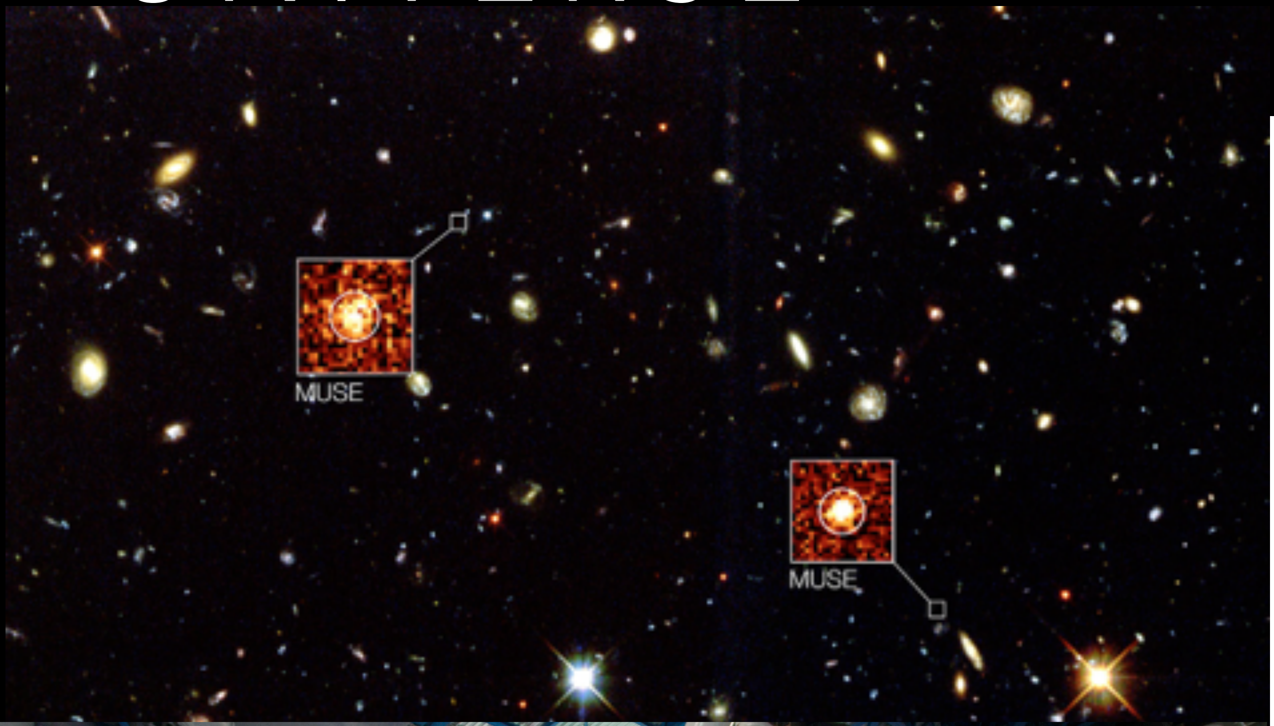


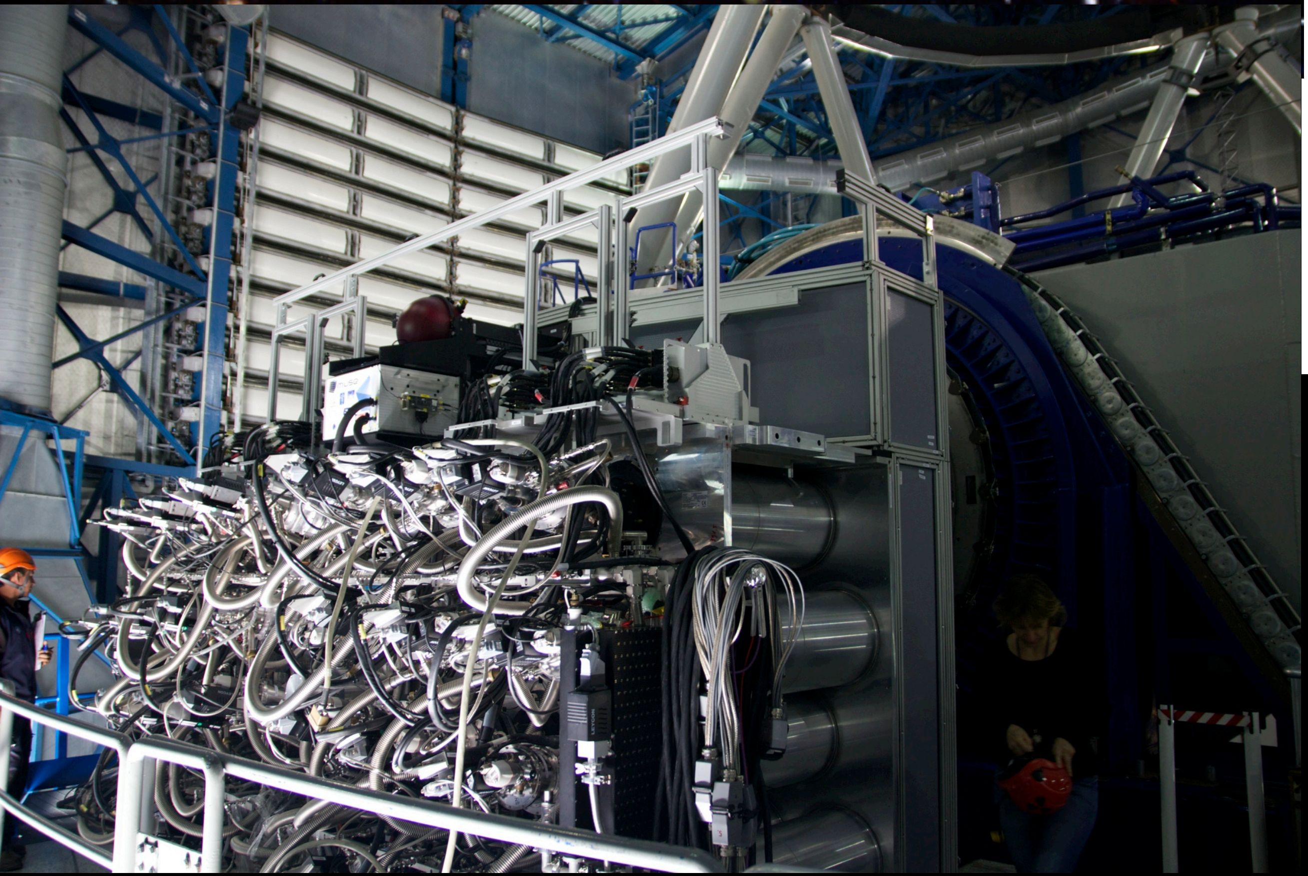


Oesch et al. 2015

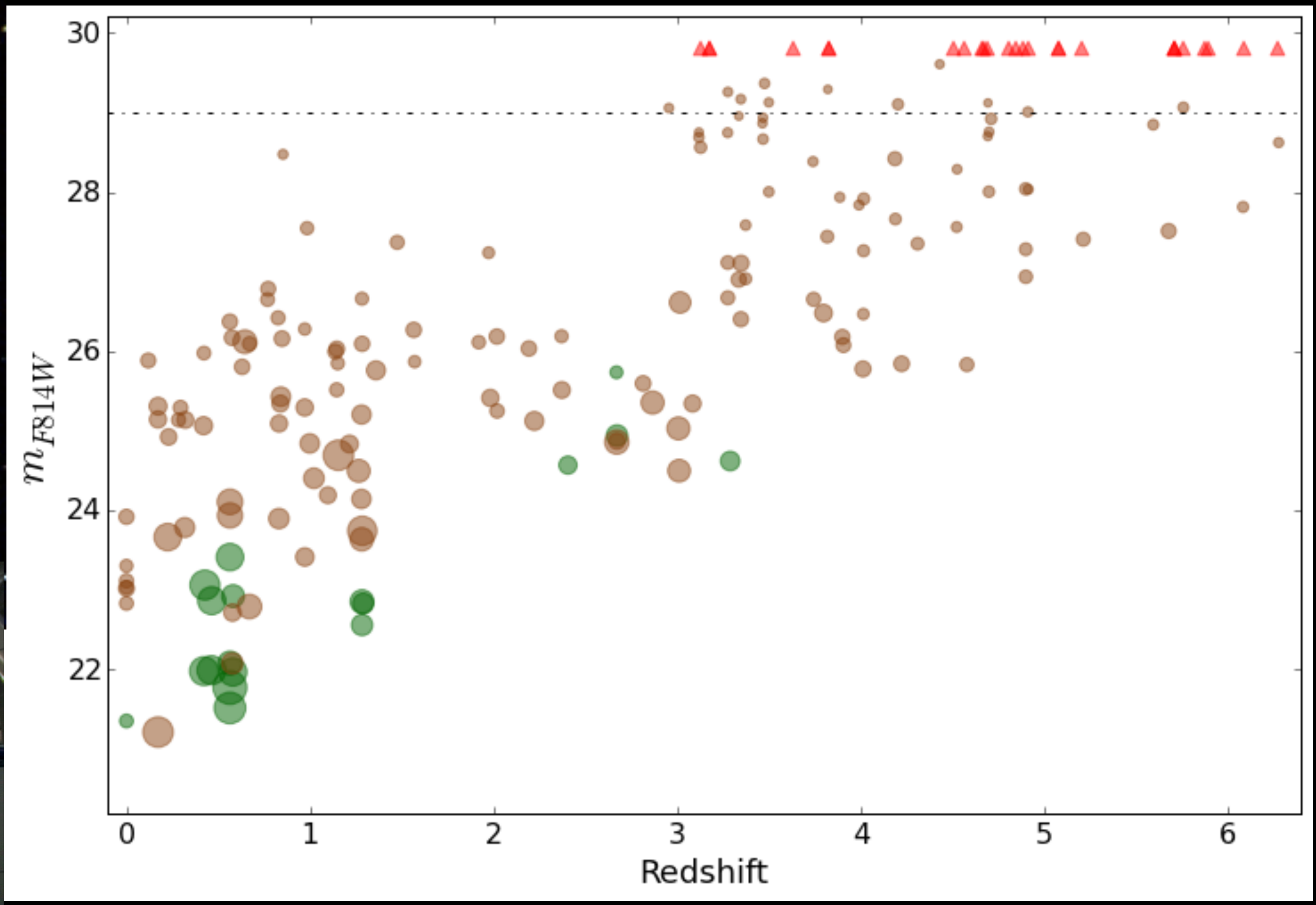
z = 7.73

MUSE AND THE LYMAN-ALPHA UNIVERSE





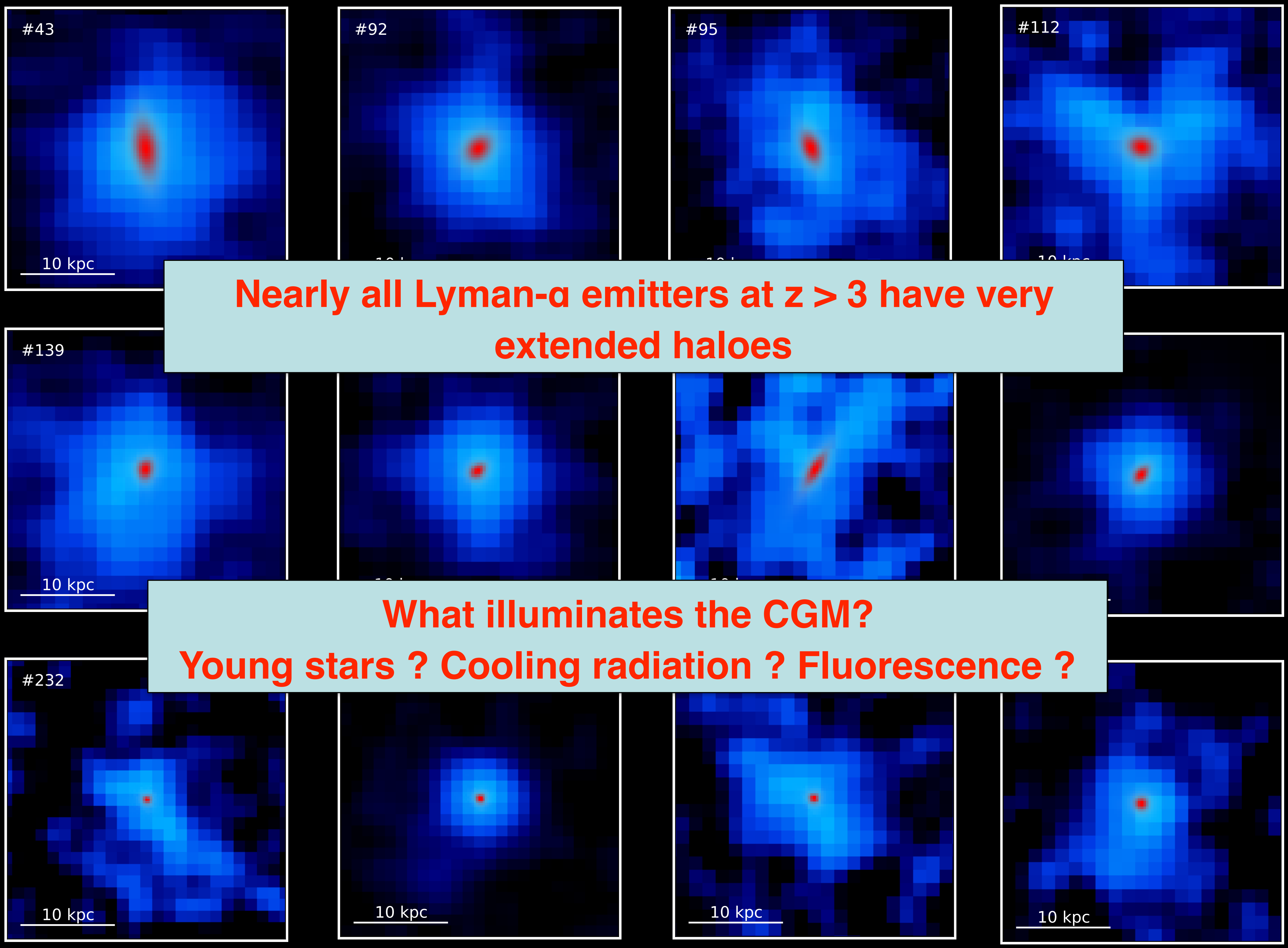
Bacon et al. 2015



Hubble Deep Field South (27 hrs obs.):

- ~ 200 LAEs at z > 3
- 26 emitters > 29.5 AB fainter than HDFS depth

Omnipresence of extended Lyα halos



Nearly all Lyman-α emitters at z > 3 have very extended haloes

What illuminates the CGM?

Young stars ? Cooling radiation ? Fluorescence ?

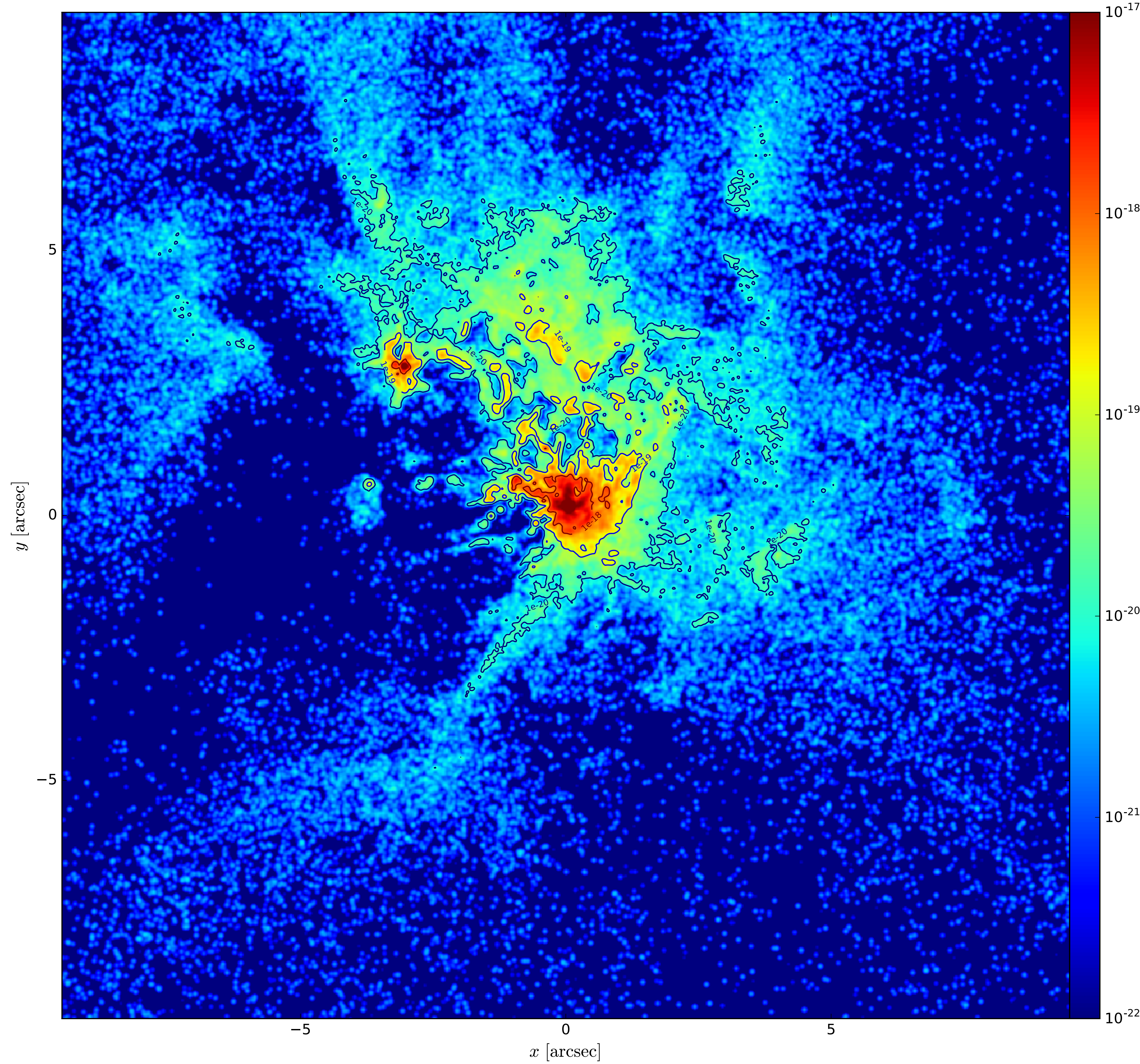
PREDICTIONS FROM SIMULATIONS

Cooling radiation is likely a significant contribution to giant nebulae (Rosdahl+12)

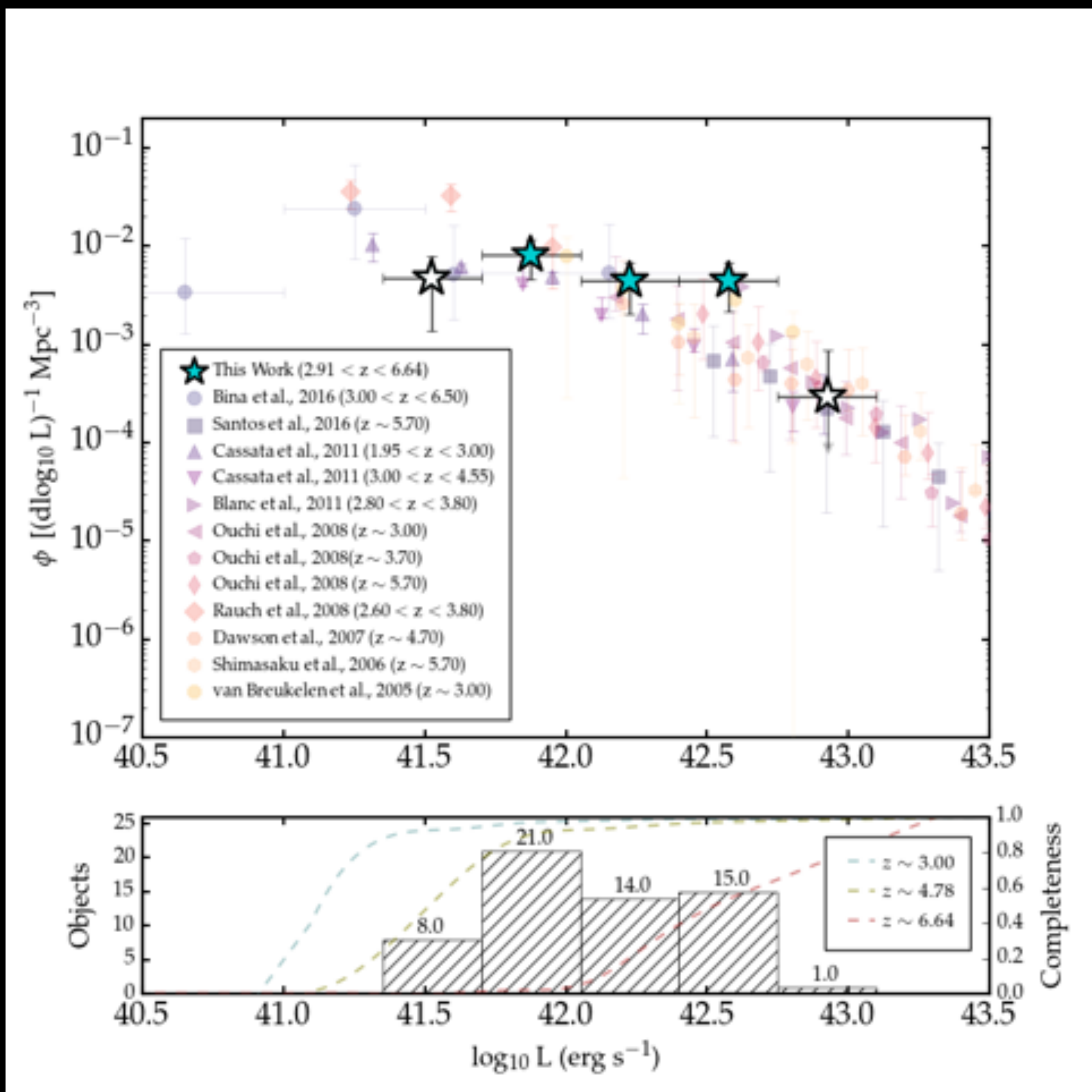
Radiative transfer in AMR simulations:

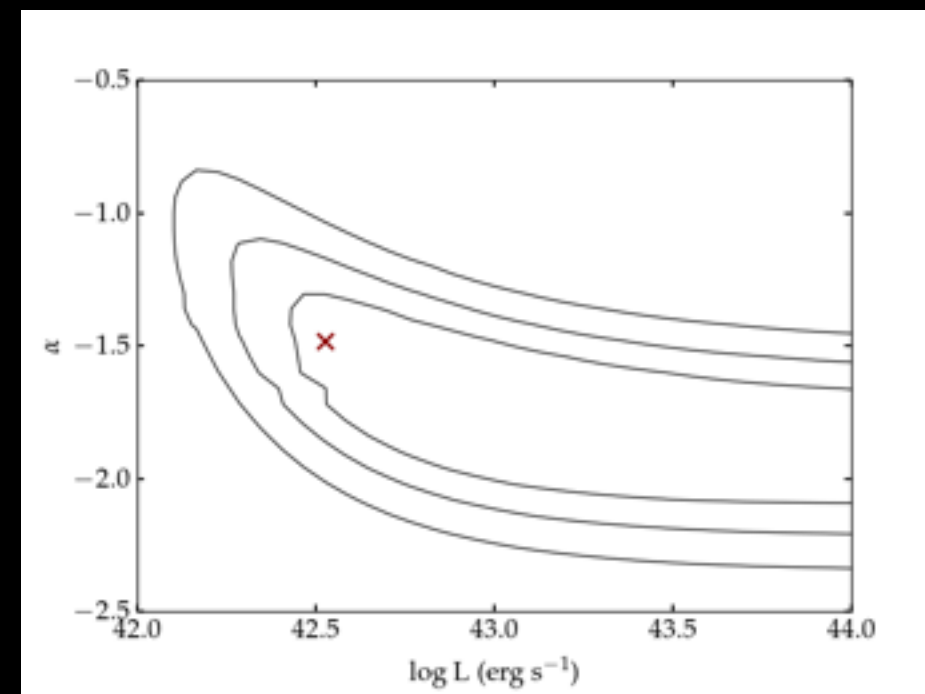
MCLyα, now RASCAS

(Verhamme, Blaizot, Michel_Dansac, Garel)



MUSE AND THE LYMAN-ALPHA UNIVERSE

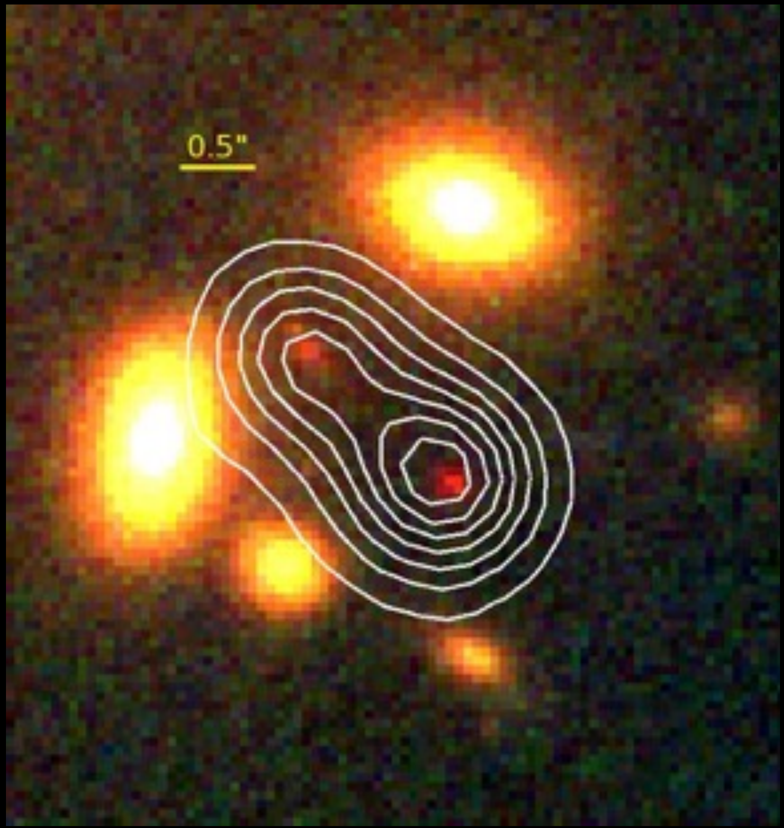




First estimates on the Lyman-alpha luminosity function from the HDFS: constraints on the faint-end slope and L*

Drake et al. 2016

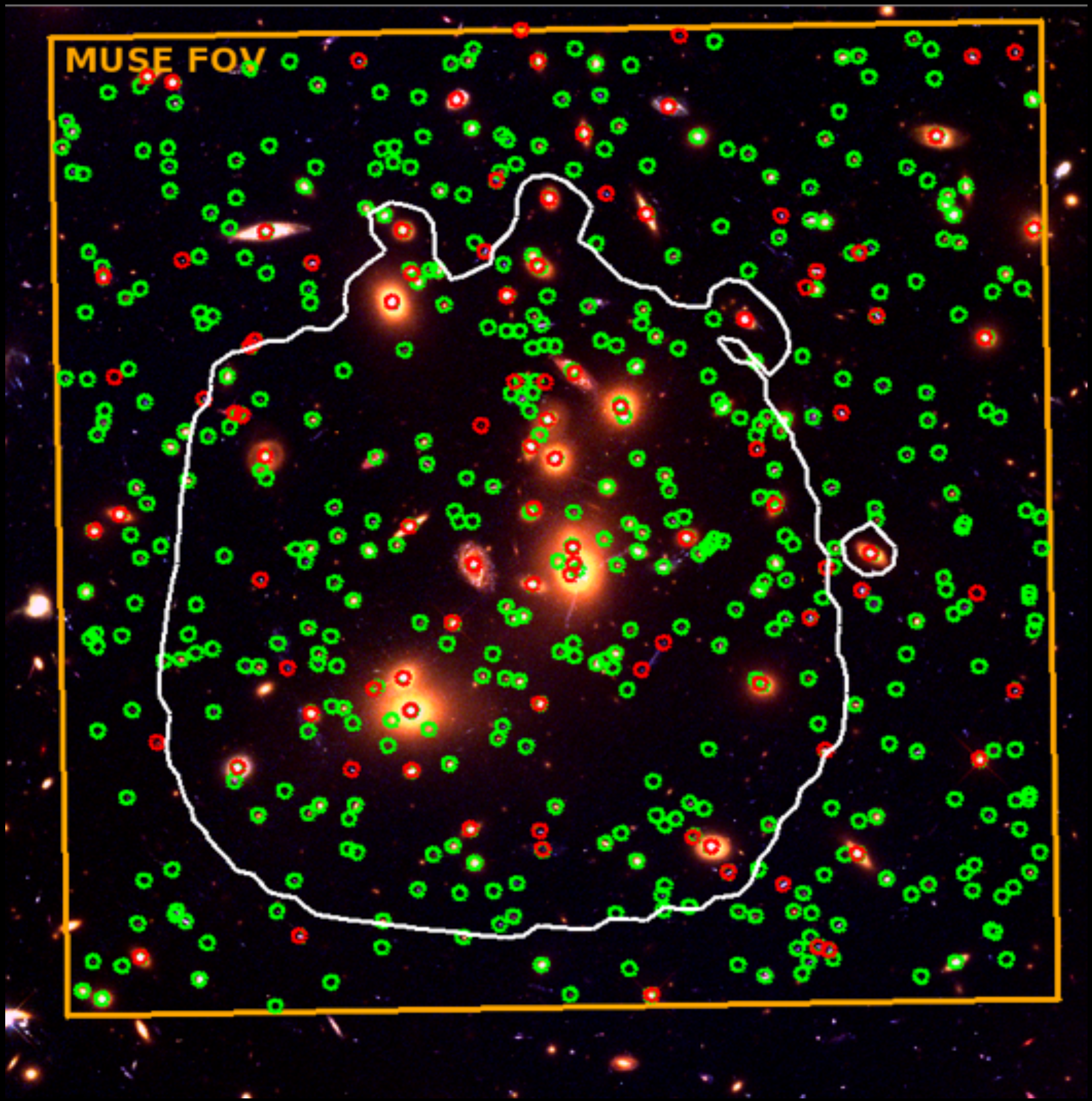
MUSE AND THE LYMAN-ALPHA UNIVERSE



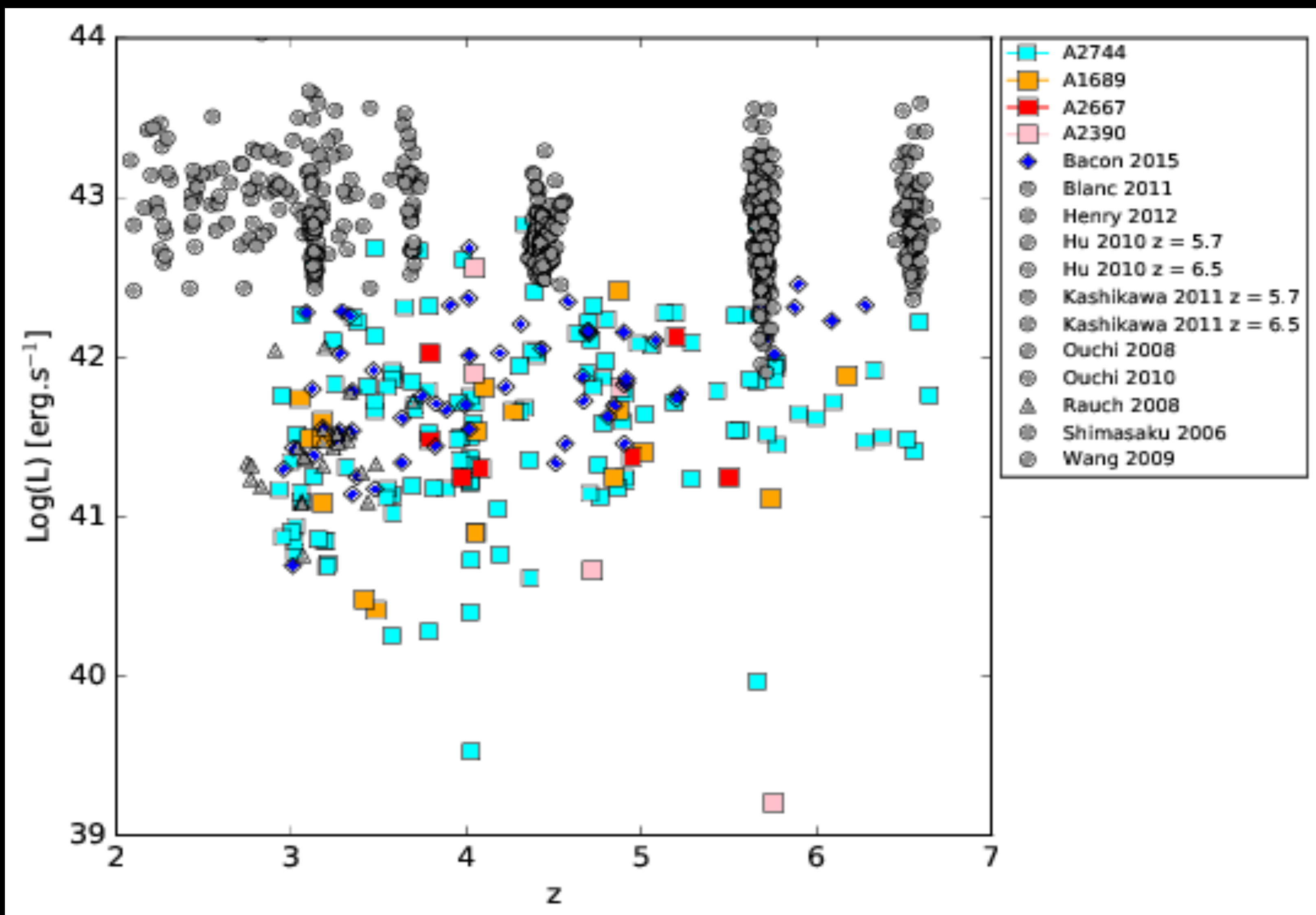
500 redshifts for 436 sources in the Frontier Field cluster A2744

~74 Lyα / arcmin^2

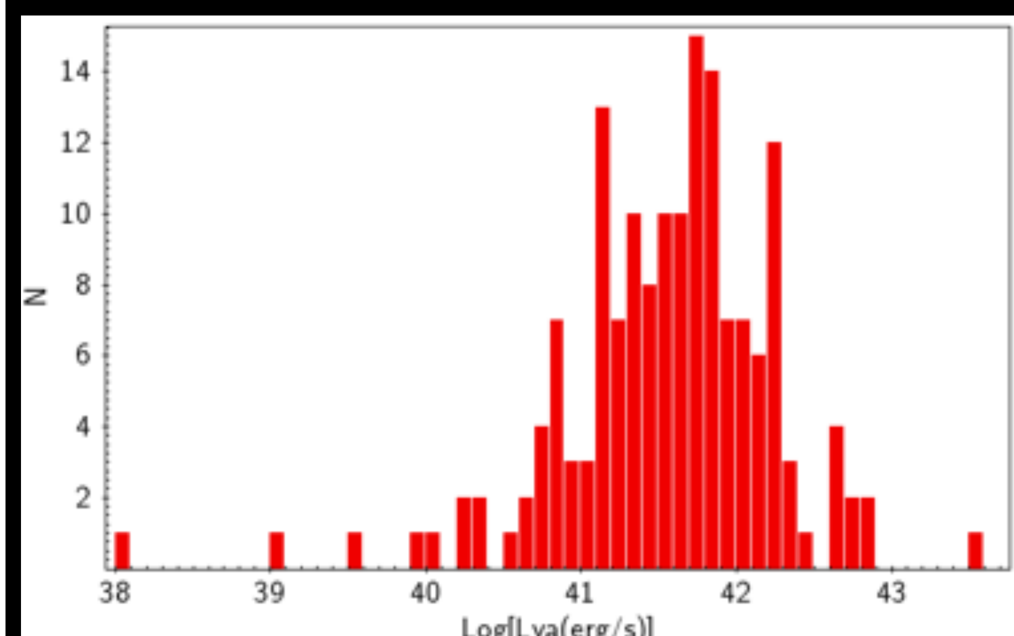
(G. Mahler, CRAL)



MUSE AND THE LYMAN-ALPHA UNIVERSE

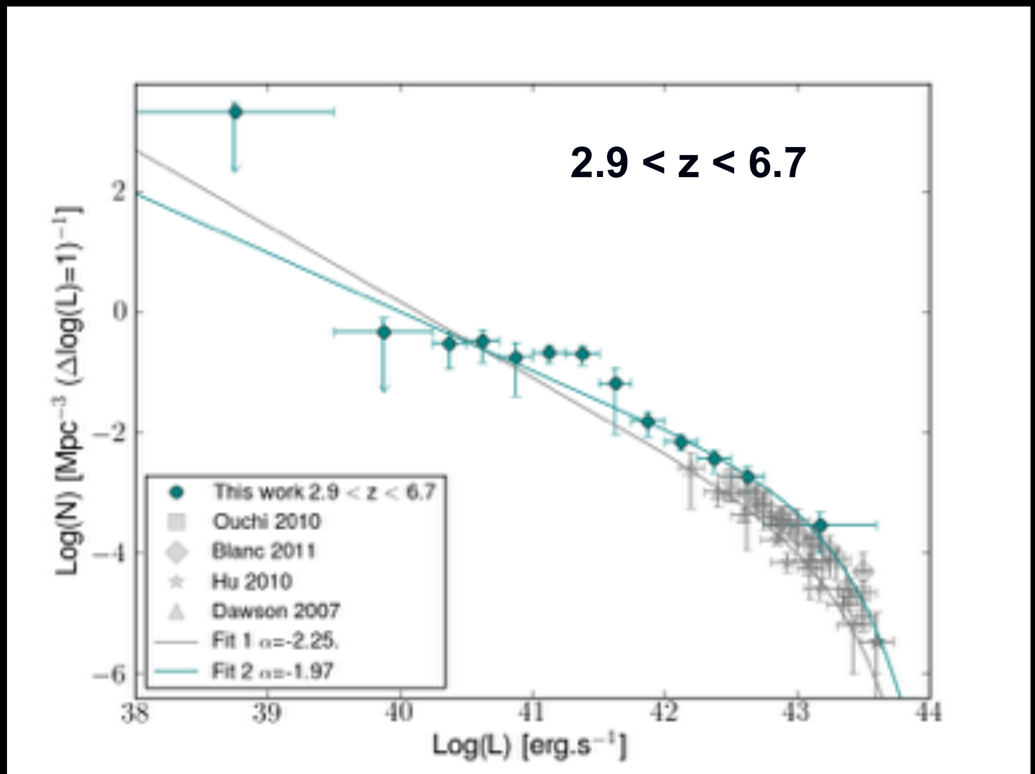


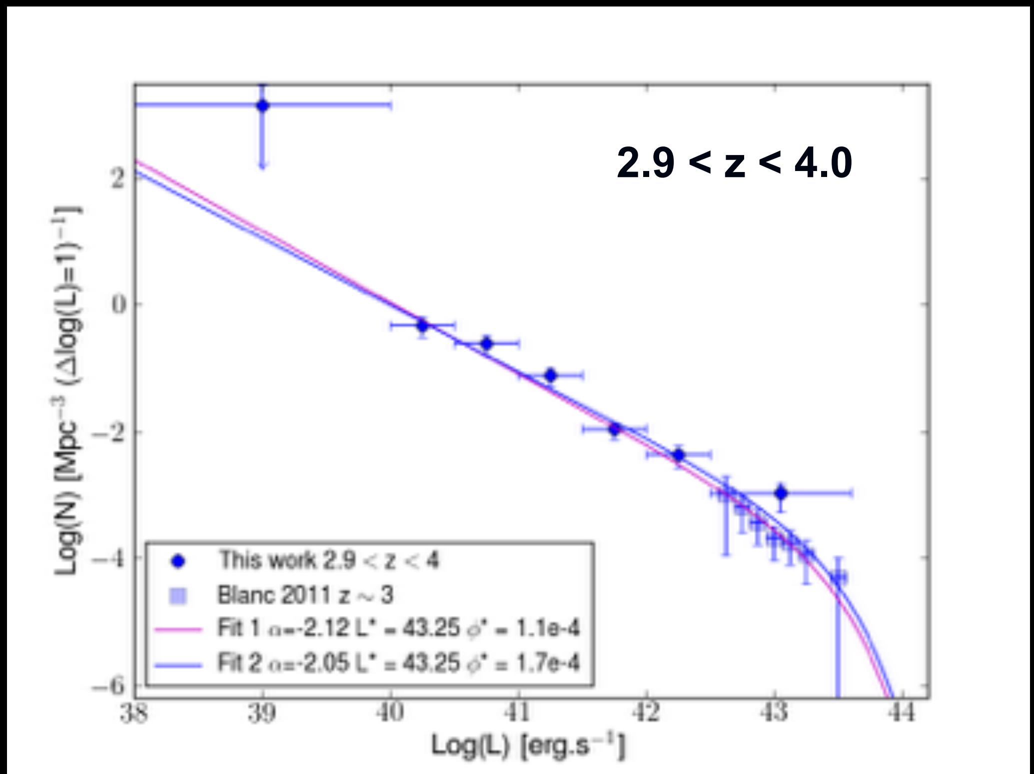
- **161 LAEs** detected behind 4 lensing clusters
- ~1/3 of them are not detected in the UV continuum
- Steep slope for the LF, with α ≲ -2

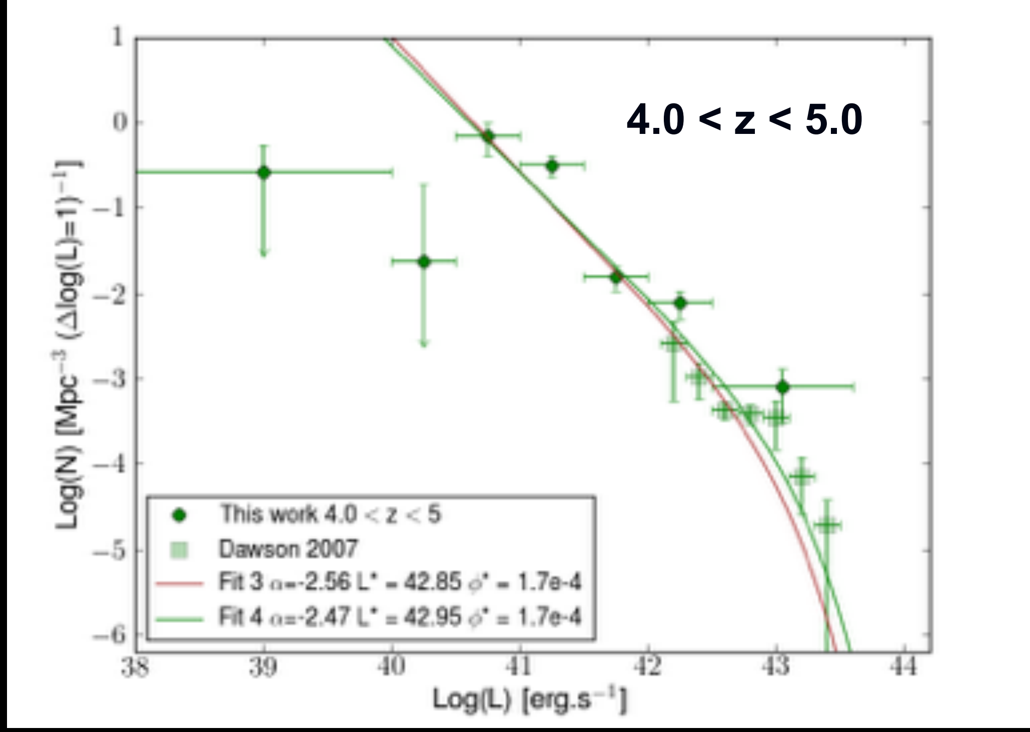


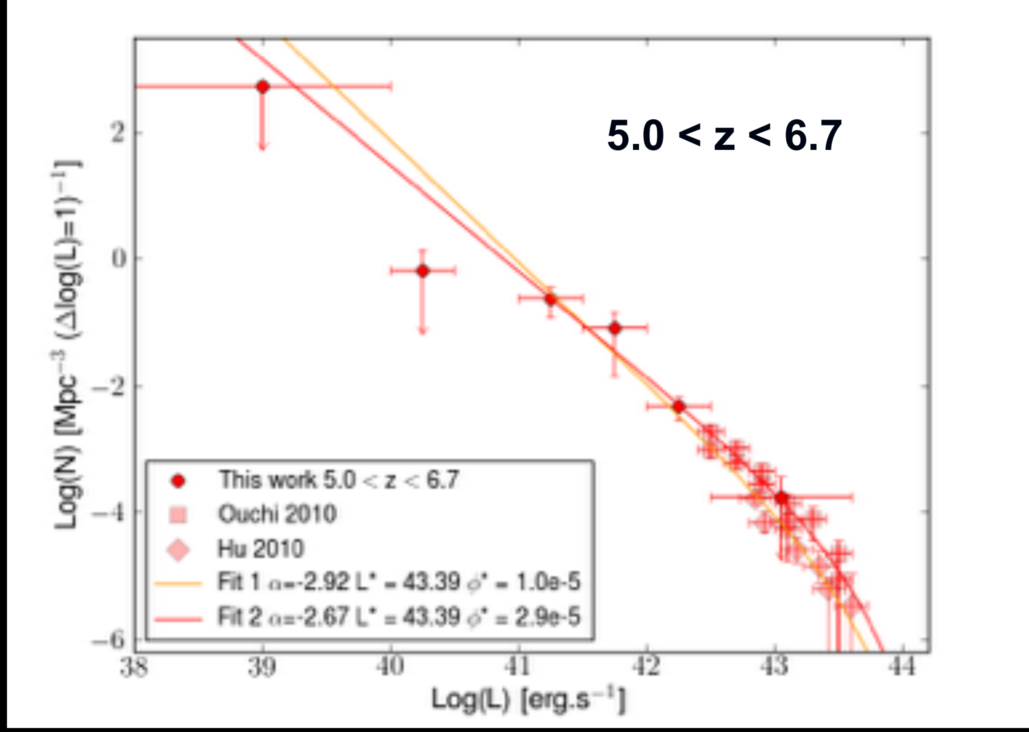
Bina, Pelló et al. 2016 and in prep.

MUSE AND THE LYMAN-ALPHA UNIVERSE







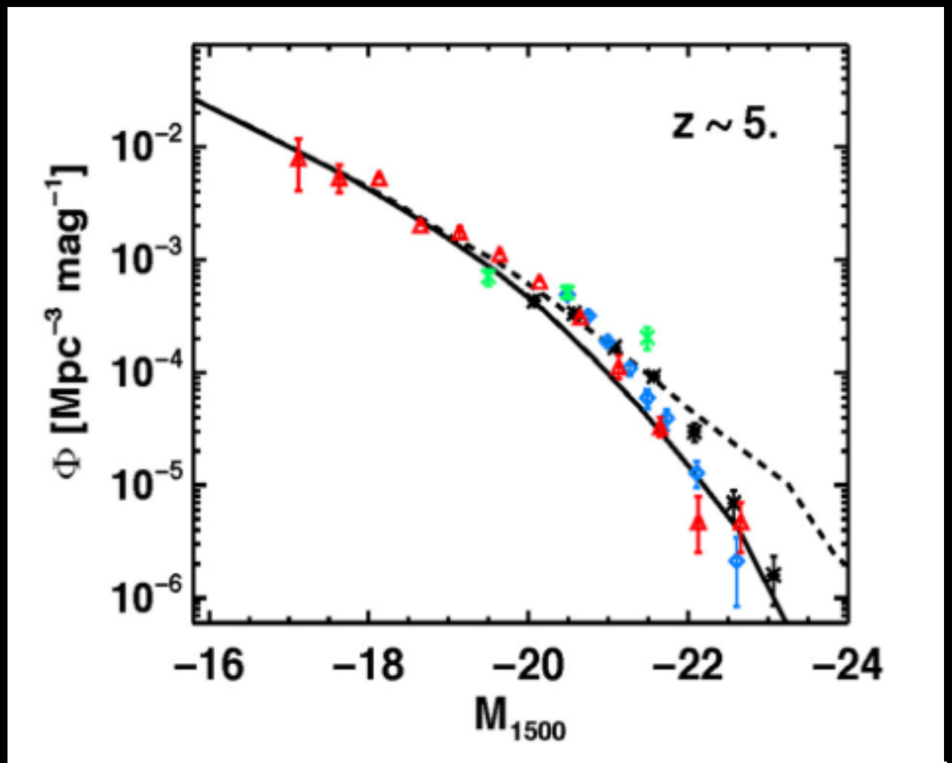


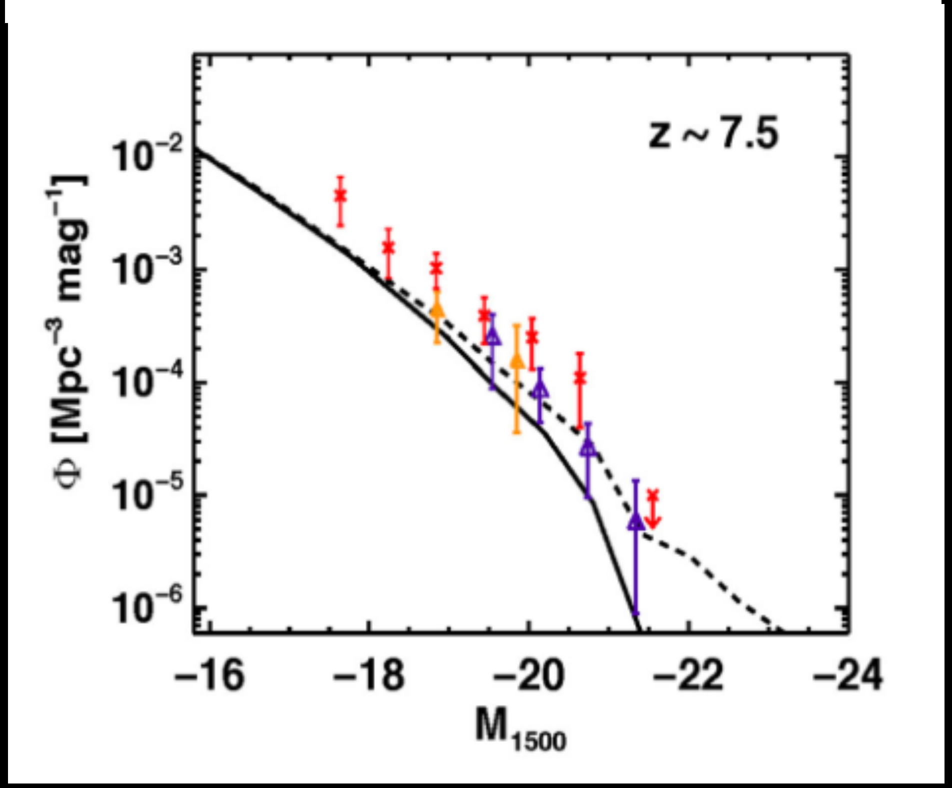
PREDICTIONS FROM SIMULATIONS

- SAMs provide a statistical view of galaxies at high redshifts.

- Predictions for the Lyman-alpha luminosity function, but also:

- the angular correlation function of LAEs
- the fraction of LAEs with redshift
- the distribution of Lyman-alpha line profiles



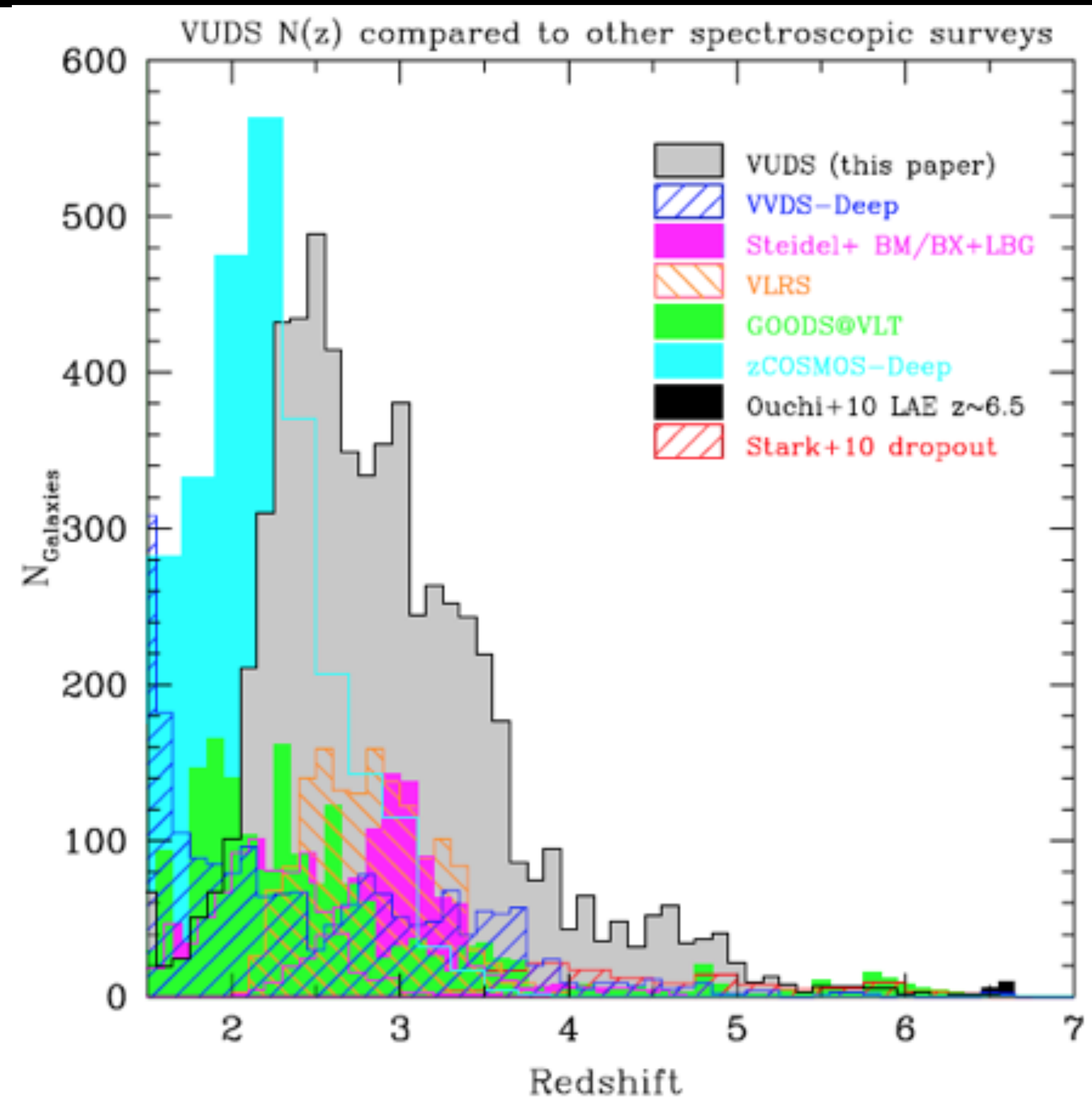


Garel+2012, 2015, 2016

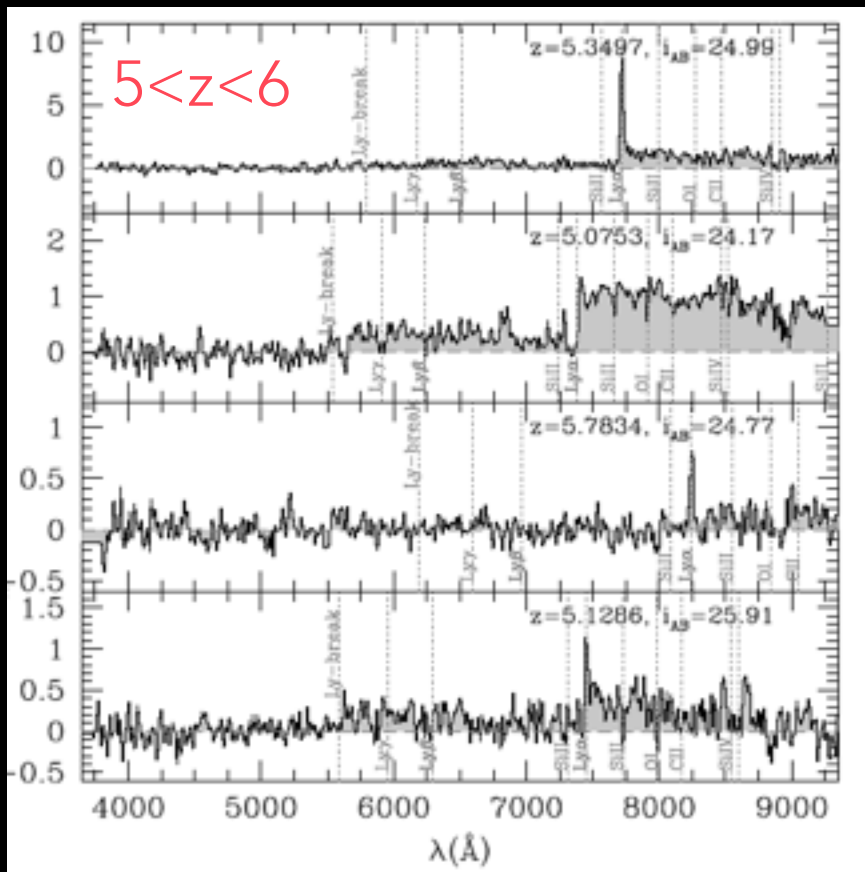
VIMOS ULTRA DEEP SURVEY (VUDS)

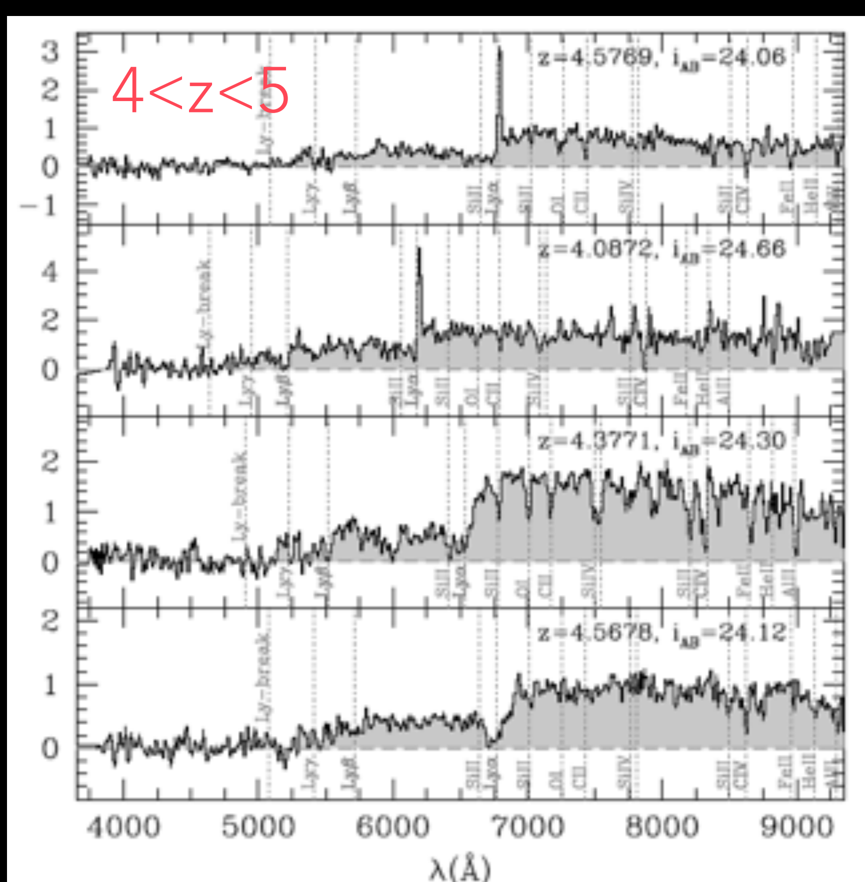
O. Lefèvre (LAM) et al.

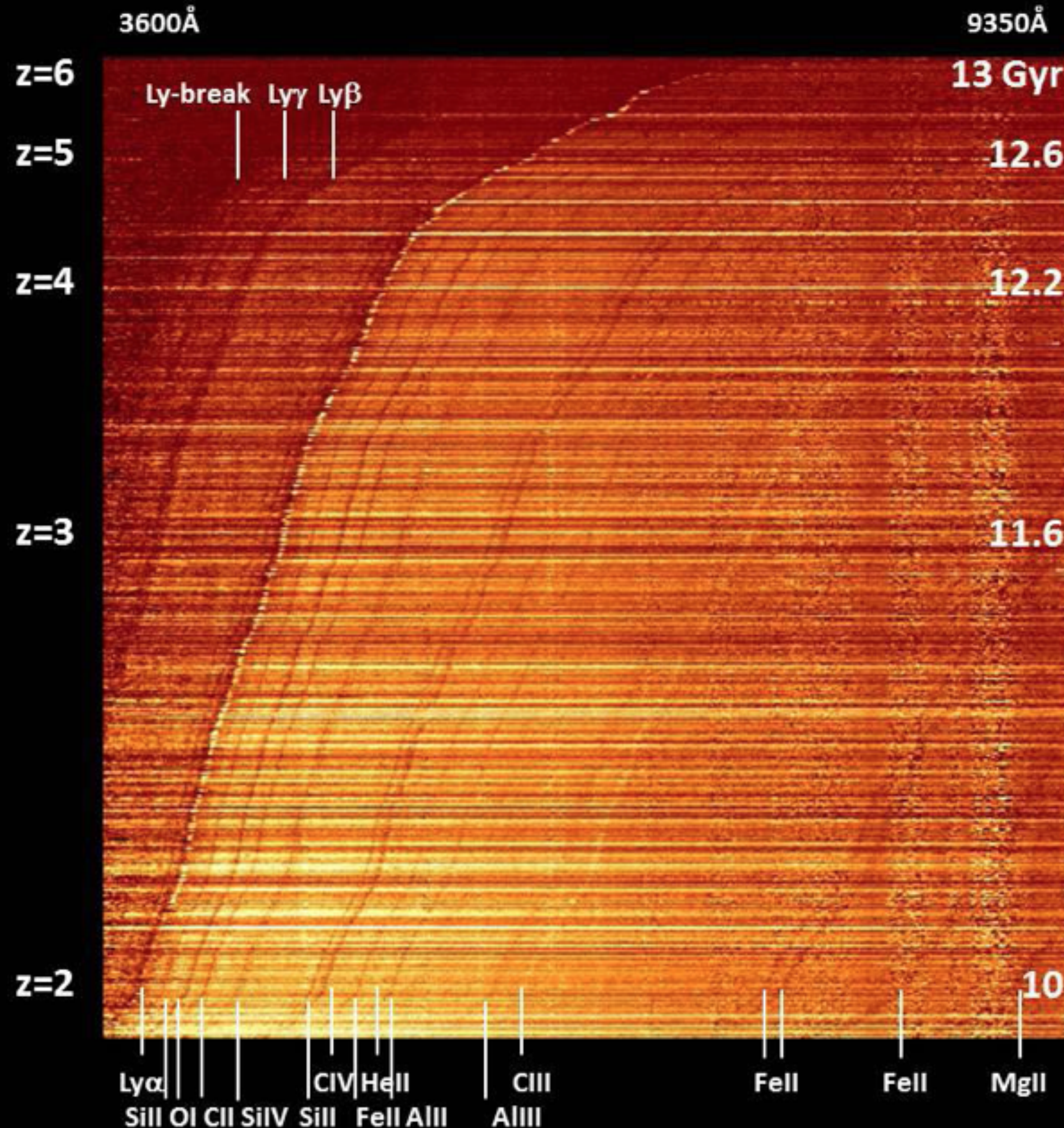
- ESO Large Program: 640h allocated (~80 nights, clear)
- VIMOS on the VLT
- Focused on 2<z<6
- 1 deg^2
- 10,000 targets
- 3 fields: mitigate cosmic variance



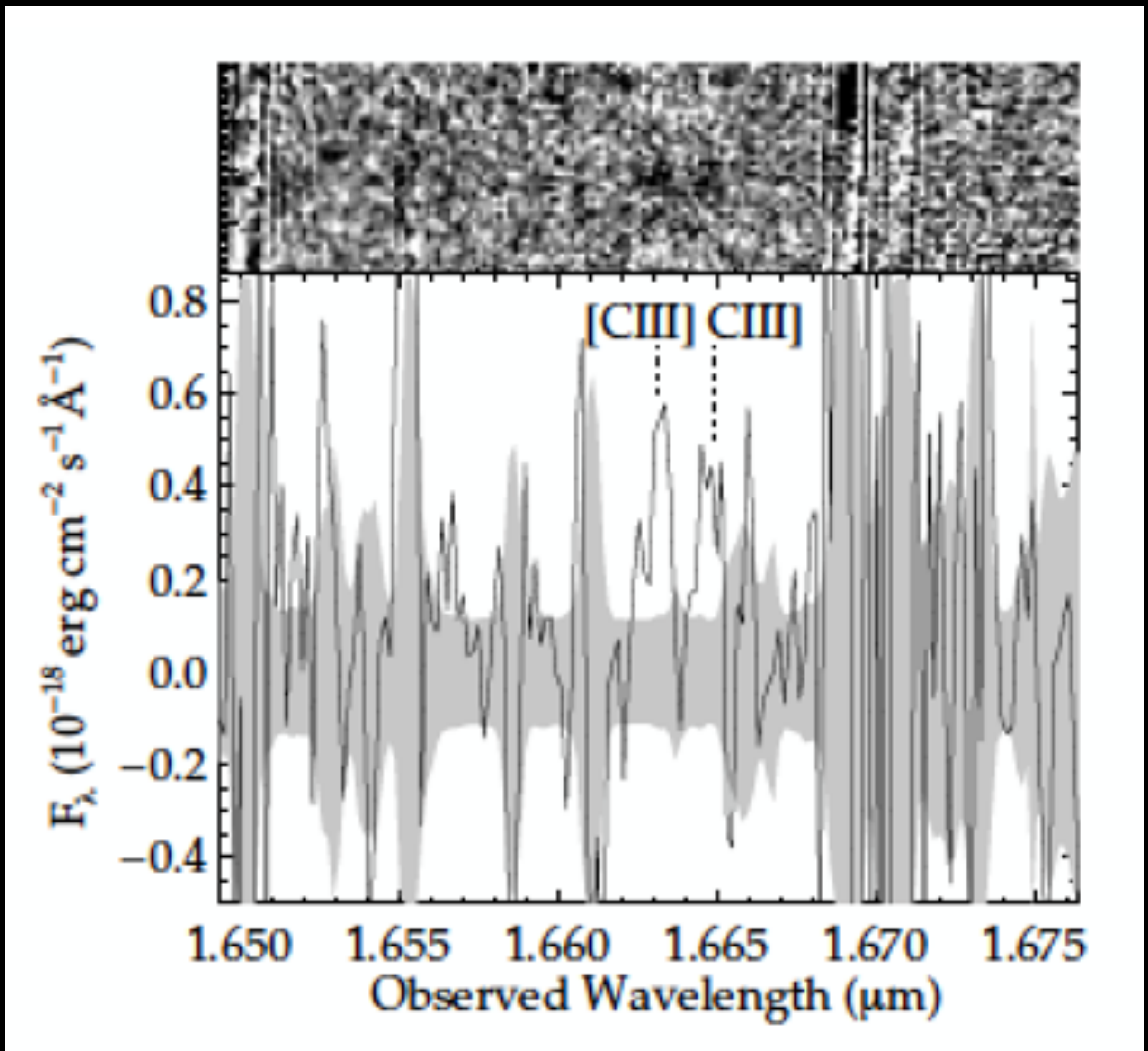
VIMOS Ultra Deep Survey
Galaxies at 2<z<~6



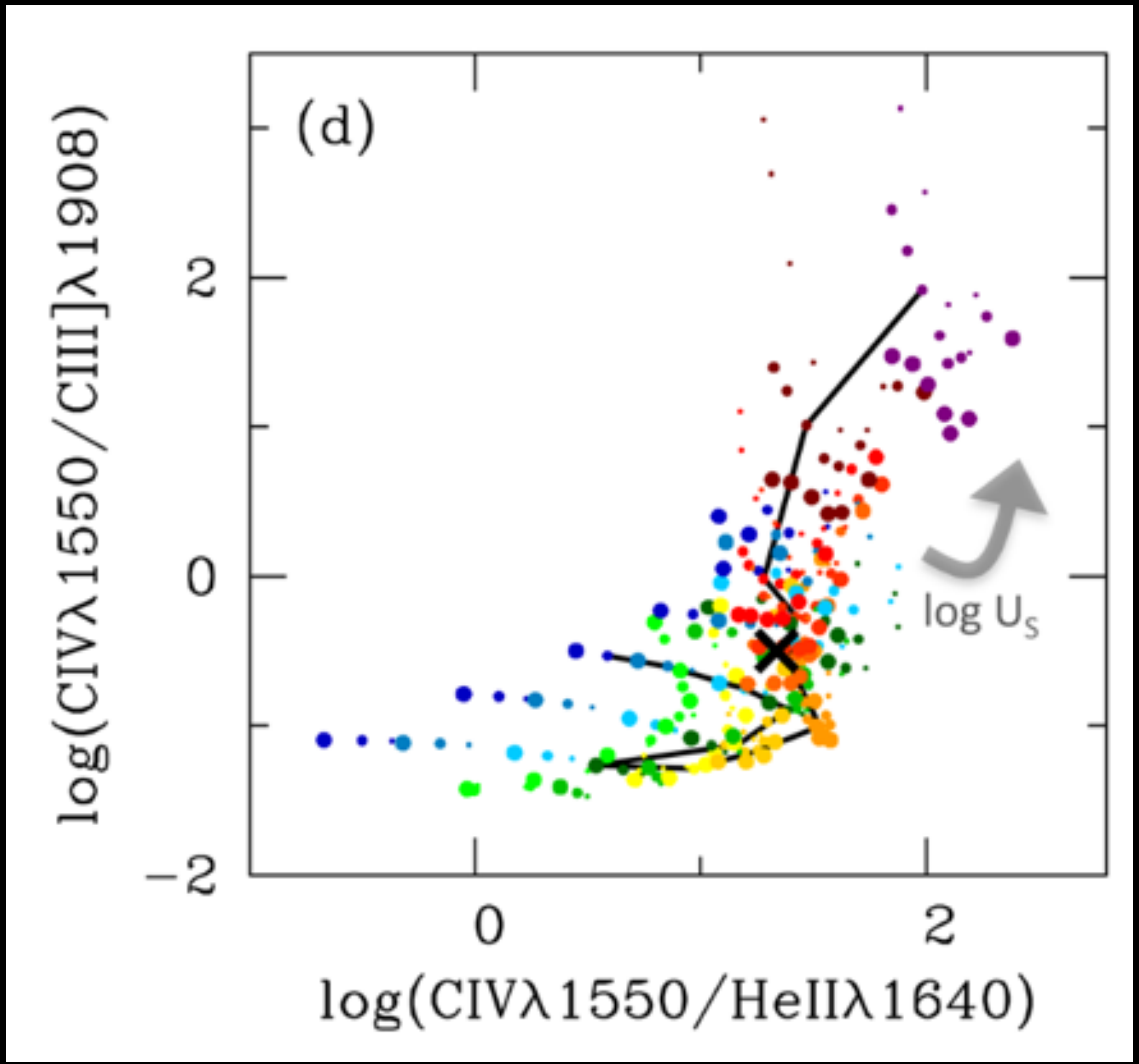




IMPACT OF EMISSION LINES



Stark et al. 2017

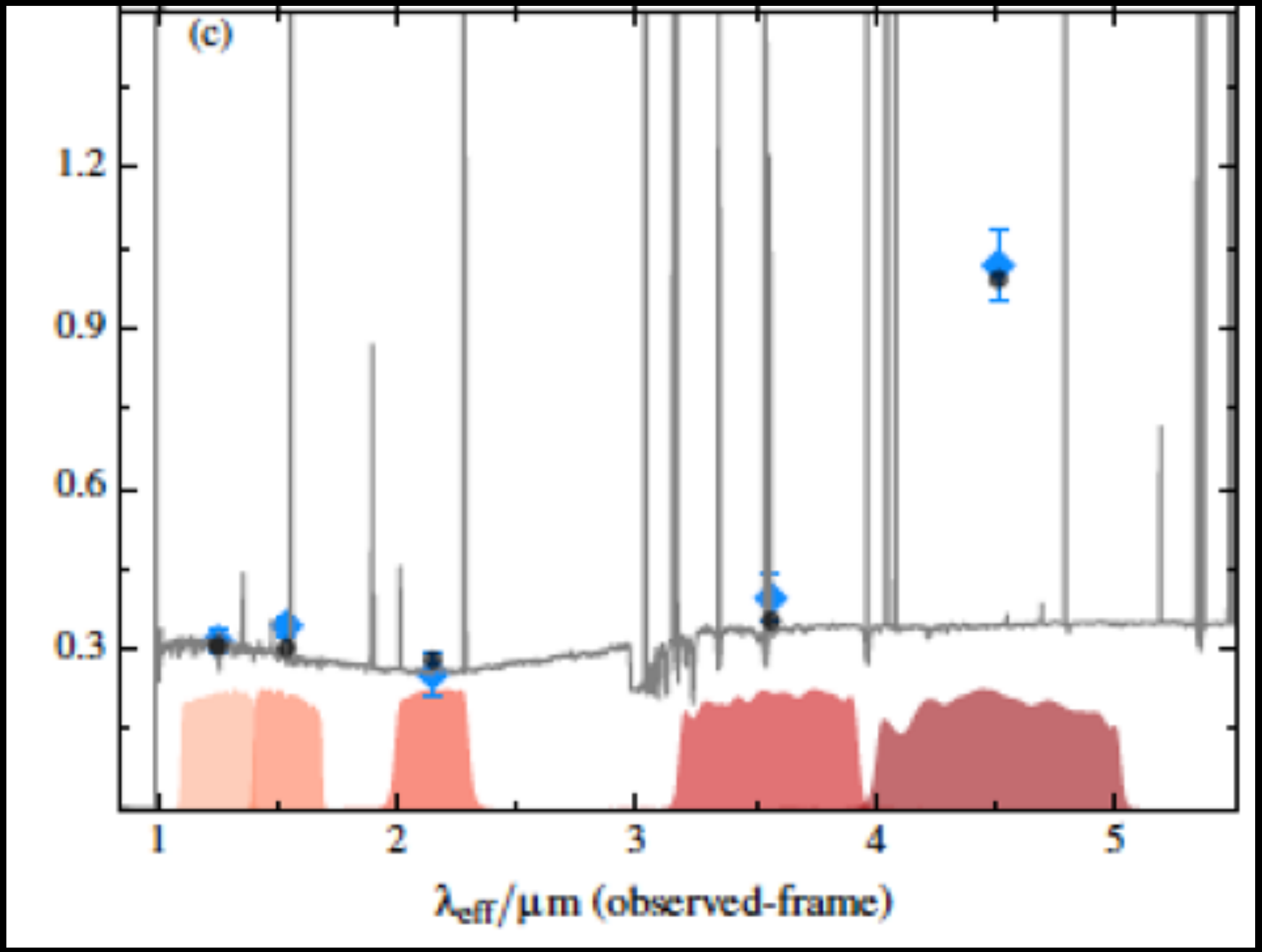


Gutkin et al. 2016

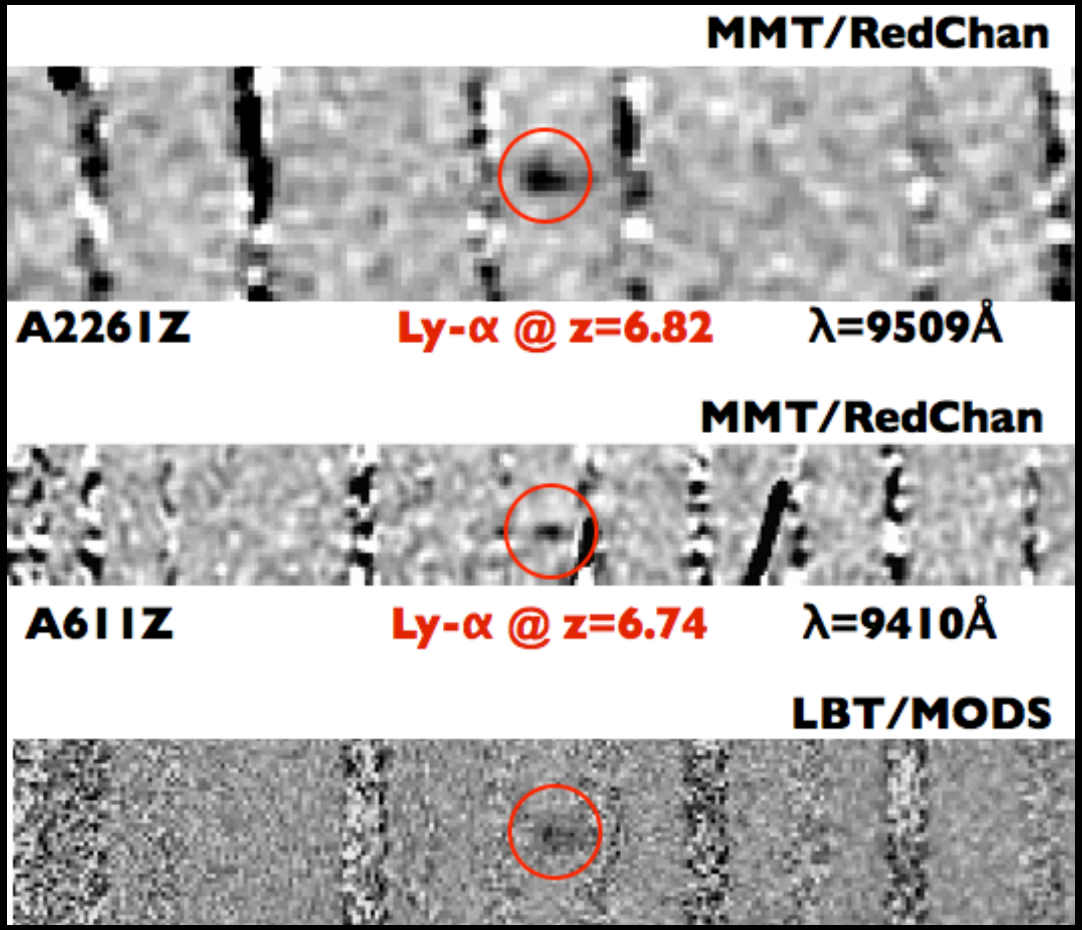
Strong interest in using other emission lines than Lyman-alpha: CIII], CIV, …

At z>6 CIII] could be the brightest spectroscopic feature when Lyman-alpha is suppressed but low equivalent width (typically 12 Angstr.)

IMPACT OF EMISSION LINES



Stark et al. 2017

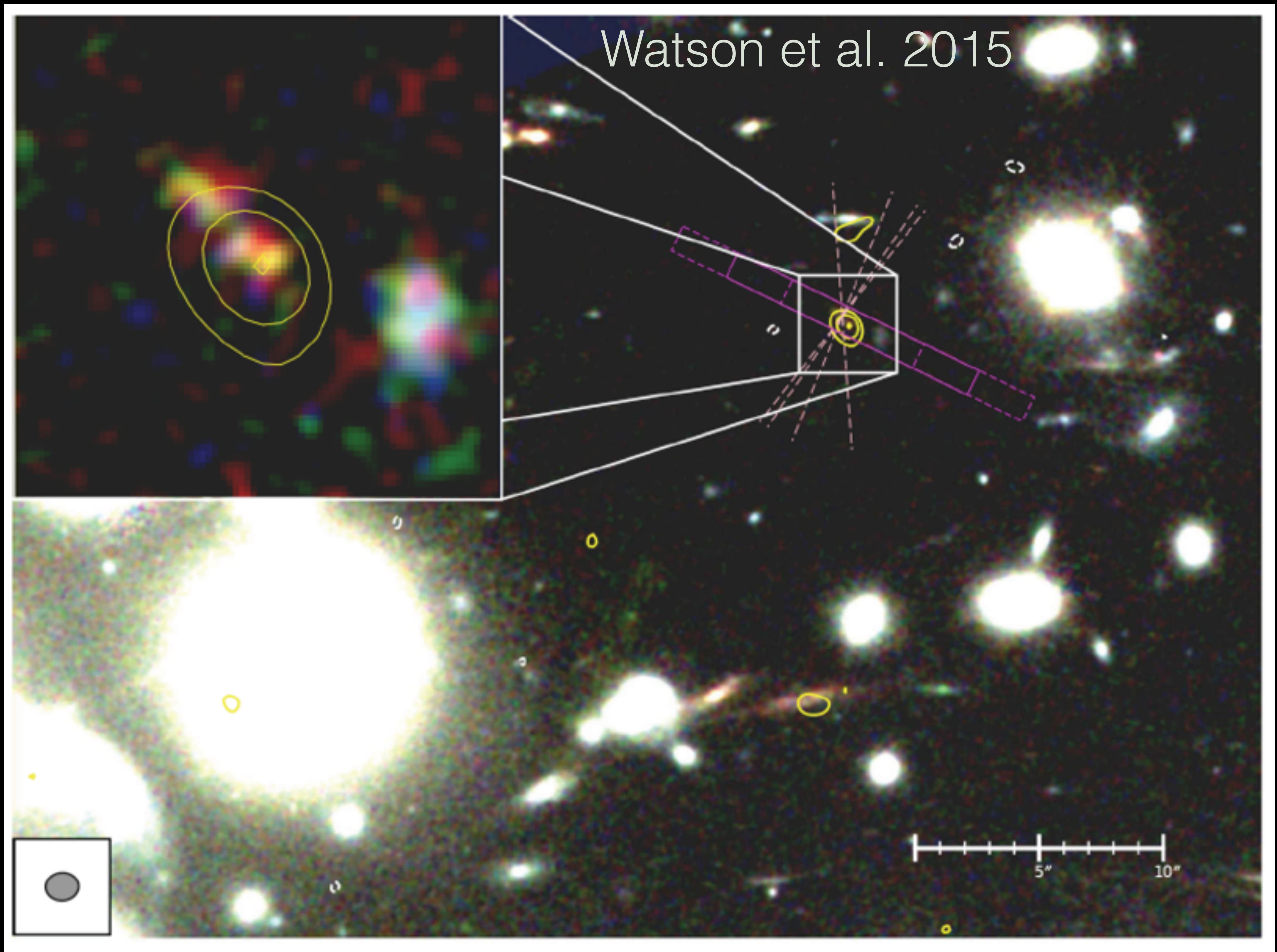


B. Clément

It is essential to account for nebular emission lines when fitting the SED of z>5 sources (e.g. BEAGLE) => lower stellar masses

For specific redshifts strong impact of emission lines in Spitzer / IRAC => selection of sources at z=6.7

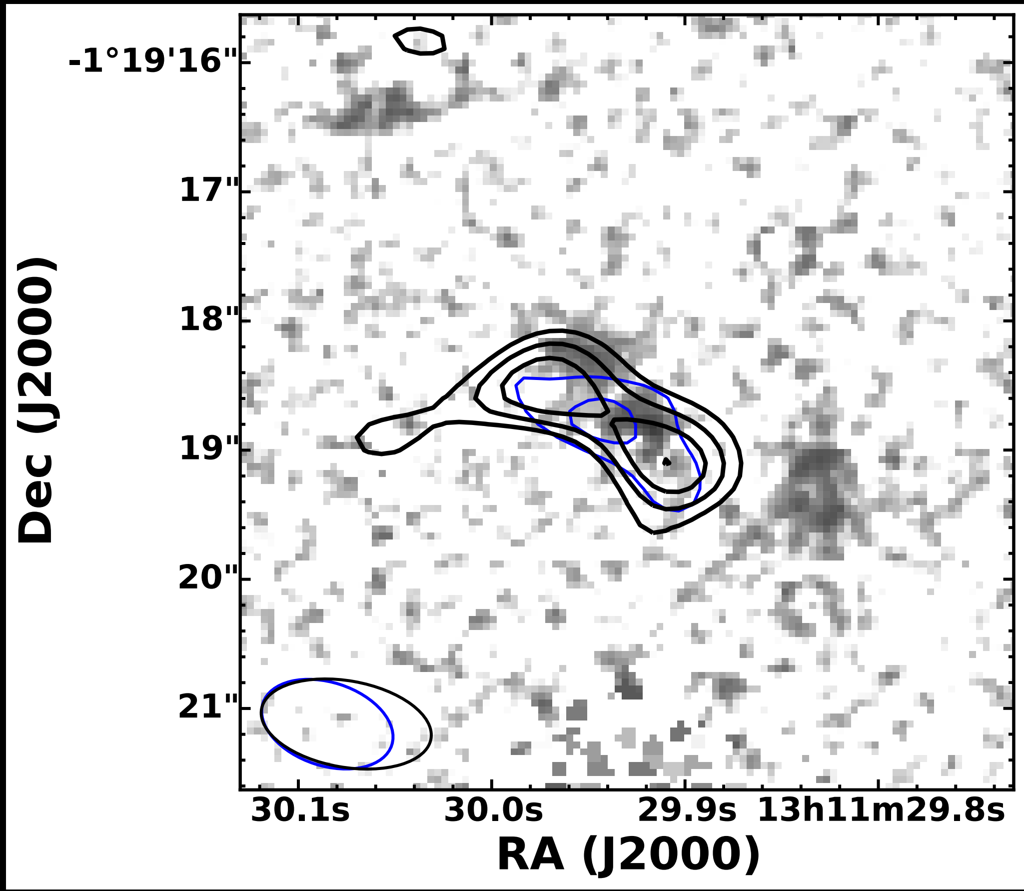
ALMA AND HIGH REDSHIFT SOURCES



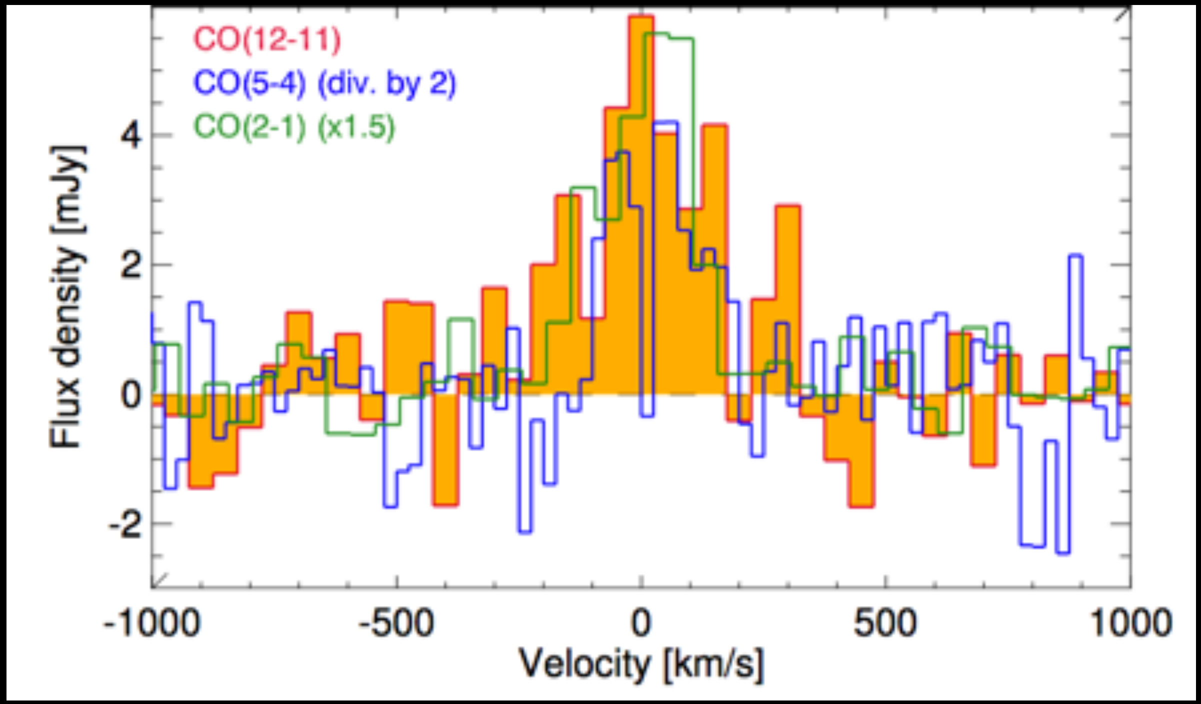
ALMA AND HIGH REDSHIFT SOURCES

- Searching for typical (~< L*) UV-selected sources at (sub)mm wavelengths starts to be possible with the combination of ALMA (and NOEMA) + lensing

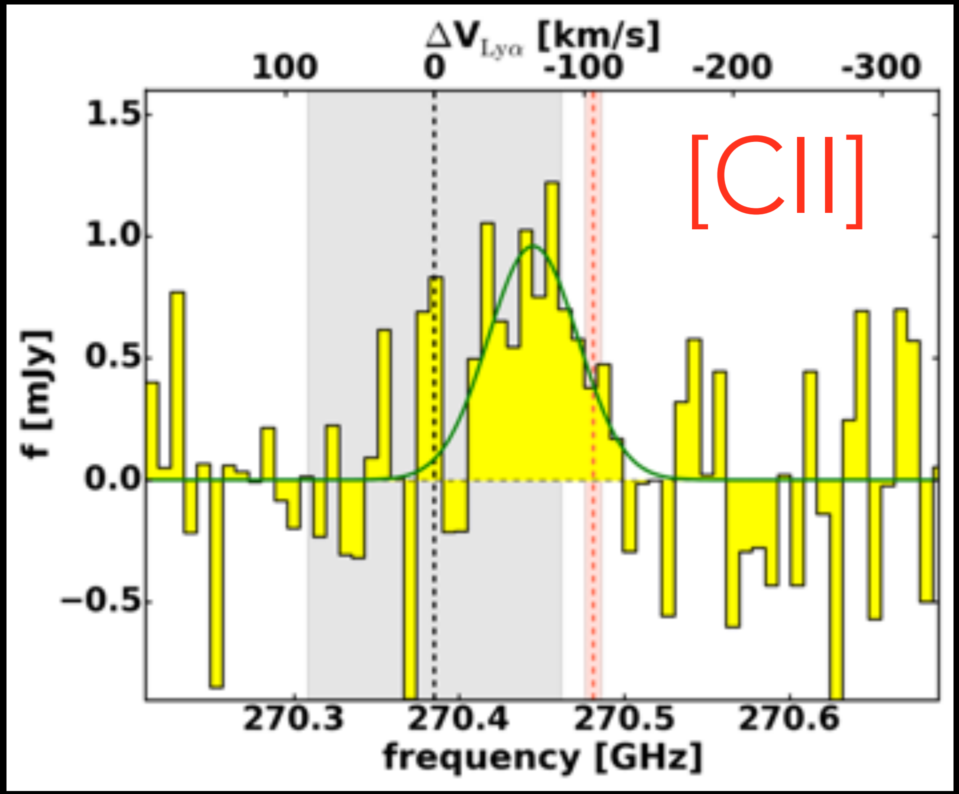
- Some [CII] detections at z>6



Béthermin et al. 2016



Knudsen et al. 2017



[CII] intensity mapping at z>4.5 with CONCERTO

3D spectrometer to map the star formation at z>4.5 with [CII].

Answer the questions of whether dusty star-formation contributes to early galaxy evolution, and whether dusty galaxies play an important role in shaping cosmic reionization

Cross-correlations:

- With [OI] and [NII] lines: ISM physics
- with HI : Capture physics during EoR, including the ionized bubble sizes and the mean ionization fraction
- With galaxy redshift surveys: When did the Universe produce dust?

- 2 Sq. Deg. during 1500 hours
- $\delta z=0.05$ at $z=7$
- 200 GHz < υ < 360 GHz

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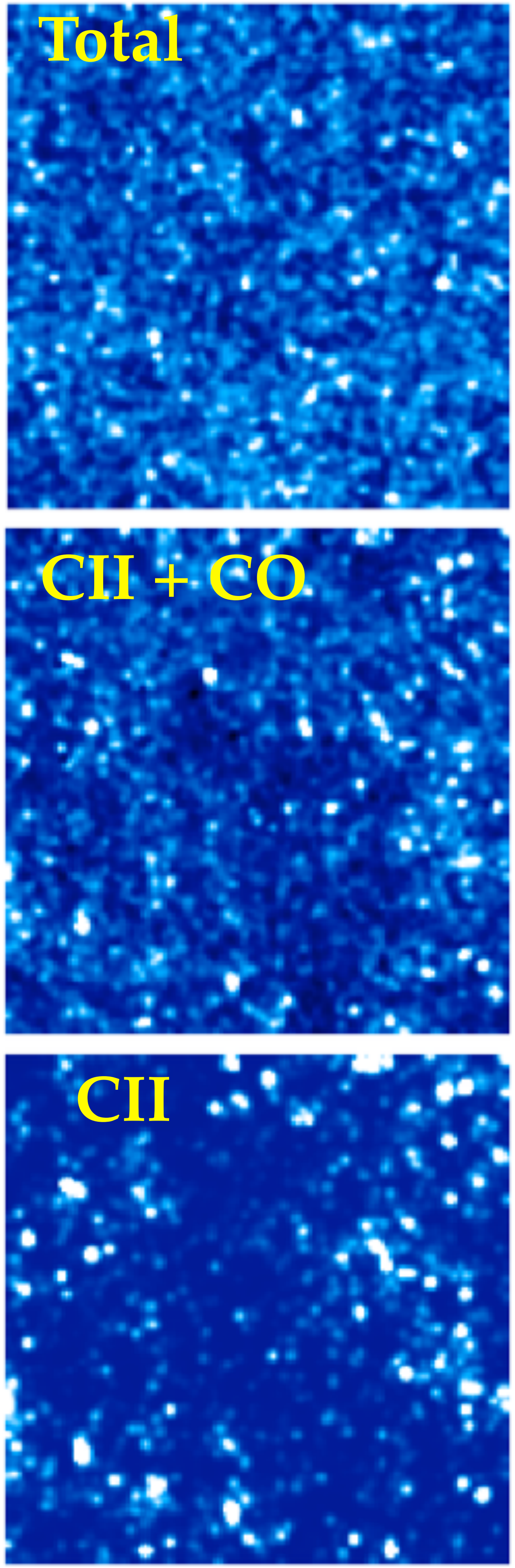
(G. Lagache)



1.4x1.4 degrees CONCERTO simulated sky maps at z=5.5±0.1

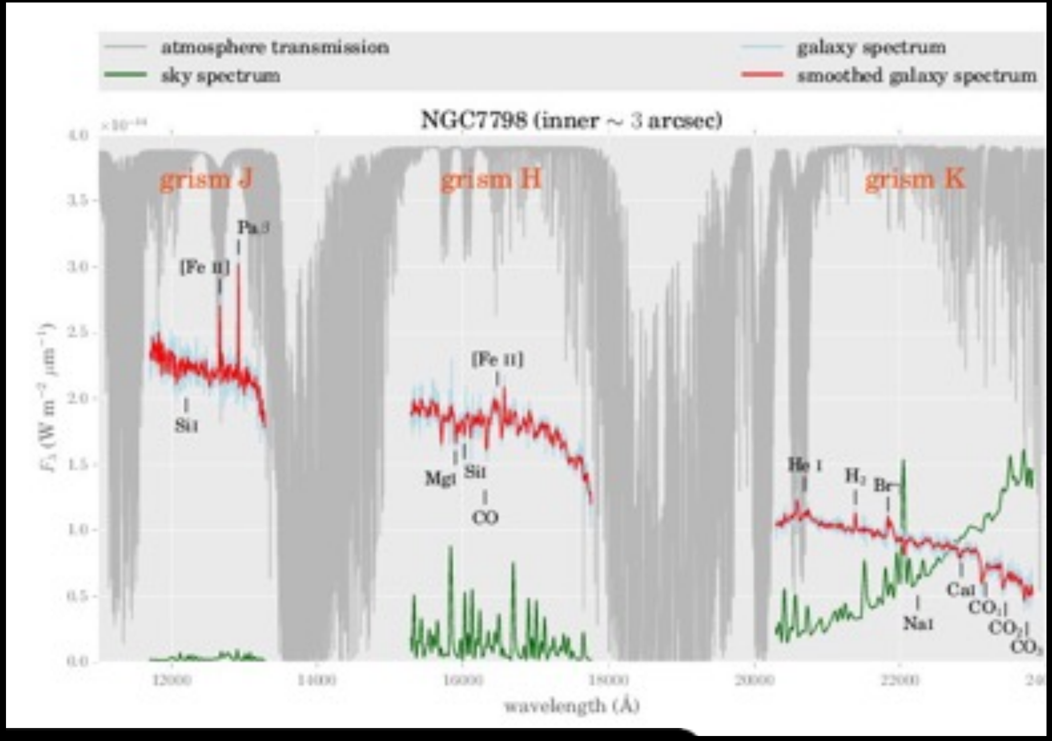
INSTRUMENTATION: EMIR

A unique view of galaxy formation and reionisation

PNCG gave support to the French teams involved in the exploitation of the EMIR/GOYA survey on GranTeCan (10.4m, Canaries)

EMIR : configurable multi-slit spectrograph in the near-infrared. Under commissionning since June 2016

French teams : IRAP, LAM et CRAL



EMIR/GTC is an ideal tool for the direct study of first galaxies and reionisation, giving access to the physical properties of galaxies at their early assembly stage.

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MUSE+AO

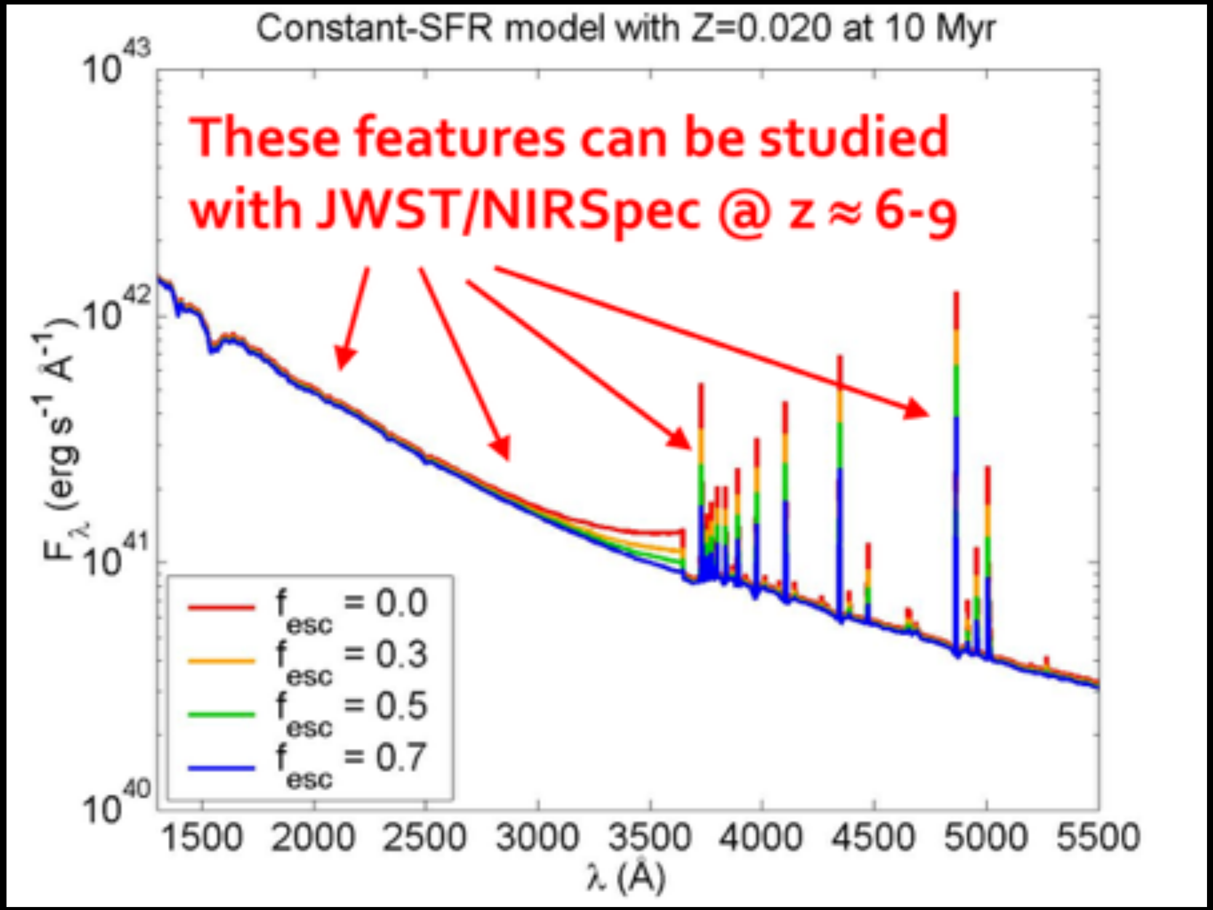
- MUSE complements HST with its deep spectroscopic capabilities
- With the advent of Adaptive Optics on VLT/UT4 the sensitivity will be even improved
- Call for public deep fields with MUSE+AO (60 nights DD time)
- Possible coordination with future JWST deep fields

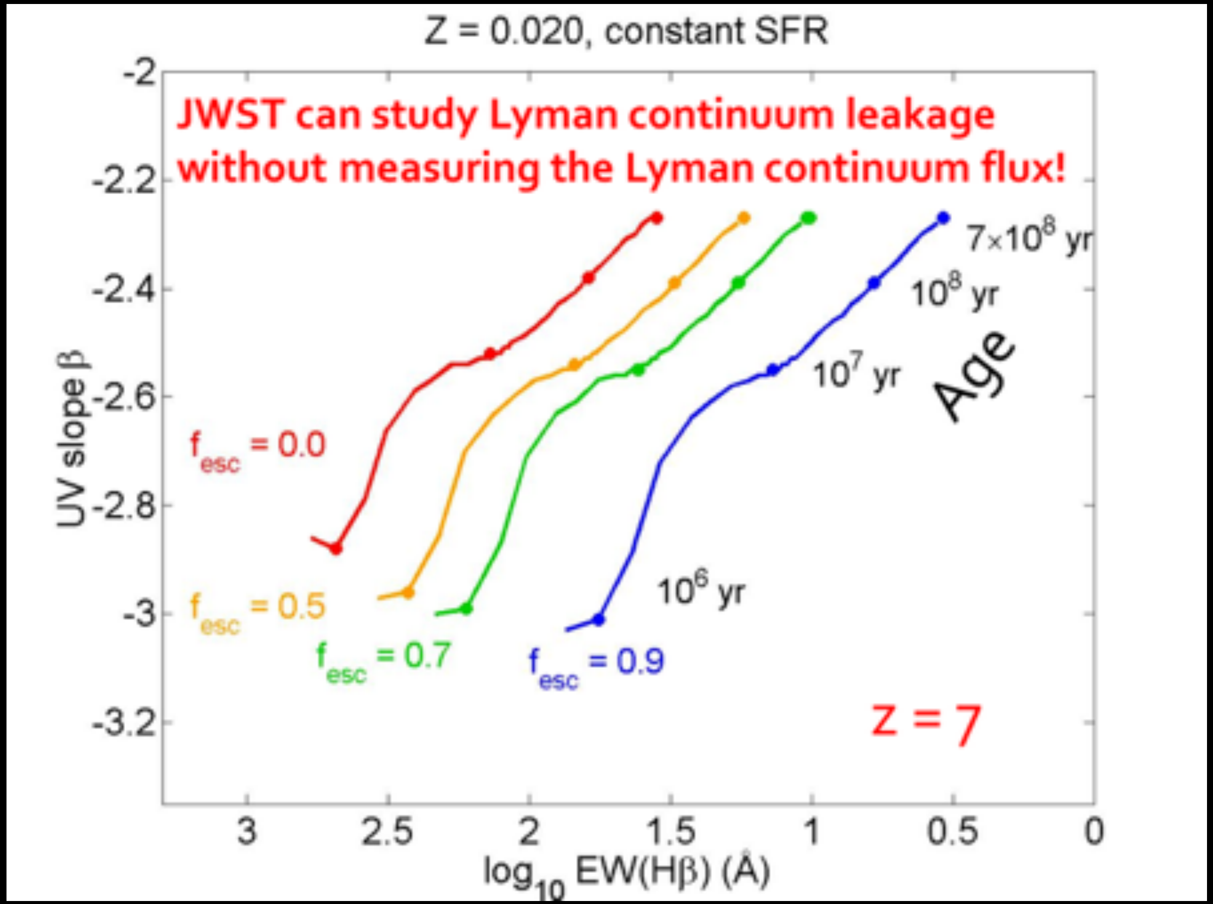
JWST

- The James Webb Space Telescope is clearly the major leap for first light sources.

Strategy foreseen:

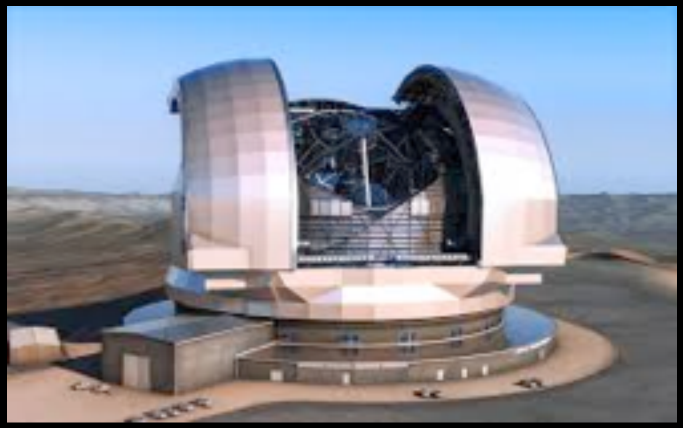
- Very deep extragalactic survey with NIRCAM
- Spectroscopic follow-up with NIRSpec (Low-res and Mid-res)
- Photometric follow-up with MIRI





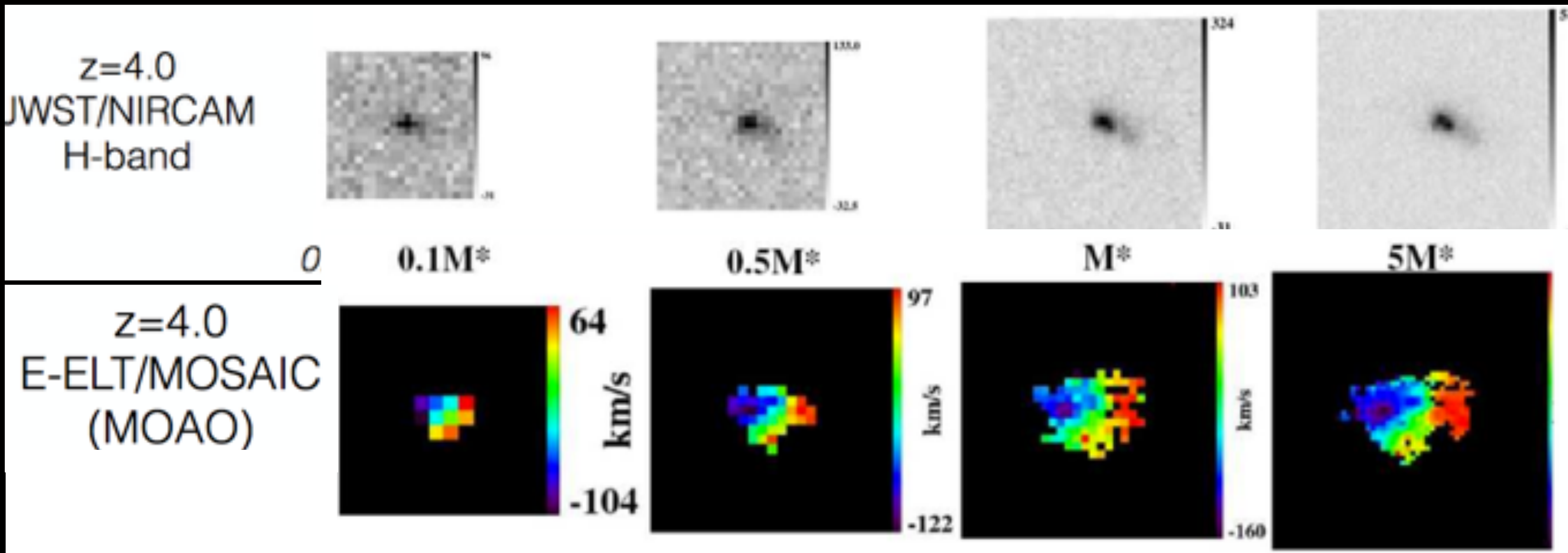
Zackrisson et al. 2013

E-ELT (~ 2024)

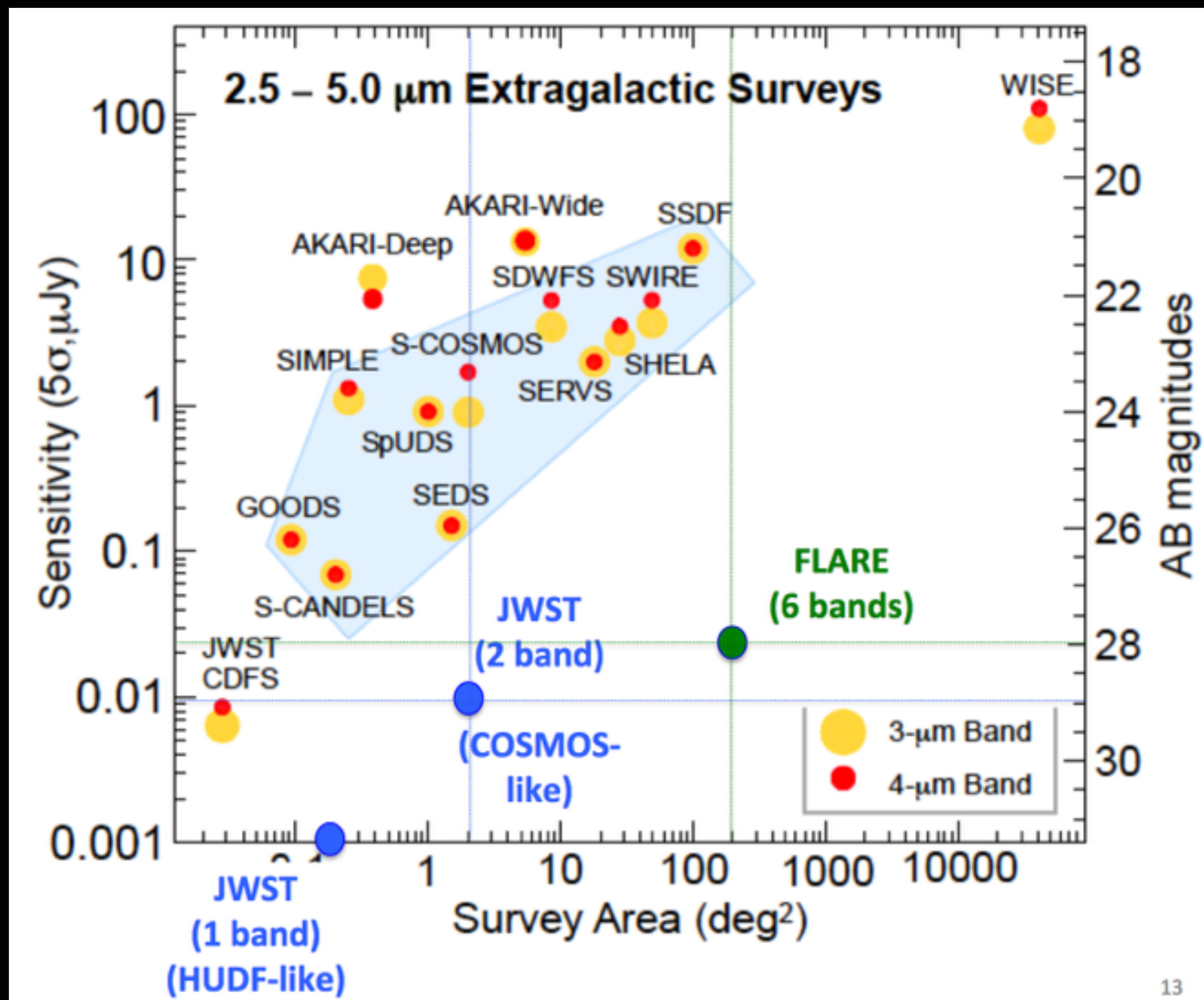


- HARMONI: **First light IFU instrument,** 0.47 - 2.5 microns
  - 0.86″ x 0.61″ with 4 mas spatial pixels: follow-up of the brightest sources at z > 3, morphology, kinematics
  - 9.12″ x 6.42″ with 60x30 mas spatial pixels: HARMONI deep fields, follow-up of faint NIRCAM-selected sources
- MOSAIC, **multi-object spectrograph**, 0.4 - 1.8 microns
  - 7 x 7 arcmin FoV with 200 x 0.6″ apertures
  - 20 IFUs of 2″ x 2″

M. Rodrigues, SF2A2015



FIRST LIGHT AND REIONIZATION EXPLORER

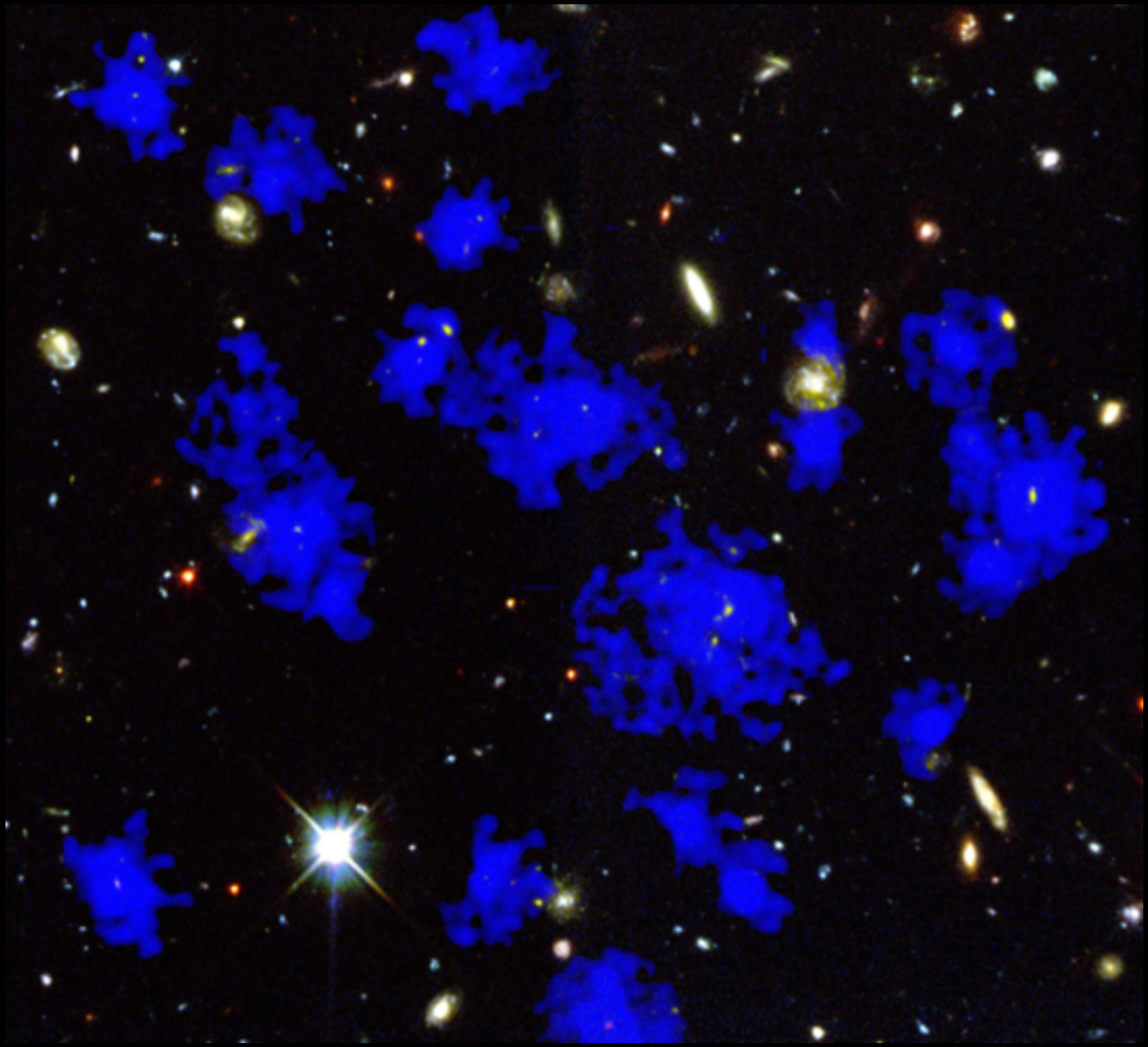


D. Burgarella

CONCLUSIONS

- The picture of reionization becomes less and less blurry between CMB, high z quasars and observations of first sources.
- Still : observing the first sources is clearly limited by small number statistics especially at $z>7$
- Assumptions on extinction, number of low-L sources and escape fraction of ionising photons.
- Large spectroscopic samples at $z > 3$ become available with MUSE deep fields (mostly LAEs) and VUDS, improving our knowledge of selection effects and the UV properties at high redshift.
- Numerical simulations are making very good progress and the future is bright in particular with JWST and EELT.

THANK YOU!



Wisotzki et al. 2016