JOHAN RICHARD

(CRAL)

First Galaxies

Journée THESEUS France - 23 septembre 2019 - Paris

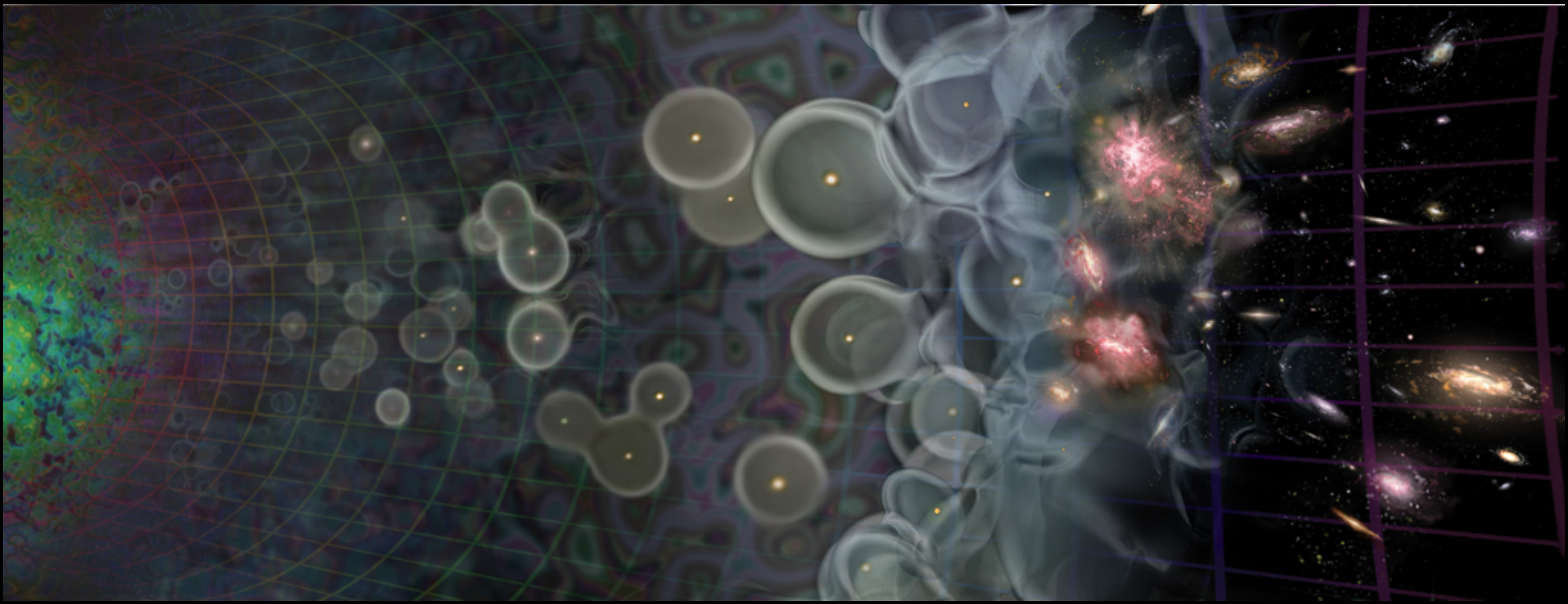
CRAL

CENTRE DE RECHERCHE ASTROPHYSIQUE DE LYON

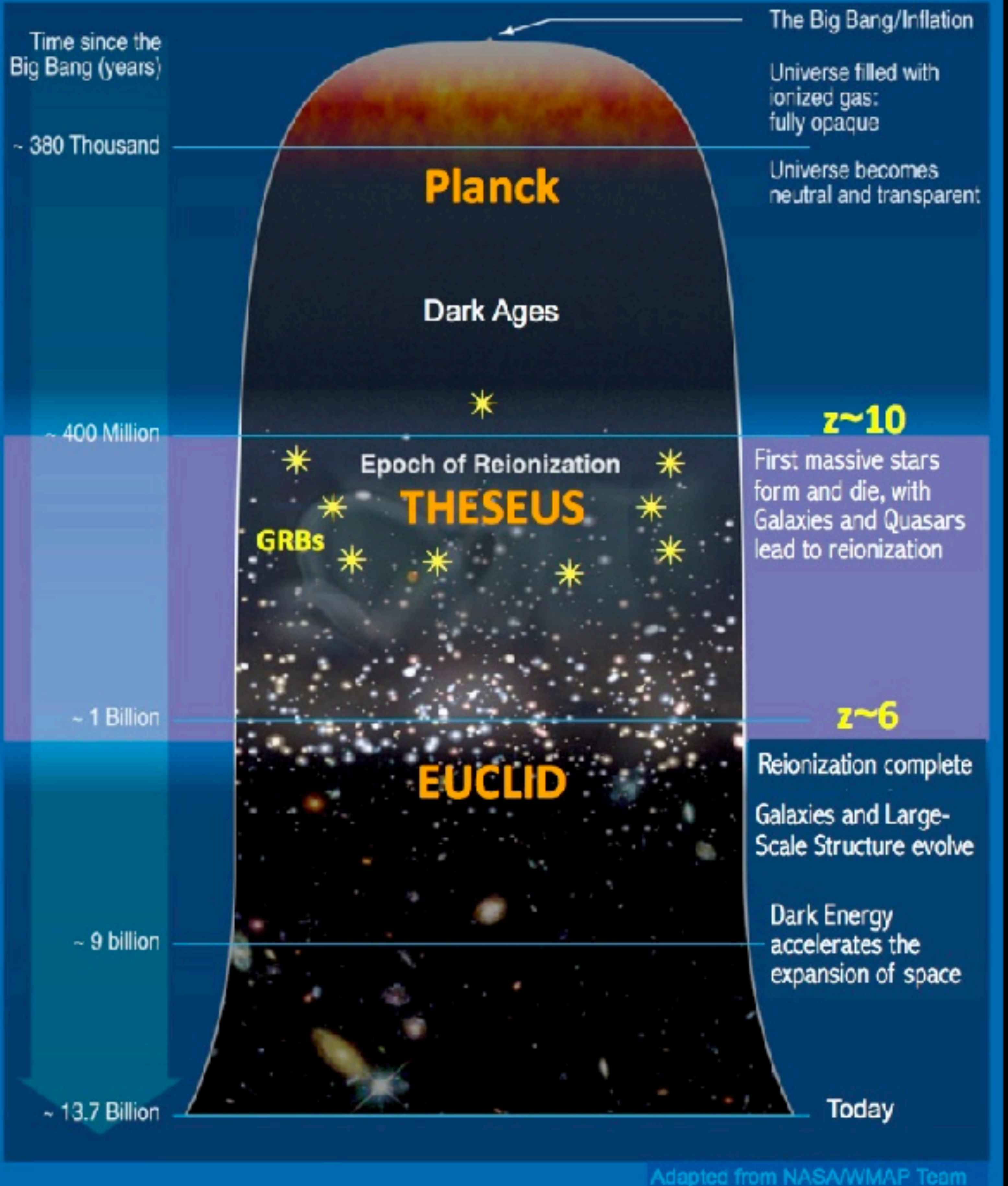
FIRST LIGHT

- What are the **first galaxies**?
- What sources caused **reionisation** ?

Observational probes,
Future instruments



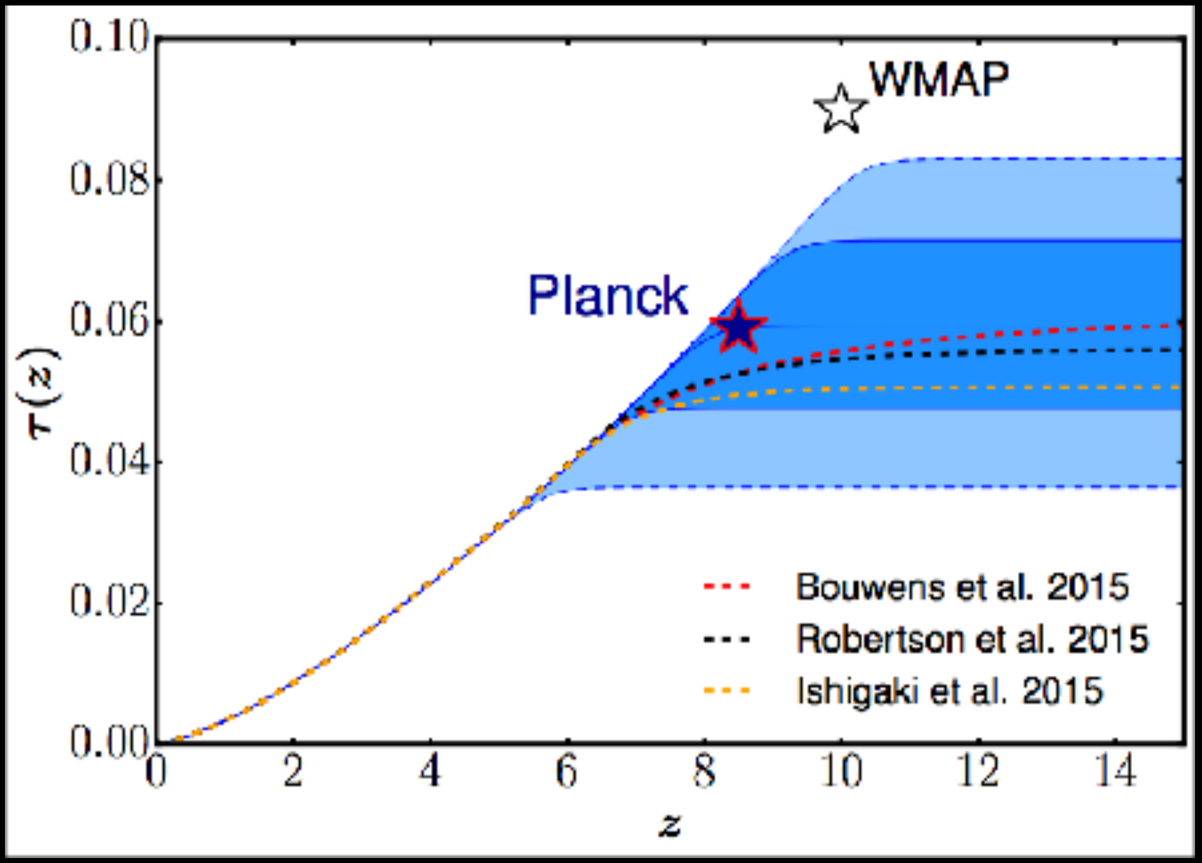
Cosmic history: THESEUS and other milestone ESA missions



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 ?

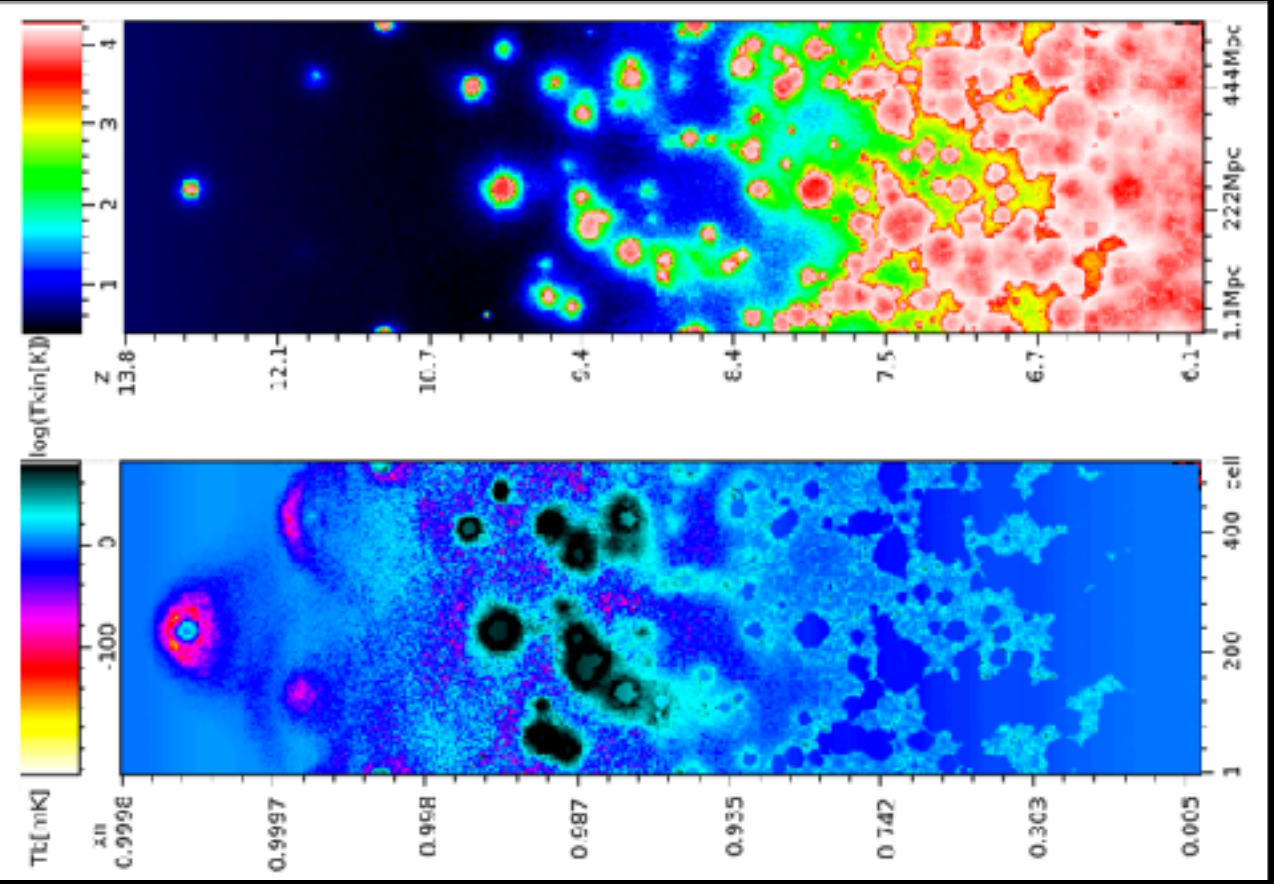


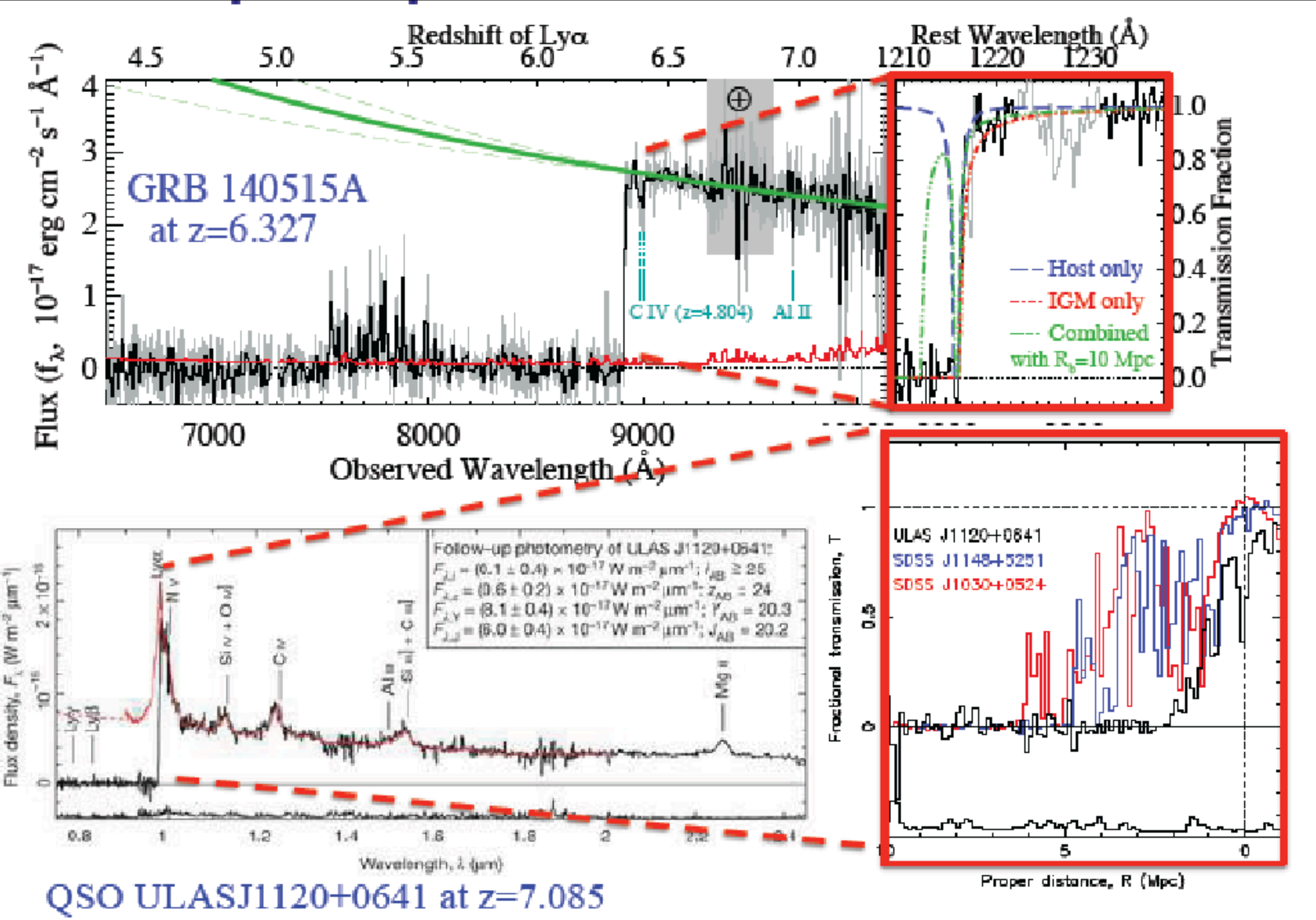
XLVII. Planck constraints on reionization history

- Simulating 21 cm signal:

e.g. anisotropies from differential brightness temperatures

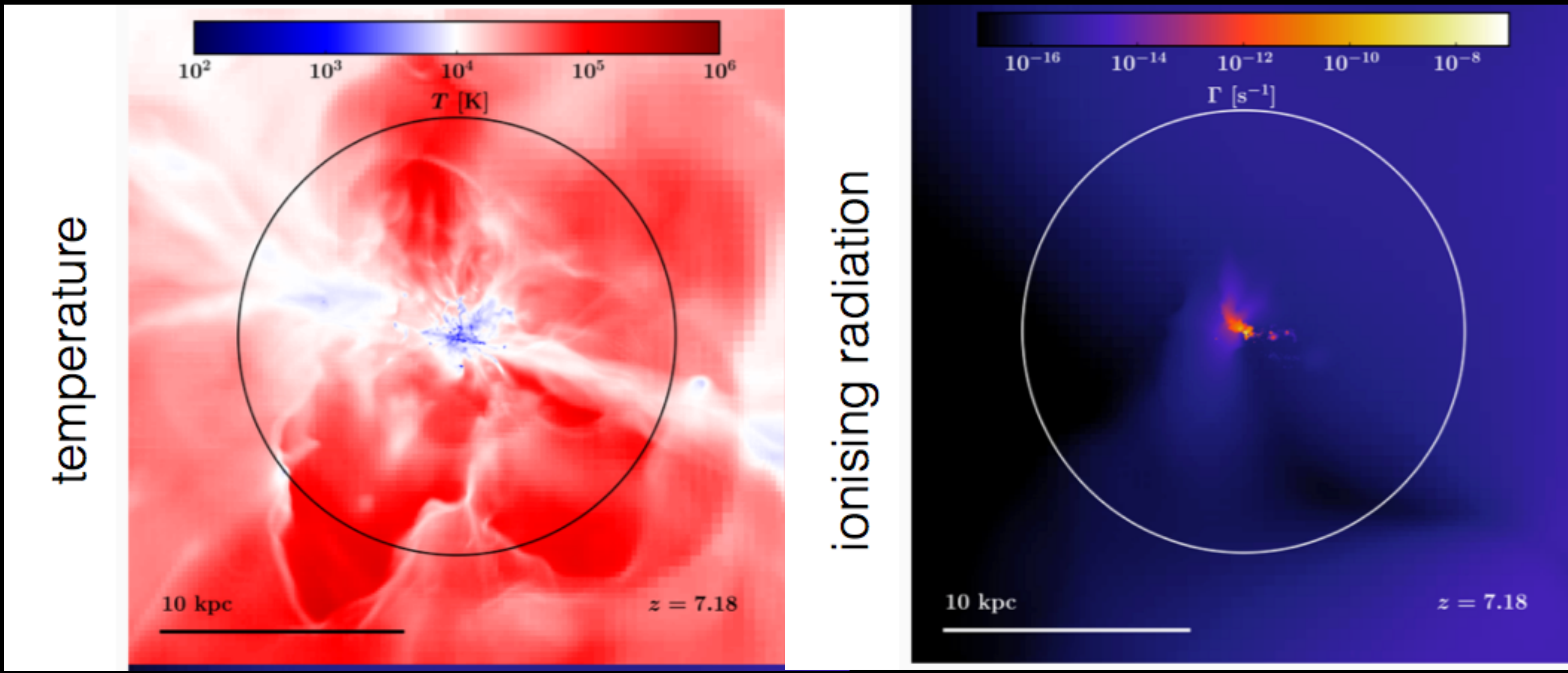
Zawada et al. 2014, predictions for SKA over 20x20 degrees





Redshift of Lyα
Rest Wavelength (Å)
GRB 140515A
at z=6.327
C IV (z=4.804)
Al II
Host only
IGM only
Combined
with R_b=10 Mpc
Transmission Fraction
Observed Wavelength (Å)
Follow-up photometry of ULAS J1120+0641:
Wavelength, λ (μm)
ULAS J1120+0641
SDSS J1148+5251
SDSS J1030+0524
Fractional transmission, T
Proper distance, R (Mpc)
QSO ULASJ1120+0641 at z=7.085

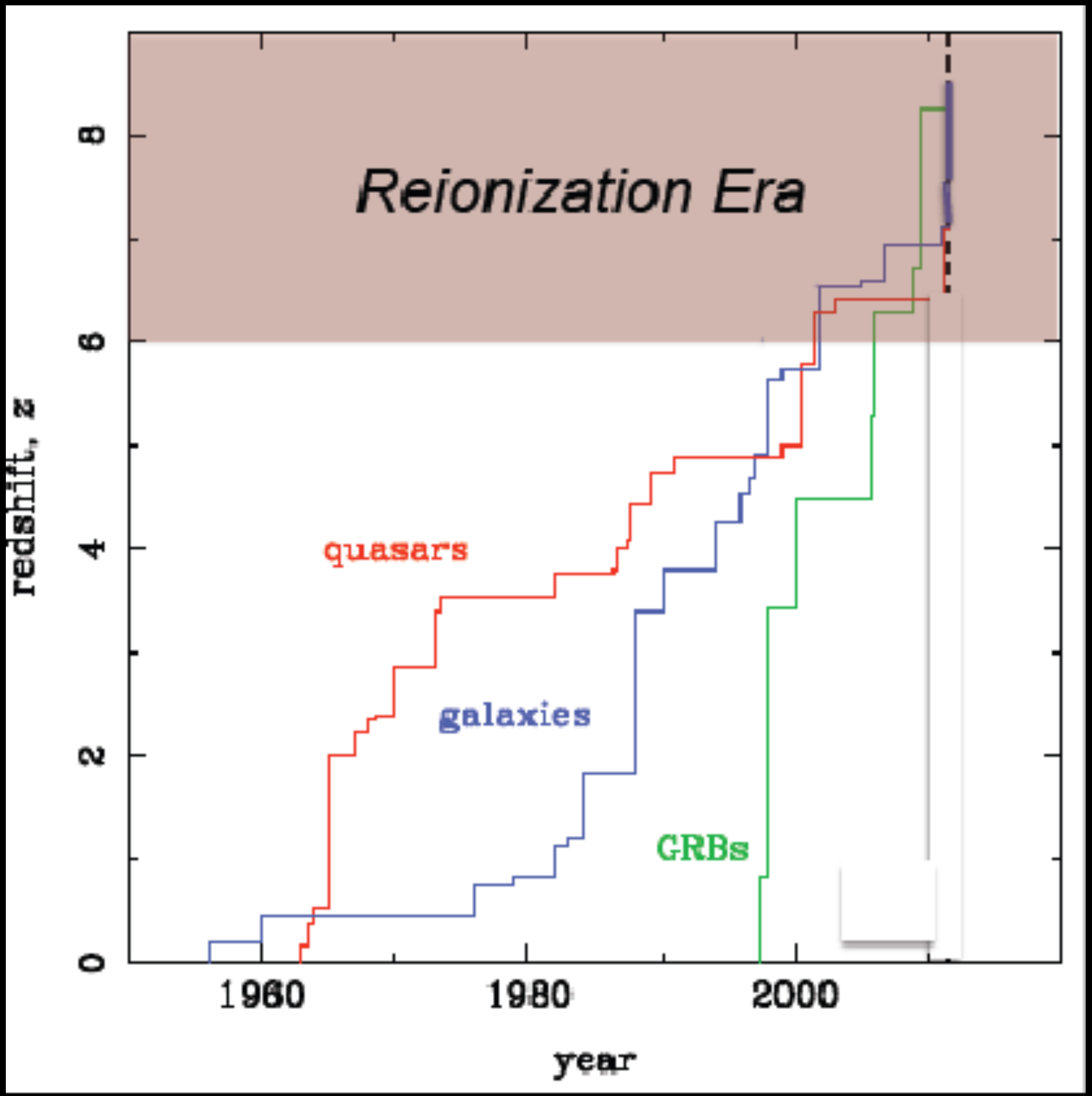
PREDICTIONS FROM SIMULATIONS



Trebitsch+16

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

SOURCES OF REIONISATION



$$\dot{n}_{ion} = \boxed{f_{esc}\,\xi_{ion}\,\rho_{UV}}$$

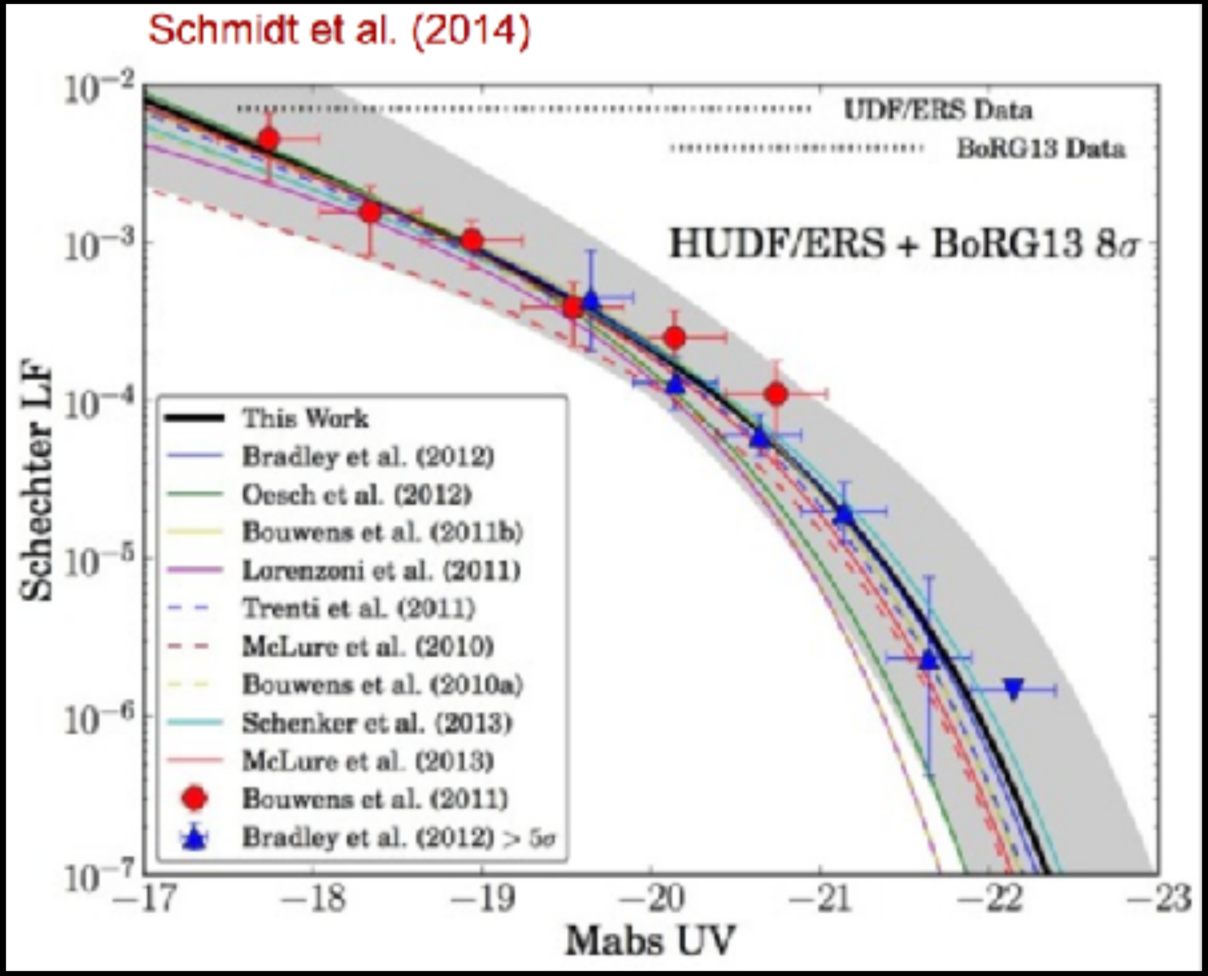
(+ clumpiness of IGM)

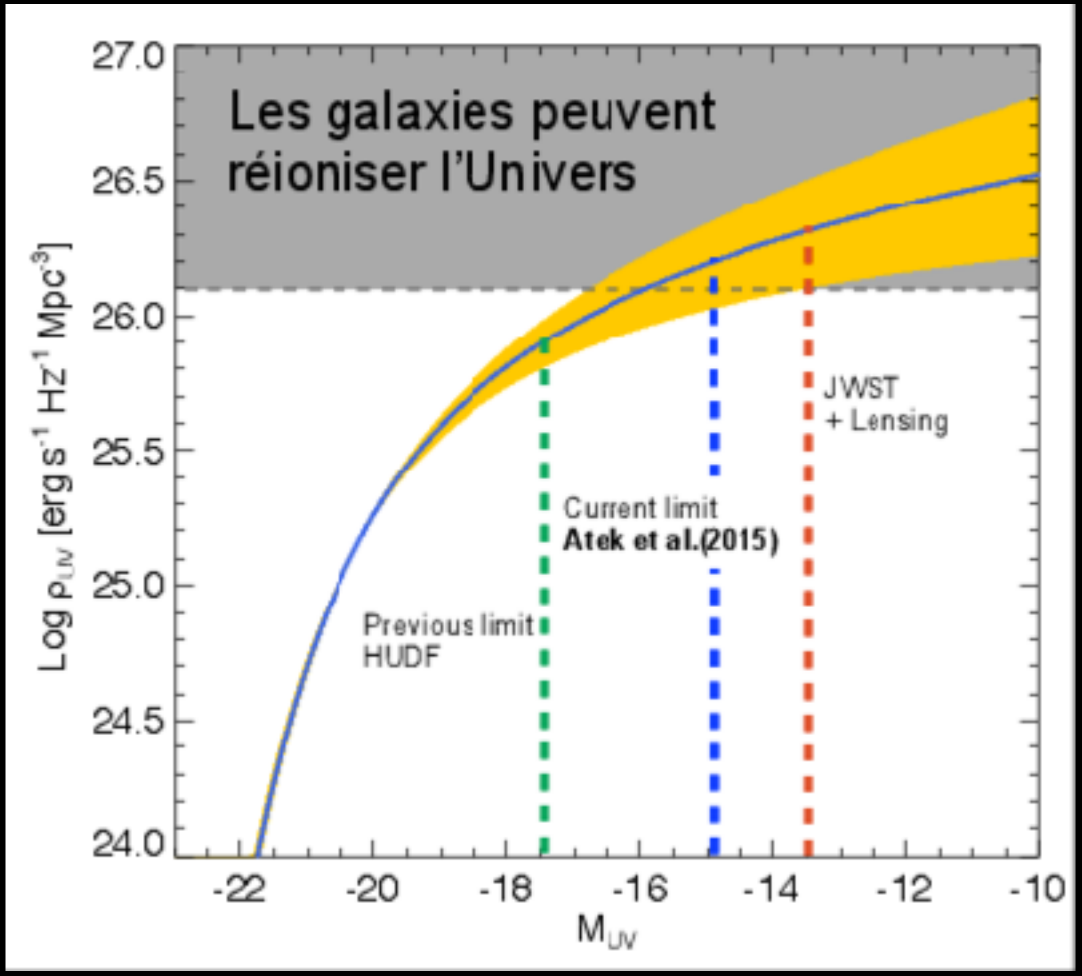
ρ_{UV} Abundance of SF galaxies

ξ_{ion} Rate of ionising photons

f_{esc} Fraction of escaping ionising photons

LUMINOSITY FUNCTION FROM DEEP FIELDS



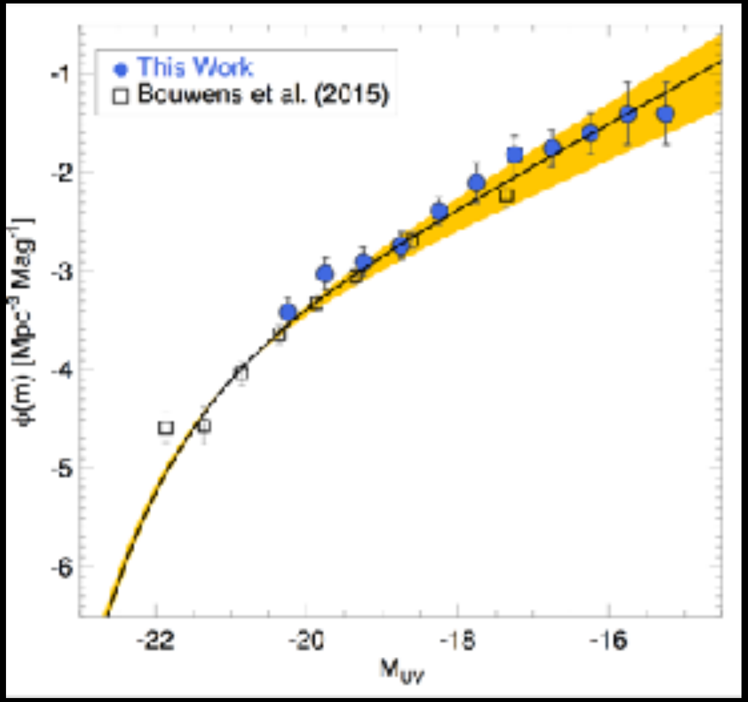


Current limits on the luminosity function:

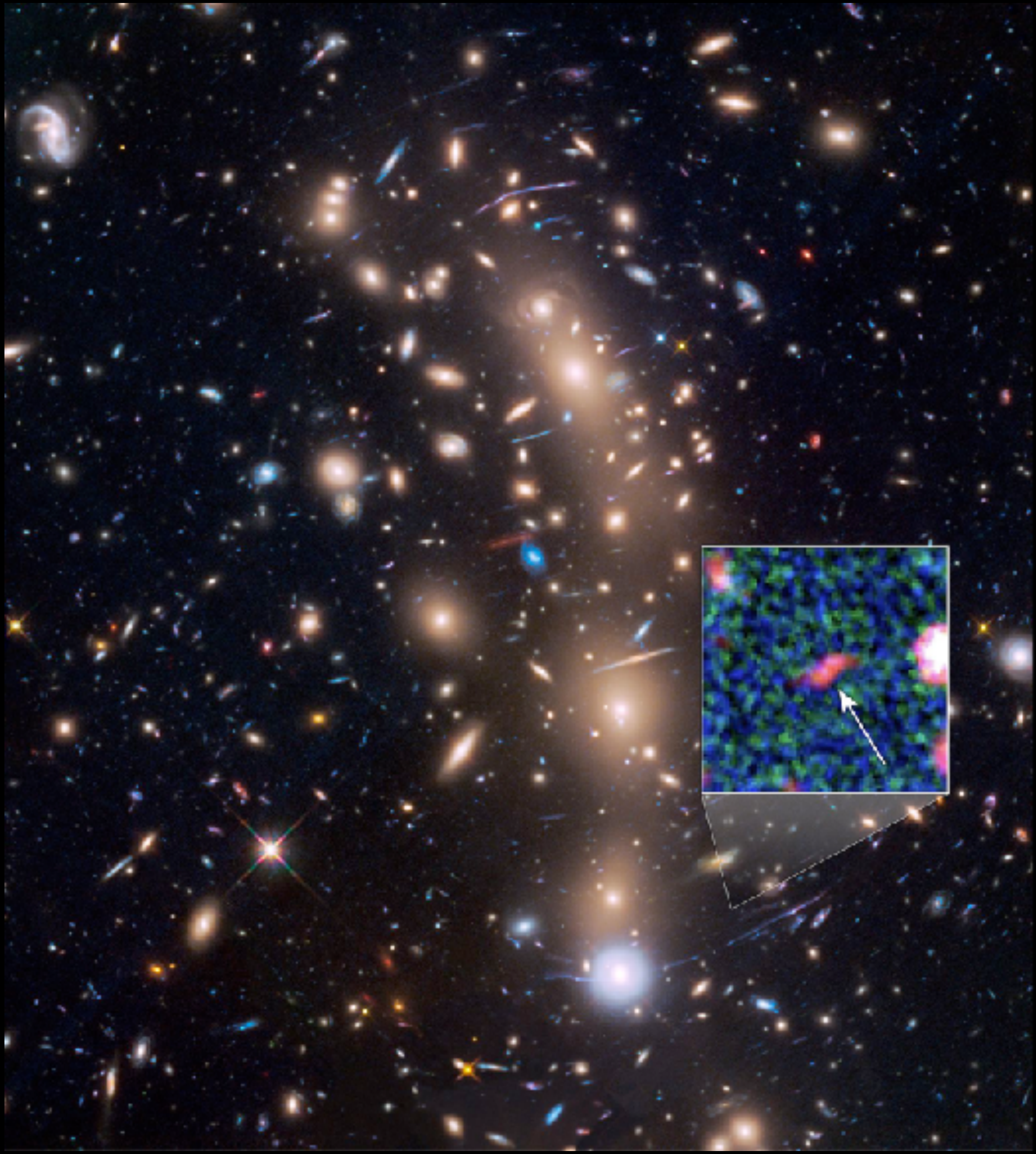
- knowledge of the redshift evolution at $z > 7$, limited by statistics
- extrapolation to the faint end (sources dominating reionisation)

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

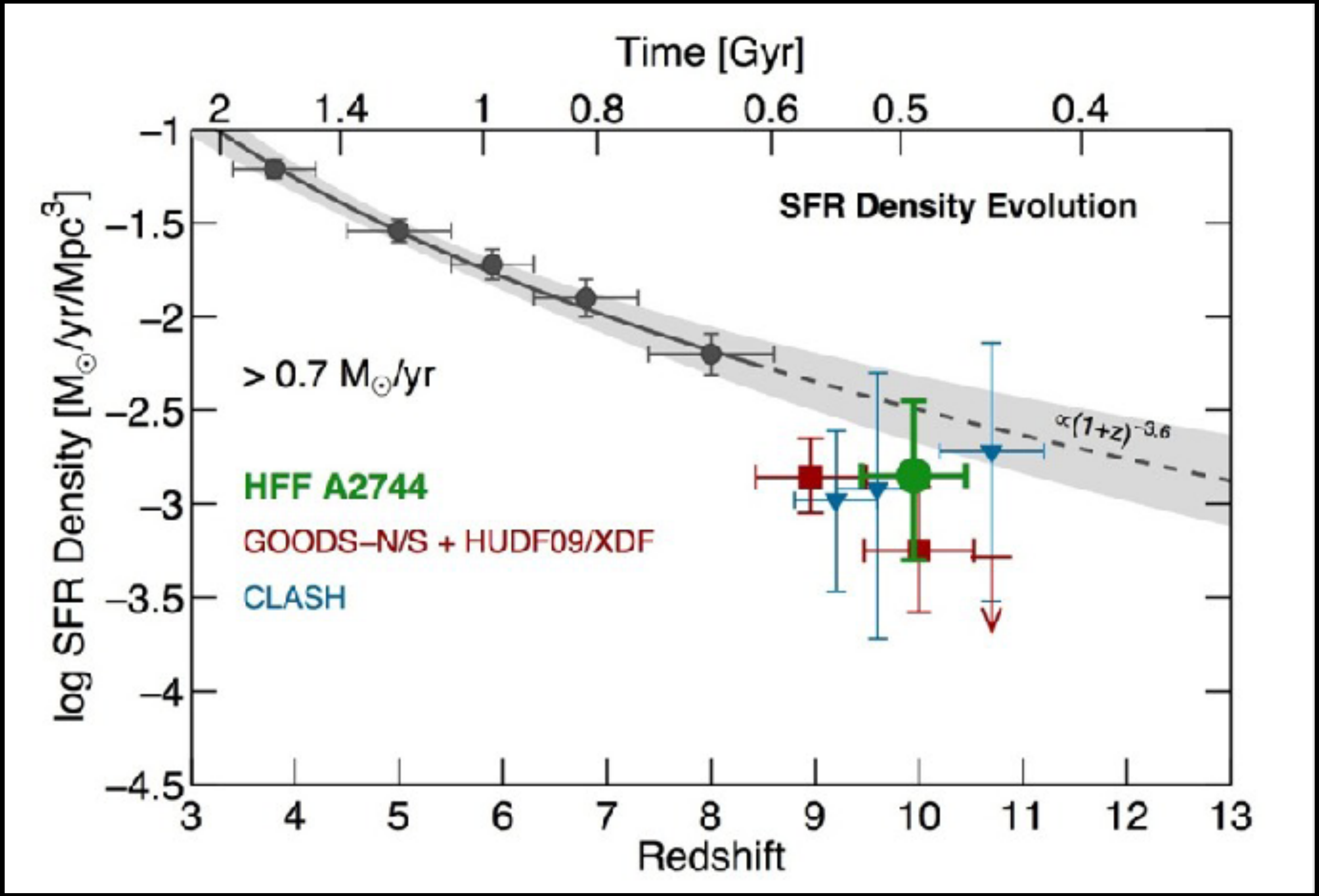


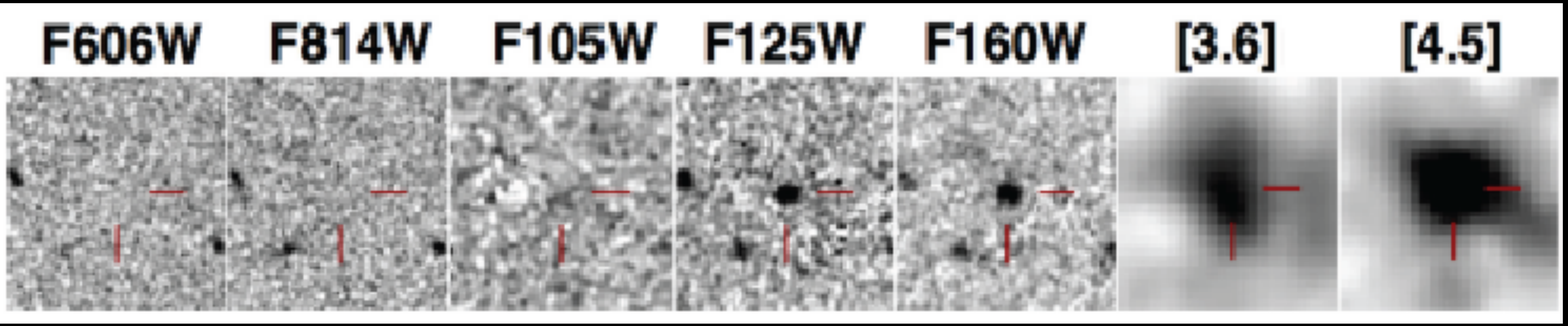
Atek et al. 2014, 2015, 2016,2018



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

FRONTIER FIELDS (2)

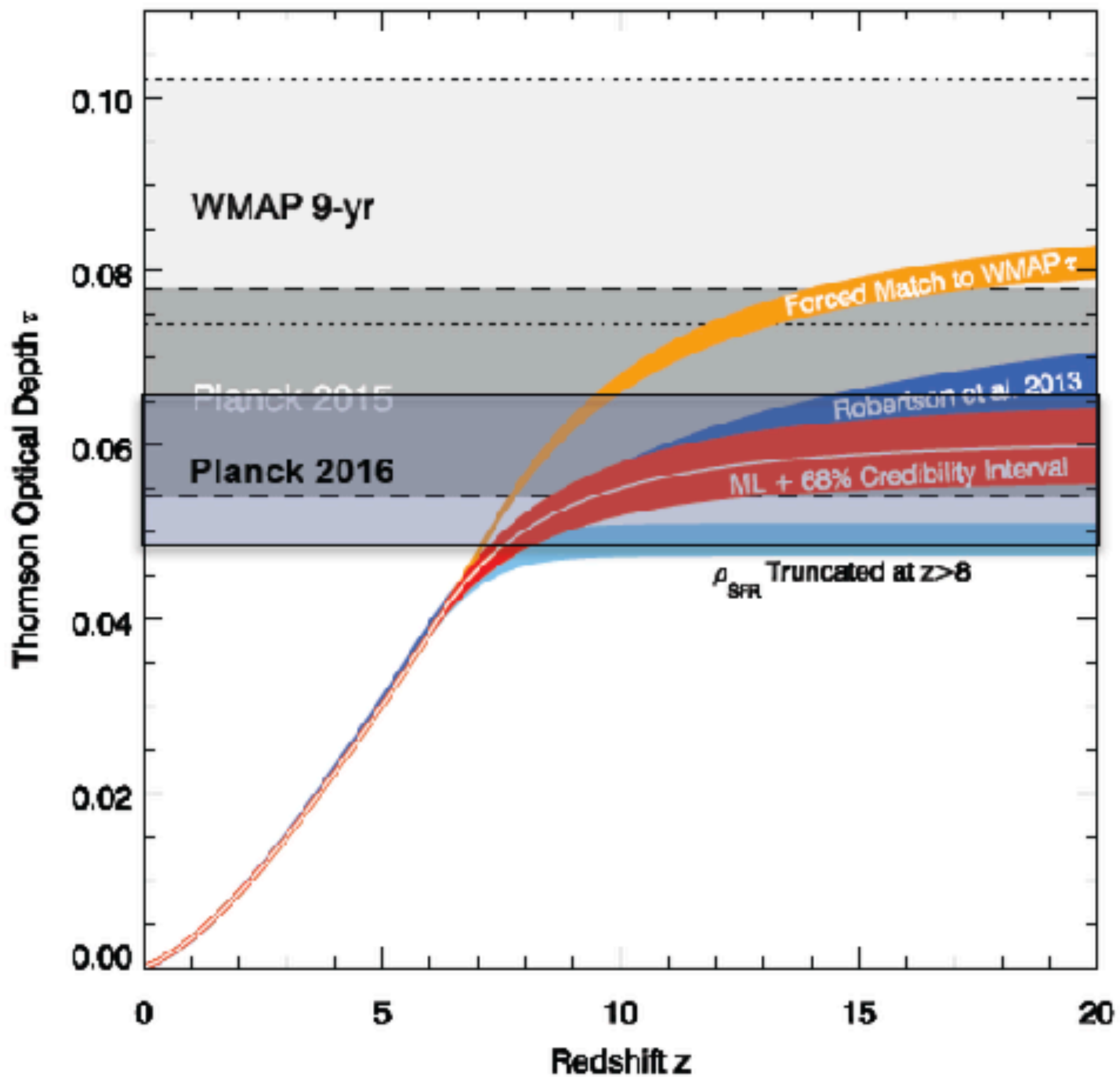




Oesch et al. 2015

z = 7.73

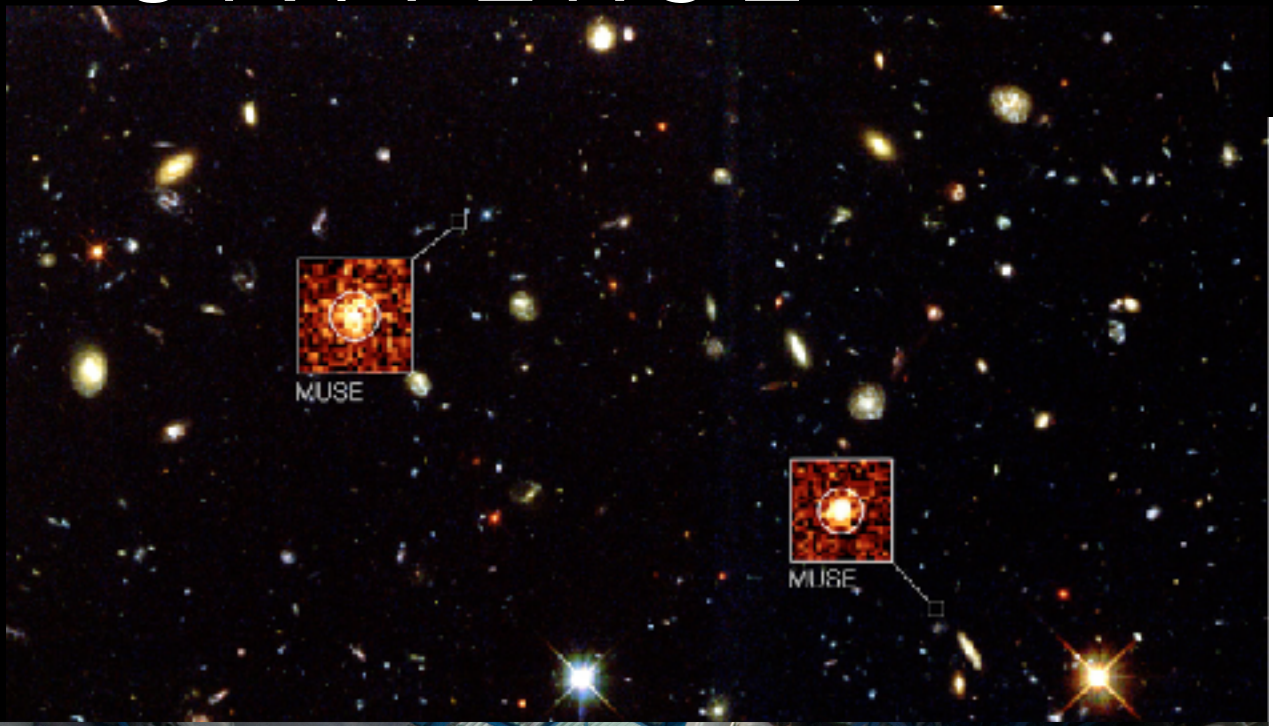
IMPLICATIONS FOR REIONIZATION

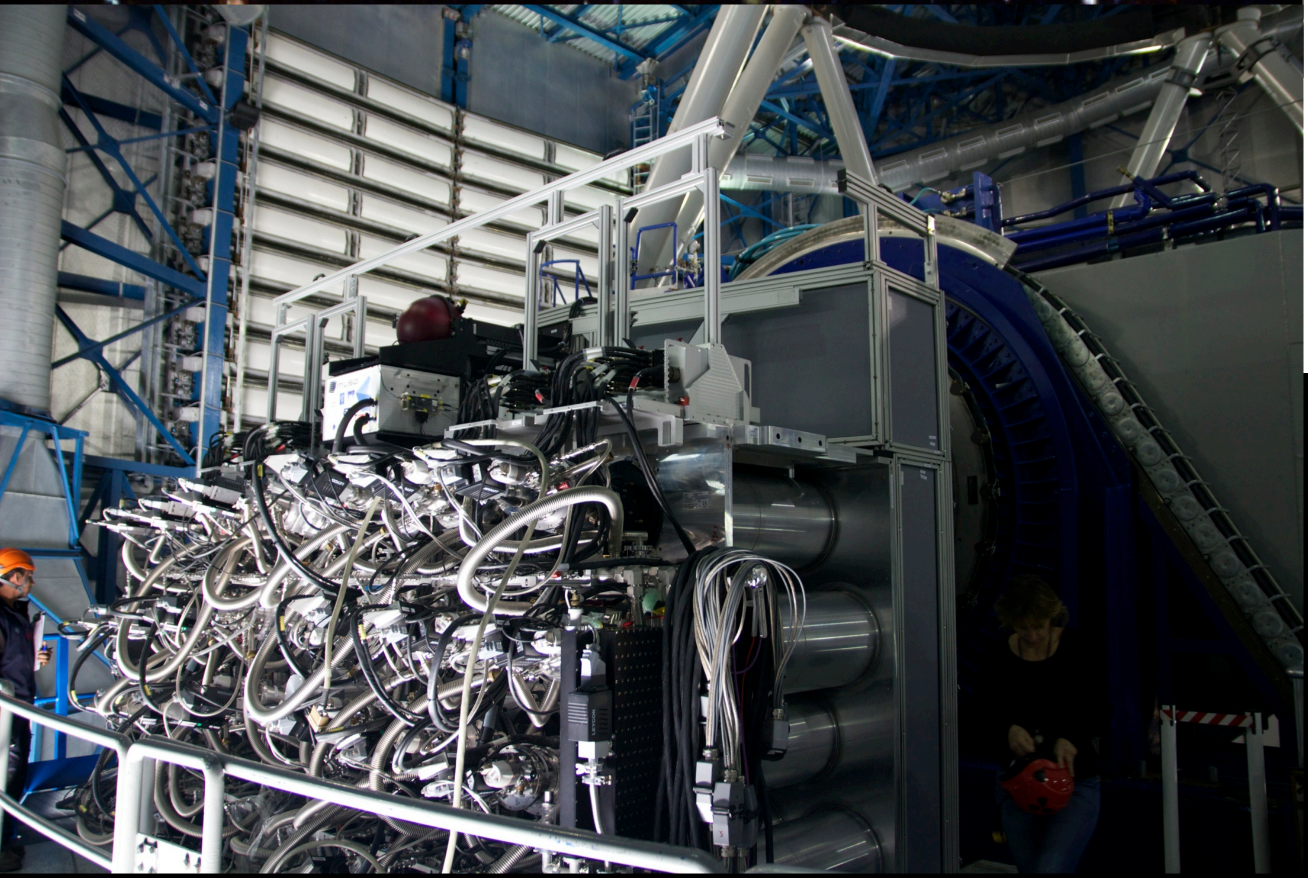


Caveats:

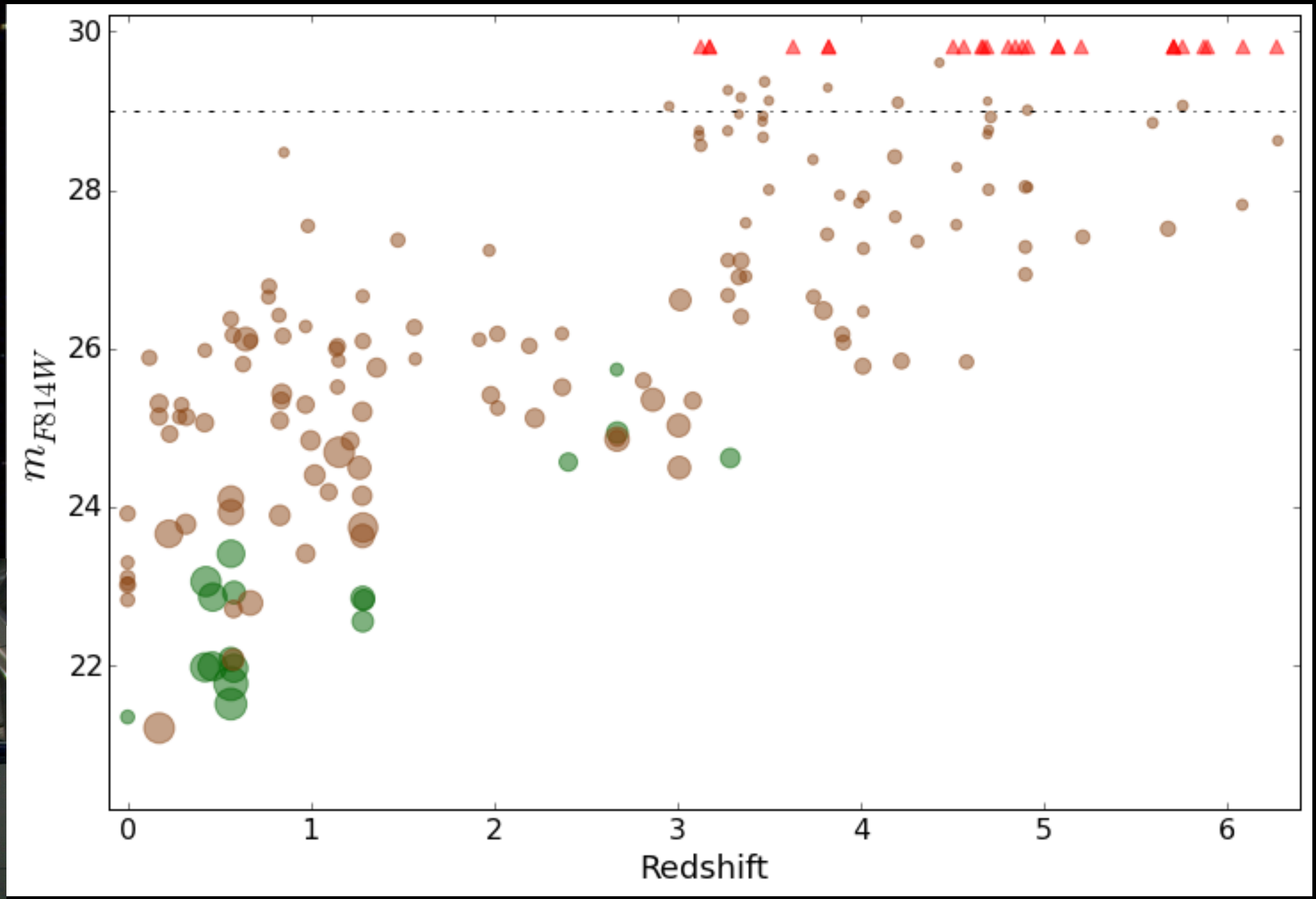
- Photometric candidates
- Extrapolation of LF
- Assumptions on ξ_{ion}
- Assumptions on f_{esc}

MUSE AND THE LYMAN-ALPHA UNIVERSE





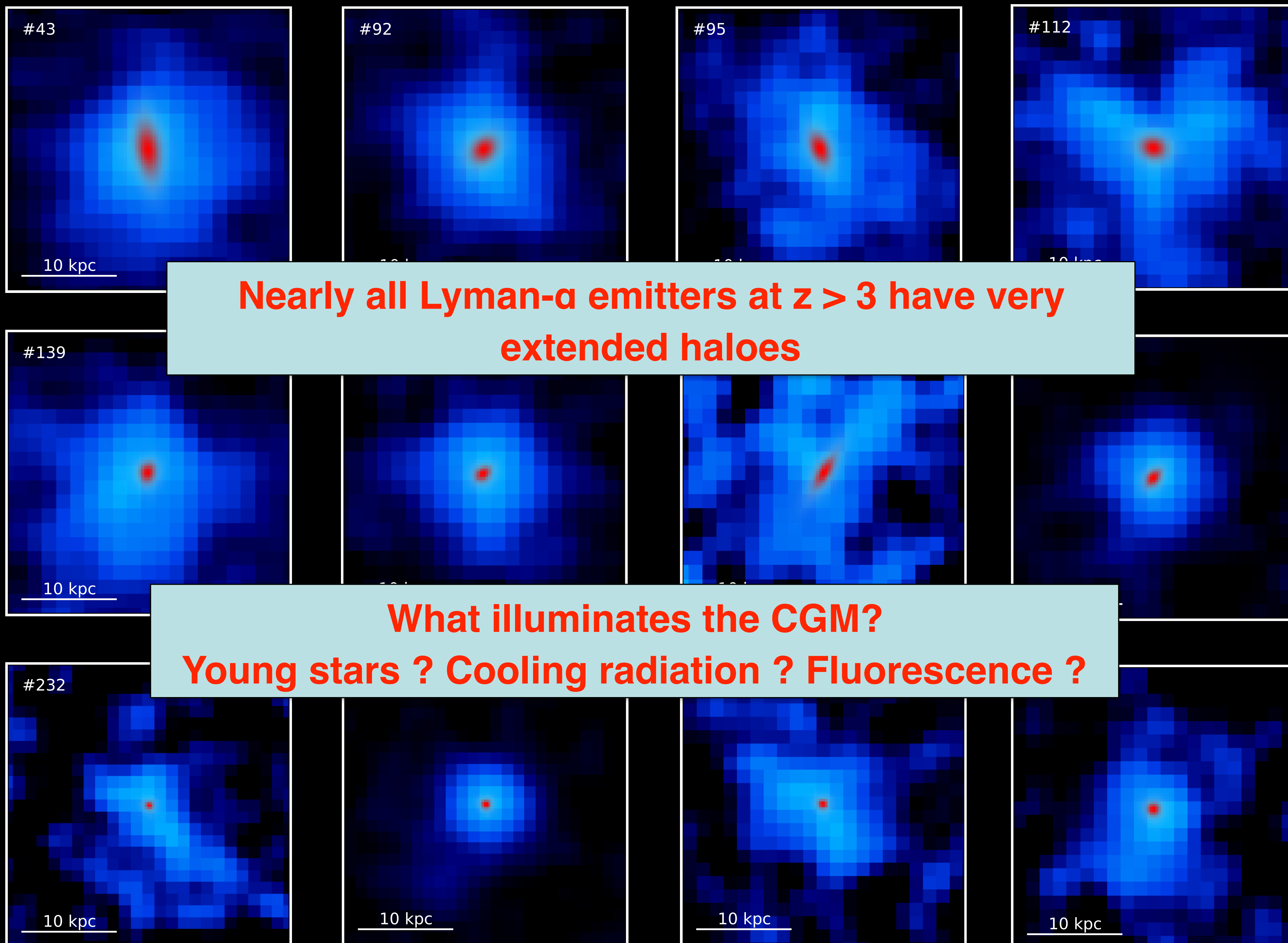
Bacon et al. 2015



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)

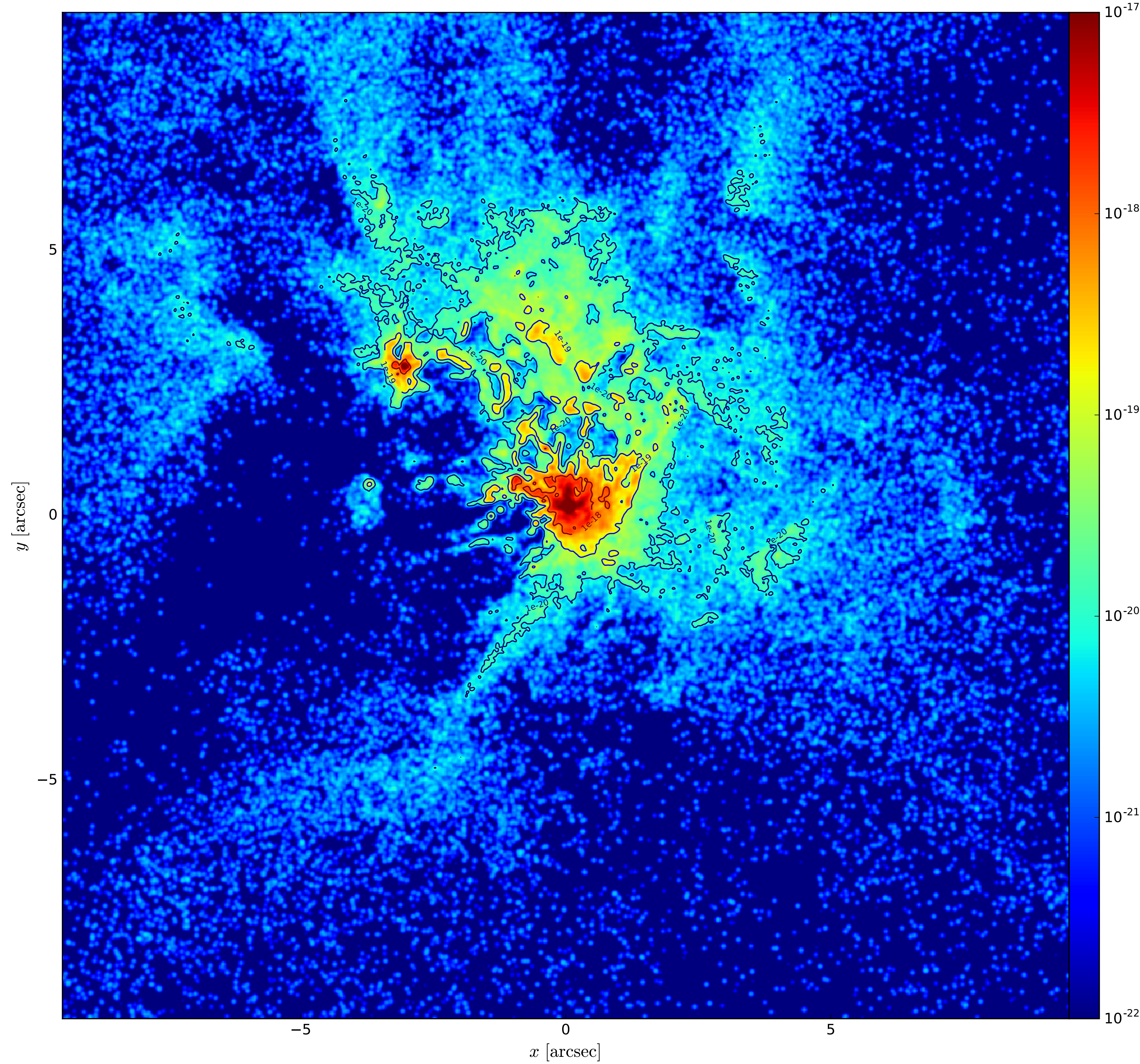
Radiative transfer in AMR simulations:

MCLyα, now RASCAS

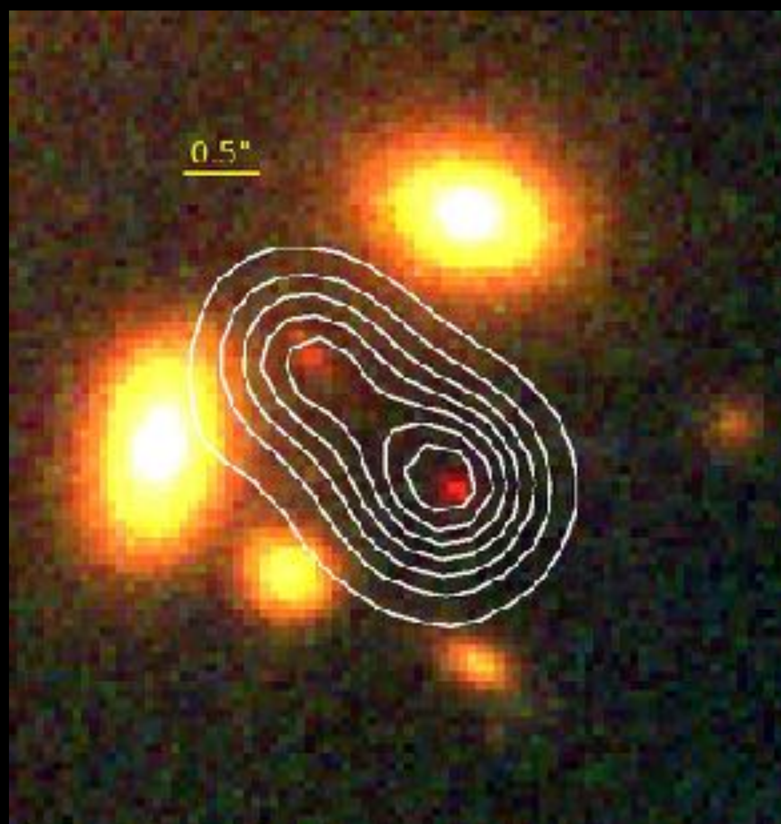
(Verhamme, Blaizot, Michel_Dansac, Garel)

<u>Test assumptions</u>

ξ_{ion} f_{esc}

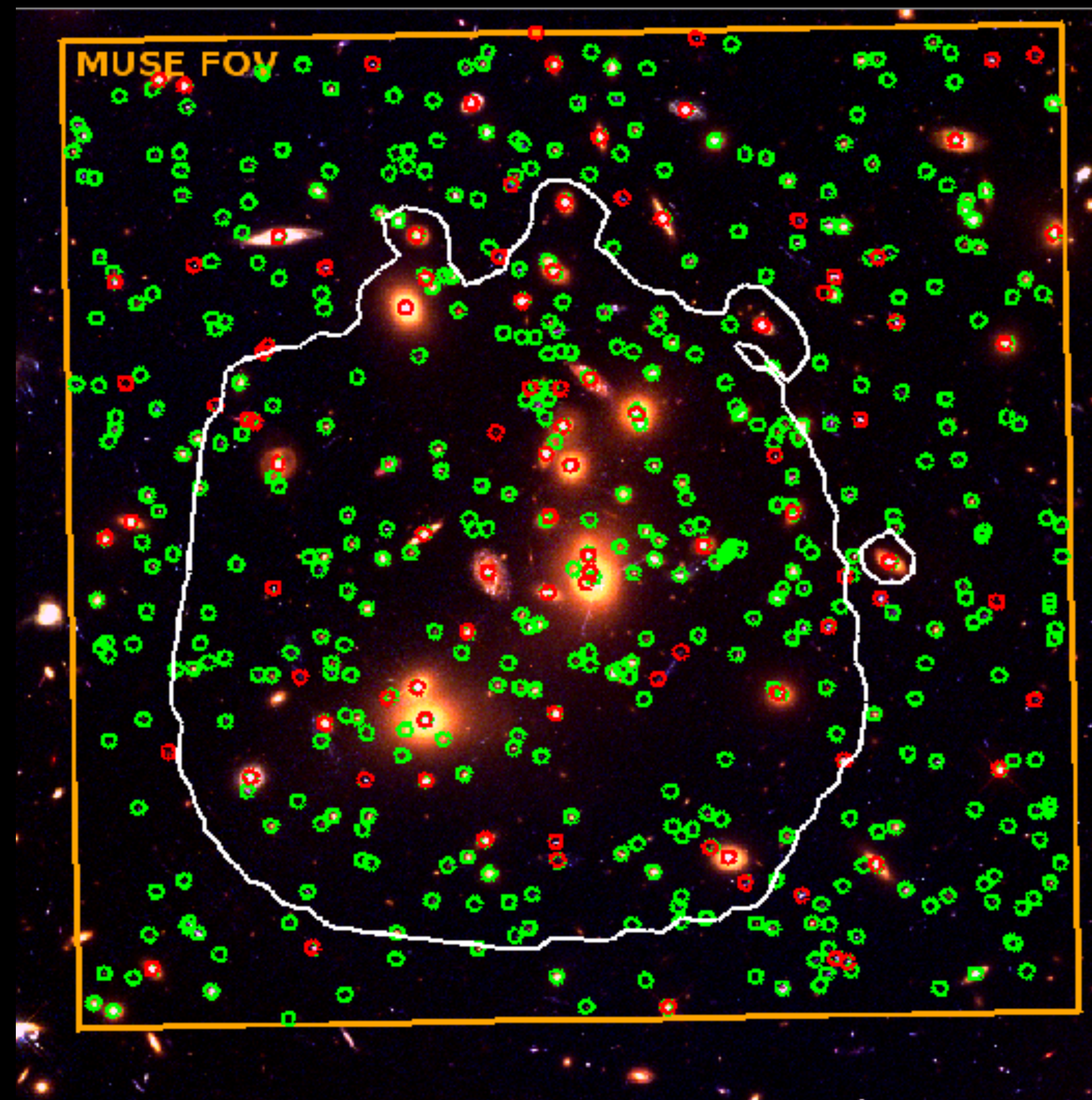


MUSE AND THE LYMAN-ALPHA UNIVERSE

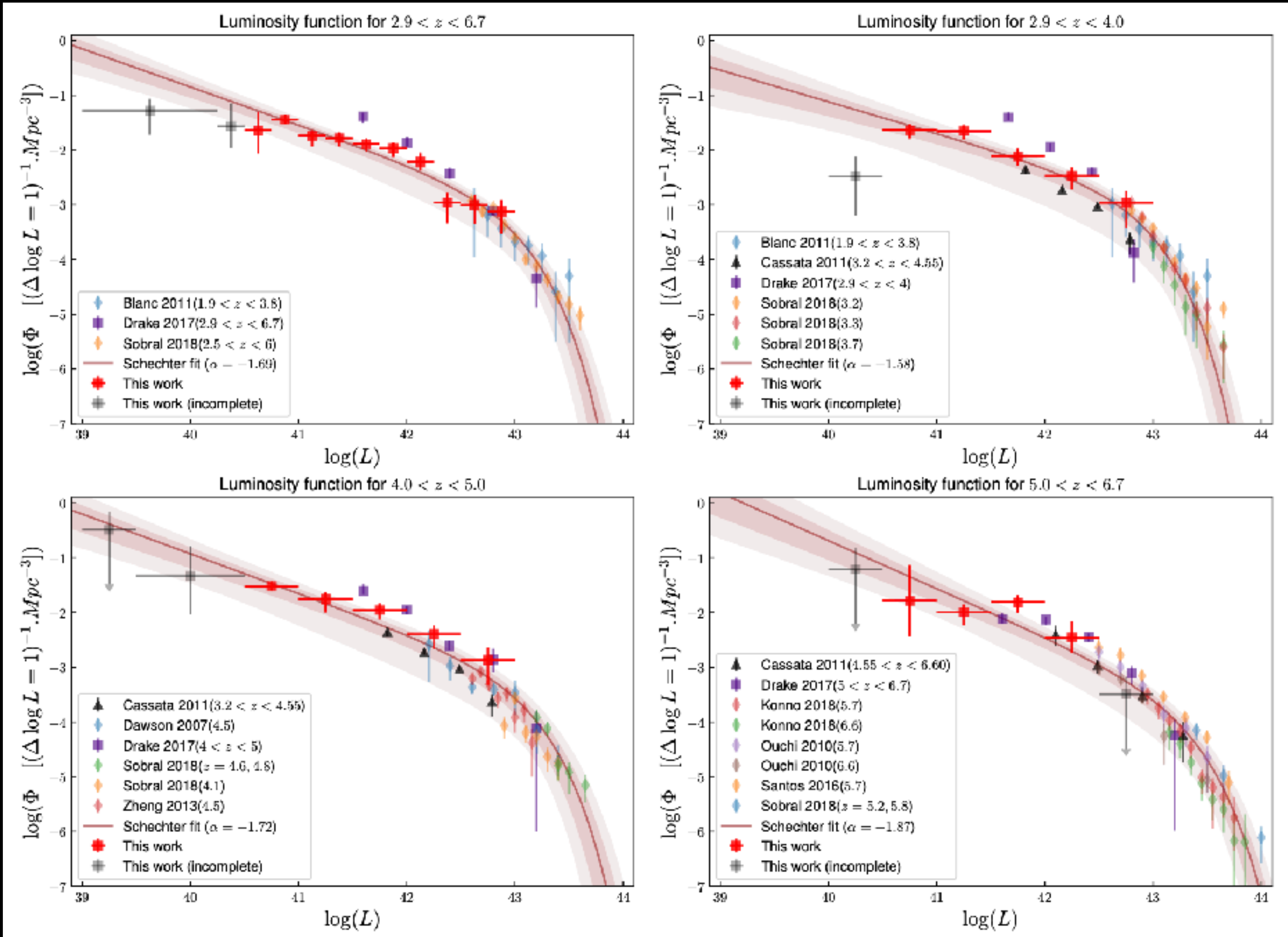


500 redshifts for 436 sources in the Frontier Field cluster A2744

~74 Lyα / arcmin^2

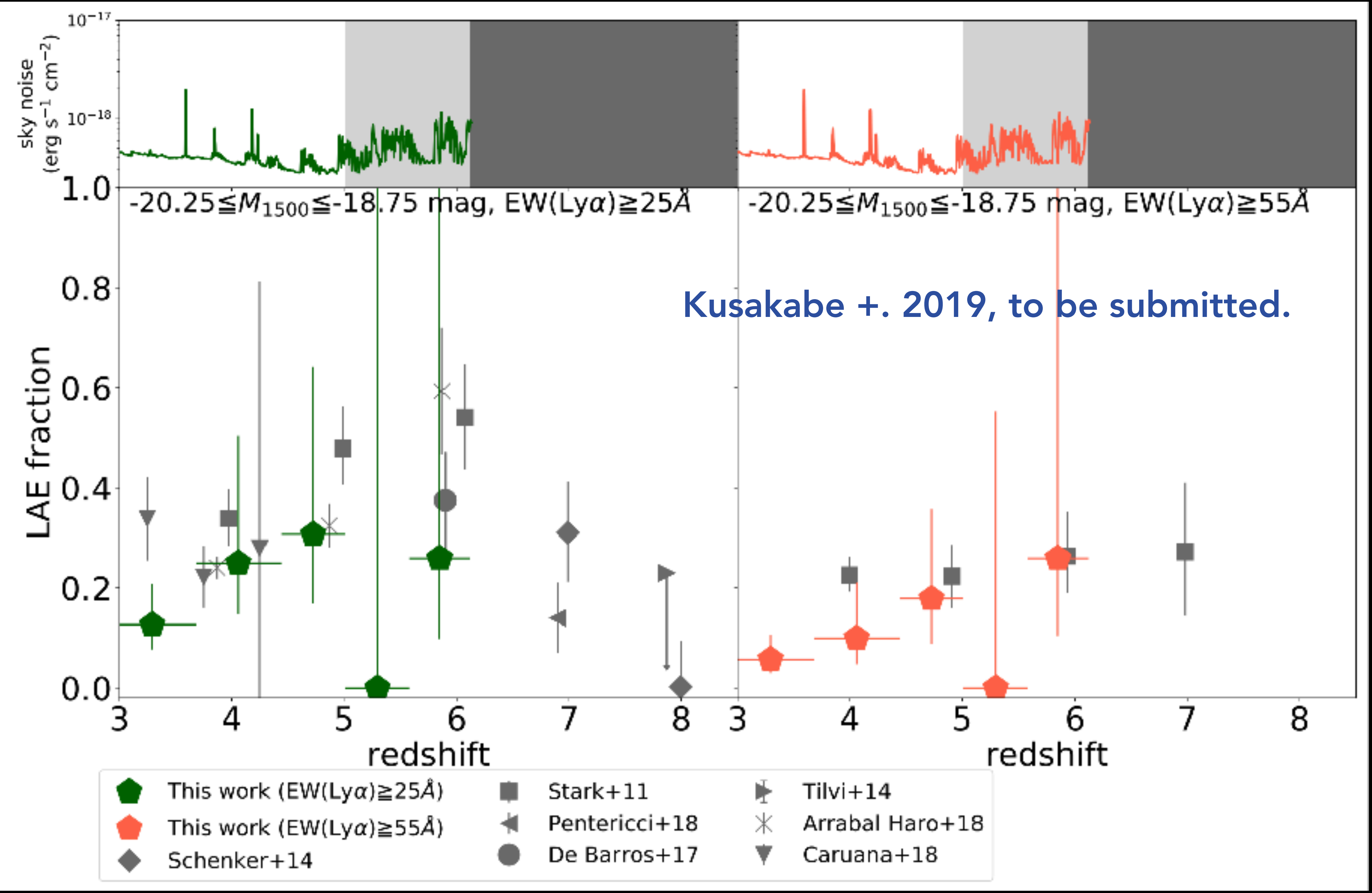


Mahler+2018



de la Vieuville+2019

MUSE AND THE LYMAN-ALPHA UNIVERSE

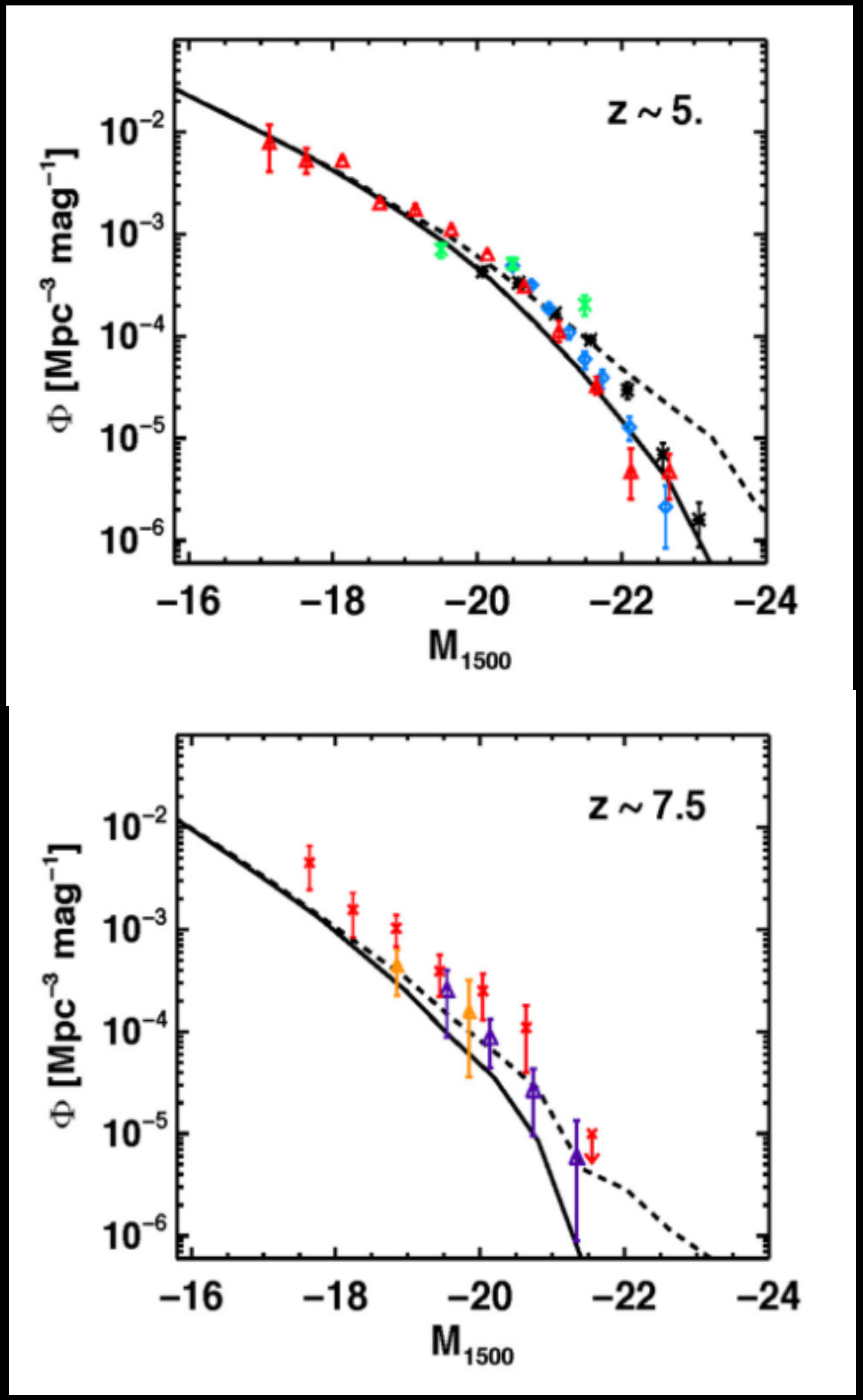


PREDICTIONS FROM SIMULATIONS

- SAMs provide a statistical view of galaxies at high redshifts.
- Predictions for the Lyman-alpha luminosity function, but also:

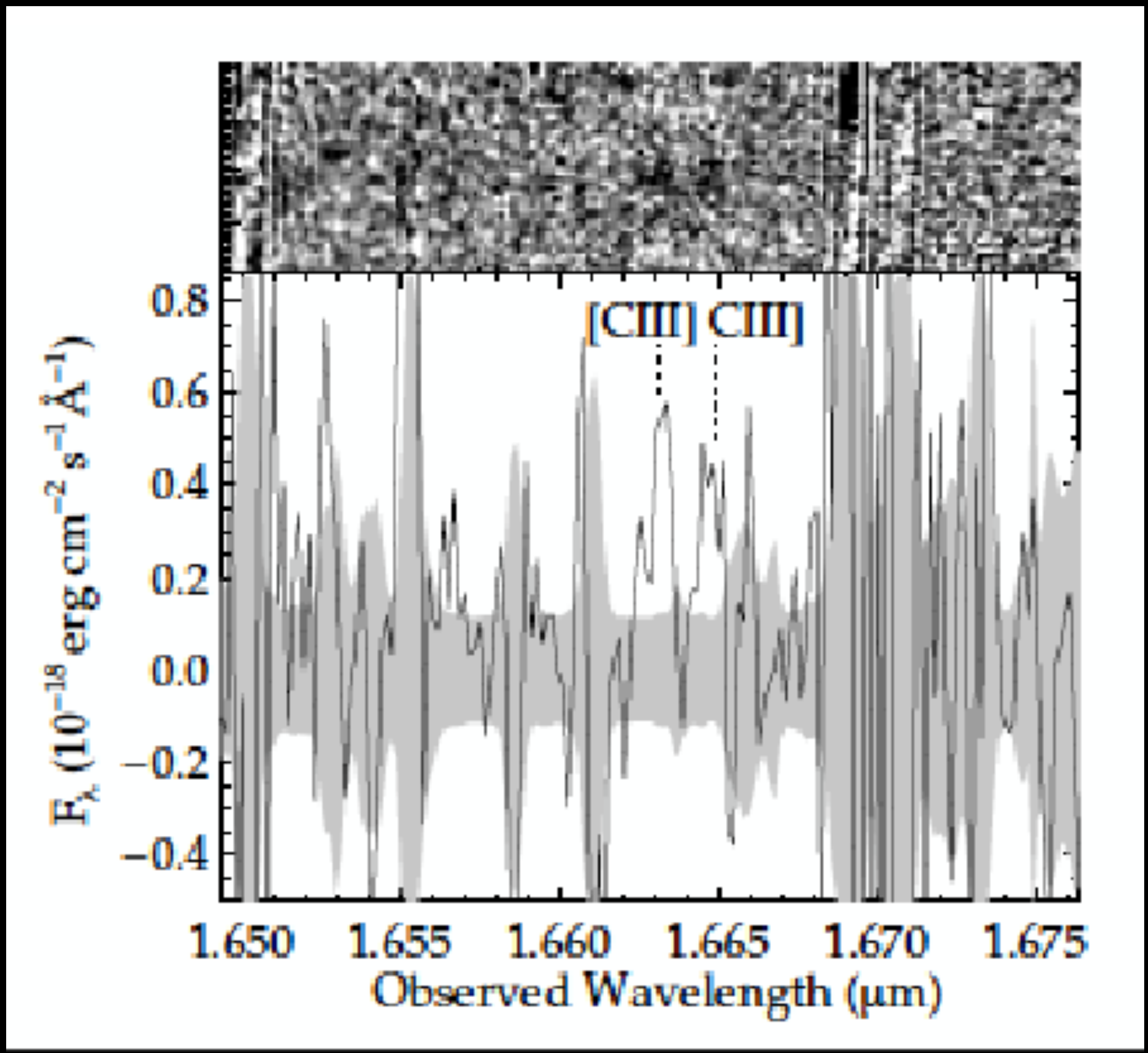
- the angular correlation function of LAEs
- the fraction of LAEs with redshift
- the distribution of Lyman-alpha line profiles

f_{esc}

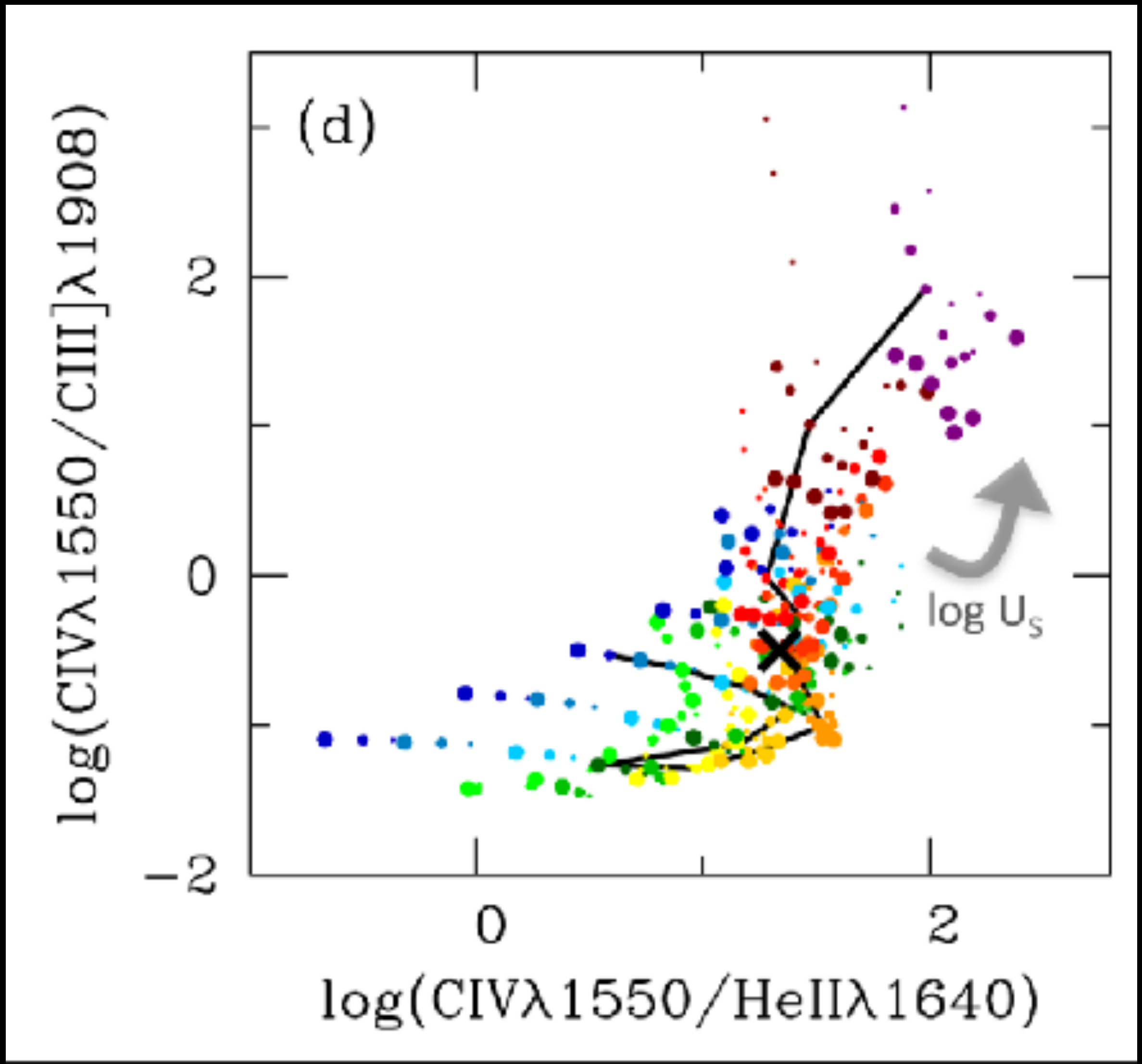


Garel+2012, 2015, 2016

UV NEBULAR EMISSION LINES



Stark et al. 2017



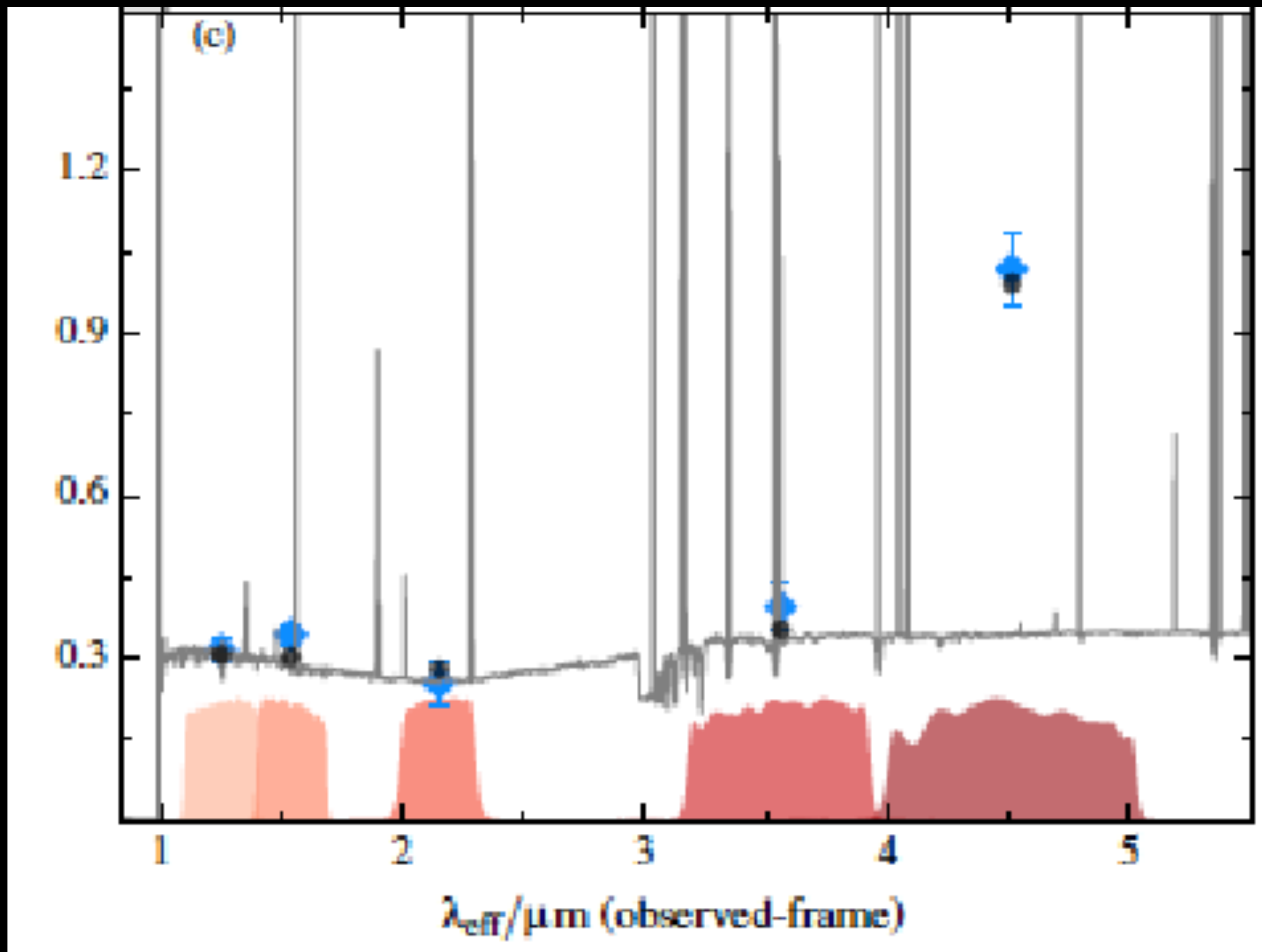
Gutkin et al. 2016

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

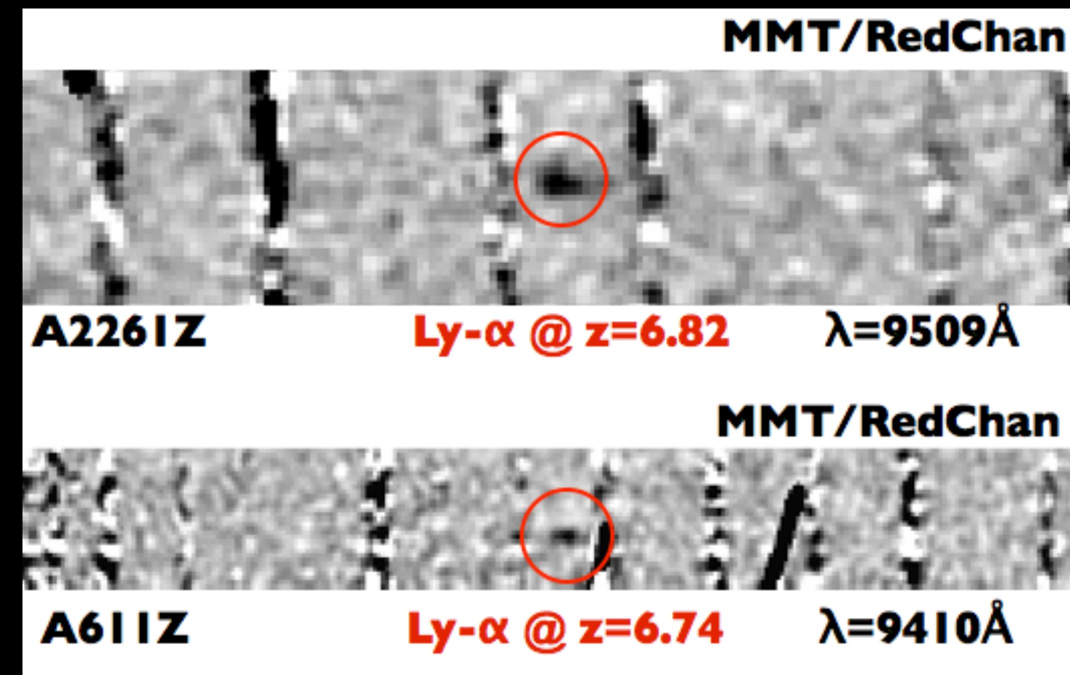
At z>6 CIII] could be the brightest spectroscopic feature when Lyman-α is suppressed but low equivalent width (typically 12 Angstr.)

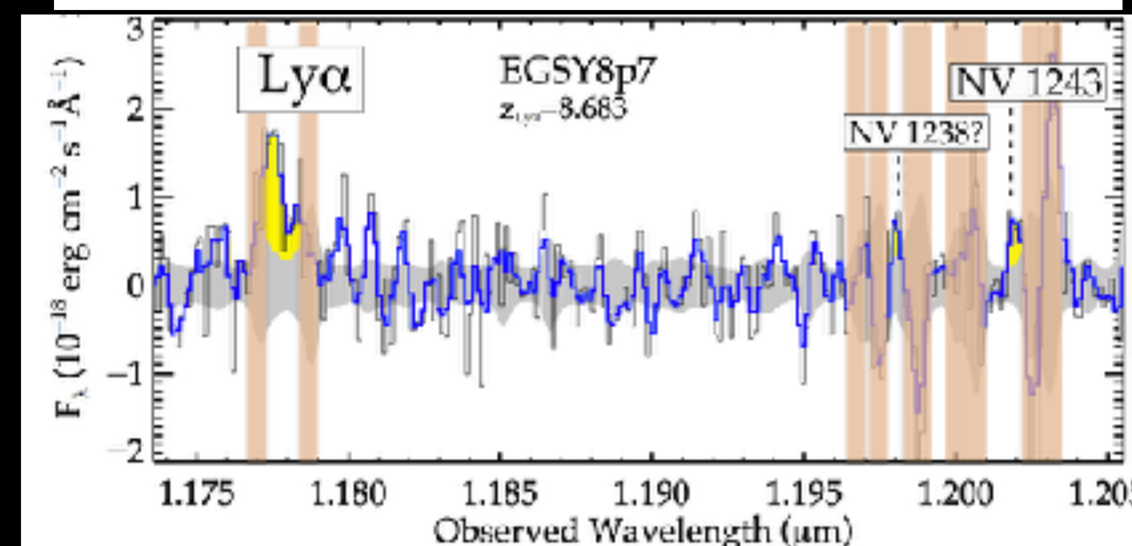
Valuable indicators of hard ionising spectra CIV (48 eV), OIII] (35 eV), CIII] (24 eV), HeII (25 eV)

STRONG NEBULAR EMISSION LINES



Stark et al. 2017



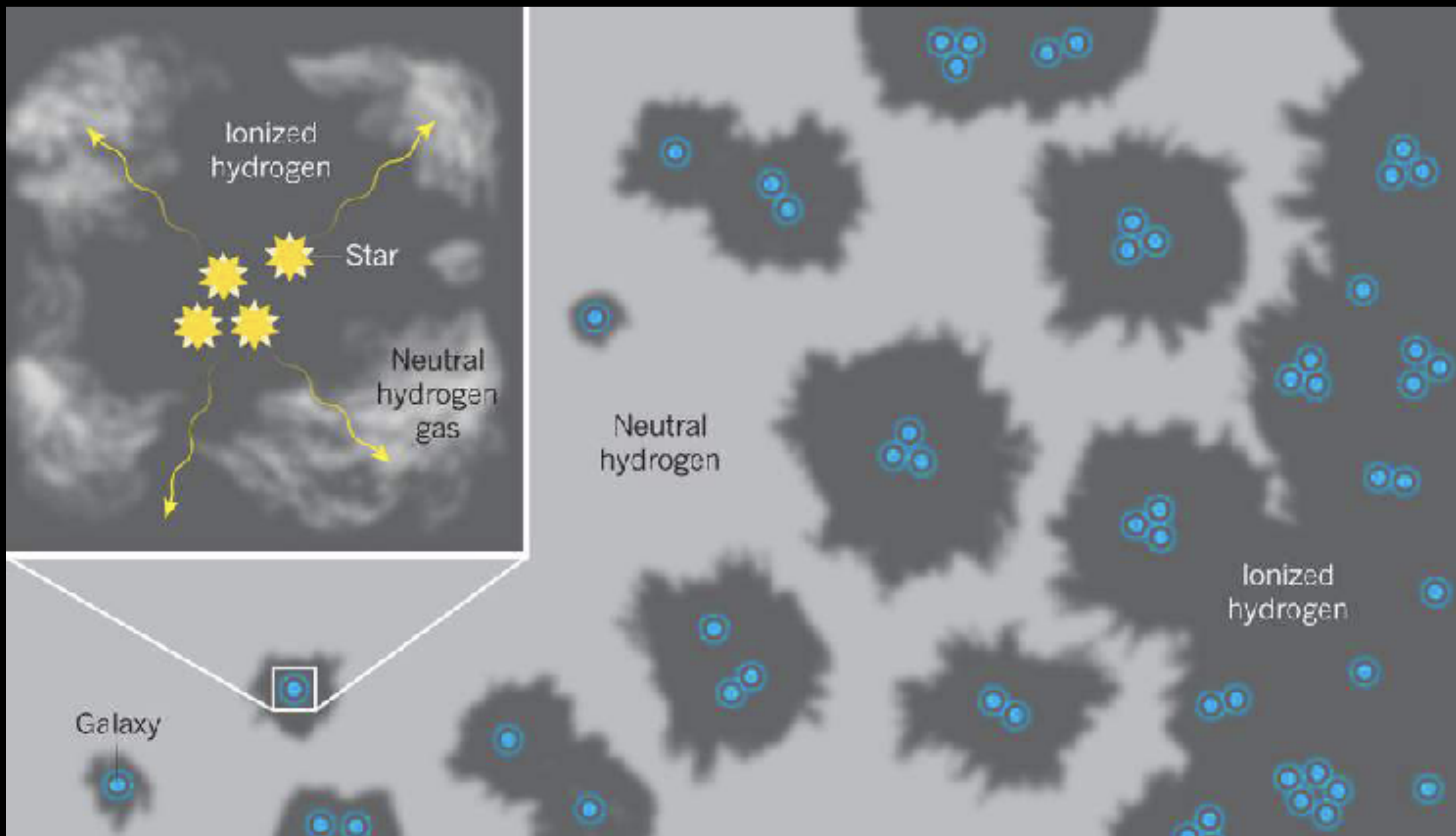


Mainiali et al. 2018

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

Confirmation of CIV and NV emission at high z: evidence for high ξ_{ion} at z>7 ?

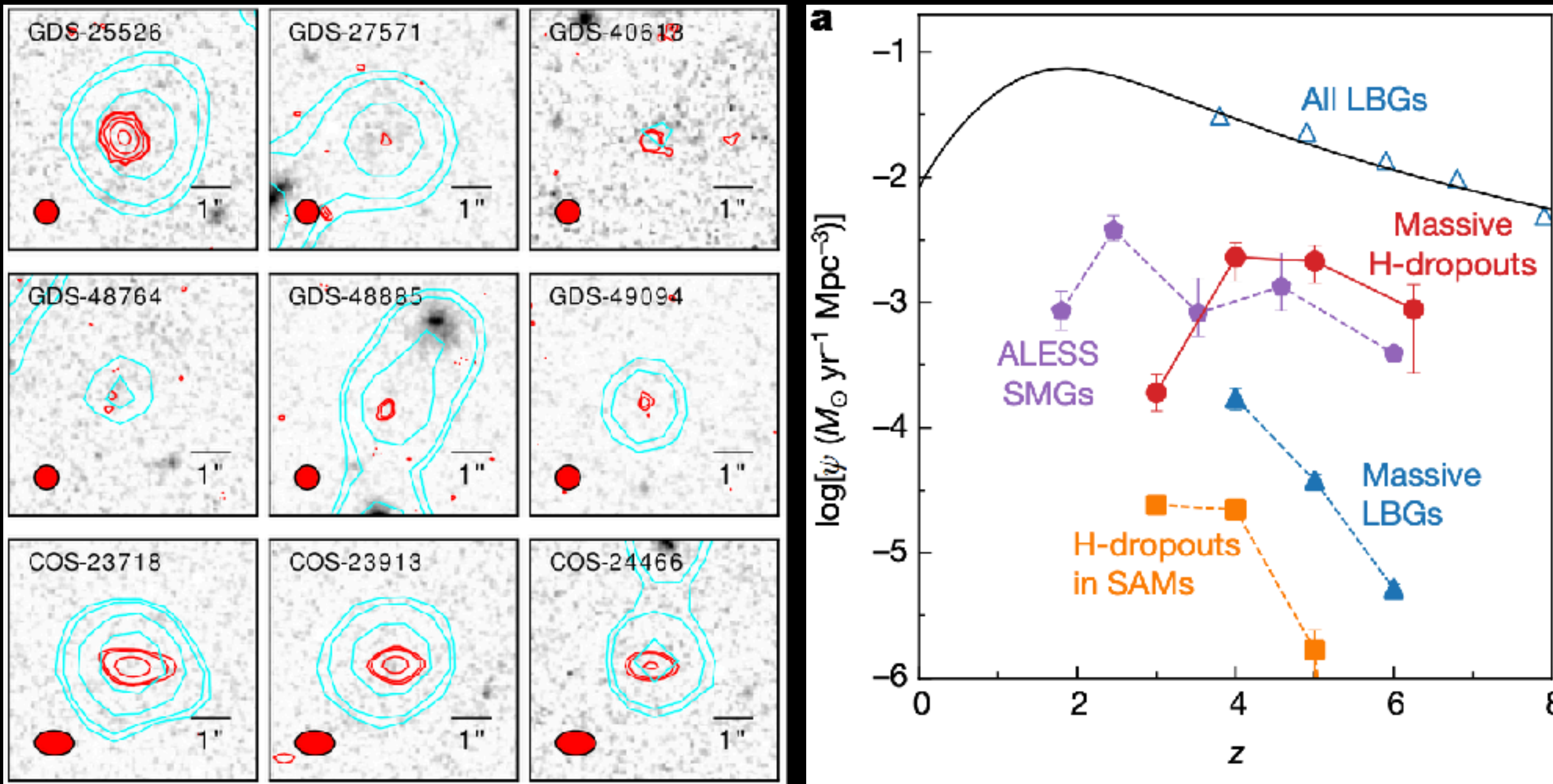
PROBING ESCAPE FRACTION f_{esc}



Observation probes:

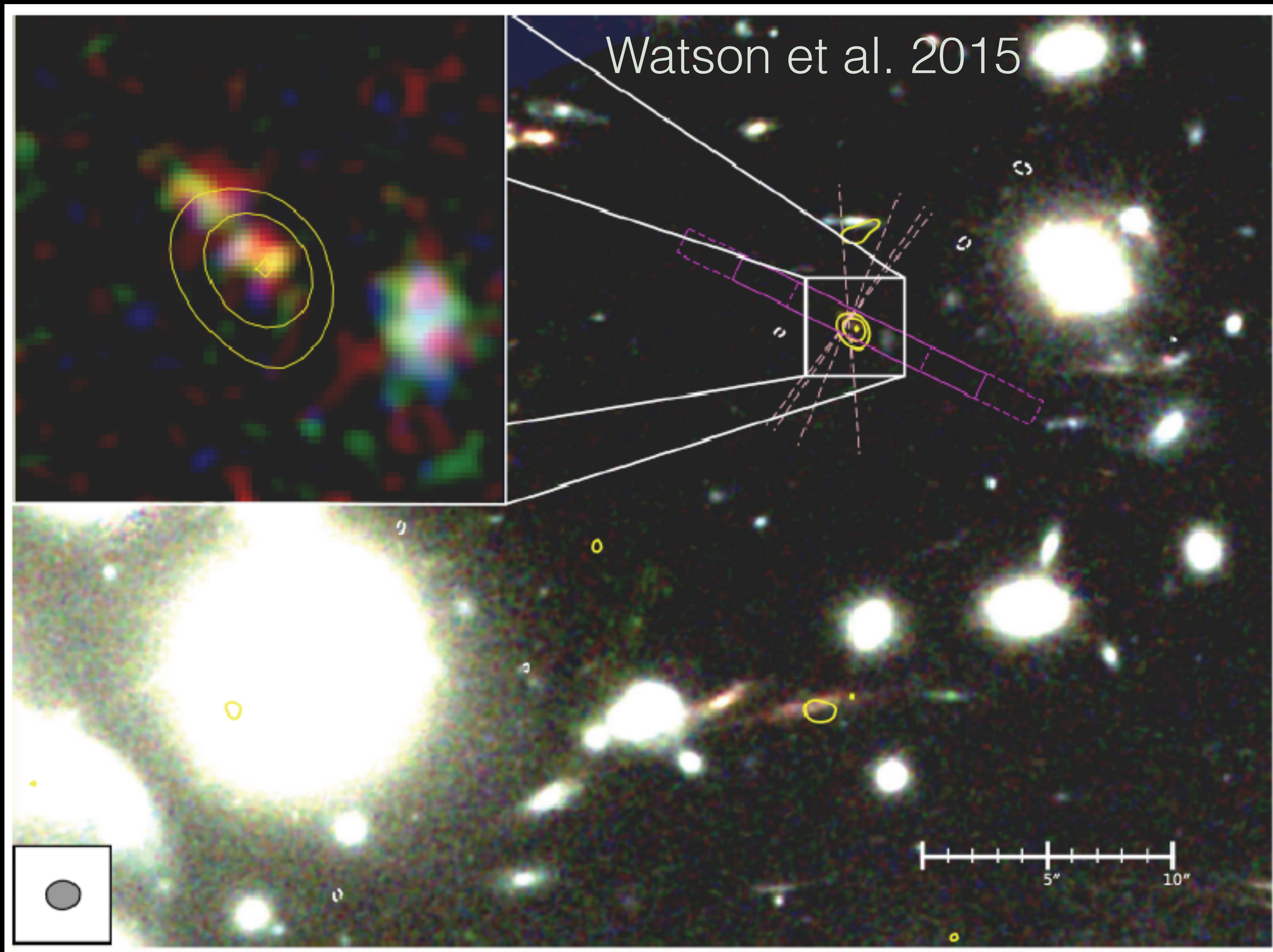
- direct measurement of Lyman Continuum (UV imaging / spectroscopy)
- outflowing neutral gas from rest-UV absorption lines
- covering fraction of low-ionisation gas from absorption lines
- recombination lines analysis

DUSTY HIGH REDSHIFT SOURCES



"Dark" galaxies seen with ALMA at z>3 (Wang et al. 2019)

DUSTY HIGH REDSHIFT SOURCES

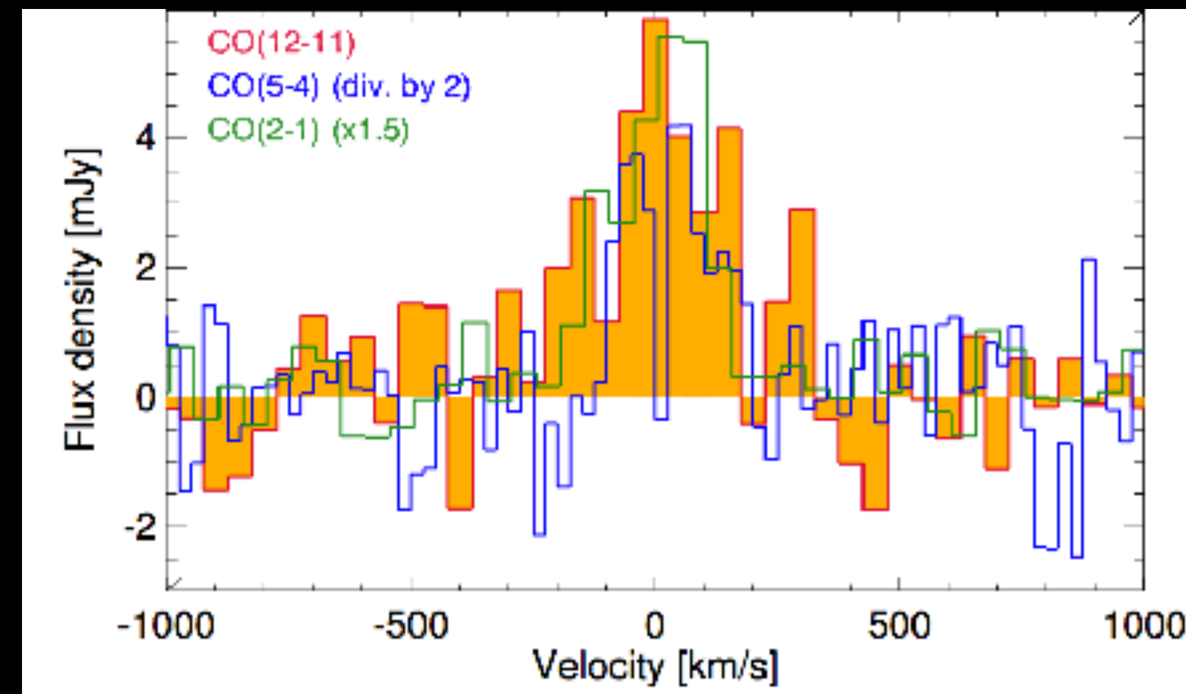


ALMA AND HIGH REDSHIFT SOURCES

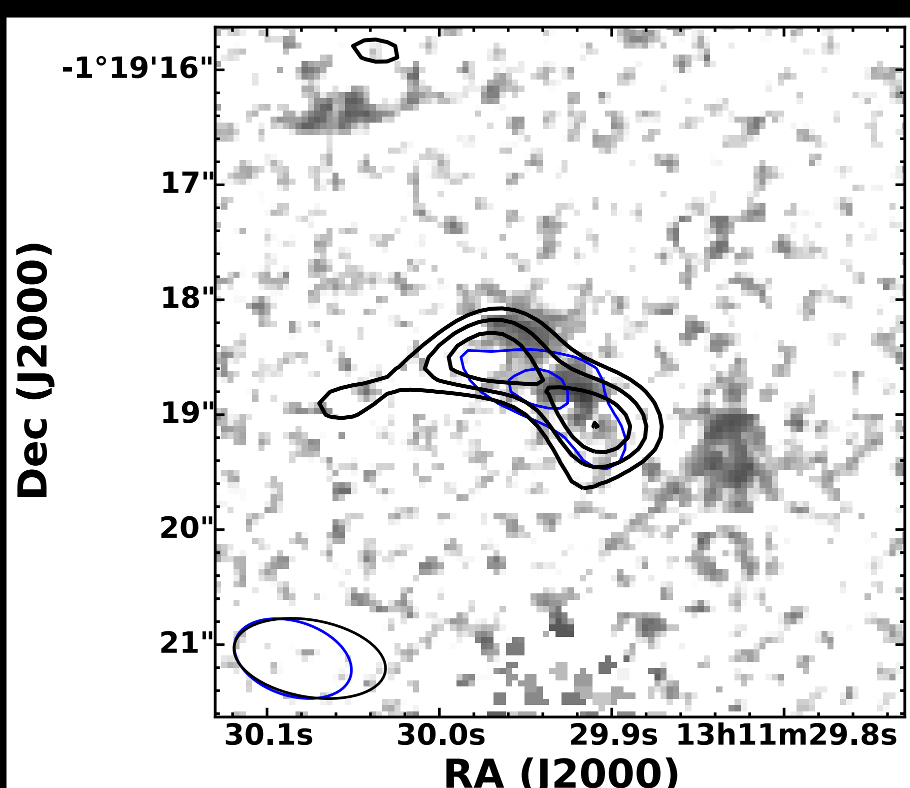
- Searching for typical (~< L*) UV-selected sources at (sub)mm wavelengths starts to be possible with the combination of ALMA (and NOEMA) + lensing

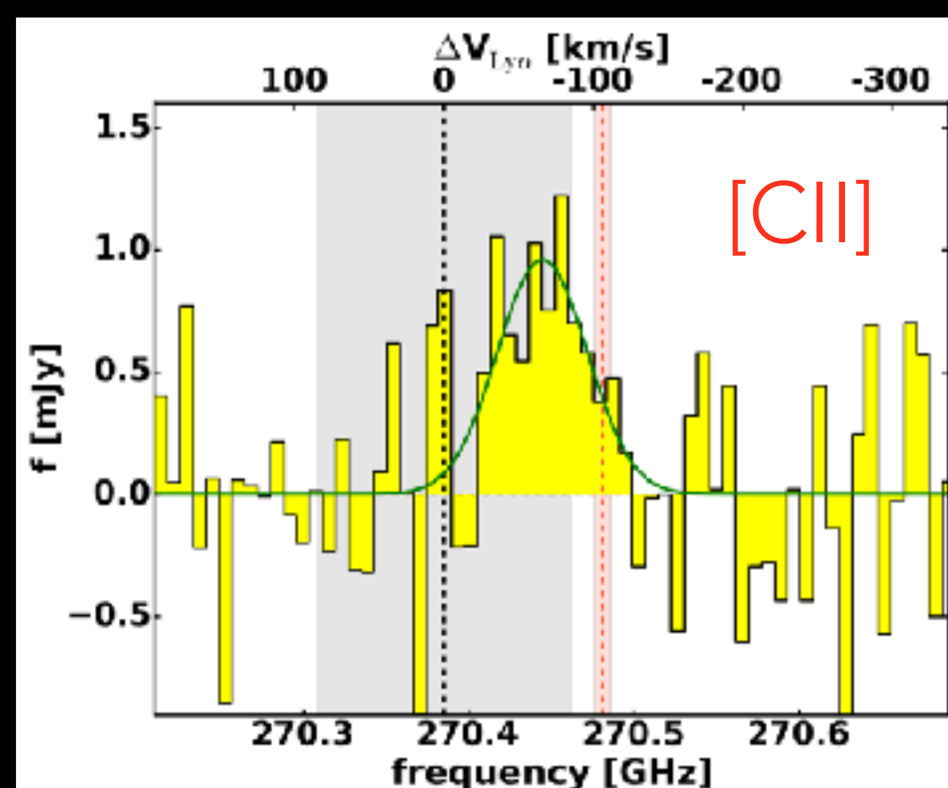
- [CII] detections at z>6

Béthermin et al. 2016

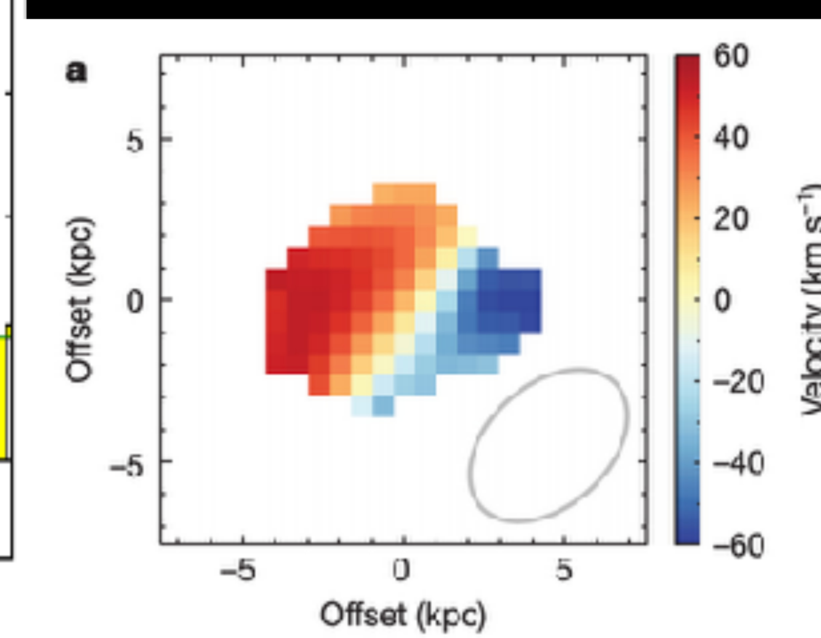


Knudsen et al. 2017





Smit et al. 2018



[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

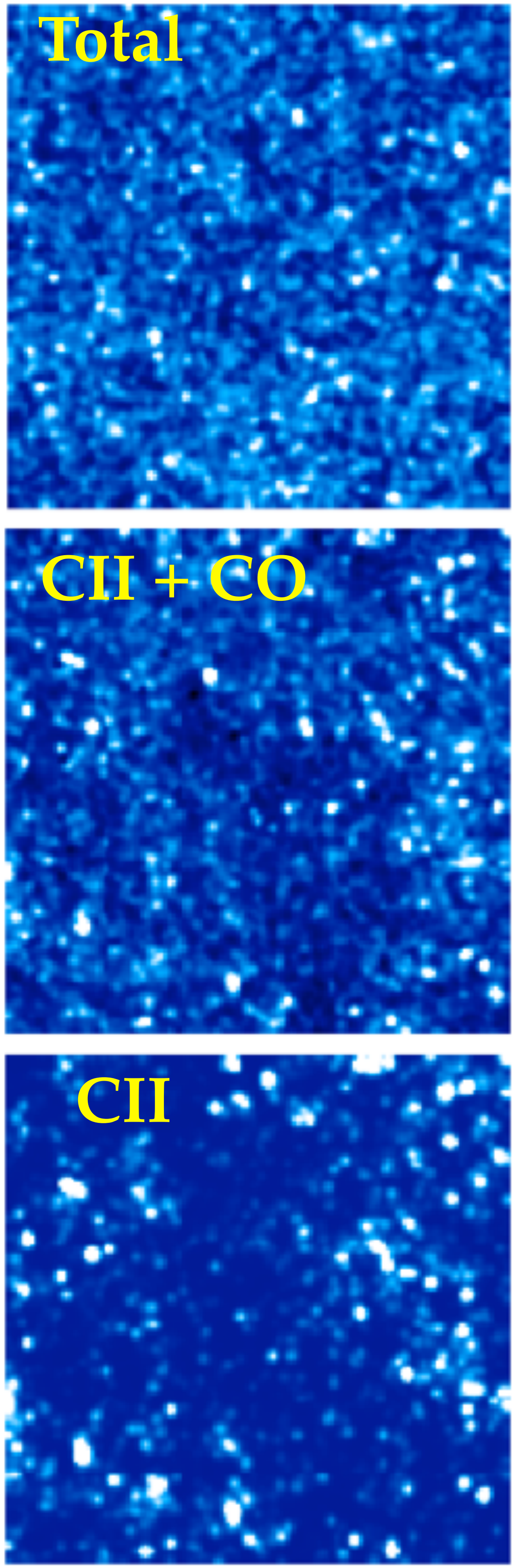
Cross-correlations:

- 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?

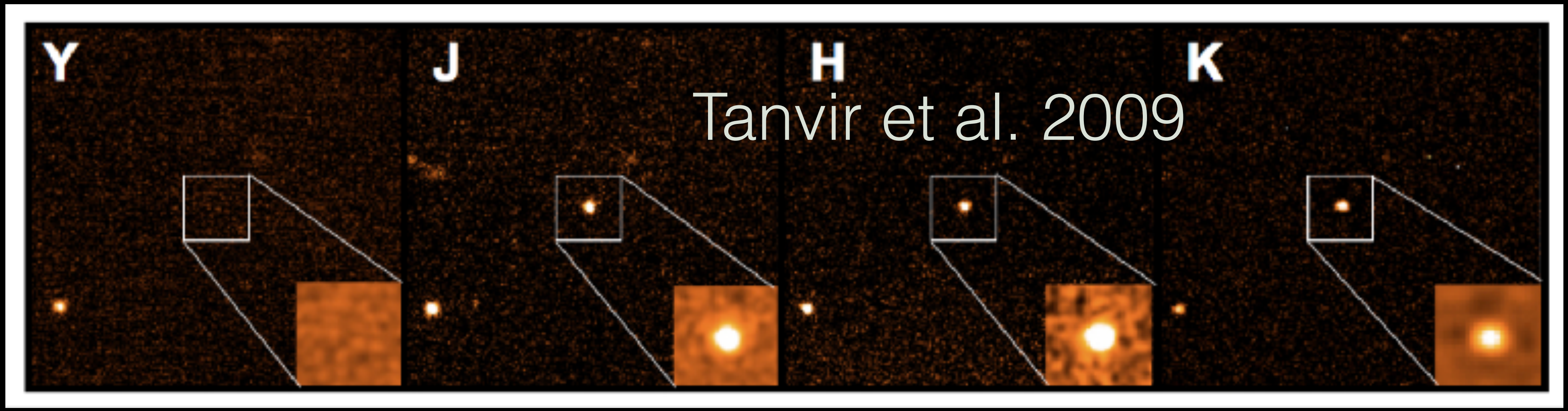
- 2 Sq. Deg. during 1500 hours
- $\delta z=0.05$ at $z=7$
- 200 GHz < υ < 360 GHz

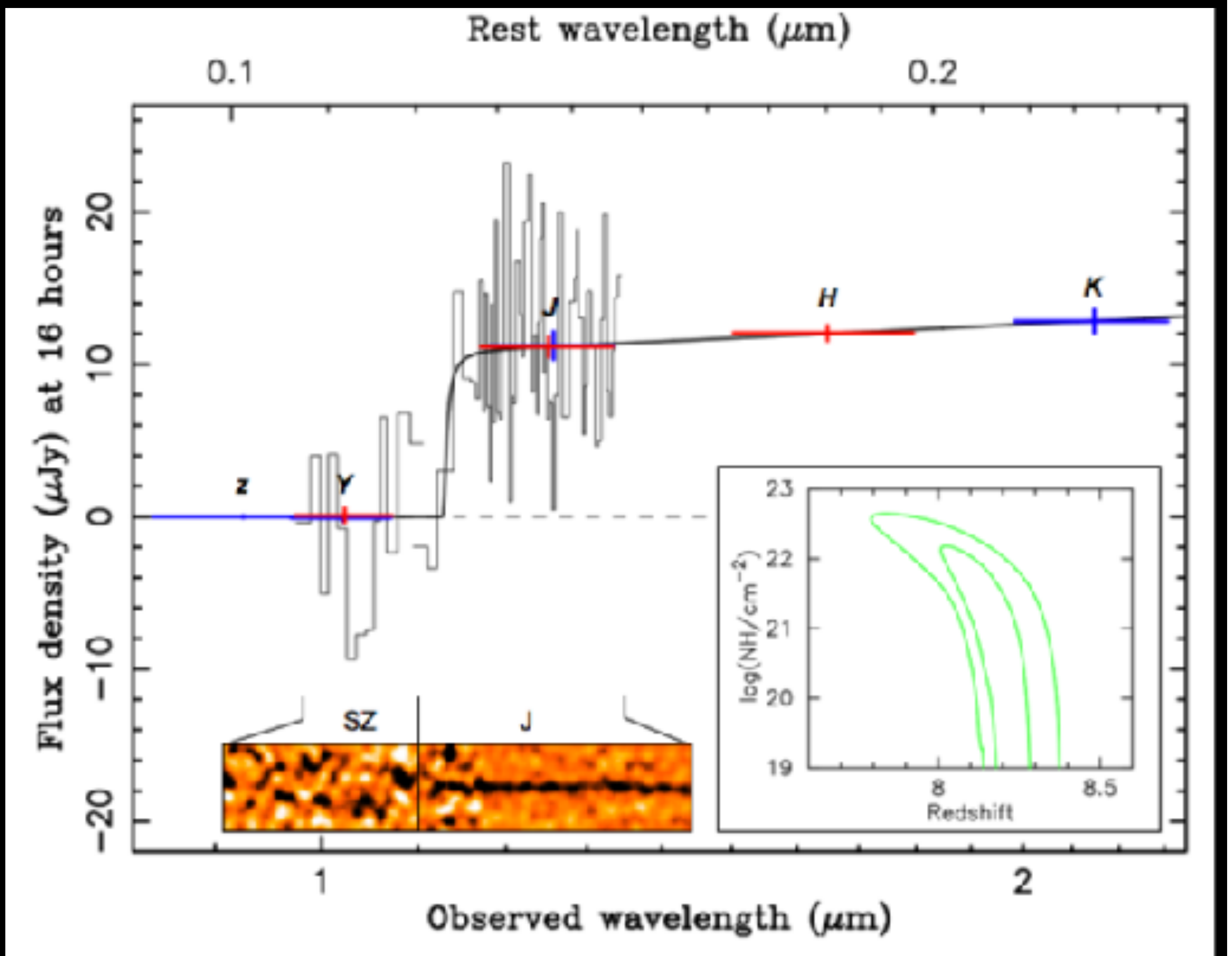
(G. Lagache)

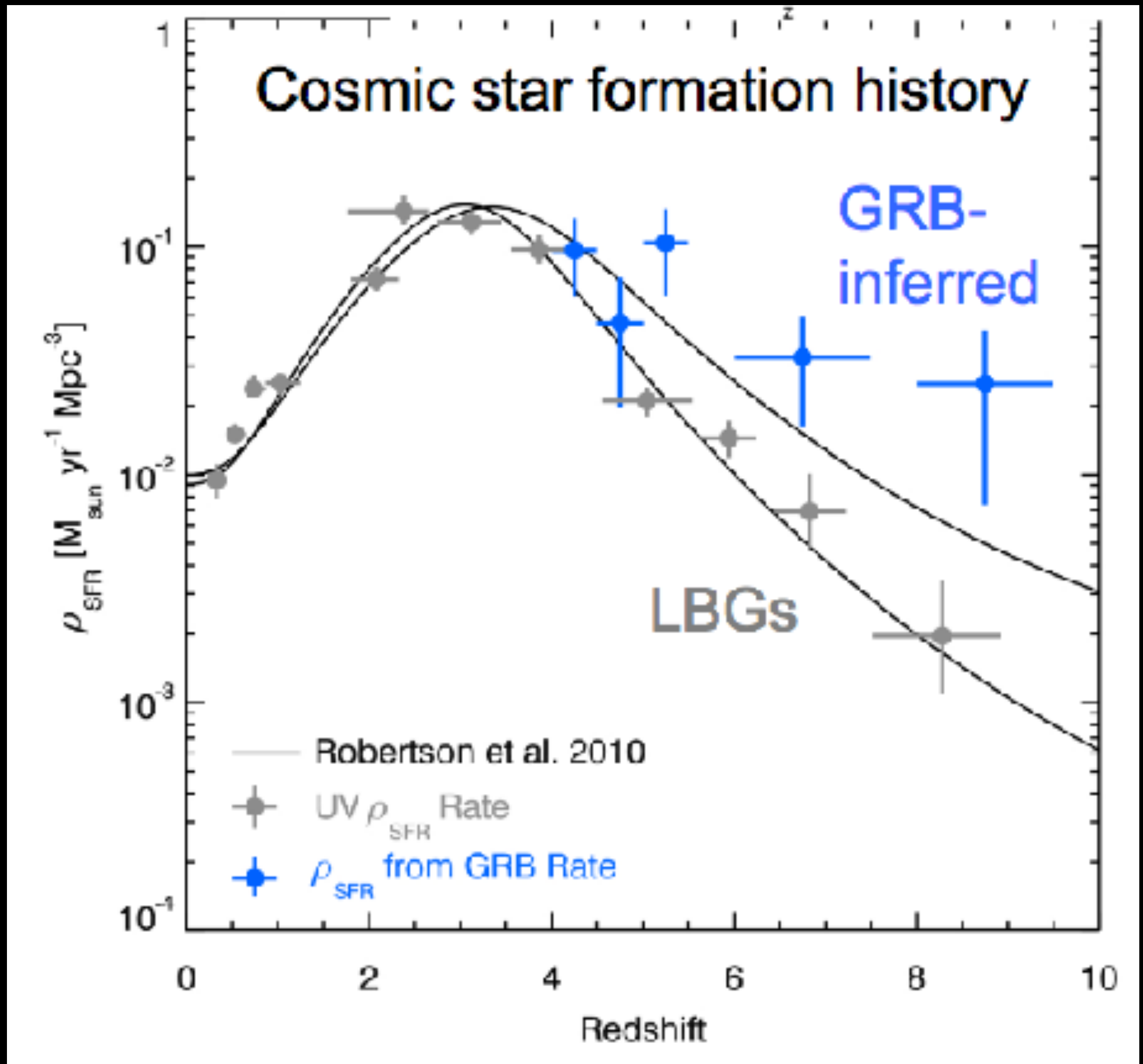
1.4x1.4 degrees CONCERTO simulated sky maps at z=5.5±0.1



GAMMA RAY BURSTS



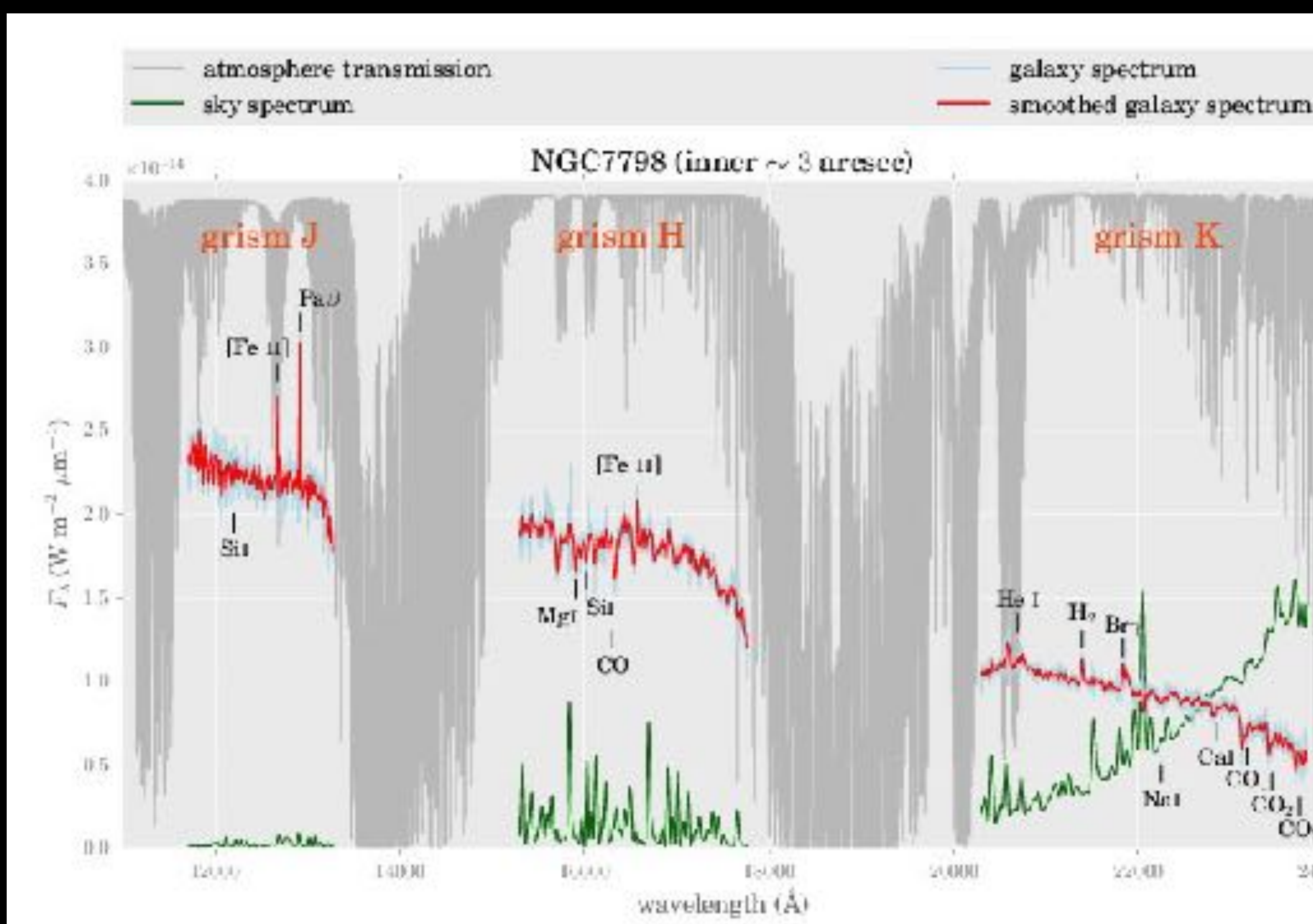




INSTRUMENTATION: EMIR

Exploitation of the EMIR/GOYA survey on GranTeCan (10.4m, Canaries)

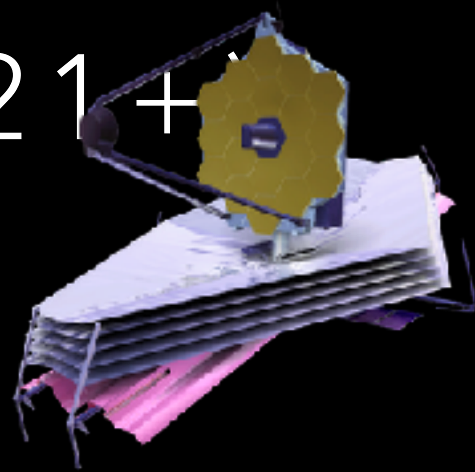
EMIR : configurable multi-slit spectrograph in the near-infrared.



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.

JWST (2021+)

f_{esc} ξ_{ion}

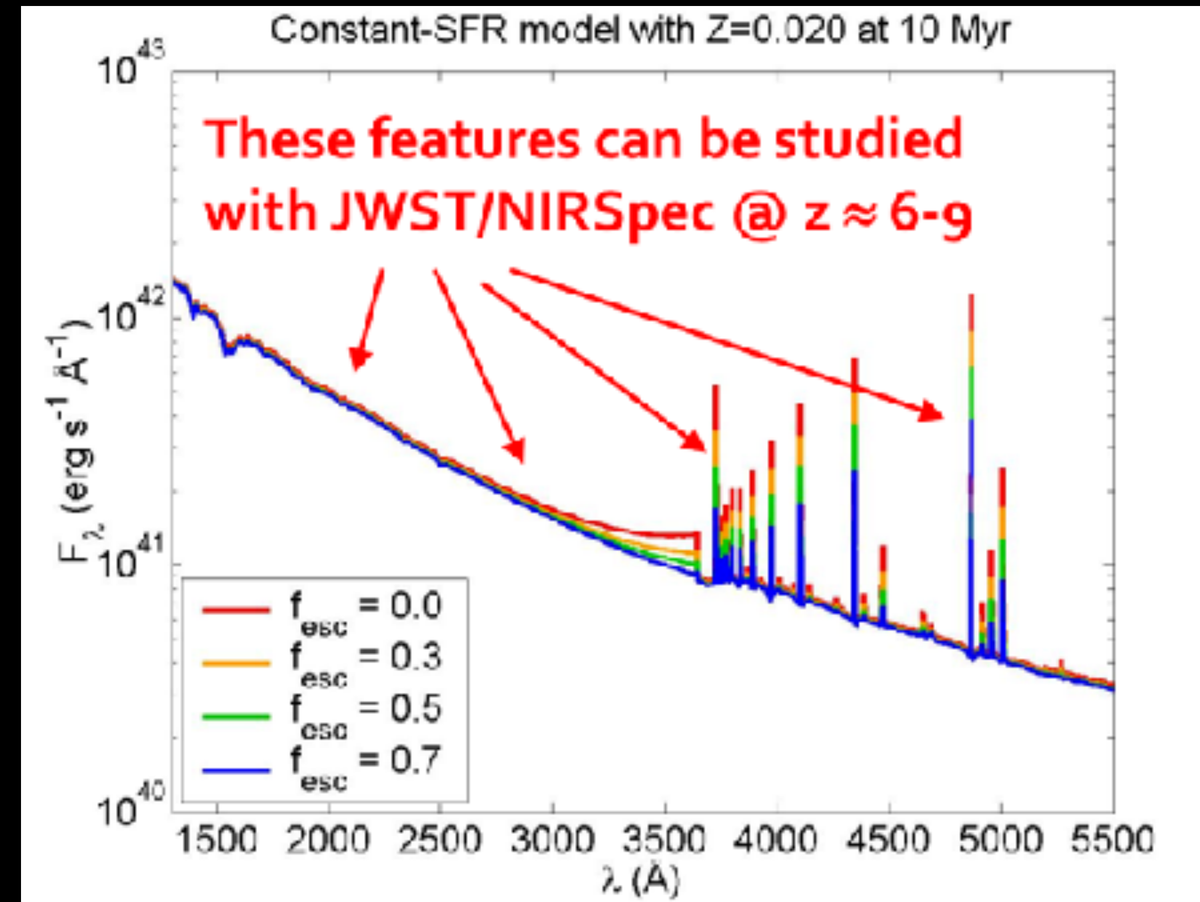


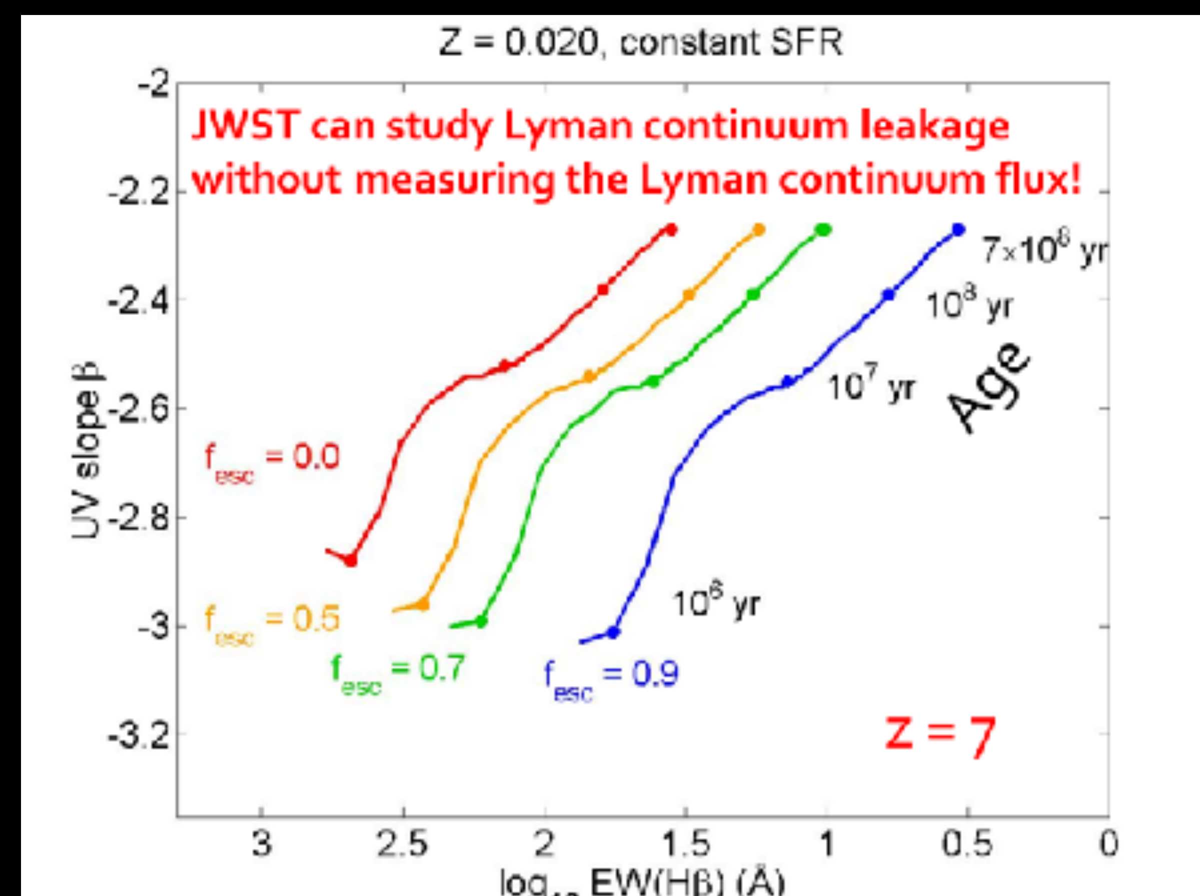
- The James Webb Space Telescope is clearly the major leap for first light sources.

Strategy foreseen:

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

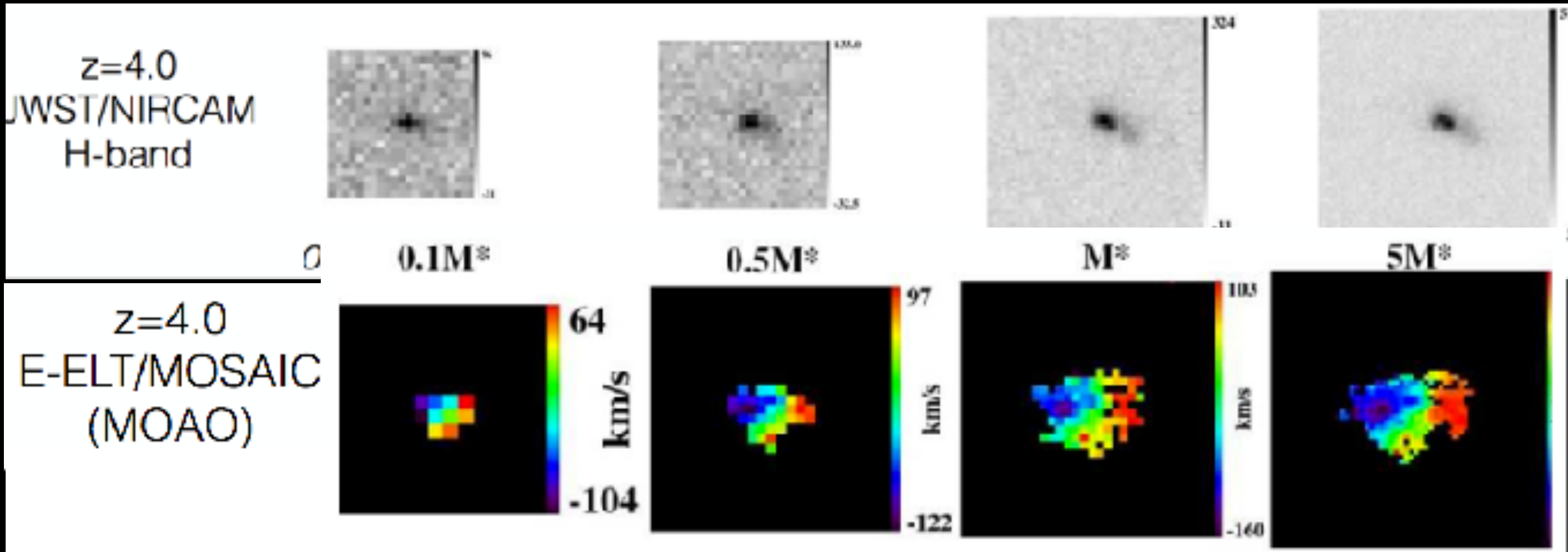
Zackrisson et al. 2013





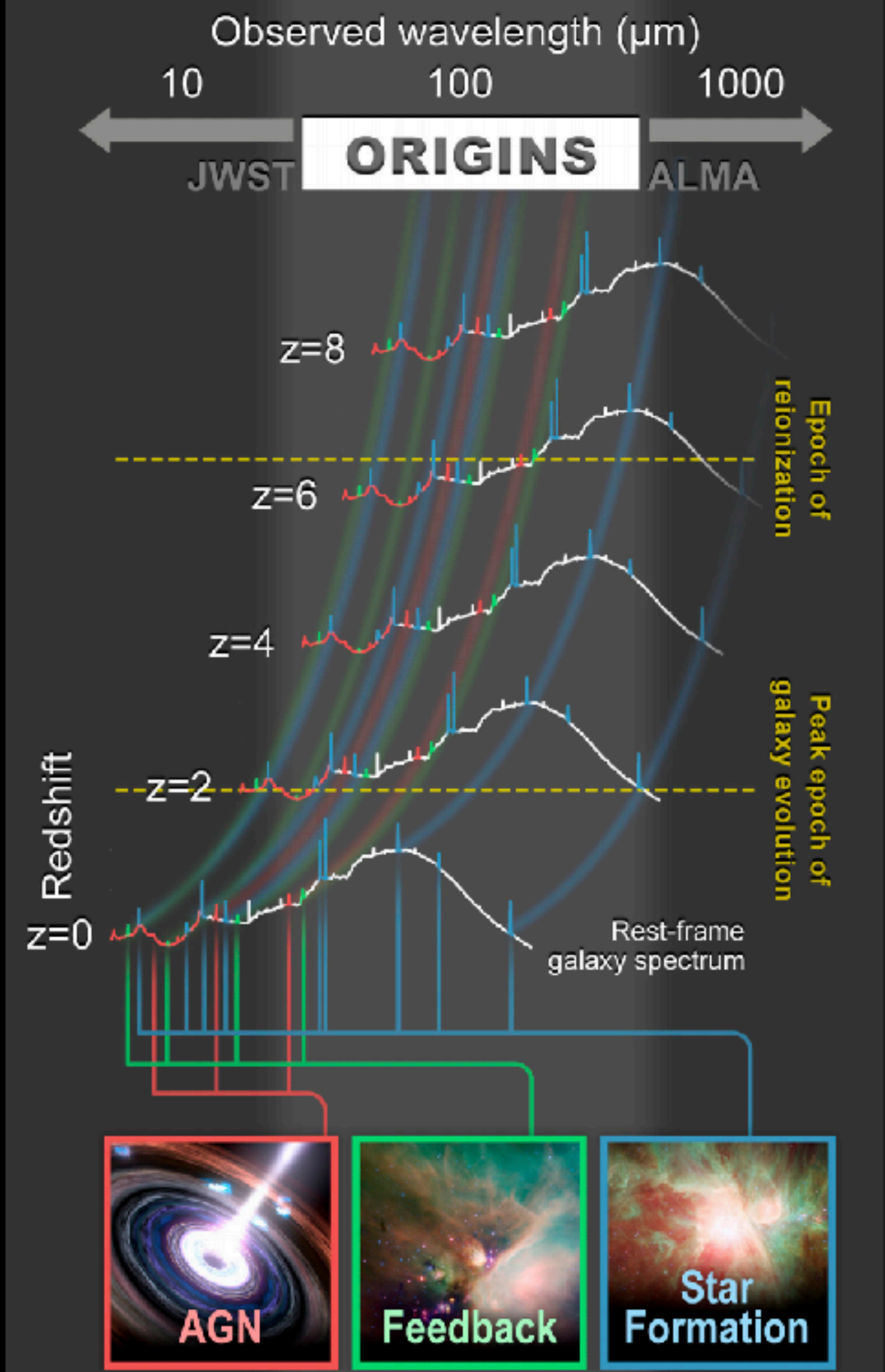
ELT (~ 2025)

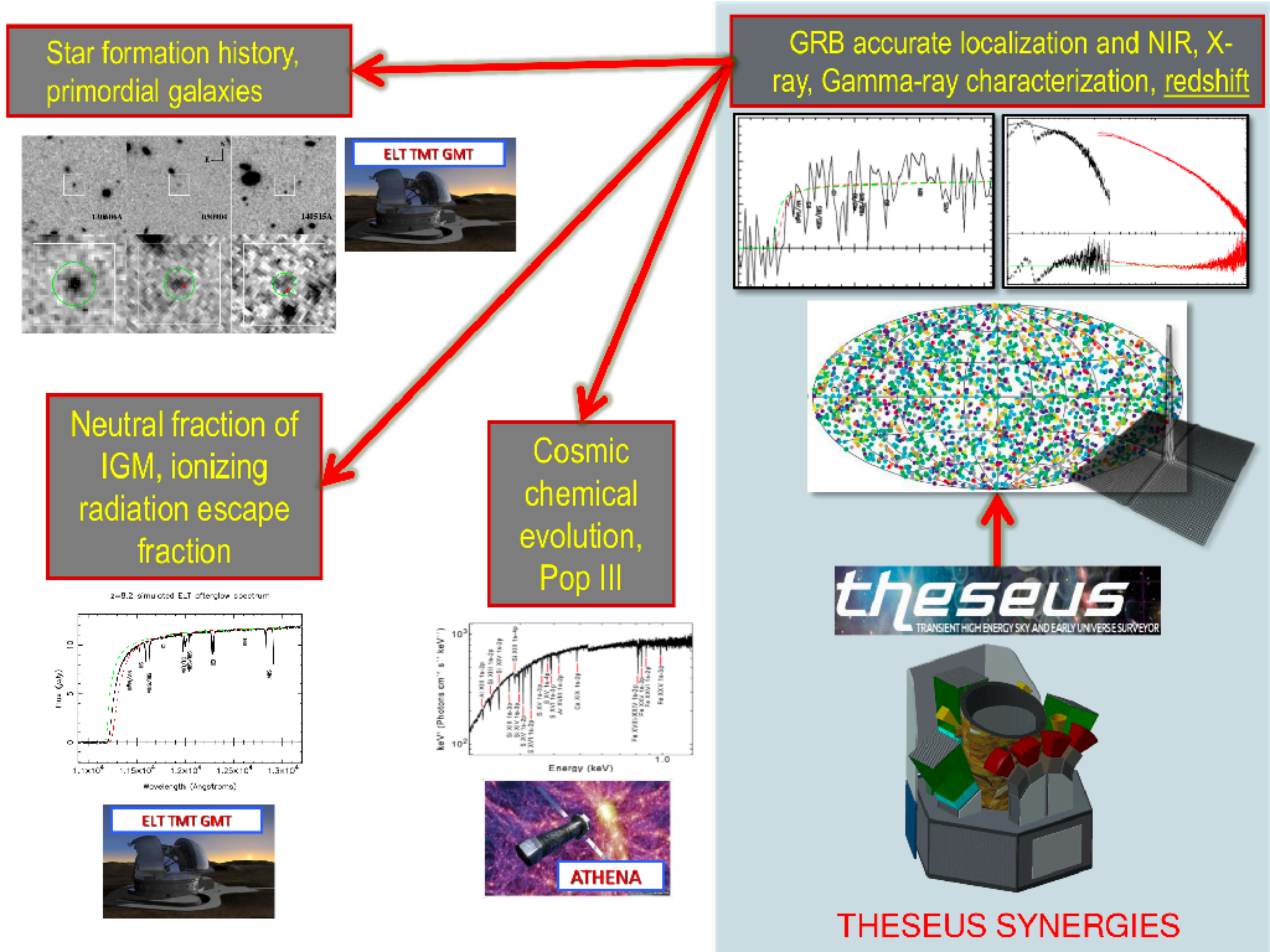
- HARMONI: **First light IFU instrument,** 0.47 - 2.5 microns
  - 0.86″ x 0.61″ with 4 mas spatial pixels: follow-up of the brightest sources at z > 3, morphology, kinematics
  - 9.12″ x 6.42″ with 60x30 mas spatial pixels: HARMONI deep fields, follow-up of faint NIRCAM-selected sources
- MOSAIC, **multi-object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



Origins will trace the metal enrichment history of the Universe, probe the first cosmic sources of dust, the earliest star formation, and the birth of galaxies.

Charting the Rise of Metals, Dust, and the First Galaxies




GRB accurate localization and NIR, X-ray, Gamma-ray characterization, redshift
Star formation history, primordial galaxies
ELT TMT GMT
Neutral fraction of IGM, ionizing radiation escape fraction
Cosmic chemical evolution, Pop III
z=8.2 simulated ELT afterglow spectrum
Wavelength (Angstroms)
ELT TMT GMT
Energy (keV)
ATHENA
theseus
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR
THESEUS SYNERGIES

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), improving our knowledge of selection effects and the UV properties at high redshift.

- Numerical simulations are making very good progress and we can expect strong impact from JWST, the ELT.

- **THESEUS will provide a more complete census of star-formation especially at z>8, and has a unique 'link' between the various tests**