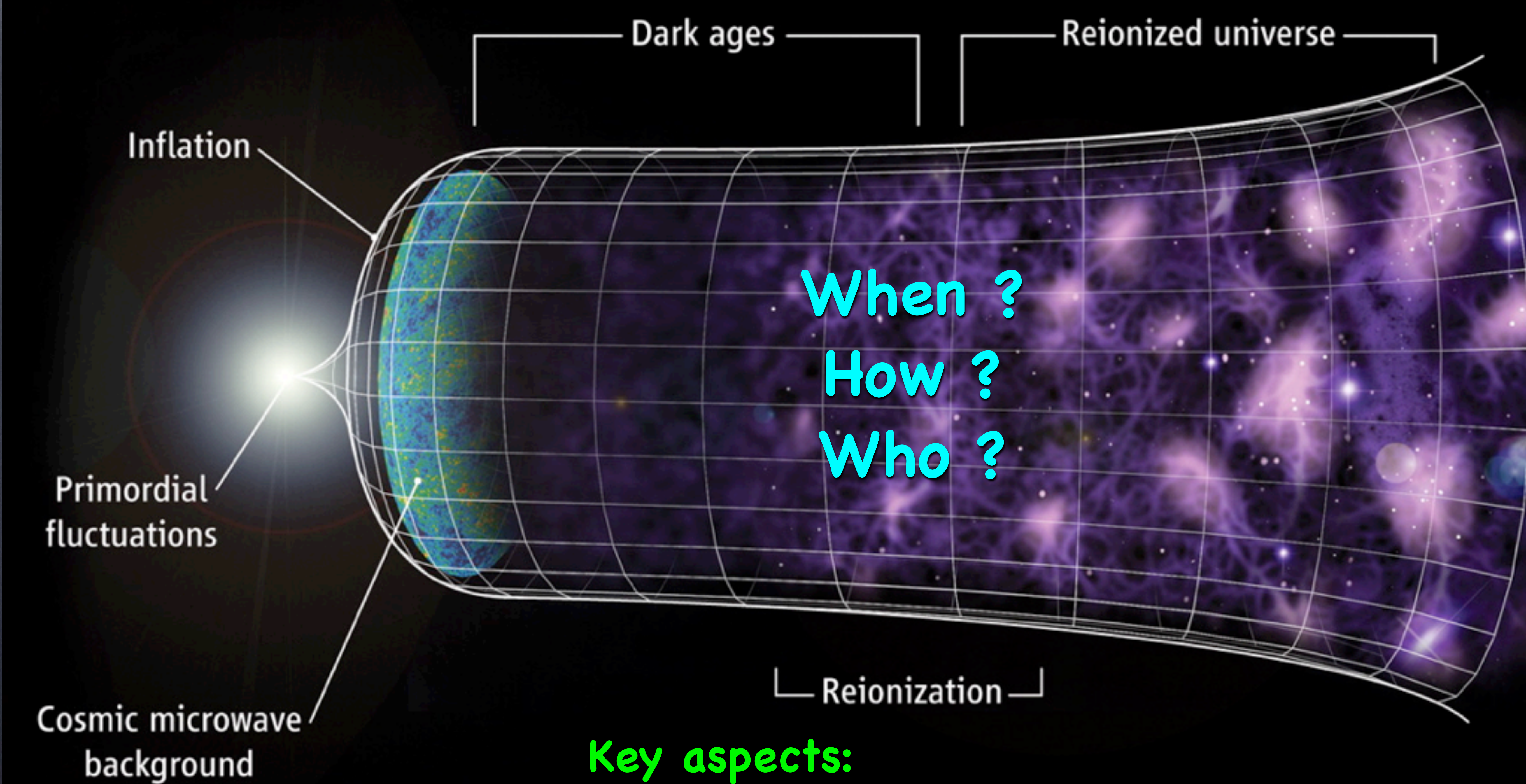
First objects and reionization epoch (Vanzella OABO)



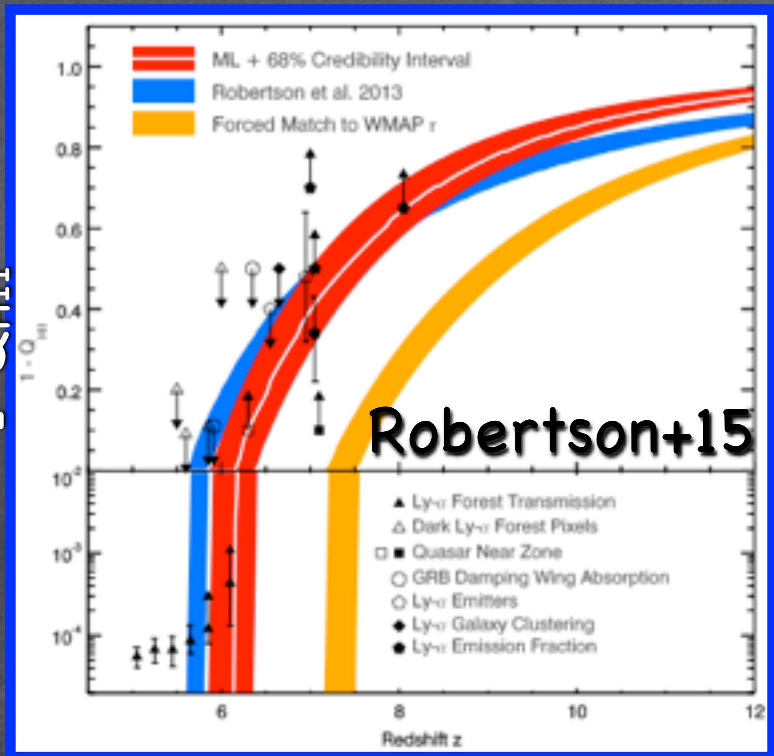
Key aspects:

- A major event in the cosmic history of the Universe that impacted on almost every baryon in the Univer
- Detailed measurements of the IGM properties inform models of high-z structure formation
- Early generation of ionizing sources influenced the formation of subsequent galaxy populations

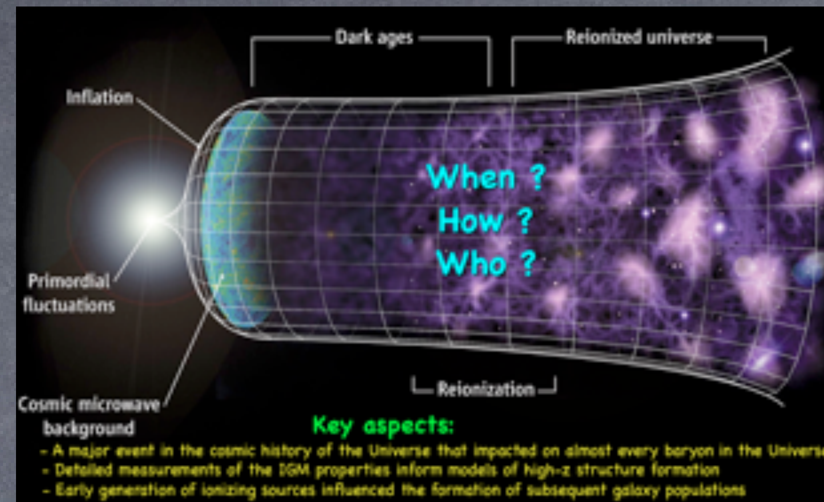
First objects and reionization epoch

(Vanzella OABO)

1−QHII



Redshift



? UV lum. funct. (N/mag/Mpc3)

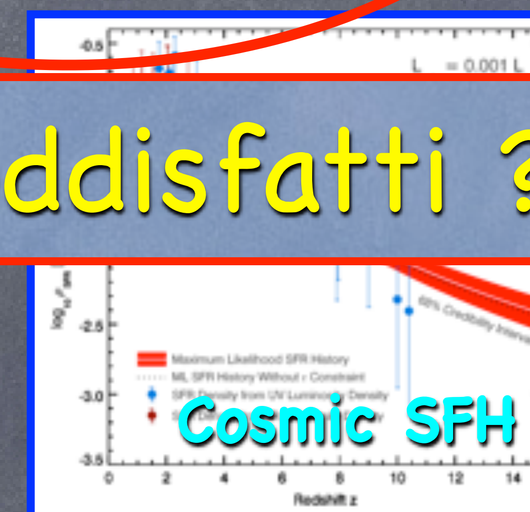
? ioniz. luminosity (phot/s)

(spectrum of sources)

? escape fraction ion. photons: transmission

$$\dot{n}_{\rm ion}^{\rm com} = \int_{M_{\rm lim}}^{\infty} {\rm d}M_{\rm UV}\, \phi(M_{\rm UV})\gamma_{\rm ion}(M_{\rm UV})\, f_{\rm esc}$$

siamo soddisfatti ?



Volume filling factor:

Volume(HII) / Volume Universe

$$\frac{{\rm d}Q_{\rm H\,II}}{{\rm d}t} = \frac{\dot{n}_{\rm ion}}{\bar{n}_{\rm H}} - \frac{Q_{\rm H\,II}}{\bar{t}_{\rm rec}}$$

$Q_{HII}=1$ ionized

$Q_{HII}(z)<1$ neutral

mean comoving hydrogen number density

$$\bar{t}_{\rm rec} = \frac{1}{C_{\rm H\,II}\alpha_{\rm B}(T_0)\,\bar{n}_{\rm H}(1+Y/4X)(1+z)^3}$$

$$\approx 0.93\ {\rm Gyr}\left(\frac{C_{\rm H\,II}}{3}\right)^{-1}\left(\frac{T_0}{2\times10^4\ {\rm K}}\right)^{0.7}\left(\frac{1+z}{7}\right)^{-3}$$

$$C_{\rm HII} \equiv \langle n_{\rm HII}^2\rangle / \langle n_{\rm HII}\rangle^2$$

Hui (2012)

$$C_{\rm H}(z) = (2.9)\left[\frac{(1+z)}{6}\right]^{-1.1}$$

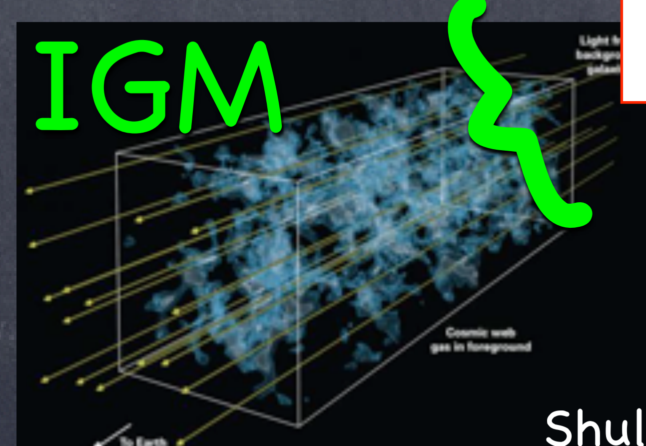
$z\sim8.8^{+1.2}_{-1.1}$ CMB

Thomson optical depth to electron scattering τ=0.066+/-0.012

Planck Collaboration (2015)

$$\tau_e(z) = \int_0^z c\,\langle n_{\rm H}\rangle\,\sigma_T\, f_e\, Q_{\rm HII}(z')\frac{(1+z')^2dz'}{H(z')}$$

Kimm & Cen (2014)



Shull et al. (2012)

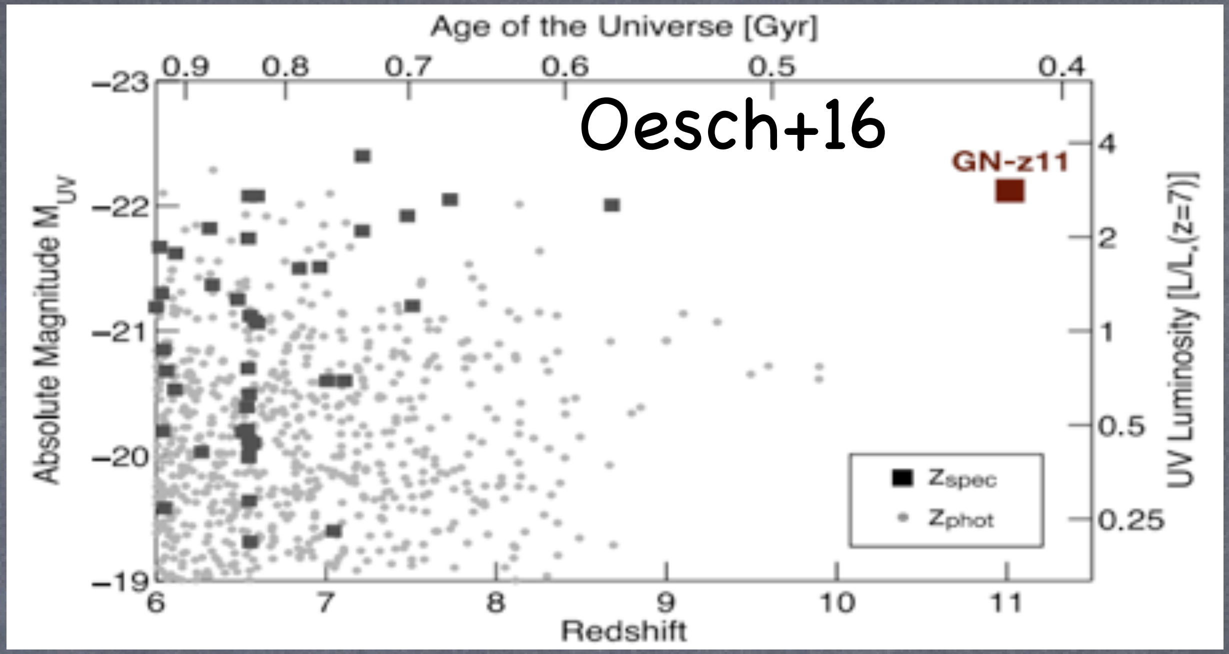
First objects and reionization: new territories

The spectroscopic view

(1)

Extend the horizon (redshift)

New wavelength domain

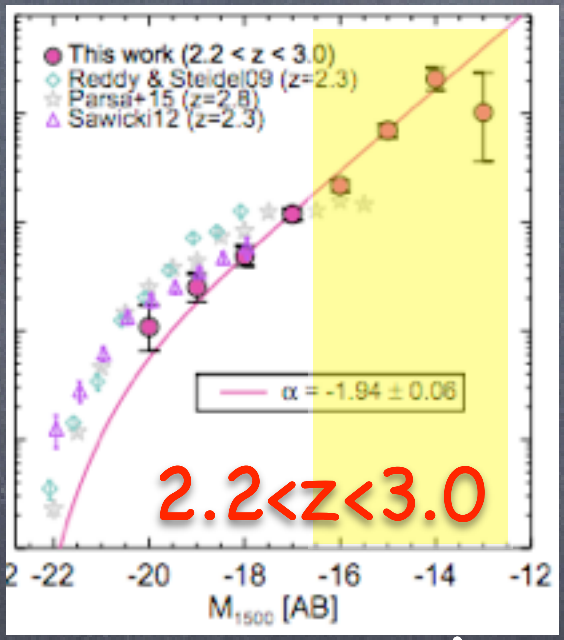


(2)

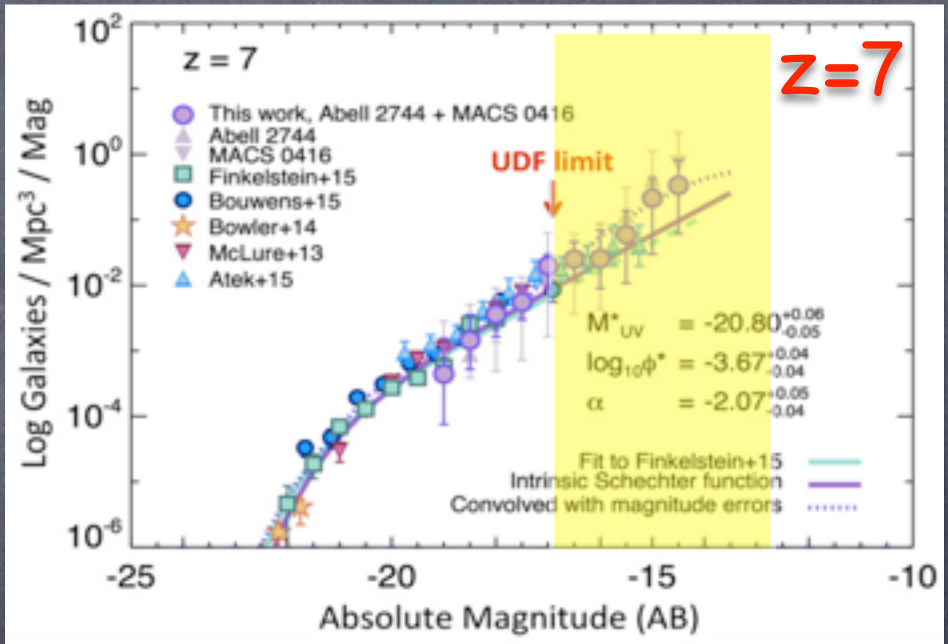
Extend the lum. regime

New mass domain, zphot

(dominate the UV lum. density)



Alavi+16



Strong lensing

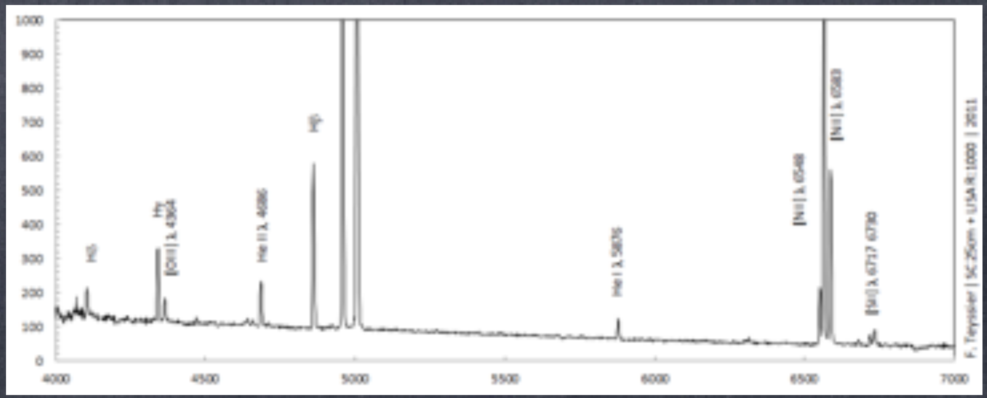
Livermore+16

(3)

Spectroscopy at the faintest limits:

nature of ionizing radiation,

ISM properties in new domains (1+2)



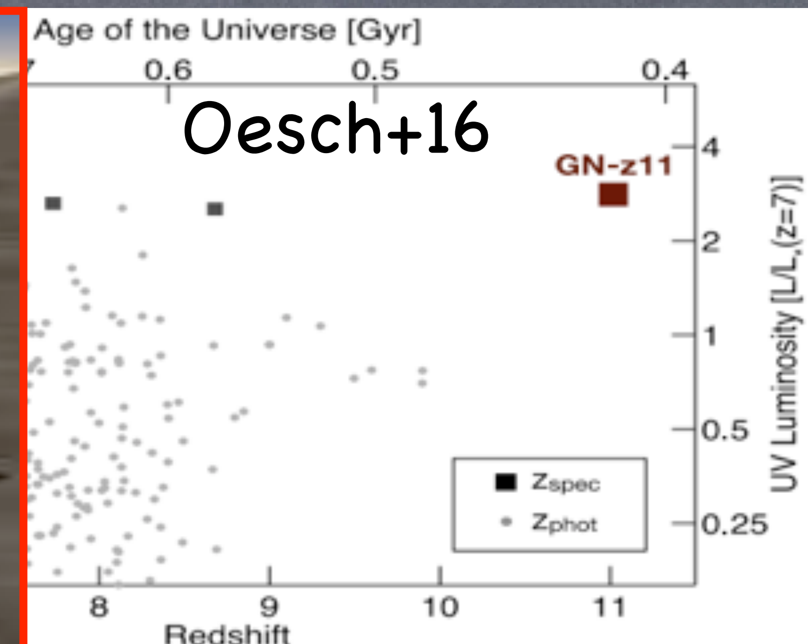
First objects and reionization: new territories

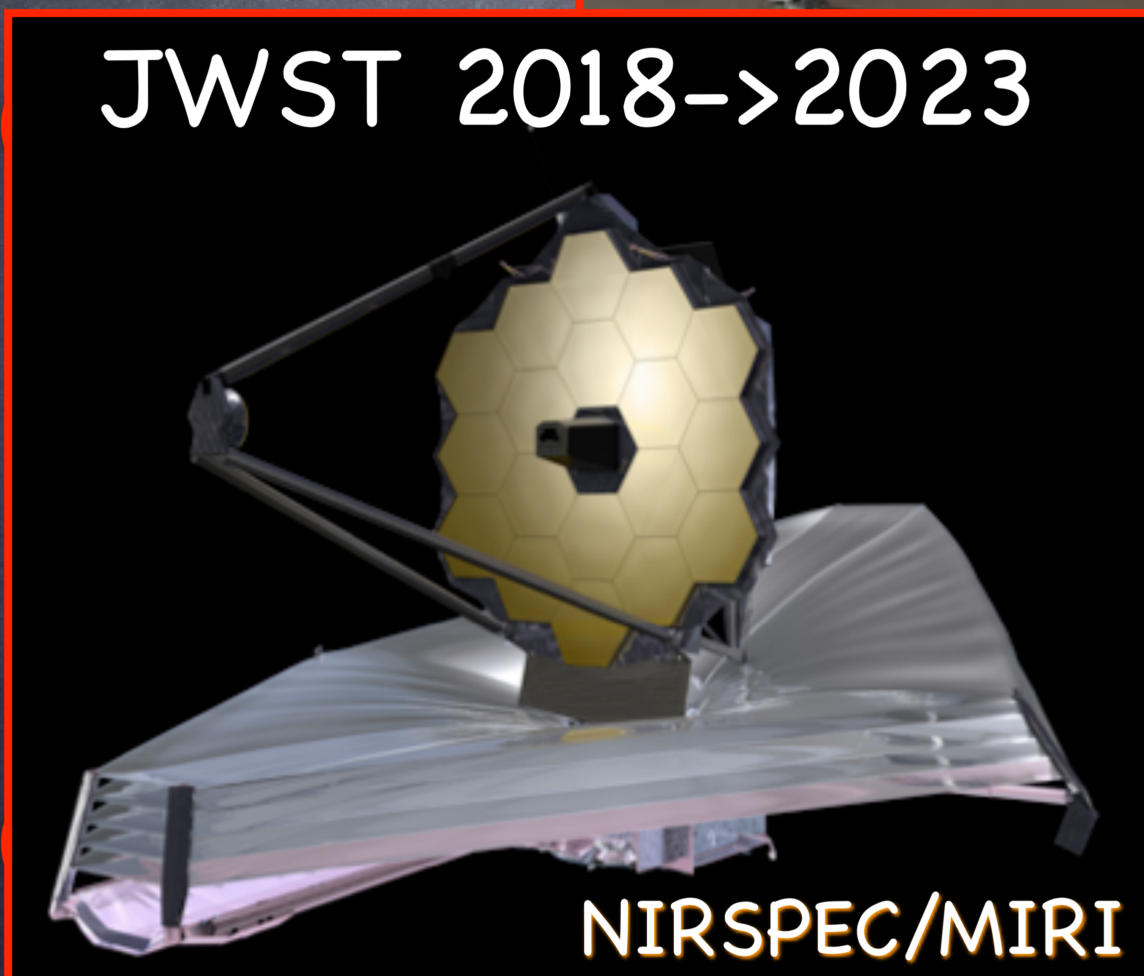
The spectro

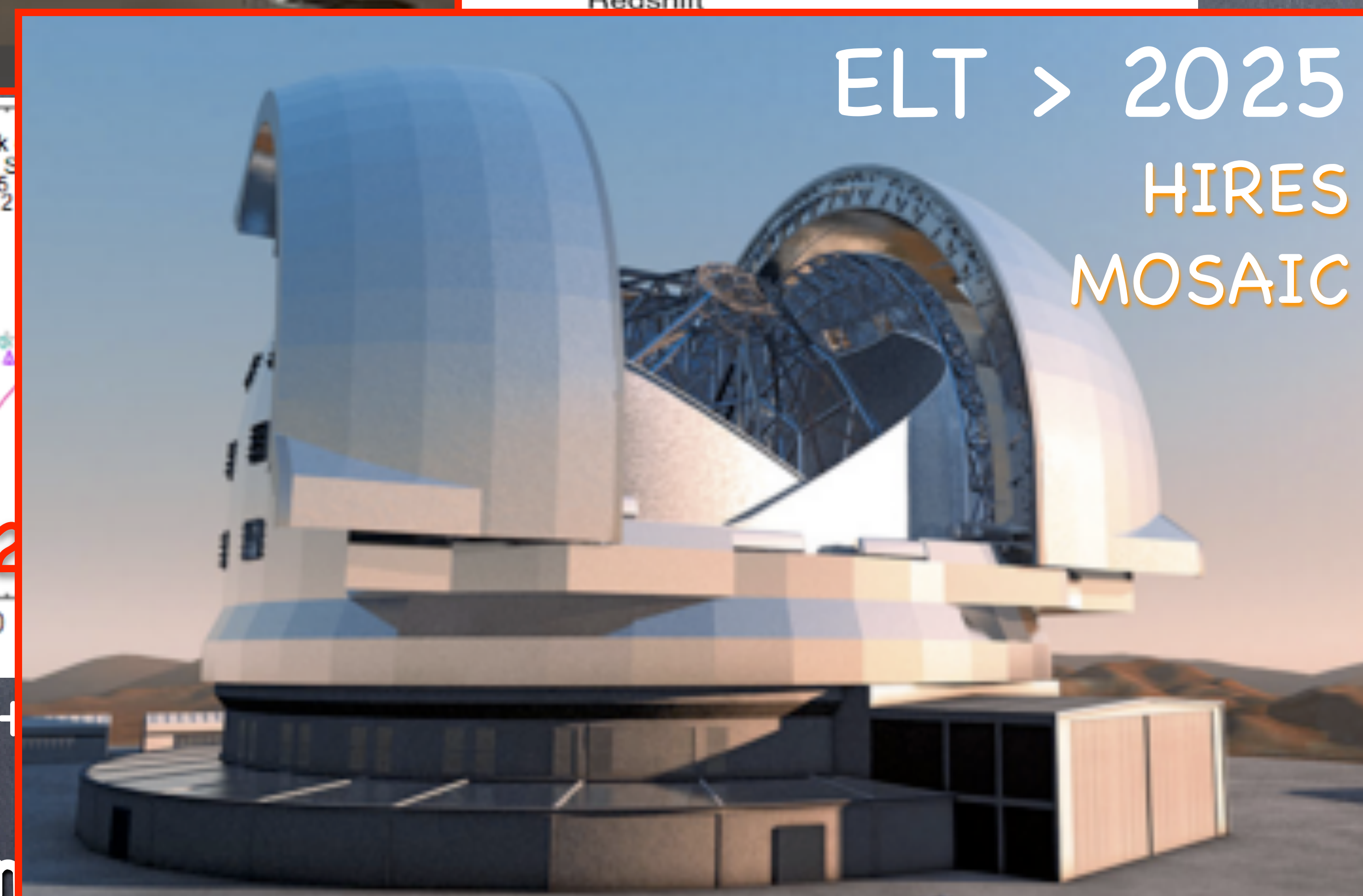
(1)

Extend the h

New wavelengt

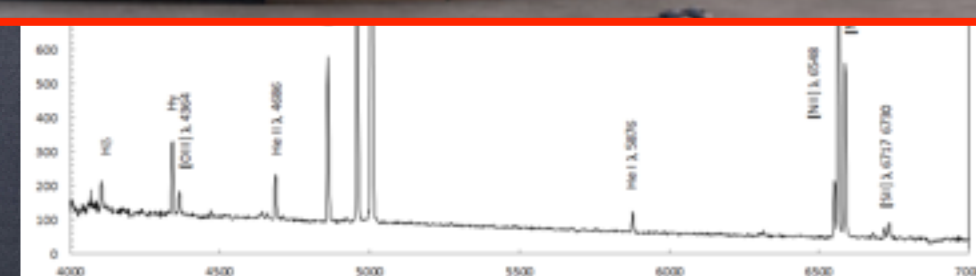






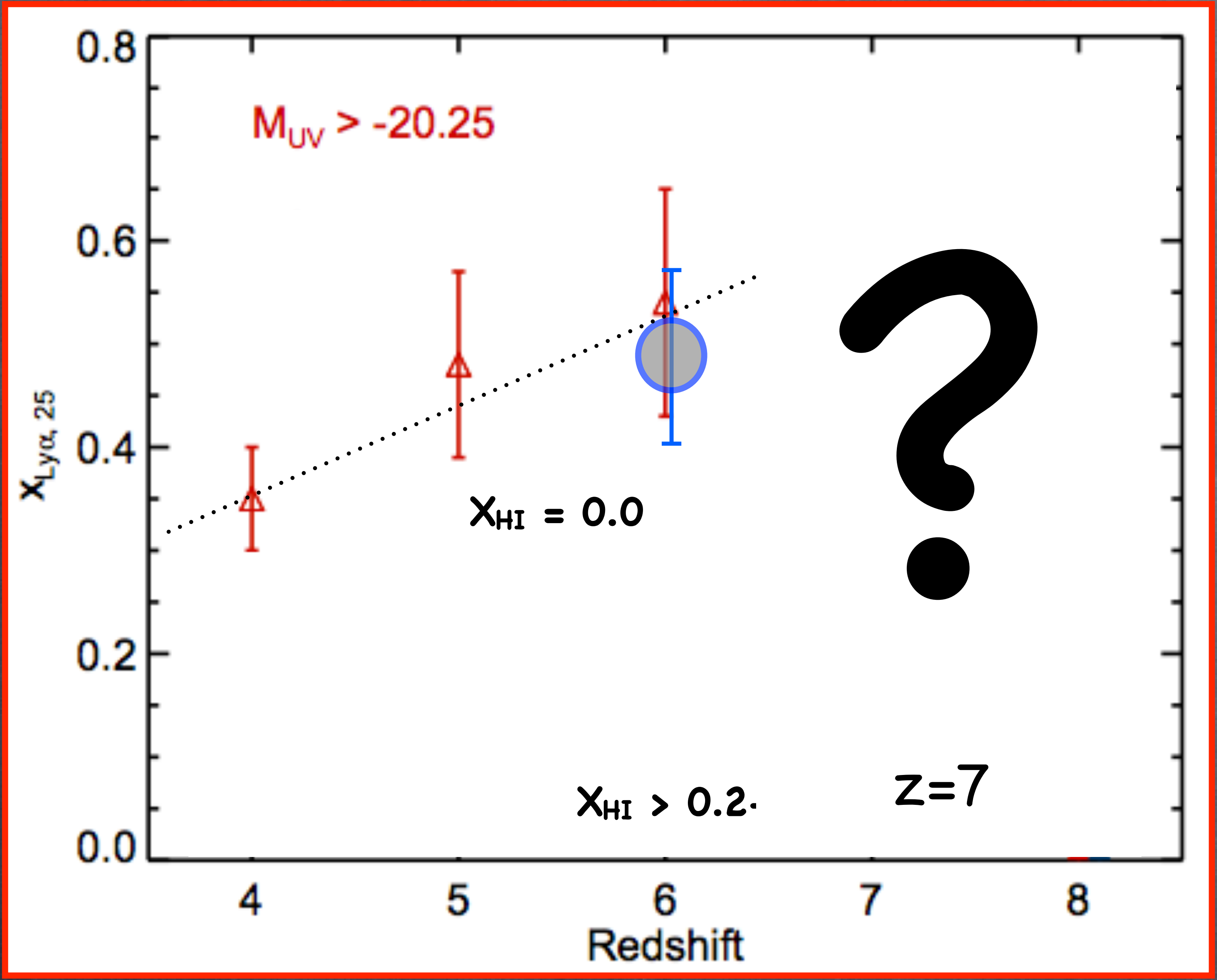
nature of ionizing radiation,

ISM properties in new domains (1+2)



(1) Extend the horizon (redshift) New wavelength domain

EW(Lya)>25A (EWlim<25A), Muv> -20.25



z>7 Entering the EoR

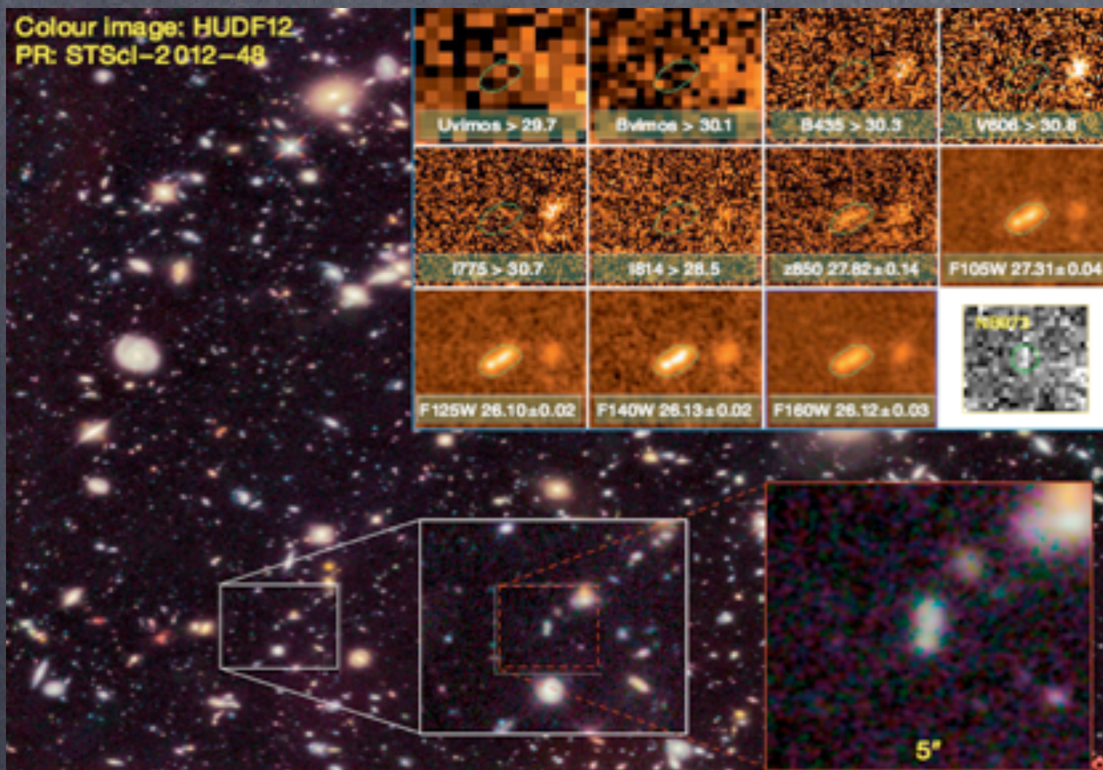
How can we measure redshifts at z>7 ?

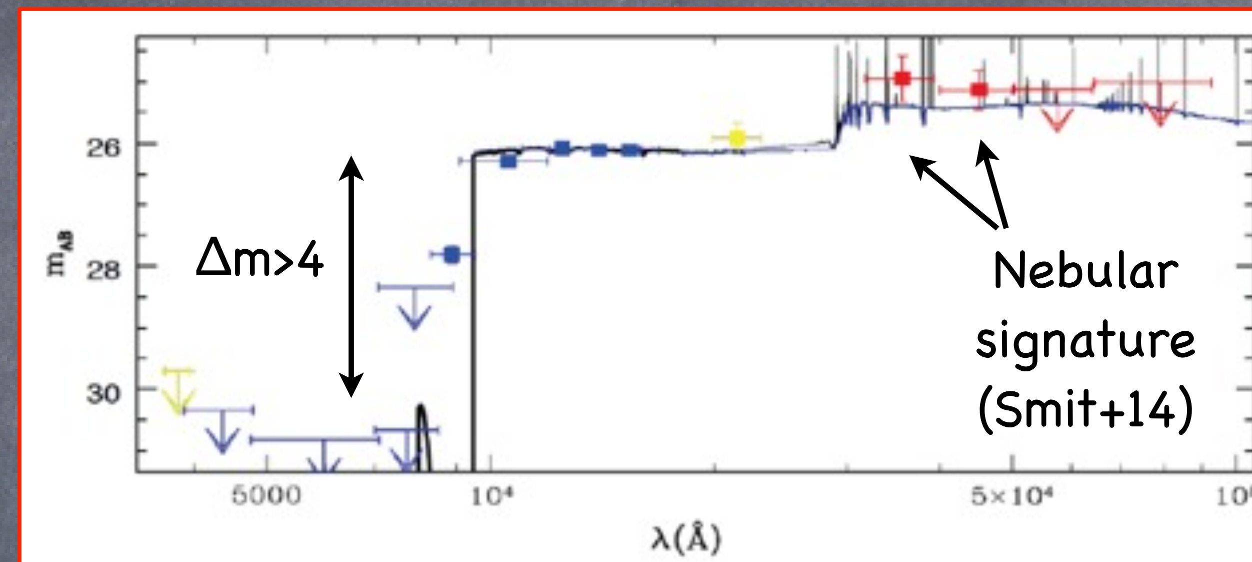
e.g., Fontana+10; EV+11; Pentericci+14

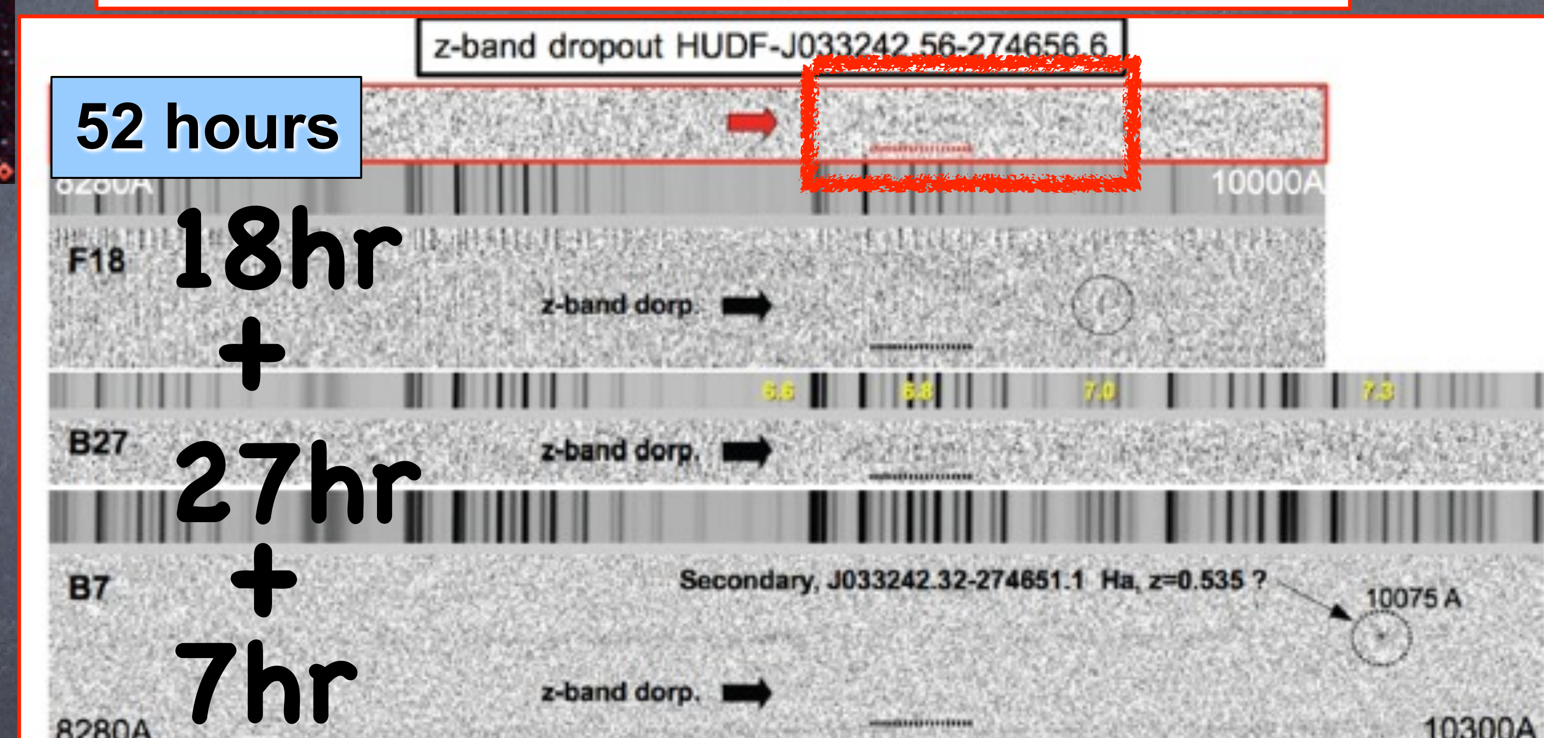
Lya line is the best feature we have to measure z at z>5-6 however it is quenched during reionization ...

(possibly high-ionization lines + ALMA ?)

Limits of the 8-10m class telescopes: an example







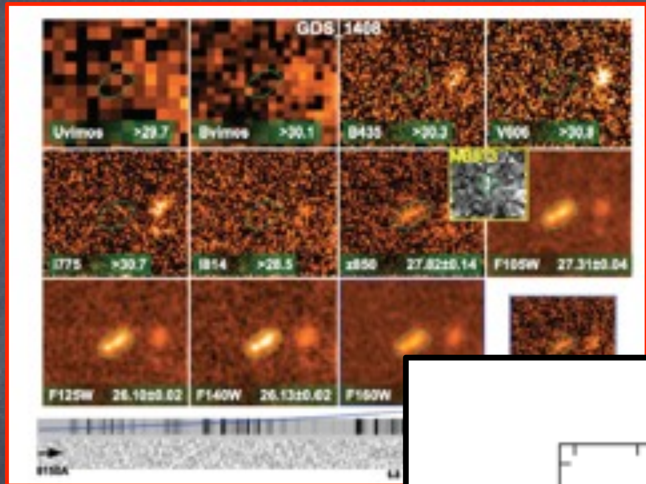
Yan & Windhorst 2004; Bouwens et al. 2004; Bouwens & Illingworth 2006; Labbé et al. 2006; Bouwens et al. 2008; Oesch et al. 2010; Fontana et al. 2010; McLure et al. 2010; Bunker et al. 2010; Yan et al. 2010; Finkelstein et al. 2010; Castellano et al. 2010; Wilkins et al. 2011; Bouwens et al. 2011; Grazian et al. 2011; McLure et al. 2013; Bouwens etal. 2014

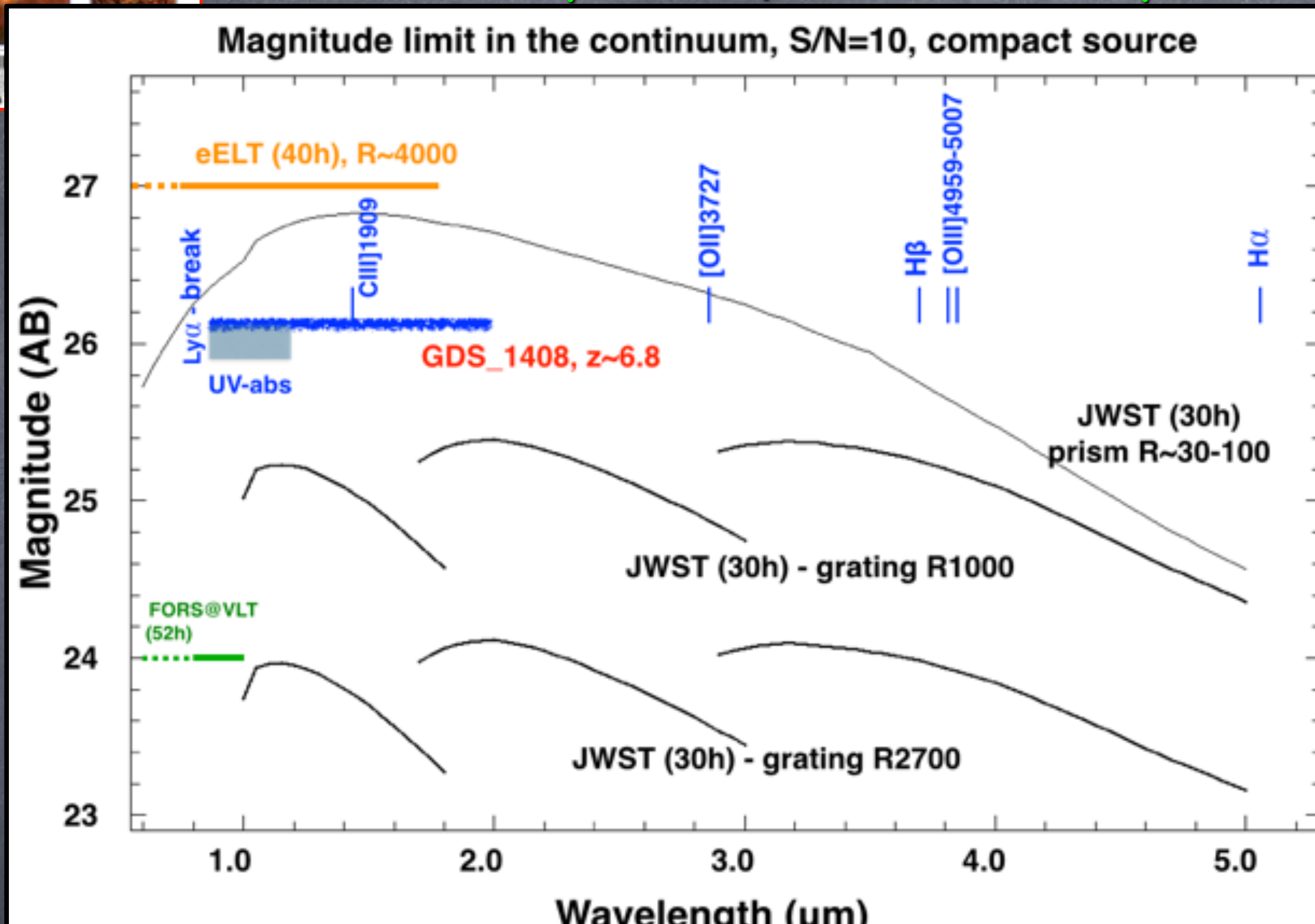
52hr @ VLT/FORS

f(Lya) < 3e-18 erg/s/cm2

Limits of the 8-10m class telescopes: an example

It would be an easy object (L* at z~7) for JWST and ELT (possibly ALMA?) z("photospec")=6.82+/-0.1





Continuum-break sources require JWST/ELT/ALMA

or

different em. lines (e.g., CIII]1909 Stark+14)

Astronomical Science

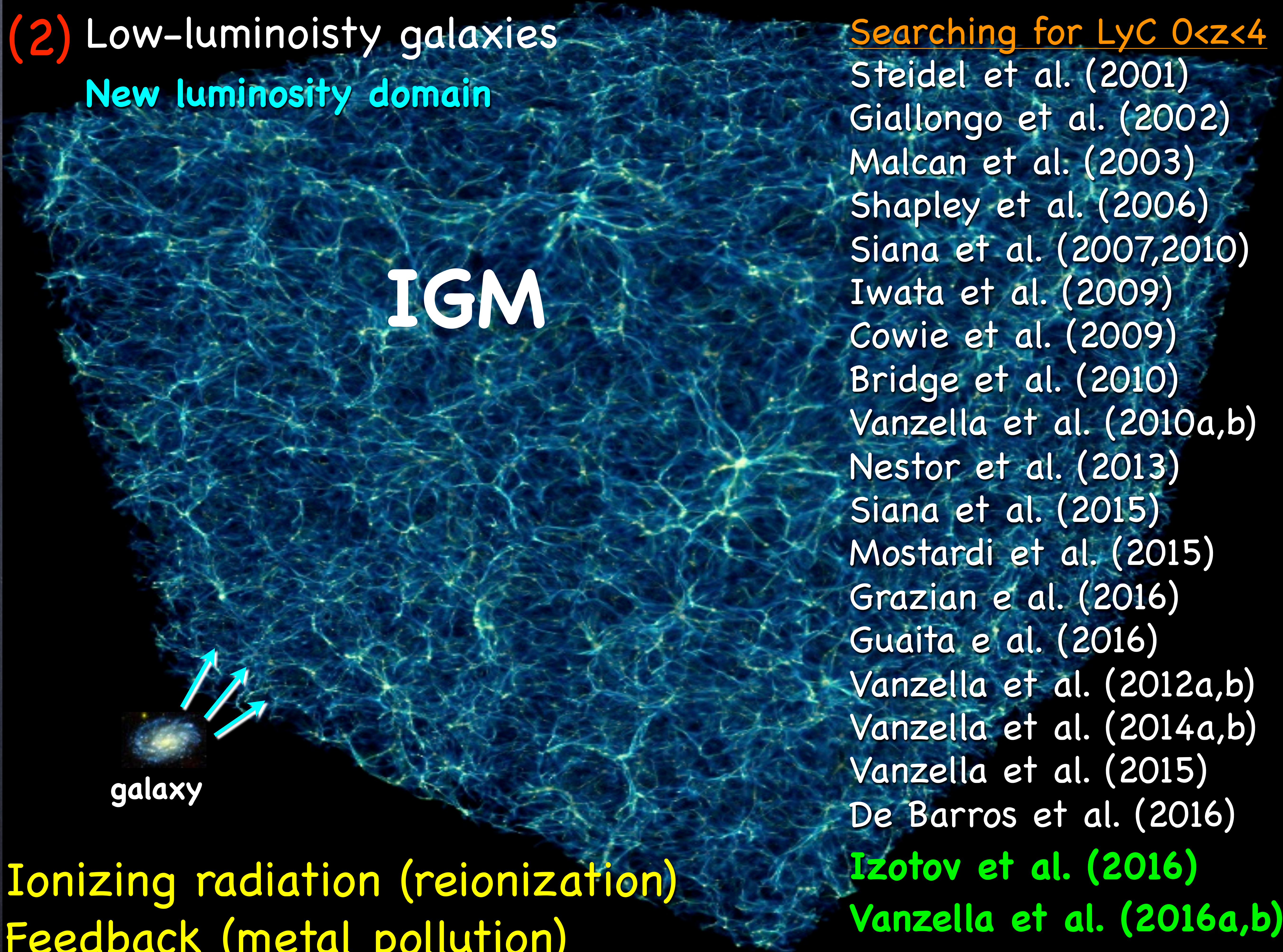
ESO Messenger 2014, no. 157

The Deepest VLT/FORS2 Spectrum of a z ~ 7 Galaxy: An Easy Target for the E-ELT

=> ~2hr integration time: redshift + UV features

(2) Low-luminoisty galaxies

New luminosity domain



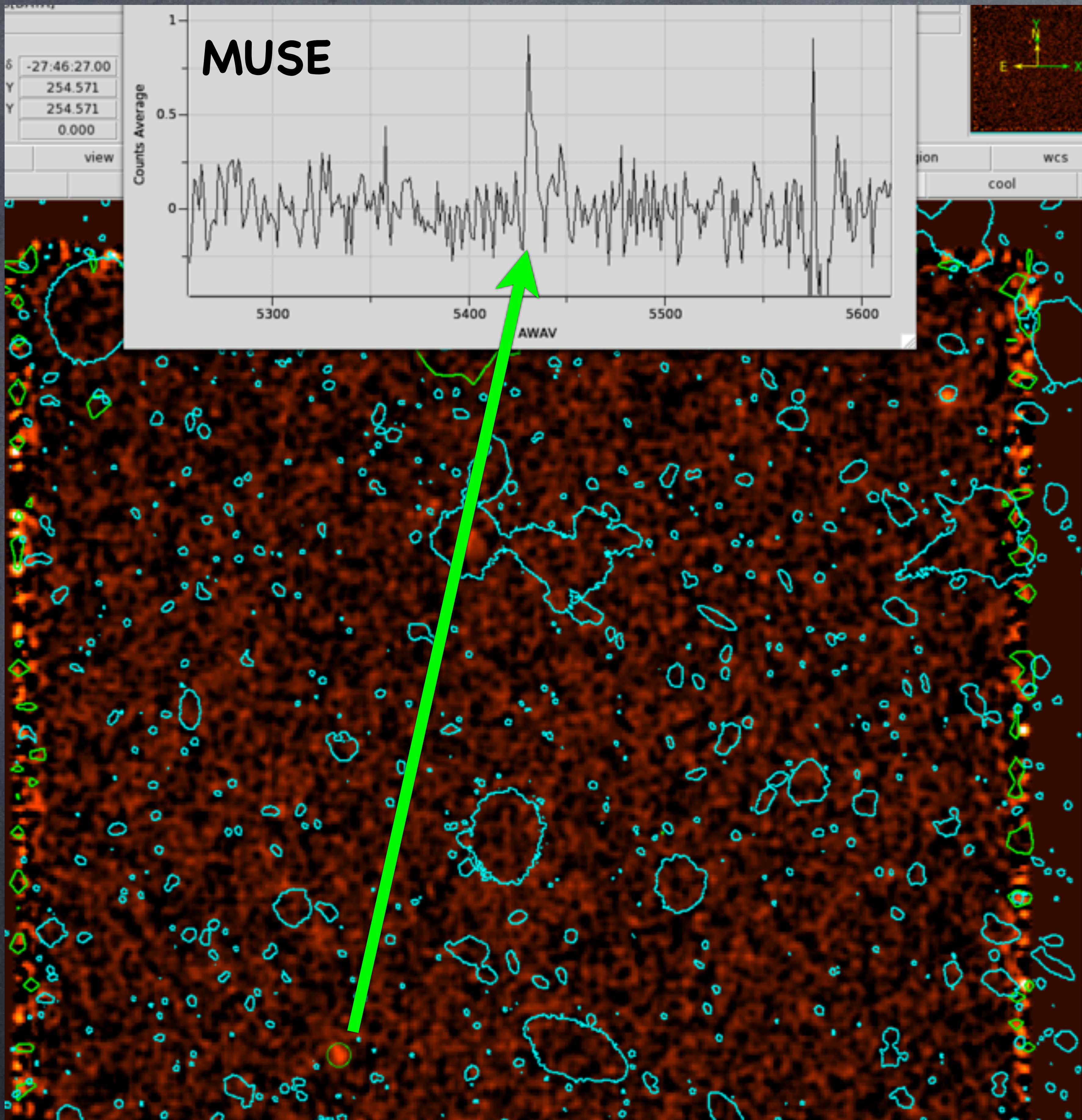
Searching for LyC 0<z<4

- Steidel et al. (2001)
- Giallongo et al. (2002)
- Malcan et al. (2003)
- Shapley et al. (2006)
- Siana et al. (2007,2010)
- Iwata et al. (2009)
- Cowie et al. (2009)
- Bridge et al. (2010)
- Vanzella et al. (2010a,b)
- Nestor et al. (2013)
- Siana et al. (2015)
- Mostardi et al. (2015)
- Grazian e al. (2016)
- Guaita e al. (2016)
- Vanzella et al. (2012a,b)
- Vanzella et al. (2014a,b)
- Vanzella et al. (2015)
- De Barros et al. (2016)
- **Izotov et al. (2016)**
- **Vanzella et al. (2016a,b)**

Ionizing radiation (reionization)

Feedback (metal pollution)

(2) Low-luminosity galaxies New luminosity domain



Hubble Ultra Deep Field

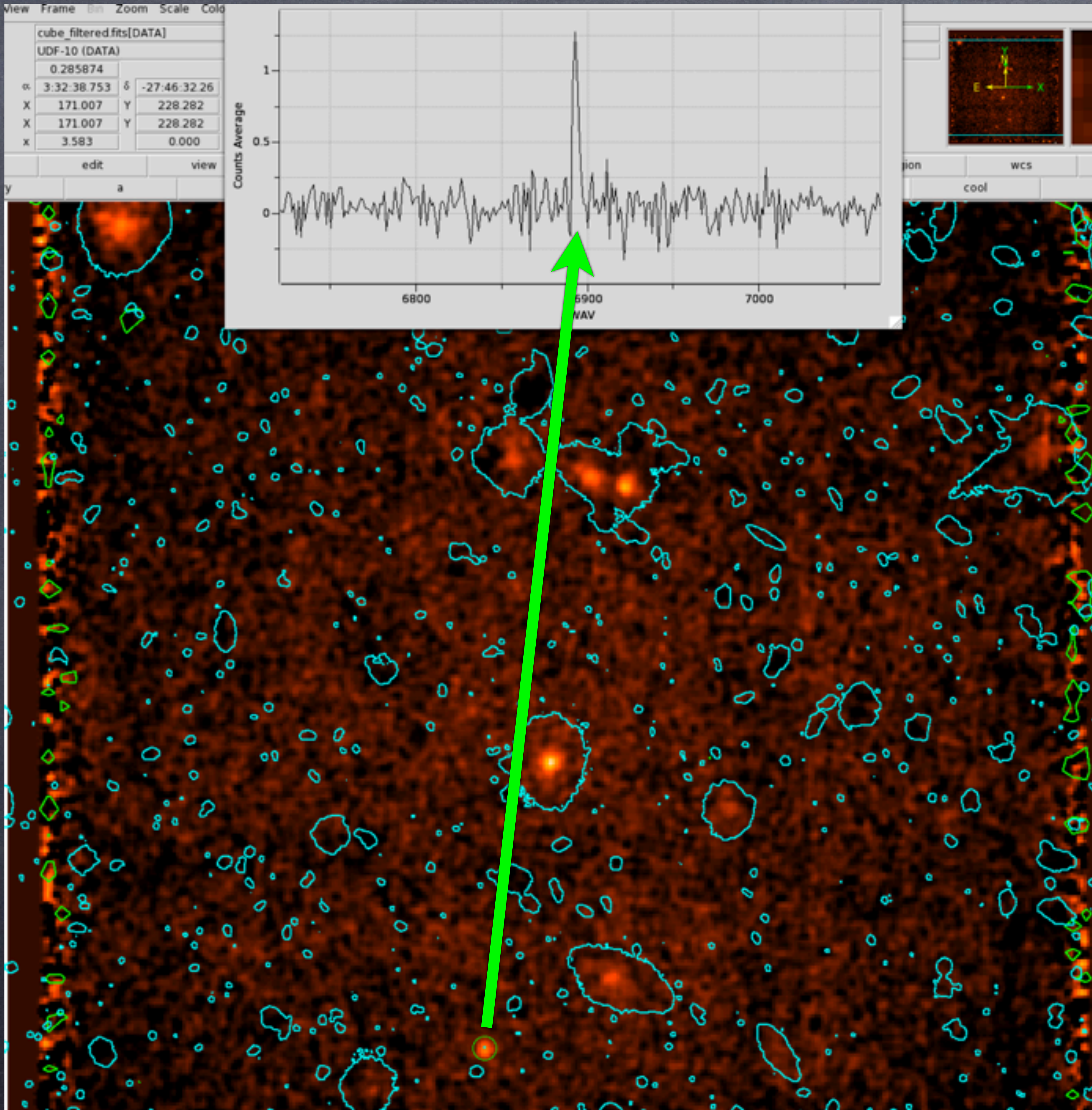
No Lensing !

V606 = **29.92** (S/N=8)

Phot. catalog (Coe+06)

z=3.465

(2) Low-luminosity galaxies New luminosity domain



V606 = **29.58** (S/N>8)

Phot. catalog (Coe+06)

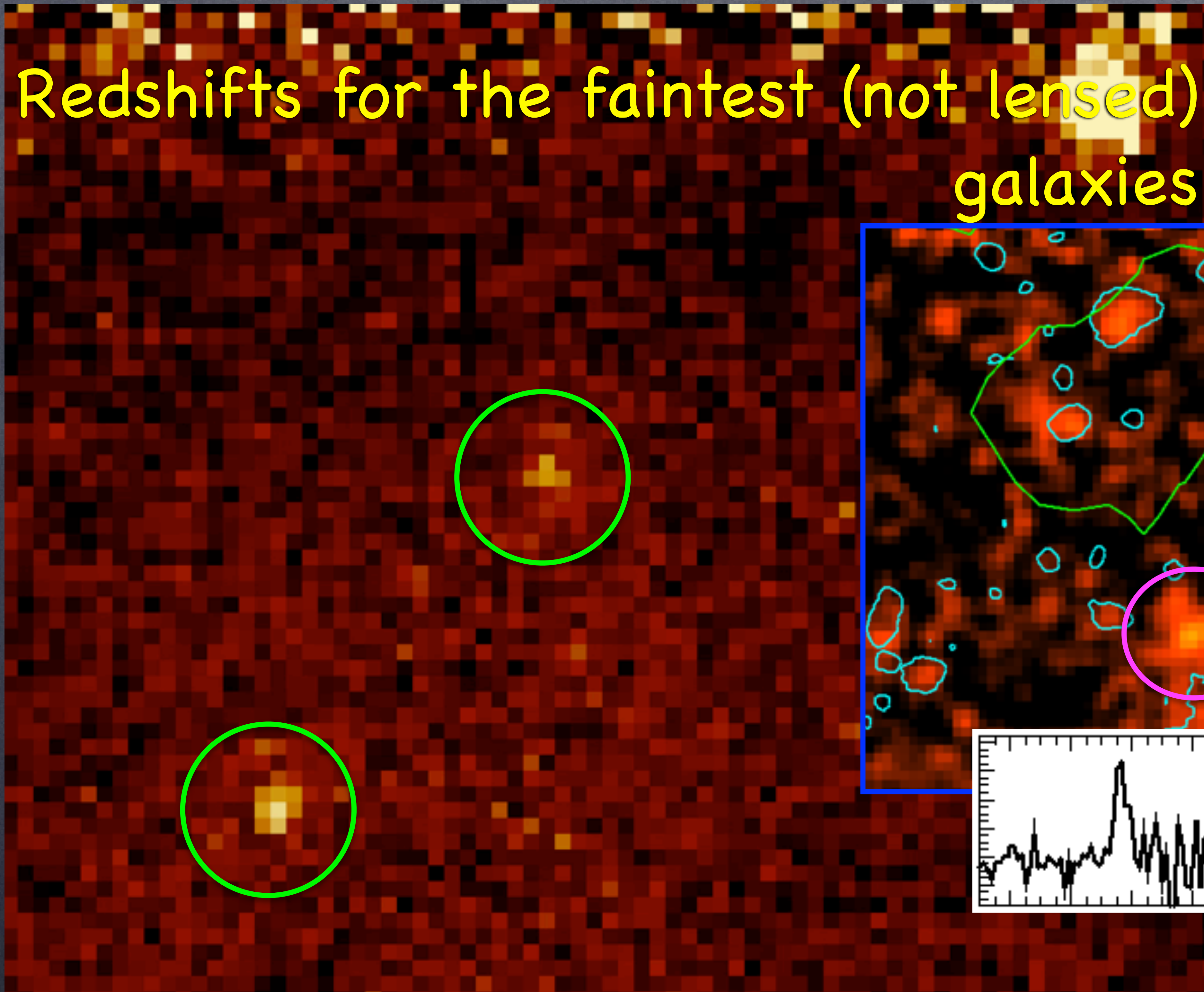
z=4.66

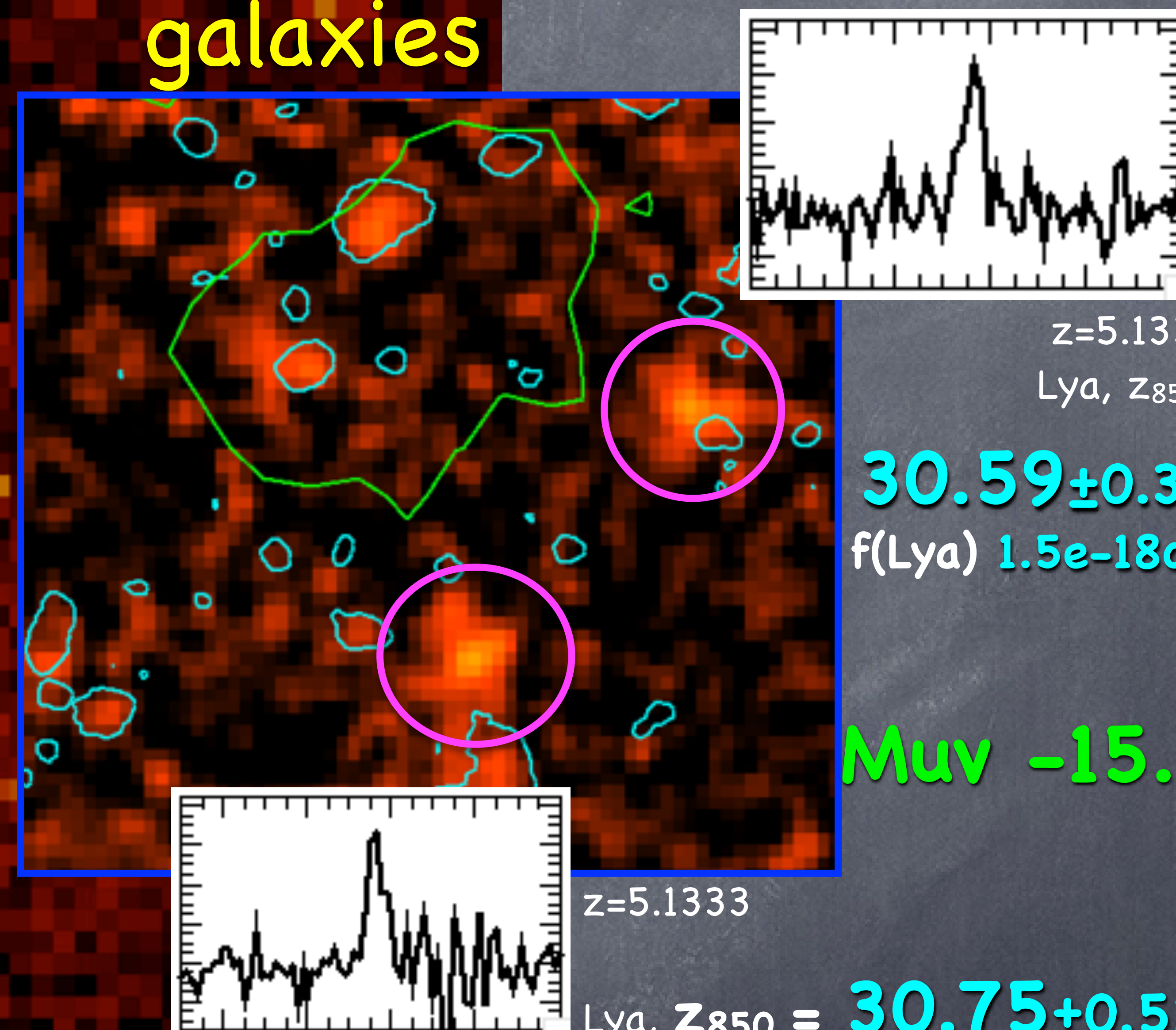
(2) Low-luminosity galaxies New luminosity domain

Vanzella

MUSE

Redshifts for the faintest (not lensed) galaxies





z=5.1330

Lya, z_{850}= **30.59±0.34**

f(Lya) 1.5e-18cgs

Muv -15.8

z=5.1333

Lya, z_{850} = **30.75±0.52**

f(Lya) 1.4e-18cgs

EW~200A rest-frame

if we could find something similar in a lensed field $m_{intr} = m_{obs} + 2.5\log_{10}(\mu)$

μ=15(10)(5) → m_{intr} = **33(32.5)(31.7)** !!

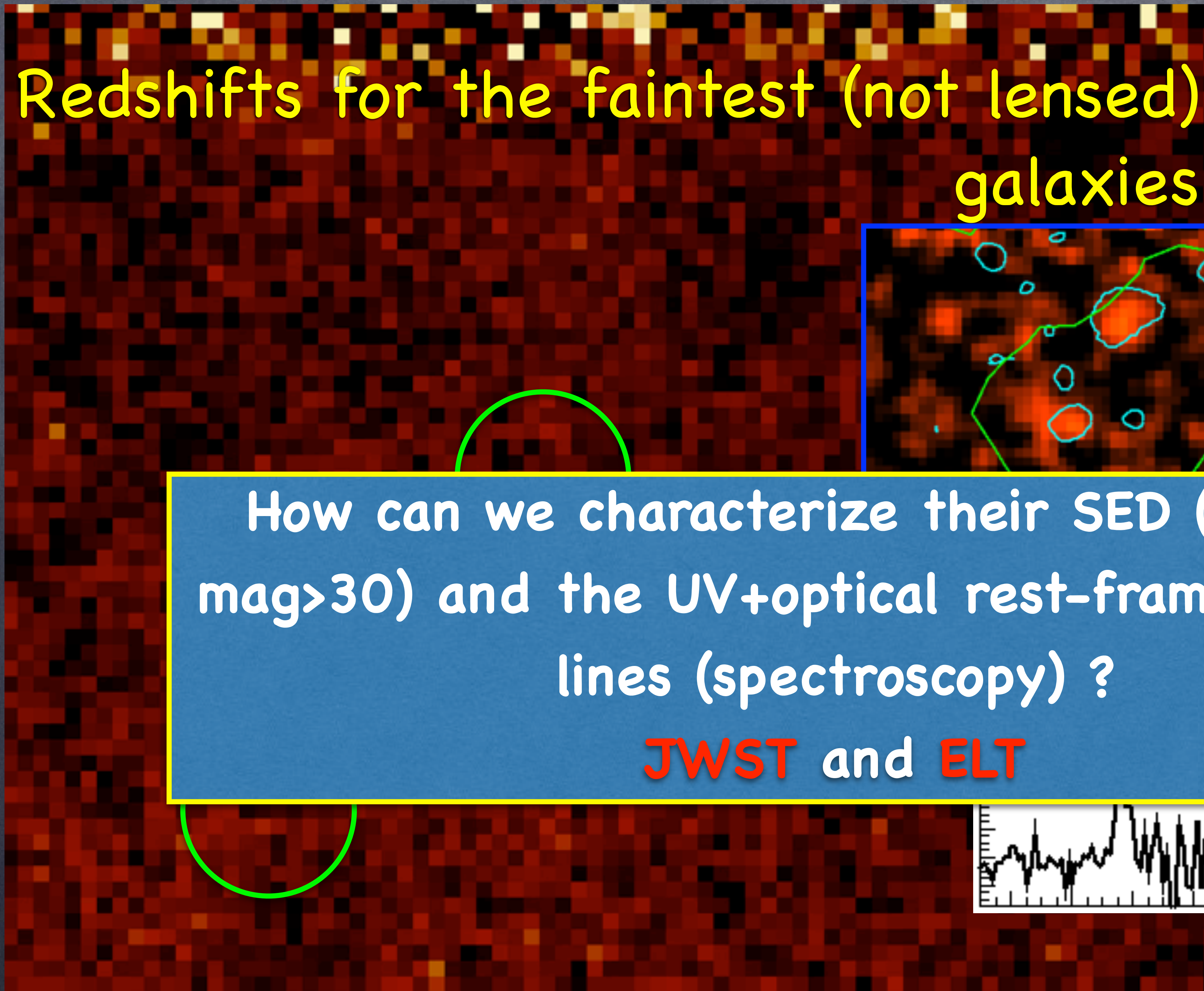
Muv -13.0 @ z 3-6.5

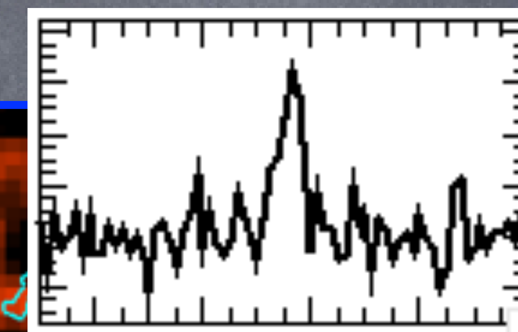
This is feasible now!

(2) Low-luminosity galaxies — New luminosity domain

Vanzella
MUSE

Redshifts for the faintest (not lensed) galaxies





z=5.1330
Lya, z_{850}= 30.59±0.34
f(Lya) 1.5e-18cgs

Muv -15.8

How can we characterize their SED (imaging, mag>30) and the UV+optical rest-frame emission lines (spectroscopy) ?

JWST and ELT

z=5.1333
Lya, z_{850} = 30.75±0.52
f(Lya) 1.4e-18cgs
EW~200A rest-frame

if we could find something similar in a lensed field $m_{intr} = m_{obs} + 2.5\log_{10}(\mu)$

μ=15(10)(5) ➜ m_{intr} = 33(32.5)(31.7) !!

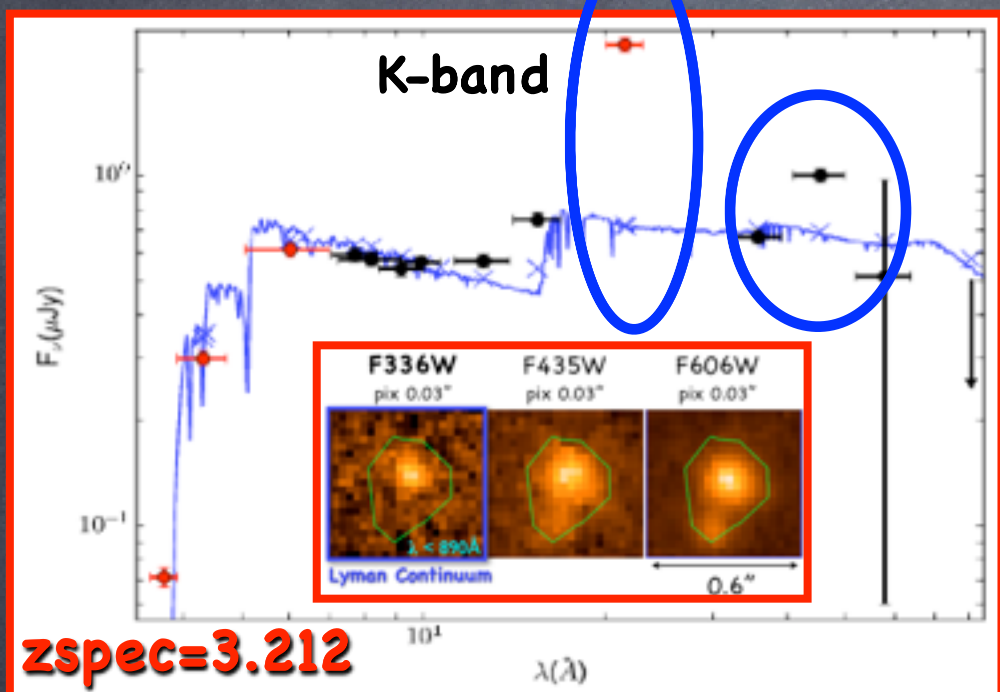
Muv -13.0 @ z 3-6.5

This is feasible now!

Searching for the Sources Responsible for Cosmic Reionization (7<z<12)

Reference sample @ z<4

EW([OIII]+Hb)=1500A!

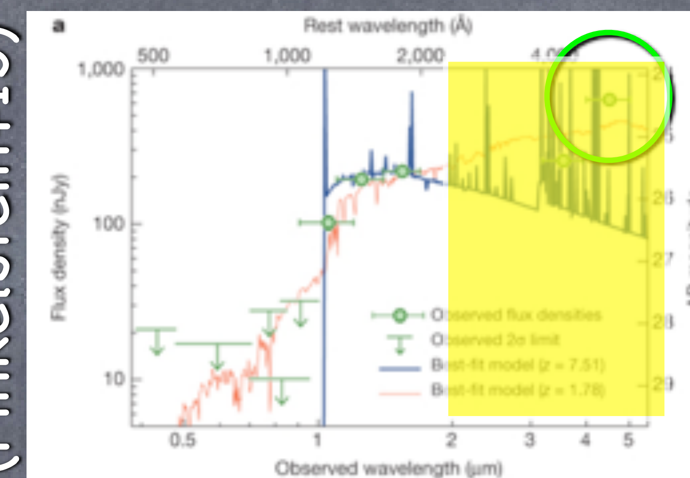


Vanzella+16b

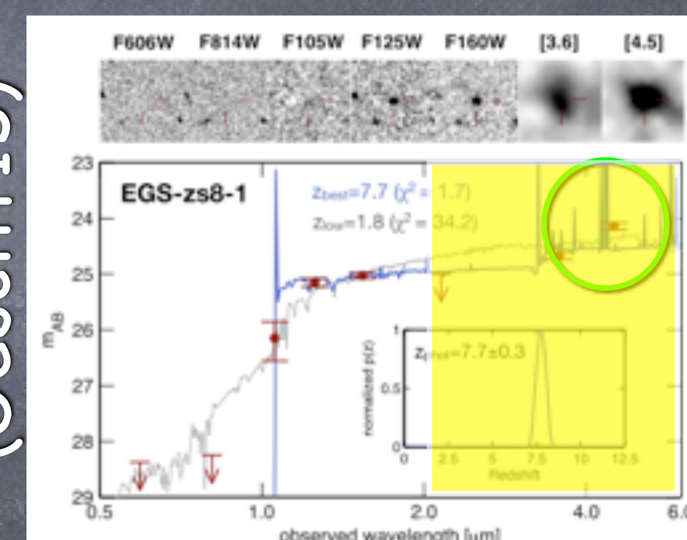
Large EW([OIII]+Hb) ~ 600-1500A rest

JWST will eventually observe rest-frame optical lines at z>6 ISM conditions & ionization

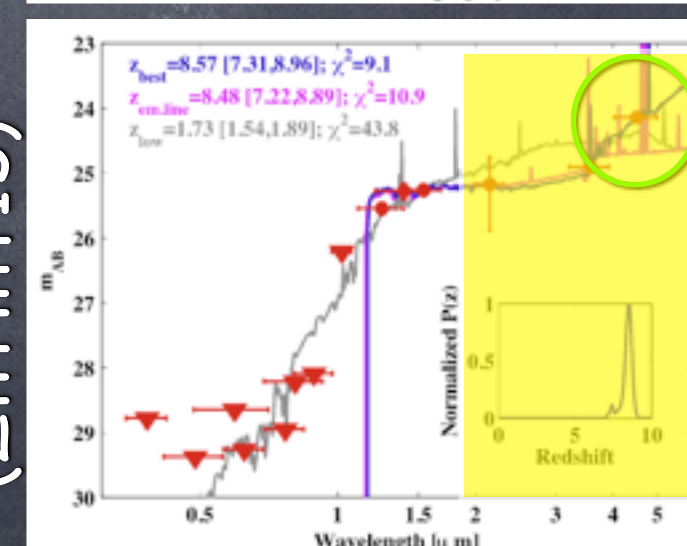
zspec=7.51 (Finkelstein+13)



zspec=7.73 (Oesch+15)



zspec=8.68 (Zitrin+15)

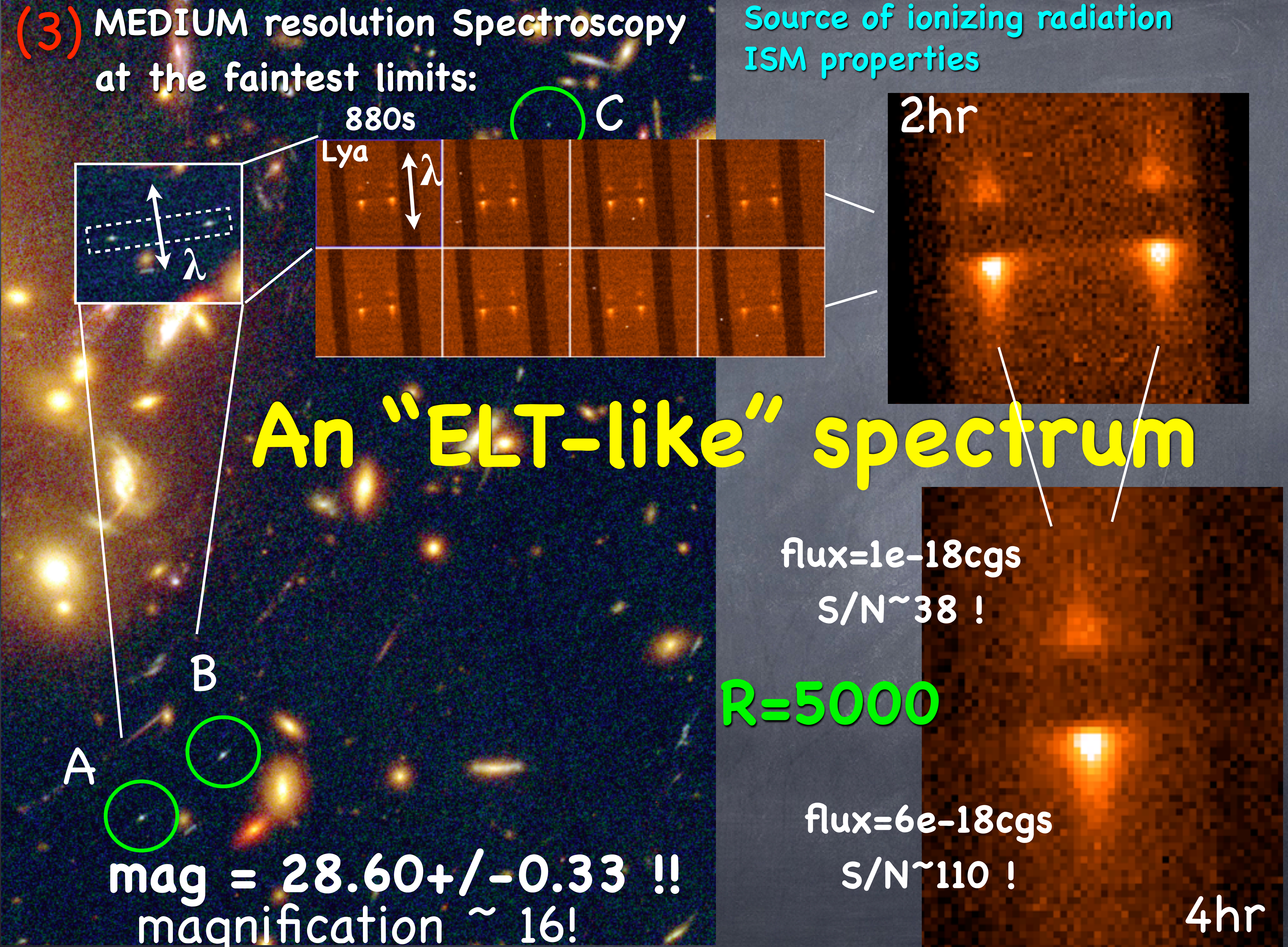


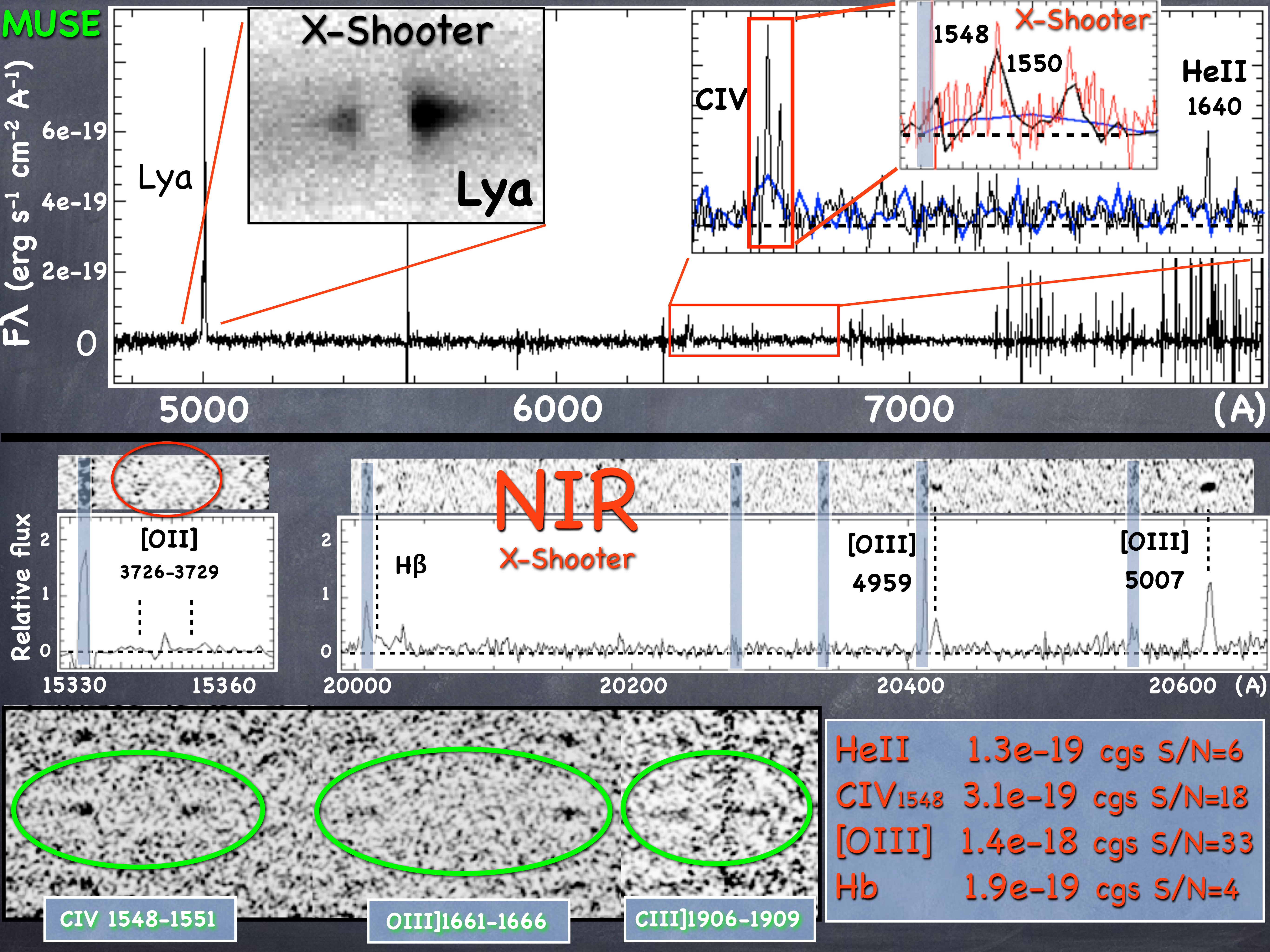
Two relevant facts:

1) **LyC emission confirmed**

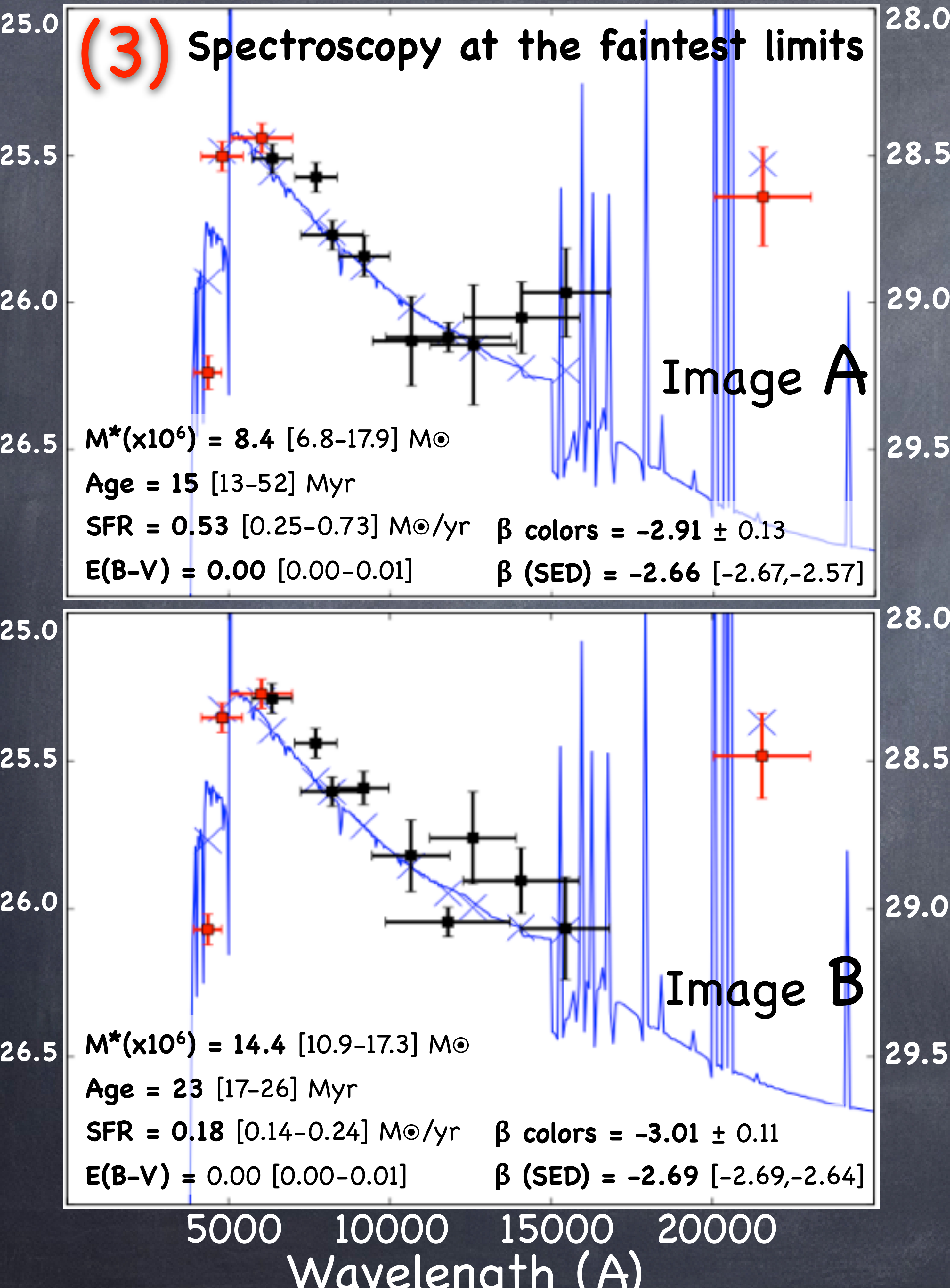
2) Strong nebular emission

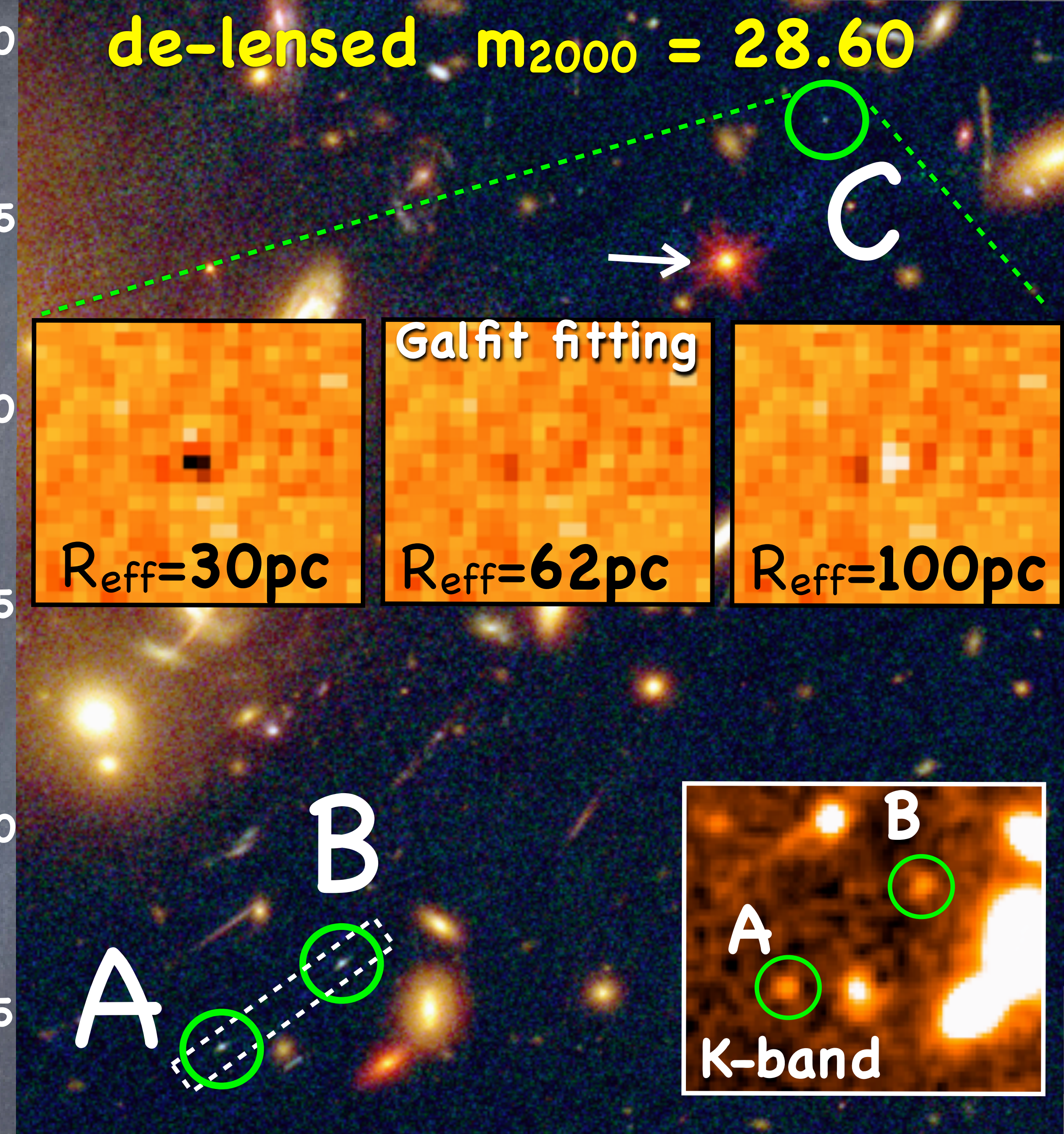
investigate ISM conditions


(3) MEDIUM resolution Spectroscopy
at the faintest limits:
Source of ionizing radiation
ISM properties
880s
C
Lya
λ
λ
2hr
An "ELT-like" spectrum
flux=1e-18cgs
S/N~38 !
R=5000
B
A
flux=6e-18cgs
S/N~110 !
4hr
mag = 28.60+/-0.33 !!
magnification ~ 16!


MUSE
Fλ (erg s⁻¹ cm⁻² A⁻¹)
6e-19
4e-19
2e-19
0
Lya
X-Shooter
Lya
CIV
1548
1550
X-Shooter
HeII
1640
5000
6000
7000
(A)
Relative flux
[OII]
3726-3729
NIR
X-Shooter
Hβ
[OIII]
4959
[OIII]
5007
2
1
0
15330
15360
20000
20200
20400
20600
(A)
CIV 1548-1551
OIII]1661-1666
CIII]1906-1909
HeII 1.3e-19 cgs S/N=6
CIV1548 3.1e-19 cgs S/N=18
[OIII] 1.4e-18 cgs S/N=33
Hb 1.9e-19 cgs S/N=4

(3) Spectroscopy at the faintest limits



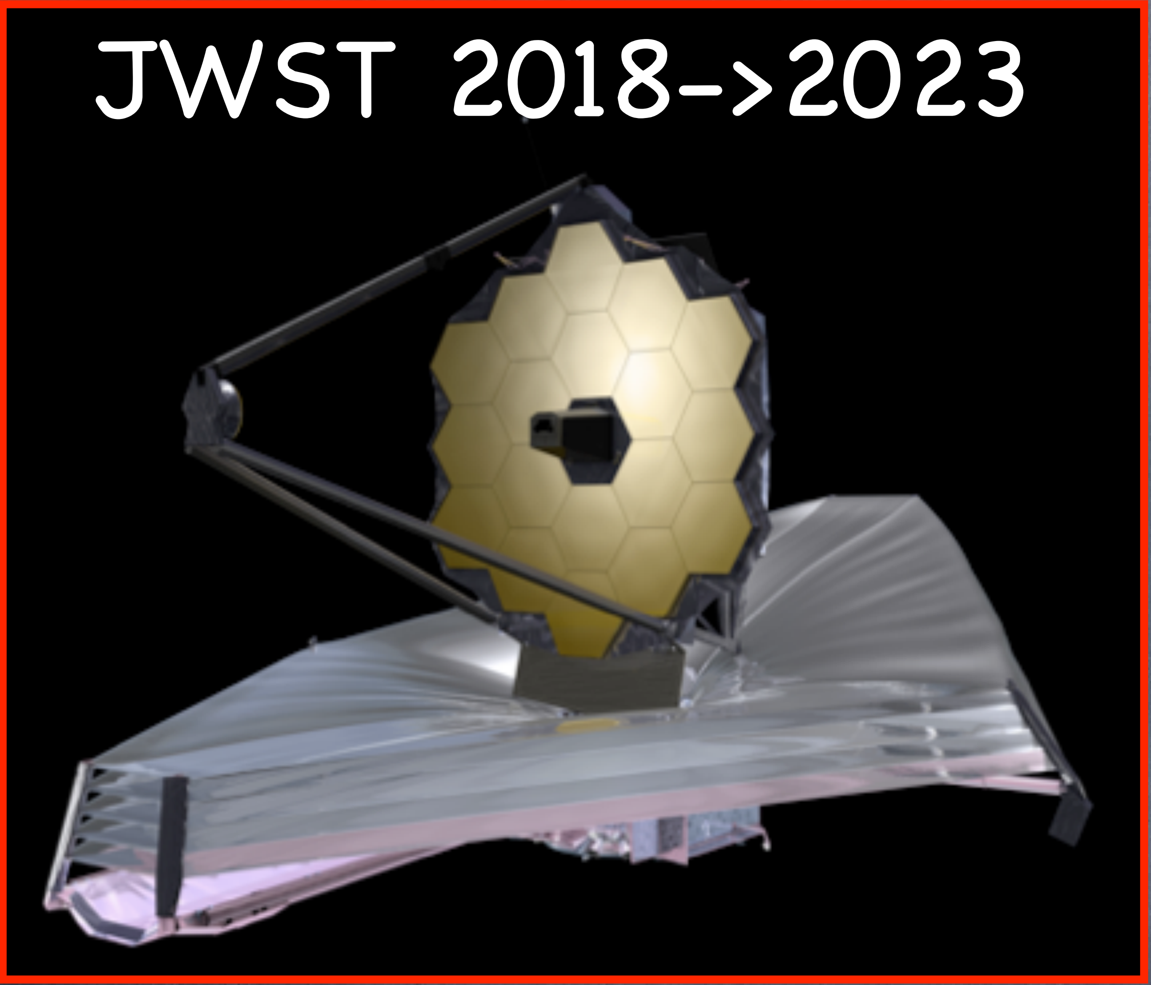


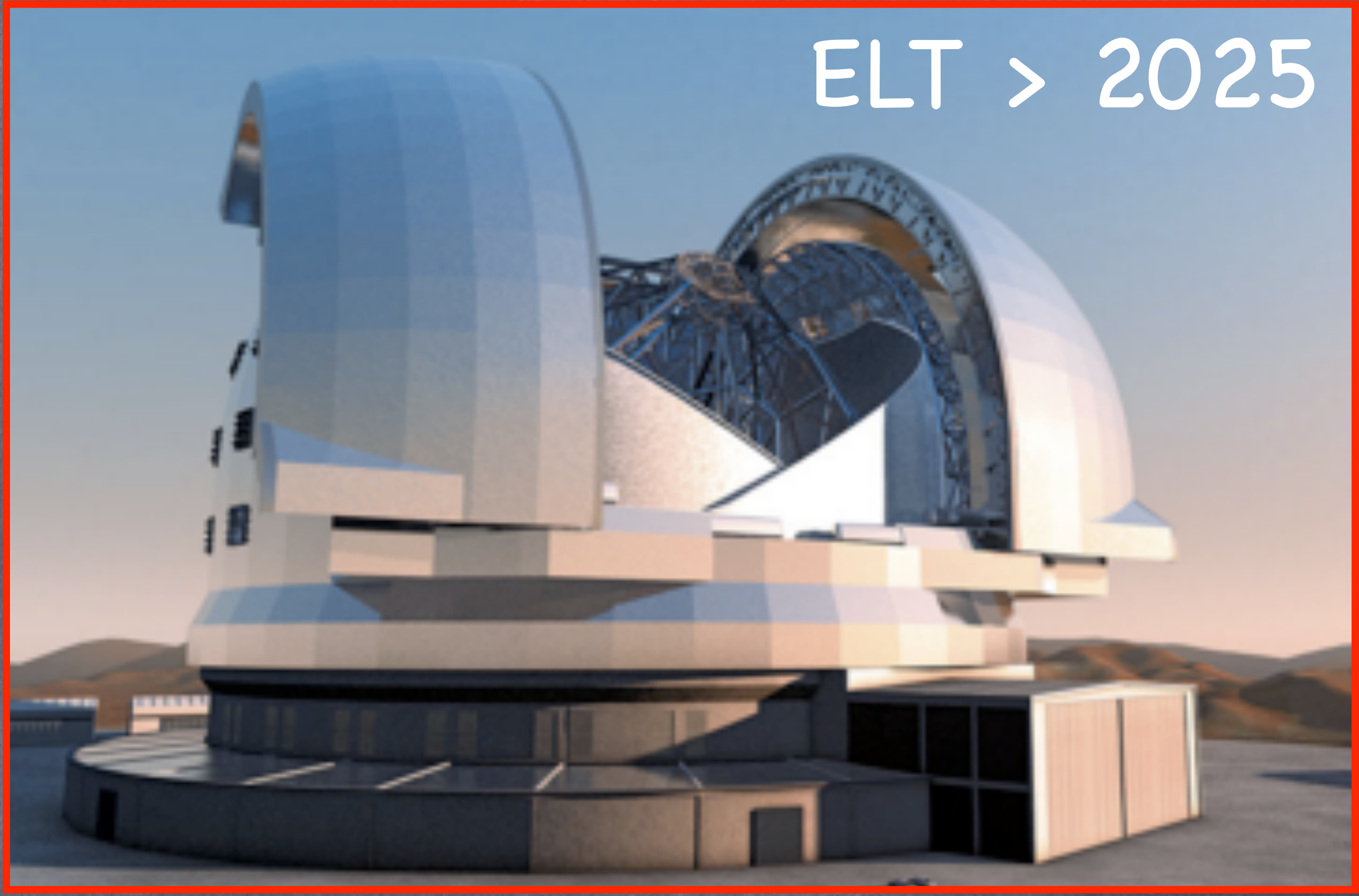
Extremely Blue, Small, Low mass, optically thin object

- M ~ 1e7 Msun;
- Reff ~ 60 pc (200 l.y. !!)
- SFR ~ 0.10 Msun/yr
- AGE ~ 20 Myr

First objects and reionization: spectroscopic view

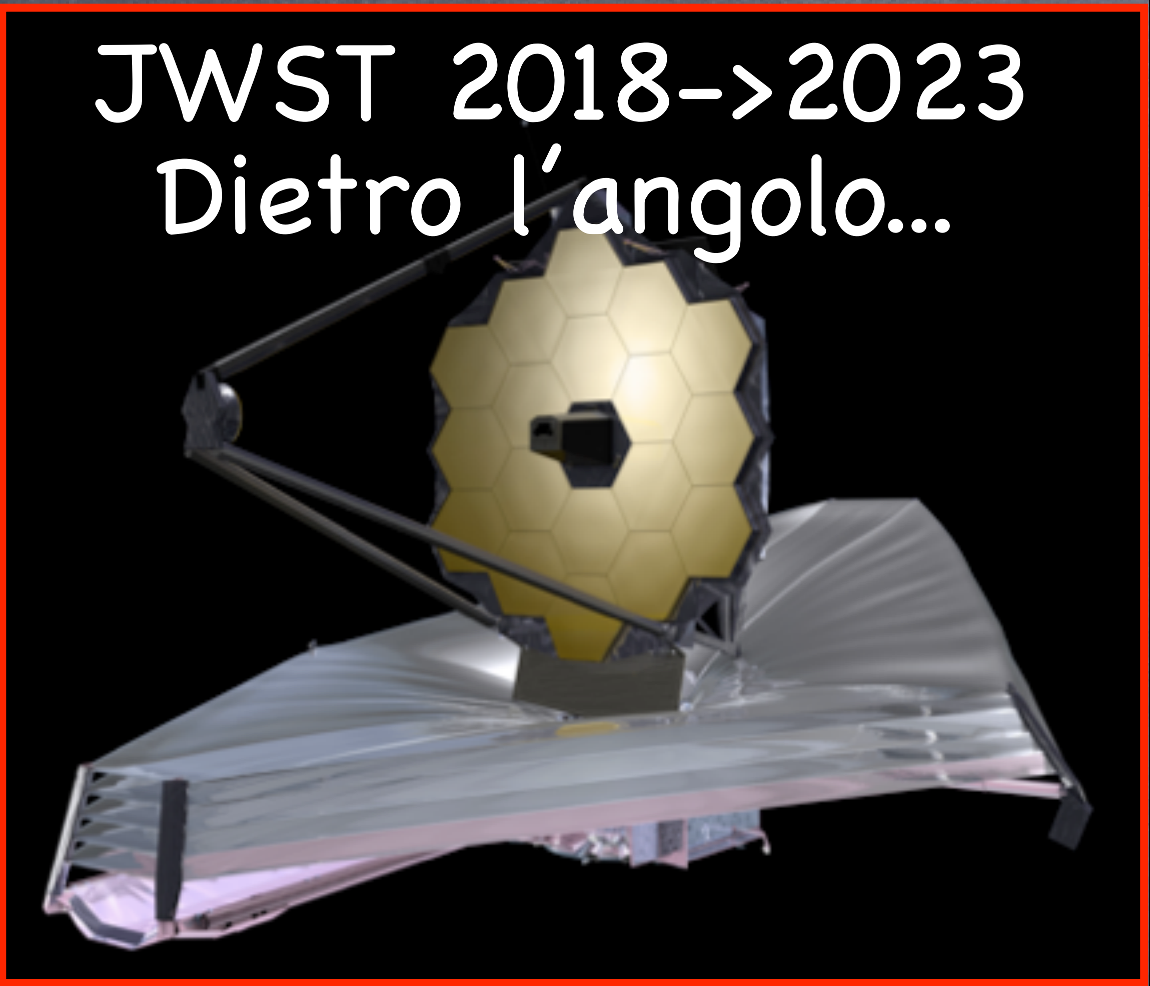
JWST sara' il principale attore almeno fino al >2023, poi ELT

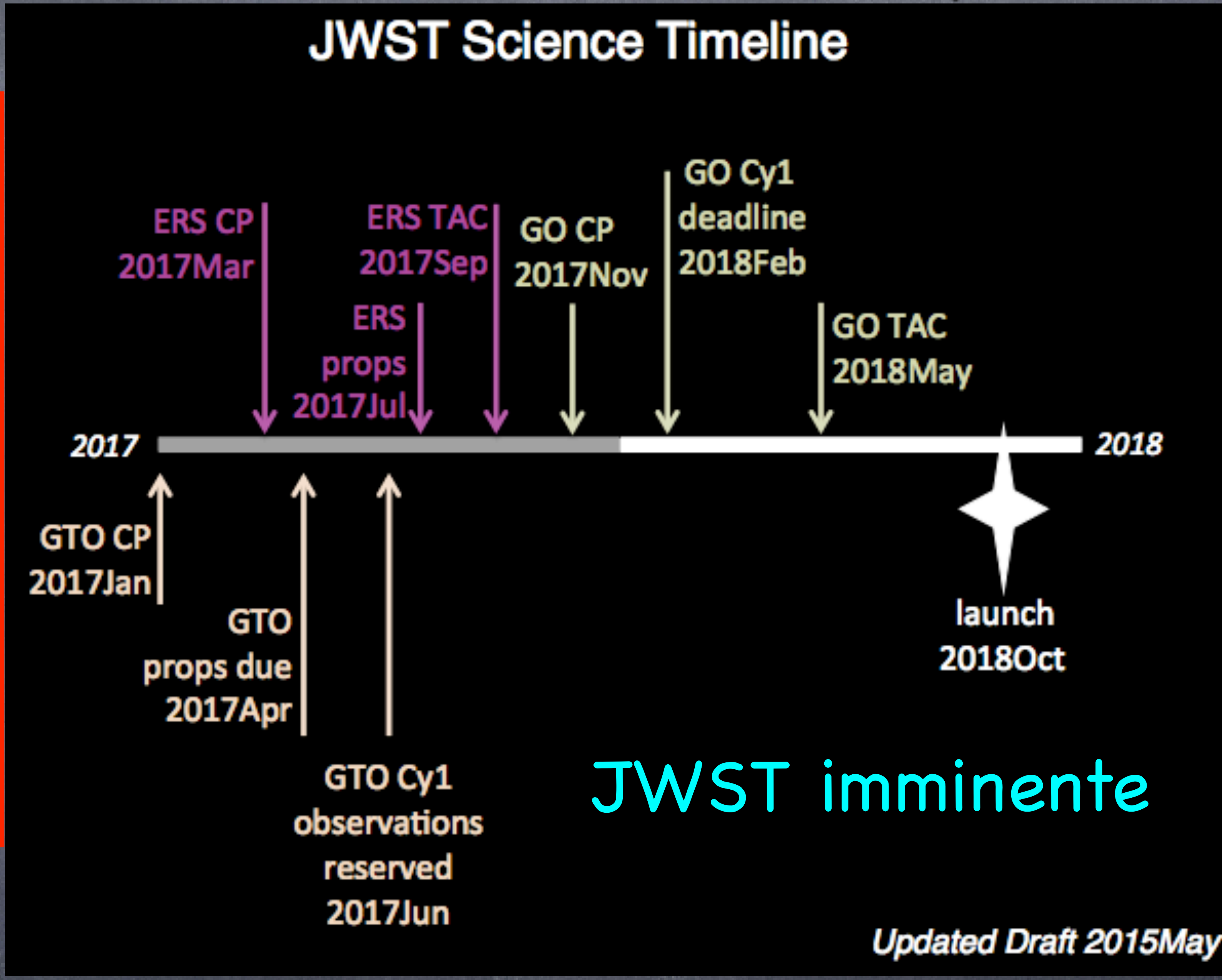




First objects and reionization: spectroscopic view

JWST sara' il principale attore almeno fino al >2023, poi ELT





Proposals (GO & ERS):

General Observers (Feb 2018)

Early Release Science (ERS) (Aug 2017) 500hr, DDT

ERS

Maximize the use of instruments & modes, provide initial discoveries and inform Cycle2 proposals; programs of 30-70hr each, avoiding GTO targets.

Conclusions

High-z Universe - First Objects - The search for reionizing sources -IGM

Next step, access new

- redshifts domains (z~10-15)

  now peak of the iceberg @ z>6

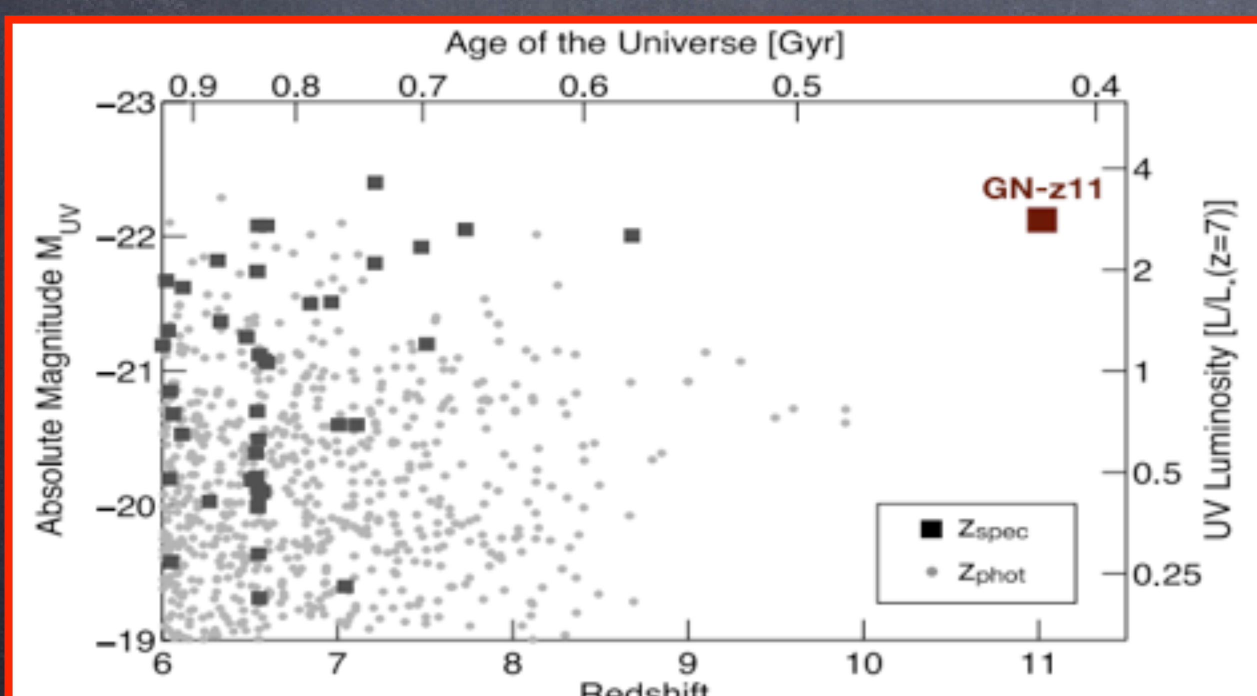
- luminosity/mass domains (down to Muv ~ -13)

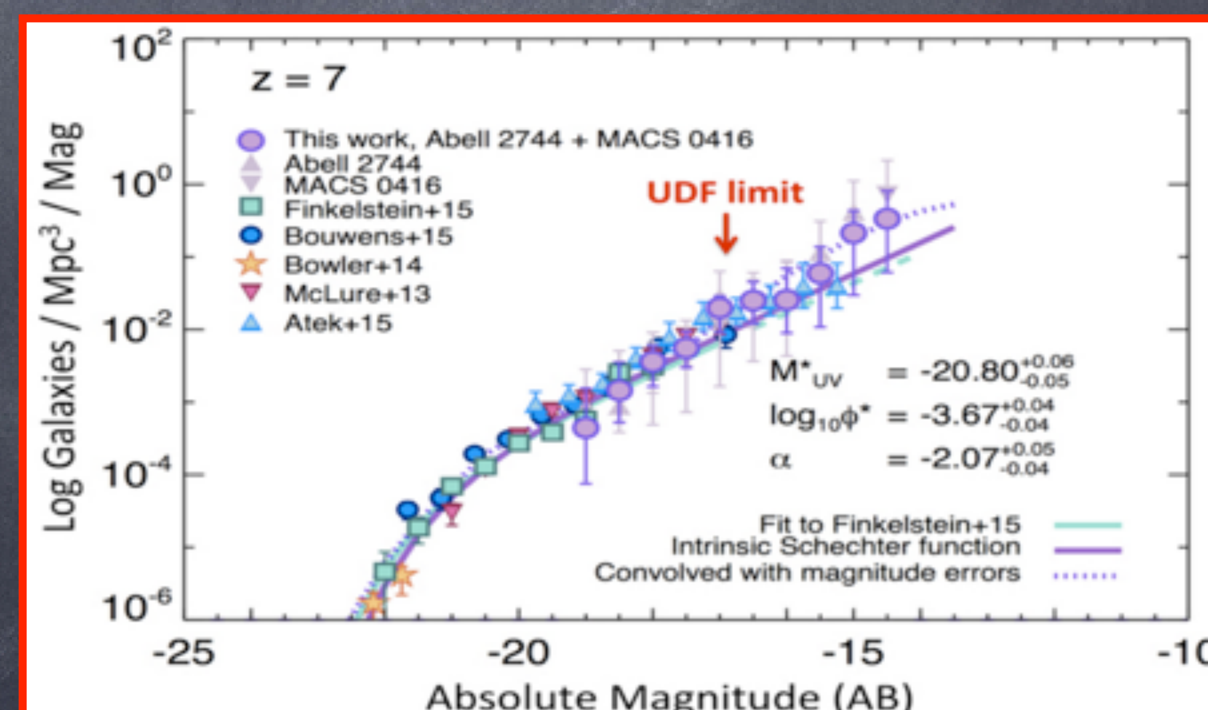
  Now, MUSE very promising!1 JWST is needed

- rest-frame optical wavelengths (z>4 up to z~10), NIR + mid-IR spectr.

Reionization (z>6)
post-reionization (z<6)
First episodes of star formation in low-mass galaxies (~10^{6-7} Msun) in the first Gyr.

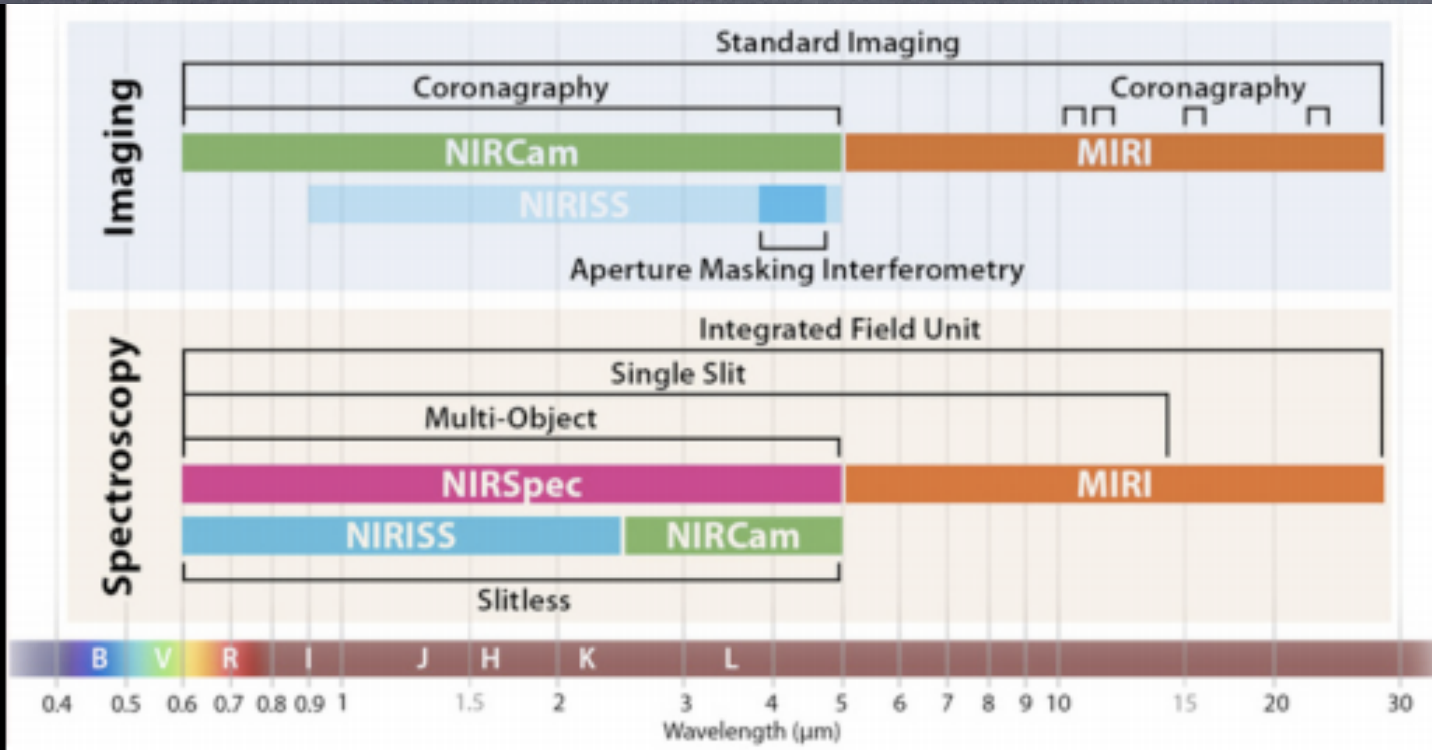
JWST(?) & ELT





JWST: Early Release Science

14 distinct observing modes (graphic by R. Hurt)



4 Science Instruments (0.6-28.3 μm):

NIRCam (Near Infrared Camera; M. Rieke)

NIRISS (Near Infrared Imager and Slitless Spectrograph; R. Doyon)

NIRSpec (Near Infrared Spectrograph; P. Ferruit)

MIRI (Mid Infrared Instrument; G. Rieke, G. Wright)

ERS Program Key Elements

- JWST ERS programs will be designed and executed by community investigators, and selected by peer-review.
- ERS will be a director's discretionary program, which will provide a total of ~500 hours of time. each 30-70hr
- ERS programs will be selected to span key JWST observing modes, data analysis challenges, and science areas. JWST offers 14 distinct imaging, coronagraphic, and spectroscopic observing modes from the optical to the mid-infrared (0.6 - 28.3 microns).
- ERS will be comprised of substantive, science-driven programs, which have the potential to enable community archival research beginning in Cycle 1, and/or to be building blocks with which the community can use to design larger JWST observing programs in the future.
- ERS observations will have no proprietary period.
- ERS observations will be among the first observations to execute after commissioning in Cycle 1.
- ERS teams will be responsible for the delivery of science enabling products to the community in coordination with the Mikulski Archive for Space Telescopes (MAST). The delivery timescale should be sufficiently rapid to support community preparation of Cycle 2 proposals.
- ERS proposals will be reviewed, selected, and publicized prior to the release of the GO Cycle 1 Call for Proposals. The ERS proposal deadline is planned for August 2017, and each prospective ERS team must submit a Notice of Intent to propose in February 2017.