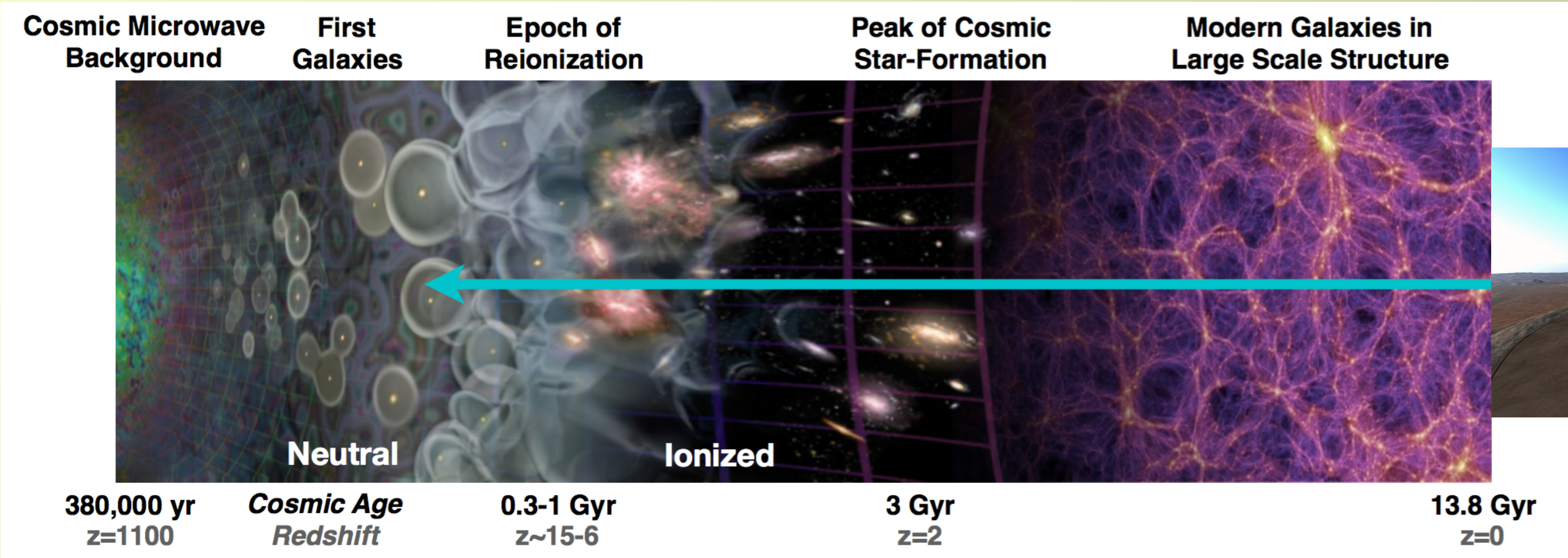
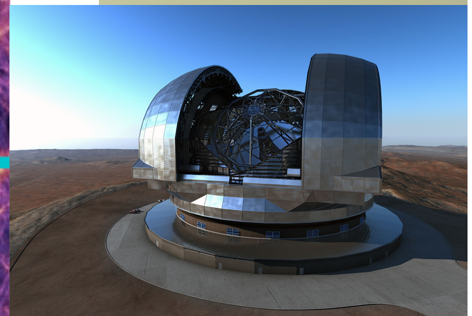
« Normal » and « extreme » stellar populations and galaxies in the early Universe

Daniel Schaerer (Geneva Observatory & CNRS)



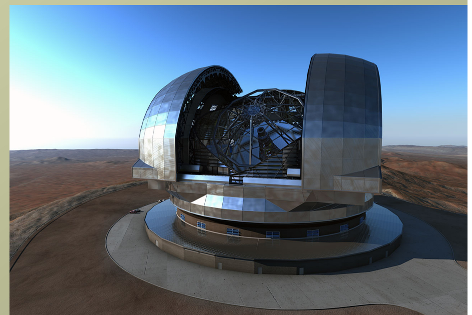


UNIVERSITÉ DE GENÈVE
irap astrophysique & planétologie

« Normal » and « extreme » stellar populations and galaxies in the early Universe

Daniel Schaerer (Geneva Observatory & CNRS)

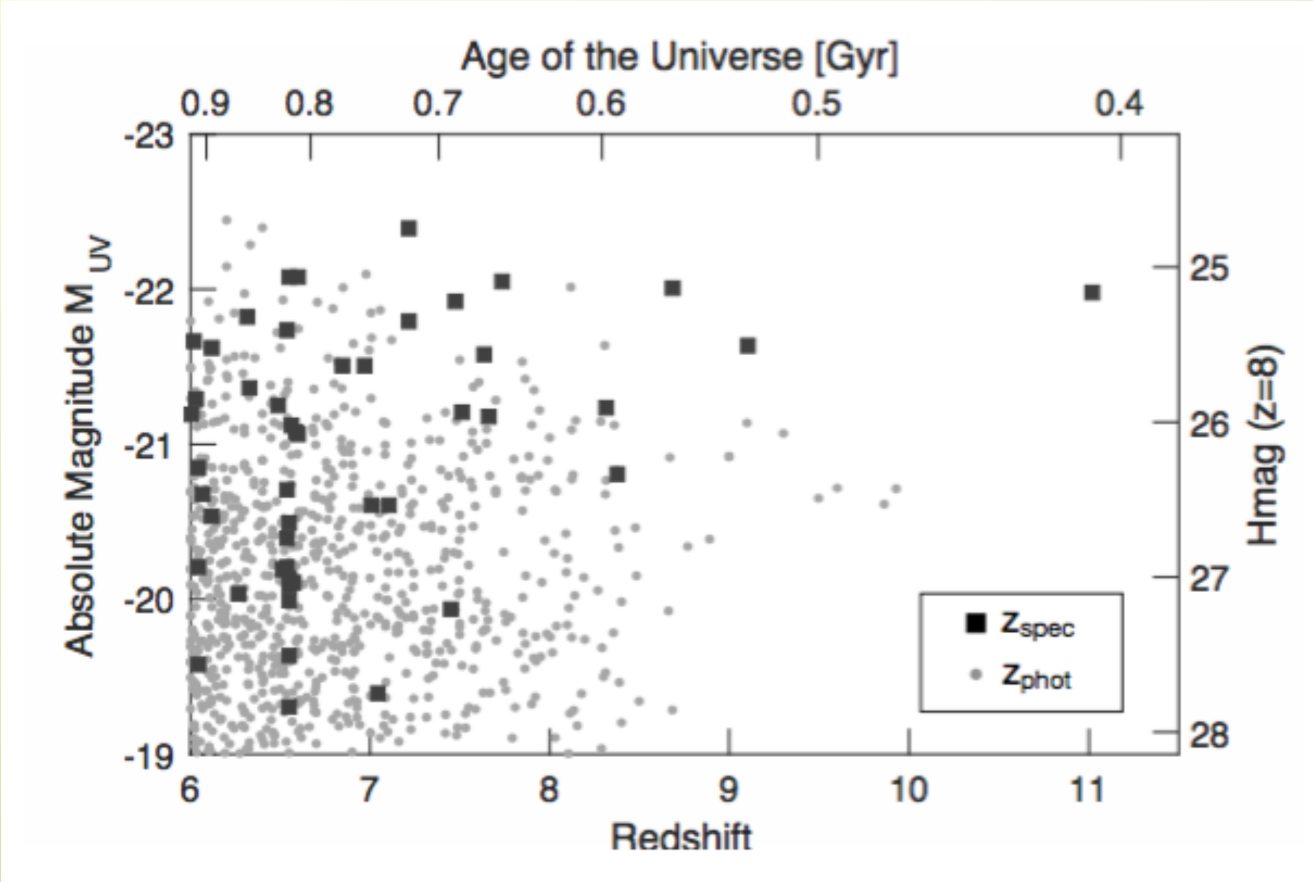
- Introduction
- Hard ionizing spectra: a solution to the long-standing HeII problem
- Spectral diagnostics for sources of cosmic reionization (Lyman continuum emitters)
- Conclusions



UNIVERSITÉ DE GENÈVE

irap astrophysique & planétologie

Our current census of high-redshift galaxies



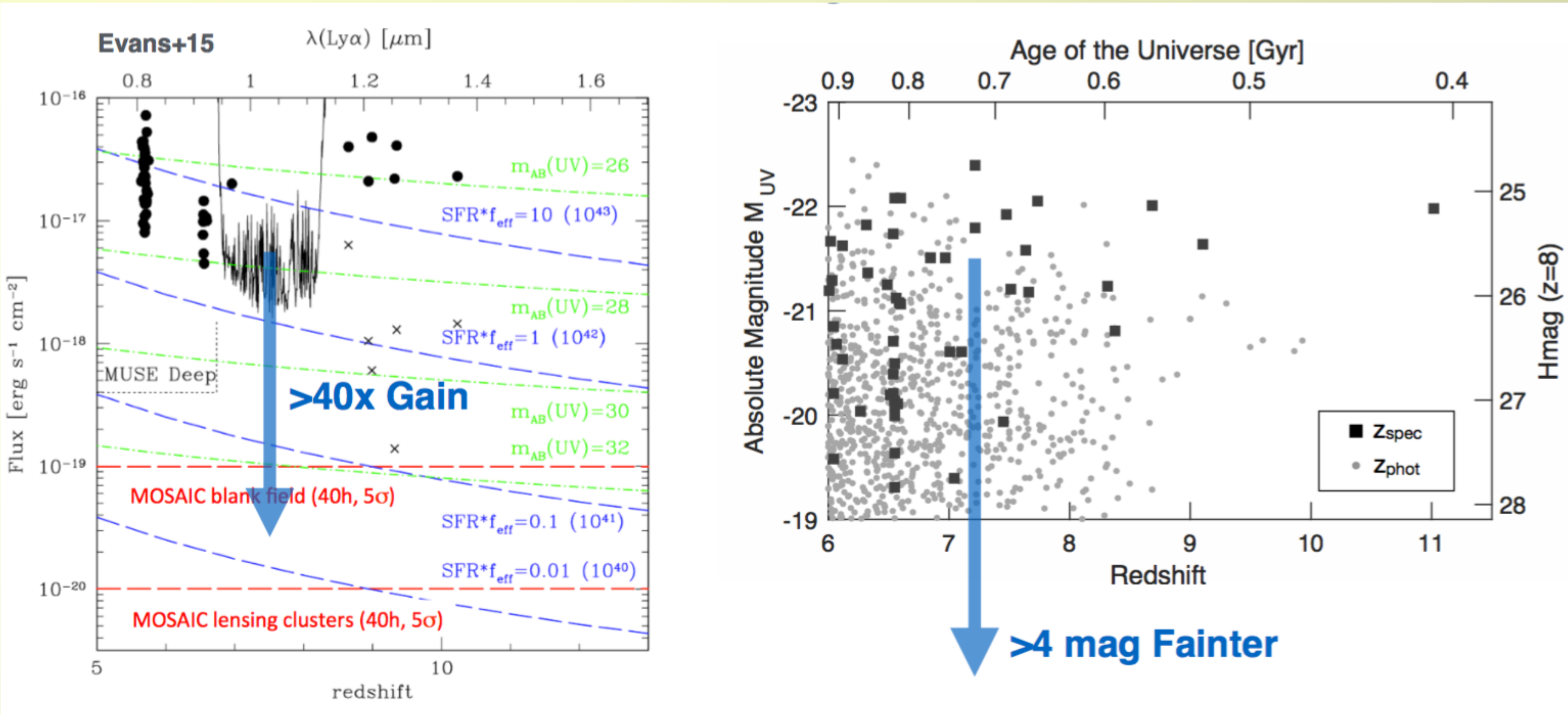
Courtesy
P. Oesch

Large number of photometrically selected galaxies in the epoch of reionization

Spectroscopy is lagging severly behind imaging

→ Limit of current facilities reached

ELTs: Enormous sensitivity gain



Courtesy
P. Oesch

- Lya and UV metal line detections down to H~28 in 10h exposures: complete spectroscopic samples
- Surface density of such targets: ~1 arcmin-2, efficient use of multiplex
- Absorption lines: « z~7 will be the new z~2 »

High-redshift galaxies: some open questions

Galaxies - physical properties

- What ISM properties ? Metallicity ?
- Stellar content ? Age ? Radiation field ?
- Pop III clusters ?

- Rotation curves, dark matter content
- Dust and gas content

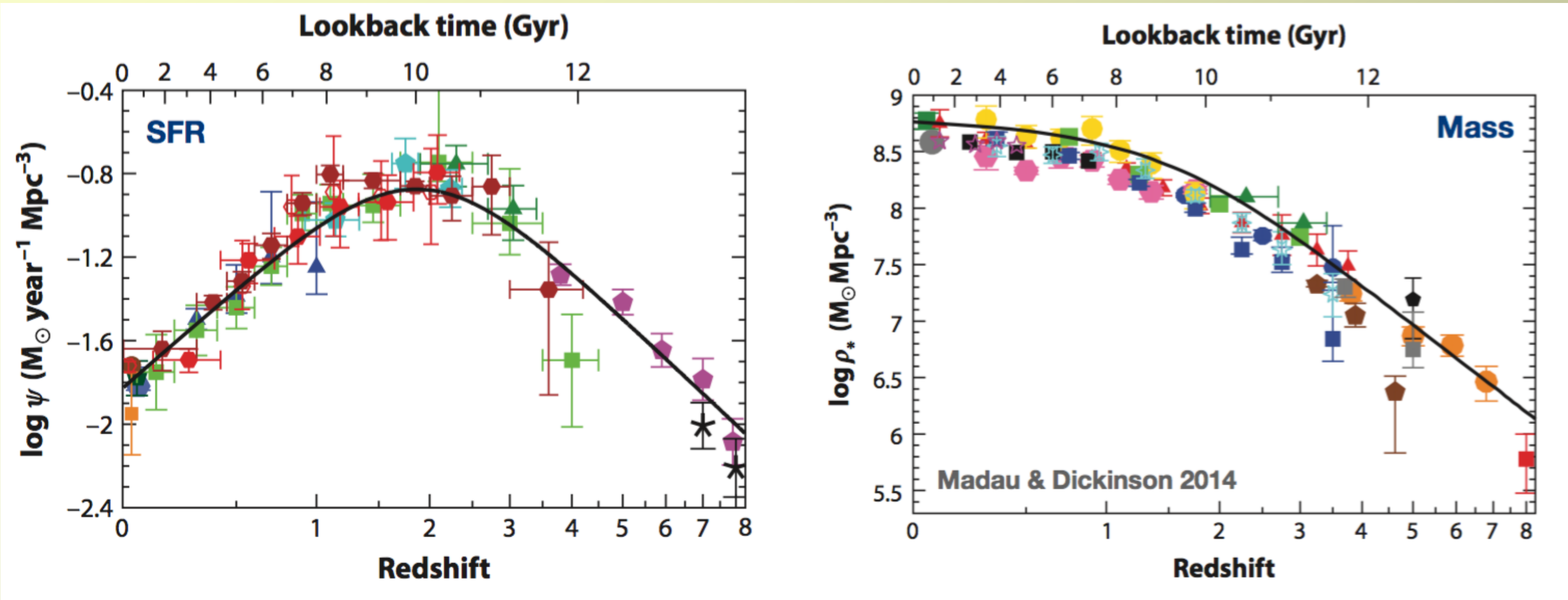
Formation of Globular Clusters

Cosmic reionization

- When does reionization occur ?
- Which sources responsible ?
- How does Lyman continuum radiation escape ?

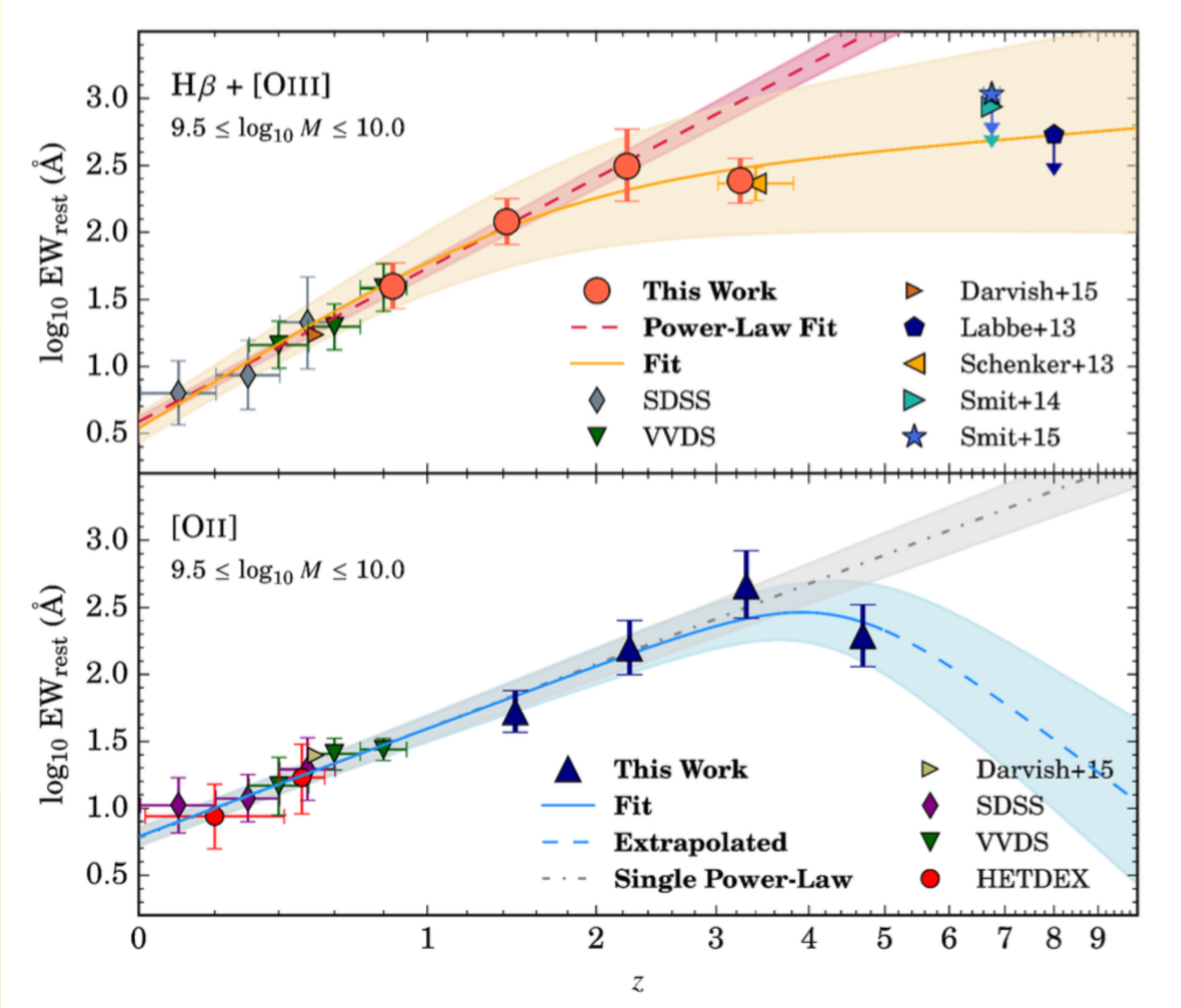
ELT
JWST
ALMA
++

Consistent galaxy SFR and mass build-up



Rapid evolution in the early Universe

Strong evolution of galaxy properties



Khostovan et al. 2016

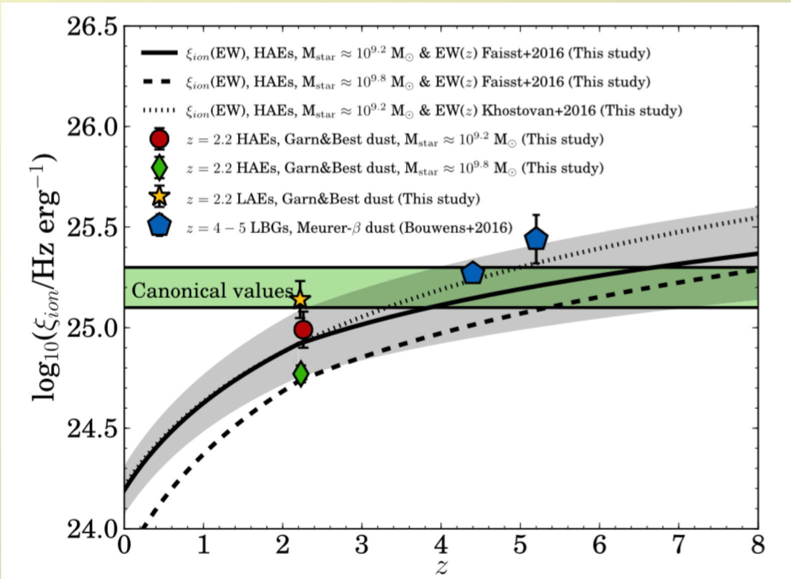
- **Increase of specific SFR(z)**
- **Increase of emission lines**

With increasing redshift we also expect - TBC:

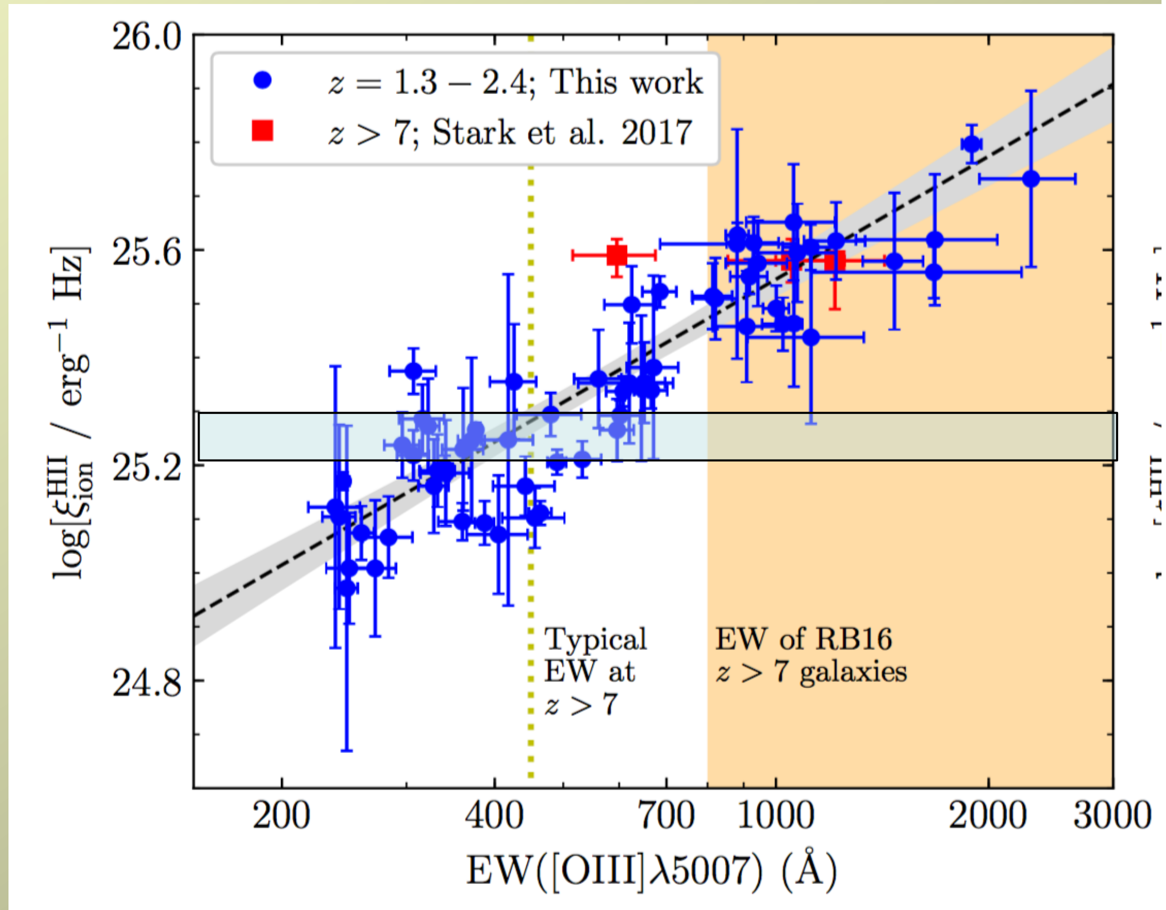
- Decrease of metallicity
- Increased intensity of the radiation field
- Increased hardness of the radiation field !?
- Higher ISM pressure / density
- Increase Lyman continuum escape

Strong evolution of galaxy properties

Increased H ionizing photon production !?



Matthee et al. 2017

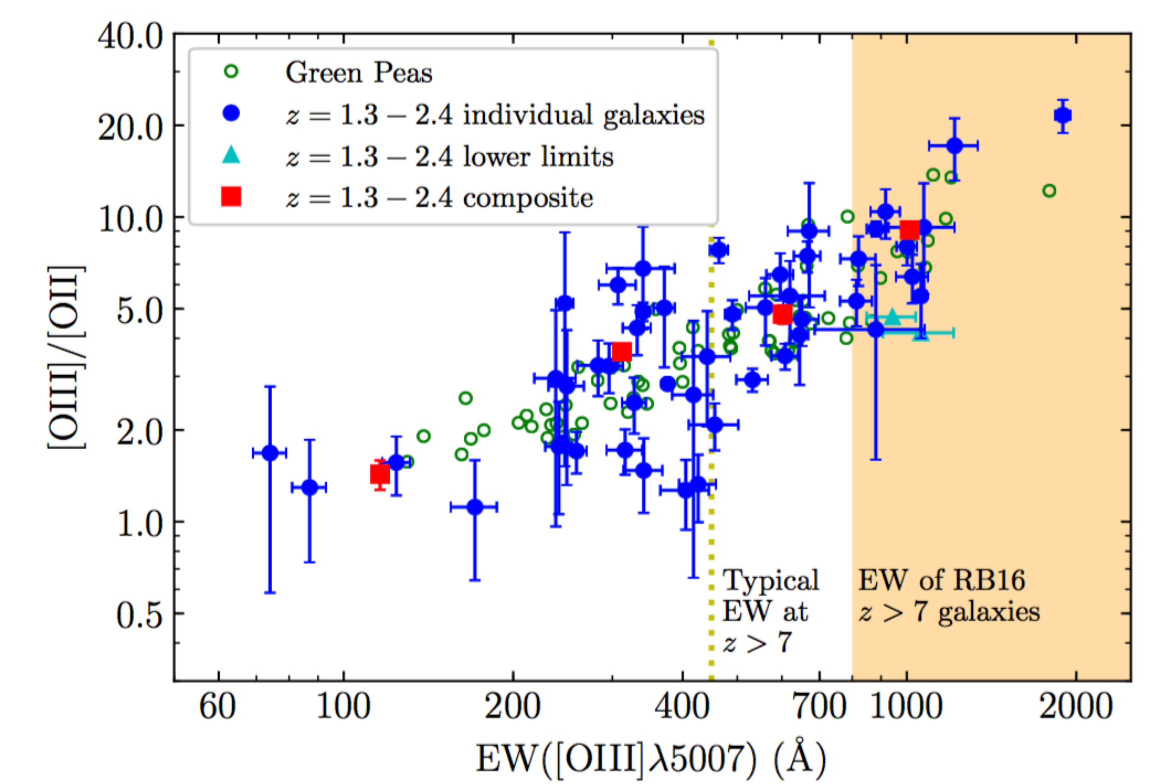


Tang et al. 2019

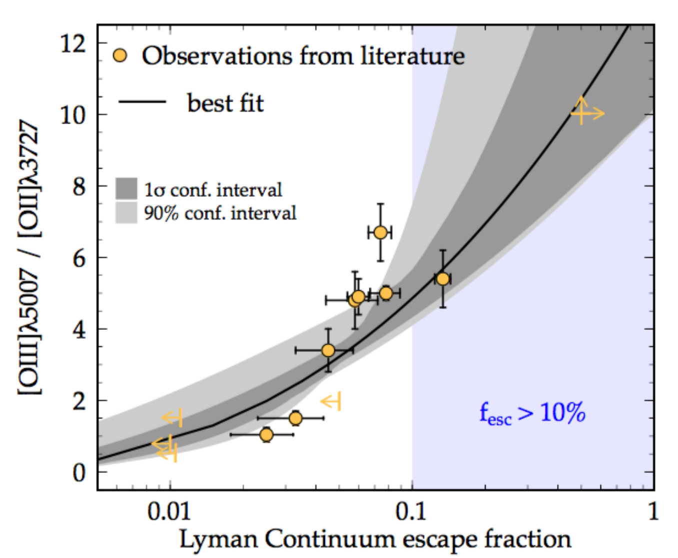
Strong evolution of galaxy properties

Higher excitation ?
[OIII[/ [OII]

Lyman continuum escape more frequent and higher ?



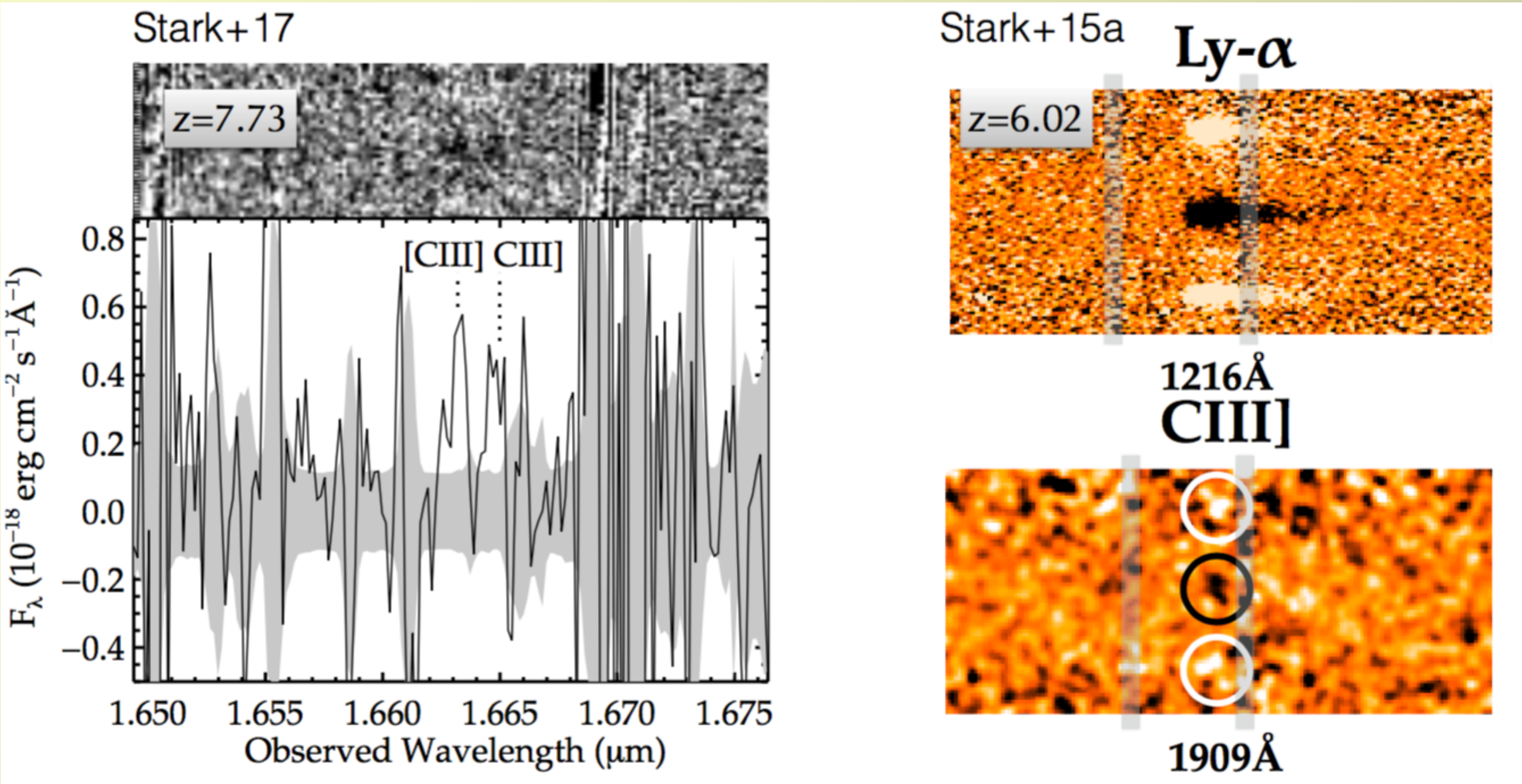
Tang et al. 2019



Nakajima & Ouchi 2014
Jaskot & Oey 2014,
Faisst et al. 2016,
Izotov et al. 2016, 2018

UV spectra of galaxies in the epoch of reionization

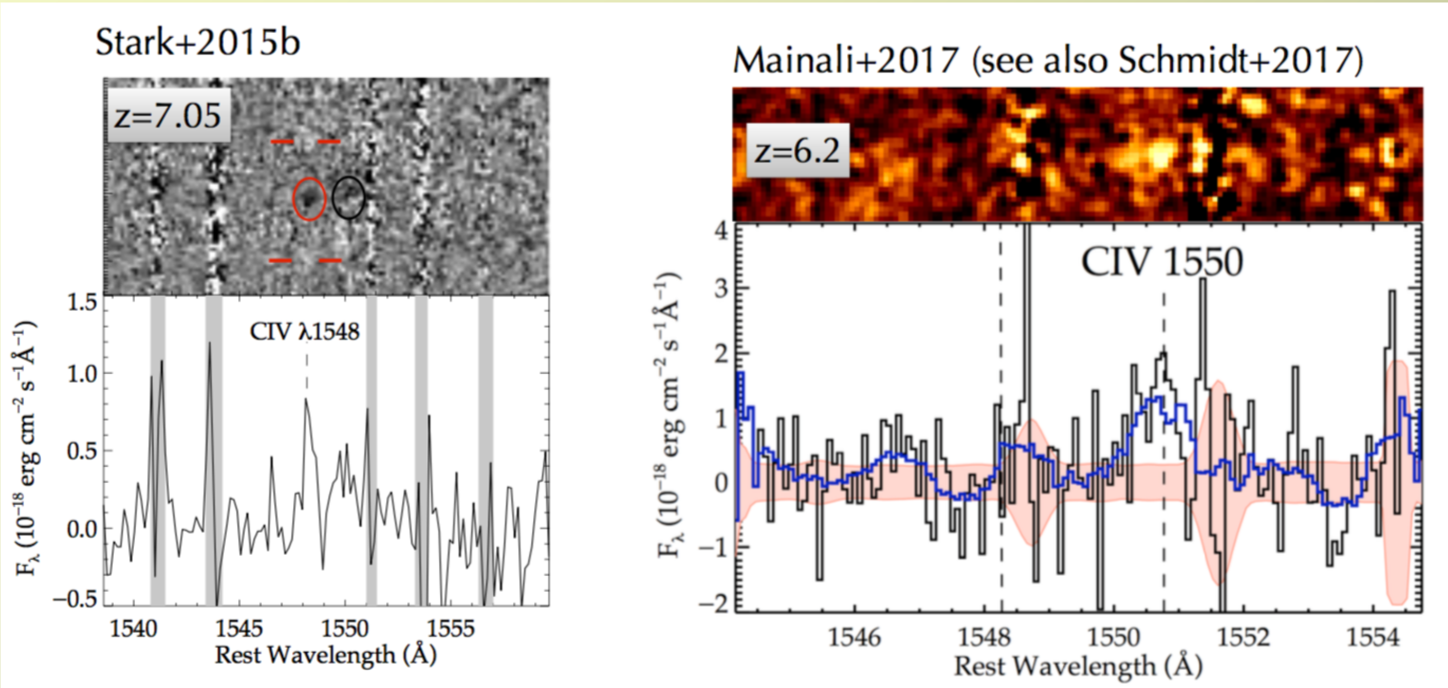
CIII] emission in strong at z>7
EW more than 10x larger than EW(CIII]) in z~3 LBG stacks



e.g. Stark+2015, 2017, Mainali+2017, 2018, Schmidt+ 2017, Laporte+ 2017

UV spectra of galaxies in the epoch of reionization

High ionization emission lines - common ?
Requires hard ionizing spectrum capable of triply ionizing carbon

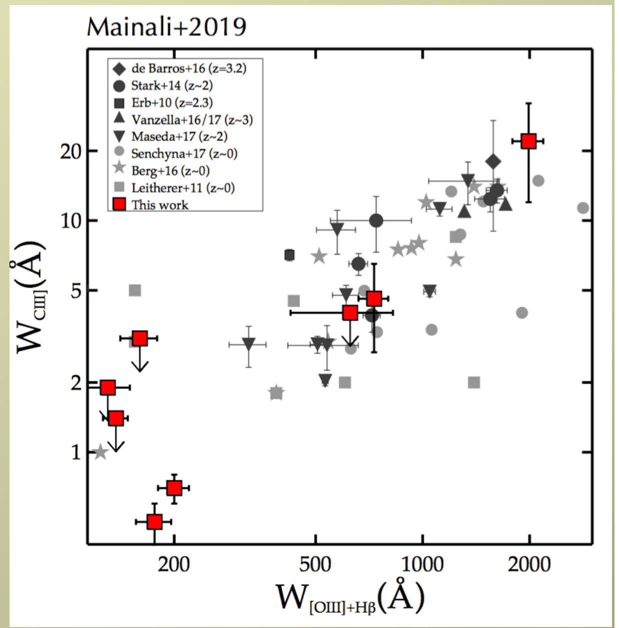


e.g. Stark+2015, 2017, Mainali+2017, 2018, Schmidt+ 2017, Laporte+ 2017

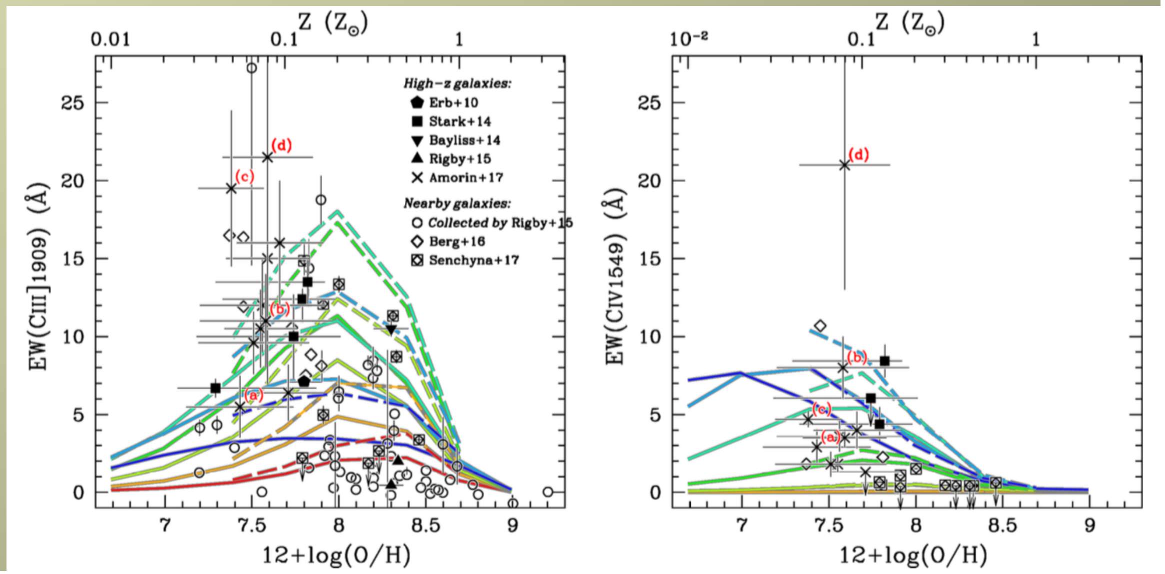
UV spectra of galaxies in the epoch of reionization

Observationally ***vast uncharted territory***
Theory / models ***many open questions***

- **Statistics** of CIII], CIV, HeII … detections
- Do we understand CIII] and CIV detections ?
- Need for (exceptionally) **hard ionizing spectra ?**
- UV line diagnostics:
  SF / AGN, radiation field, metallicity,…
  Lyman continuum escape ?!



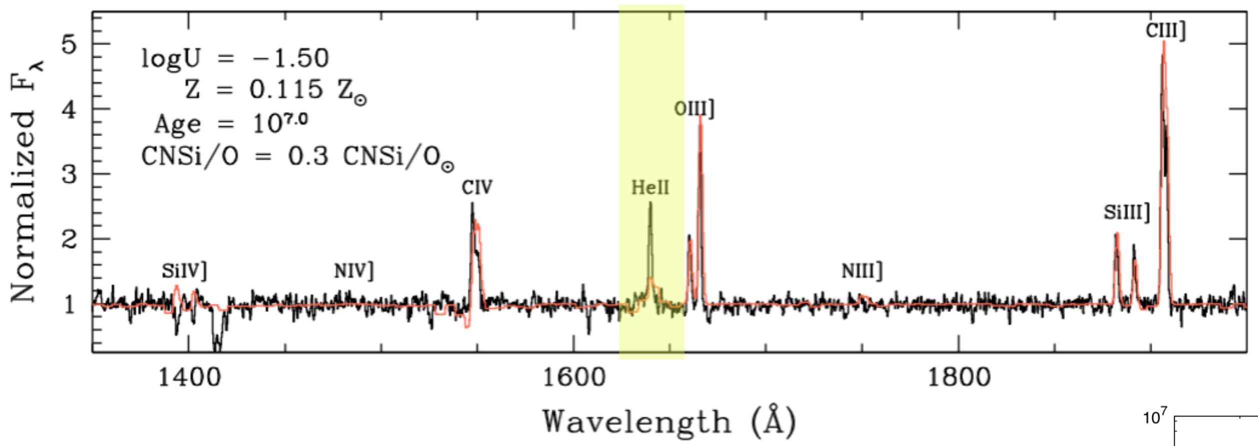
Nakajima+2018



UV spectra of galaxies in the epoch of reionization

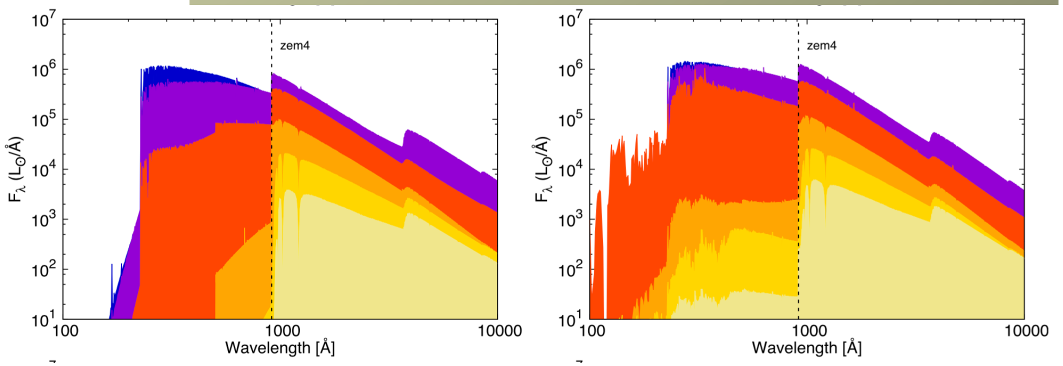
Observationally ***vast uncharted territory***
Theory/models ***many open questions***

- Need for (exceptionally) **hard ionizing spectra ?**
  → nebular HeII emission unexplained (>54 eV)



Berg+2018

Uncertainties/diffs in SEDs
(single/binary stars, rotation, …)



Xiao, Stanway, Elridge+2018

The HeII problem

ARTICLES

Detection of an X-ray-ionized nebula around the black hole candidate binary LMC X-1

M. W. Pakull* & L. P. Angebault†

* Institut für Astronomie und Astrophysik, TU Berlin, Sekr, PN 8-1, Hardenbergstrasse 36, D-1000 Berlin 12, West Germ
† European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-8046 G... hing, West Germany

Optical spectra of the black hole candidate X-ray binary LM... em is surrounded ... highly ionized He III region, N159F, which appears ... of an X-ray-pho... The spatially resolved temperature and io... previously unc... ultraviolet (EUV) luminosity of an...

THE ASTROPHYSICAL JOURNAL, 373:458–464, 1991 June 1

He II EMISSION IN EXTRAGALACTIC H II REGIONS[1]

DONALD R. GARNETT
Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218
ROBERT C. KENNICUTT, JR.[2]
Steward Observatory, University of Arizona, Tucson, AZ 85721
YOU-HUA CHU[2]
Astronomy Department, University of Illinois, 1002 West Green Street, Urbana, IL 61801
AND
EVAN D. SKILLMAN
Astronomy Department, University of Minnesota, 116 Church Street, S. E., Minneapolis, MN 55455

Received 1990 September 21; accepted 1990 November 21

ABSTRACT

We present spectroscopic observations which confirm that the He ... SMC H II region N76 and demonstrate that the ... extended. Several H II regions are now ... N44C and N159F in the LMC ... specific star; in one, an ... binary LMC X-... shock...

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
Mon. Not. R. Astron. Soc. 421, 1043–1063 (2012)
doi:10.1111/j.1365-2966.2012.20439.x

Strongly star forming galaxies in the local Universe with nebular He II λ4686 emission

Maryam Shirazi★ and Jarle Brinchmann
Leiden Observatory, Leiden University, PO Box 9513, 2300 RA Leiden, the Netherlands

Accepted 2011 December 7. Received 2011 December 7; in original form 2011 September 15

ABSTRACT

We present a sample of 2865 emission-line galaxies with strong nebular He II λ4686 emissions in the Sloan Digital Sky Survey Data Release 7 and use this sample to investigate the origin of this line in star-forming galaxies. We show that star-forming galaxies and galaxies dominated by an active galactic nucleus form clearly separated branches in the He II λ4686/Hβ versus [N II] λ6584/Hα diagnostic diagram and derive an empirical classification scheme which separates the two classes. We also present an analysis of the physical properties of 189 star-forming galaxies with strong He II λ4686 emissions. These star-forming galaxies provide constraints on the hard ionizing continuum of massive stars. To make a quantitative comparison with observation, we use photoionization models and examine how different stellar population models affect the predicted He II λ4686 emission. We confirm previous findings that the models can predict He II λ4686 emission only for instantaneous bursts of 20 per cent solar metallicity or higher, and only for ages of ∼4–5 Myr, the period when the extreme-ultraviolet continuum is dominated by emission from Wolf–Rayet stars. We find, however, that 83 of the star-forming galaxies (40 per cent) in our sample do not have Wolf–Rayet features in their spectra despite showing strong nebular He II λ4686 emission. We discuss possible reasons for this and possible mechanisms for the He II λ4686 emission in these galaxies.

Key words: stars: Wolf–Rayet – galaxies: evolution – galaxies: star formation – galaxies: stellar content.

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS 472, 2608–2632 (2017)
Advance Access publication 2017 August 16
doi:10.1093/mnras/stx2059

Ultraviolet spectra of extreme nearby star-forming regions – approaching a local reference sample for *JWST*

Peter Senchyna,[1★] Daniel P. Stark,[1] Alba Vidal-García,[2] Jacopo Chevallard,[3] Stéphane Charlot,[2] Ramesh Mainali,[1] Tucker Jones,[4,5†] Aida Wofford,[6] Anna Feltre[7] and Julia Gutkin[2]

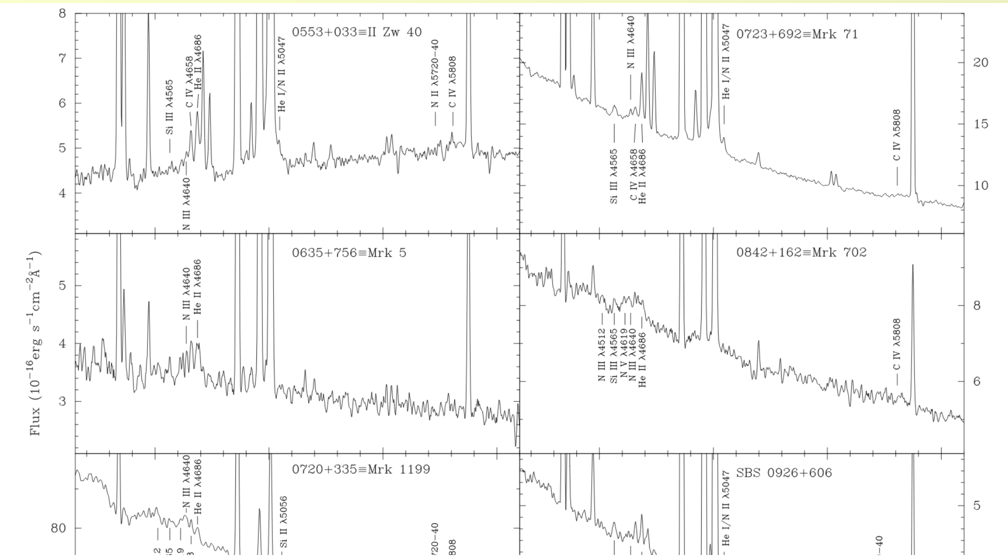
[1]Steward Observatory, University of Arizona, 933 N Cherry Ave, Tucson, AZ 85721, USA
[2]Sorbonne Universités, UPMC-CNRS, UMR7095, Institut d'Astrophysique de Paris, F-75014 Paris, France
[3]Scientific Support Office, Directorate of Science and Robotic Exploration, ESA/ESTEC, Keplerlaan 1, NL-2201 AZ Noordwijk, the Netherlands
[4]Department of Physics, University of California Davis, 1 Shields Avenue, Davis, CA 95616, USA
[5]Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822, USA
[6]Instituto de Astronomía, UNAM, Ensenada, CP 22860, Baja California, Mexico
[7]Centre de Recherche Astrophysique de Lyon, Université Lyon 1, 9 Avenue Charles André, F-69561 Saint Genis Laval Cedex, France

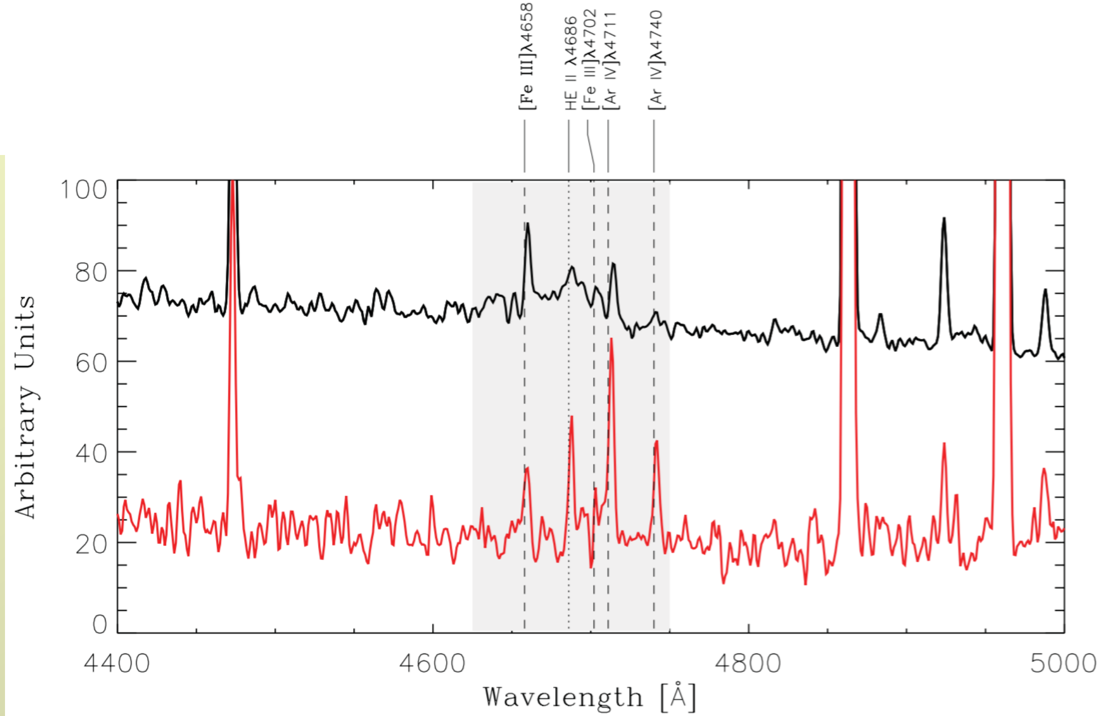
Accepted 2017 August 4. Received 2017 August 4; in original form 2017 June 2

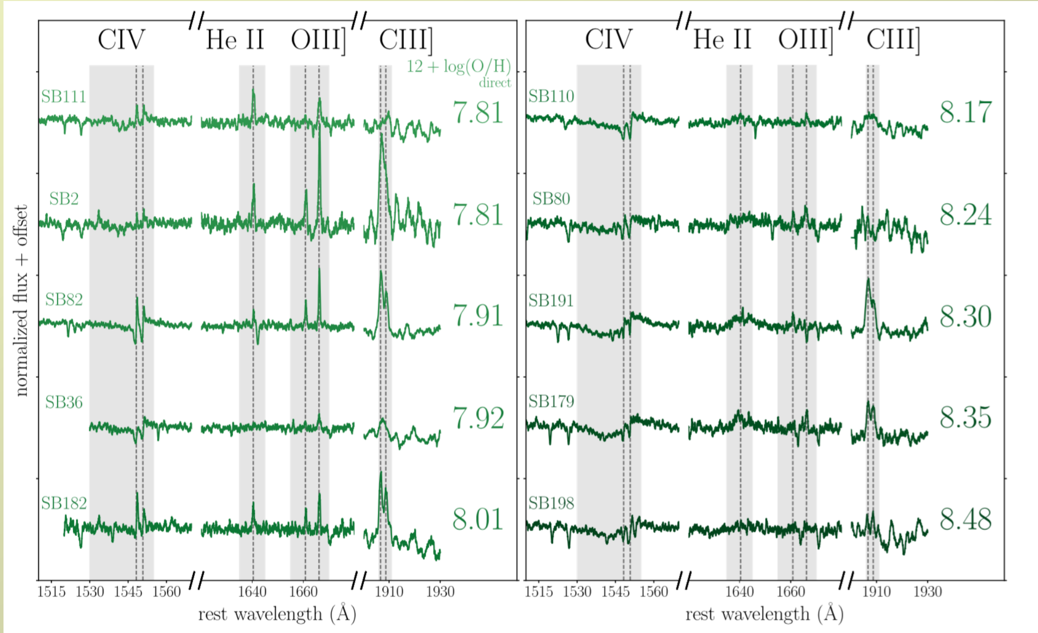
ABSTRACT

Nearby dwarf galaxies provide a unique laboratory in which to test stellar population models below $Z_\odot/2$. Such tests are particularly important for interpreting the surprising high-ionization ultraviolet (UV) line emission detected at $z > 6$ in recent years. We present *HST*/COS UV spectra of 10 nearby metal-poor star-forming galaxies selected to show He II emission in SDSS optical spectra. The targets span nearly a dex in gas-phase oxygen abundance ($7.8 < 12 + \log O/H < 8.5$) and present uniformly large specific star formation rates (sSFR $\sim 10^2$ Gyr^{-1}). The UV spectra confirm that metal-poor stellar populations can power extreme nebular emission in high-ionization UV lines, reaching C III] equivalent widths comparable to those seen in systems at $z \sim 6$–7. Our data reveal a marked transition in UV spectral properties with decreasing metallicity, with systems below $12 + \log O/H \lesssim 8.0$ ($Z/Z_\odot \lesssim 1/5$) presenting minimal stellar wind features and prominent nebular emission in He II and C IV. This is consistent with nearly an order of magnitude increase in ionizing photon production beyond the He$^+$-ionizing edge relative to H-ionizing flux as metallicity decreases below a fifth solar, well in excess of standard stellar population synthesis predictions. Our results suggest that often-neglected sources of energetic radiation such as stripped binary products and very massive O-stars produce a sharper change in the ionizing spectrum with decreasing metallicity than expected. Consequently, nebular emission in C IV and He II powered by these stars may provide useful metallicity constraints in the reionization era.

The HeII problem



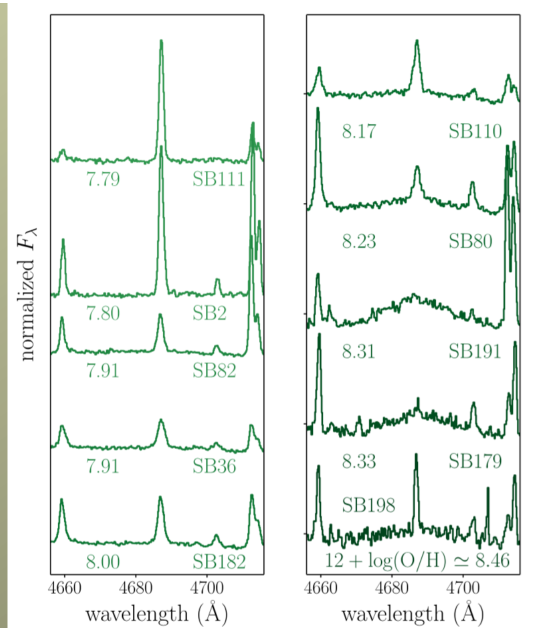




Nebular HeII 4686 and HeII 1640

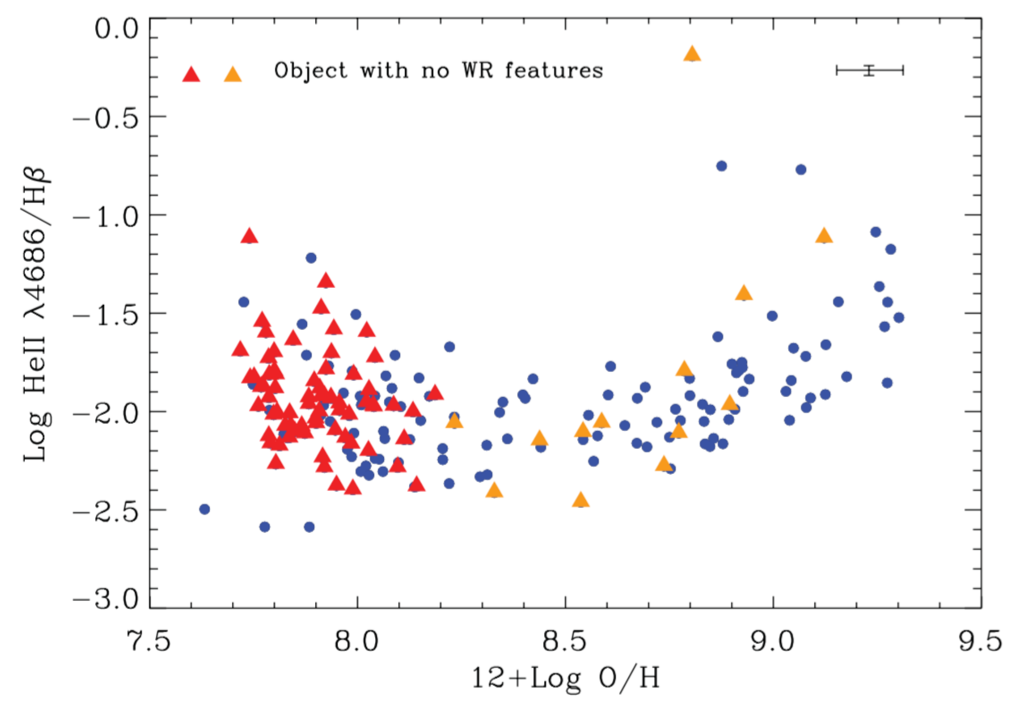
z~0 dwarf galaxies and HII regions

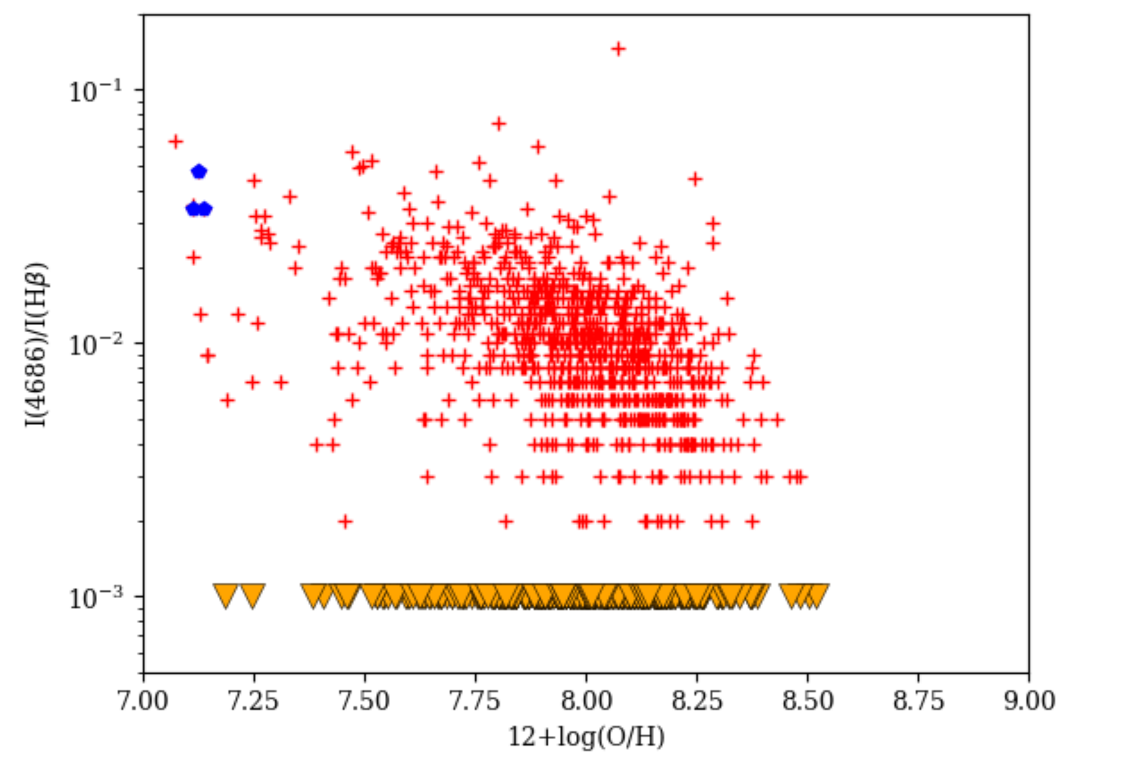
Guseva et al. 2000, Shirazi & Brinchmann 2002,….
Senchyna+ 2017



The HeII problem

→ **Nebular HeII/Hβ intensity increases at low metallicity**

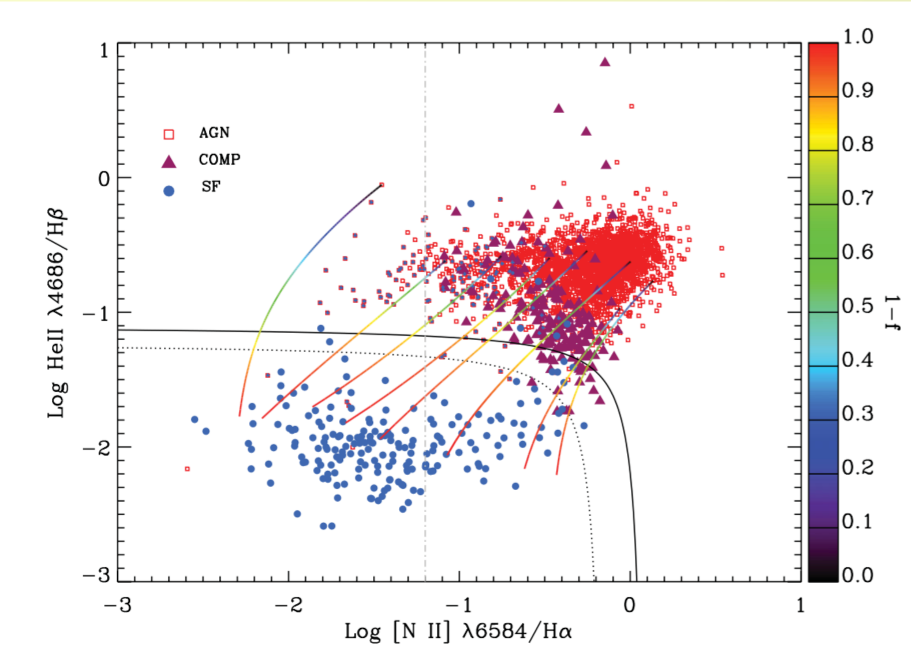




SDSS, DR7: Shirazi & Brinchmann 2002

SDSS DR14+:
~1463 SF galaxies with HeII measurements
Schaerer, Izotov, Fragkos 2019

The HeII problem



Shirazi & Brinchmann (2002)

Star-forming galaxies, NOT AGN

Possible sources:

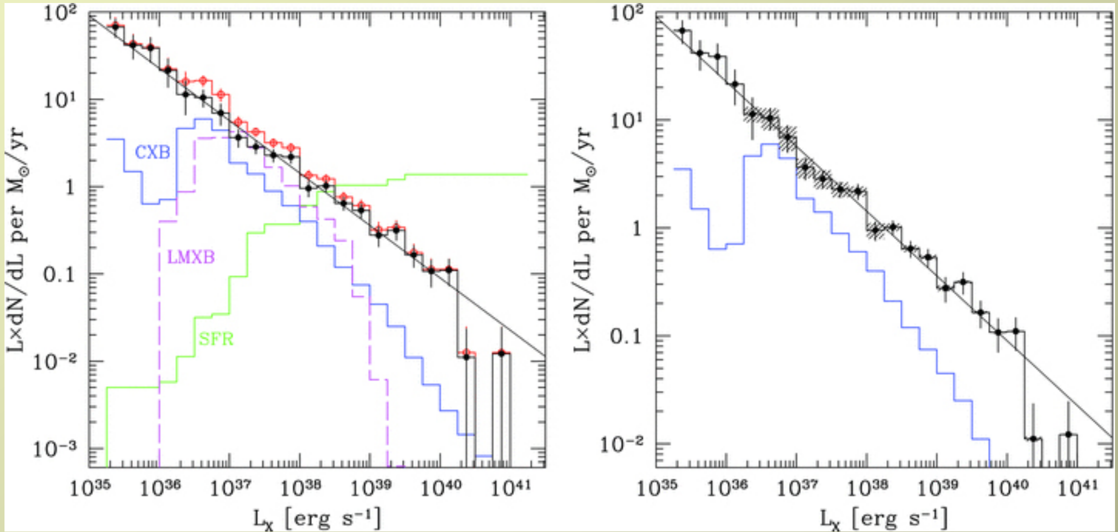
- Very hot stars (Teff>~80-10 kK)
  → Hot Wolf-Rayet stars
  → Rapidly rotating stars
  → Binaries
  → PopIII
  → post-AGB

- Shocks
- X-ray binaries

→ ***no consistent quantitative explanation so far***

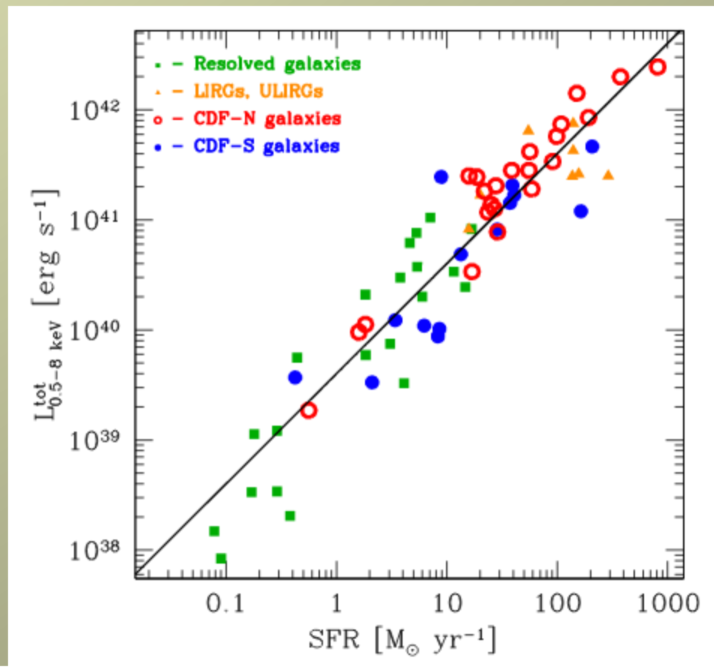
A fresh look at the HeII problem - (I) X-rays

X-ray emission in SFGs dominated **by point-like sources** (HMXB, ULX)

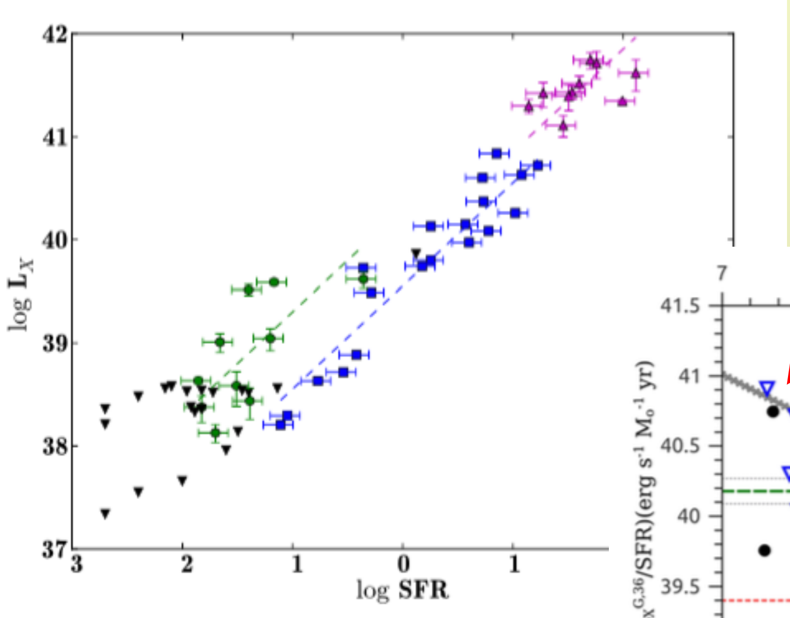


e.g. Mineo et al. 2012, 2014

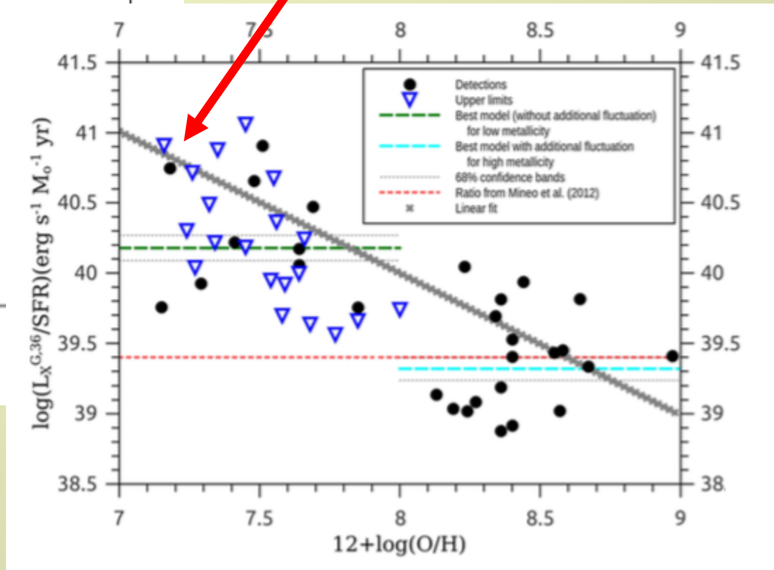
Total L_X correlates with SFR



A fresh look at the HeII problem - (I) X-rays



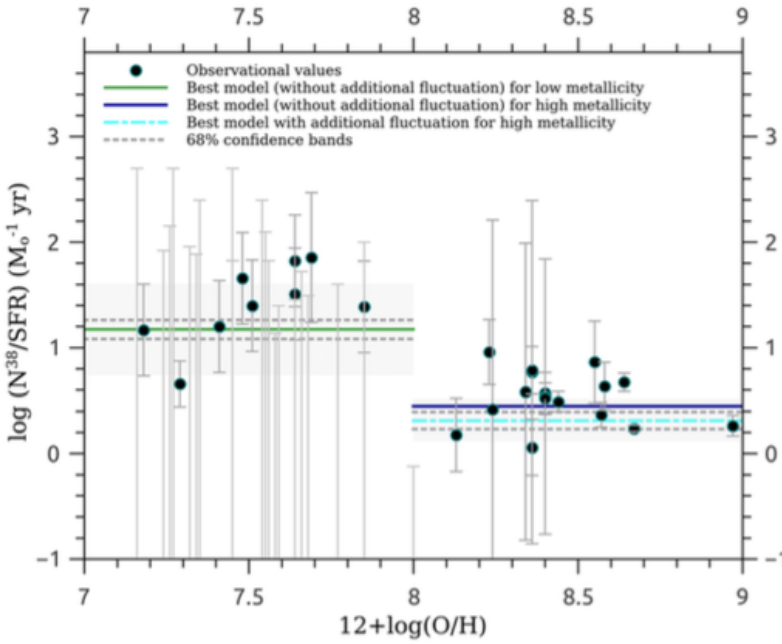
I Zw 18



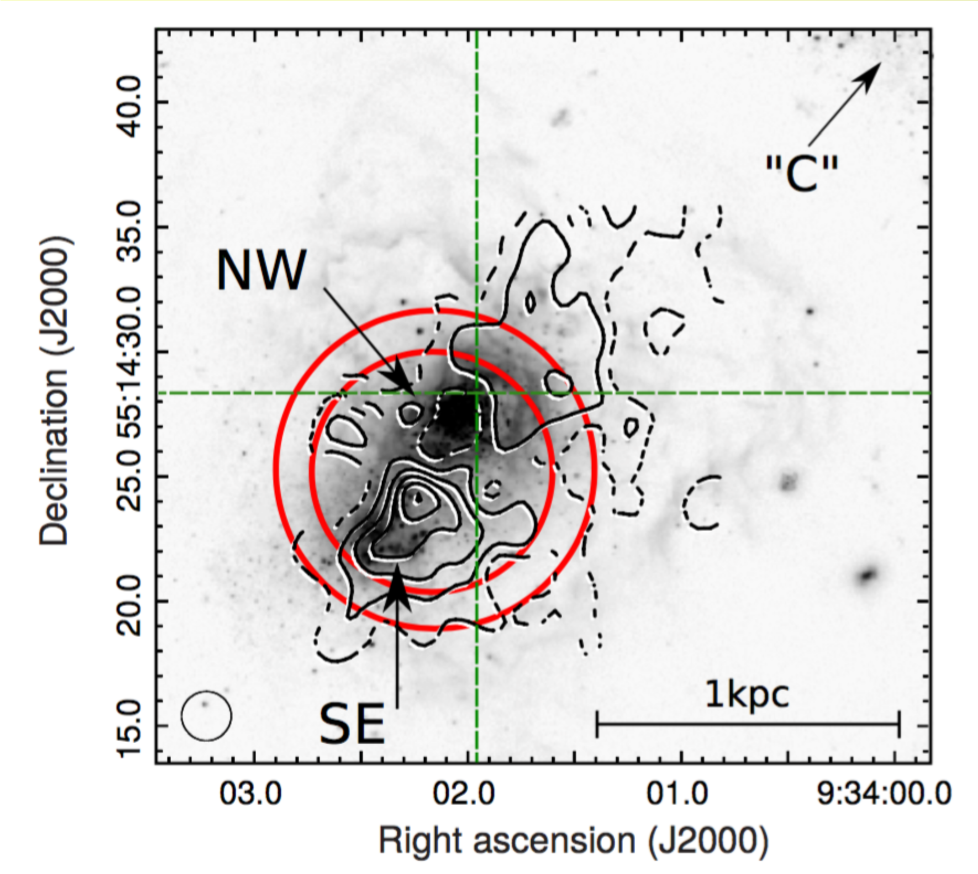
Brorby et al. 2016,
Douna et al. 2015

Excess of X-ray emission L_X/SFR at low metallicities
(cf. Linden et al. 2010, Basu-Zych et al. 2016…)

Scatter in X-rays due to stochasticity of HMXBs

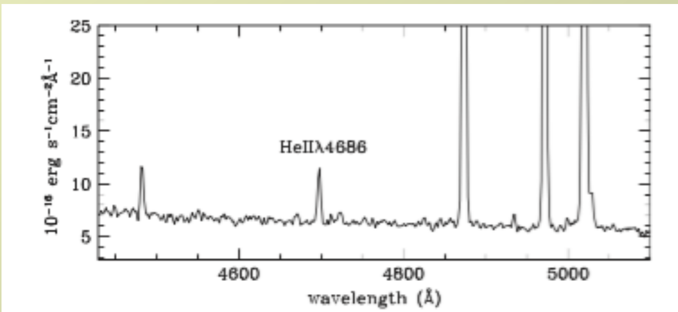


A fresh look at the HeII problem - (II) I Zw 18

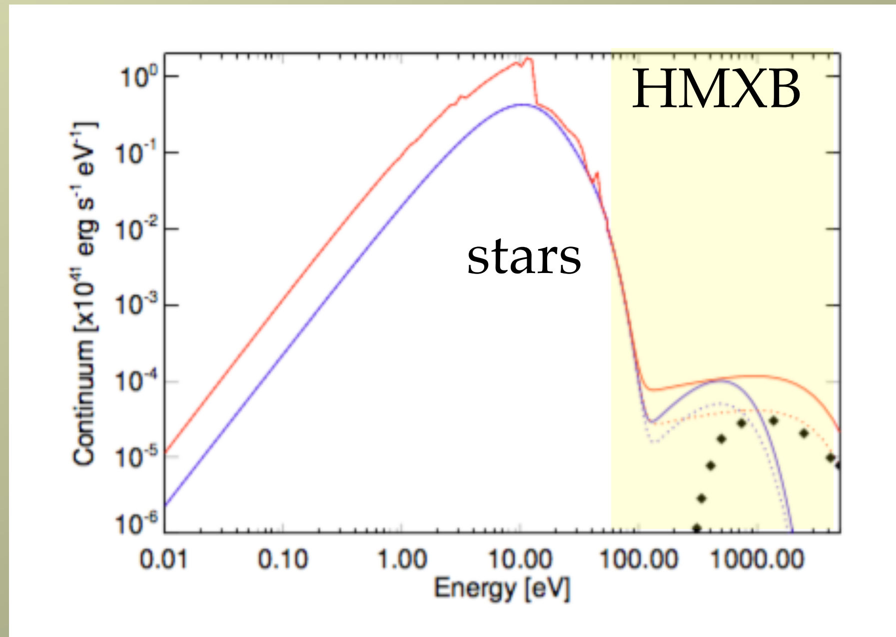


Empirically:
point-line X-ray source coincides with HeII region

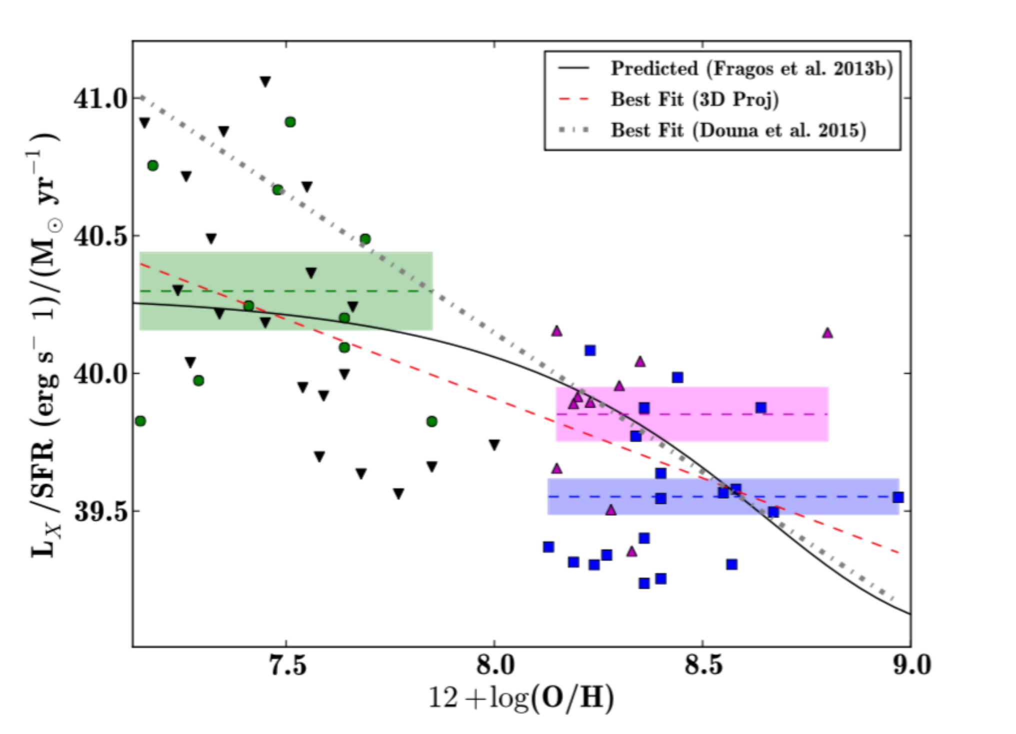
L_X=(0.3-1.4)10^{40} erg/s
F(HeII4686) ➔ Q(He+)=1.3^{e}50 photon/s
➔ Q(He+)/L_X ~2e10 photon/erg



Thuan+ 2004
Kaaret & Feng 2013
Leboutellier+ 2017



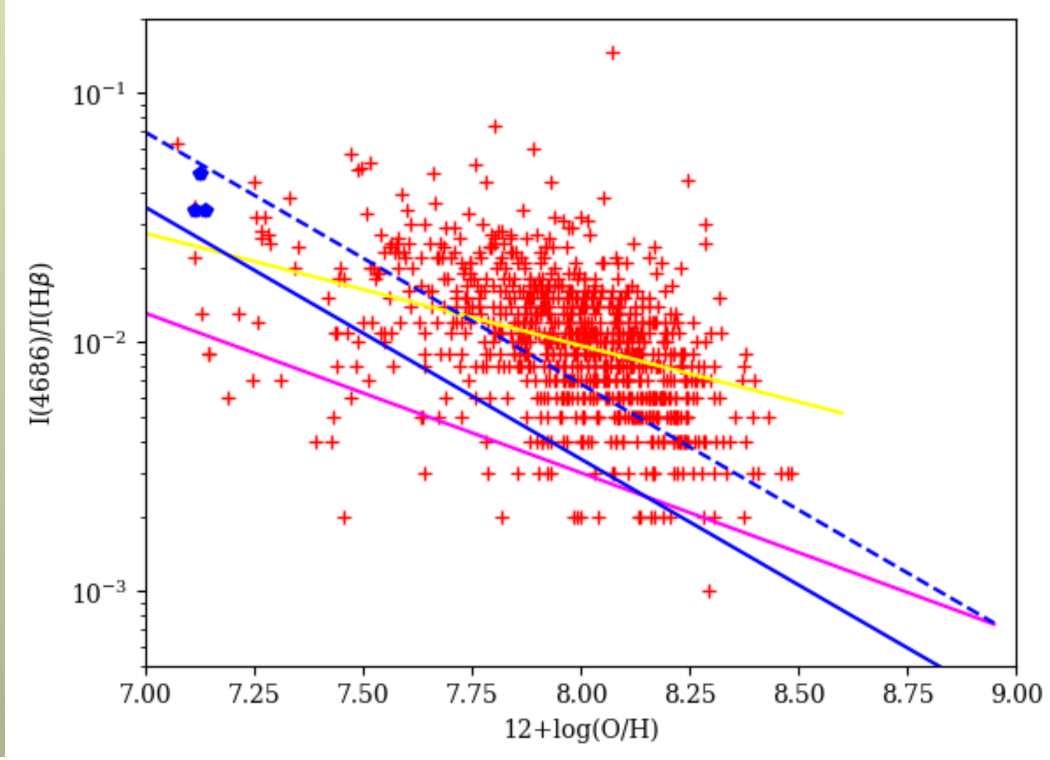
A fresh look at the HeII problem – putting it together



Brorby et al. 2016

L_X/SFR ~ Q(He+)/SFR
~ Q(He+)/Q(H) ~ HeII4686/Hb
Assumes: - SFR=const
- Q(He+)/L_X from I Zw 18

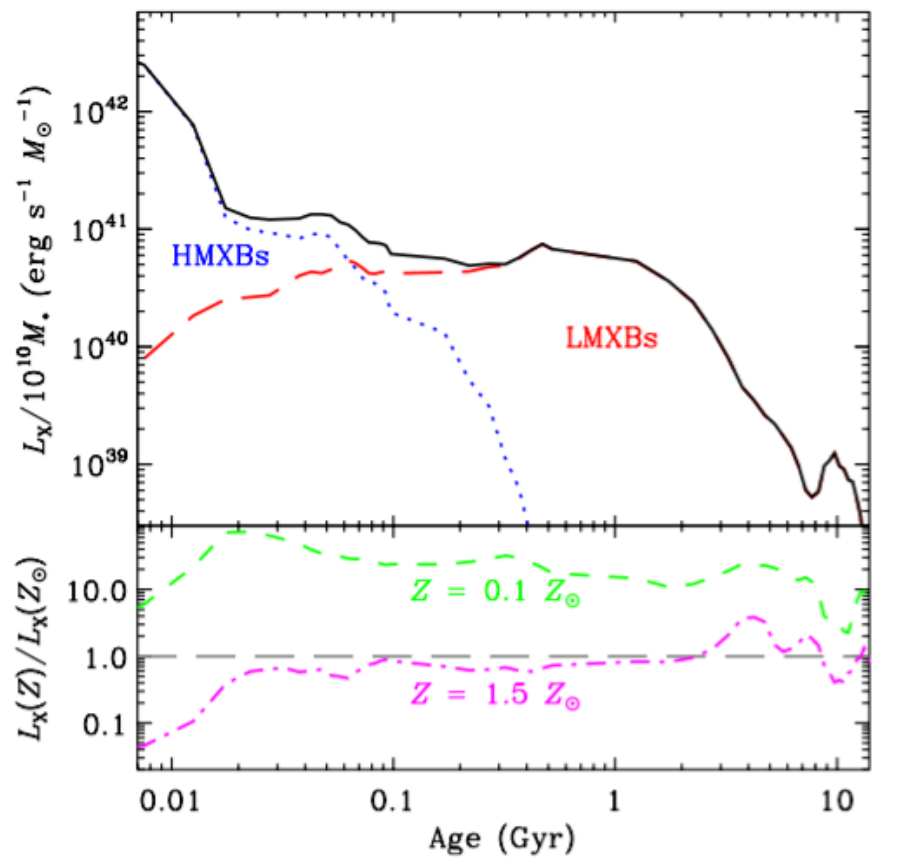
Schaerer et al. (2019)



Observed L_X/SFR reproduces naturally observed metallicity dependence of HeII intensity

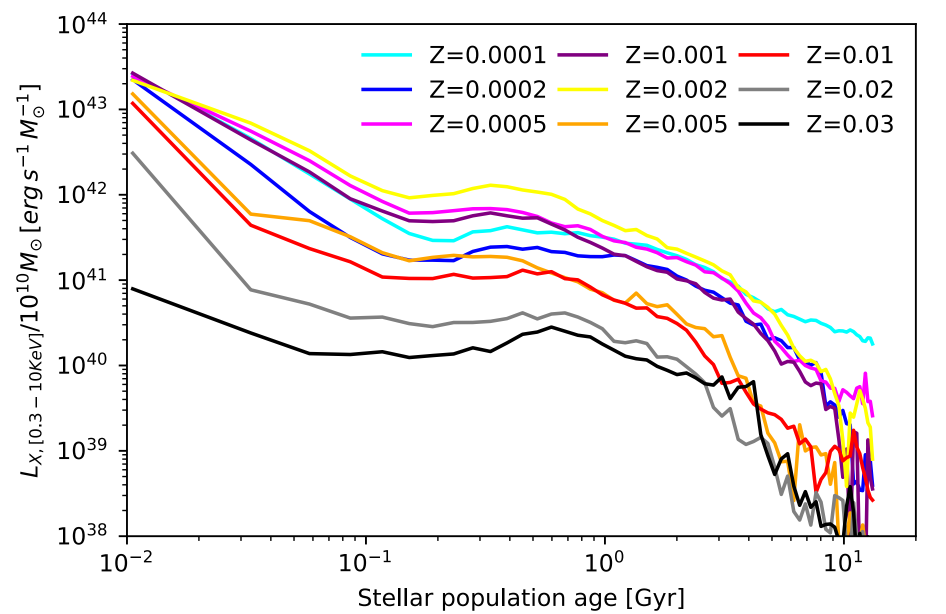
A fresh look at the HeII problem – (III) HMXB population models

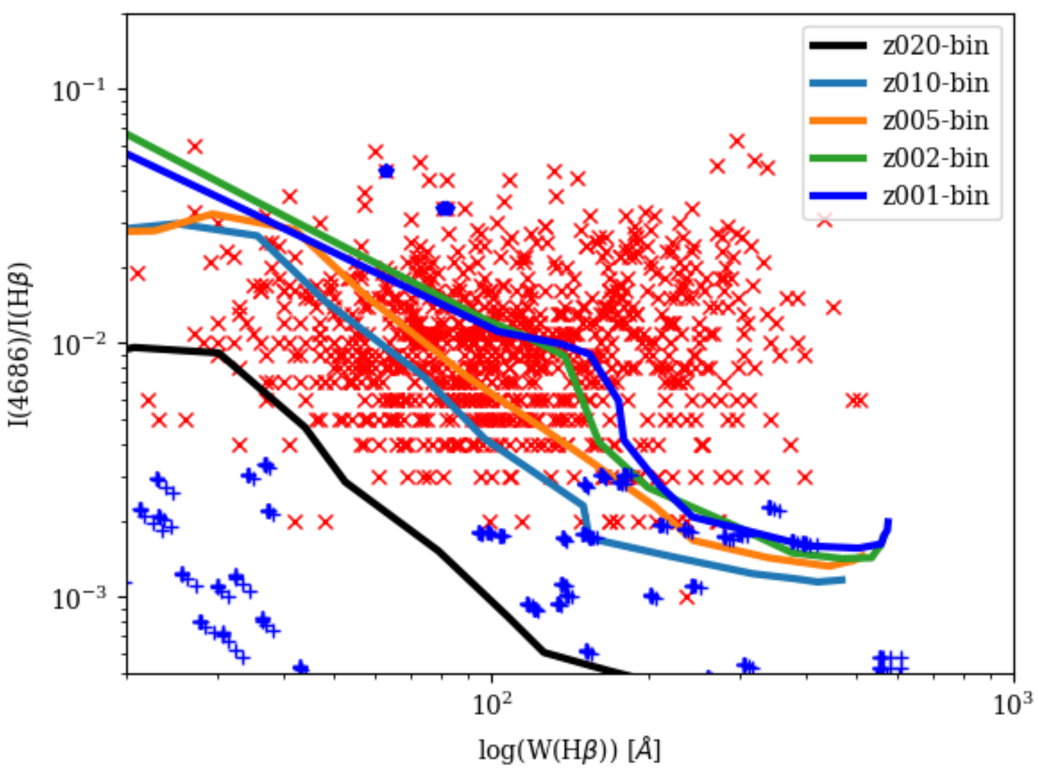
- **Strong age-dependence of L_X**
- **Strong increase of L_X at low metallicity**: lower stellar mass loss →
  More massive + numerous BH population
  Less binary angular momentum loss → tighter orbits → more overflow
  → *more numerous and more luminous X-ray binaries*



Fragos et al. 2013
Madau & Fragos 2017

Schaerer et al. (2019)





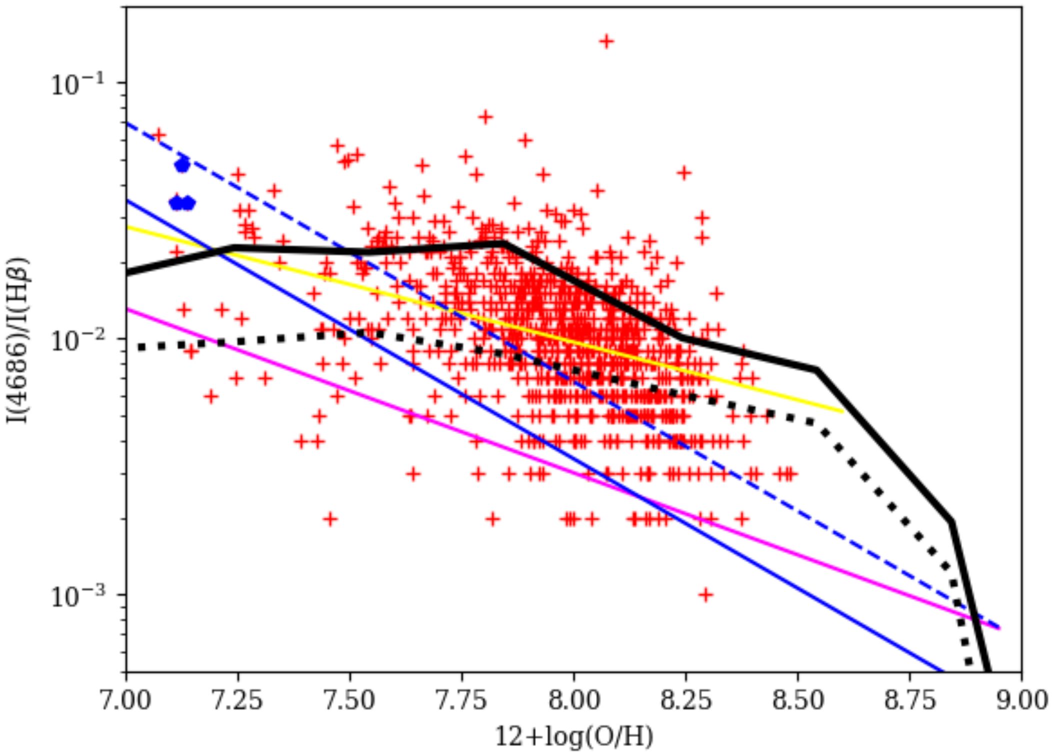
HMXB population models
+ assumed Q(He+)/L_X from I Zw 18

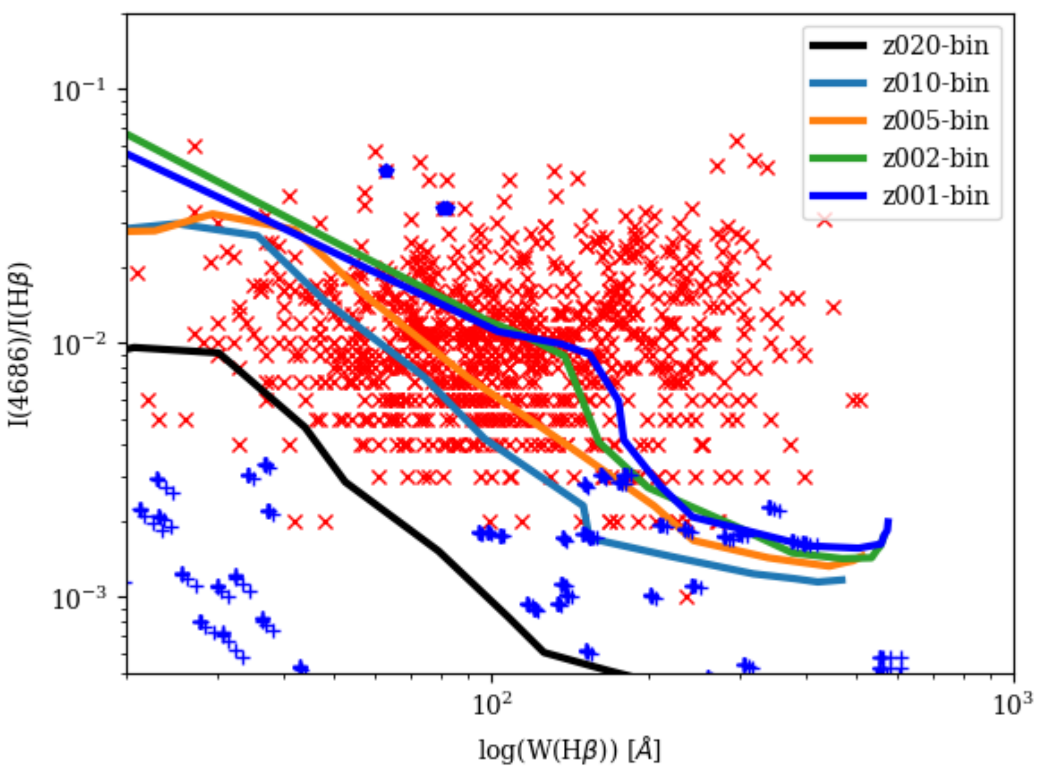
→ **Predicts observed HeII line intensities and their metallicity dependence**

Schaerer et al. (2019)

Burst models

Assume SFR=const





HMXB population models
+ assumed Q(He+)/L_X from I Zw 18

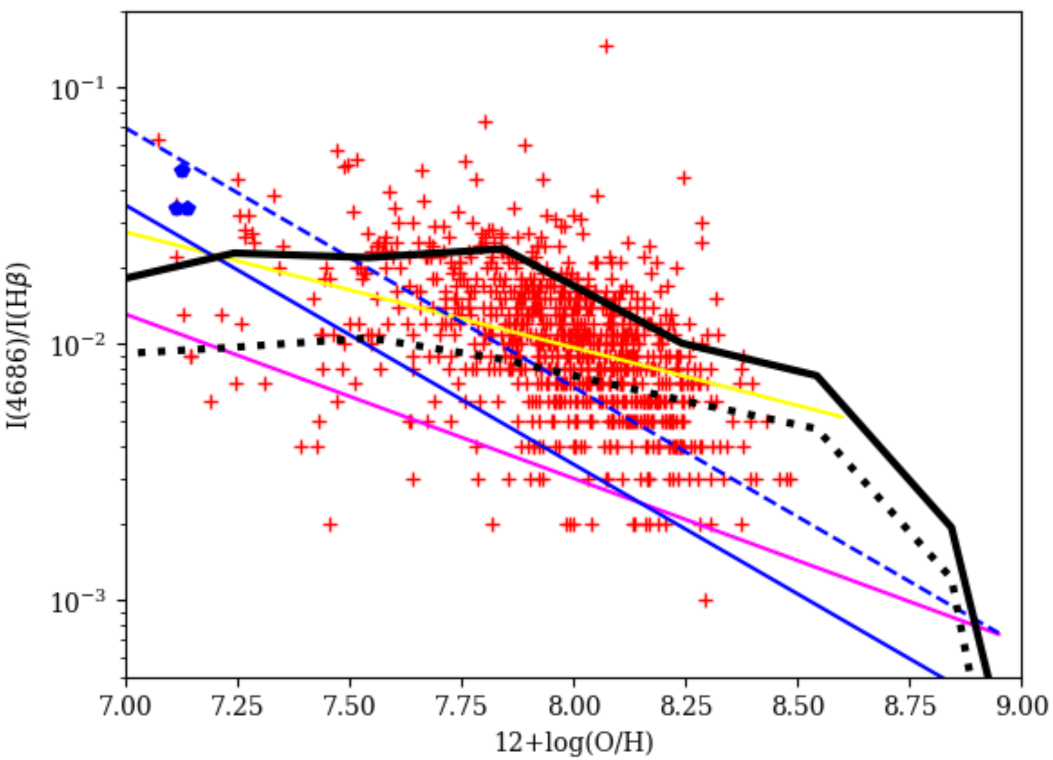
→ **Predicts observed HeII line intensities and their metallicity dependence**

Schaerer et al. (2019)

~1/3 of sources at 12+log(O/H)<8.4 show non-detection of HeII

Can be explained by:

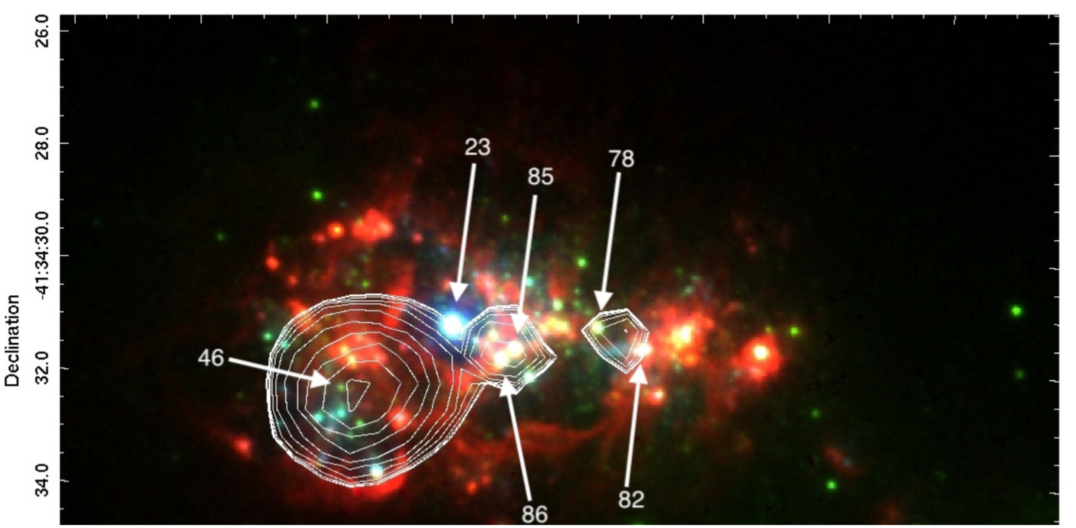
- « Stochastic » effects (absence or variability of HMXB)
- Variations of HMXB SED
- Low ionization parameter

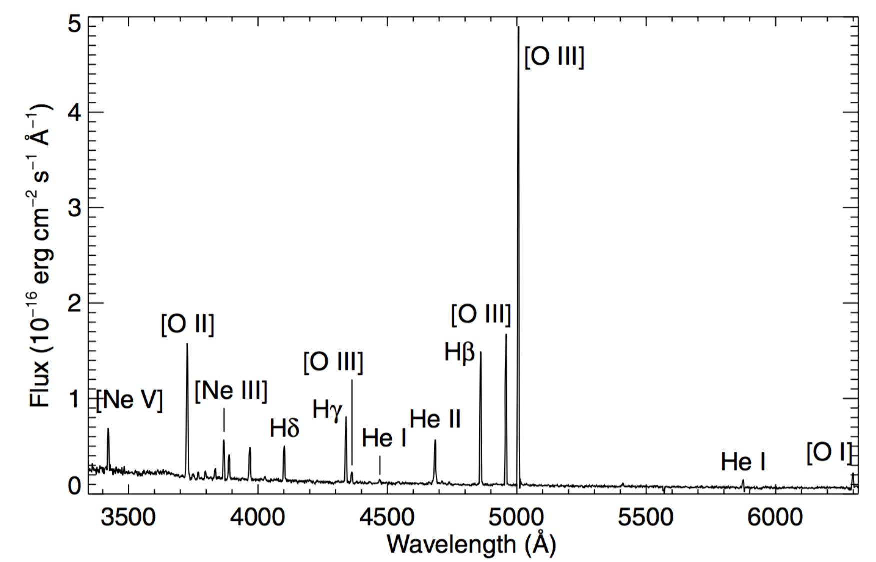


Next steps, improvements

- **HeII 1640 predictions (Schaerer+ 2019)**
- **Impact on UV diagnostics**

- More individual studies of X-ray + HeII ?!
- Systematic study of known HMXB/ULX





Letter to the Editor

On the contribution of ULXs to stellar feedback: an intermediate mass black hole candidate and the population of ULXs in the low-metallicity starburst galaxy ESO 338-4★

Lidia M. Oskinova[1,2], Arjan Bik[3], J. Miguel Mas-Hesse[4], Matthew Hayes[3], Angela Adamo[3], Göran Östlin[3], Felix Fürst[5], Héctor Otí–Floranes[4]

Kaaret & Corbel, 2009

The quest for the sources of cosmic reionisation

- Faint, low mass galaxies thought to be main contributors to cosmic reionization
- Numerous searches for « Lyman continuum leakage » from star-forming galaxies at low and high-z
  → **sources elusive, so far!**

→ **New strategies needed**

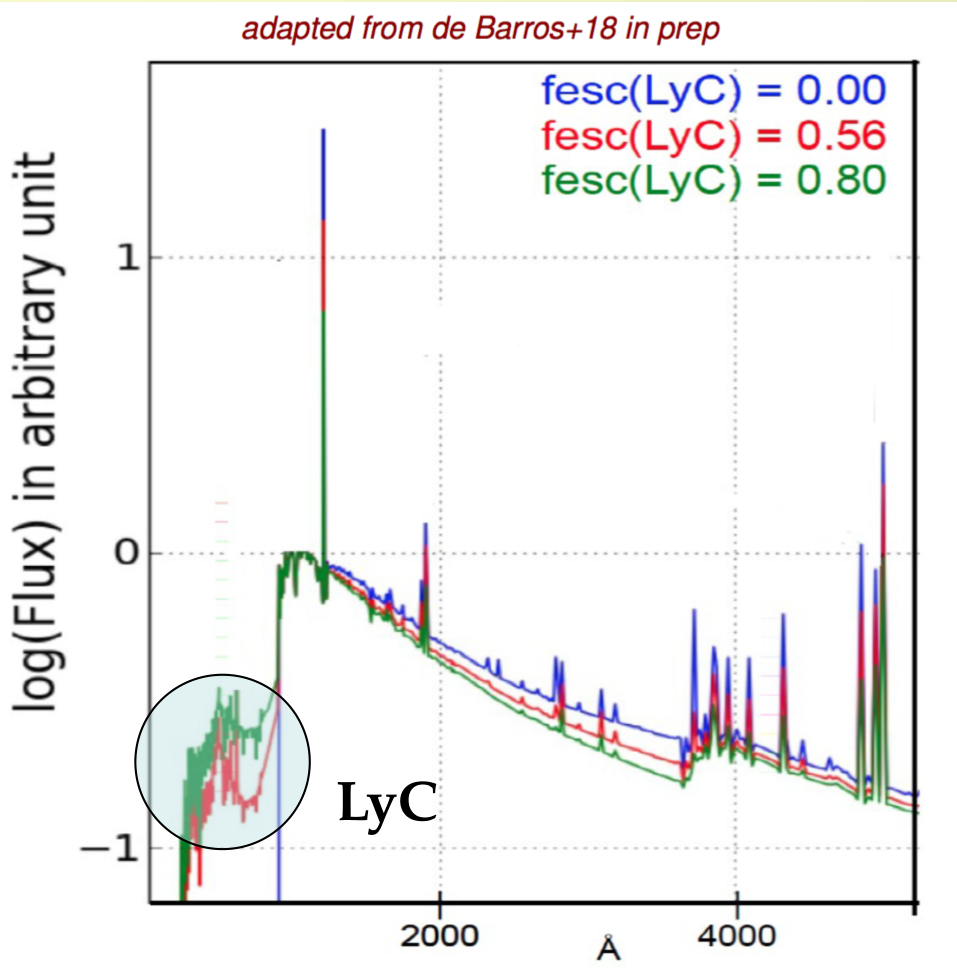
→ **How to identity and find the sources of reionisation?**

→ **Study their properties**

$$\dot{n} = f_{\rm esc}\, \xi_{\rm ion}\, \rho_{\rm SFR}$$

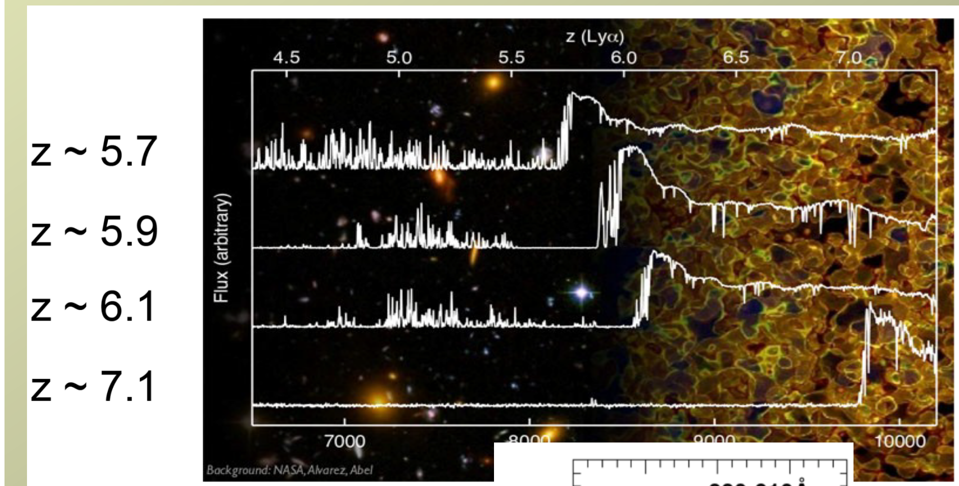
escape fraction ($f_{\rm esc}$); ionizing photons / UV luminosity ($\xi_{\rm ion}$); UV luminosity density ($\rho_{\rm SFR}$)

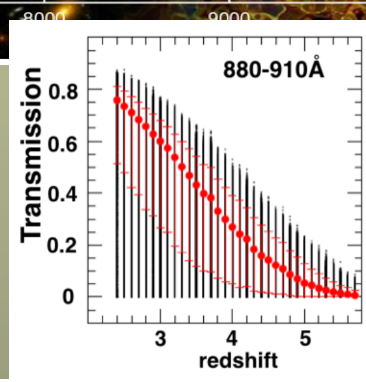
Signatures of the sources of cosmic reionisation



Direct Lyman continuum (LyC) detection impossible at high redshift

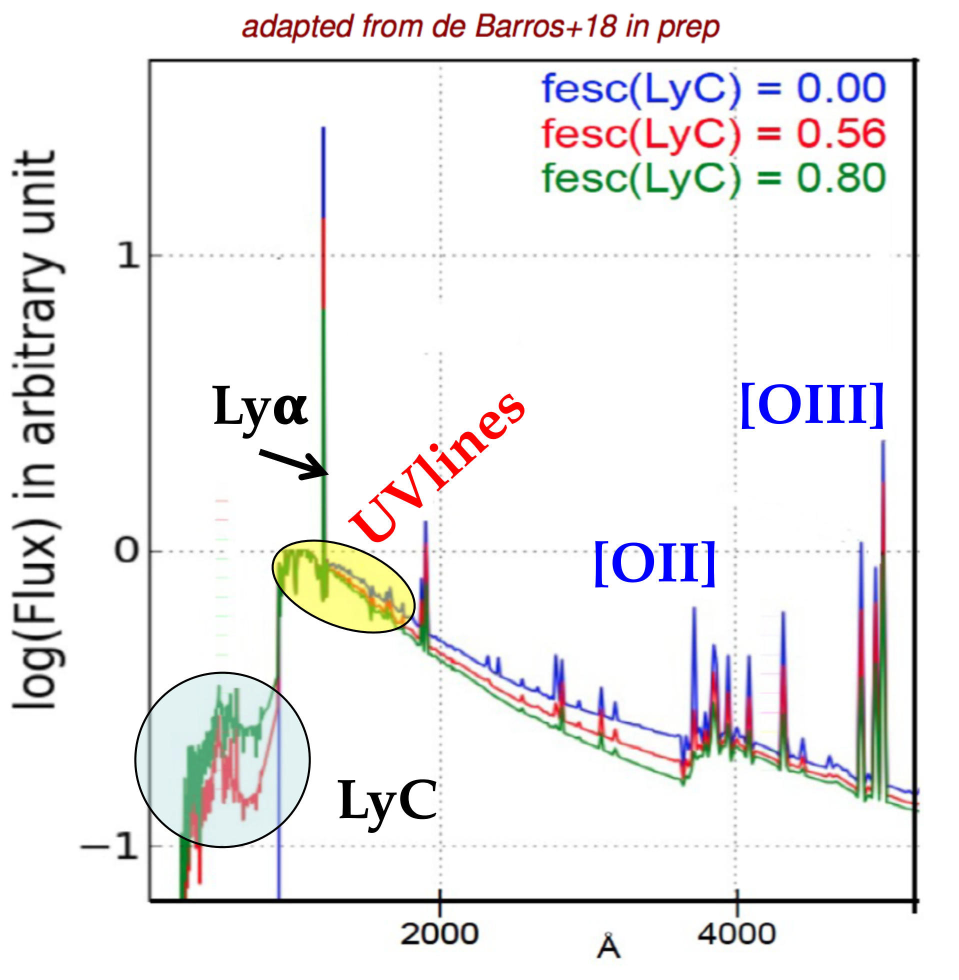
→ Need for ***indirect*** LyC probes !





Inoue+,
Siana+

Signatures of the sources of cosmic reionisation



Indirect LyC probes:

- High [OIII]/[OII] ratio
  Jaskot & Oey 2013, Nakajima+ 2014
- Lyman-alpha emission
  Verhamme+ 2015, Djikstra & Gronke 2016
- UV absorption lines
  e.g. Heckman+ 2011

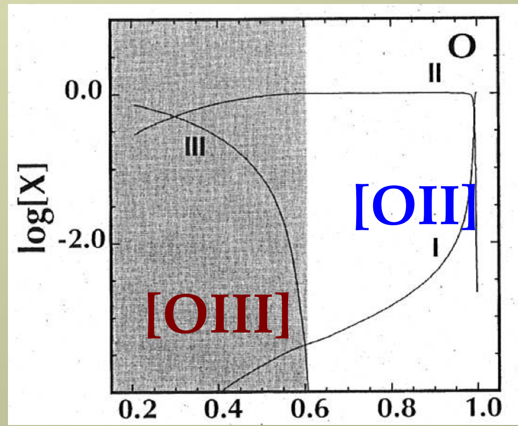
The quest for the sources of cosmic reionisation - a recent breakthrough

COS-HST cycle 22+24 programs: *measure Lyman continuum and test indirect indicators* (Izotov, Schaerer, Verhamme, Thuan, Orlitova, Guseva)

Object selection (from Sloan):

- **High [OIII]/[OII] ratio**
- **Compact SF galaxy – « Green Pea » like**
- z~0.3 and UV-bright for « easy » Lyman-continuum detection with COS

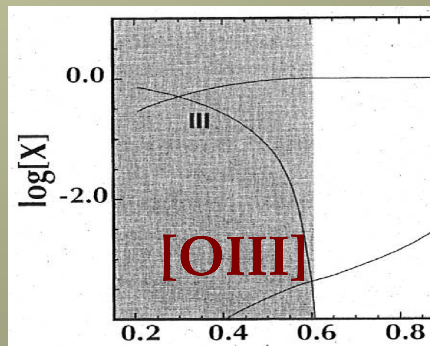
→ 5 galaxies selected



Strömgren radius ↑

G140M, G160M grism observations to cover:

- Lyman continuum
- Lyman alpha
- UV absorption lines

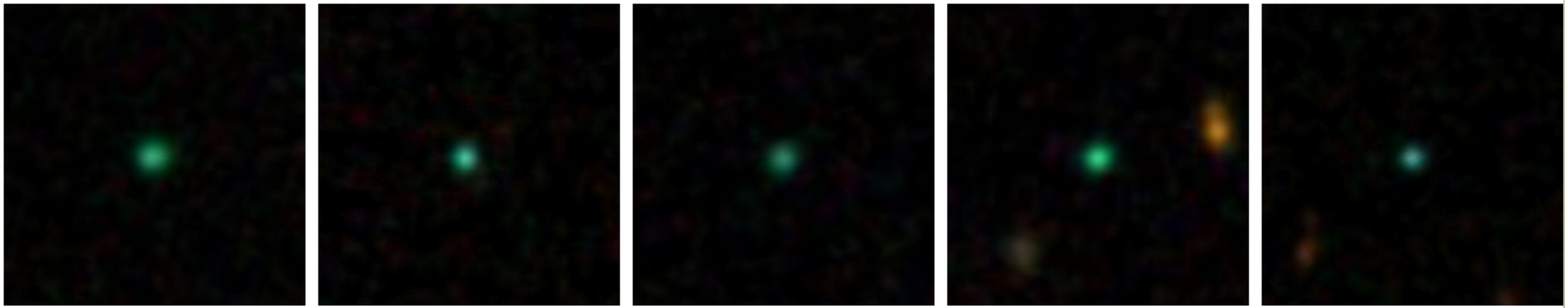


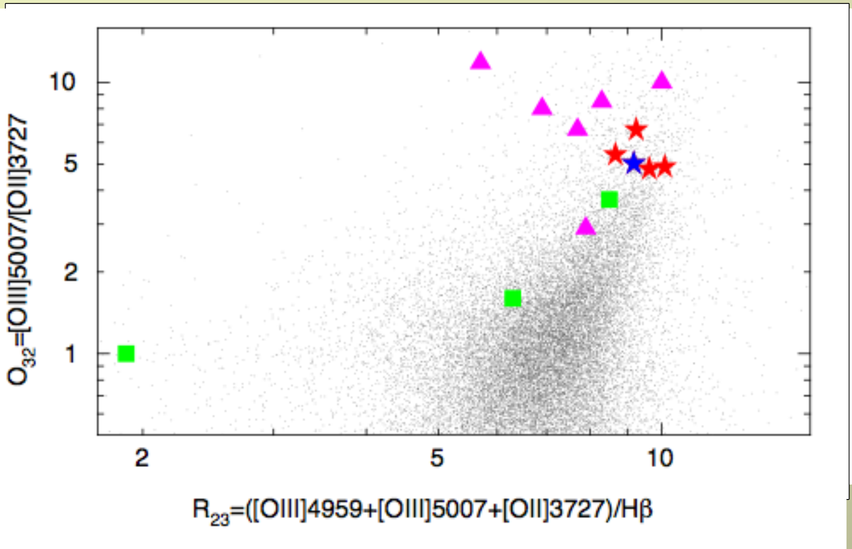
[OII] miss ing

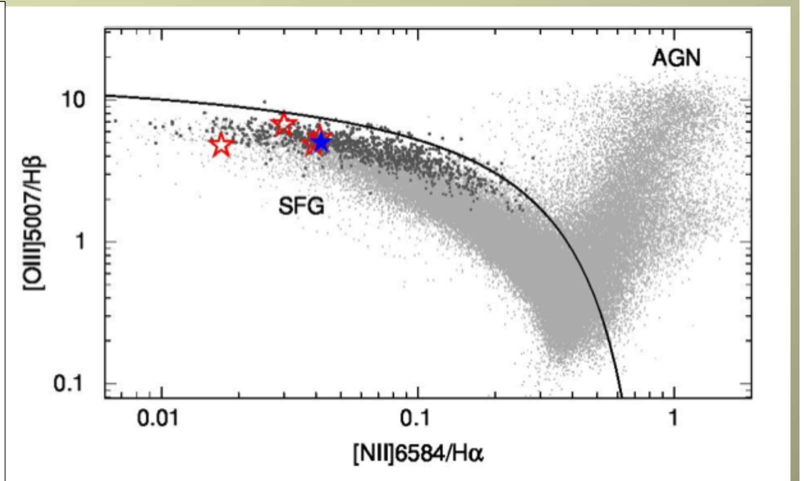
Strömgren radius ↑

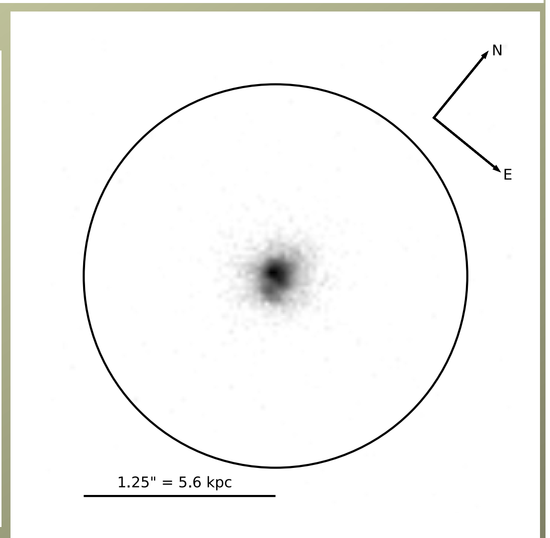
The quest for the sources of cosmic reionisation

Cycle 22 COS-HST program: *measure Lyman continuum and test indirect indicators* (Thuan, Izotov, Orlitova, Verhamme, Schaerer, Guseva)



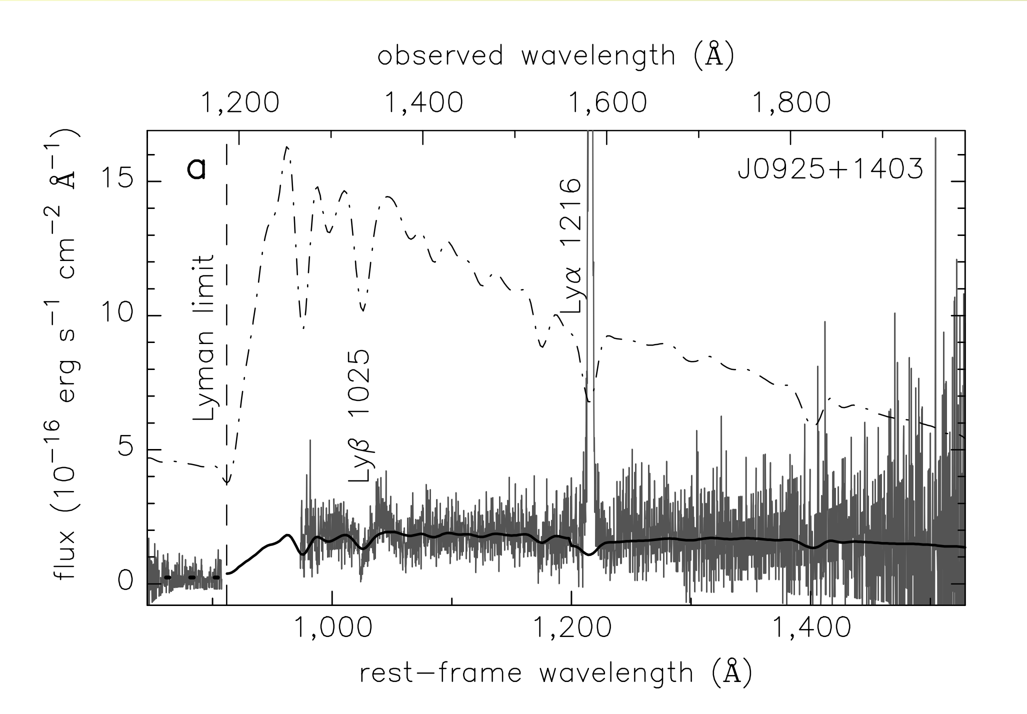


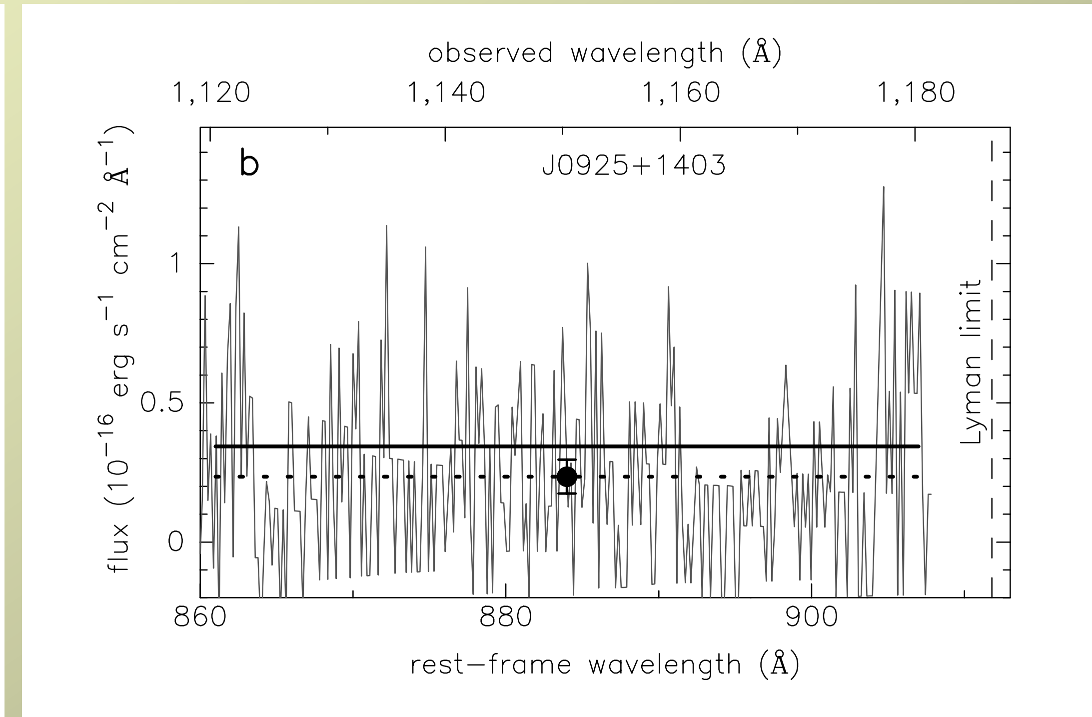




Strong Lyman continuum leakers at z=0.3

Cycle 22 COS-HST program: *measure Lyman continuum and test indirect indicators*
Izotov, Orlitova, Schaerer, Thuan, Verhamme, Guseva, Worseck (2016)





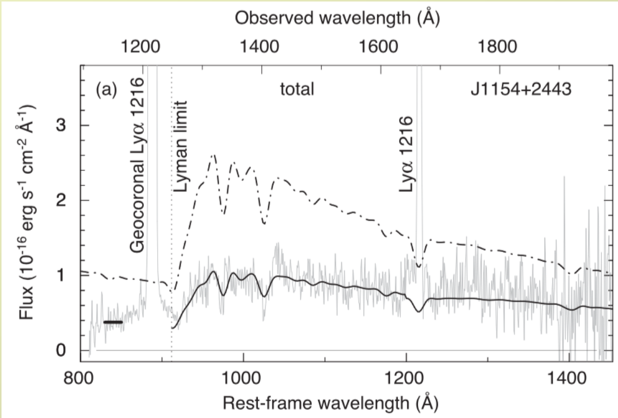
✔ Lyman continuum leakage

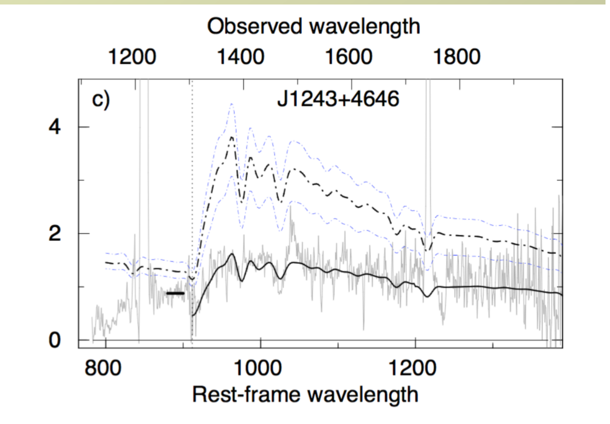
- 11.8 sigma detection $(3.43 \pm 0.29) \times 10^{-17}$ erg s^{-1} cm^{-2} $A^{\circ -1}$
- Absolute **fesc=7.8±1.1** % (highest so far at low redshift)
- ~model-independent fesc determination (from H recombination lines + LyC)

Strong Lyman continuum leakers at z=0.3

Cycle 25 observations:
6 new sources with O32>10
→ Total 11 z~0.3-0.4 galaxies

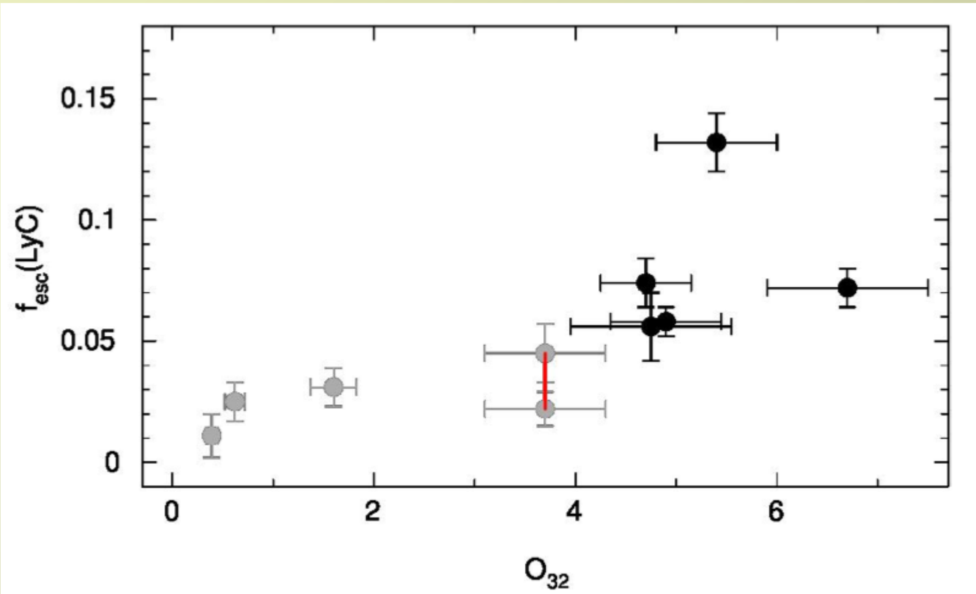
- **100% LyC detection → efficient selection criteria** (O32/>4, compact, strong EL)
- **3 sources with fesc > 40%**
- **Wide range of fesc**

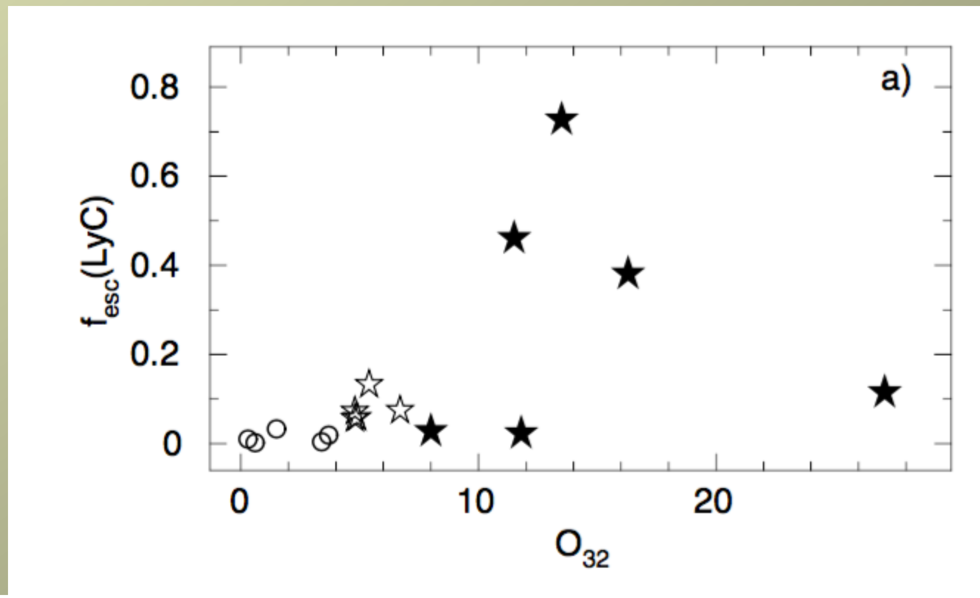




Izotov et al. (2016b)

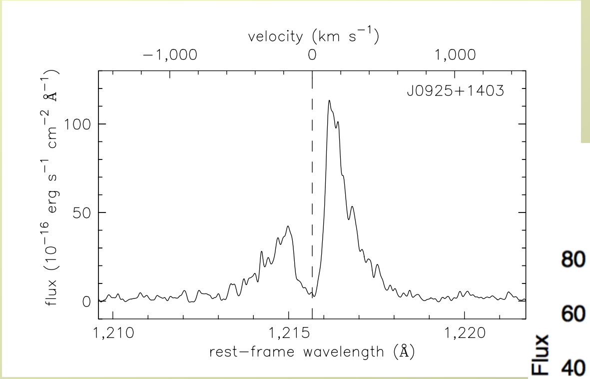
Izotov et al. (2018ab)

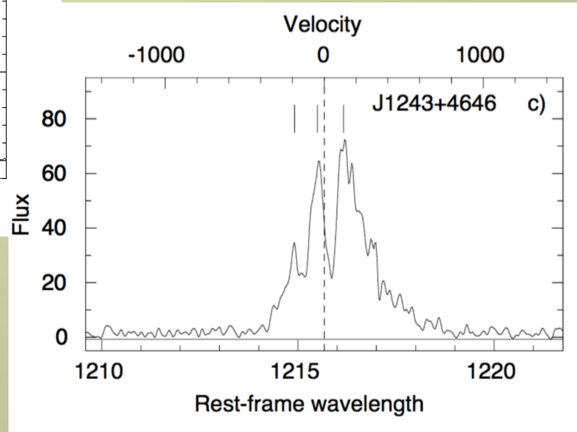




Lyman-alpha properties of Lyman continuum leakers

Verhamme et al. (2017, A&A 597, A13)





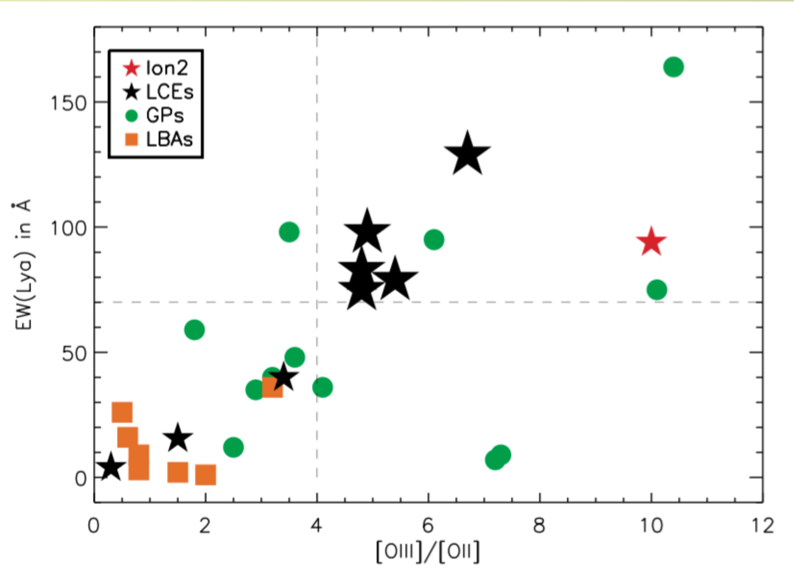
- **Strong Lyα emission (EW>70 Ang)**
- **Double-peaked profiles**
- **Small peak separation**

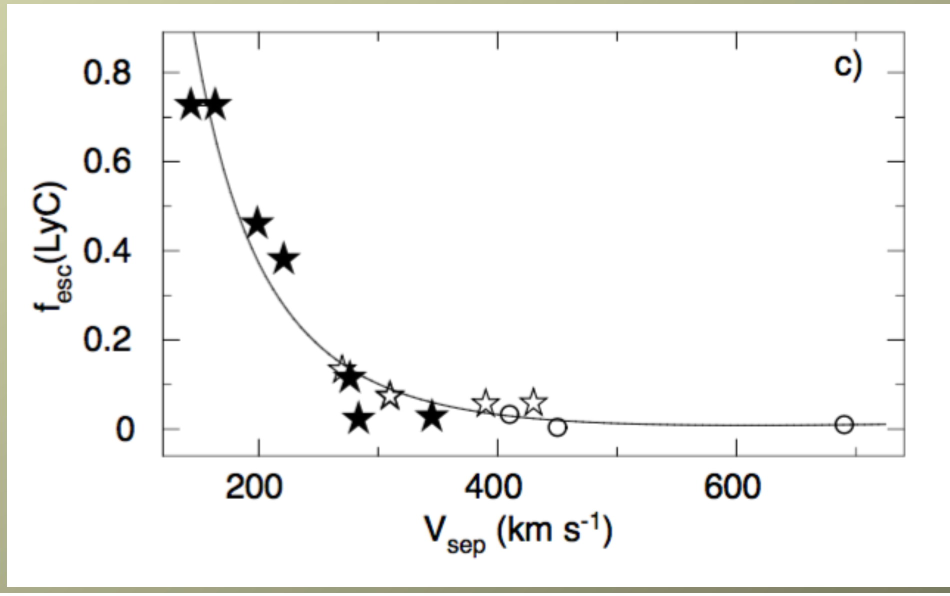
  as predicted by Verhamme et al. (2015)

→ **Intense star formation, low dust content**

→ **Low HI column density**

Izotov et al. (2018)





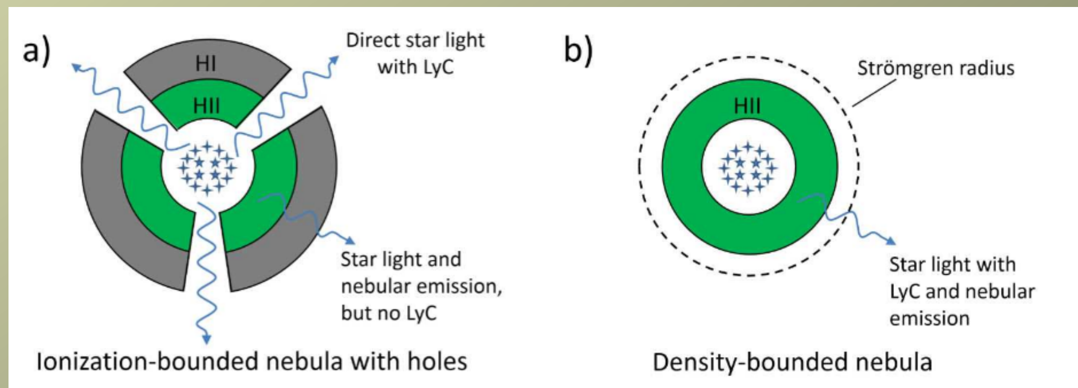
Neutral gas properties of LyC emitting galaxies

Analys of UV absorption lines (Lyman series, and metal lines) of known LyC leakers and comparison sources:

- 9 known LyC leakers (COS spectra, z~0-0.3)
- 6 other star-forming galaxies with COS Lyman-series coverage (z~0.1-0.3)
- High-res (R~3000-4000) rest–UV spectra of lensed galaxies at z~2-3 including 'Cosmic Horseshoe' (MEGASAURA, Rigby+ 2017)

==> Determination of ISM covering fraction, HI and OI column densities

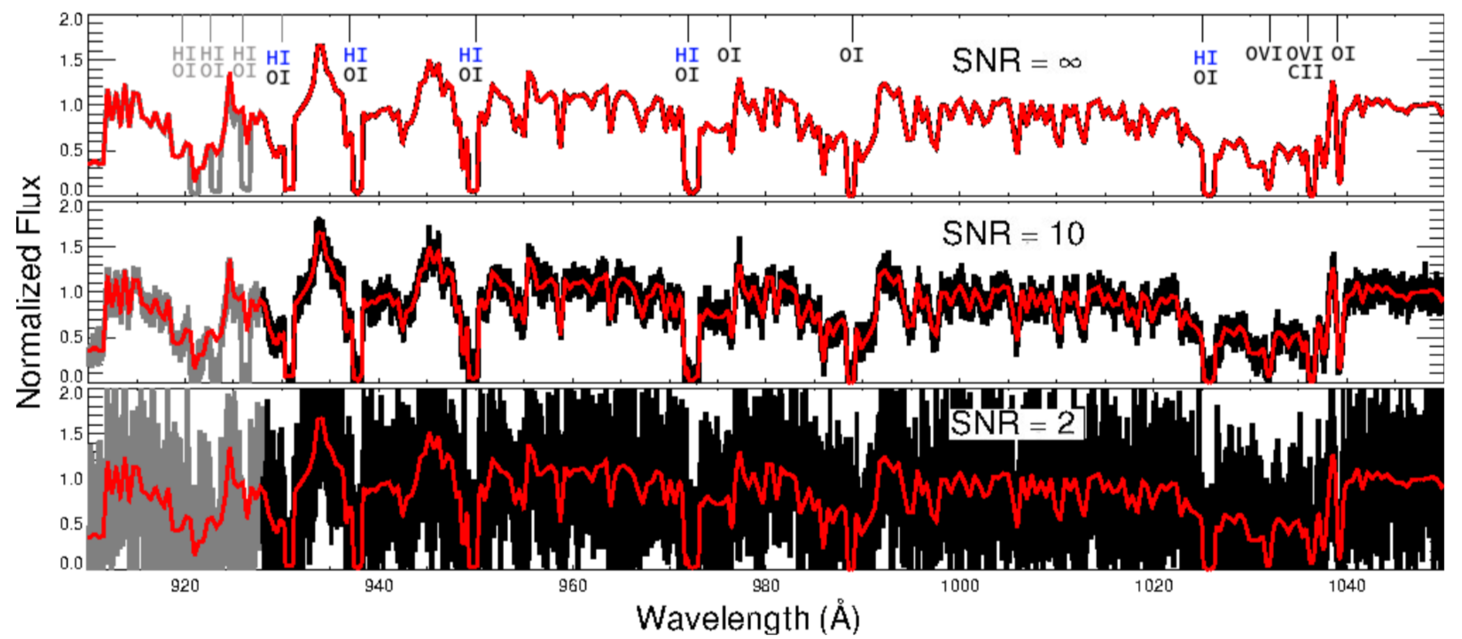
→ Gazagnes et al. (2018), Chisholm et al. (2018)

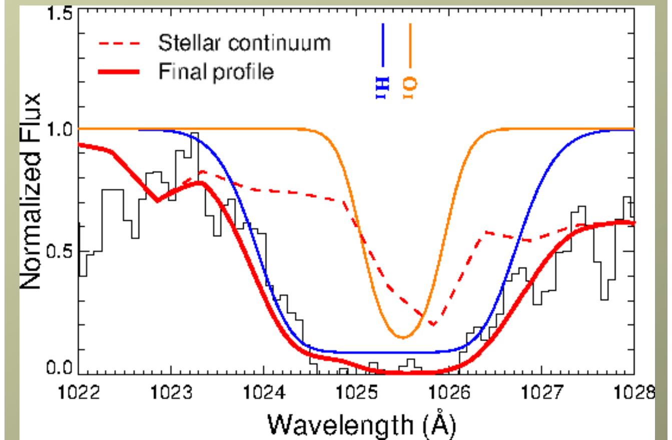


Neutral gas properties of LyC emitting galaxies

UV spectral fitting of:

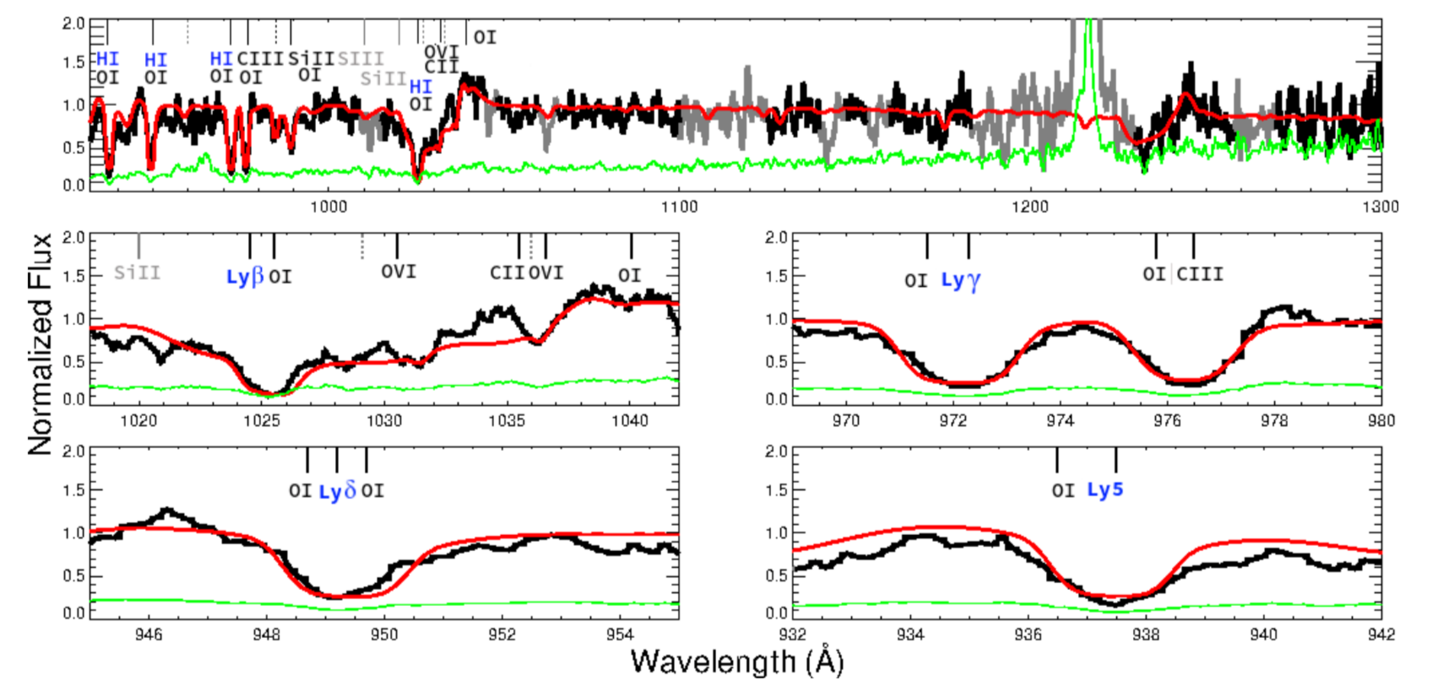
- stellar continuum + lines (theoretical Starburst99)
- UV attenuation (Reddy+ 2017 + other laws)
- ISM absorption lines (HI, OI, OVI, CII, CIII, SiII)





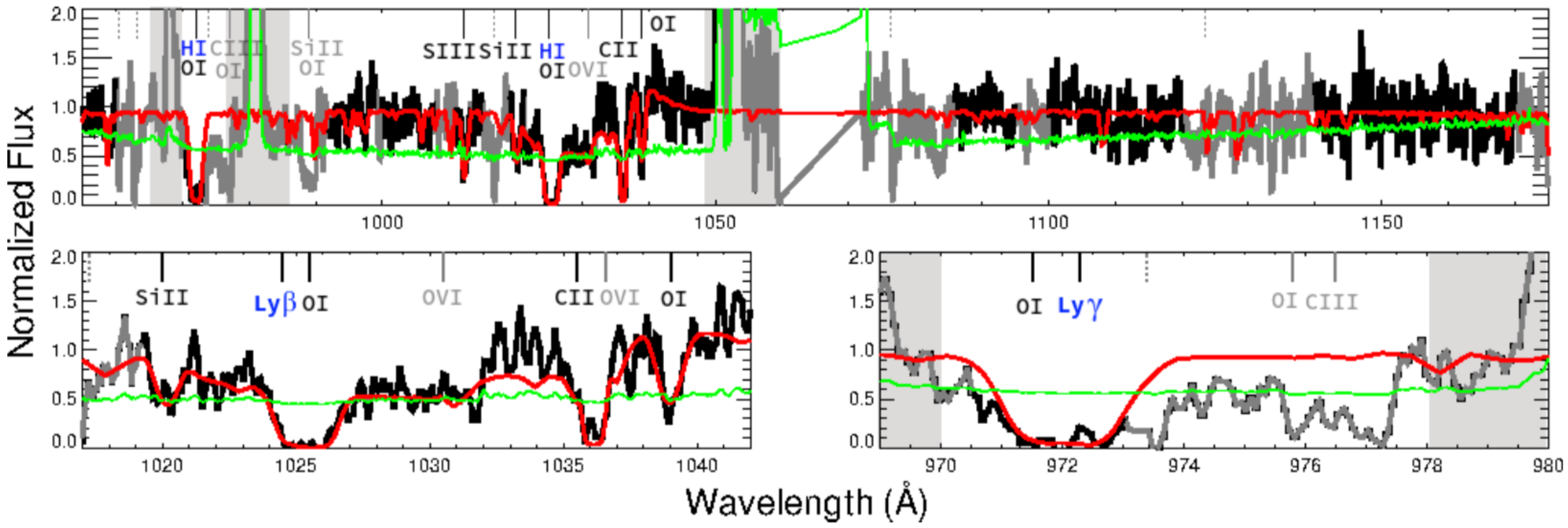
Gazagnes et al. (2018)

Neutral gas properties of LyC emitting galaxies



confirmed leaker
J1503+3644
(Izotov+ 2016)

GP 1244+0216
(Henry+ 2015)

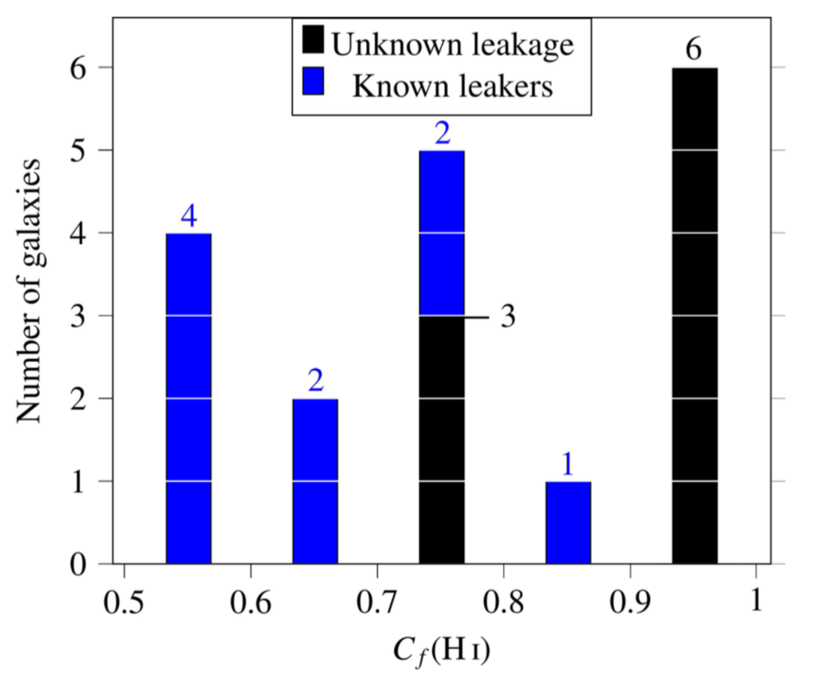


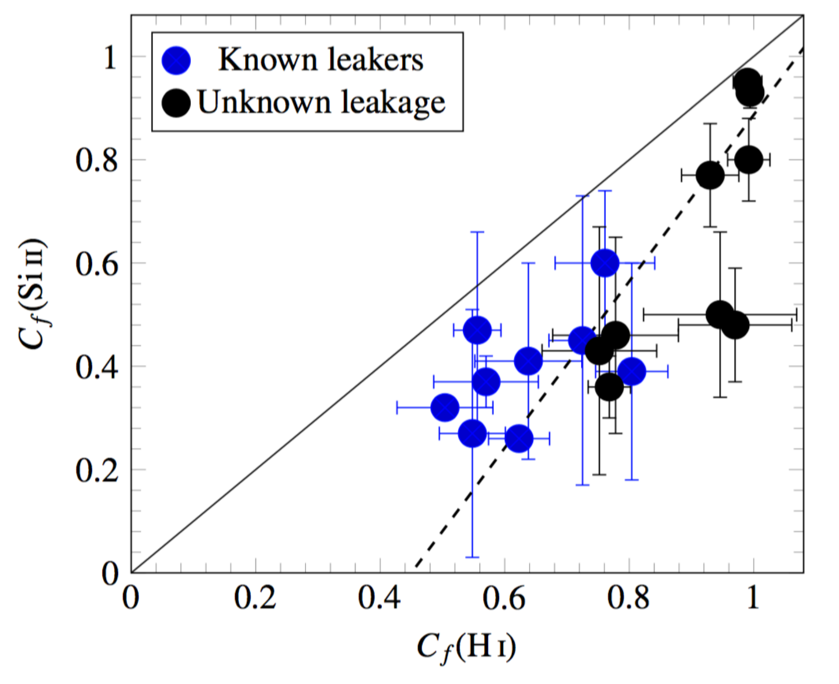
Gazagnes
et al.
(2018)

Neutral gas properties of LyC emitting galaxies

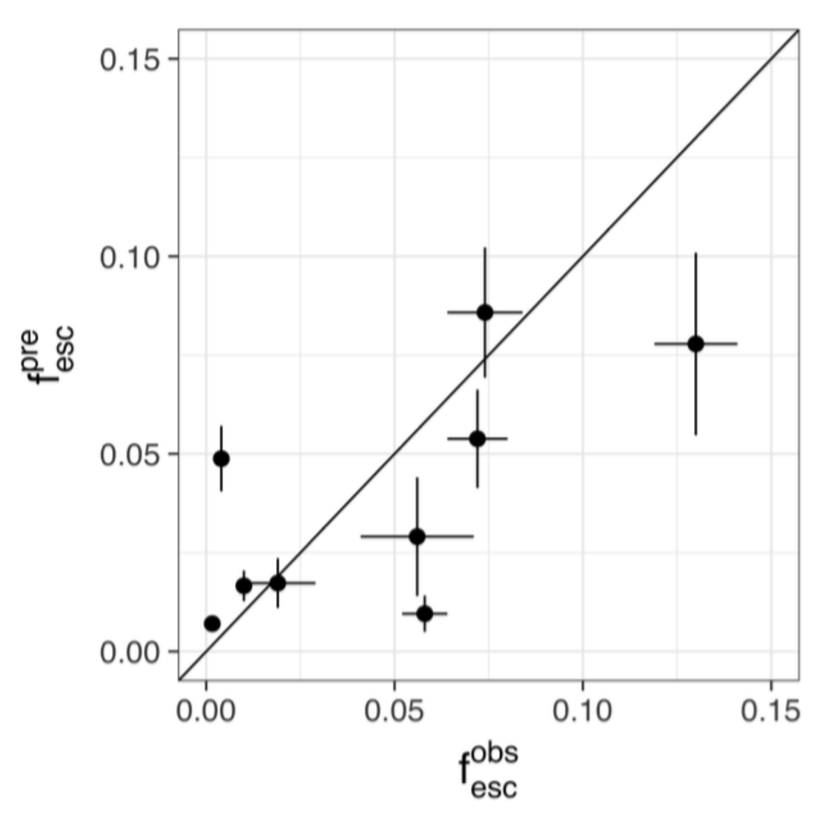
Main results (Gazagnes et al. 2018):

- **HI lines are saturated** (but mostly not damped; $N_{HI} \sim 10^{16}$ to 10^{20} cm^{-2})
  N(HI) values from unsatured OI lines (using known metallicity O/H)
- LyC leakers have covering fraction < 1
  → **escape of photons through holes**
- SiII 1190, 1260 Å covering fraction is lower than HI C_f
  → empirical relation between SiII and HI

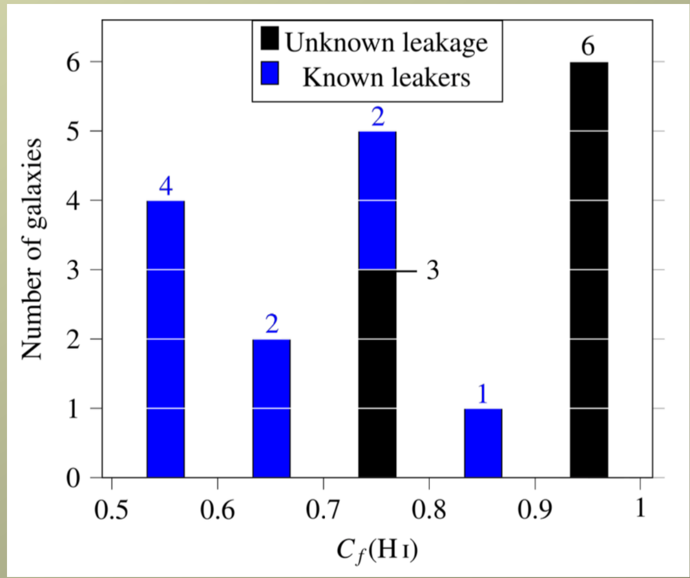




Predicting ionizing photon escape from UV absorption lines (+UV modeling!)



- Measured HI covering fraction
  → **good agreement with observed LyC escape fraction**
- UV attenuation fundamental for accurate fesc prediction (consistent modeling!)



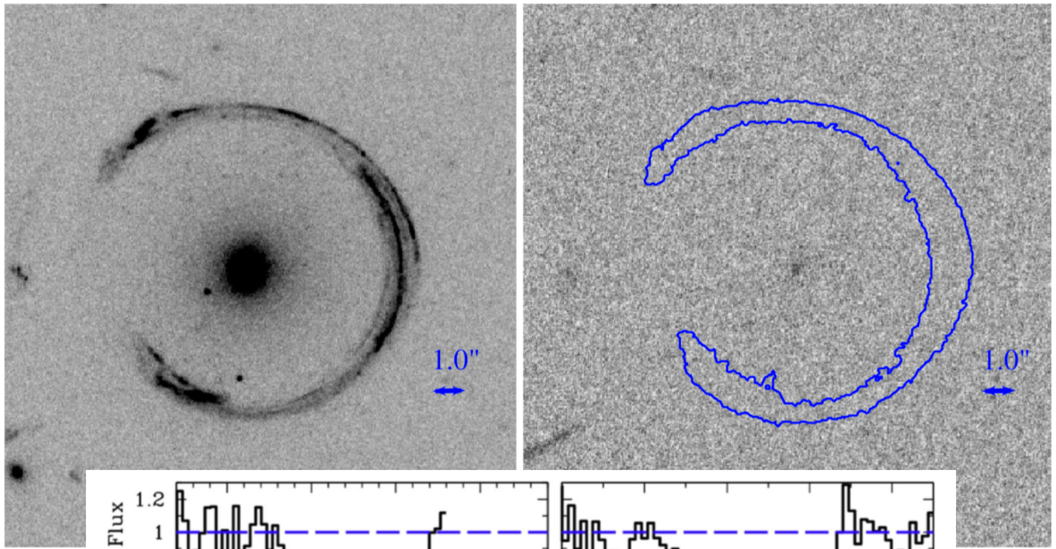
$$f_{\rm esc}^{\rm pre} = 10^{-0.4{\rm E}_{B-V}k_{912}} \times \left(1 - C_f^{\rm H}\right)$$

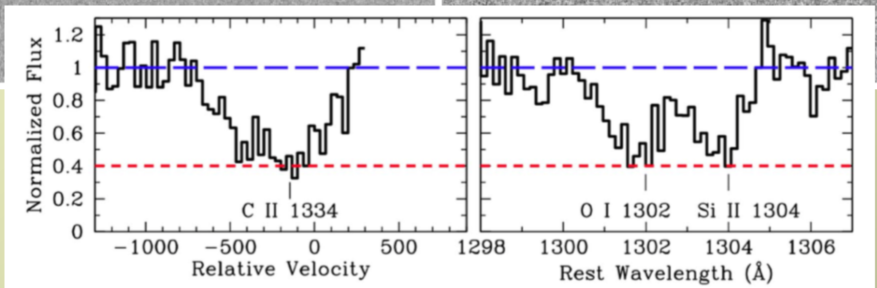
Chisholm et al. (2018)

Predicting ionizing photon escape from UV absorption lines (+UV modeling!)

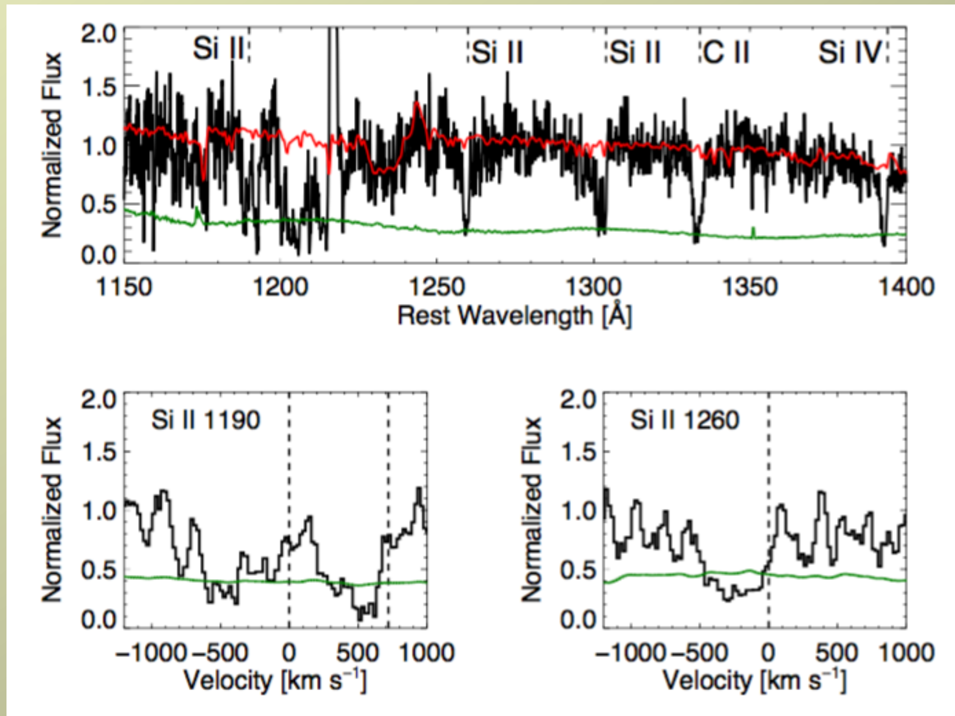
→ **UV absorption lines – Lyman series and SiII 1190, 1260 Å – can be used to infer LyC escape fraction indirectly**

The Cosmic Horseshoe (z=2.3812)



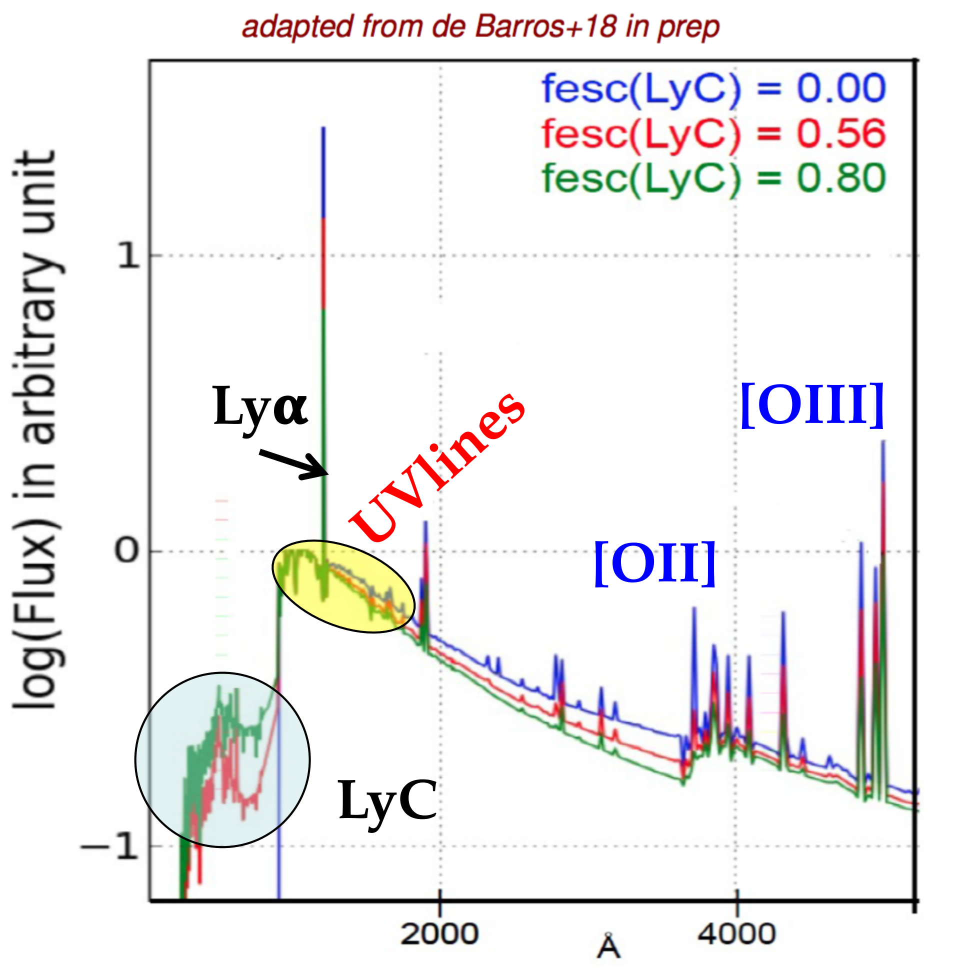


Vasei et al. (2016), Quider et al. (2009):
→ **Observed fesc,abs < 0.02**



Chisholm et al. (2018):
SiII covering fraction = 0.77
E(B-V)=0.16
→ **Predicted fesc = 0.009 +-0.003**

Signatures of the sources of cosmic reionisation

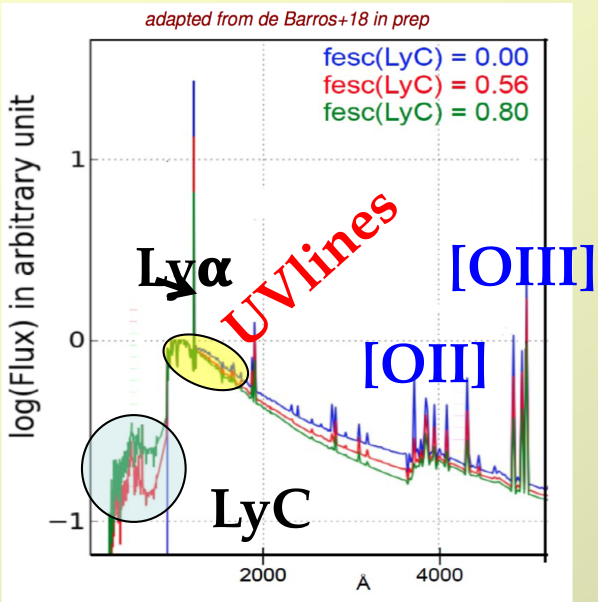


Indirect LyC probes:

- ✓ High [OIII]/[OII] ratio
  Jaskot & Oey 2013, Nakajima+ 2014
- ✓ Lyman-alpha emission
  Verhamme+ 2015, Djikstra & Gronke 2016
- ✓ UV absorption lines
  e.g. Heckman+ 2011, Chisholm+ 2018

→ Diagnostics validated for JWST + ELTs!!

Signatures of the sources of cosmic reionisation



→ HST Large Program (Jaskot) – LyC exploration

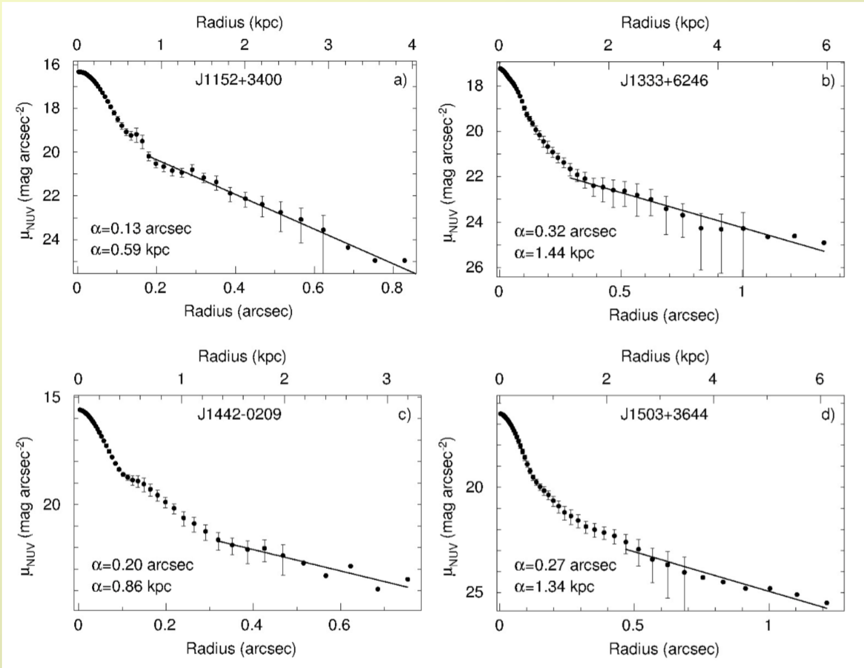
→ LyC from very low mass galaxies ? Izotov+

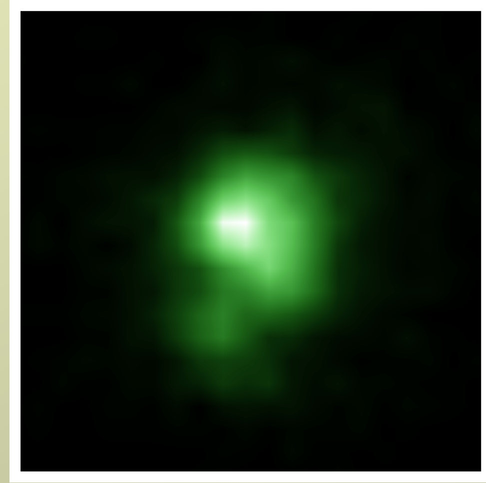
Other indicators ?

- fesc(Lya) – fesc(LyC) connection
- MgII 2800 Å (Henry+ 2018, Chisholm+)
- [SII] deficiency (Wang, Heckman+ 2019)
- Weaker CIII] 1909Å ?
  (Jaskot & Ravindranath 2016, Schaerer+ 2019)

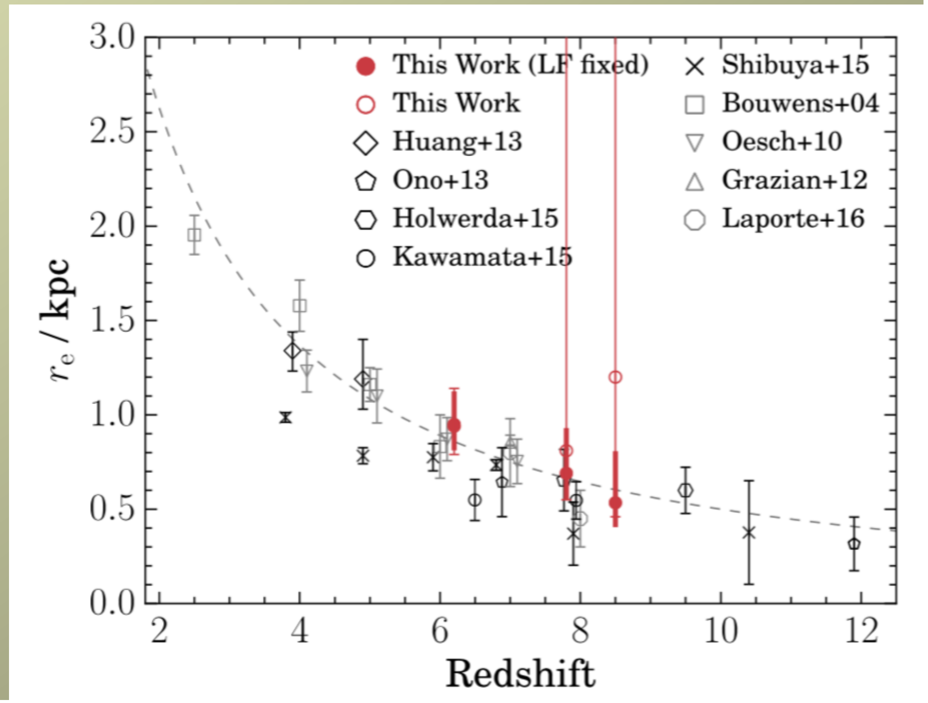
Properties of strong LyC leakers at z=0.3

Compact SF galaxies – « Green Pea » like





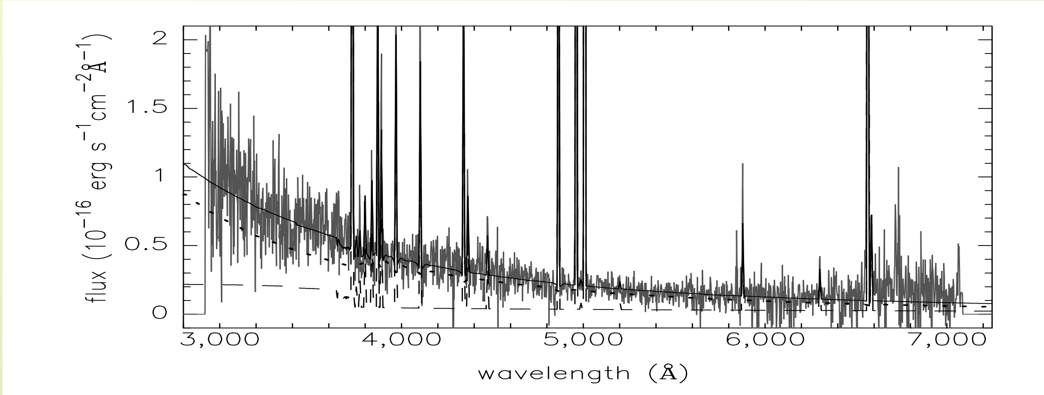
UV half-light radii <0.4 kpc

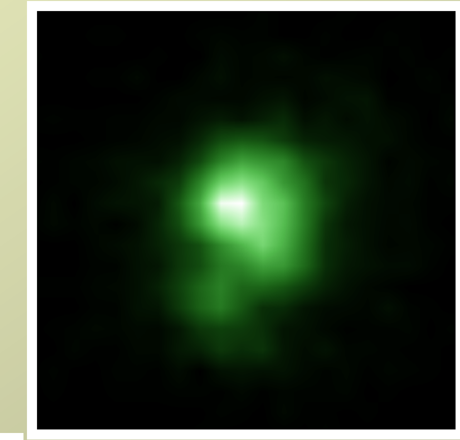


Kawamata et al. 2018

Properties of strong LyC leakers at z=0.3

J0925+1403
other properties

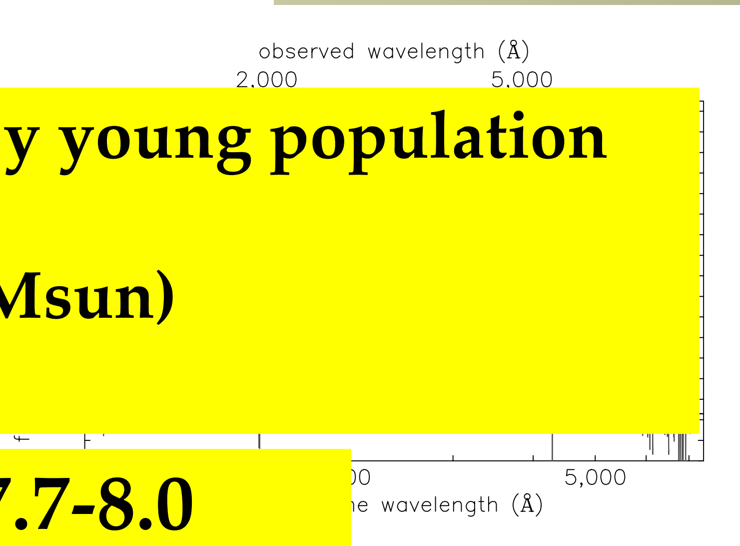




Extended Data Table 3 | Global characteristics of J0925+1403

Parameter	Value
$I_{H\beta}$†	
Redshi	
Lumino	
$L_{H\beta}$††	
SFR‡‡	
Q_H*	
Q_H(esc)	
t(burst)	
$M_y/M_\odot$	
$M_*/M_\odot$	

†Extinction-corrected flux densit
‡In units of Mpc.
††Extinction- and aperture-corre
‡‡Star-formation rate in $M_\odot$ yr^{-1} derived from the Hβ luminosity
*Q_H and Q_H(esc) are the number
**Burst age in Myr.



- **UV-optical spectrum dominated by young population (3-5 Myr)**
- **Low stellar masses (median ~10^9 Msun)**
- **High SFR (~14-40 Msun/yr)**

Metallicity 12+log(O/H)~7.7-8.0
~(0.12-0.25) solar

Low extinction: A_V~0.18-0.36

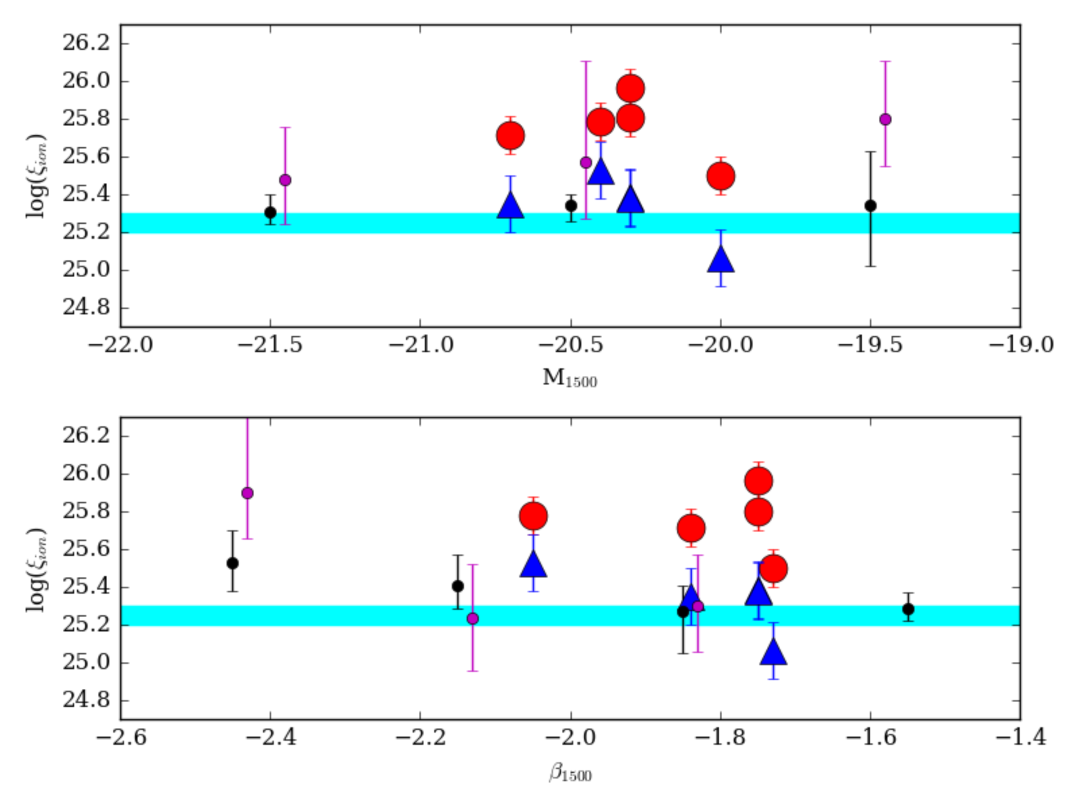
Lyman continuum leakers at z=0.3: Ionising photon production

Direct measure of ξ_{ion} :

→ **Factor ~2-5 times more ionizing photons produced** ***per unit UV luminosity than commonly assumed***

→ ***Intrinsic*** ξ_{ion} – corrected for extinction – is ~(1-2) times « standard » value

Best analogs for sources of cosmic reionisation



Schaerer et al. (2016)

LyC leakers at z=0.3: comparison with high-z galaxies

→ Schaerer et al. (2016, A&A 591, L8)

Best ***high-z*** *Lyman continuum source:*

z=3.218 galaxy « Ion2 »in GOODS-S/Candels

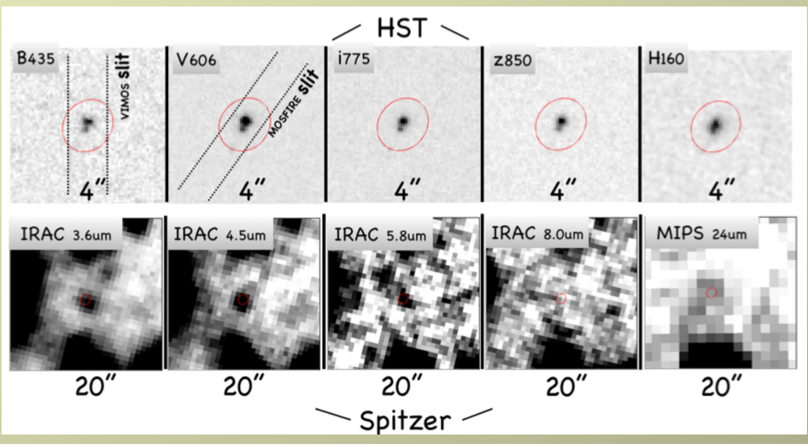
UV rest-frame mag_AB~24.5-25

→ Low metallicity (1/6 $Z_{\odot}$), ~low mass (1.6 10^{9} $M_{\odot}$)

→ Strong Lya emission

→ **High ratio [OIII]/[OII]>10, high [OIII]+Hb equivalent width (~1600 Ang)**

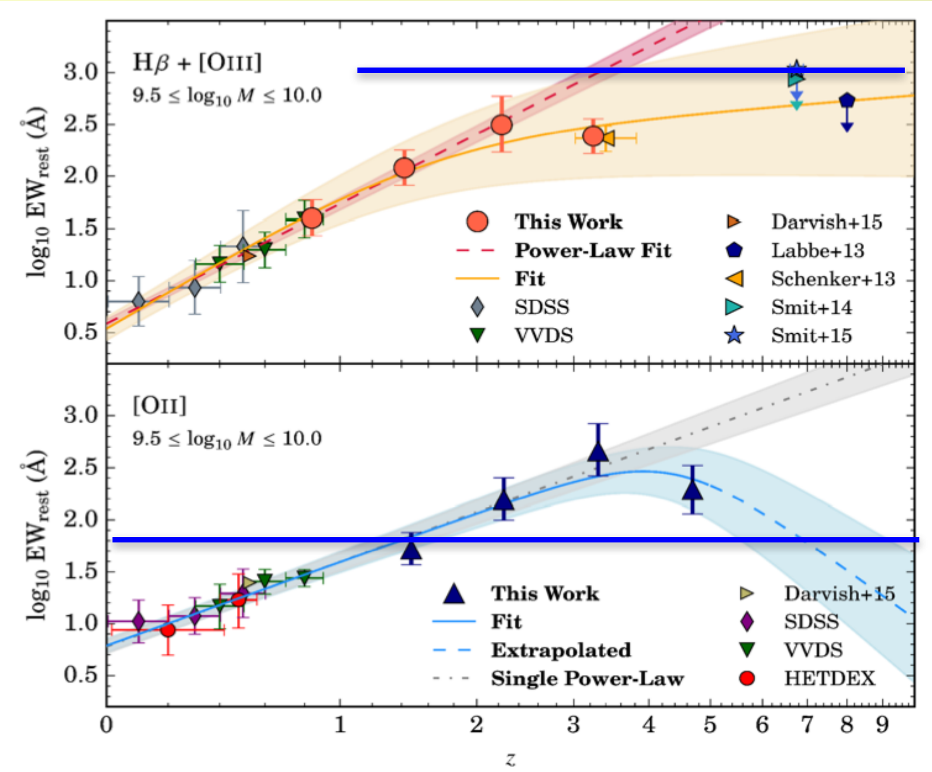
Vanzella et al. (2015), de Barros et al. (2016)



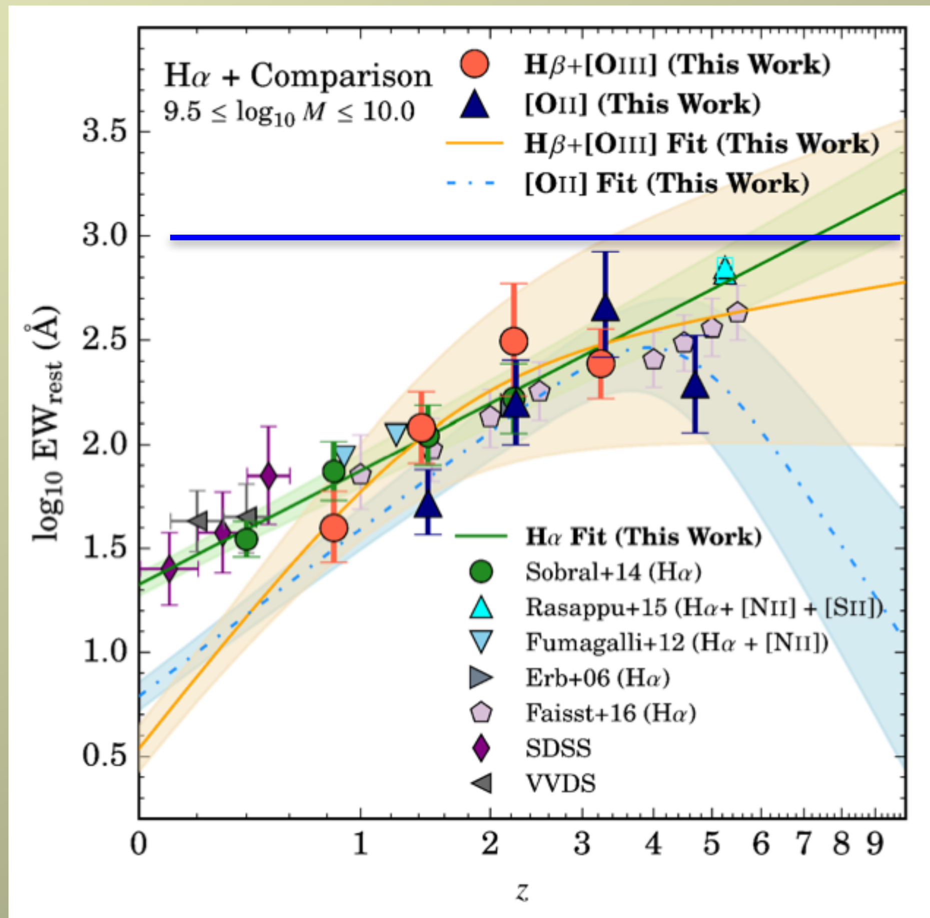
EL ratios, equivalent widths, stellar mass of our z~0.3 LyC leakers:

→ Comparable to Ion2

Strong Lyman continuum leakers at z~0.3
Comparison with high-z galaxies



Khostovan et al. (2016)



Properties of **rare** z~0.3 leakers are comparable to **typical** z~7 galaxies
→ Best local analogs

EW, stellar mass, size, SFR, SFR/area
…high gas density

Conclusions

- **New insight into the ionizing SED of star-forming galaxies**
  - Hard ionizing spectra of star-forming galaxies: HMXB/ULX provide a natural solution to the long-standing HeII problem
- **Spectral diagnostics for sources of cosmic reionization (Lyman continuum emitters)**
  - 3 or more indirect diagnostics validated

→ **New tools for the interpretation of Big Eyes observations**

Key insight from «low-z » galaxies on our understanding of the most distant galaxies