The MUSE Hubble Ultra Deep Field

R. Bacon
CRAL

LAM
Marseille, Sep 8 2017

CRAL
CENTRE DE RECHERCHE ASTROPHYSIQUE DE LYON

erc
European Research Council
Established by the European Commission

muse
multi unit spectroscopic explorer

The HDFS precursor

Hubble Ultra Deep Field

Survey description, data reduction

Spectroscopic redshifts

Photometric redshifts

Lyα luminosity function

Lyα equivalent widths

Properties of CIII] emitters

Spatially resolved kinematics

Fe II Emission in Star-Forming Galaxies

Evolution of the galaxy merger rate

Extended Lyα haloes

ESO

NOVA

ETH

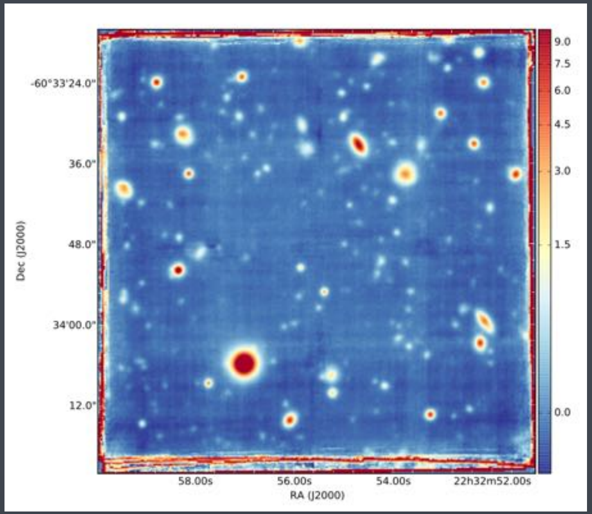
CRAL

AIP

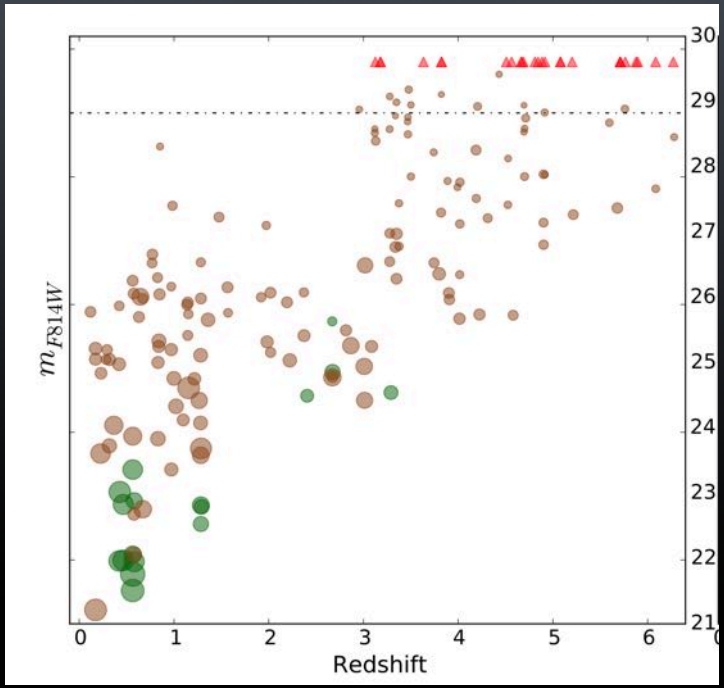
Institut für Astrophysik Göttingen

irap
astrophysique & planétologie

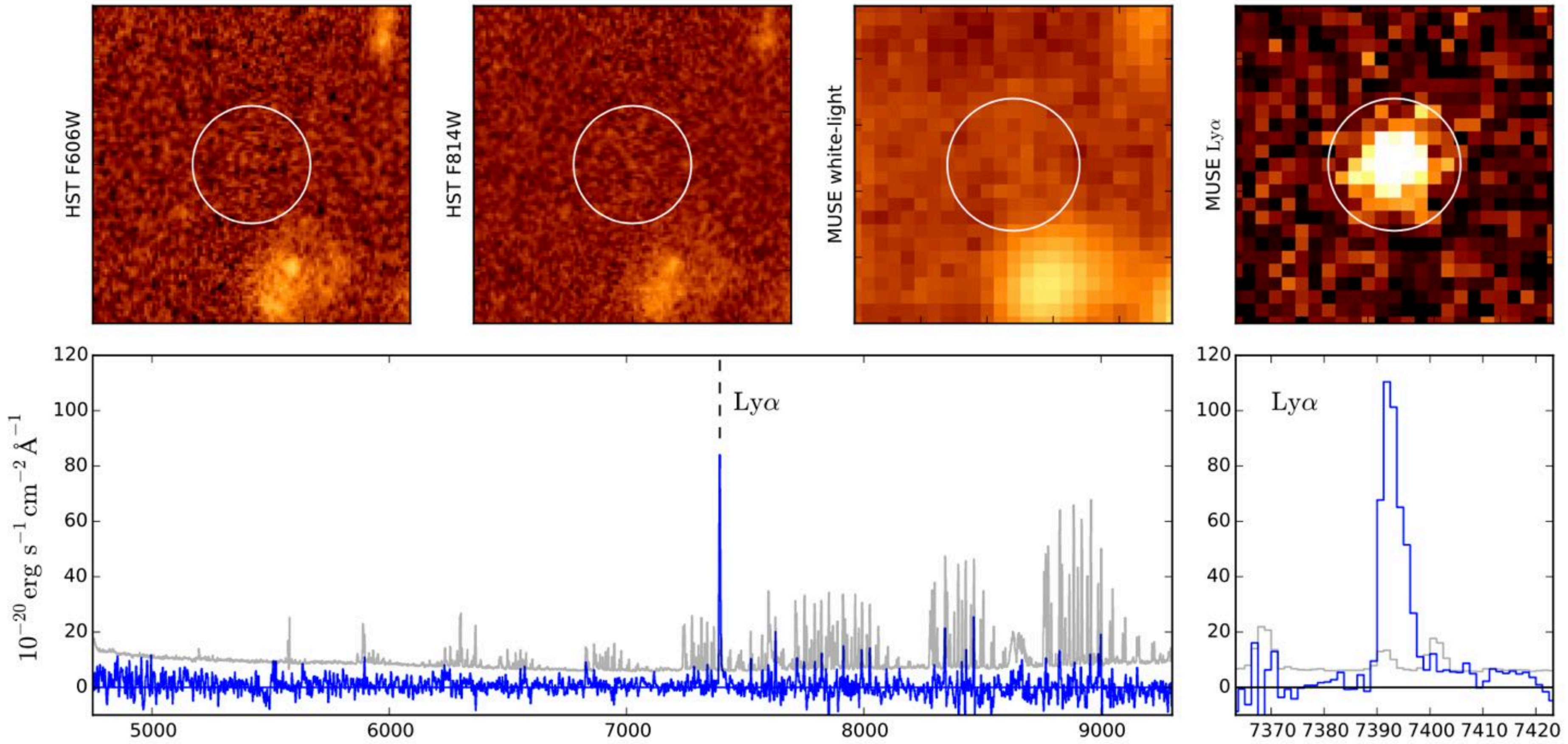
MUSE Hubble Deep Field South observations



- 27 hours observation performed during commissioning (Aug 2014)
- 189 spectroscopic redshifts (x10)
- 26 Lya emitters with no HST counterpart



Bacon et al 2015



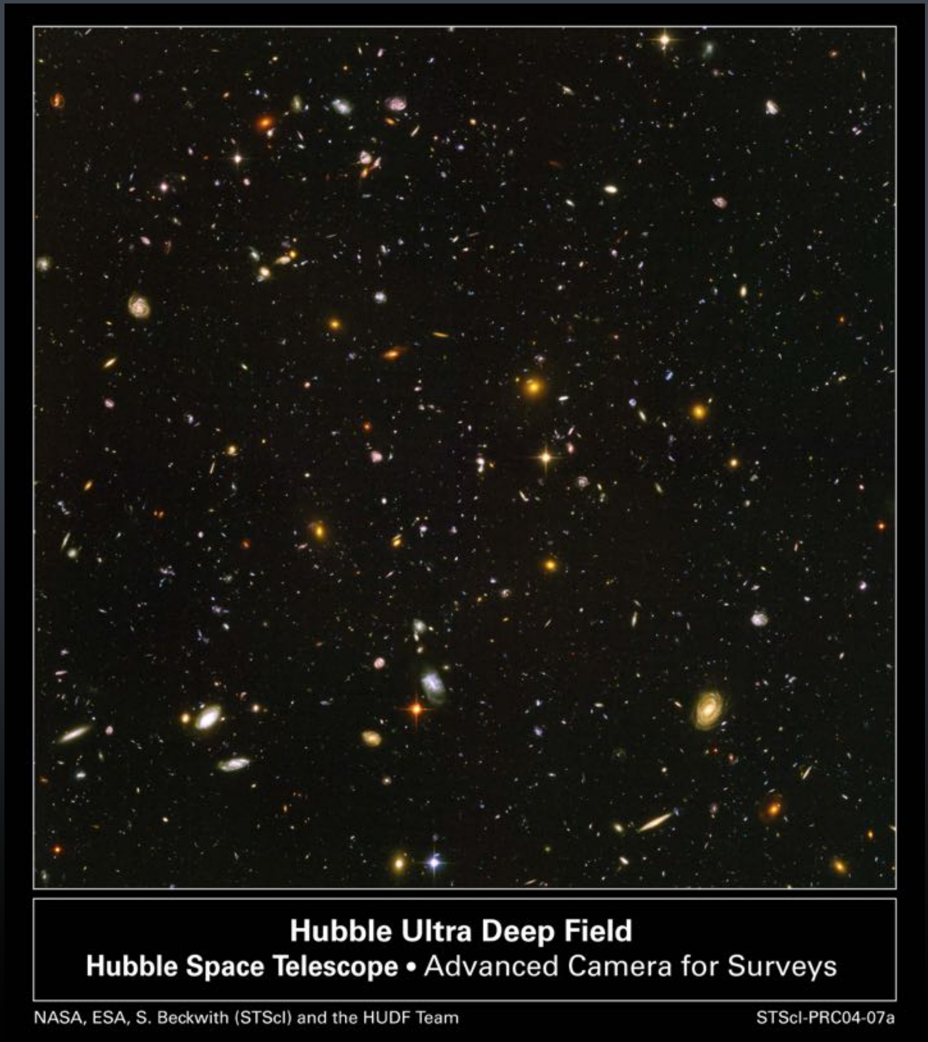
Bacon et al 2015

HDFS results

- Wisotzki et al. 2016: discovery of extended Lyα halos in the circumgalactic medium around high redshift galaxies
- Contini et al. 2016: study of gas kinematics
- Drake et al. 2017: the Lyα luminosity function
- Carton et al. 2017: measurement of metallicity gradients
- Finley et al. 2017: the property of galactic winds at high z.

The Hubble Ultra Deep Field

- 2003, ACS 10^6 s exposure, Beckwith et al 2006
- ACS FUV & WFC3 NIR, (Bouwens et al 2011, Ellis et al 2013)
- Chandra, XMM, ALMA, Spitzer, VLA
- Reference deep field

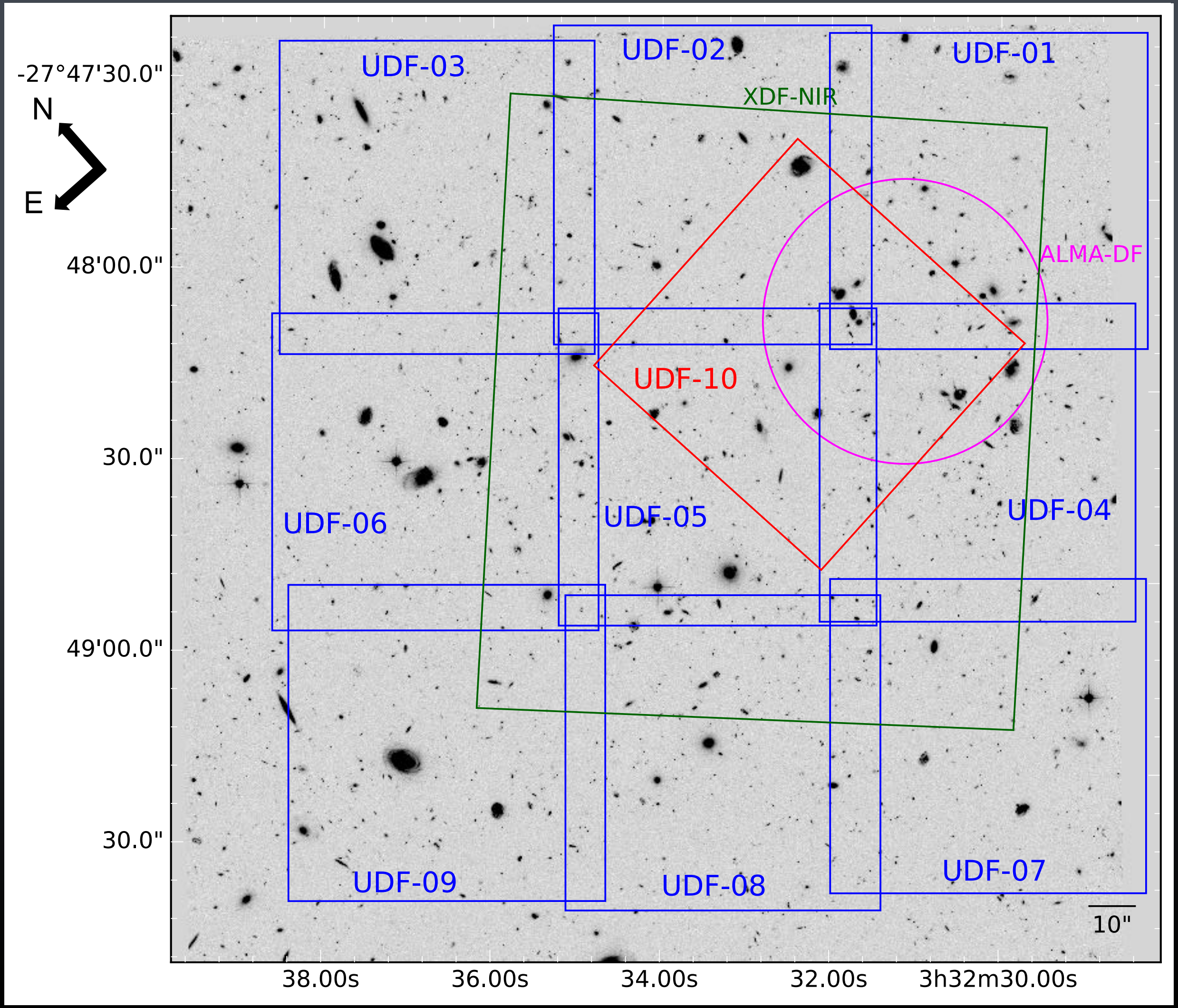


Survey description, data reduction and source detection Roland Bacon et al

- 9 GTO runs 2014-2016
- 137 hours of telescope time, 116 hours of open shutter time (86% efficiency)
- 278 x 25 mn exposures in dark time & good seeing ~0.8”

Paper I: Bacon et al 2017

Mosaic and UDF-10 fields



Paper I: Bacon et al 2017

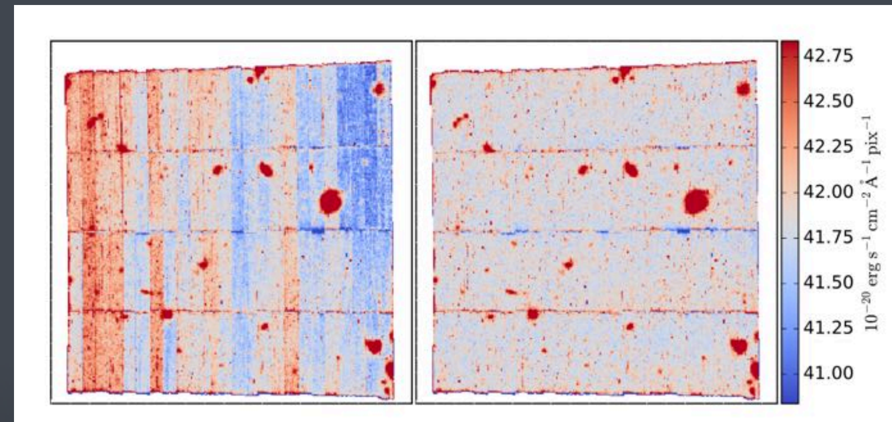
Workflow

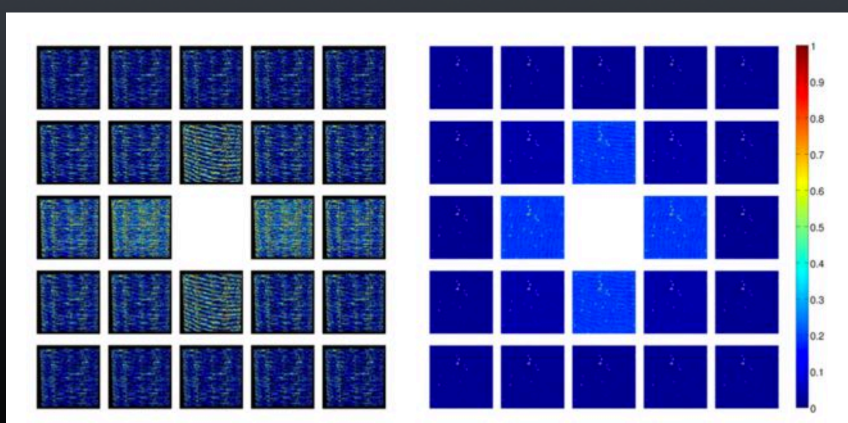
- Advanced data reduction
- Source Detection
  - HST Prior
  - ORIGIN emission line source detection software
- Source Extraction
  - Optimal extraction
- Redshift assessment
  - Muse-Marz tool
- Emission Line fitting
  - Platefit + Complex Fit for Lya
- Catalog and source production
- Analysis

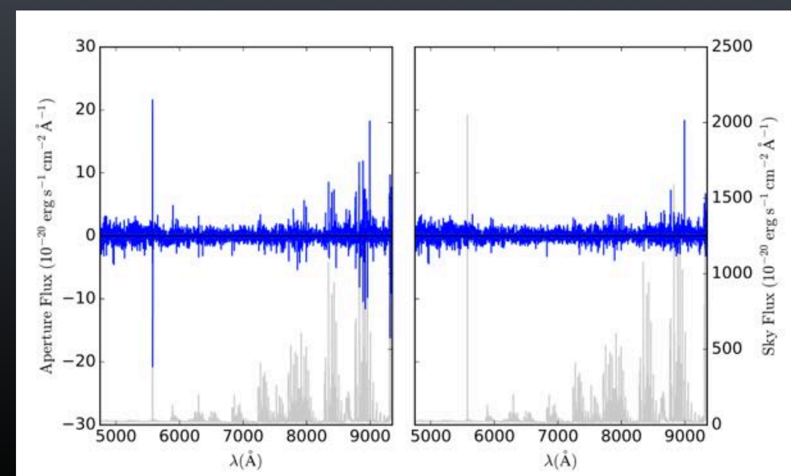
Improved data reduction

Simon Conseil (CRAL)

- Self calibration
- Inter-stack masking
- Sky subtraction
- Variance estimation and propagation
- Sky transparency correction
- PSF estimation



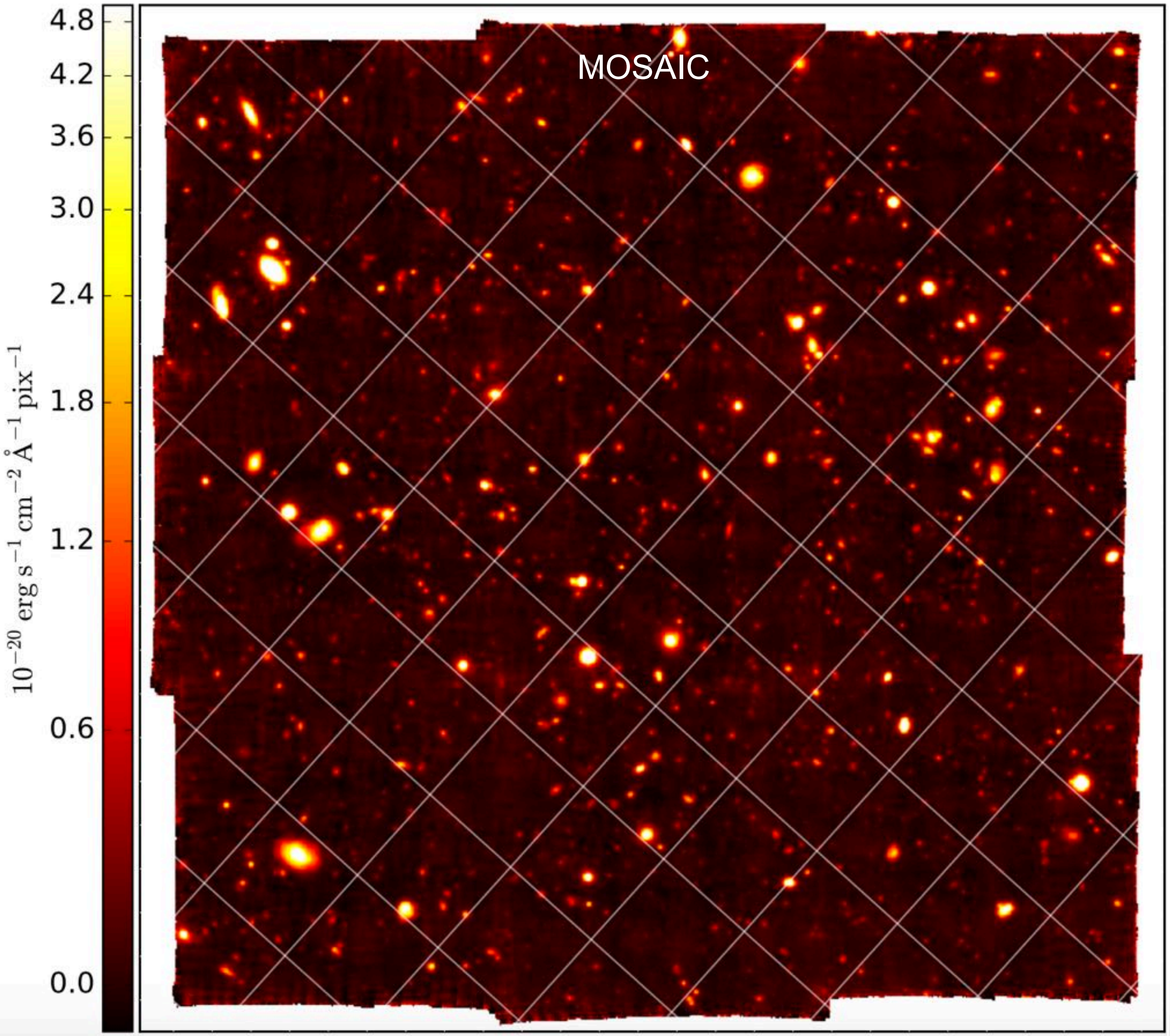


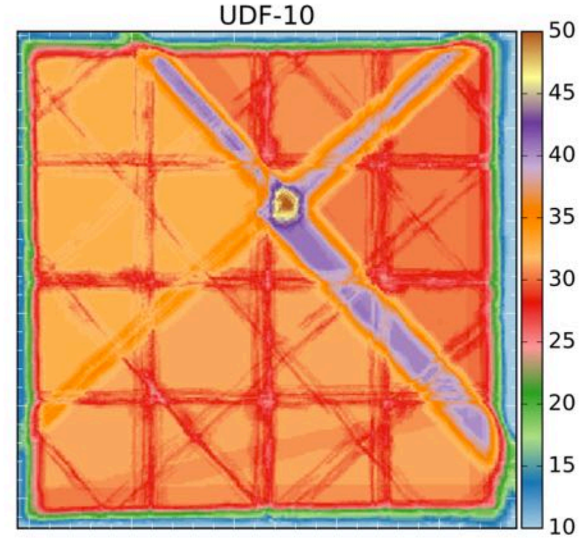


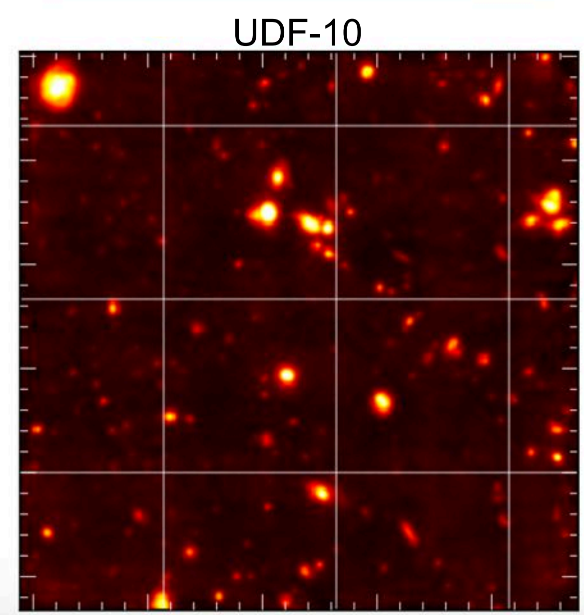
Paper I: Bacon et al 2017

White Light Images

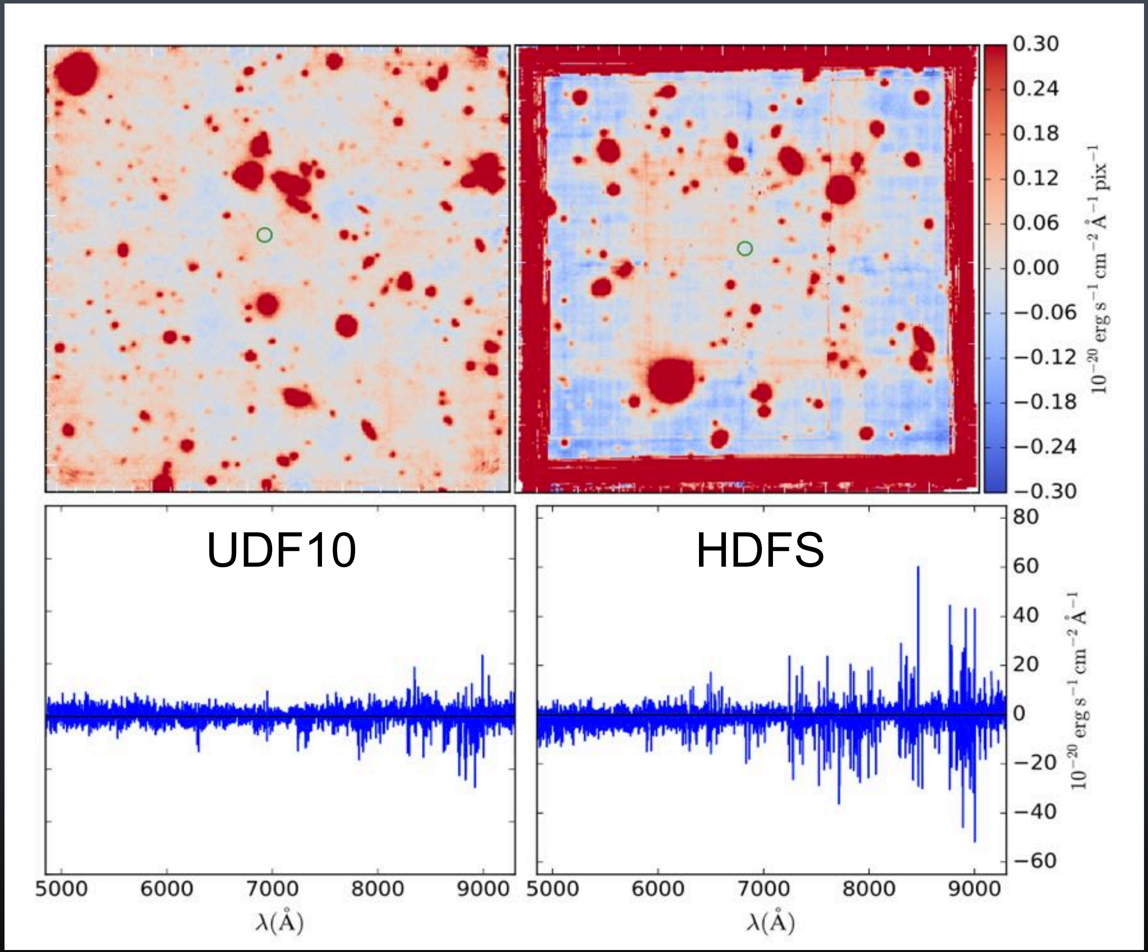
Paper I: Bacon et al 2017







UDF10 – HDFS Comparison



<u>1 σ surface brightness sensitivity:</u>

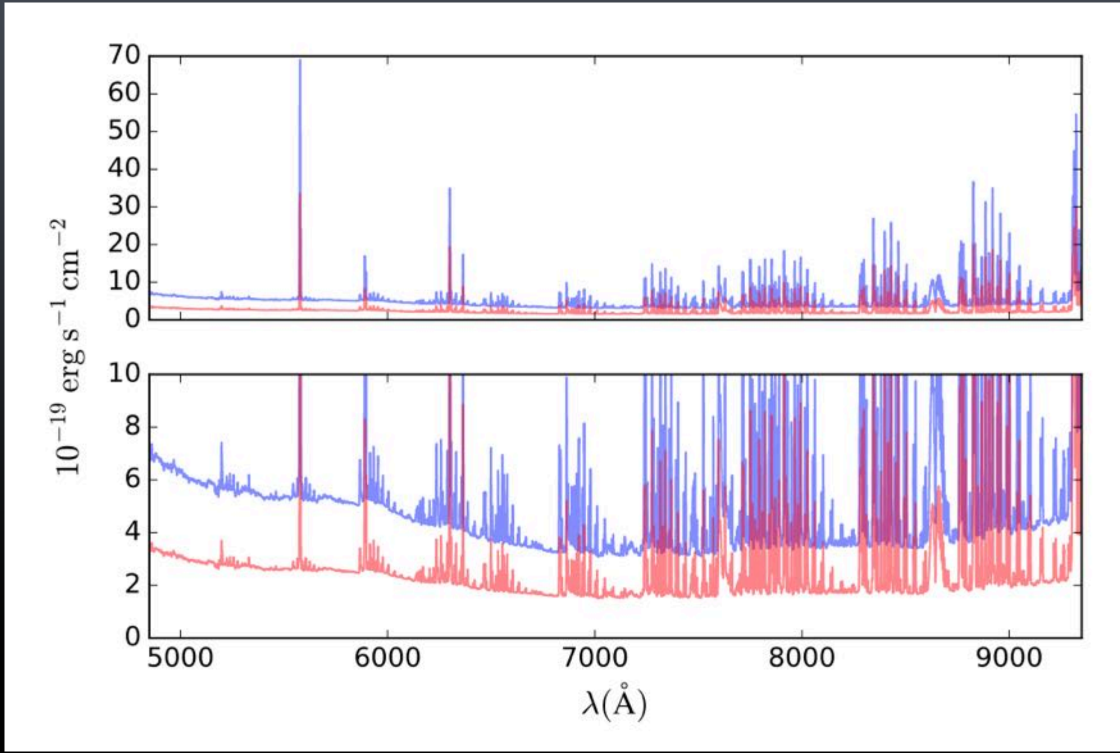
HDFS: 4.5 10^{-20} erg.s^{-1}.cm^{-2}.A^{-1}.arcsec^{-2}

UDF10: 2.8 10^{-20} erg.s^{-1}.cm^{-2}.A^{-1}.arcsec^{-2}

Paper I: Bacon et al 2017

Achieved Sensitivity

- 3σ point source detection for emission line (3.7A)
- UDF10: 1.5 10^{-19} $erg.s^{-1}.cm^{-2}$
- MOSAIC: 3.1 10^{-19} $erg.s^{-1}.cm^{-2}$



Paper I: Bacon et al 2017

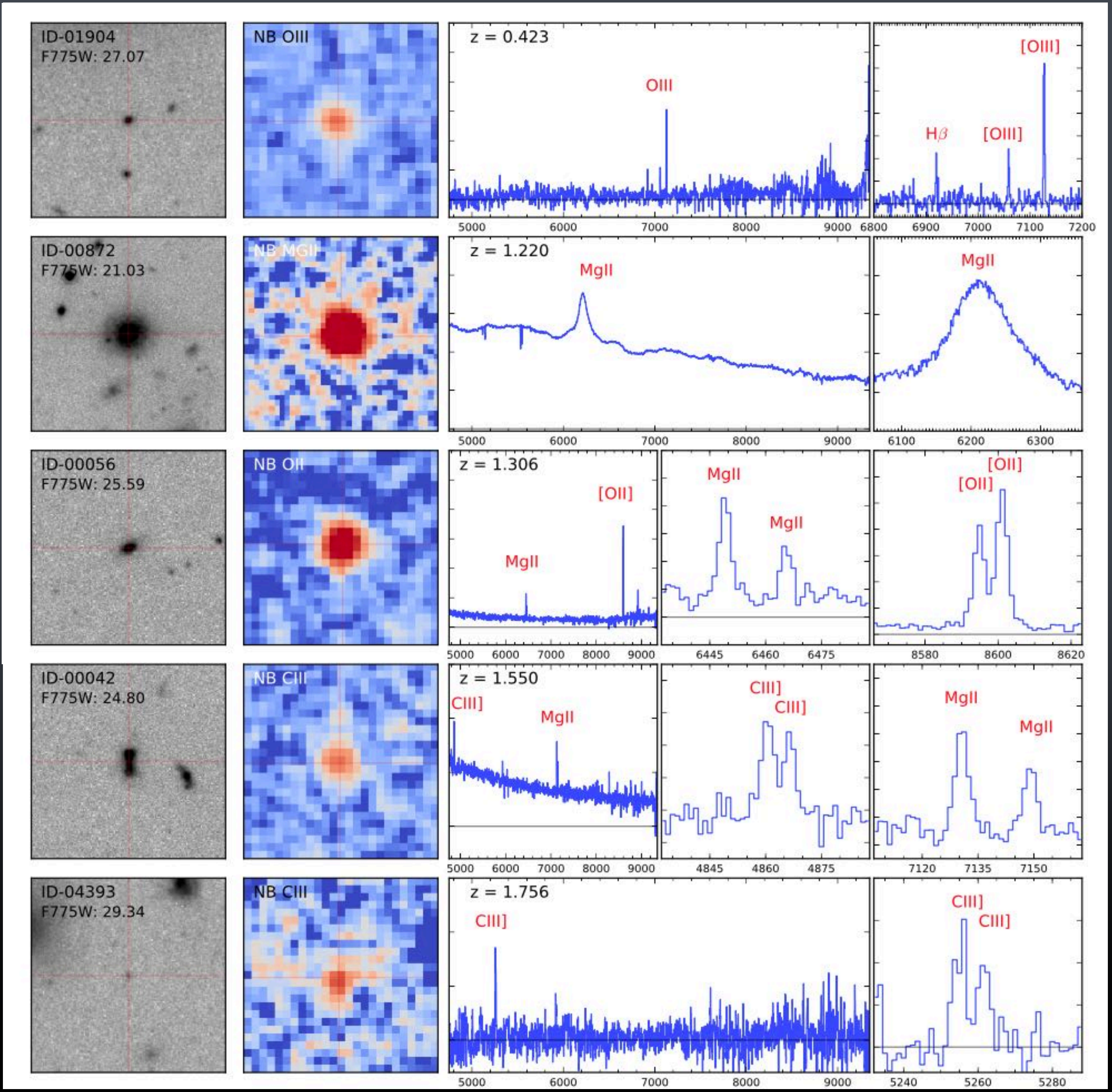
z = 0.423 AB = 27.07

z = 1.220 AB = 21.03

z = 1.306 AB = 25.59

z = 1.550 AB = 24.80

z = 1.756 AB = 29.34



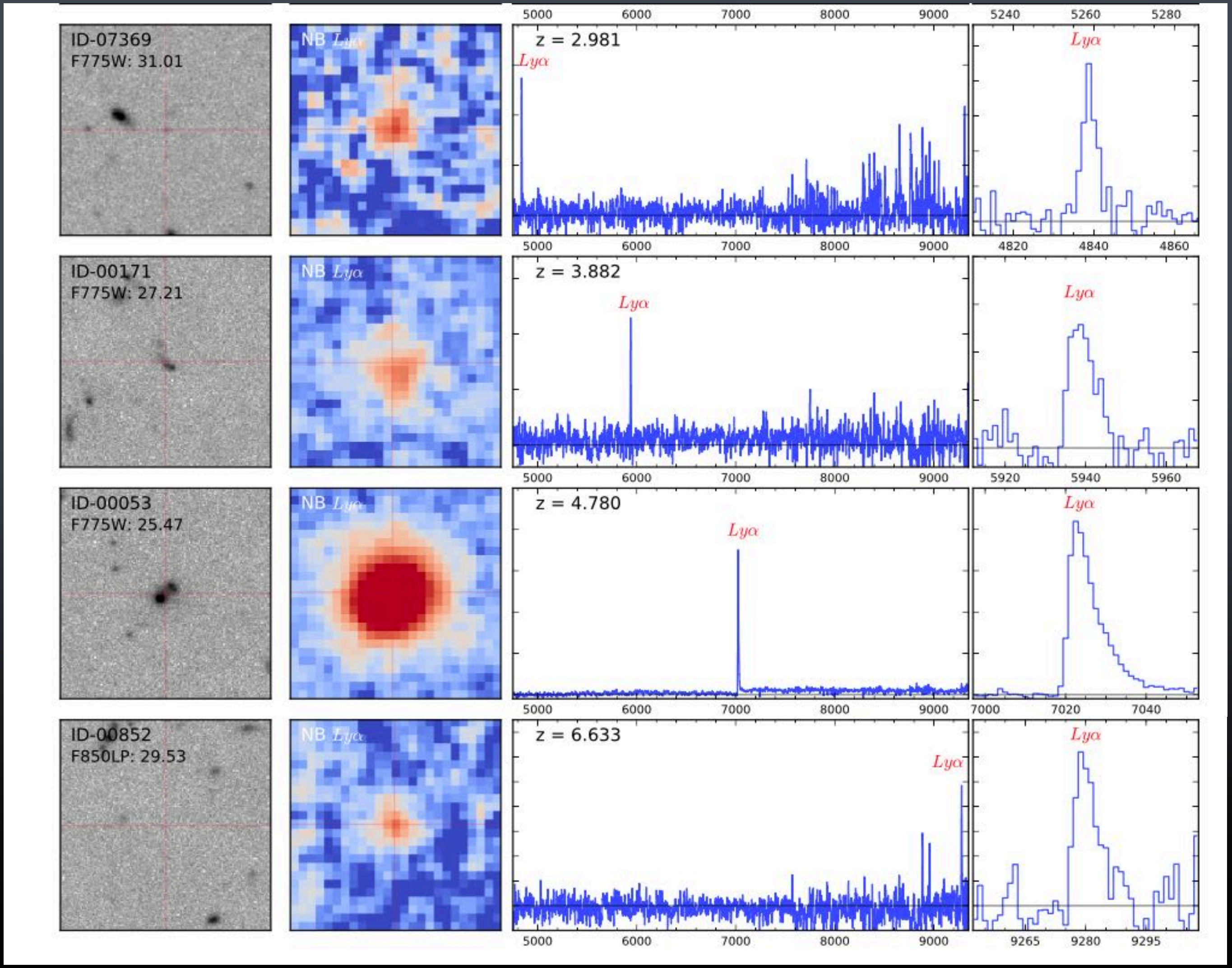
ESO - Göttingen - Leiden - Lyon - Potsdam - Toulouse - Zurich

z = 2.981 AB = 31.01

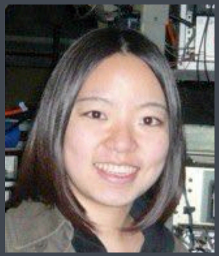
z = 3.882 AB = 27.21

z = 4.780 AB = 25.47

z = 6.633 AB = 29.53



Spectroscopic Redshift and Line Flux Catalogue
Hanae Inami et al

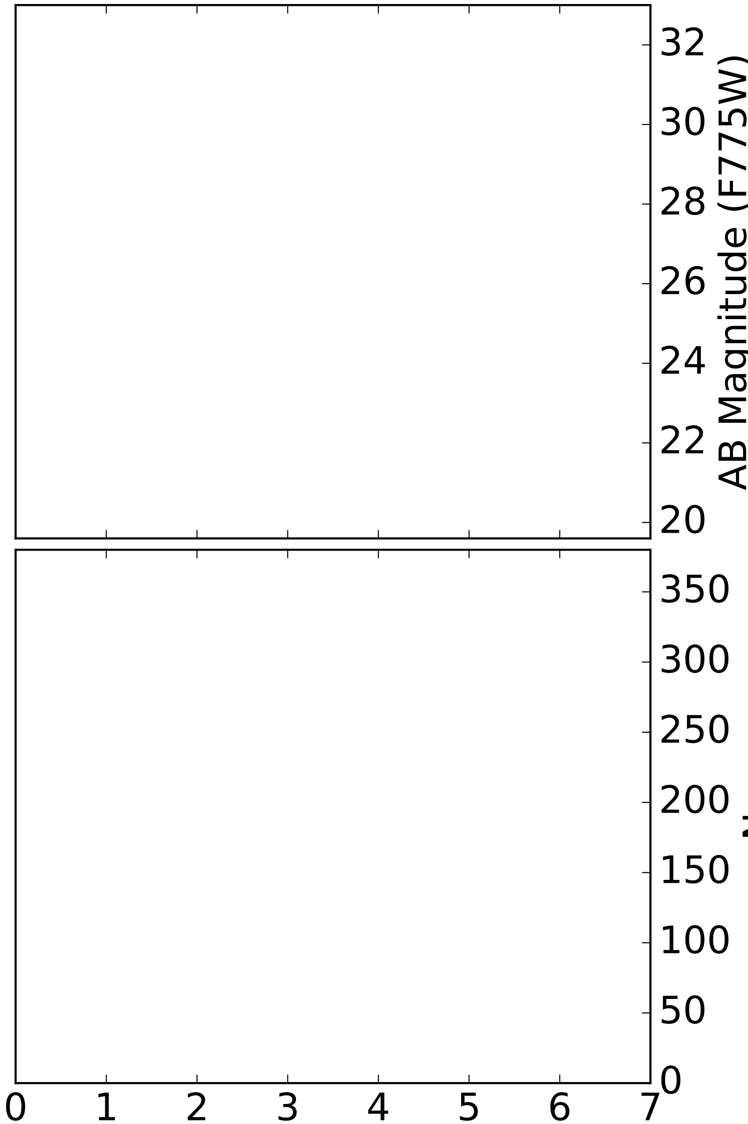


- **Redshift identification of sources in datacubes**
  - Standard tool e.g. AutoZ using extracted spectra
  - Narrow band image of identified line is critical
  - Specific tool: Muse-Marz from Marz (Hinton et al 2016)

Paper II: Inami et al 2017

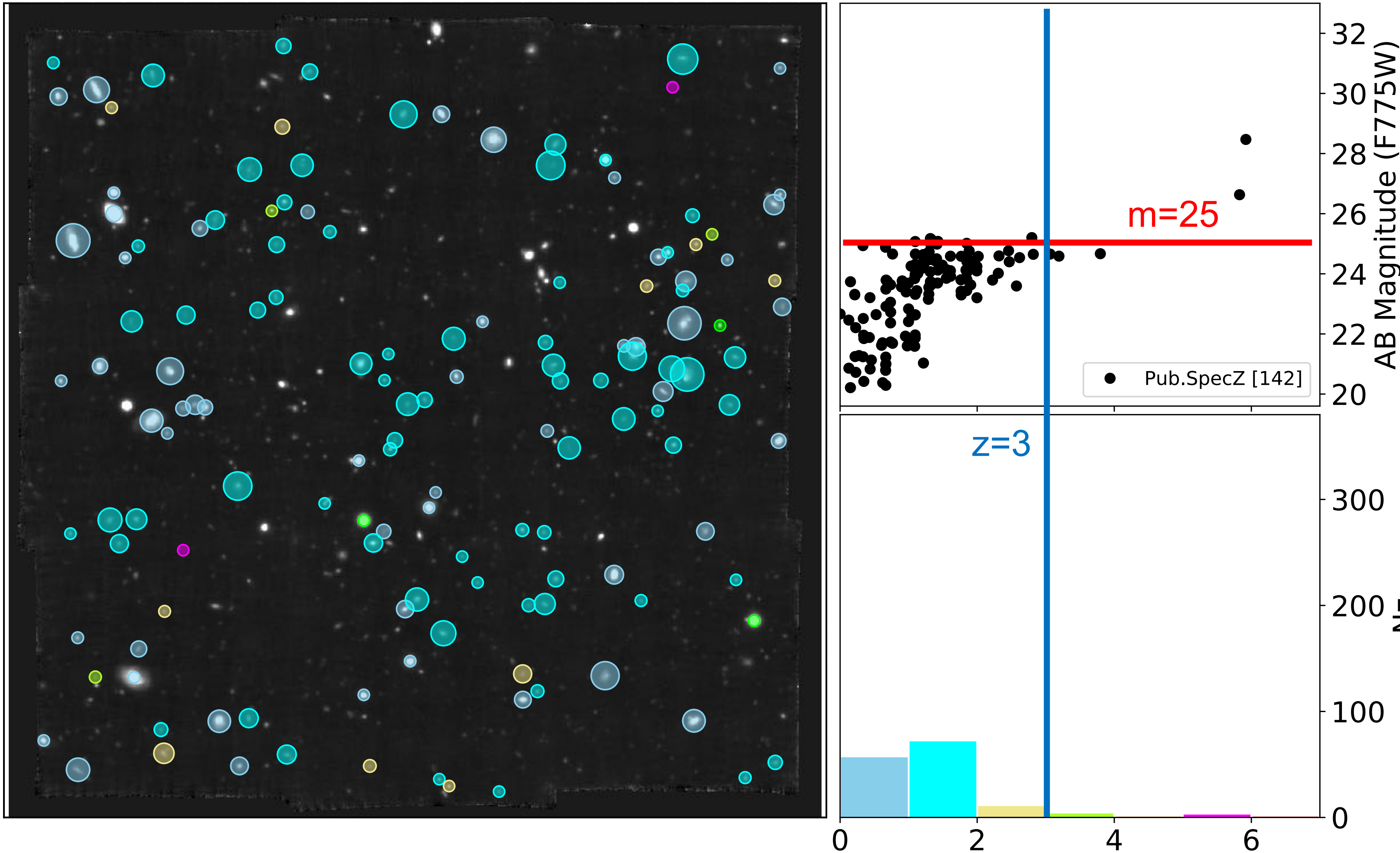
Redshifts in the mosaic field

MUSE mosaic white-light image

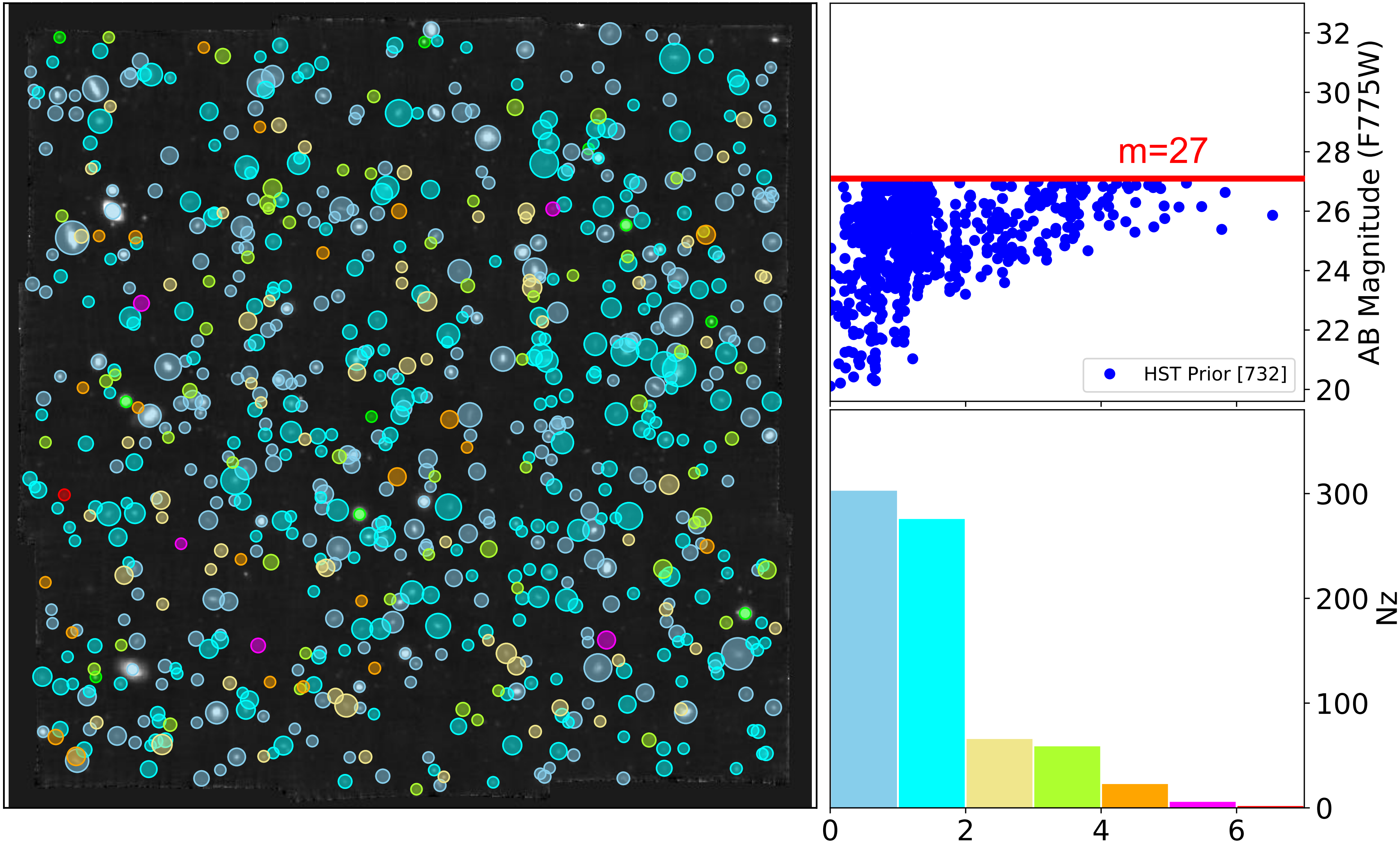


Redshifts in the mosaic field

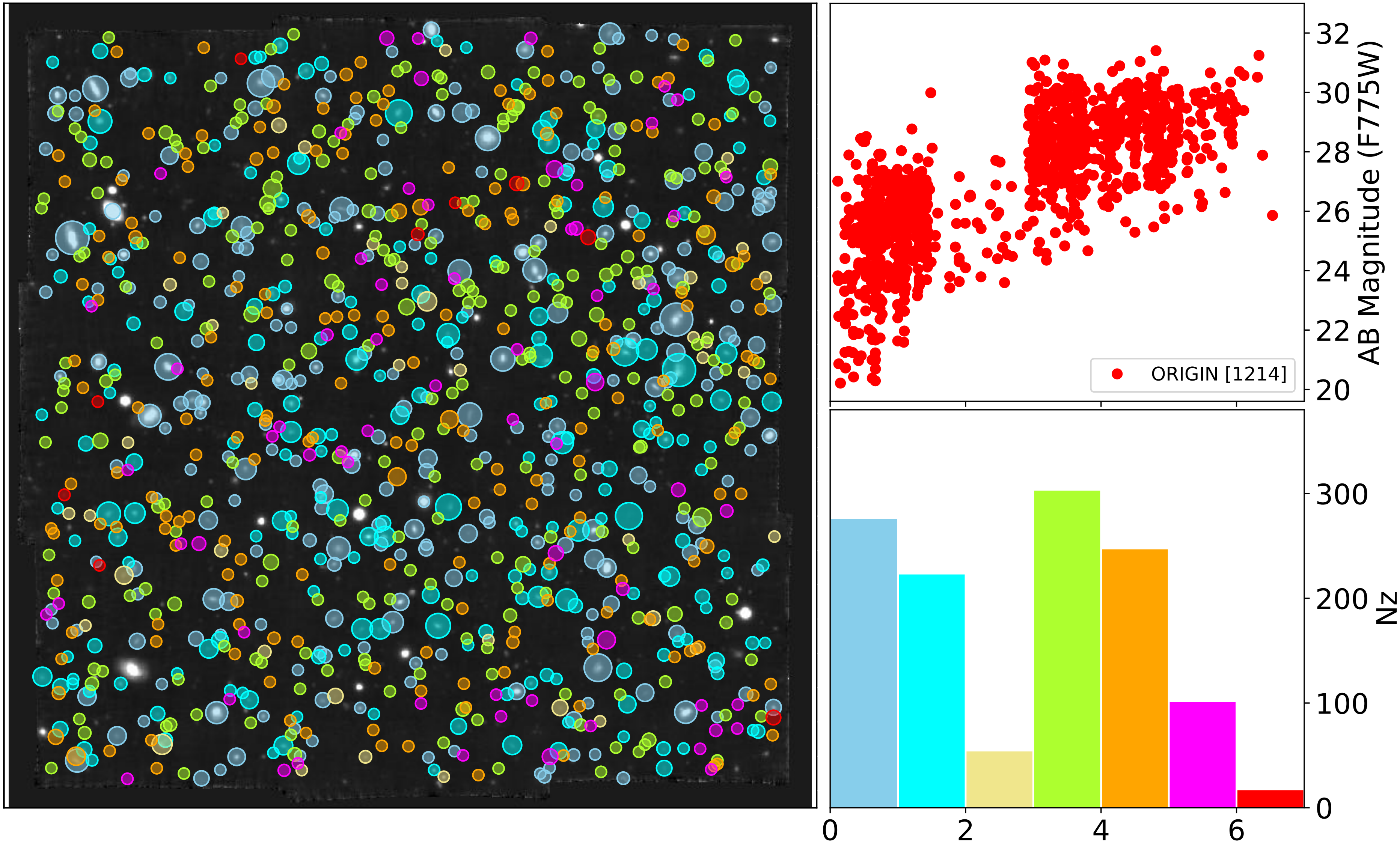
Previous spectroscopic redshifts [142]



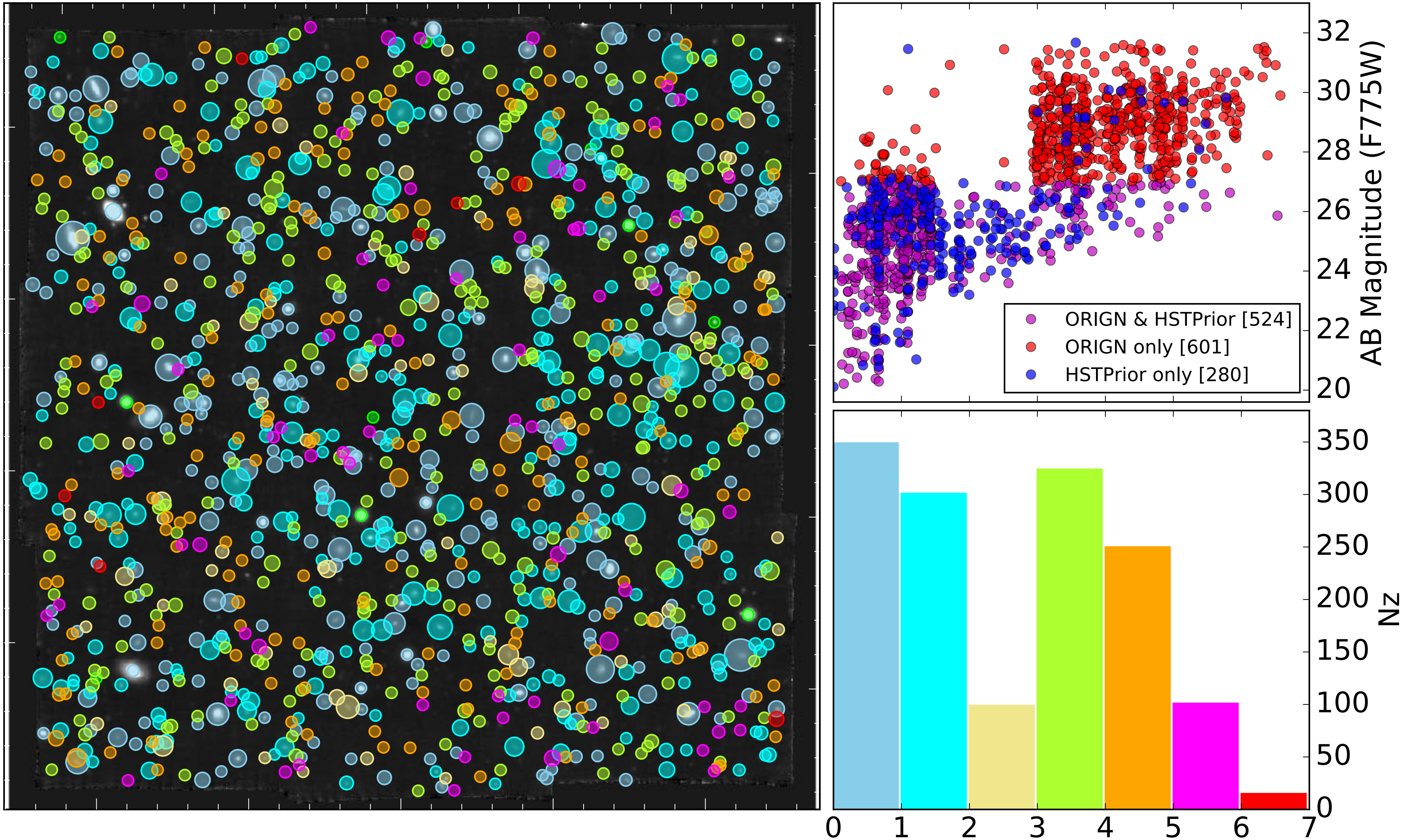
MUSE redshifts HST Prior [732]



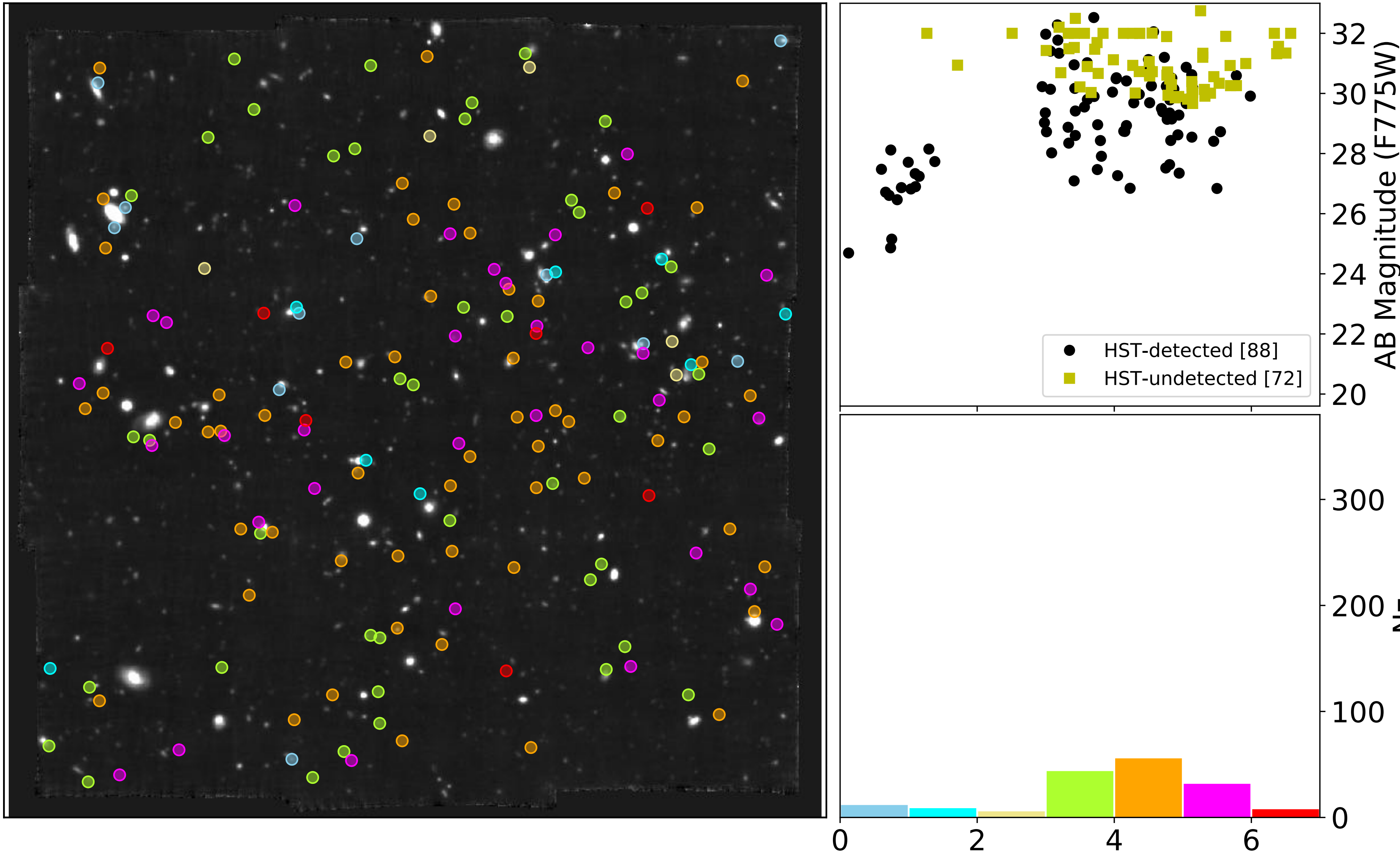
MUSE redshifts ORIGIN [1214]



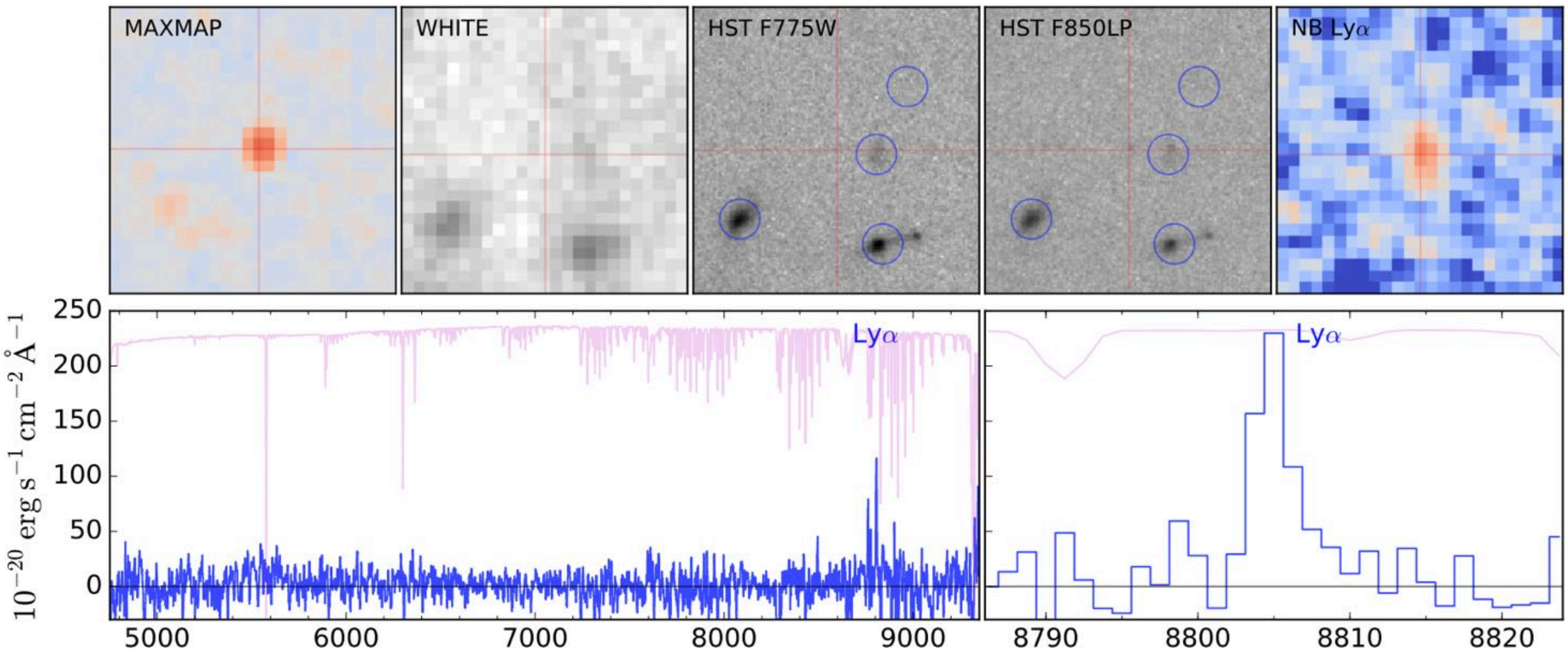
MUSE redshifts ORIGIN & HSTPrior [1443]



MUSE redshifts not in Rafelski[160]



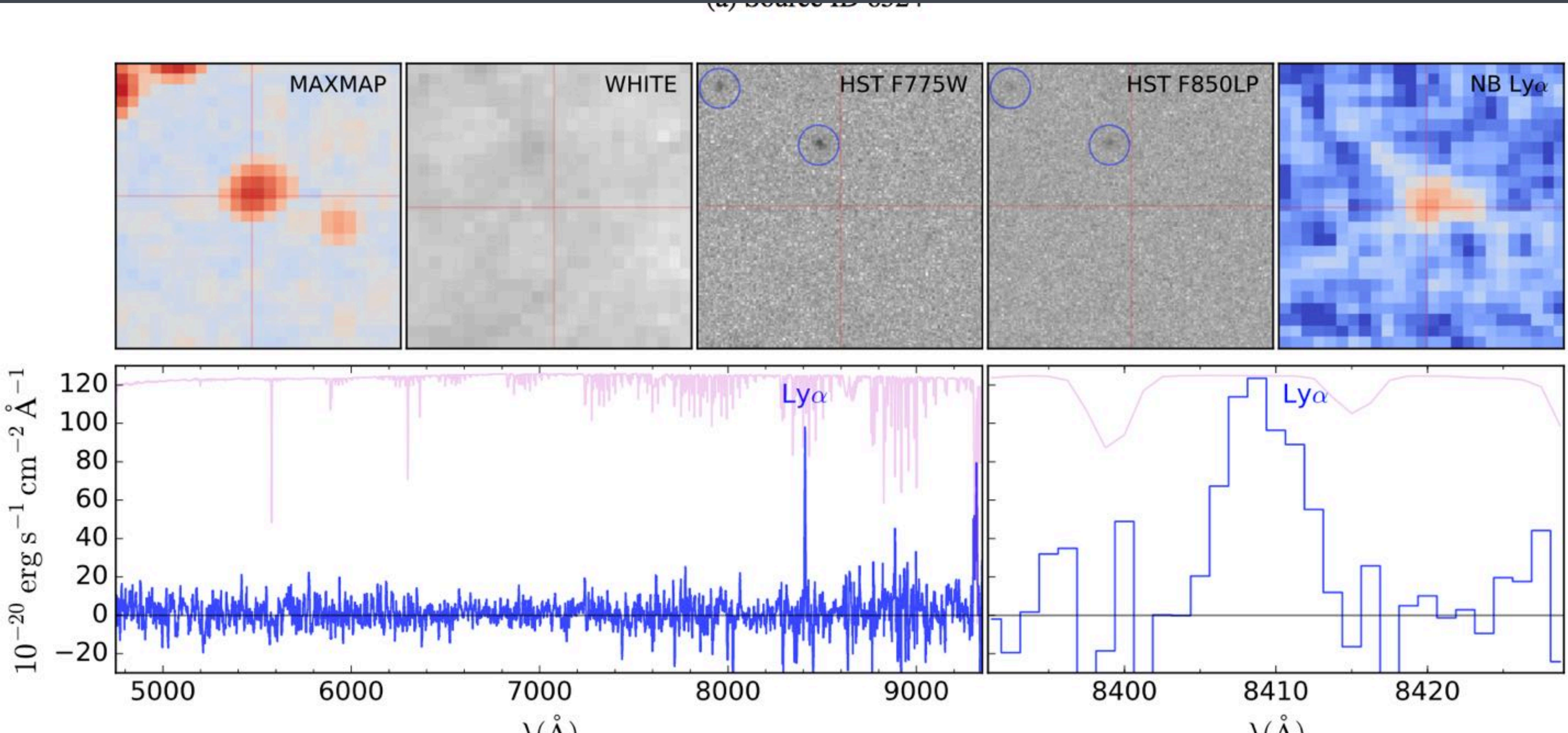
ID 6524



Lya Z = 6.24
AB F850LP 29.48 ± 0.18

Paper I: Bacon et al 2017

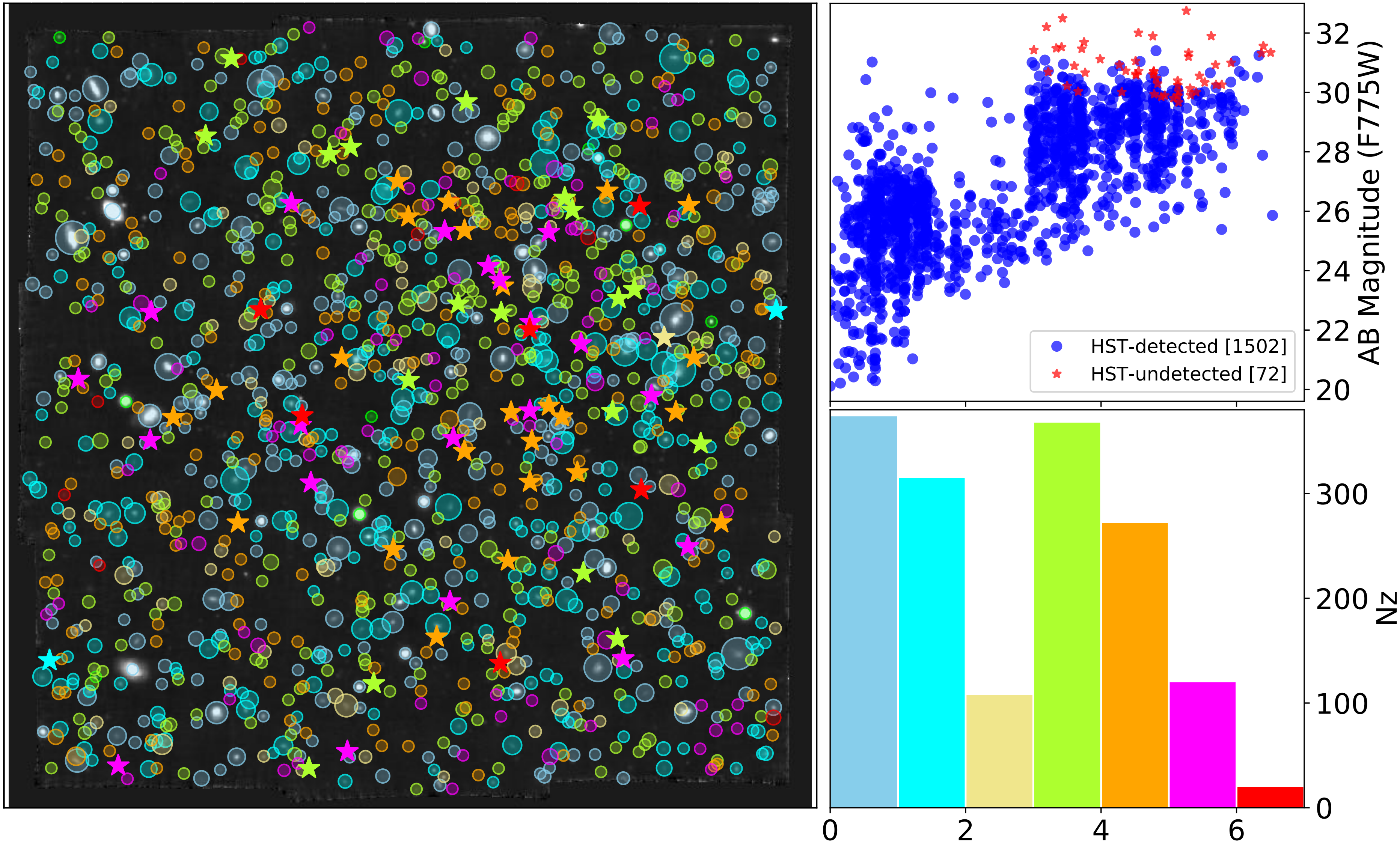
ID 6326



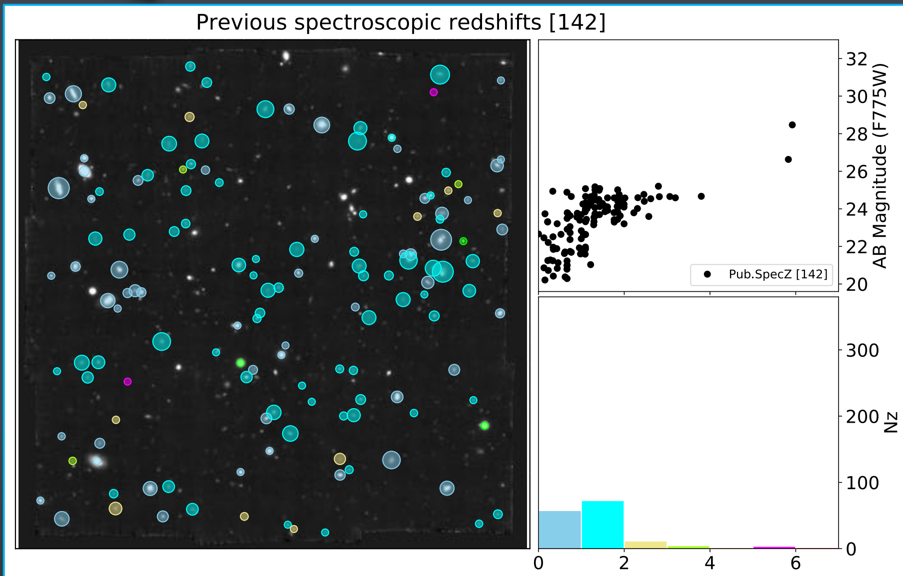
Lya Z = 5.91
AB F850LP > 30.7

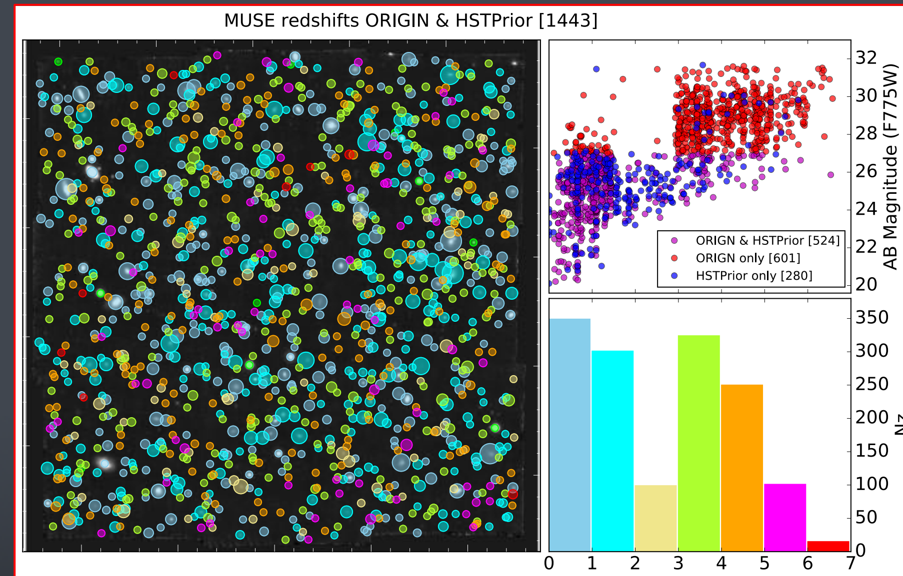
Paper I: Bacon et al 2017

MUSE redshifts [1574] HST undetected [72]



Summary





Pre MUSE
142 spectro-z
AB<25
z<3

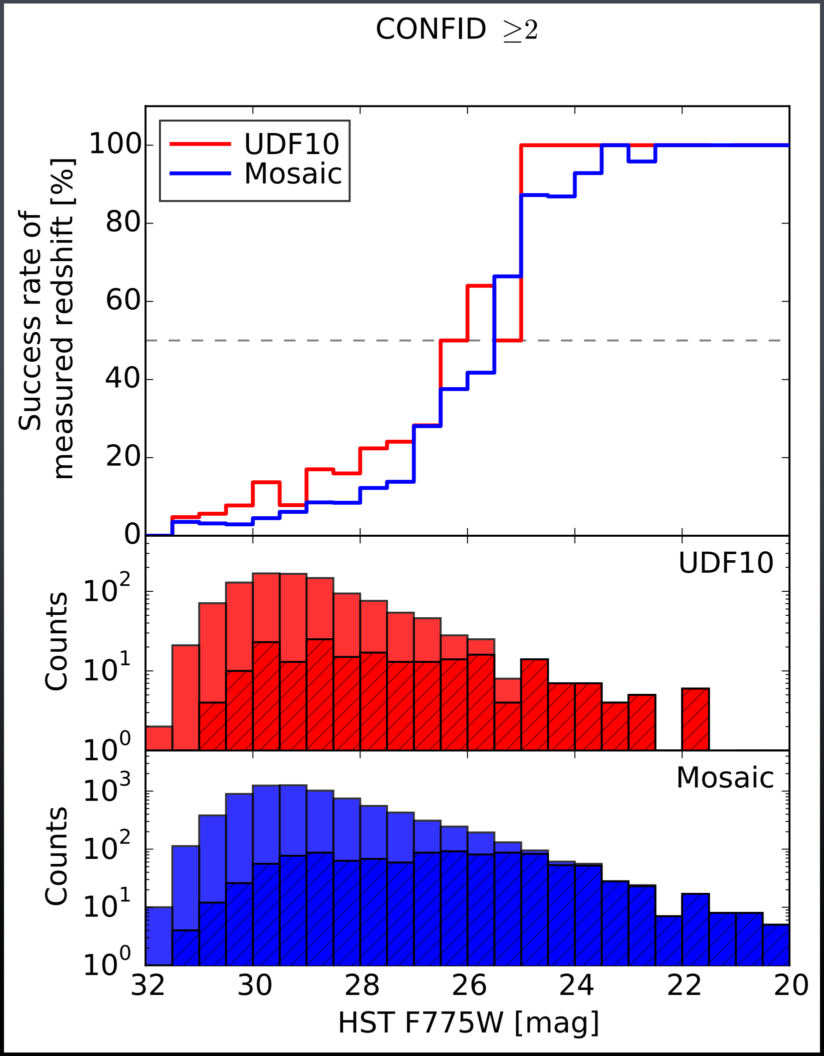
In 10 years

x 10 spectro-z
+ 6 magnitudes
+ 4 z bins

MUSE
1443 spectro-z
AB<31
z<7

In 100 hours of VLT

Completeness



<u>50% completeness</u>

UDF10: F775W AB 26.5

Mosaic: F775W AB 25.5

20% AB 29 in UDF10

Paper II: Inami et al 2017

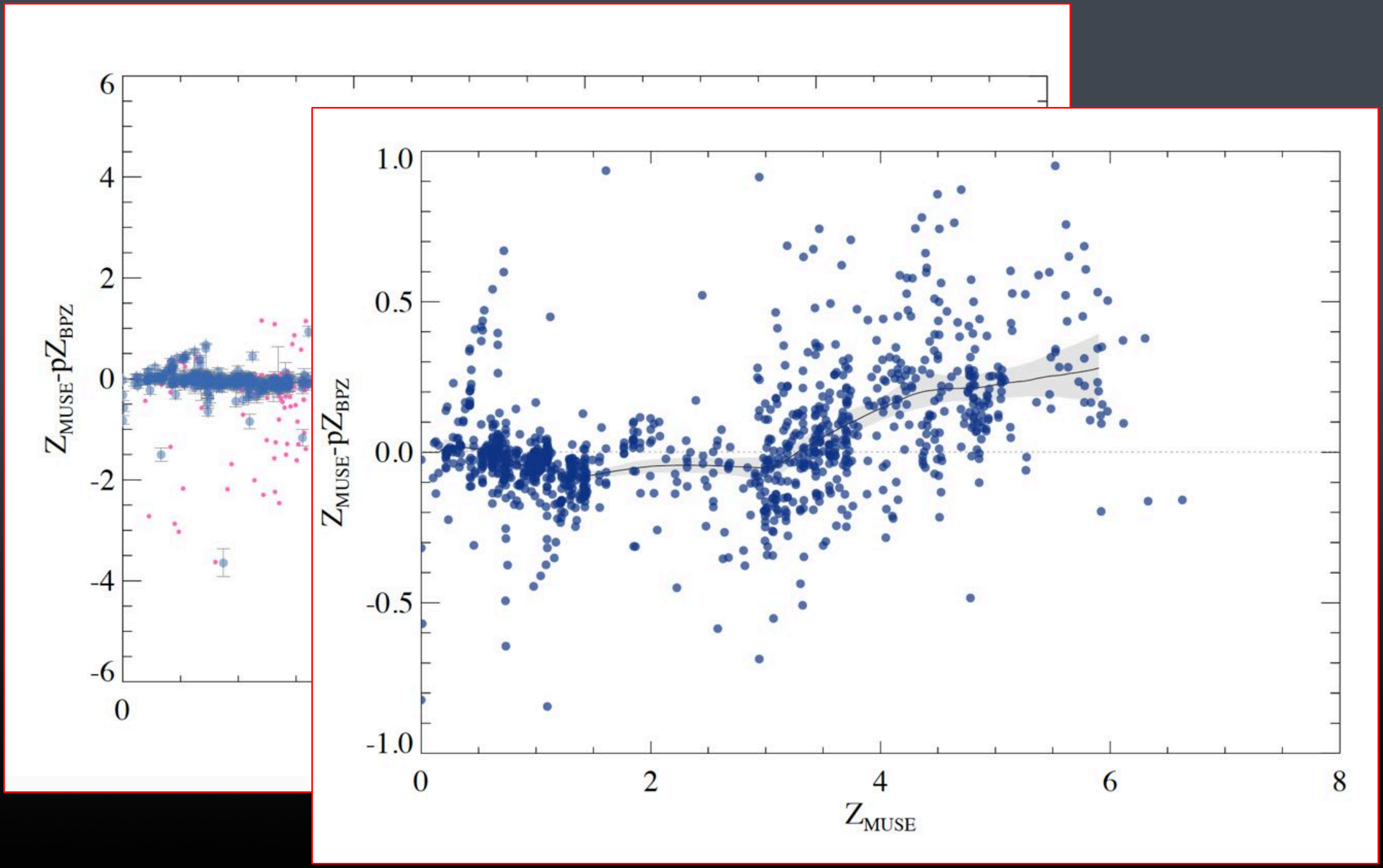
Photometric redshifts to 30th magnitude
Jarle Brinchmann (Leiden) et al

- Photo-z provide 100x more z than spectro-z
- Weak lensing surveys (KiDS, DES, LSST, Euclid, WFIRST) requires very accurate photo-z
  - Current $\Delta z < 0.05\,(1+z)$
  - Future $\Delta z < 0.001\,(1+z)$

Paper III: Brinchmann et al 2017

UDF photo-z versus MUSE z

Rafelski et al 2015 photo-z



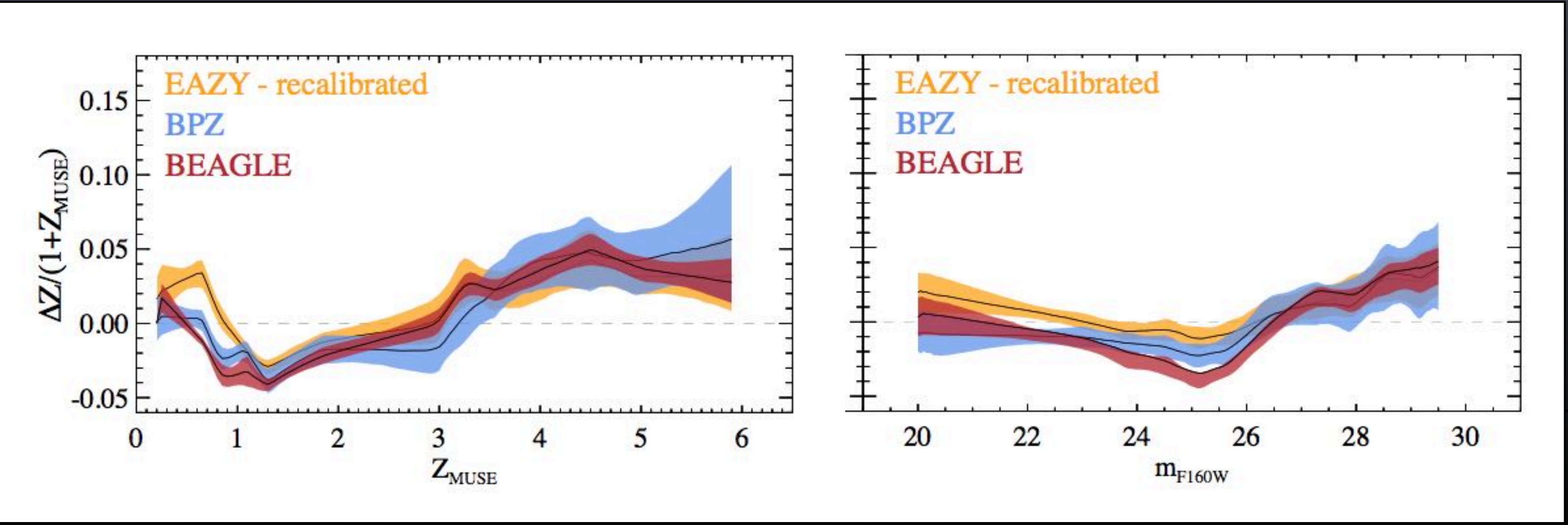
Paper III: Brinchmann et al 2017

ESO - Göttingen - Leiden - Lyon - Potsdam - Toulouse - Zurich

Photo-z Accuracy

Bias < 0.05
Systematic offset at z>3 and z 0.4-1.5

EAZY (Bramer et al 2008)
BPZ (Benitez 2000)
BEAGLE (Chevallard & Charlot 2016)

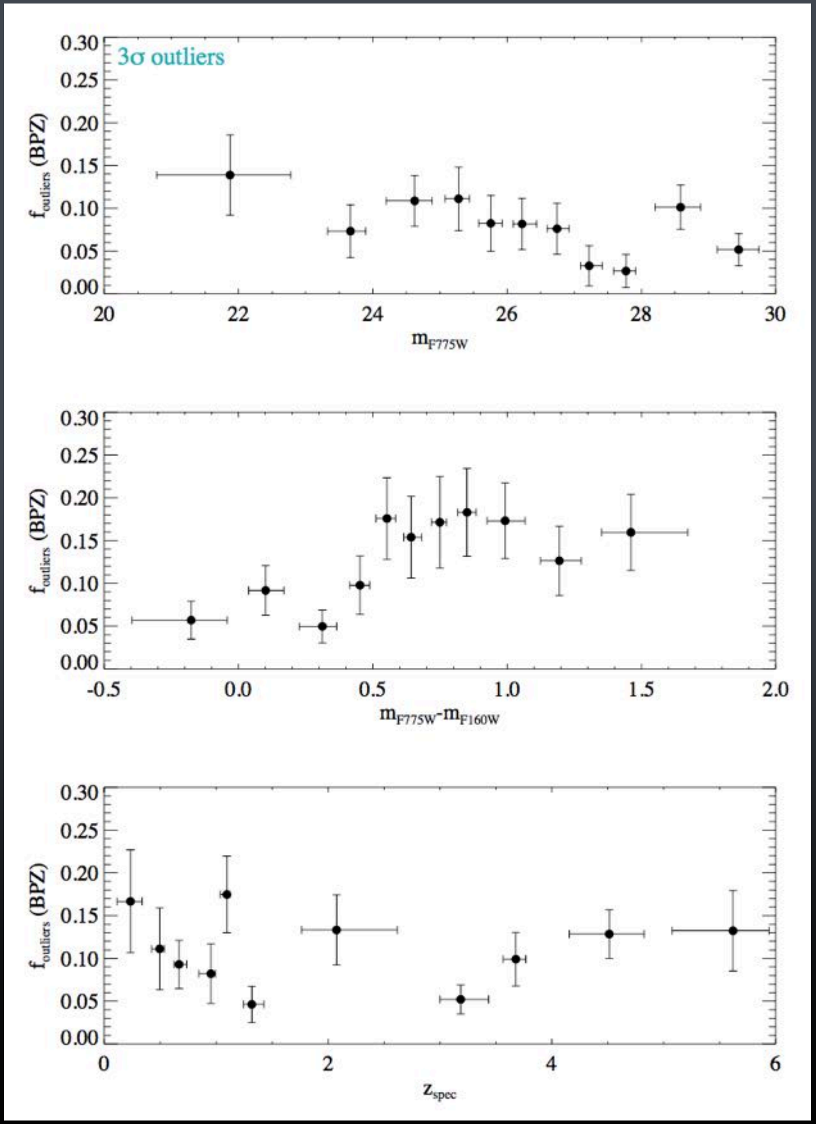


Paper III: Brinchmann et al 2017

Outliers

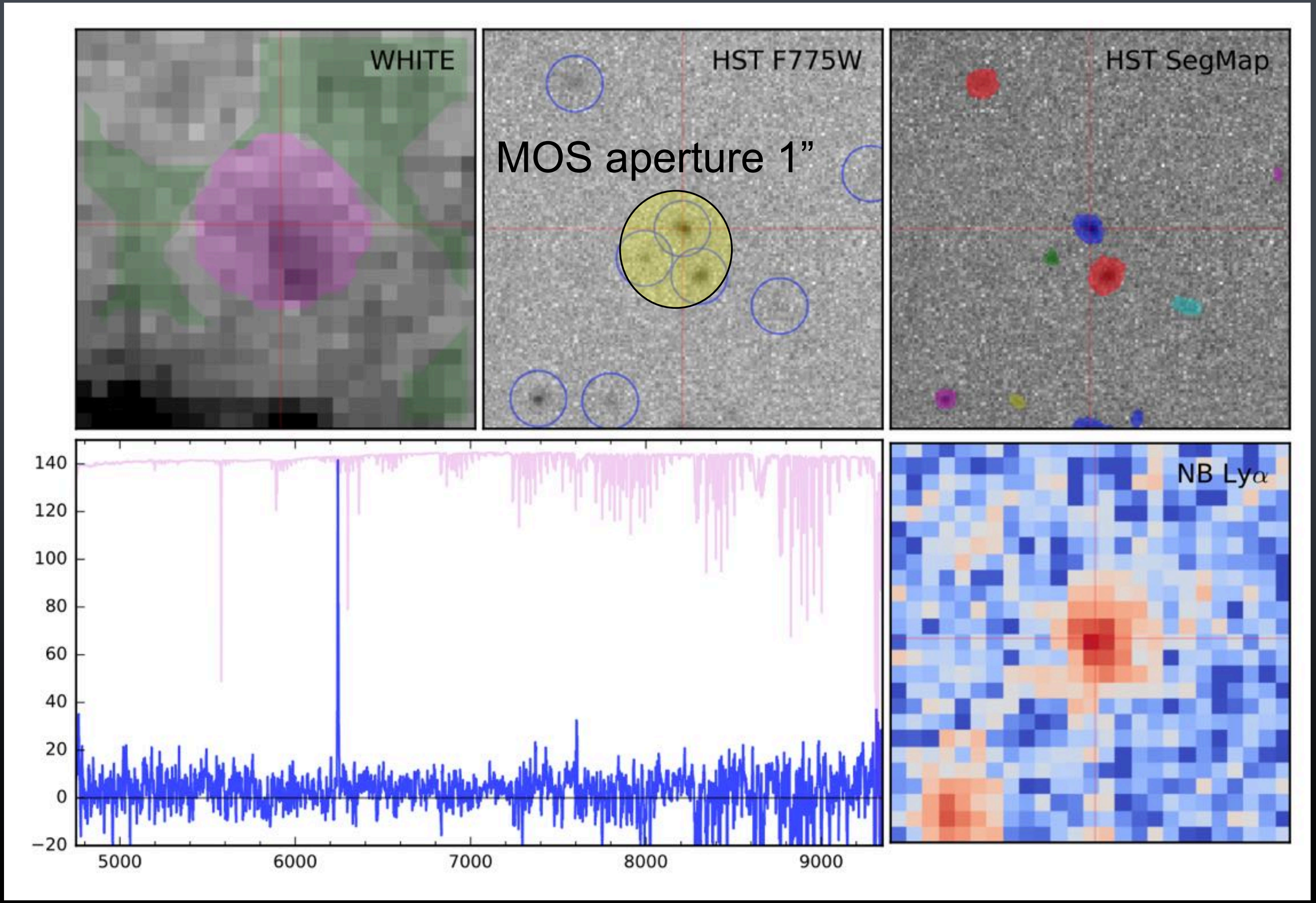
Rafelski et al 2015 photo-z
Fraction outliers 2.4-3.8%

Fractions measured in MUSE: 8-10%



Paper III: Brinchmann et al 2017

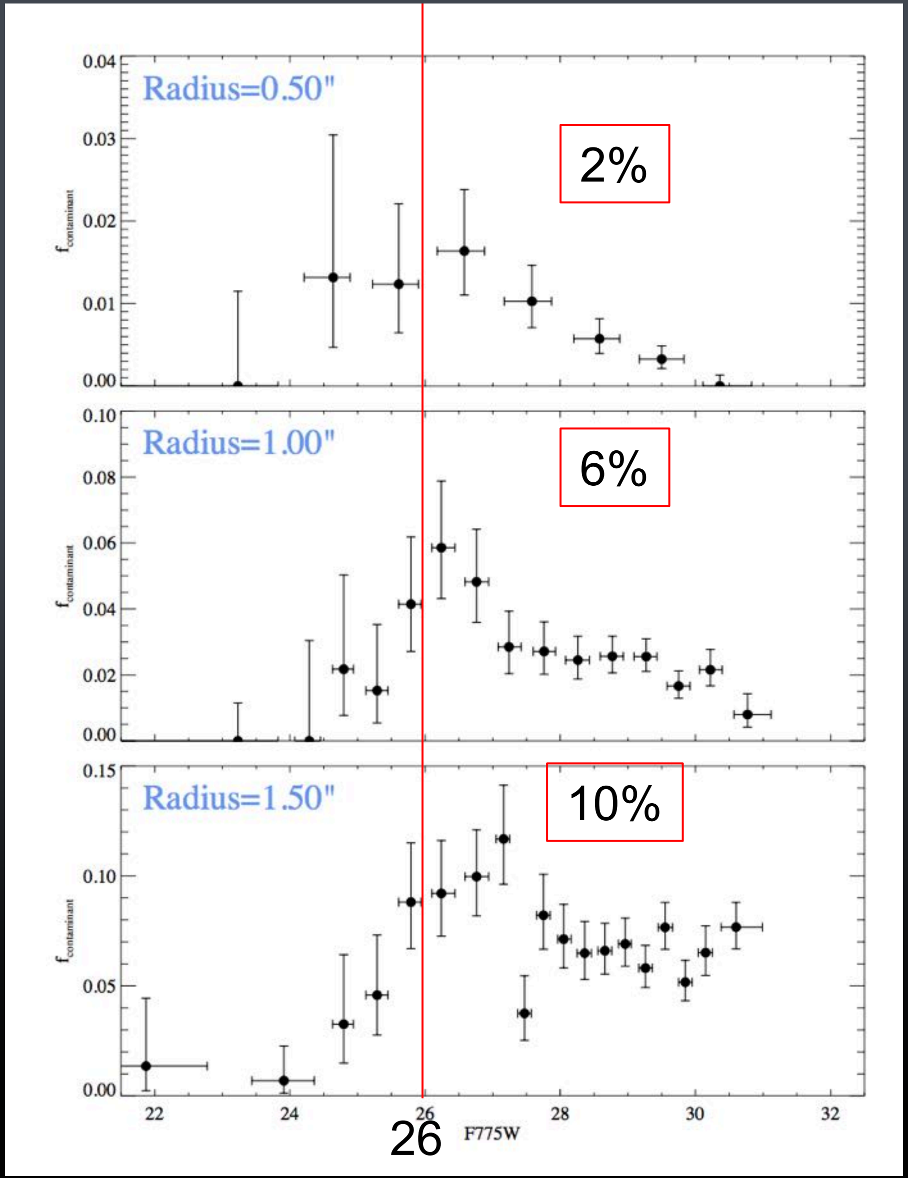
Impact of blending



Paper I: Bacon et al 2017

Impact of blending

When going deep (AB>26) source blending impact MOS spectroscopy



Paper III: Brinchmann et al 2017

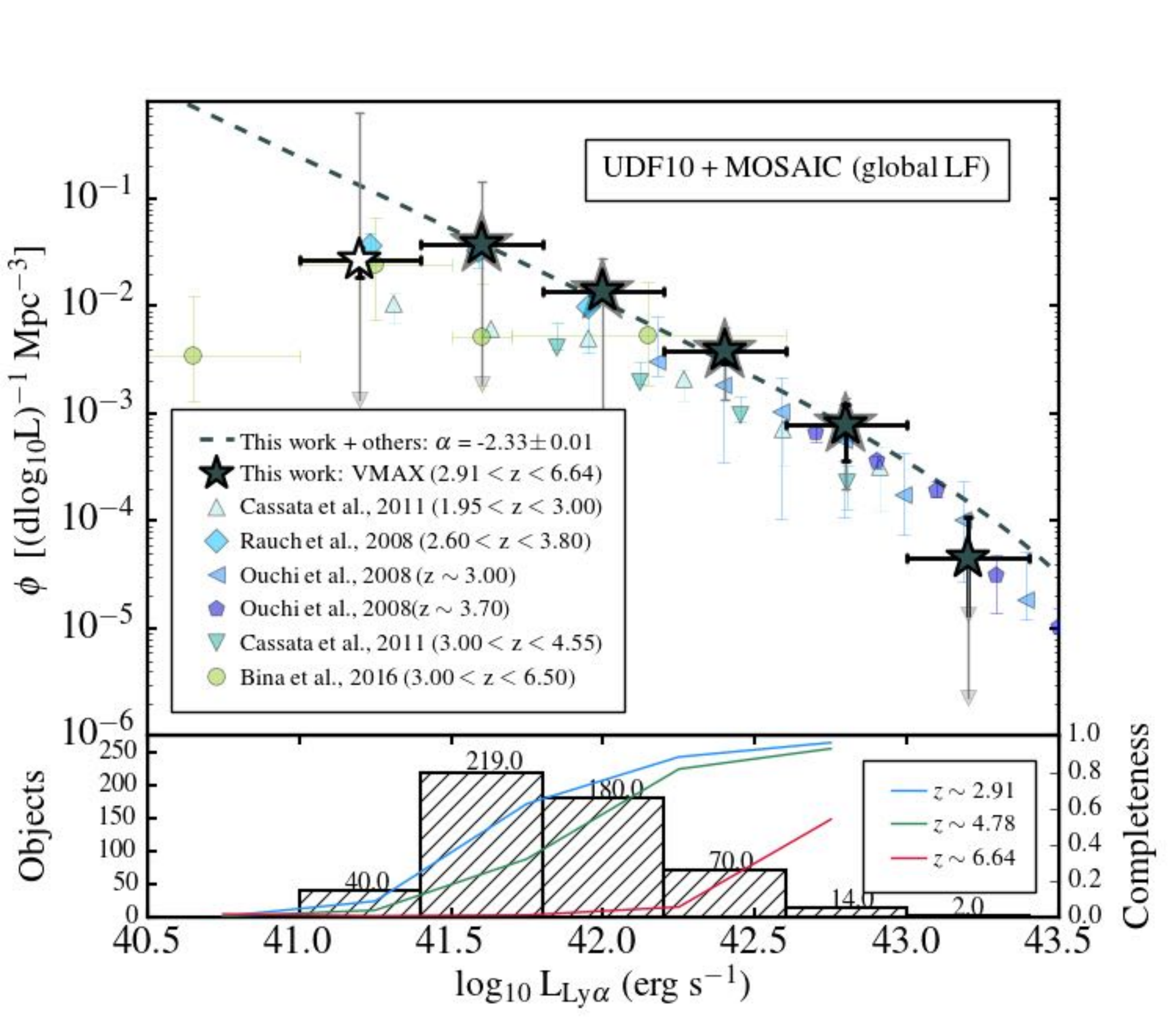
The Lyα Luminosity Function
Alyssa Drake et al

- Explore the faint end of the Lyα Luminosity function at high z
- Is the Lyα luminosity density enough to maintain an ionised IGM at redshift ≈ 6 ?
- 525 Lyα Emitters
  - Redshift range 2.8-6.7
  - Luminosity range Log_{10} L = 41-43.5

Paper VI: Drake et al 2017

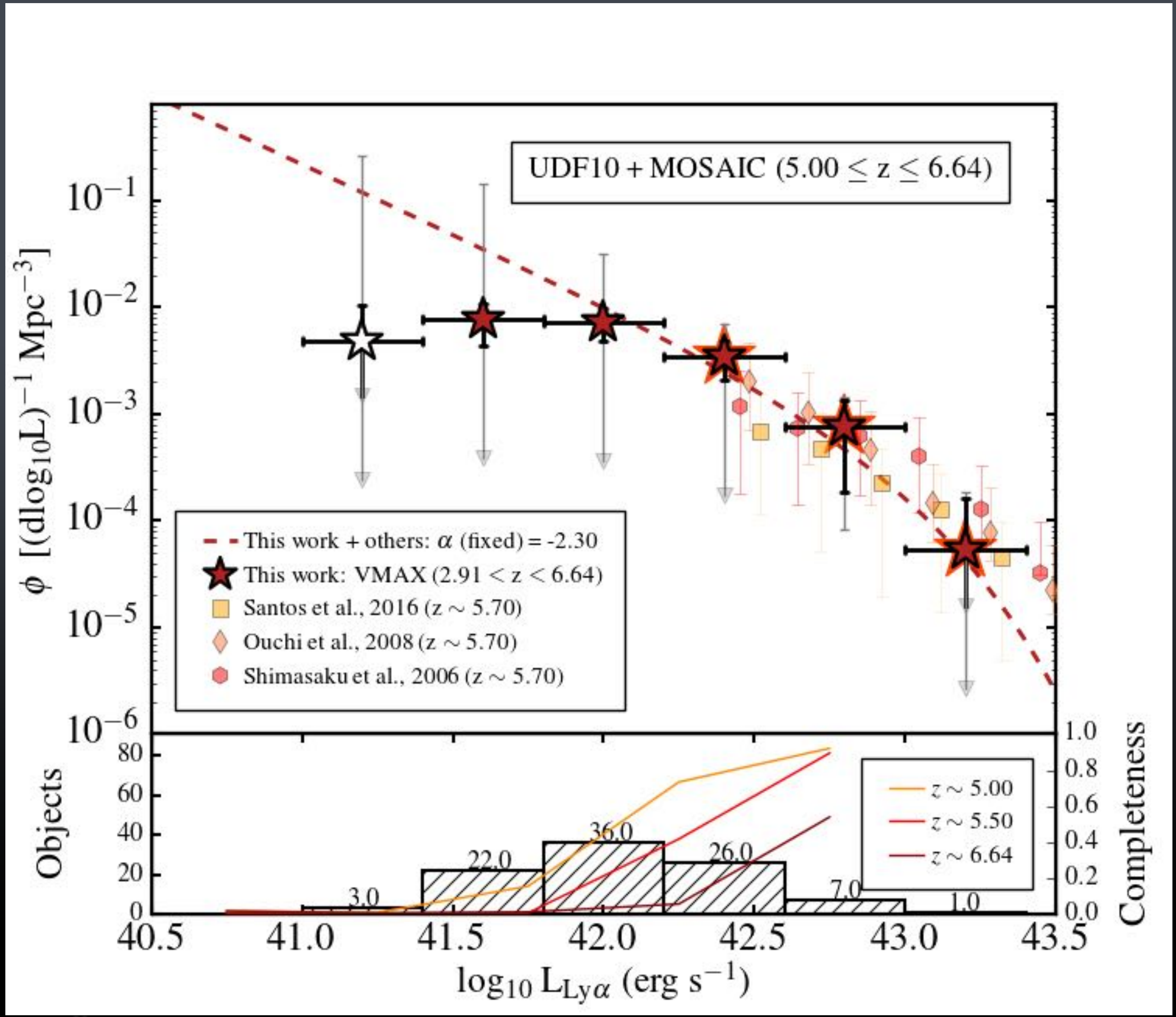
V/V$_{max}$ Lyα LF z=2.8-6.7

Paper VI: Drake et al 2017



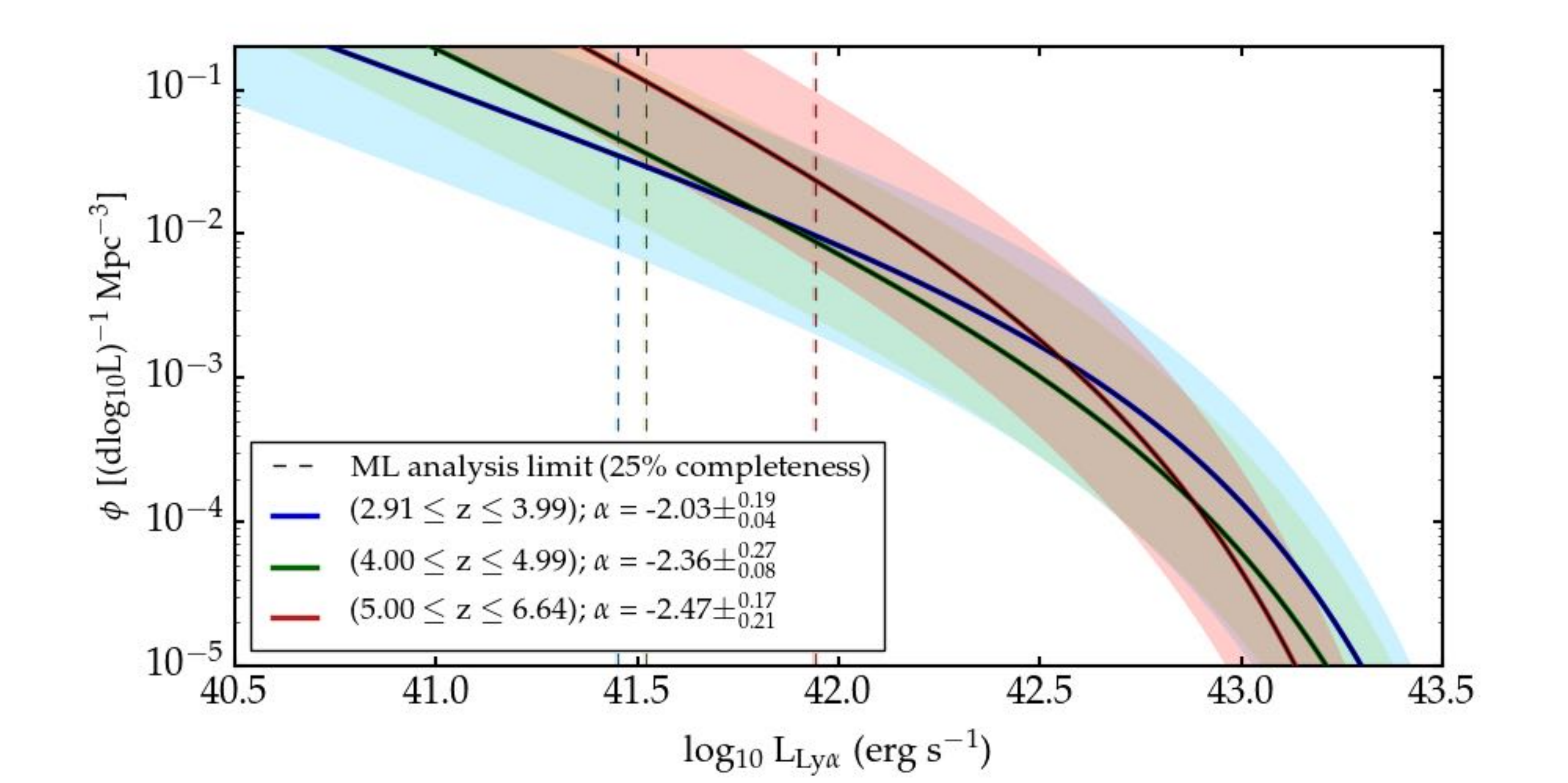
Evolution with z

Paper VI: Drake et al 2017



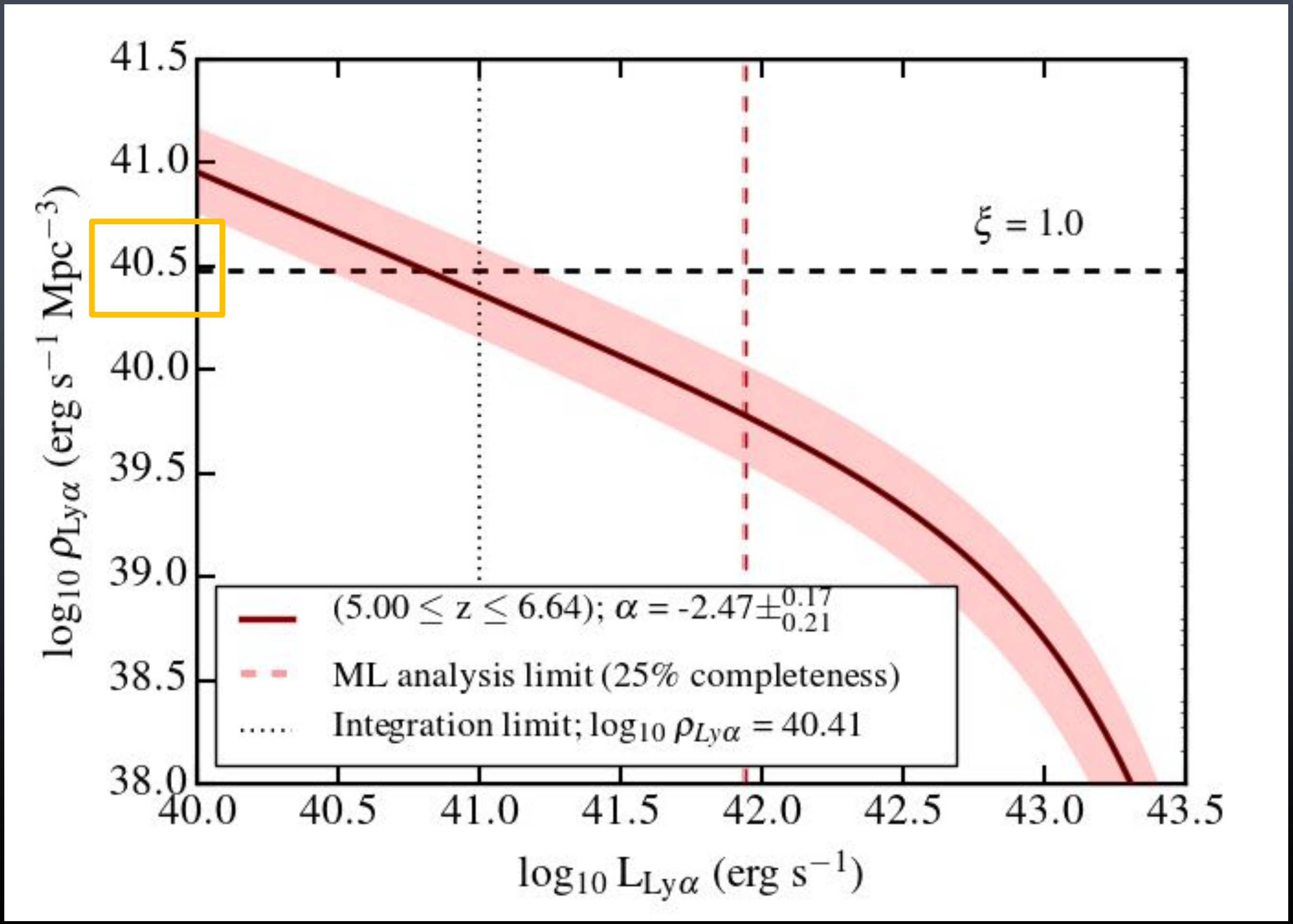
Maximum likelihood Schechter Fit

Paper VI: Drake et al 2017



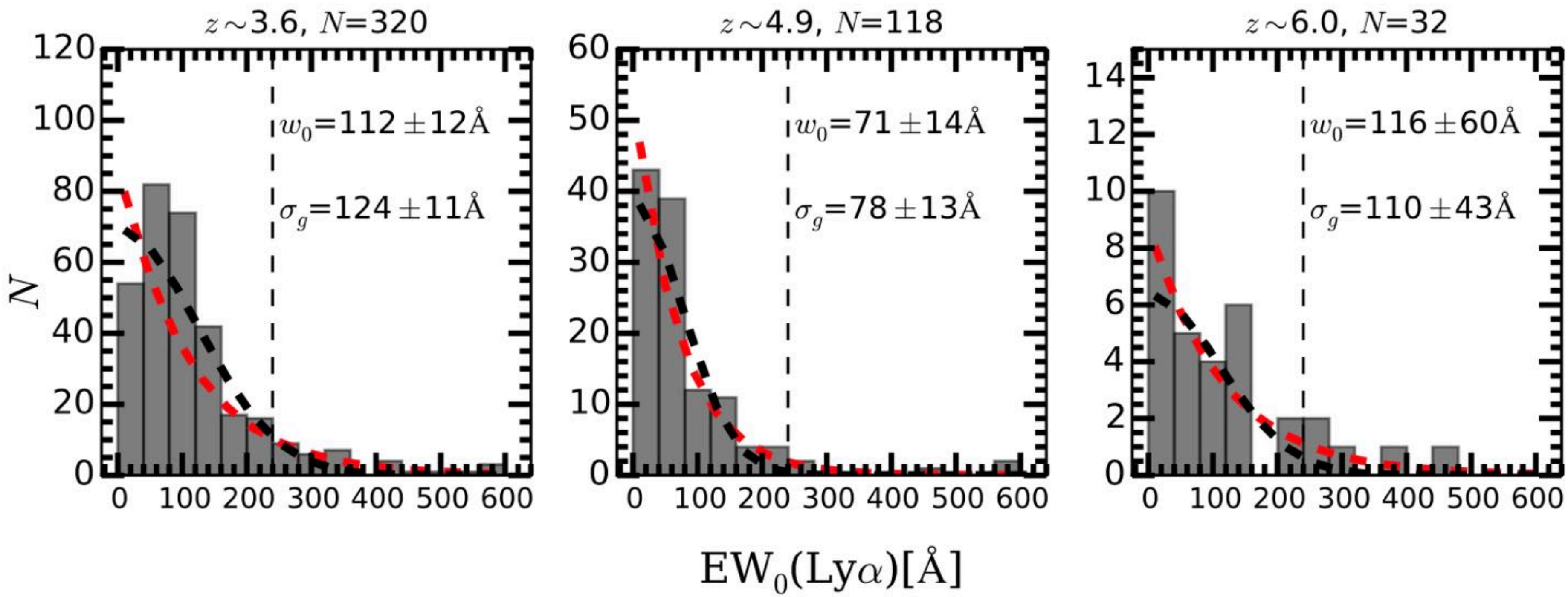
Reionisation

Martin et al 2008: $\log_{10} \rho_{Lya}$ = 40.48 ionized IGM at z = 5.7



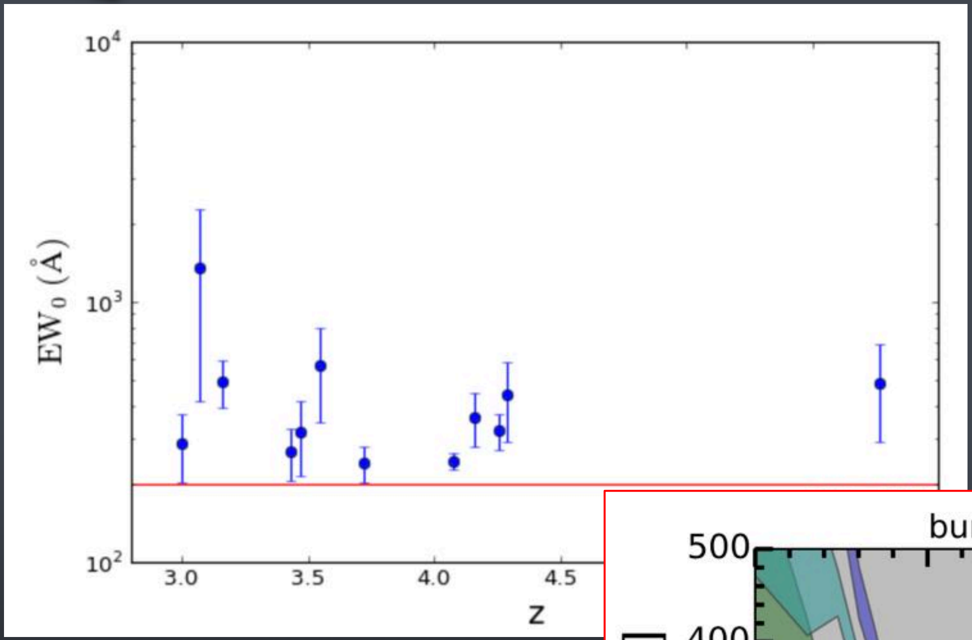
Paper VI: Drake et al 2017

Lyα Equivalent Widths
Takuya Hashimoto (CRAL, Univ Tokyo)

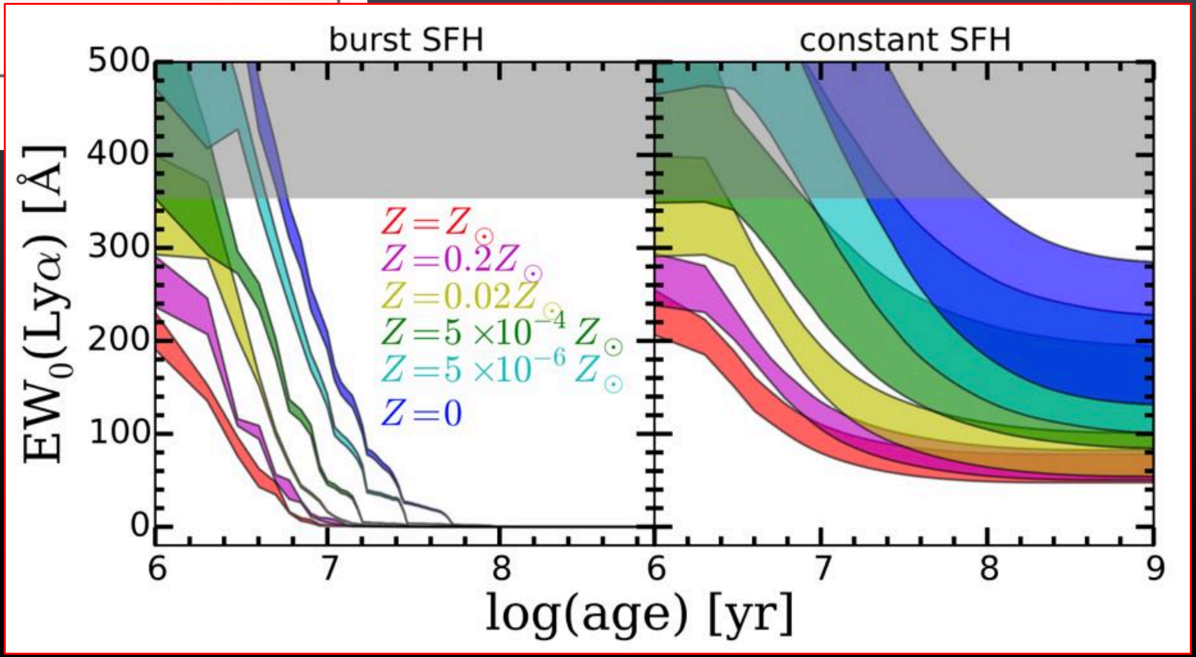


Paper VII: Hashimoto et al 2017

High Equivalent Width



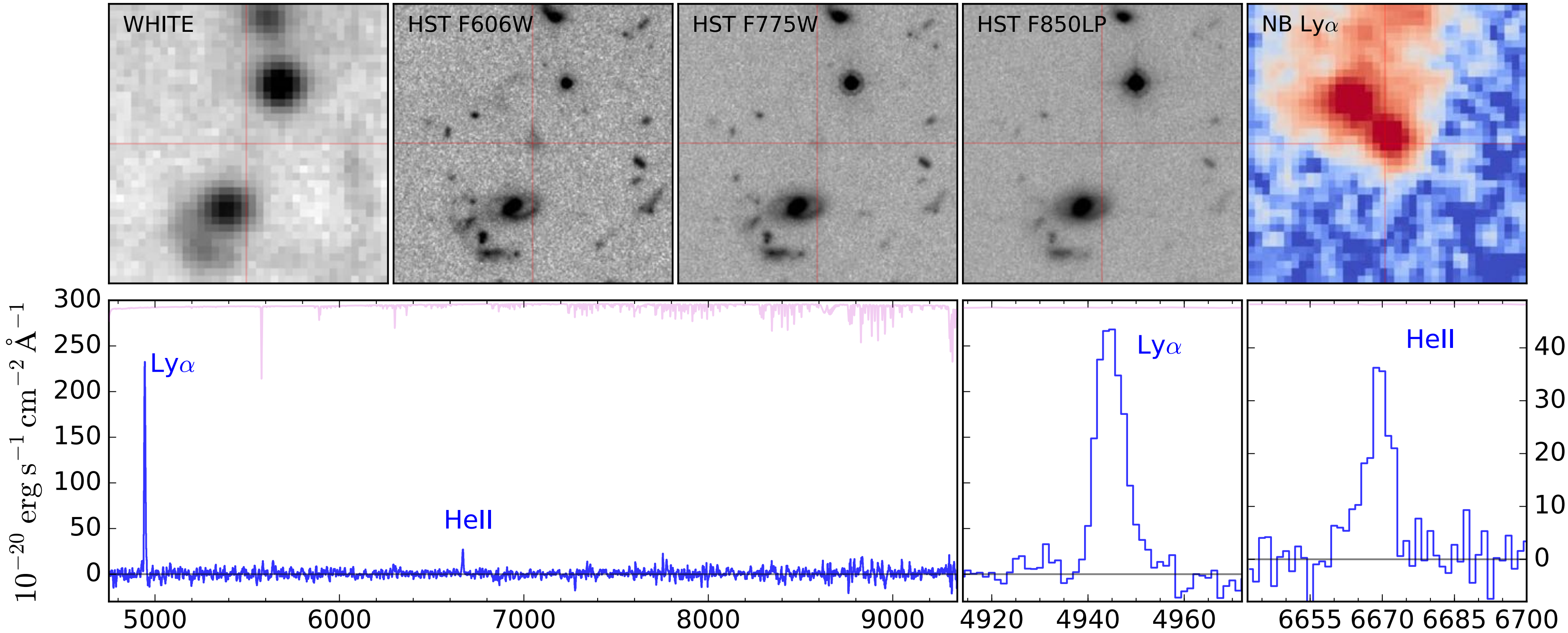
Schaerer 2003, Raiter et al 2010



Paper VII: Hashimoto et al 2017

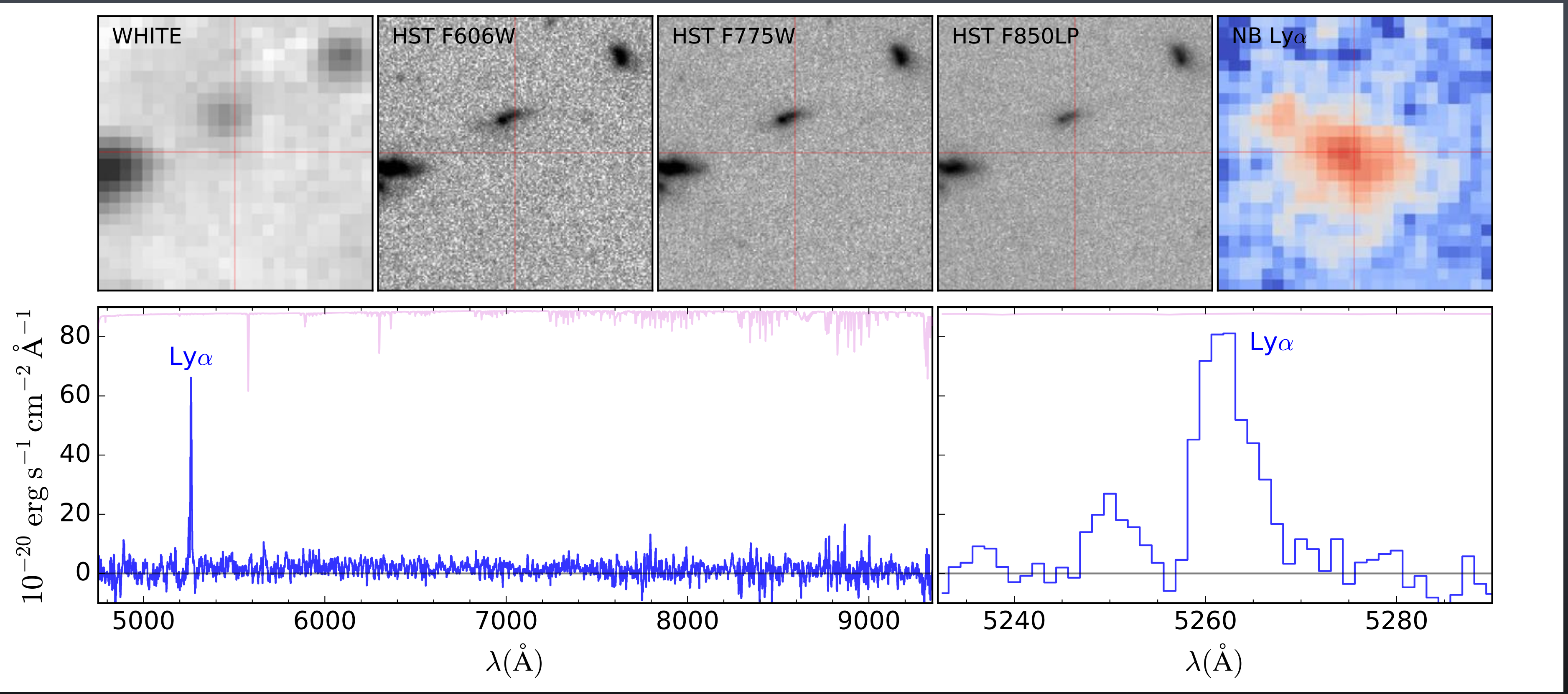
Extreme Equivalent Width

EW (Lyα) = 1347 +/- 933 A



Paper VII: Hashimoto et al 2017

Extreme Equivalent Width



log(Lyα) = 42.1 ± 0.1 erg.s^{-1}

M_{UV1500} < -14.7

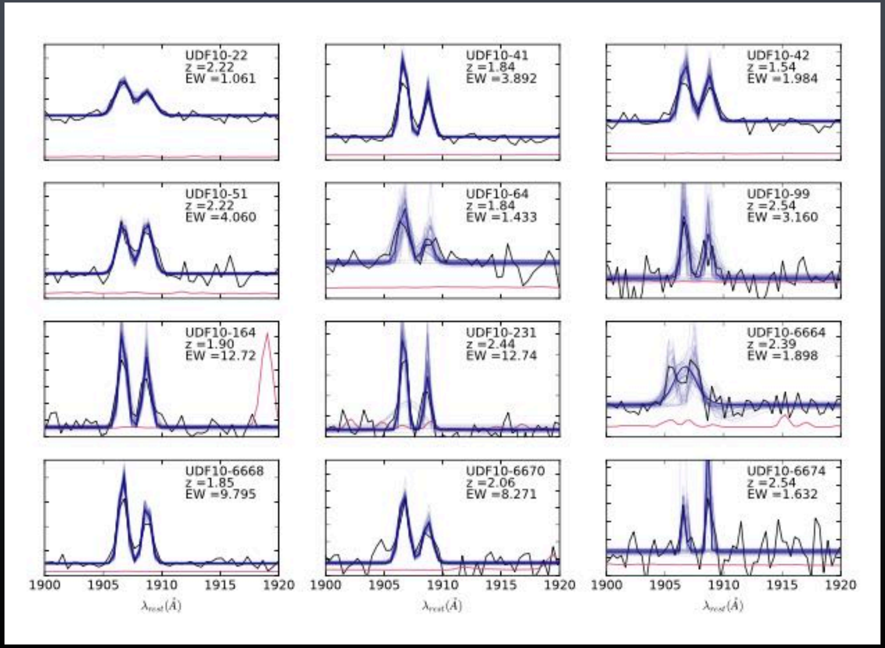
EW (Lyα) > 2226 A

Paper VII: Hashimoto et al 2017

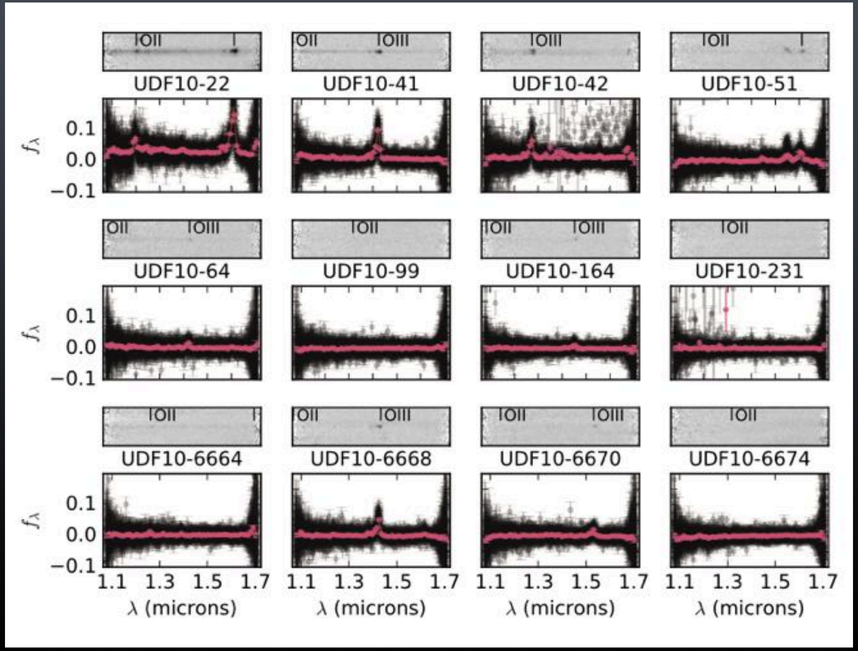
An Overview of C III] Emitters
Michael Maseda (Leiden) et al

- **CIII] as Lyα alternative at z>6**

CIII] MUSE

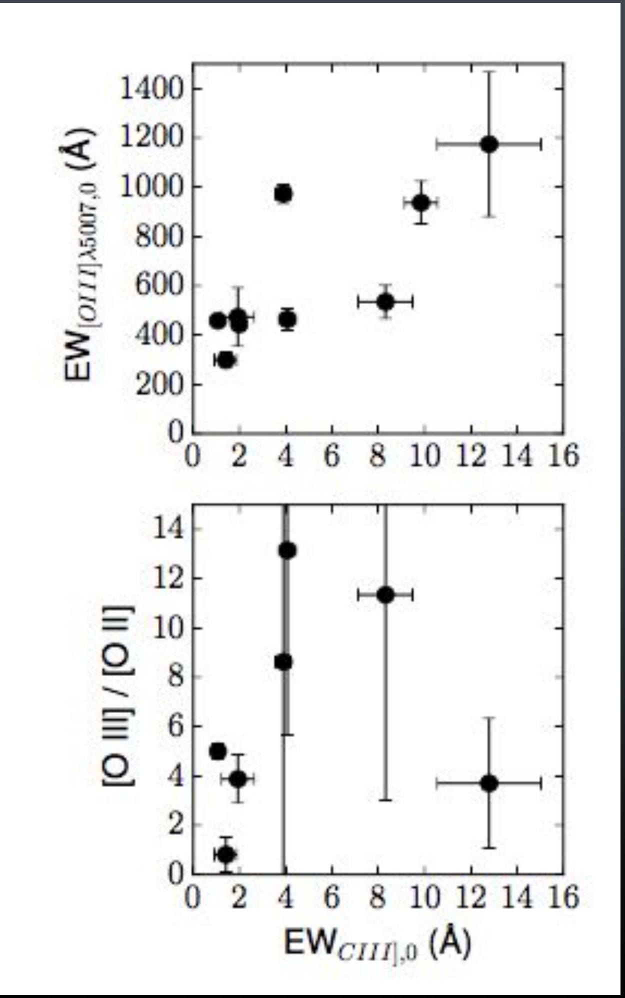


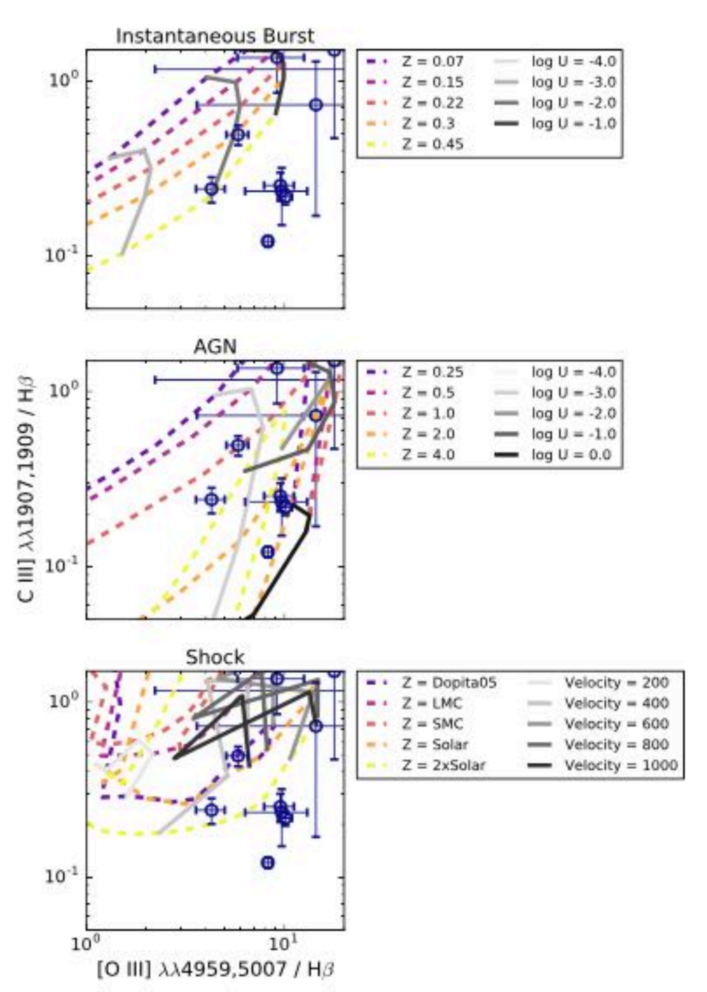
[OII] [OIII] HST WFC3/G141



Paper IV: Maseda et al 2017

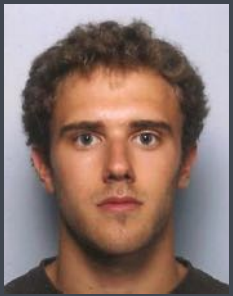
CIII emitters as alternative to Lya at high z

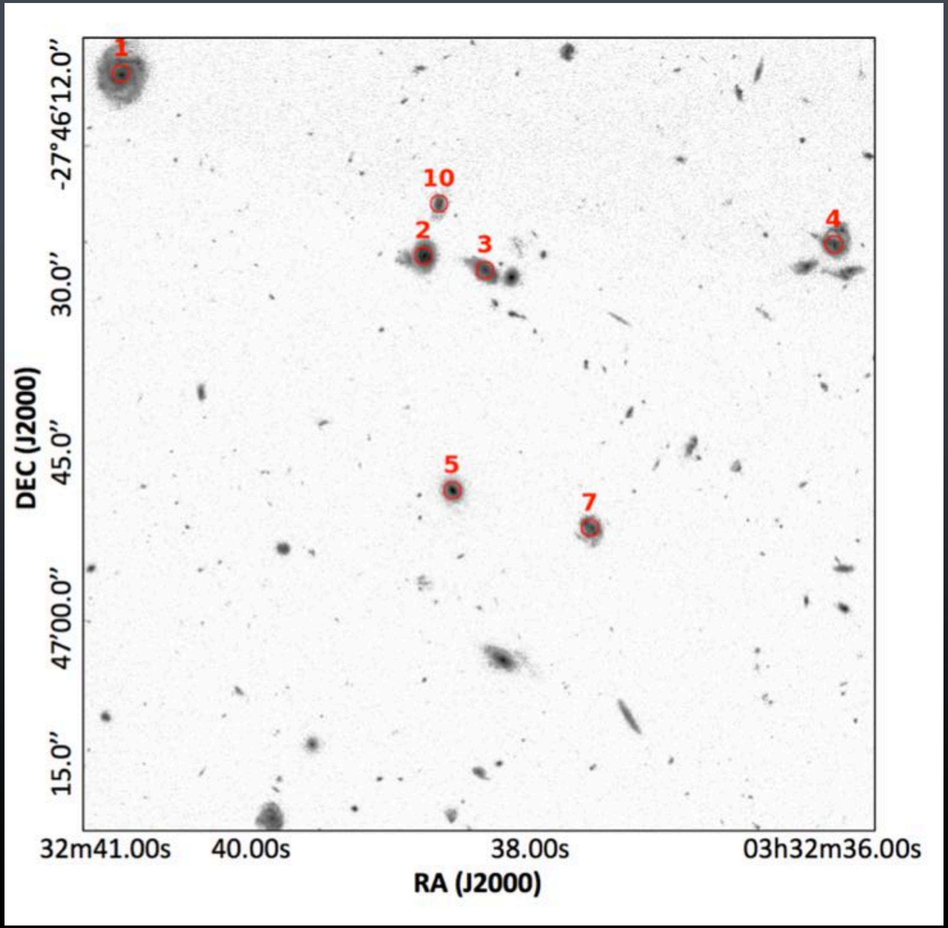




Paper IV: Maseda et al 2017

Spatially resolved stellar kinematics of galaxies at 0.2 < z < 0.8
Adrien Guérou (ESO) et al

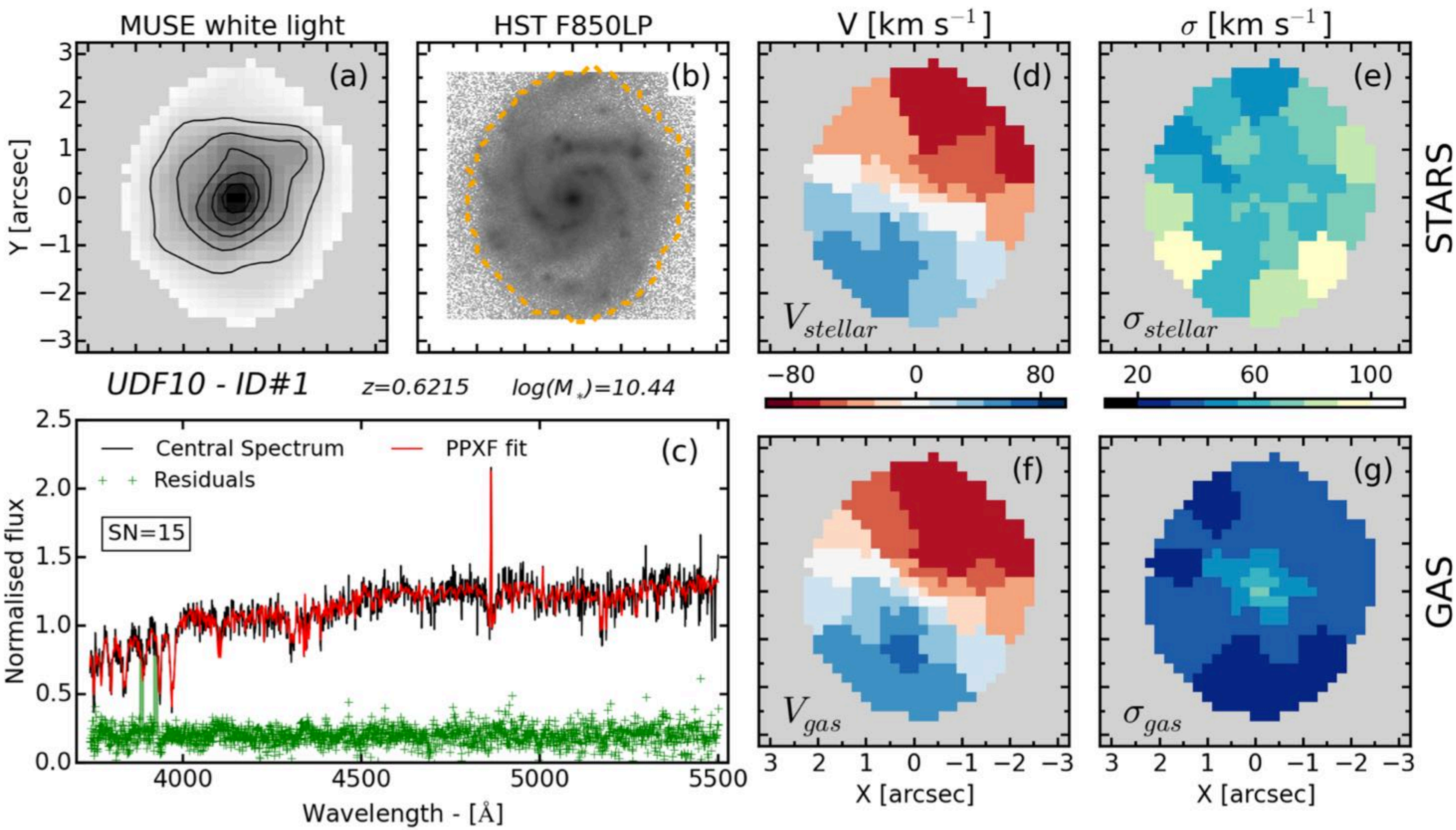




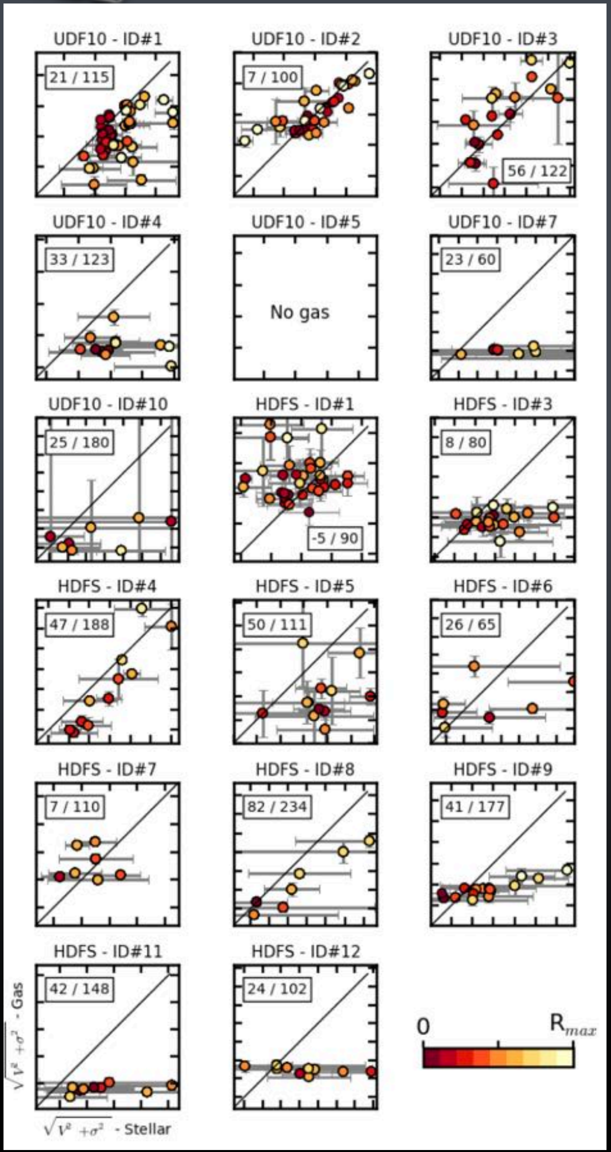
Paper V: Guerou et al 2017

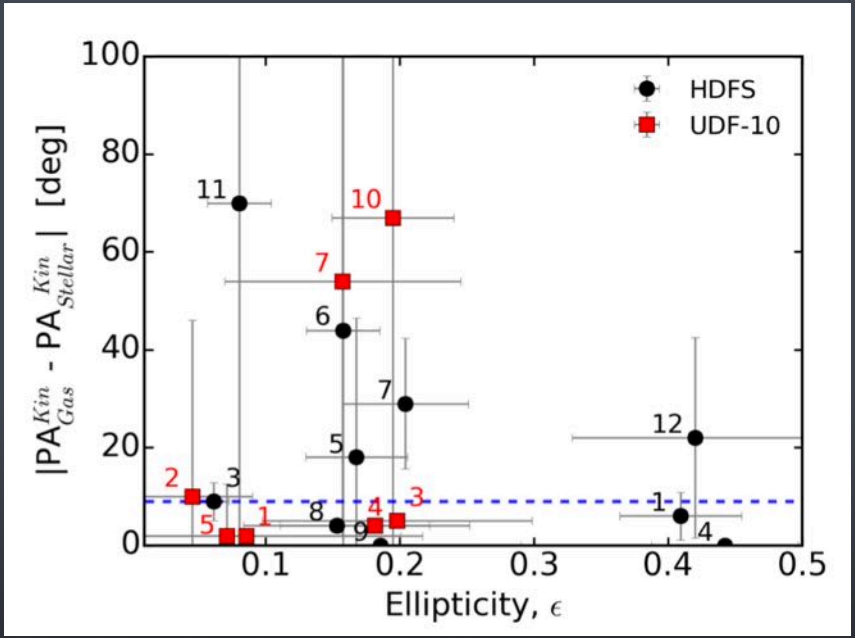
UDF-01 z=0.62

Paper V: Guerou et al 2017



Comparison of Stars and Gas kinematics.





Galaxy -	M_* (1)	M^S_{dyn} (2)	$M^S_{dyn}(R_e)$ (3)	$M^G_{dyn}(R_e)$ (4)
HDFS-ID #4	$0.72^{+0.35}_{-0.23}$	$10.2^{+0.05}_{-0.06}$	$5.7^{+0.2}_{-0.4}$	$6.3^{+0.3}_{-0.2}$
UDF10-ID #1	$2.75^{+0.48}_{-0.56}$	$14.9^{+0.1}_{-0.07}$	$4.5^{+0.3}_{-0.2}$	$5.6^{+2.6}_{-1.5}$

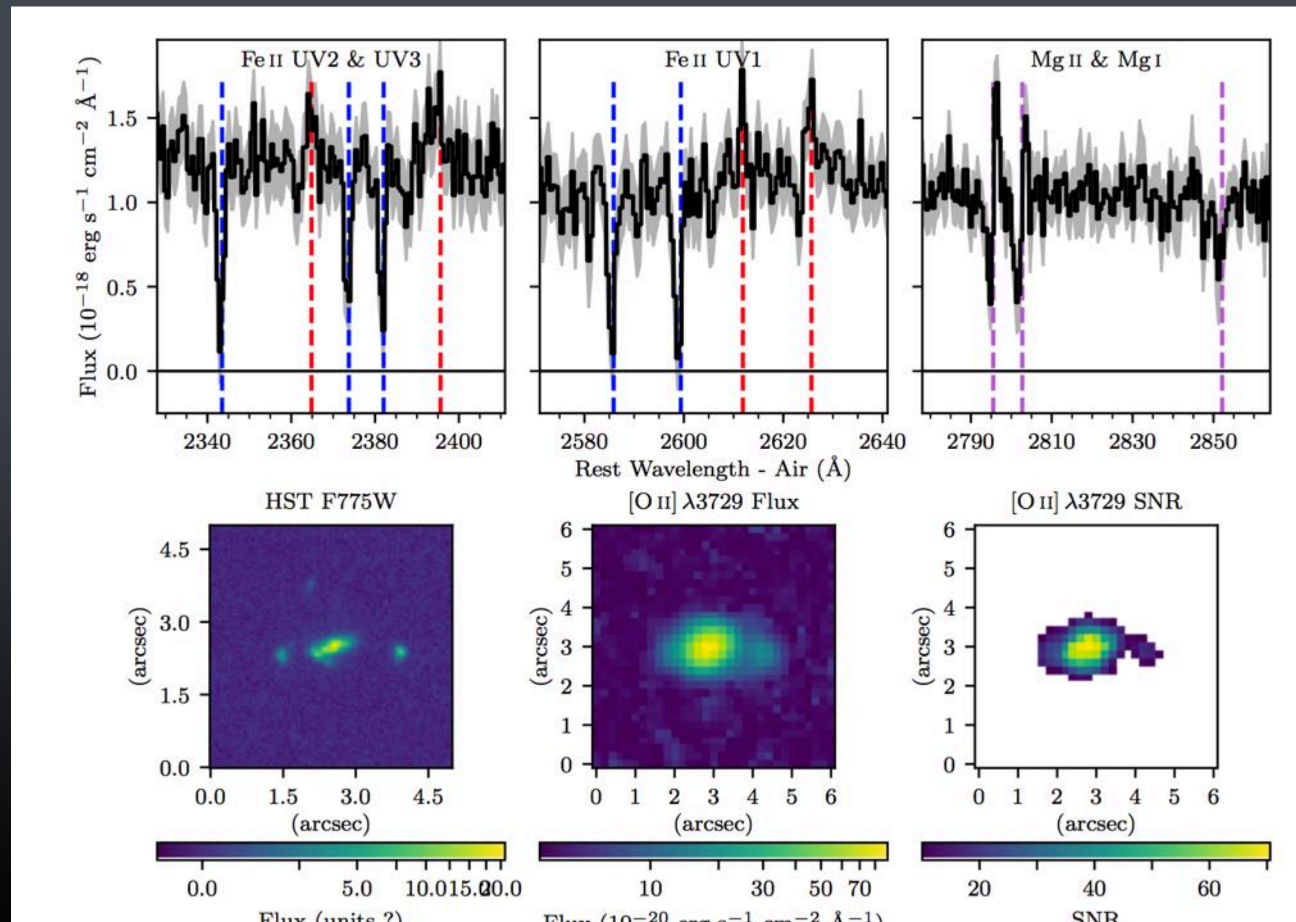
Paper V: Guerou et al 2017

Fe II* Emission in Star-Forming Galaxies
Hayley Finley (IRAP) et al

Non-resonant FeII* emission can potentially trace galactic winds in emission

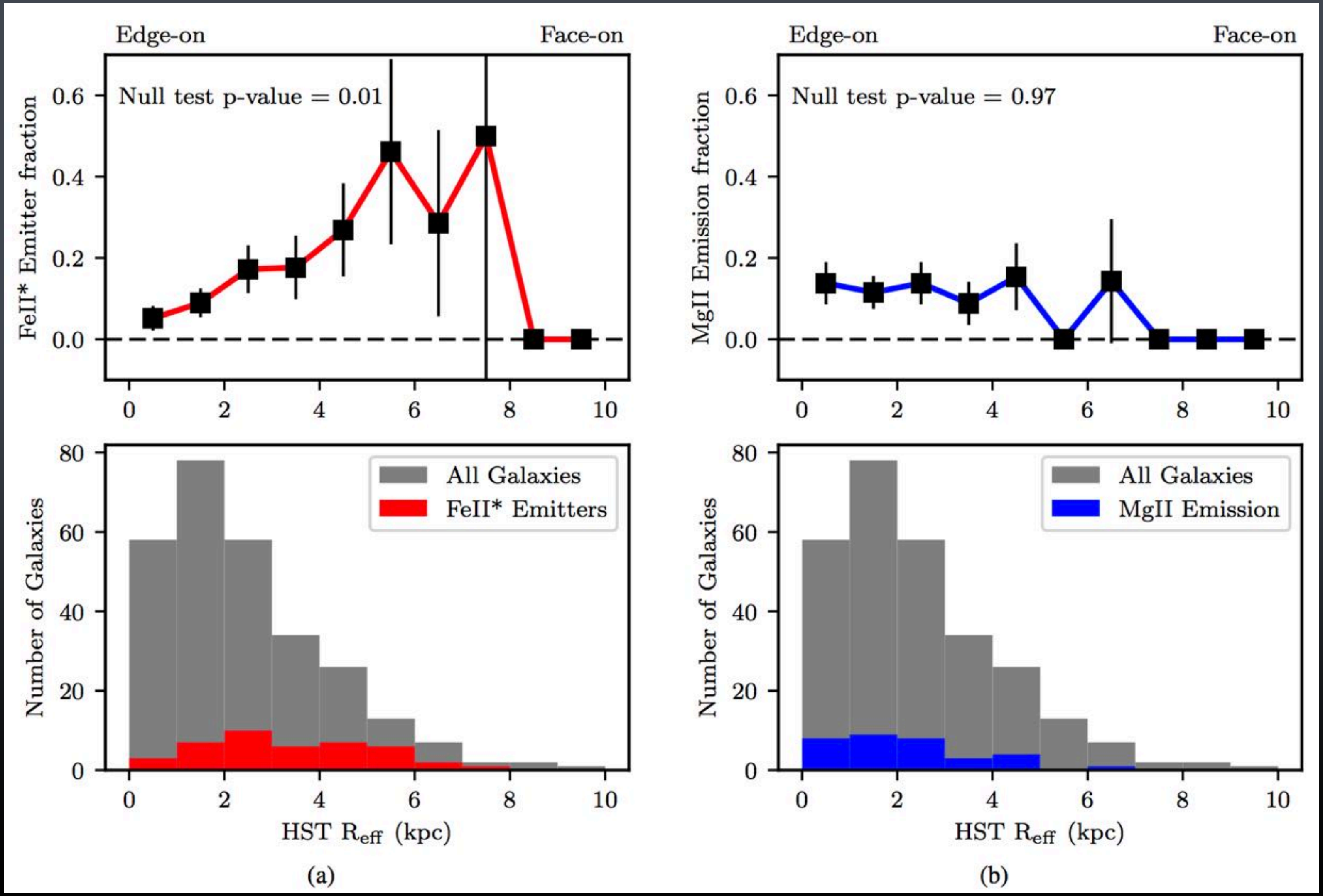
42 FeII* emitters

incl 12 MgII emitters



Paper VII: Finley et al 2017

FeII* emission is function of galaxy orientation

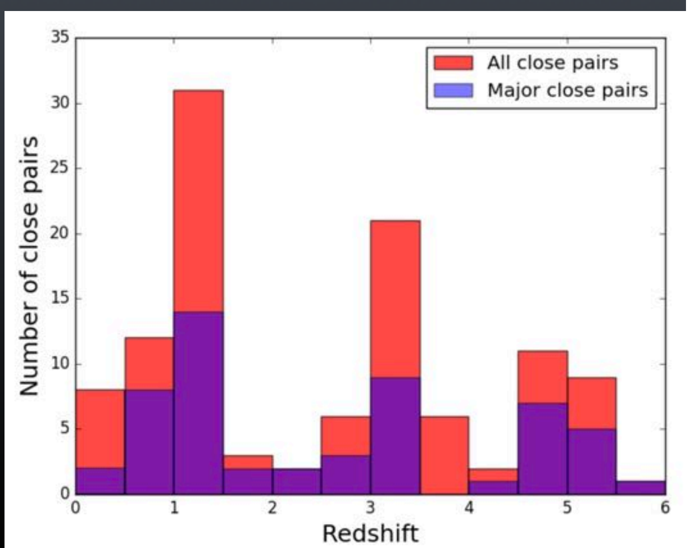


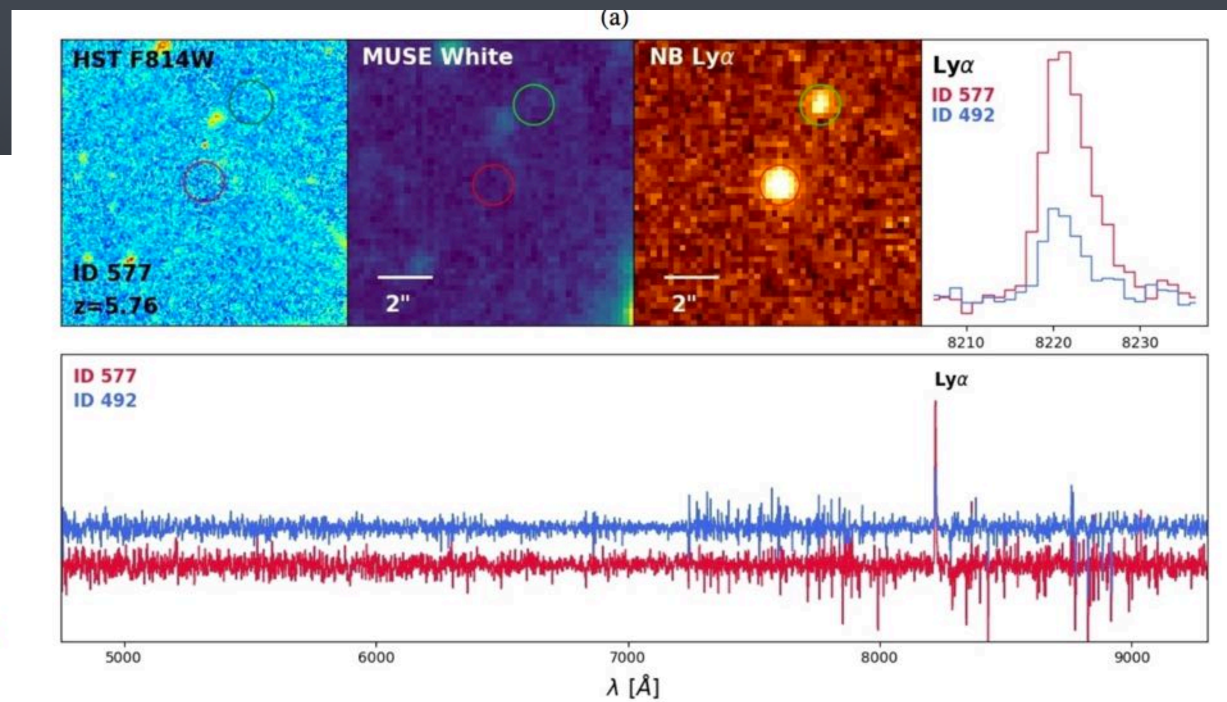
Paper VII: Finley et al 2017

Evolution of the major galaxy merger rate
Emmy Ventou (IRAP) et al

- **Spectroscopic pair counts**
- **UDF + HDFS cubes**
  - 113 pairs

Example of close pair of LAE at z=5.8

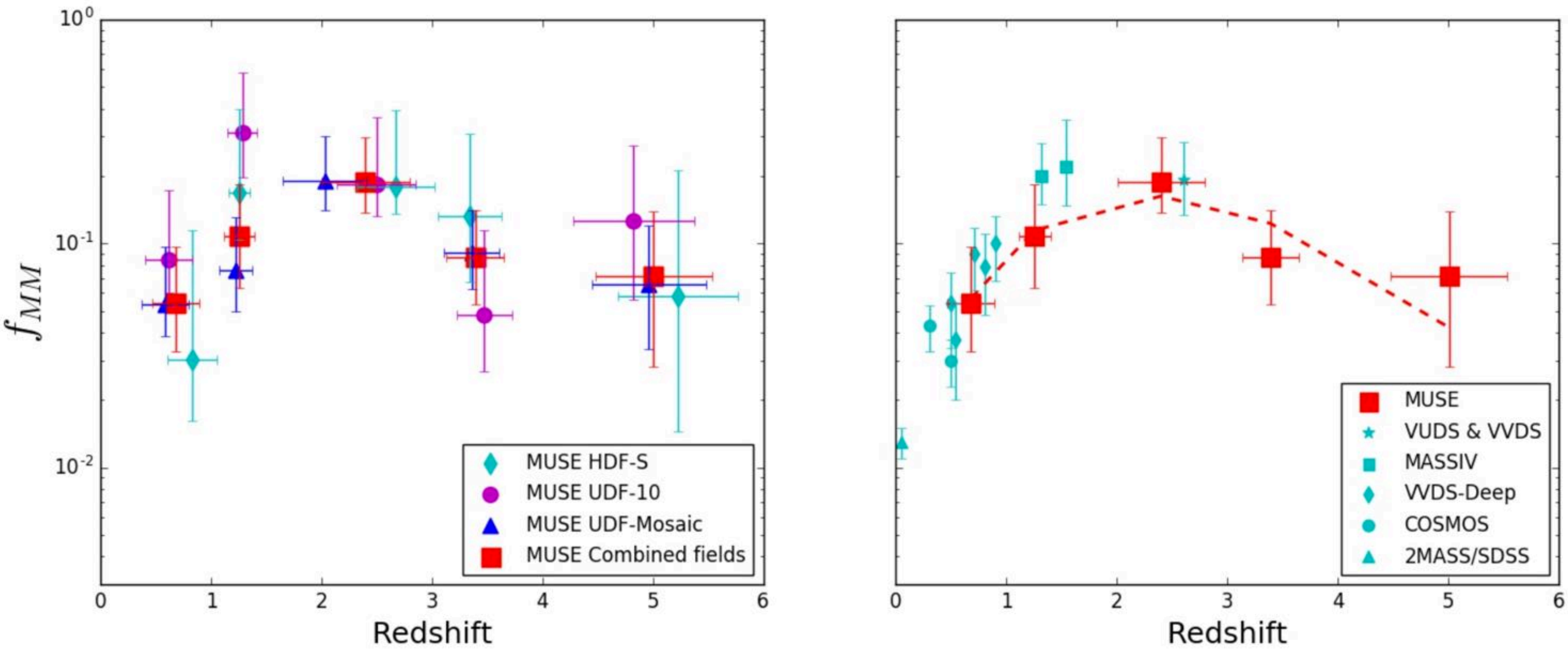




Paper IX: Ventou et al 2017

First constraints at z >3

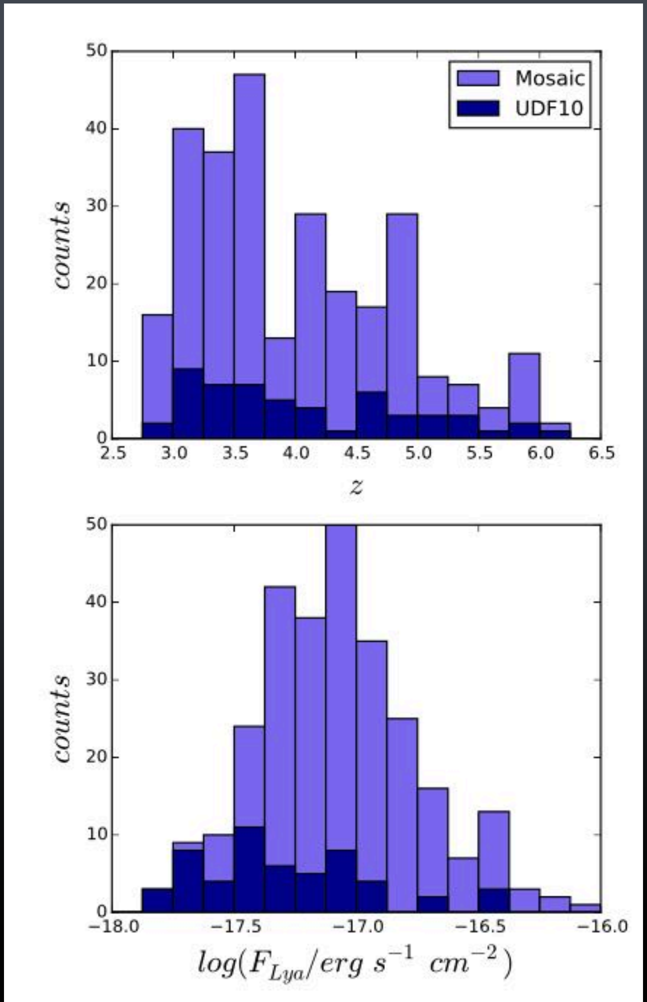
Paper IX: Ventou et al 2017



At z > 3 decrease of f_{MM} from 20% to 10%

Extended Lya Haloes (LAH) Floriane Leclerq (CRAL) et al

- **Wisotzki et al. 2016 HDFS**
  - Sample of 26 Lyα emitters
  - 21/26 detected extended halos 10x larger than continuum
- **This paper**
  - Larger sample: 224 Lyα emitters
  - Improved depth

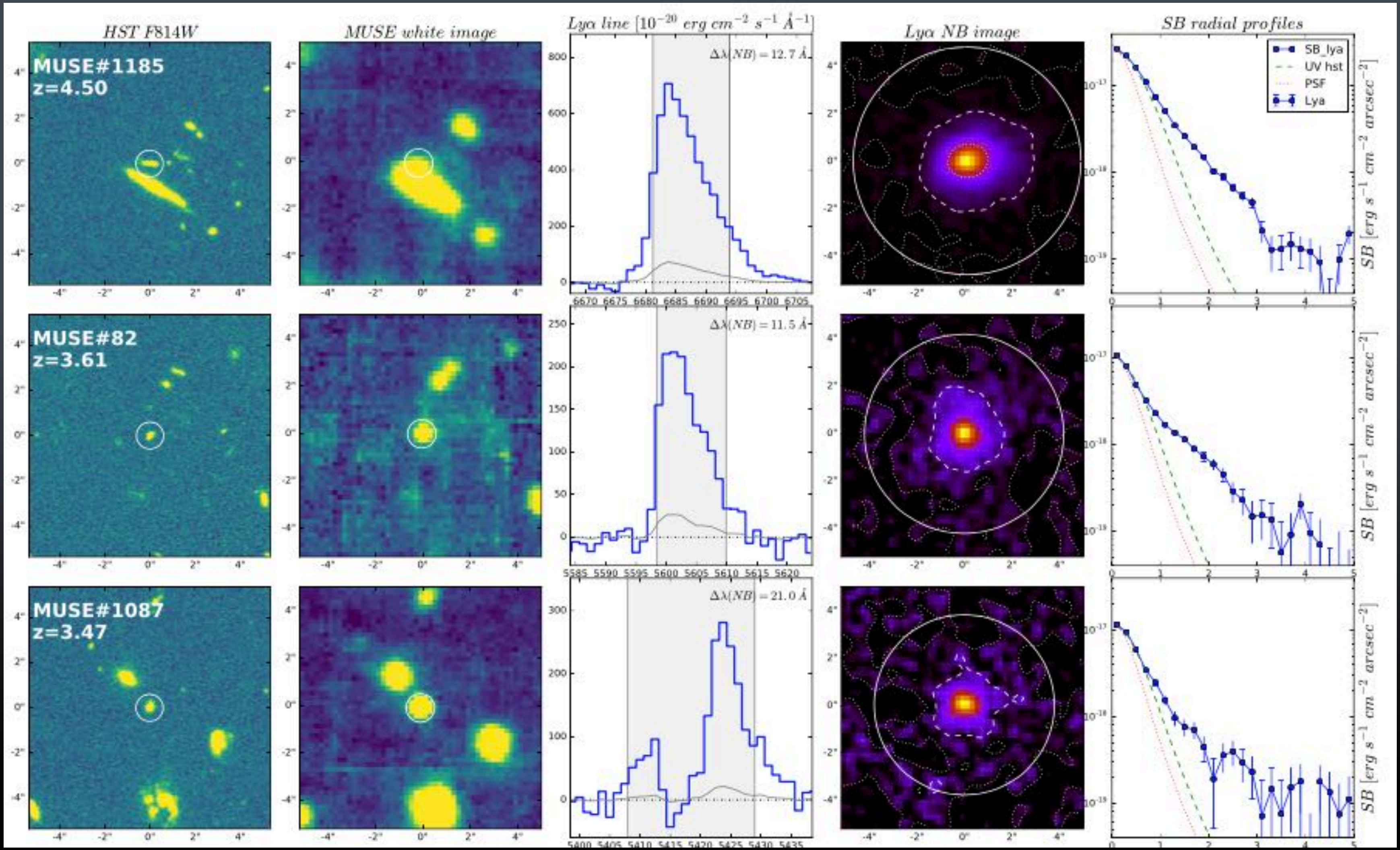


Paper VIII: Leclercq et al 2017

ESO - Göttingen - Leiden - Lyon - Potsdam - Toulouse - Zurich

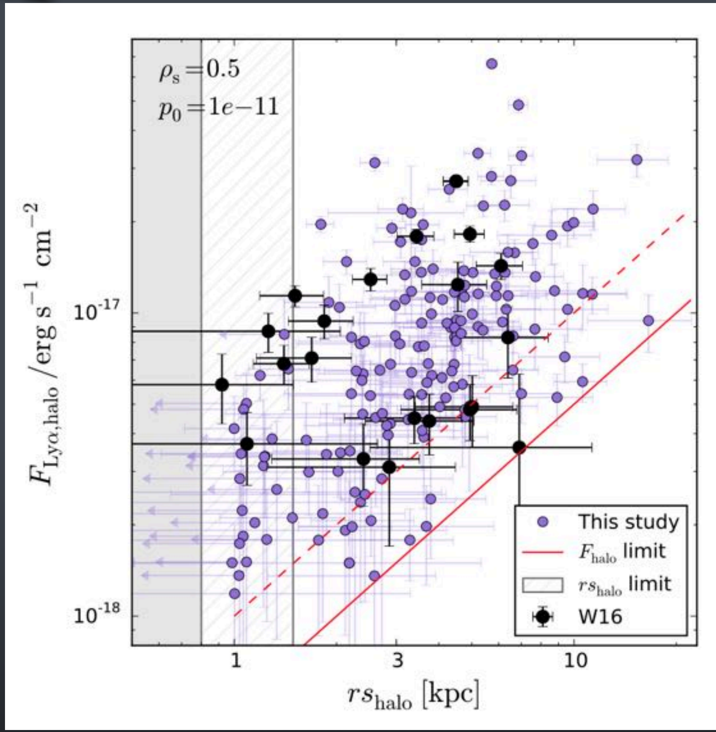
LAH Detection and Modelling

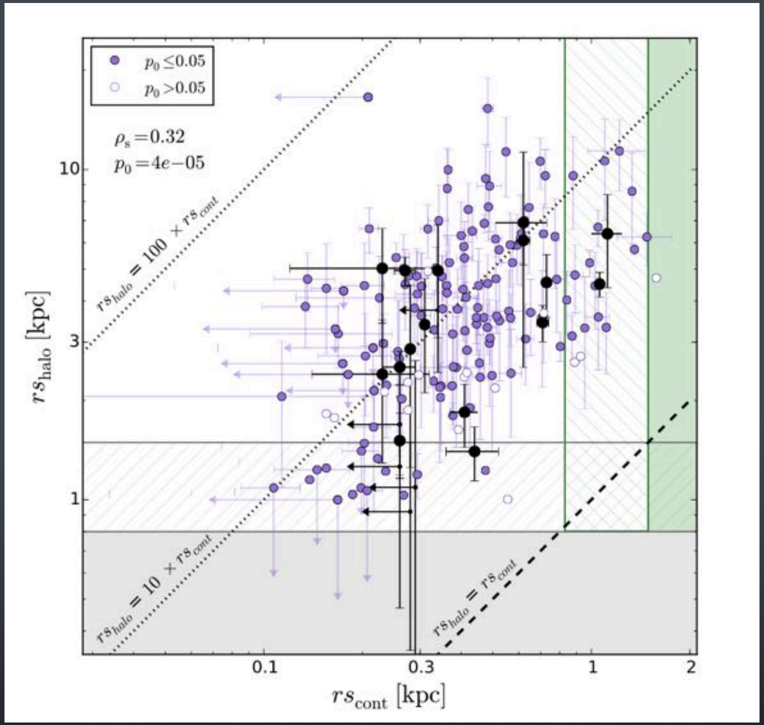
Paper VIII: Leclercq et al 2017



LAH properties

Paper VIII: Leclercq et al 2017





- **Discovery of extended Lya halo in 80% of Lya emitters selected sample**
- **Scale length 1-16 kpc (~10 x stellar continuum scale length), probe 50% of CGM virial radius**
- **Up to 70% of Lya flux in halo**
- **Properties of halo correlated to UV magnitude and size of host galaxy**

The MUSE Hubble UDF survey

- 100 hours of VLT with MUSE on the HUDF provide
  - the deepest spectroscopic survey ever made (3σ point source detection $1.5\ 10^{-19}$ $erg.s^{-1}.cm^{-2}$)
  - 1289 (mosaic) & 309 (udf10) high quality sources
  - Z=0-6.7 AB=21-31+
  - including 160 sources not in HST catalogs (~72 beyond HST HUDF 5 σ limit AB~31)
  - This is one order magnitude more spectroscopic redshifts compared to the data that has been accumulated on the UDF over 10 years.

The MUSE Hubble UDF survey

- **This unique data set allows us to**
  - Quantify the accuracy of **photo-z** at faint magnitude and high z
  - Explore the faint end of the **Lyα luminosity function**
  - Measure the **Lyα EW distribution,** including a few **extreme high EW** sources
  - Evaluate the **CIII] properties** as an alternative to Lyα at z>6
  - Get spatially **resolved stellar kinematics** of galaxies at z ~0.8
  - Study **galactic winds** using **FeII* emitters** at z=0.8-1.5
  - Get the first evolution of the major **galaxy merger rate at z>3**
  - Identify and characterize **extended Lyα haloes** as probe of the **CGM** at z>3
  - … and much more, stellar formation history, kinematical properties, …
- **To appear soon as a series of 10 papers in A&A**

muse

The future is bright ...