The MUSE Hubble Ultra Deep Field survey

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and the MUSE consortium

Tokyo Spring Lyman-alpha Workshop

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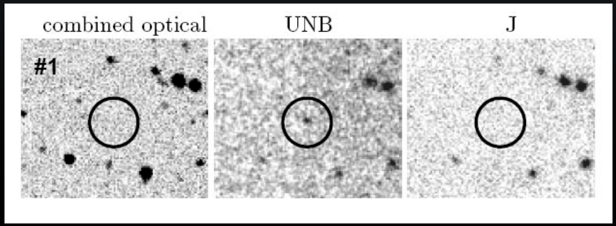
The search for Lyα emitters: Imaging or Spectroscopy ?

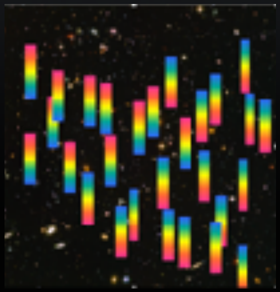
Imaging Narrow Band Survey

- Can cover very large field
  - Eg: SUBARU Hyper Suprime Cam
- Produce LAE candidates
  - Need spectroscopic confirmation or interloper efficient detection
- Limited to "clean" window wrt OH lines
- Best to explore the bright end of the LAE luminosity function (~10^{-17} erg.s^{-1}.cm^{-2})
- Blind survey (no preselection)
  - But in practice the interloper detection introduce some bias
- Limited information (Lyα flux) available



Spectroscopic Survey

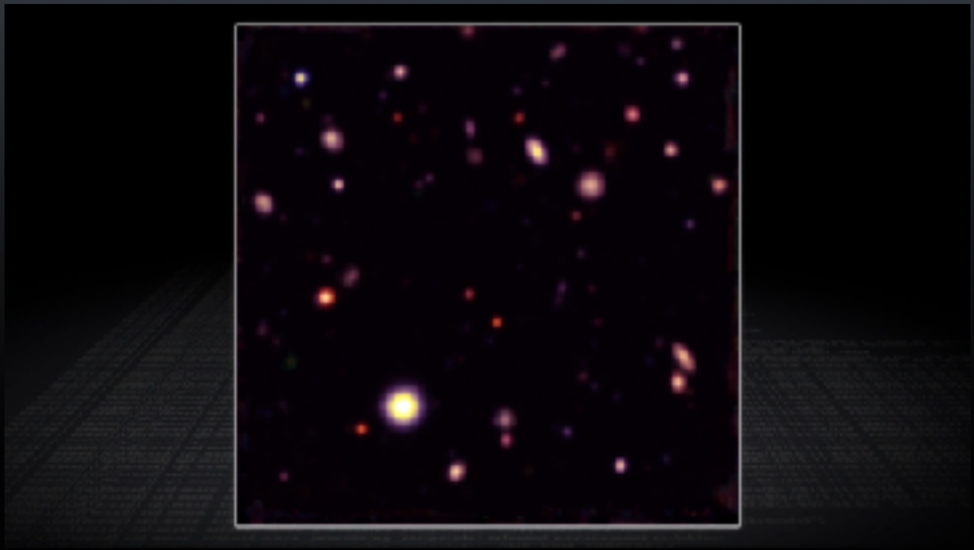
- Limited multiplex capabilities
  - Eg: VIMOS 400 slits
- Need preselection
  - Biased survey based on continuum/color preselection
  - Not very efficient
- Expensive in telescope time
- Can reach fainter flux (~10^{-18} erg.s^{-1}.cm^{-2}) but on a limited number of targets
- Spectroscopic information available
  - Eg line shape



The search for Lyα emitters: Imaging and Spectroscopy

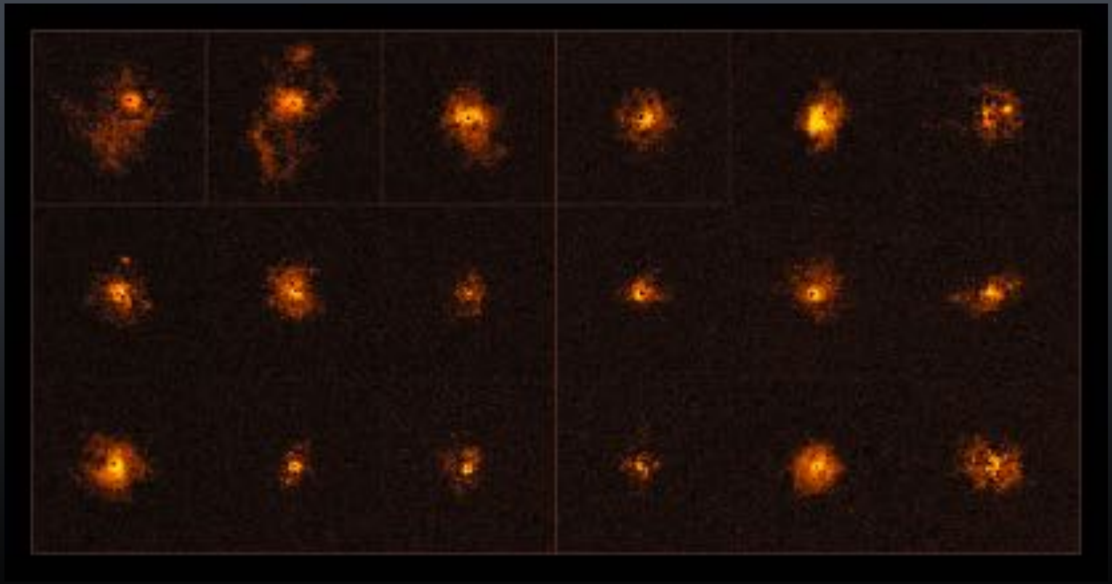
- A large field Integral Field Survey can achieve both capabilities
  - Blind survey (no preselection)
  - Faint limiting flux detection (< 10^{-18} erg.s^{-1}.cm^{-2})
- In practice, the field of view limited by cost (optics/detectors) and instrument size
  - Best suited for dense field, ie deep enough
- Can explore the faint end of the LAE luminosity function

MUSE HDFS datacube



The search for Lyα emitters: Imaging and Spectroscopy

- Blind spectroscopy of all spaxels
  - Can detect diffuse emission at low surface brightness
  - In the case of Lyα MUSE can probe ionised Hydrogen at large scale (eg CGM and IGM)



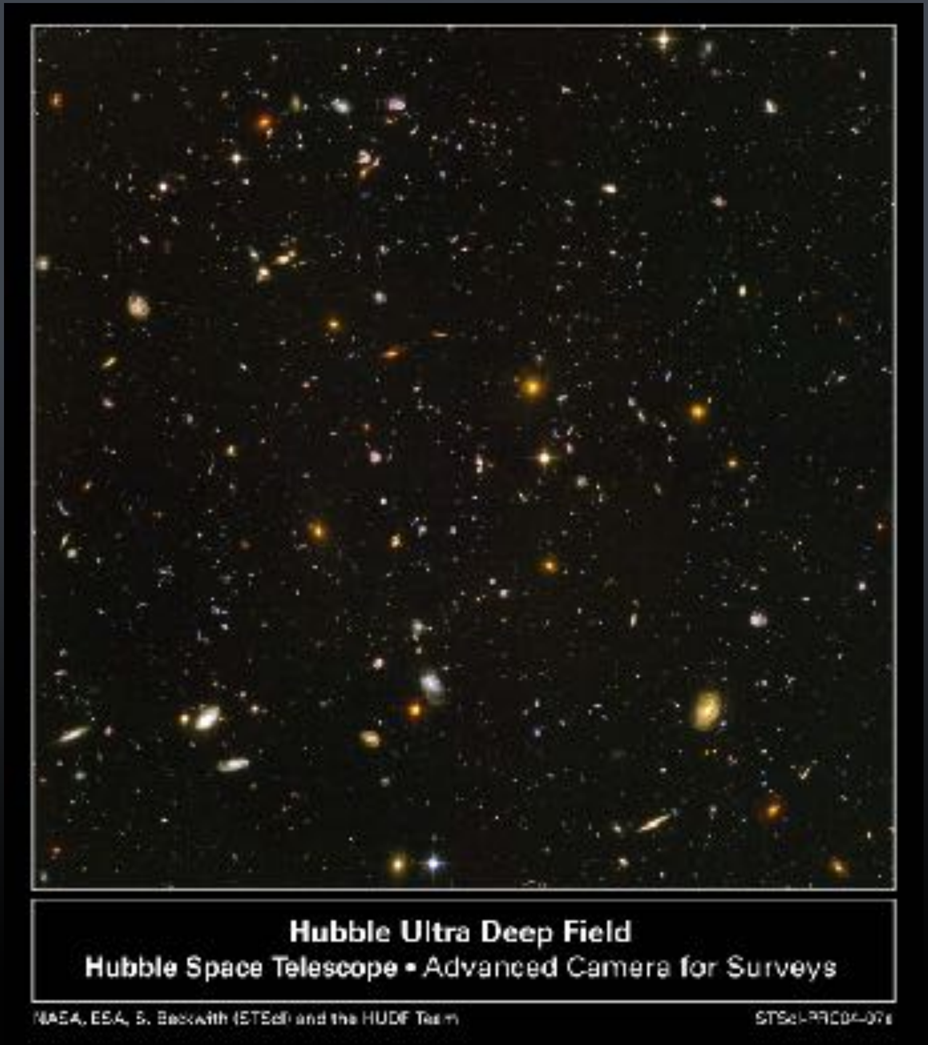
Ubiquitous Giant Lyα Nebulae around the Brightest Quasars at z ~3.5 Revealed with MUSE, E. Borisova et al, 2016

MUSE in a nutshell

- Large field IFU 2nd generation VLT instrument
- Visible 480-930 nm, R~3000
- Field 1'x1', 0.2" (WFM)
- Field 7"x7", 0.025" (NFM)
- Coupled to ESO AO Facility
  - 0"5 (WFM) & diffraction limited (NFM) resolution
- Throughput
  - 40% end-to-end

- Consortium
  - CRAL,IRAP,Leiden,AIP, AIG, ETH, ESO
- Time-line
  - 2001: Call for idea
  - 2004: ESO Contract
  - 2014: First light non AO WFM
  - 2017: First light GLAO WFM
  - 2018: First light LTAO NFM
- Cost: 20 M€ (7 M€ Hardware)
- GTO
  - 255 nights
  - Science team: ~80 scientists

MUSE Hubble Deep Fields



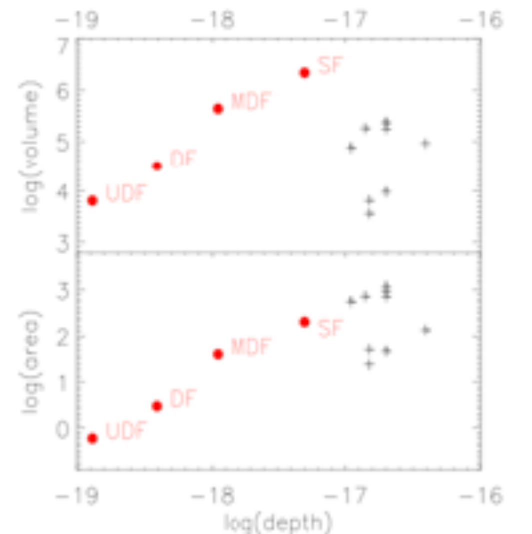
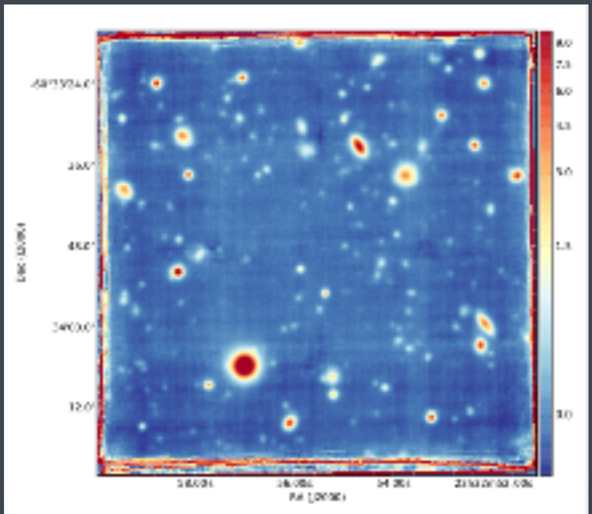


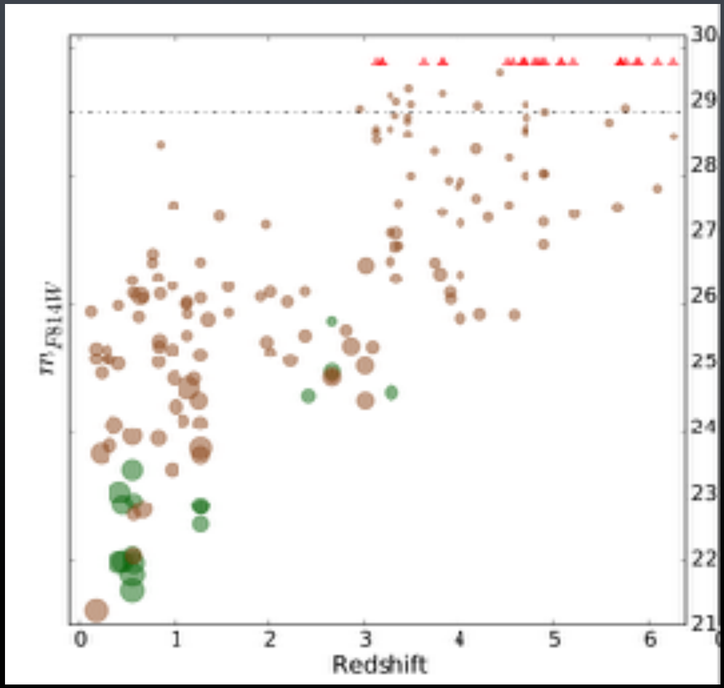
Figure 2-1: Sampled area (in arcmin²) and sampled volume (comoving Mpc³) of MUSE deep fields (red circles) versus the current Ly_α surveys (cross) discussed in Table 2-1 (section 2.2).

MUSE science case
Bacon et al, 2004

MUSE Hubble Deep Field South observations



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

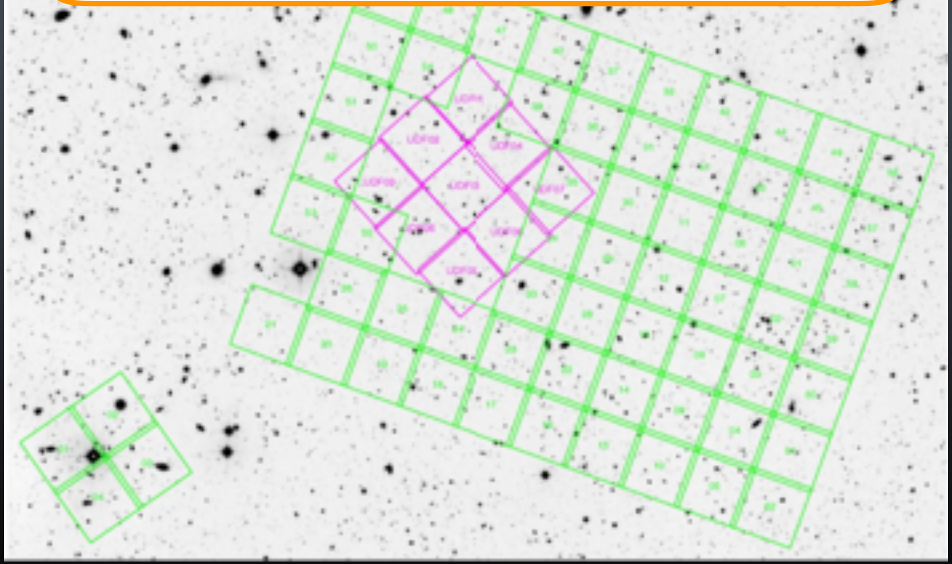


Bacon et al. 2015: The MUSE 3D view of the Hubble Deep Field South
Wisotzki et al. 2016: Discovery of extended Lyα halos in the circumgalactic medium around high redshift galaxies
Contini et al. 2016: study of gas kinematics
Drake et al. 2017: the Lyα luminosity function
Carton et al. 2017: measurement of metallicity

MUSE spectroscopic surveys in the CDFS area

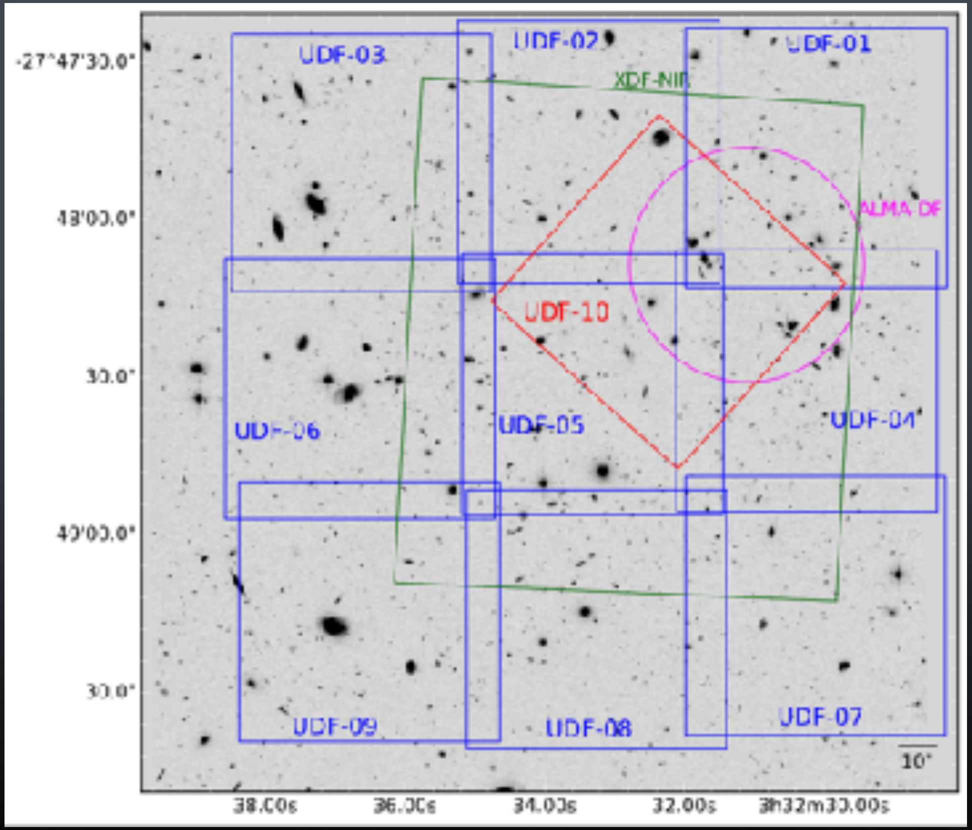
- MUSE Wide
  - Field: 78 arcmin^2
  - GLAO: No
  - Depth: 1h
  - Status: completed
- MUSE Deep
  - Field: 9 arcmin^2
  - GLAO: No
  - Depth: 10h
  - Status: completed
- MUSE Ultra Deep
  - Field: 1 arcmin^2
  - GLAO: No
  - Depth: 30h
  - Status: completed
- MUSE eXtreme Deep
  - Field: 1 arcmin^2
  - GLAO: Yes
  - Depth: 100-150h
  - Status: planned

- Tanya Urrutia: The MUSE-Wide survey: A (not so) shallow survey in deep fields (Poster)
- Kasper Schmidt: Probing the ISM at z>3 using rest-frame UV emission lines from MUSE Data of ~1000 LAEs (Talk)
- Josephine Kerutt: Stacking HST data of MUSE LAEs to find Lyman continuum emission (Talk)
- Rikke Saust: Lyman-alpha Haloes of UV Bright Galaxies in the MUSE-Wide Survey (Poster)



The MUSE Hubble Ultra Deep Field Survey

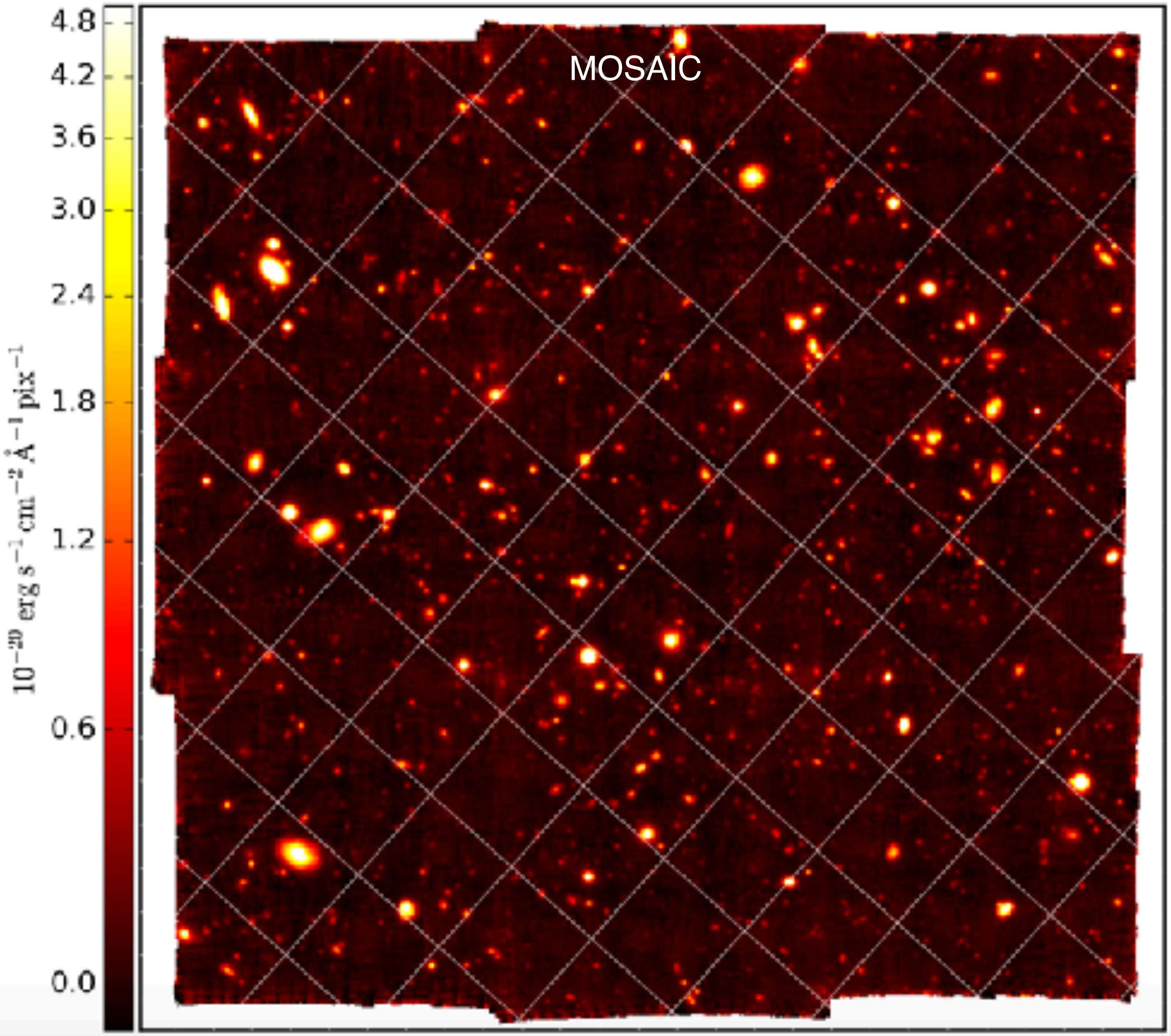
- 9 GTO runs 2014-2016
- 137 hours of telescope time, 116 hours of open shutter time (86% efficiency)
- 278 x 25 mn exposures in dark time & good seeing ~0.8”

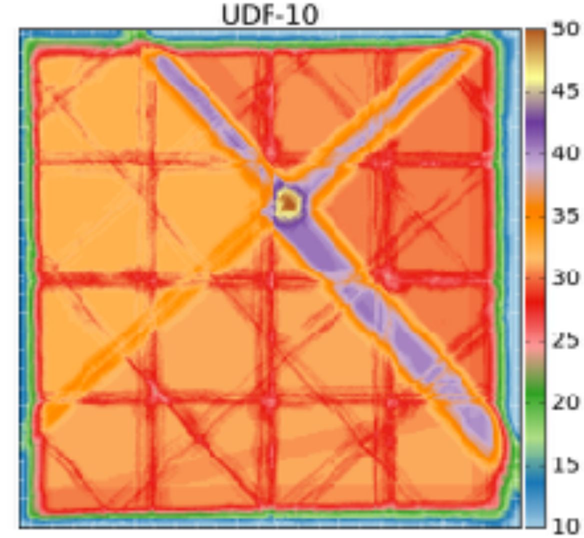


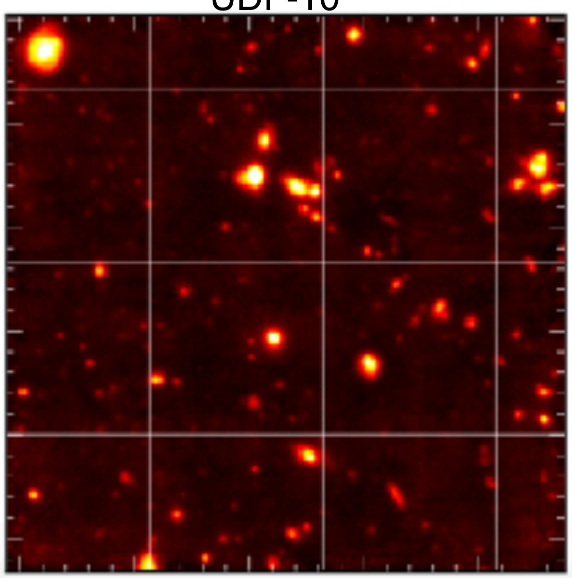
Workflow

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

White Light Images

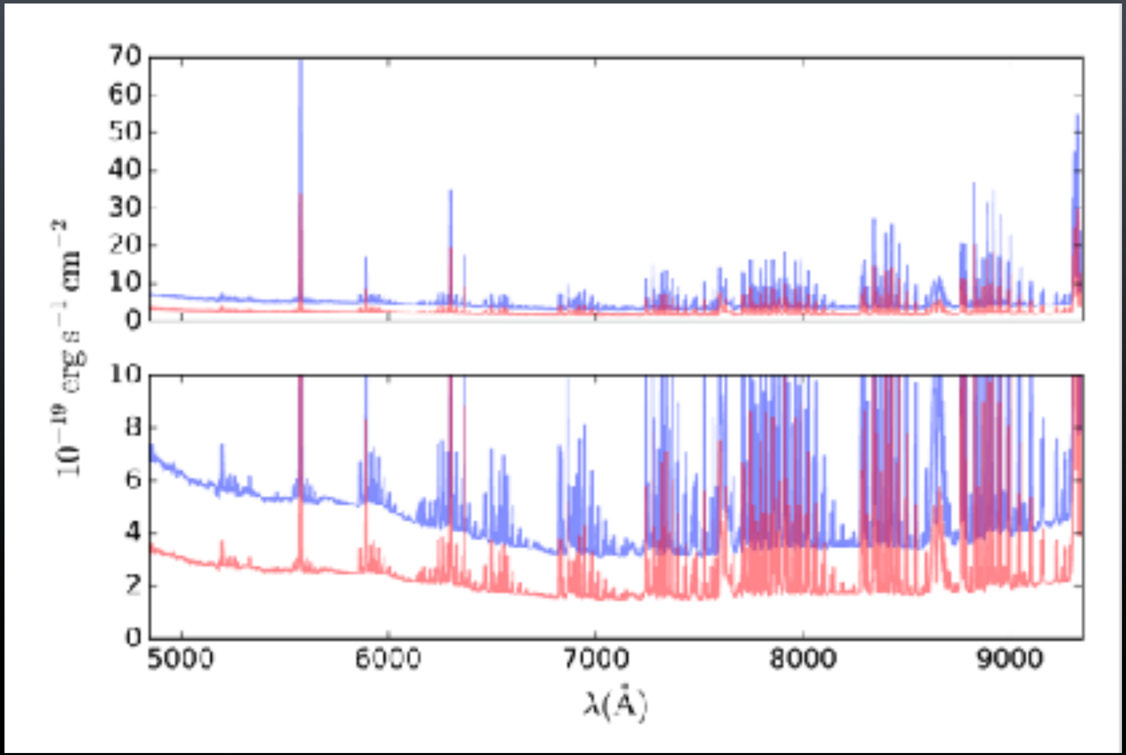




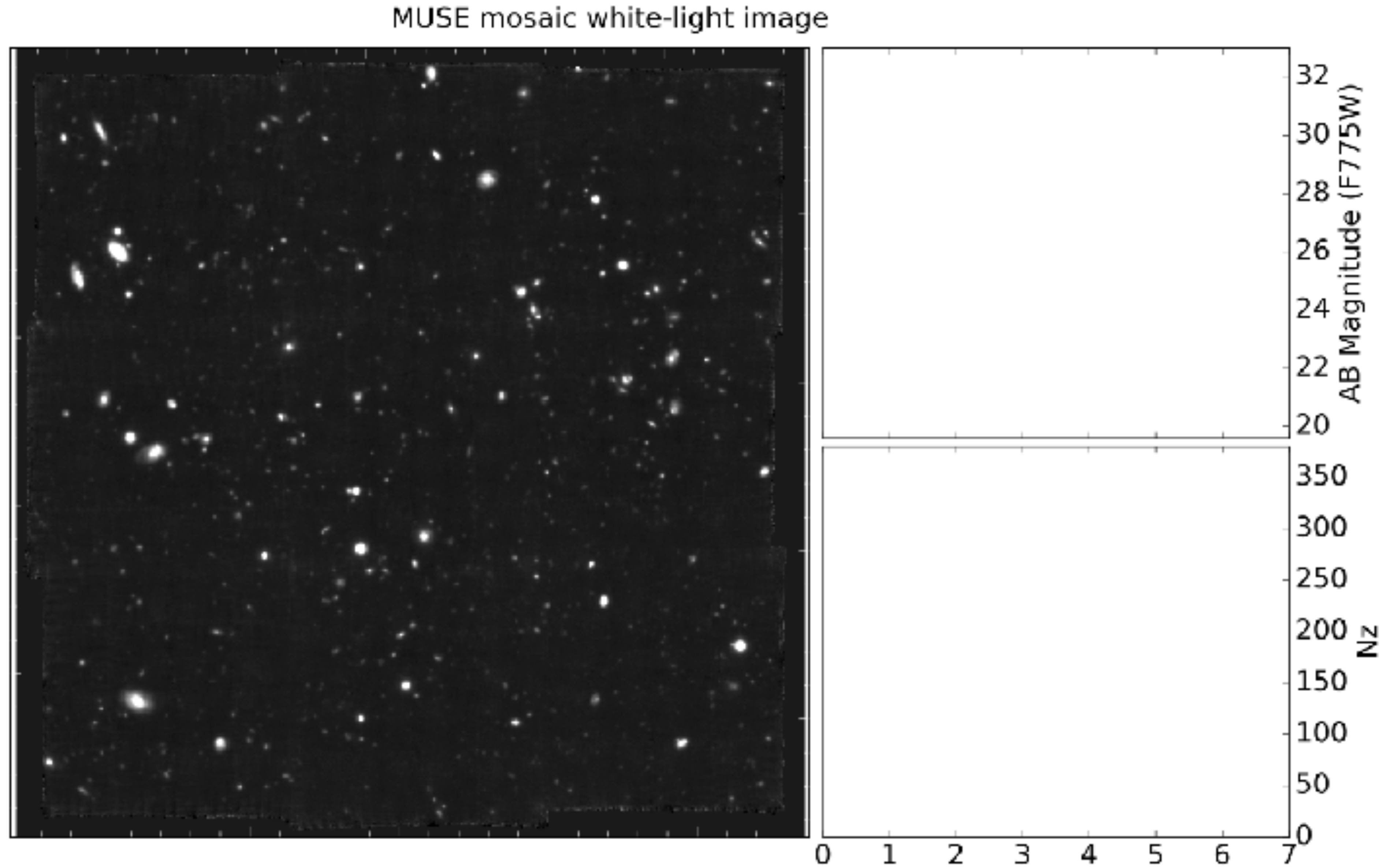


Achieved Sensitivity

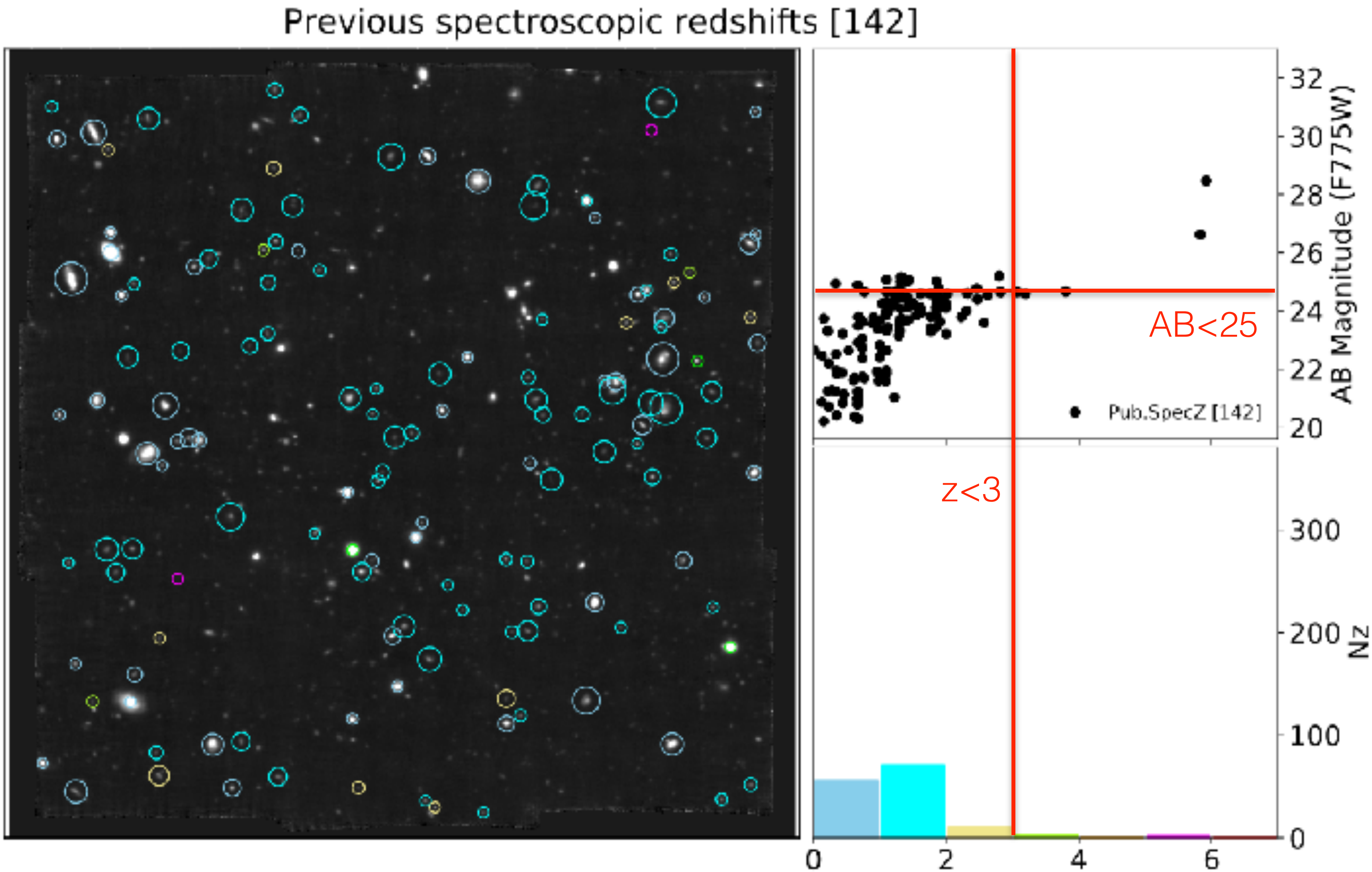
- 3σ point source detection for emission line (3.7A)
- UDF10: 1.5 10^{-19} $erg.s^{-1}.cm^{-2}$
- MOSAIC: 3.1 10^{-19} $erg.s^{-1}.cm^{-2}$



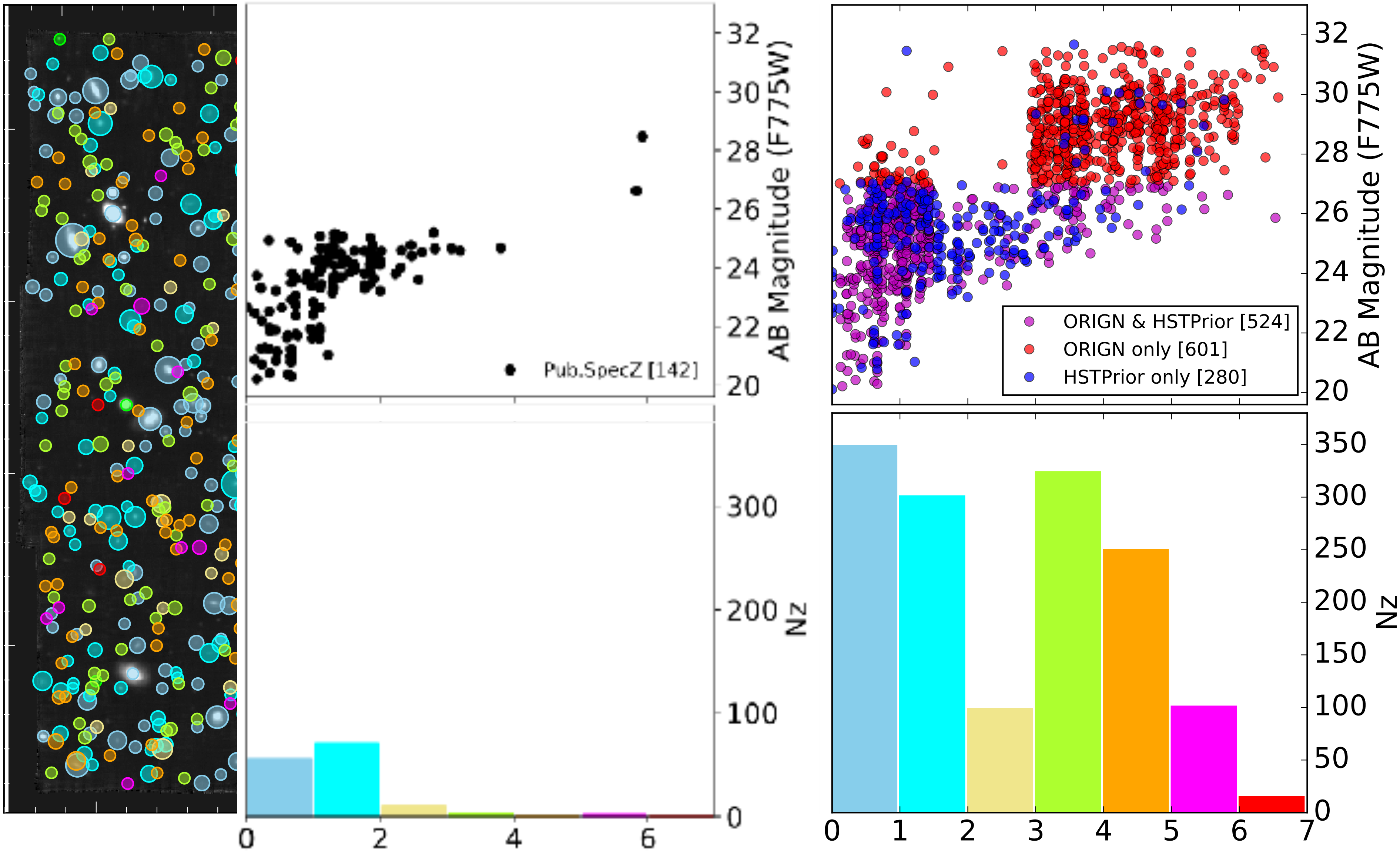
Redshifts in the MUSE field



Redshifts in the MUSE field



MUSE redshifts ORIGIN & HSTPrior [1443]



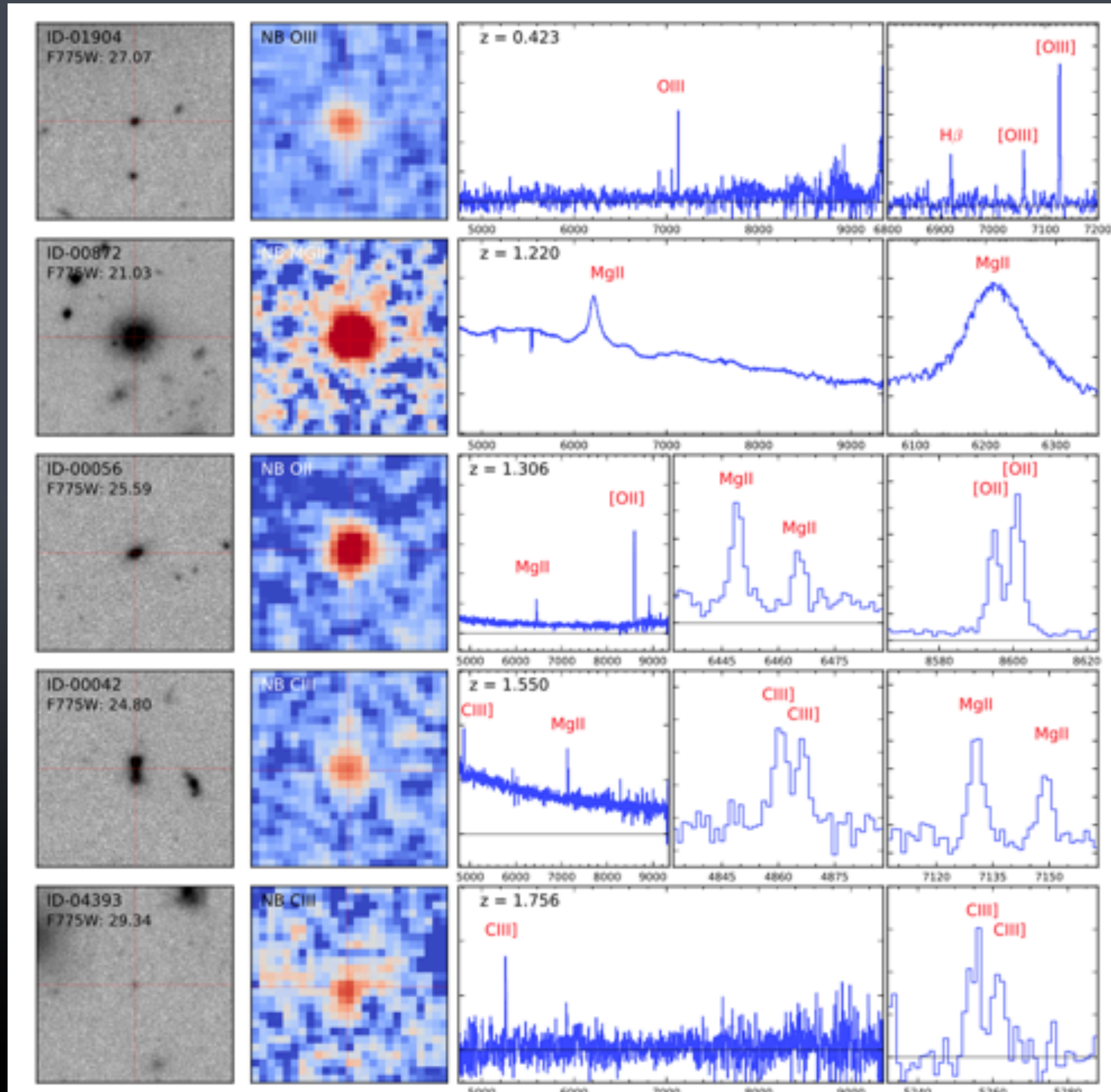
z = 0.423 AB = 27.07

z = 1.220 AB = 21.03

z = 1.306 AB = 25.59

z = 1.550 AB = 24.80

z = 1.756 AB = 29.34



LAE

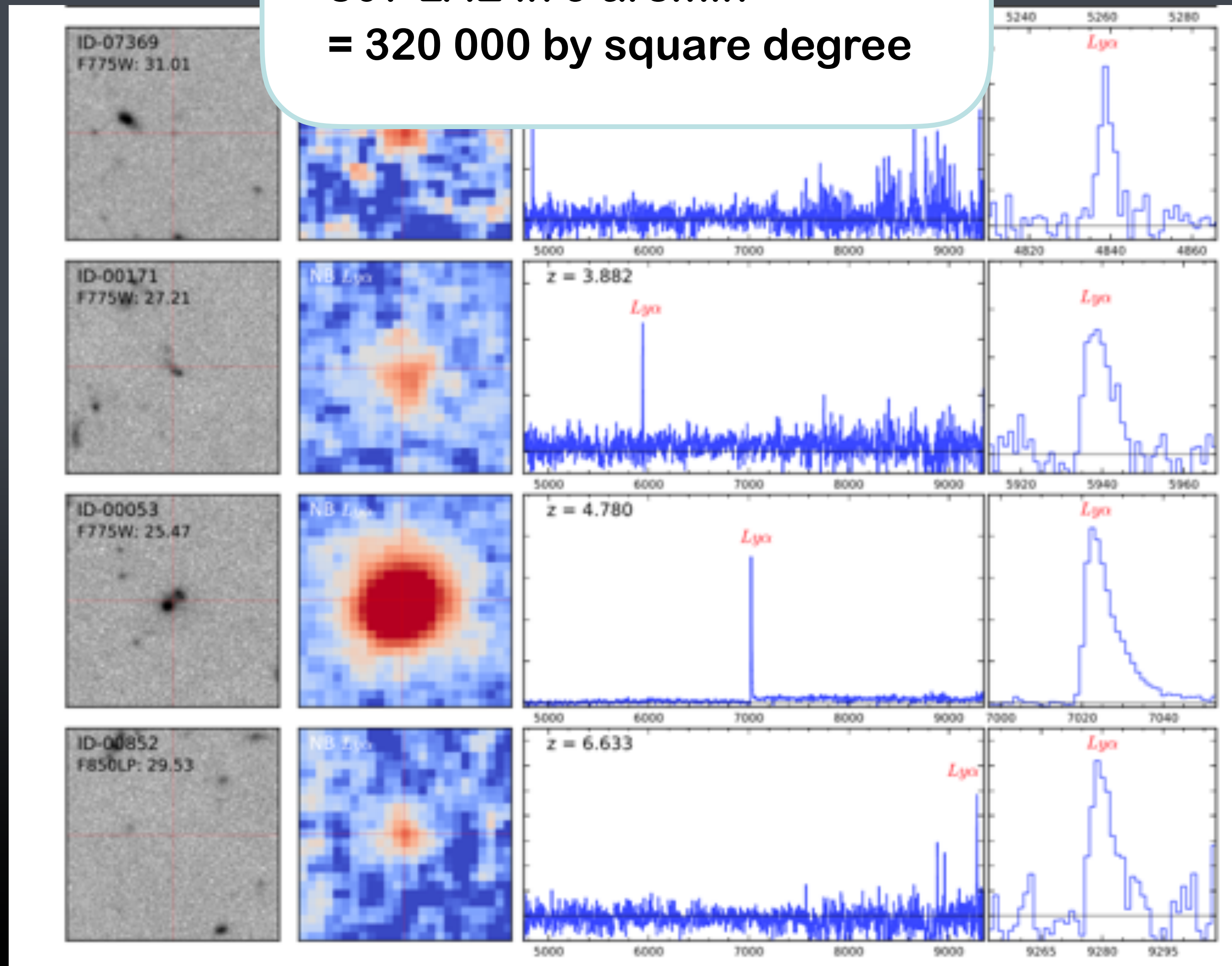
807 LAE in 9 arcmin²
= 320 000 by square degree

z = 2.981 AB = 31.01

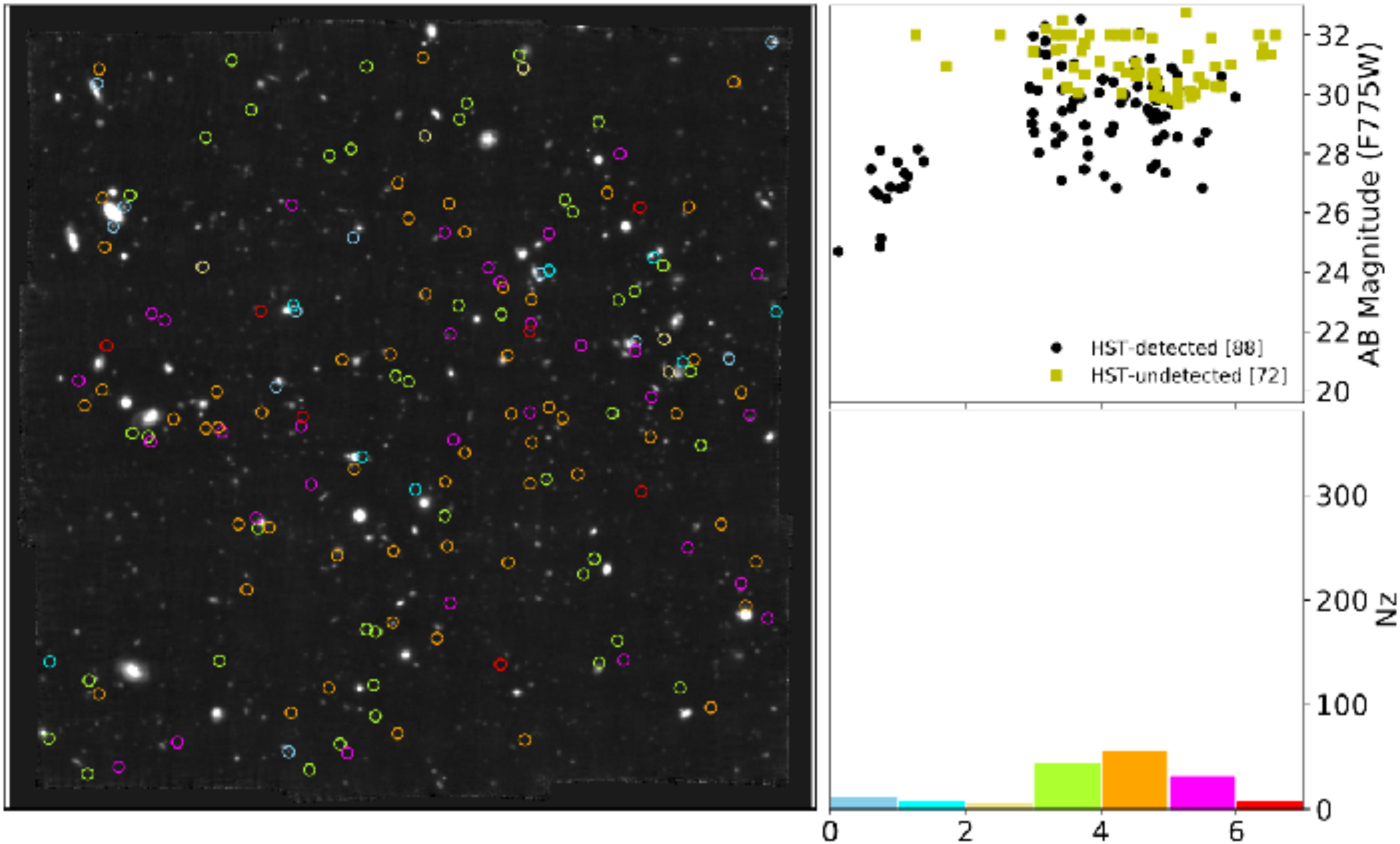
z = 3.882 AB = 27.21

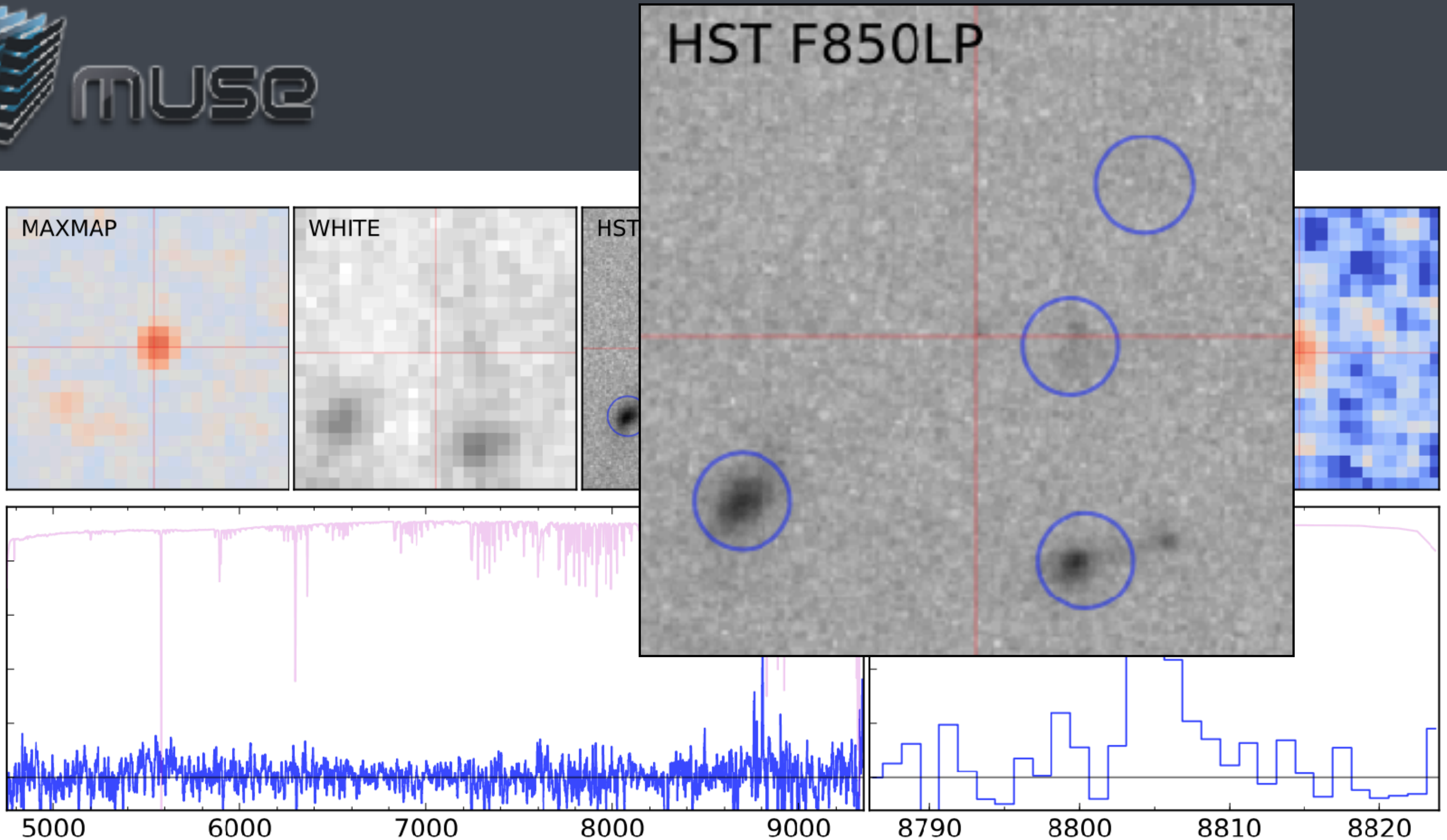
z = 4.780 AB = 25.47

z = 6.633 AB = 29.53



MUSE redshifts not in Rafelski[160]



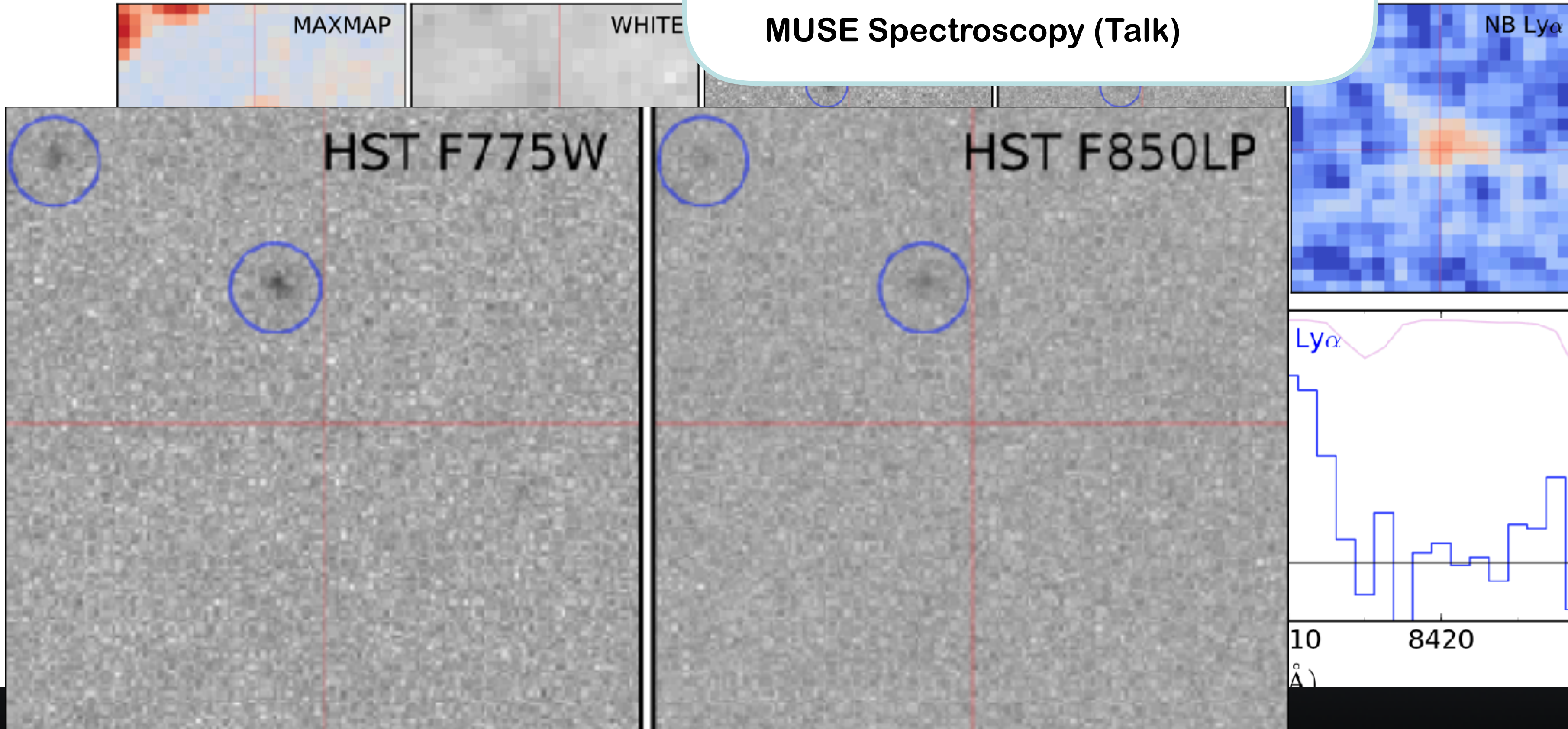


Lya Z = 6.24
AB F850LP 29.48 ± 0.18

Paper I: Bacon et al 2017

ID 6326

More by Michael Maseda:
HST-undetected LAEs from MUSE Spectroscopy (Talk)

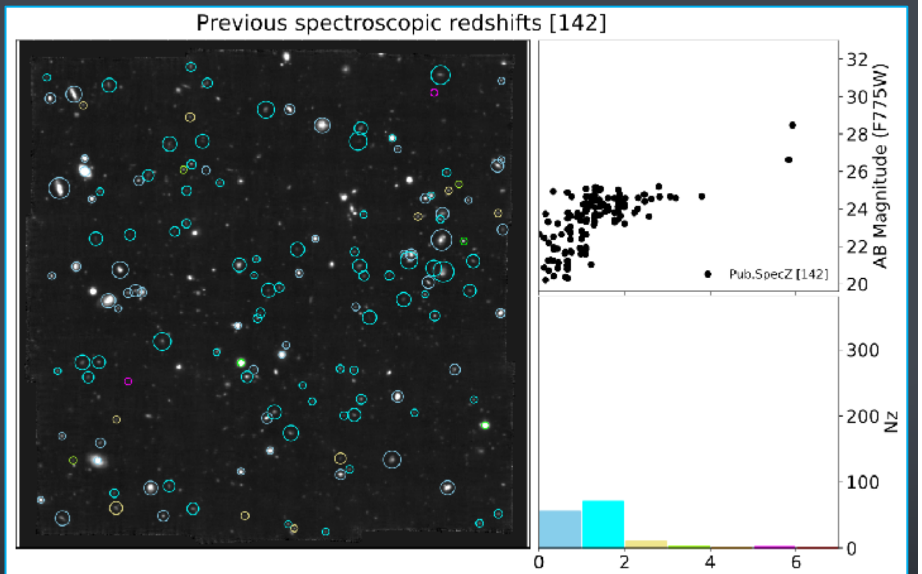


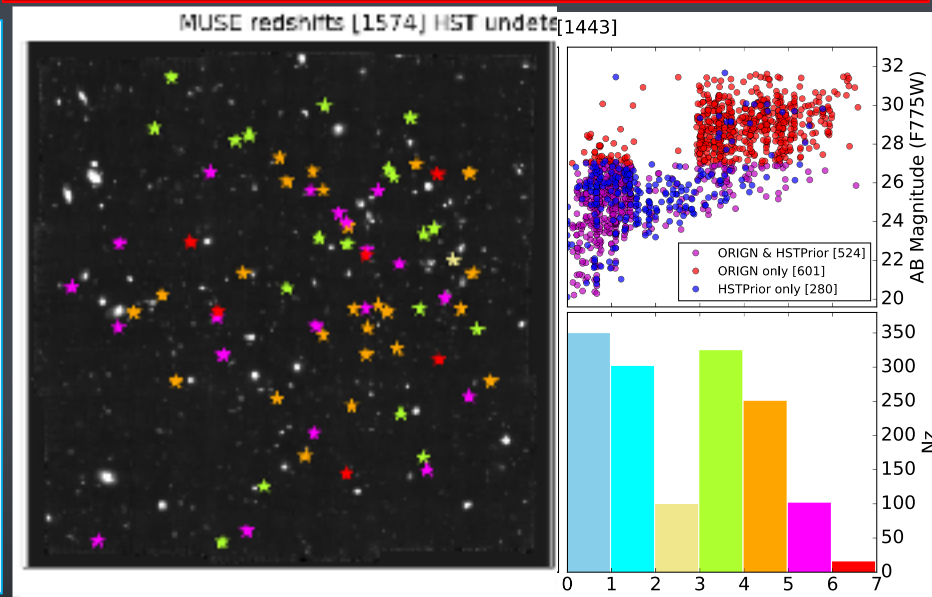
Lya Z = 5.91
AB F850LP > 30.7

Paper I: Bacon et al 2017

The MUSE Hubble Ultra Deep

72 Lyα without HST counterpart





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

The MUSE Hubble Ultra Deep Field Survey

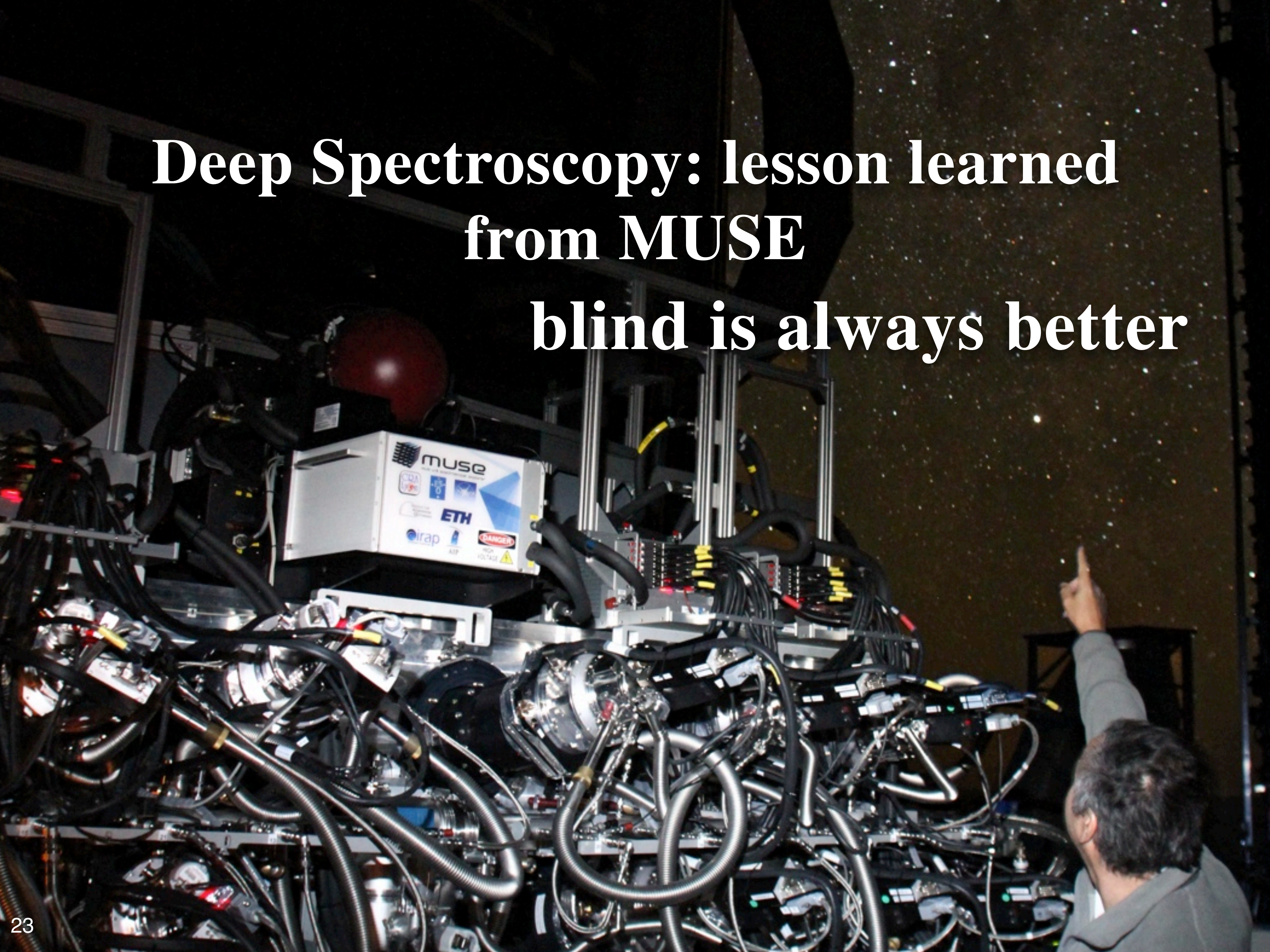
muse

A&A Special Issue 2017, 610, A1 … A10

I. Survey description, data reduction and source detection, Bacon et al
II. Spectroscopic redshifts and comparisons to color selections of high-redshift galaxies, Inami et al.
III. Testing photometric redshifts to 30th magnitude, Brinchmann et al.
IV. Global properties of C III] emitters, Maseda et al.
V. Spatially resolved stellar kinematics of galaxies at redshift $0.2<z<0.8$, Guerou et al.
VI. The Faint-End of the Lyα Luminosity Function at $2.91 < z < 6.64$ and Implications for Reionisation, Drake et al.
VII. FeII* Emission in Star-Forming Galaxies, Finley et al.
VIII. Extended Lyman-alpha haloes around high-redshift star-forming galaxies, Leclercq et al. [Talk]
IX. Evolution of galaxy merger fraction since z~6, Ventou et al.
X. Lyα Equivalent Widths at $2.9<z<6.6$, Hashimoto et al. [Poster]

Deep Spectroscopy: lesson learned from MUSE

blind is always better



Deep investigation

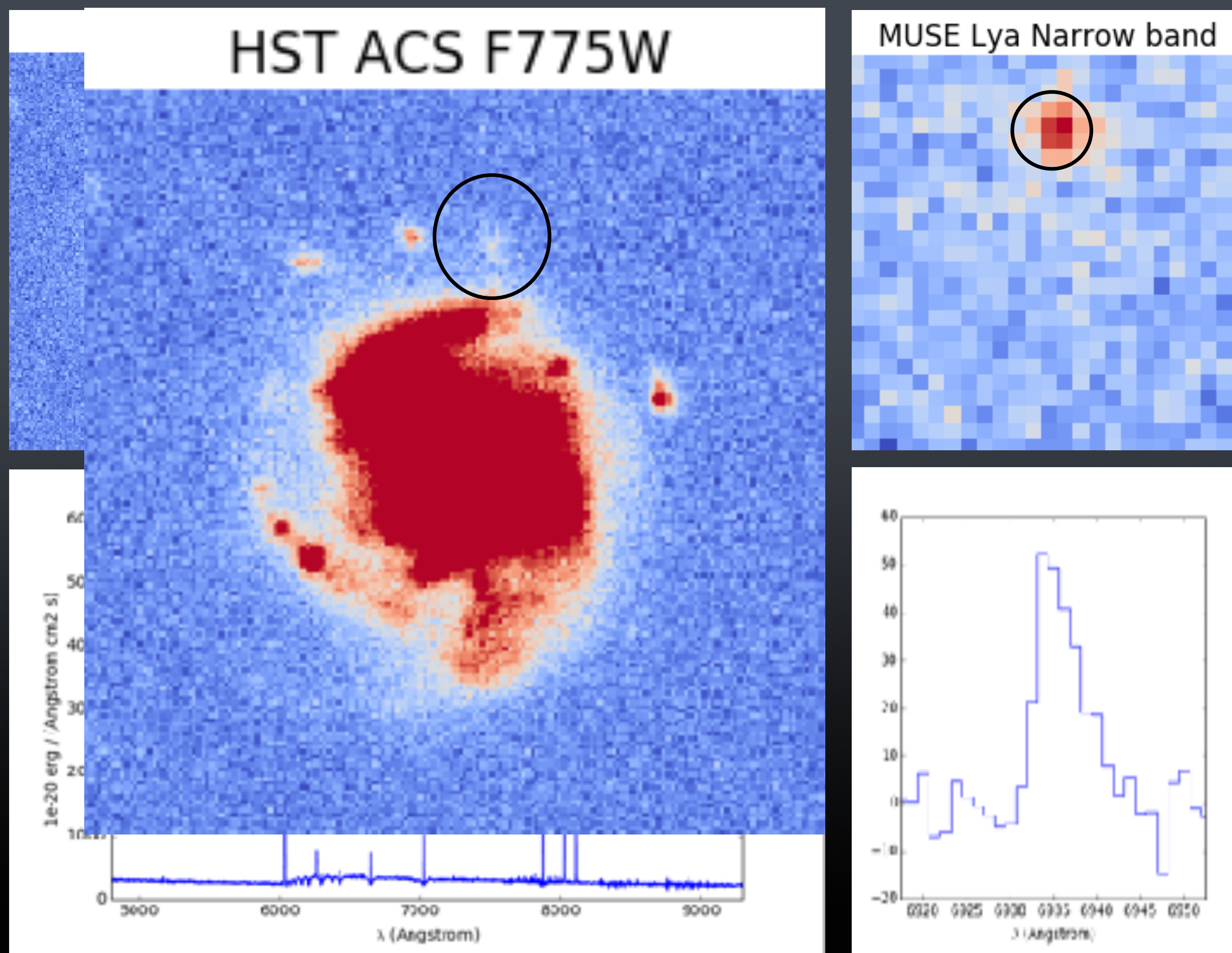
F775W 21.9

z=0.63

Lyα

z=4.7

F(Lyα)=3.1 10^{-18}



Deep investigation

F775W 26.2

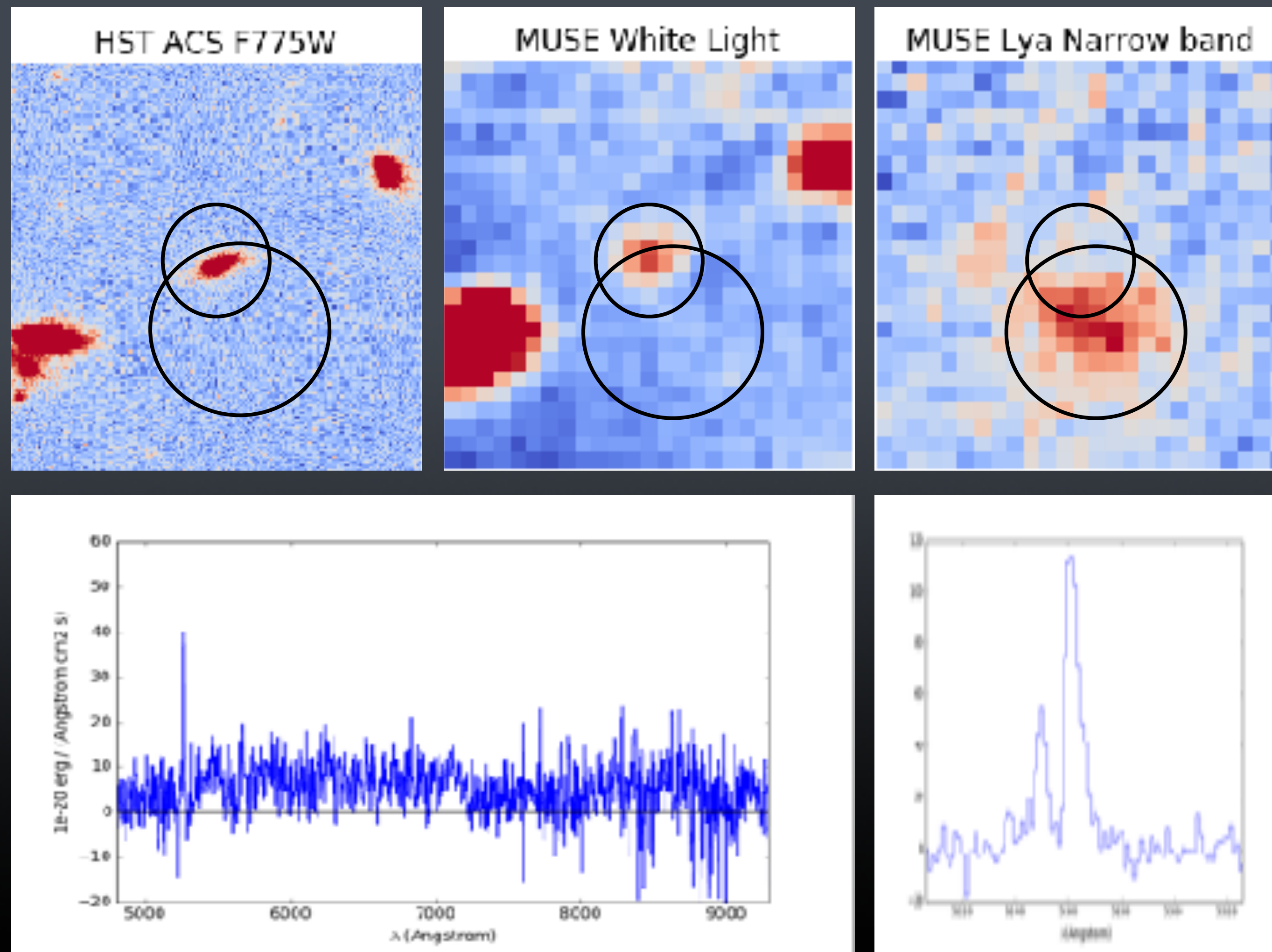
Lyα z=3.3

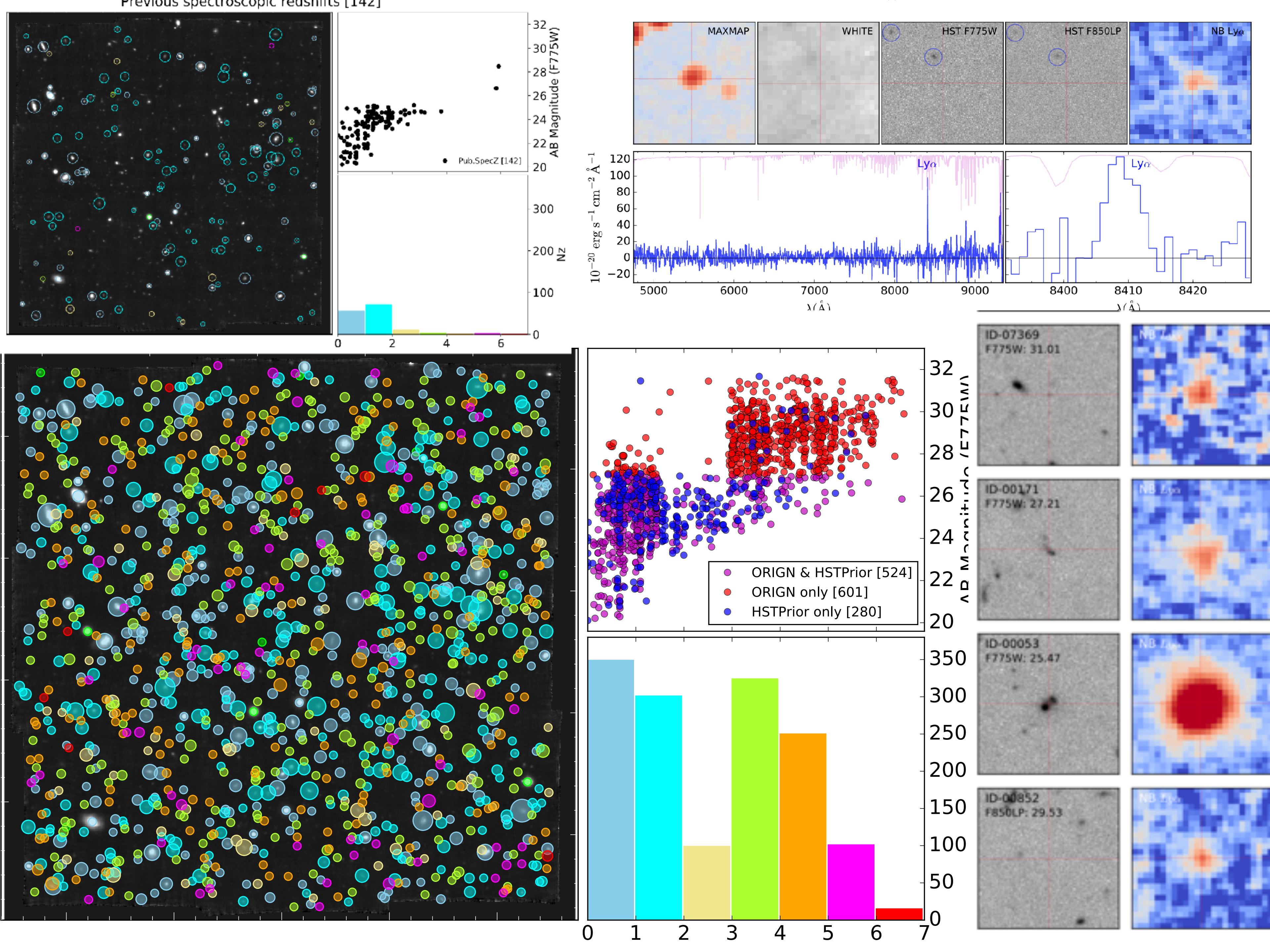
F(Lyα)=2.4 10^{-18}

EW_0=8

F(Lyα)=1.1 10^{-17}

EW_0>4300





Previous spectroscopic redshifts [142]
AB Magnitude (F775W)
Pub.SpecZ [142]
Nz
MAXMAP
WHITE
HST F775W
HST F850LP
NB Lyα
Lyα
λ(Å)
ID-07369
F775W: 31.01
ID-00171
F775W: 27.21
ID-00053
F775W: 25.47
ID-00852
F850LP: 29.53
ORIGN & HSTPrior [524]
ORIGN only [601]
HSTPrior only [280]