The MUSE Hubble Ultra Deep Field survey

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Tokyo Spring Lyman-alpha Workshop
Mar 27 2018
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 Ly$\alpha$ 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
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 Lyα surveys (cross) discussed in Table 2-1 (section 2.2).
MUSE Hubble Deep Field South observations

- 27 hours observation performed during commissioning (Aug 2014)
- 189 spectroscopic redshifts (x10)
- 26 Ly\(\alpha\) 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 Ly\(\alpha\) halos in the circumgalactic medium around high redshift galaxies
Contini et al. 2016: study of gas kinematics
Drake et al. 2017: the Ly\(\alpha\) 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"

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

- $3\sigma$ point source detection for emission line (3.7Å)
- UDF10: $1.5 \times 10^{-19}$ erg.s$^{-1}$.cm$^{-2}$
- MOSAIC: $3.1 \times 10^{-19}$ erg.s$^{-1}$.cm$^{-2}$
Redshifts in the MUSE field
Redshifts in the MUSE field

Previous spectroscopic redshifts [142]

AB<25

z<3
$z = 0.423 \ AB = 27.07$

$z = 1.220 \ AB = 21.03$

$z = 1.306 \ AB = 25.59$

$z = 1.550 \ AB = 24.80$

$z = 1.756 \ AB = 29.34$
807 LAE in 9 arcmin$^2$ = 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
Lya $Z = 6.24$
AB F850LP $29.48 \pm 0.18$

Paper I: Bacon et al 2017
Lya $Z = 5.91$
$AB$ F850LP $> 30.7$

More by Michael Maseda:
HST-undetected LAEs from MUSE Spectroscopy (Talk)
The MUSE Hubble Ultra Deep

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

In 10 years

**MUSE**
1443 spectro-z
AB<31
z<7

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

In 100 hours of VLT

72 Lyα without HST counterpart
The MUSE Hubble Ultra Deep Field Survey

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 Ly\(\alpha\) 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. Ly\(\alpha\) 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
$z=0.63$

$\text{Ly}_\alpha$
$z=4.7$
$F(\text{Ly}_\alpha)=3.1 \times 10^{-18}$
Deep investigation

$F(\text{Ly}\alpha) = 2.4 \times 10^{-18}$

$EW_0 = 8$

$F(\text{Ly}\alpha) = 1.1 \times 10^{-17}$

$EW_0 > 4300$