Clusters And LENsing Distant Sources

Spectroscopic surveys of the Frontier Fields clusters

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Multiple images and mass modelling

High redshift dropouts


Multiple images and mass modelling

Atek, Richard et al. 2014a,b

High redshift dropouts

Additional science with spectroscopy

Multiple images and mass modeling

- Confirm identification of multiple images
- Pinpoint the source redshift to improve mass modelling
- Necessary to measure cosmology with strong lensing (Jullo et al. 2010)

High redshift dropouts

- Confirm high redshift identification (through Lyman-alpha emission)
- Measure Lyman-alpha equivalent width (test for reionization)
- Other emission lines: measure physical properties (outflows, …)
Pre-HFF spectroscopy of multiple systems


- No spec-z was available for Abell 2744 and AS1063 during pre-HFF lens modelling effort.
- VLT/FORS2 and Magellan/LDSS3 optical spectroscopy provided redshifts for all modellers in A2744, AS1063, A370.
- Some redshifts confirmed by Johnson et al. 2014, in press.
Primary Goals:
- Confirm $z > 3$ dropouts through Lyman-alpha emission
- Confirm / identify more multiple images for high precision mass modeling

Secondary Goals:
- If present, measure the physical properties of extended arcs
- Dynamics of cluster members

- 1x1 arcmin$^2$ integral field spectrograph
- 0.2” spaxel sampling, <0.2” IQ
- 4650-9300 Angstroms
- R=1500-3500
- 35% throughput end-to-end
Primary Goals:
• Confirm $z > 3$ dropouts through Lyman-alpha emission
• Confirm / identify more multiple images for high precision mass modeling

Secondary Goals:
• If present, measure the physical properties of extended arcs
• Dynamics of cluster members
Test case: SMACSJ2031.8-4036

- Massive galaxy cluster at z=0.331
- HST imaging F606W/F814W
- Strong lensing constrained by 3 multiple systems
- 1 specz @ z=3.5073 (Christensen et al. 2012a,b)
- MUSE commissioning: 10 hrs in ~1.0-1.1” seeing
Continuum color image

Composite narrow-band image

Ly$\alpha$  CIII$\lambda$  [OII]$\lambda$
Confirmation and spectroscopic redshifts for 11 systems
Physical properties of a bright system at z=3.5
Patricio et al. in prep.
MUSE SV program: AS1063
(Co-PI: Clément & Caputi)

- 3 hrs 10 min / 4 OBs (8x1420s exposures)
- Seeing 1.2”-1.4”
- Covered the majority of multiple systems and a known spiral at z=0.6
- Known z=6.107 LAE
  Monna et al. 2014
  Boone et al. 2014
  Balestra et al. 2014
MUSE SV program: AS1063

- Redshifts for known multiple images
- New singly and multiply-imaged Lyman-alpha emitters
- Currently updating the mass model (Clément et al.)

Karman et al. 2015, submitted
MUSE GTO program: A2744

- 5 x 2 hrs mosaic to cover central region + almost full WFC3 fov.
- Sep. and Oct. 2014 runs
- Average Seeing 0.6”-0.8”
- Preliminary results from first reduction!
A2744: first analysis

- First fishing expedition.
- Emission line sources: 82+ redshifts
- $z<1.5$
- $z>1.5$
- Systematic extraction of HST sources including multiple images/dropouts
A2744: first analysis

z=5.66 dropout

18.1
18.2
A2744: first analysis

z=5.66 dropout

fLya=9e-17

18.1

18.2
A2744: first analysis

z=5.66 dropout

18.3
Analysis of known multiple systems

System 5

MUSE-NB

HST-WFC3 STACK

z=6 dropout $\mu=30+/-8$ each

System 33
Analysis of known multiple systems
Analysis of known multiple systems

MUSE-NB

HST-WFC3 STACK
Analysis of known multiple systems
Analysis of known multiple systems
Analysis of known multiple systems

MUSE-NB

HST-WFC3 STACK
Analysis of known multiple systems
Analysis of known multiple systems
Analysis of known multiple systems

$f_{\text{Ly}a}=3.7 \times 10^{-17}$
New multiply-imaged systems

MUSE

STACKED WFC3
(all bands)
New multiply-imaged systems

MUSE

STACKED WFC3 (all bands)

z=4.191

W>80Å

z=2.949
New multiply-imaged systems

MUSE

STACKED WFC3 (all bands)

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W>80Å

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… To Be Continued!
VLT / KMOS spectroscopy

- **SV program Abell1689:**
  - Targetting the FF clusters A2744 and AS1063
  - 4h per cluster, 20 targets
  - Redshift measurements for multiple images through H$\alpha$, H$\beta$, [OIII] and [OII] in H+K band

- **FF program:**
  - Targetting the FF clusters A2744 and AS1063
  - 4h per cluster, 20 targets
  - Redshift measurements for multiple images through H$\alpha$, H$\beta$, [OIII] and [OII] in H+K band

Richard et al. in preparation
Conclusions – Future work

• Spectroscopic follow-up is very useful and successful at confirming multiply-imaged lensed systems and measuring their physical properties.

• **MUSE** shows very promising results already on the Frontier Field clusters. In 2-4 hours, we can identify new multiply imaged systems with large equivalent width emission lines, deeper than the HST-FF data.

• More MUSE-GT time will be used to increase the depth in FF clusters

• In addition, we will be able to use (1) the velocity field in giant arcs (2) the kinematics of cluster members as a constraint to the mass models.

• **KMOS** is also an excellent asset to measure redshifts of faint multiply imaged systems.