MUSE Science Cases
Galaxies at Intermediate Redshifts: 0.2 < z < 1.5

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Formation & Evolution des galaxies dans le contexte de MUSE
Lyon, 7-9 Novembre 2007
Evolution of galaxies and large-scale structures on cosmological timescales

→ constraints on models of galaxy formation & evolution

- When and how did galaxies form?
- Links between high-z ("young") and local ("old") galaxies?
- Timescales for galaxy evolution?
- Dependance with environment?
- ....

Introduction

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Introduction

✓ Needs for large statistical samples of galaxies at various epochs

✓ "Local" Universe: \( \sim 10^6 \) galaxies up to \( z \sim 0.2 \)

✓ "Small" (\( \sim 10^3 \) galaxies) samples between \( z=0.5 \) and \( z \sim 4 \) obtained in the 90's: CFRS (up to \( z \sim 1 \)), LBGs (\( z \sim 3-4 \)), etc

✓ Large (VVDS, DEEP2, COSMOS, GDDS...) surveys on the largest telescopes (VLT, Keck, Gemini...) to gather large numbers of high-redshift galaxies in large volumes, similarly to SDSS & 2dF
### Current large & deep spectroscopic surveys up to z~1.5

<table>
<thead>
<tr>
<th>Survey</th>
<th>Redshift range</th>
<th>$R = \frac{\lambda}{\Delta \lambda}$</th>
<th>Ngal</th>
<th>Limiting mag</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDSS, 2dF</td>
<td>$z &lt; 0.3$</td>
<td>~2000</td>
<td>~$10^6$</td>
<td>$R_{AB} &lt; 17.8/19.5$</td>
</tr>
<tr>
<td>VVDS</td>
<td>$0.2 &lt; z &lt; 1.5$</td>
<td>~250</td>
<td>~$10^4$</td>
<td>$I_{AB} &lt; 24$</td>
</tr>
<tr>
<td>COSMOS</td>
<td>$0.2 &lt; z &lt; 1.5$</td>
<td>~600</td>
<td>~$10^4$</td>
<td>$I_{AB} &lt; 22.5$</td>
</tr>
<tr>
<td>DEEP2</td>
<td>$0.5 &lt; z &lt; 1.5$</td>
<td>~2000</td>
<td>~$10^4$</td>
<td>$R_{AB} &lt; 24$</td>
</tr>
</tbody>
</table>
Introduction

MUSE advantages for intermediate-z galaxy studies

✓ no pre-selection
✓ probe fainter galaxies
✓ high resolution in AO mode -> spatially-resolved properties

Main drawback

✓ Smaller size samples (~$10^2$ galaxies) compared with current spectroscopic surveys (~$10^4$ galaxies)
Spatially-Resolved spectroscopy

- MUSE sensitivity & high-resolution
  - spatially resolved properties of galaxies up to \( z \sim 1 \)
- At \( 0.5 < z < 1 \), the MUSE AO-corrected PSF (\( \sim 0.3 \) arcsec) corresponds to a physical size of \( \sim 2 \) kpc
- Well suited to study internal variations of:
  - Stellar population ages & metallicities
  - ISM properties: metallicity, reddening, etc
  - w/ full 2D star & gas kinematics
- Evolution of the star formation & metal enrichment histories of spheroids, disks & irregulars over the last 10 Gyr
- For each galaxy, relationships between local kinematics, gas metallicity & reddening, and the stellar population ages & metallicities
- Census of the 0.5 < z < 1.0 galaxy populations at level of details comparable to SDSS
- Crucial tests for galaxy evolution scenarios (eg. downsizing)
Main topics

1. Galaxy Kinematics

2. Chemical abundances

3. Stellar populations
Spectral features

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Star-forming

Early-type

\[ \text{[OII]}3727 \quad \text{H} \beta \quad \text{[OIII]}4959,5007 \quad \text{[NeIII]}3869 \quad \text{H} \alpha + \text{[NII]}6584 \quad \text{[SII]}6717,6731 \]

0.2<z<1.5 zCOSMOS composite spectra (Lilly et al. 07)
Spectral features

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$0 < z < 0.25$

$\text{H}\alpha + [\text{NII}]_{6584}$

$[\text{OIII}]_{4959, 5007}$

$\text{H}\beta$

$\text{[SII]}_{6717, 6731}$

$0.2 < z < 1.5$

$z\text{COSMOS}$ composite spectra (Lilly et al. 07)

Star-forming

Early-type

$\text{MgI}_{5175}$

$\text{Ca, Fe}_{5269}$

$\text{NaD}_{5892}$

$\text{H}\beta_{4861}$
Spectral features

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0.25 < z < 0.4

Star-forming

Early-type


0.2 < z < 1.5 zCOSMOS composite spectra (Lilly et al. 07)

Hβ, Hδ, MgI5175, Ca, Fe5269, NaD5892
Spectral features

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0.2 < z < 1.5 zCOSMOS composite spectra (Lilly et al. 07)

Star-forming

Early-type

0.4 < z < 0.85
Spectral features

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0.85 < z < 1.3

Star-forming

Early-type

0.2 < z < 1.5 zCOSMOS composite spectra (Lilly et al. 07)
Spectral features

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1.3 < z < 1.5

Star-forming

Early-type

$0.2 < z < 1.5$ zCOSMOS composite spectra (Lilly et al. 07)
1. Galaxy kinematics

Spatially-resolved kinematics from 2D velocity fields in emission lines

At z~1, the velocity field can be mapped with MUSE to ~2 x disk scale length

SPH dynamical simulations (courtesy of V. Debattista & L. Mayer)
MUSE 80h integration
Disk galaxy at z~1 with h=0.4" 
F(EL)=10^{-17} ergs^{-1} cm^{-2}
1. Galaxy kinematics

Spatially-resolved kinematics from 2D velocity fields in emission lines

- Overview of the dynamical properties of galaxies (rotating disks, spheroids, mergers, etc) up to z~1
- Evolution of the Tully-Fisher relation for disk galaxies
- Resolved sub-structures → dynamical perturbations due to close companion, starburst-driven gas outflows, etc
- Relationships between internal dynamics & other galactic properties (SFR, metallicity, stellar populations, etc)
1. Galaxy kinematics

Evolution of the Tully-Fisher relation up to $z \approx 1$
Flores et al. 06

35 galaxies @ $0.4 < z < 0.75$
3D spectroscopy w/ FLAMES/GIRAFFE
No AO - seeing $\sim 0.4''-0.8''$ - pixel=$0.52''$

Kinematical classification:
- rotating disks ($\sim 35\%$)
- perturbed or complex kinematics
1. Galaxy kinematics

Evolution of the Tully-Fisher relation up to z~1
Flores et al. 06

Rotating disks follow the local TF relation

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Velocity $\sigma$ S/N
1. Galaxy kinematics

Evolution of the Tully-Fisher relation up to z~1
Flores et al. 06

Dispersion in TF relation due to galaxies w/ perturbed kinematics

Velocity $\sigma$ S/N
1. Galaxy kinematics

On-going 3D NIR spectroscopic observations @ $z > 1$

ESO LP (300h - Contini et al.)

SINFONI with AO/LGS
FoV = 3”x3” - pixel size = 0.1”

~140 VVDS galaxies
@ $1 < z < 2$

Lemoine-Busserolle et al. 08

VVDS220014252
z=1.3097

$\text{H}_\alpha$ [NII]
1. Galaxy kinematics

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On-going 3D NIR spectroscopic observations @ \( z > 1 \)

Also …

\( 2 < z < 3 \)

- Foerster-Schreiber, Genzel et al. with VLT/SINFONI
- Law, Erb, Steidel et al. with Keck/OSIRIS

\( 3 < z < 5 \)

- Maiolino et al. with VLT/SINFONI

And more to come in COSMOS/VVDS field with MOIRCS & SINFONI
2. Chemical abundances

Metal enrichment of galaxies

Gas-phase metallicity (O/H) derived from EL ratios:

<table>
<thead>
<tr>
<th>Redshift range</th>
<th>0.00 – 0.25</th>
<th>0.25 – 0.40</th>
<th>0.40 – 0.85</th>
<th>0.85 – 1.30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission lines</td>
<td>H(\beta), [OIII]</td>
<td>[OII]</td>
<td>[OII]</td>
<td>[OII], [NeIII], H(\delta)</td>
</tr>
<tr>
<td></td>
<td>H(\alpha), [NII]</td>
<td>H(\beta), [OIII]</td>
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<td></td>
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</tbody>
</table>
2. Chemical abundances

Metal enrichment of galaxies: evolution of the M-Z relation

- zCOSMOS $z=0.1-1.5$ SF galaxies ($N=2903$)
- $z \sim 0.1$ (SDSS - Tremonti et al. 2004)
- $z \sim 2.0$ (Erb et al. 2006)
- $0.00 < z < 0.28$ - $N = 630$
- $0.28 < z < 0.50$ - $N = 661$
- $0.50 < z < 0.67$ - $N = 800$
- $0.67 < z < 1.50$ - $N = 812$

- VVDS - $I_{AB}<24$
  (Lamareille et al. 07)
  $z \sim 0.9$

- zCOSMOS - $I_{AB}<22.5$
  (Contini et al. 08)
2. Chemical abundances

Metal enrichment of galaxies: evolution of the $M-Z$ relation

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$z \sim 0$
$z \sim 2$

- VVDS - $I_{AB} < 24$
  (Lamareille et al. 07)

- MUSE

p.24 ESO - Göttingen - Leiden - Lyon - Potsdam - Toulouse - Zurich
2. Chemical abundances

Metal enrichment of galaxies

✓ Evolution of the M-Z relation up to z~1.3 extending the VVDS/zCOSMOS studies to lower-mass (~10^9 M_{sun}) metal-poor galaxies
✓ Spatially-resolved O/H measurements for brighter galaxies
metallicity gradients → diagnostic for the building up of galaxy disks
At $z \sim 1$, the spatially-resolved stellar ages & metallicities of galaxies should be recovered from MUSE spectra.

Simulations using BC03
MUSE 80h integration
Galaxy at $z \sim 1$ with S/N=15 spectra
3. Stellar populations

Stellar populations

✓ High sensitivity, spectral & spatial resolutions of MUSE
  → spatially-resolved stellar population properties (age, metallicity, etc)

✓ Relationships with dynamics, ISM properties, etc
  → tests for scenarios of stellar mass assembly in massive galaxies
Expected number density of galaxies in MUSE field
(based on VVDS/zCOSMOS number counts):

~ 10 per arcmin$^{-2}$ for $I_{AB} < 22.5$
~ 5 per arcmin$^{-2}$ for $F_{\text{line}} > 10^{-17}$ ergs$^{-1}$cm$^{-2}$

→ Sample of a few $10^2$ galaxies
at intermediate redshifts in
several Deep & Medium Deep MUSE Fields