AMAZE with LSD: Metallicity evolution in the early Universe

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Galaxy Formation
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Metallicity: a fundamental parameter

- Indirectly traces the integrated galaxy SFH, not only the current SFR
- Relative element abundances reflect the cycling of gas through stars, and any exchange of gas between galaxy and its environment (infall/outflows)

Understanding its evolution is essential to isolate the physical mechanisms that drive Star Formation
The mass-metallicity relation

Possible Drivers:
- star formation history and mass lost
- downsizing
- inflows and merging
- outflows and feedback (AGN, SNe)
- evolution in IMF
- …

Crucial test for models!
Especially at high-z, where the predictions of different models diverge more

AMAZE... ...with LSD

1. Near-IR Integral Field Spectroscopy with SINFONI@VLT

**AMAZE** (Assessing the Mass-Abundance redshift($Z$) Evolution):
- seeing limited, a sample of 30 LBGs at 3<z<5

**LSD** (Lyman-break galaxies Stellar populations and Dynamics):
- diffraction limited with AO, an unbiased sample of 10 LBGs at 3<z<4
- 70h (PI: Mannucci) Mannucci et al. 2009, Gnerucci et al. 2010, Sommariva et al. 11

2. Near-IR Multi Object Spectroscopy with LUCIFER@LBT
- 4 Steidel fields, ~10 z=3 LBGs/field
- 40h (PI: Cresci) observations ongoing...
Measuring metallicities

Gas phase metallicity from strong lines

Nagao et al. 06: improved calibrations with low metallicity samples
Evolution of the mass-metallicity relation

M-Z relation already in place at z\~3.5

Strong and fast evolution of the M-Z relation beyond z\~2?

(BUT: it is not tracing the evolution of individual galaxies)
Inflows and Outflows

In a “closed box model” with instantaneous recycling, instantaneous mixing, and low metallicities:

\[ Z = y_{\text{true}} \cdot \ln(1/f_{\text{gas}}) \]

\( y_{\text{true}} = \text{stellar yield}, \) i.e., the ratio between the amount of metals produced and returned to the ISM and the mass of stars.

The measured values of \( y_{\text{eff}} = Z/\ln(1/f_{\text{gas}}) \) could differ from the true stellar yields \( y \) if some of the assumptions do not hold, in particular if the system is not a closed box.

Inflows and outflows
Metallicity Gradients

Interplay between in- and out-flows, redistribution of mass within galaxies, radially dependent SFH, mixing due to a stellar bar, clump migration, etc

Negative radial metallicity gradient in local spiral galaxies: the central disk region is more metal-enriched than the outer regions. (but see also Werk et al. 2010)

At higher redshift, steeper gradients measured in two gravitationally lensed galaxies at z~1.5 and z~2 with near-IR IFU spectra, supporting “inside-out formation” (see T. Jones poster)

But more complex situation in larger samples: even positive “inverted” gradients at z~1.5 in MASSIV galaxies

Contini et al. 2011
Thanks to the AMAZE/LSD data

**First metallicity maps at z~3:**
- Three undisturbed disks
- Well defined regions close to the SF peak are less metal enriched than the disk

**Metallicity Gradients**

Direct evidence for massive infall of metal poor gas feeding the star formation

*Cresci et al. 2010, Nature*
Is there a relation between metallicity, mass and SFR?

- **Stellar Mass**: SED fitting + spectra
- **SFR**: Hα (Kennicutt) + Balmer dec.
- **Gas metallicity**: strong lines: \([\text{NII}] / \text{H}\alpha\) and R23

141,000 local SDSS galaxies, selected to have SNR(Hα)>25, z>0.07
The Fundamental Metallicity Relation

Small scatter => Long lasting equilibrium between gas accretion, star formation and metal ejection (e.g. Dave', Finlator & Oppenheimer 2011)

Dispersion of the original Mass-Met:
- half systematic (SFR)
- half intrinsic: ~12%

Mannucci, Cresci et al. 2010
Going to higher $z$ with $z$COSMOS

From a parent sample of 7700 $z$COSMOS DR2 star forming galaxies with VIMOS spectroscopy, with:

- $S/N(H\#) > 15$ for $z < 0.45$
- $S/N(H\$) > 10$ for $z > 0.49$
- $S/N > 2$ for all other lines

Using $[\text{NII}] / H\#$ 131 galaxies
Using $R_{23}$ 171 galaxies

M-Z relation is evolving at $z \approx 0.62$

... but no evolution of the FMR

Cresci et al. 2011
Is the mass-metallicity really evolving?

Adding distant Galaxies at: $z=0.8$ (Savaglio et al. 2009, Ledoux et al. 2008, Savaglio et al. 2009). Increasing the SFR with $z$, at least up to $z=3.3$ (Maiolino et al. 2008, Mannucci et al. 2009).

See also C. Maier’s poster.
Still not convinced?

The presence of a FMR up to $z \sim 2.5$ confirmed by several other *independent* observations of *differently selected* galaxy samples at low and high $z$.

*Long GRB host galaxies* (Mannucci et al. 2011, Vergani et al. 2011)

*Stacked Ly $\alpha$ emitters at* $z=2.2$ (Nakajina et al. 2011)
Erb et al. (2010)    Q2343-BX418    z=2.3
Deep spectrum: 12h Keck time

Observed $12+\log(O/H)=7.90\pm0.2$
SFR $= 15 \pm 2 \, M_\odot/yr$
Some more?

Richard et al. 2010: Gravitationally Lensed galaxies at $z \sim 2.5$

Sampling lower SFRs

See also Contini et al. 2011 at $z \sim 1.5$, Kassin et al. 2011 at $z \sim 0.8$, Yates et al. and J. Scudder’s poster at $z \sim 0$.
Summary

➡️ Metal Content in Galaxies

Fundamental to understand the main drivers of galaxy evolution, especially meaningful when considered in concert with stellar and gas content.

➡️ Chemical evolution in high-z star-forming galaxy:

Evidence for rapid metal enrichment and significant inflows/outflows at high-z;

Resolved metallicity gradients provide evidence of pristine gas accretion in star forming disks at high redshift;

First measure of stellar metallicity in high-z star forming galaxies

➡️ Fundamental Metallicity Relation:

Local galaxies define a tight surface in this 3D space SFR-Met-M$_*$, which appear not to evolve up to z~2.5;

It has to be explained by the interplay of infall of pristine gas, outflow of enriched material and star formation history (see e.g. Dave’, Finlator & Oppenheimer 2011).