The oxygen abundance in the IFU era

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Two highlights:

I. The IFS approach to abundance gradients

II. On the origin of the mass-metallicity relation
IFS nearby galaxies sample

3.5m telescope Calar Alto, Spain (PMAS/PPAK instrument)

Rosales-Ortega PhD 2009
Rosales-Ortega et al. 2010

IFS nearby galaxies sample

Mármol-Queraltó et al. 2011
Feasibility study for the CALIFA survey (Sánchez et al. 2012)

38 late-type galaxies in the local Universe (0.001 < z < 0.025)

Continuous coverage spectra ~3700–7000 Å
IFS-based HII region extraction

HIIexplorer (Sánchez et al. 2012; submitted)

~2500 high S/N, spectra of HII regions (aggregations)

The largest spatially-resolved, nearby spectroscopic HII region survey ever accomplished
I. A statistical (IFS) approach to abundance gradients

Density of HII regions in normalized axes

- Average linear fit (all galaxies) ~0.12 dex/Re
- Linear fit to all HII regions ~0.11 dex/Re
- Mean value at radial bins ~0.15 Re
- Average abundance of solar neighborhood at $R_{\text{Sun}}$

Discussion session!

Characteristic value of the slope!
II. On the origin of the mass-metallicity relation

**Lequeux et al. 1979:** metallicity is strongly correlated with galaxy mass

Established observationally using 53,000 galaxies in the SDSS up to $z \sim 0.1$

What is the physical mechanism underlying the M-Z relation?

- Loss of enriched gas by outflows
  (e.g. Tremonti+ 2004, Kobayashi+ 2007, etc.)

- Accretion of pristine gas by inflows
  (e.g. Finlandor & Davé 2008)

- Variations in the initial mass function (IMF)
  (e.g. Köppen et al. 2007)

- Selective star-formation efficiency or downsizing
  (e.g. Brooks+ 2007, Ellison+ 2008, Calura+ 2009, Vale Asari+ 2009)

There has been no major effort to test the M-Z relation using spatially-resolved information
Literature background:

surface mass density vs. gas metallicity relation

McCall 1982, PhD
Edmunds & Pagel 1984

Plus few other examples in the literature, but almost an overlooked relation

Vila-Costas & Edmunds 1992
Surface mass density

\[ \Sigma_{\text{Lum}} \]

- B and V-band surface brightness were extracted directly from the IFS data, within the area encompassed by our IFS-segmented HII regions (emission lines removed).

- Use B–V colors to B-band mass-to-light ratio to derive the (luminosity) surface mass density (Bell & de Jong 2001).

- Radial mass profiles compared with K-band profiles of common galaxies in our sample with the DiskMass survey (Bershady et al. 2010, Martinsson 2011 PhD).
  - Agreement within ~20%

\[ 12 + \log(O/H) \]

- Gas-phase oxygen abundances:
  - O3N2 calibrator (Pettini & Pagel 2004)
  - R23 for those regions with [OII] 3727
The **local** mass-metallicity relation

HII regions: surface mass density vs. metallicity

Rosales-Ortega et al. (submitted)

Mean value at bins $\sim 0.15$ dex $\Sigma_{\text{Lum}}$

Polynomial fit to the data

Tremonti et al. 2004 fit ($\pm 0.1$ dex)

$Z \sim 0.15$ dex

$M \sim 5.0$ dex

3 orders of magnitude in $\Sigma_{\text{Lum}}$

factor of $\sim 8$ in metallicity

The local M-Z relation stands with 90% within the 95% of the T04 relation

Same shape and fit for other calibrators (e.g. $R_{23}$ by T04), but larger scatter $\sim 20\%$
The local mass-metallicity relation

HII regions: surface mass density vs. metallicity

The relation holds for individual galaxies!

There is also a relation with $|EW(\text{H}\alpha)|$ (emission)

Rosales-Ortega et al. (submitted)
The *local* mass-metallicity-EW(H\(\alpha\)) relation
The **local** mass-metallicity-EW(H\(\alpha\)) relation

EW(H\(\alpha\)) vs surface mass density projection

EW(H\(\alpha\))

- Scales with the SFR per unit mass, i.e. the Specific SFR (SSFR)
- Proxy of the stellar birthrate parameter or \(b\)-Scalo

\[
b = \frac{SFR}{\langle SFR \rangle_{past}}
\]

(Kennicutt et al. 1994, Kennicutt 1998)

lower (inner) values of \(|EW(H\alpha)\)| lower SSFR and vice versa
Is the **global** M-Z relation a consequence of the **local** one?

**Test:** simulate galaxies *assuming* the local M-Z relation and the SDSS aperture effect

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**Draw randomly:**

\[-15 < M_B < -23\]

\[-0.4 < B-V < 1\]

**redshift**

\[\mu \sim 0.1 \quad \sigma = 0.05 \quad z < 0.02\]

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**Surface brightness**

Exponential light distribution

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**Effective radius**

Luminosity-scale relation (e.g. Brooks et al. 2011) assuming \(\sigma = 0.3\) dex (Shen et al. 2003)

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**Surface mass density**

Aperture equal to the SDSS fibre (3 arcsec)

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**Gas metallicity**

*local* M-Z relation

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**Luminosity Mass**

Integrated \(M_B + B-V\) + average \(M/L\) (Bell & de Jong 2001)

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**Mock galaxy**

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**10,000 realizations**
Simulated galaxies in the M-Z plane assuming a local M-Z relation

Outstanding agreement!

Rosales-Ortega et al. (submitted)

Mean value at bins ~0.15 dex $\Sigma_{\text{Lum}}$

Polynomial fit to the data

Tremonti et al. 2004 fit (± 0.1 dex)

Range in mass and metallicity of our galaxy sample

(Kewley & Ellison 2008)
The origin of the \textit{local} mass-metallicity-\textit{EW}(H\alpha) relation

Natural consequence of the radial gradients in spiral galaxies

- Mass
- Metallicity vs. \textit{Radius}
- \textit{EW}(H\alpha) (SSFR proxy)

“inside-out” galaxy disc growth

+ chemical evolution in discs

The origin of the \textit{global} M-Z relation

- Existence of the \textit{local} M-Z relation
- Aperture bias of SDSS

The existence of the fundamental M-Z-SFR

(Lara-López et al. 2010, Mannucci et al. 2010)

Follows naturally from of the existence of the \textit{local} M-Z-SSFR relation
Conclusions

- Using IFS ~2500 HII regions of the local Universe, we demonstrate the existence of a local relation between:

  **Surface mass density – Gas metallicity – EW(Hα)**

  *local M-Z relation*

- Explained as the combination of well-known physically-based relationships between mass and metallicity with their differential distributions in spiral discs.

- We reproduce—*with an outstanding agreement*—the global M-Z relation by means of a simple simulation assuming:
  1. The local M-Z relation
  2. Aperture effect of the SDSS fibre

- The existence of a fundamental M-Z-SFR relation can be explained by the presence of the local M-Z-SSFR correlation.

**M-Z relation drivers:**
- Star formation history
- downsizing