Evolution of the interstellar medium in star-forming galaxies

Thiago S. Gonçalves
(OV/UFRJ)
Antara Basu-Zych, Kartik Sheth,
Catherine Vlahakis, Laura Pérez,
D. Christopher Martin,
The Schmidt-Kennicutt relation

\[ \Sigma_{SFR} = A \Sigma_{gas}^n \]
The “Main Sequence” of galaxies

Noeske+07

The main sequence evolves!!

Rodighiero+11
Galaxies had more gas and less metals in the past
Galaxies are different at different epochs...

BUT: studies at high-z are hard!!

- Luminosity distances are large!
- Cosmic surface brightness dimming
The sample of Lyman break analogs

\[ L_{\text{FUV}} \geq 2 \times 10^{10} \ L_\odot \]
\[ I_{1530} \geq 10^9 \ L_\odot \ \text{kpc}^{-2} \]

Hoopes et al. (2007)
Overzier et al. (2009)
LBAs are similar to high-z starbursts!

Low extinction

Mass-metallicity relation

Overzier+11

Santos-de-Oliveira et al., in prep
IFU: LBAs are turbulent

Gonçalves+10
The molecular gas in LBAs

- 15 antennas in Cedar Flat, California
- CO(1-0) survey of Lyman break analogs with CARMA (~100h)
- D configuration, spatial resolution ~5"

080844

Flux (mJy)

Flux (mJy)

Velocity (km s⁻¹)

Velocity (km s⁻¹)
**High gas fractions in starbursts**

Very similar to other high-z samples

Erb+06, Gonçalves+14
The populations are split in this diagram and are not well fit by prototypical starbursts, although they only reach an SFR of a few M$_\odot$ yr$^{-1}$ kpc$^{-2}$. Disks (F. Salmi et al. 2010, in preparation), brown crosses are disks (Tacconi et al. 2007). The situation changes substantially when introducing the dynamical timescale ($\tau_{\text{dyn}}$). The empty squares are SMGs: Bouché et al. (2007). The lower solid line is a fit to Main-sequence SFGs by Moretti et al. (2003) and SMGs. SFRs are derived from IR luminosities for the case of a Chabrier IMF.

The slope of 1.42 is slightly larger than that of Equation (2), $\log \Sigma_{\text{gas}} = \log \Sigma_{\text{SFR}} - 2\log M_{\odot}$ pc$^{-2}$, $\log \Sigma_{\text{gas}} = \log \Sigma_{\text{SFR}} - 2\log M_{\odot}$ pc$^{-2}$. The situation changes substantially when introducing the dynamical timescale ($\tau_{\text{dyn}}$). The empty squares are SMGs: Bouché et al. (2007). The lower solid line is a fit to Main-sequence SFGs by Moretti et al. (2003) and SMGs. SFRs are derived from IR luminosities for the case of a Chabrier IMF.

The slope of 1.42 is slightly larger than that of Equation (2), $\log \Sigma_{\text{gas}} = \log \Sigma_{\text{SFR}} - 2\log M_{\odot}$ pc$^{-2}$, $\log \Sigma_{\text{gas}} = \log \Sigma_{\text{SFR}} - 2\log M_{\odot}$ pc$^{-2}$.

The slope of 1.42 is slightly larger than that of Equation (2), $\log \Sigma_{\text{gas}} = \log \Sigma_{\text{SFR}} - 2\log M_{\odot}$ pc$^{-2}$, $\log \Sigma_{\text{gas}} = \log \Sigma_{\text{SFR}} - 2\log M_{\odot}$ pc$^{-2}$.

The slope of 1.42 is slightly larger than that of Equation (2), $\log \Sigma_{\text{gas}} = \log \Sigma_{\text{SFR}} - 2\log M_{\odot}$ pc$^{-2}$, $\log \Sigma_{\text{gas}} = \log \Sigma_{\text{SFR}} - 2\log M_{\odot}$ pc$^{-2}$.

The slope of 1.42 is slightly larger than that of Equation (2), $\log \Sigma_{\text{gas}} = \log \Sigma_{\text{SFR}} - 2\log M_{\odot}$ pc$^{-2}$, $\log \Sigma_{\text{gas}} = \log \Sigma_{\text{SFR}} - 2\log M_{\odot}$ pc$^{-2}$.
The conversion factor for starburst galaxies

IR-bright galaxies: hot AND turbulent! =>
High CO luminosities

Narayanan+11, Papadopoulos+12

$a_{CO} \sim 4$ (MW), $a_{CO} \sim 0.9$ (ULIRGs)

The conversion factor for metal-poor galaxies
High-z galaxies?

**Figure 3.** Inferred dependence of the CO 1-0 luminosity to molecular gas mass, conversion factor \( \alpha_{\text{CO}1-0} \) on gas phase oxygen abundance. The molecular gas mass (including helium) for the high-z galaxies is computed from the best-fit z_{10} KS-relation (updating the data in Genzel et al. 2010) with the additional SFGs in Tacconi & Combes, 2010.

**BUT:** UV-bright galaxies are turbulent AND metal-poor!!
Figure 3. Inferred dependence of the CO 1-0 luminosity to molecular gas mass, conversion factor (\(\alpha_{\text{CO} 1-0}\)) on gas phase oxygen abundance. The molecular gas mass (including helium) for the high-z galaxies is computed from the best-fit z\(_1\) KS-relation (updating the data in Genzel et al. 2010 with the additional SFGs in Tacconi & Combes, 28).

Gonçalves+14
The FIR-CO relation

The figure shows a graph plotting the relationship between the CO luminosity ($L'_\text{CO}$, in K km s$^{-1}$ pc$^2$) and the logarithm of the far-infrared (FIR) luminosity ($L_{\text{FIR}}/L_\odot$). Two sets of data points are shown: estimated and measured values. The estimated data points are represented by red circles, while the measured data points are represented by blue dots.

The graph includes a best-fit line that describes the trend of the data. The data is taken from Gonçalves et al. (2014).

The equation for the best-fit line is:

$$L'_\text{CO} = 10 \times 10^7 \times (L_{\text{FIR}}/L_\odot)^{0.6}$$
Assuming high alpha...

S-K Law? $\alpha(Z)$? $L'(CO)-L(FIR)$?
Galaxies in the past had more gas and less metals; how were they formed? Cold flows, mergers?

LBAs make an excellent case for local analogs to star forming galaxies at $z\sim2-3$, and can be studied in more detail.

LBAs have a lot of very dense, turbulent gas, but still follow S-K relation.

The $a_{CO}$ problem: very unclear for high-z galaxies.