Galaxies in 3D across the Universe
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Molecular gas content in typical L^* galaxies at $z \sim 1.5 - 3$

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Abstract. To extend the molecular gas measurements to typical L^* star-forming galaxies (SFGs) at $z \sim 1.5 - 3$, we have observed CO emission for five strongly-lensed galaxies selected from the *Herschel* Lensing Survey. The combined sample of our L^* SFGs with CO-detected SFGs at $z > 1$ from the literature shows a large spread in star formation efficiency (SFE). We find that this spread in SFE is due to variations of several physical parameters, primarily the specific star formation rate, but also stellar mass and redshift. An increase of the molecular gas fraction ($f_{\rm gas}$) is observed from $z \sim 0.2$ to $z \sim 1.2$, followed by a quasi non-evolution toward higher redshifts, as found in earlier studies. We provide the first measure of $f_{\rm gas}$ of $z > 1$ SFGs at the low-stellar mass end between $10^{9.4} < M_*/{\rm M}_\odot < 10^{9.9}$, which shows a clear $f_{\rm gas}$ upturn.

Keywords. gravitational lensing: strong - galaxies: high-redshift - ISM: molecules

1. Introduction

Improvements in the sensitivity of the IRAM Plateau de Bure Interferometer (PdBI) have made it possible to start getting a census of the molecular gas content in star-forming galaxies near the peak of the cosmic star formation activity. However, the sample of CO-detected objects at $z = 1-3$ is still small and mostly confined to the high star formation rate and high stellar mass end of main-sequence SFGs (Daddi *et al.* 2010; Tacconi *et al.* 2010, 2013; Saintonge *et al.* 2013). We could extend the dynamical range of star formation rates and stellar masses of SFGs with observationally constrained molecular gas contents below SFR < 40 M$_\odot$ yr^{-1} and $M_* < 2.5 \times 10^{10}$ M$_\odot$ by observing five strongly-lensed SFGs with the PdBI and 30 m telescope, selected from the *Herschel* Lensing Survey (Egami *et al.* 2010). We hence build up a sample of $L^\star$ galaxies at $z \sim 1.5 - 3$ with CO measurements (Dessauges-Zavadsky *et al.* 2014) to which we add the well-known strongly-lensed MS 1512-cB58 and Cosmic Eye (Baker *et al.* 2004; Coppin *et al.* 2007).

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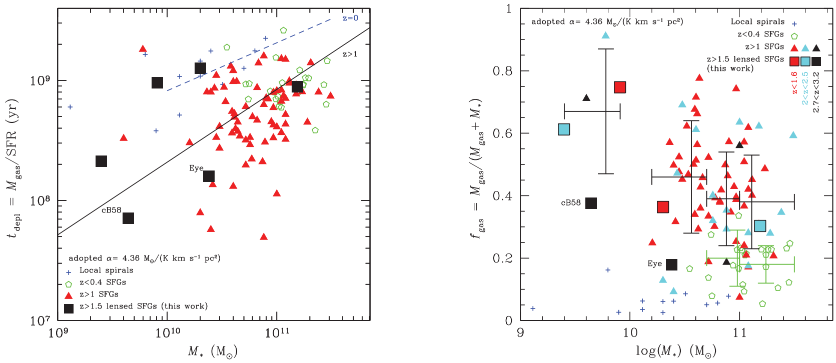

Figure 1. *Left.* Trend for a molecular gas depletion timescale increase with stellar mass. *Right.* Stellar mass dependence of the molecular gas fraction, an upturn is observed at the low-M_* end.

2. L^* galaxies in the context of galaxies with CO measurements

The combined sample of L^* SFGs with CO-detected SFGs at $z > 1$ from the literature shows a large spread in SFE with a dispersion of 0.33 dex, such that SFE now extend well beyond the low values of local spirals and overlap the distribution of $z > 1$ sub-mm galaxies. What drives this large spread in SFE or equivalently in molecular gas depletion timescale ? We find that it is due to variations of primarily the specific star formation rate, but also stellar mass and redshift. Correlations of the SFE with the offset from the main-sequence and the compactness of the starburst are less clear. The increase of the molecular gas depletion timescale with M_* now revealed by the low stellar mass SFGs at $z > 1$ (Fig. 1), and also observed at $z = 0$, is opposed to the constant molecular gas depletion timescale generally admitted and refutes the linear Kennicutt-Schmidt relation.

3. Molecular gas fraction of high-redshift galaxies

Various physical processes at play in the evolution of galaxies (e.g., accretion, star formation, and feedback) have direct impact on the molecular gas fraction. Thus, a solid way to test galaxy evolution models is to confront their predictions with the $f_{\rm gas}$ behaviour. We observe an increase of $f_{\rm gas}$ from $z \sim 0.2$ to $z \sim 1.2$, followed by a quasi non-evolution toward higher redshifts, in contrast with the expected steady redshift increase of $f_{\rm gas}$. At each redshift the gas fraction shows a large dispersion, due to the dependence of $f_{\rm gas}$ on M_*, producing a gradient of increasing $f_{\rm gas}$ with decreasing M_*. We provide the first measure of $\langle f_{\rm gas} \rangle = 0.67 \pm 0.20$ of $z > 1$ SFGs at the low-M_* end $10^{9.4} < M_*/{\rm M}_\odot < 10^{9.9}$, which shows a clear $f_{\rm gas}$ upturn (Fig. 1). This upturn, predicted by models, has a strength varying with the outflow/feedback/wind which are taking place in the galaxy.

References

Baker A. J., *et al.* 2004, *ApJ*, 604, 125
Coppin K. E. K., *et al.* 2007, *ApJ*, 665, 936
Daddi E., *et al.* 2010, *ApJ*, 713, 686
Dessauges-Zavadsky M., *et al.* 2014, *A&A*, submitted [arXiv:1408.0816]
Egami E., *et al.* 2010, *A&A*, 518, L12
Saintonge A., *et al.* 2013, *ApJ*, 778, 2
Tacconi L. J., *et al.* 2010, *Nature*, 463, 781
Tacconi L. J., *et al.* 2013, *ApJ*, 768, 74

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