

Molecular gas content in typical L^* galaxies at $z \sim 1.5 - 3$

Miroslava Dessauges-Zavadsky¹, Michel Zamojski¹, Daniel Schaerer¹,
Françoise Combes², Eiichi Egami³, A. Mark Swinbank⁴,
Johan Richard⁵, Panos Sklias¹, Tim D. Rawle⁶, Jean-Paul Kneib⁷,
Frédéric Boone⁸ and Andrew Blain⁹

¹Observatoire de Genève, Université de Genève,
51 Ch. des Maillettes, 1290 Versoix, Switzerland
email: miroslava.dessauges@unige.ch

²Observatoire de Paris, LERMA, 61 Avenue de l'Observatoire, 75014 Paris, France

³Steward Observatory, University of Arizona,
933 North Cherry Avenue, Tucson, AZ 85721, USA

⁴Institute for Computational Cosmology, Durham University,
South Road, Durham DH1 3LE, UK

⁵CRAL, Observatoire de Lyon, Université Lyon 1,
9 Avenue Ch. André, 69561 Saint Genis Laval Cedex, France

⁶ESAC, ESA, PO Box 78, Villanueva de la Canada, 28691 Madrid, Spain

⁷Laboratoire d'Astrophysique, Ecole Polytechnique Fédérale de Lausanne (EPFL),
Observatoire de Sauvigny, 1290 Versoix, Switzerland

⁸CNRS, IRAP, 14 Avenue E. Belin, 31400 Toulouse, France

⁹Department of Physics & Astronomy, University of Leicester,
University Road, Leicester LE1 7RH, UK

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_{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_{gas} of $z > 1$ SFGs at the low-stellar mass end between $10^{9.4} < M_*/M_\odot < 10^{9.9}$, which shows a clear f_{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 $\text{SFR} < 40 M_\odot \text{ yr}^{-1}$ 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^* 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).

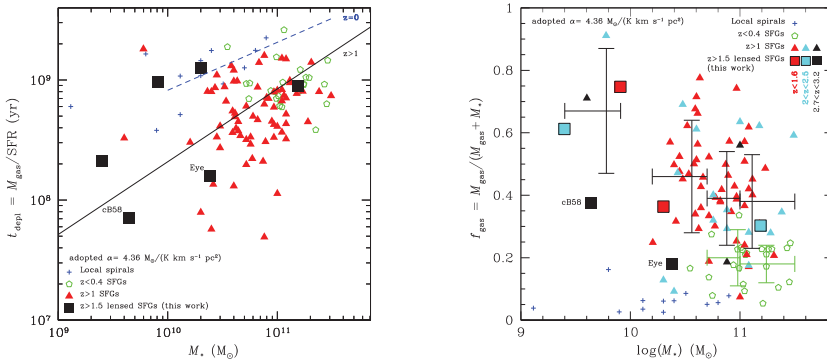


Figure 1. *Left.* Trend for a molecular gas depletion timescale increase with stellar mass. *Right.* Stellar mass dependence of the molecular gas fraction, an upturn is observed at the low- M_* end.

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_{gas} behaviour. We observe an increase of f_{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_{gas} . At each redshift the gas fraction shows a large dispersion, due to the dependence of f_{gas} on M_* , producing a gradient of increasing f_{gas} with decreasing M_* . We provide the first measure of $\langle f_{\text{gas}} \rangle = 0.67 \pm 0.20$ of $z > 1$ SFGs at the low- M_* end $10^{9.4} < M_*/M_\odot < 10^{9.9}$, which shows a clear f_{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