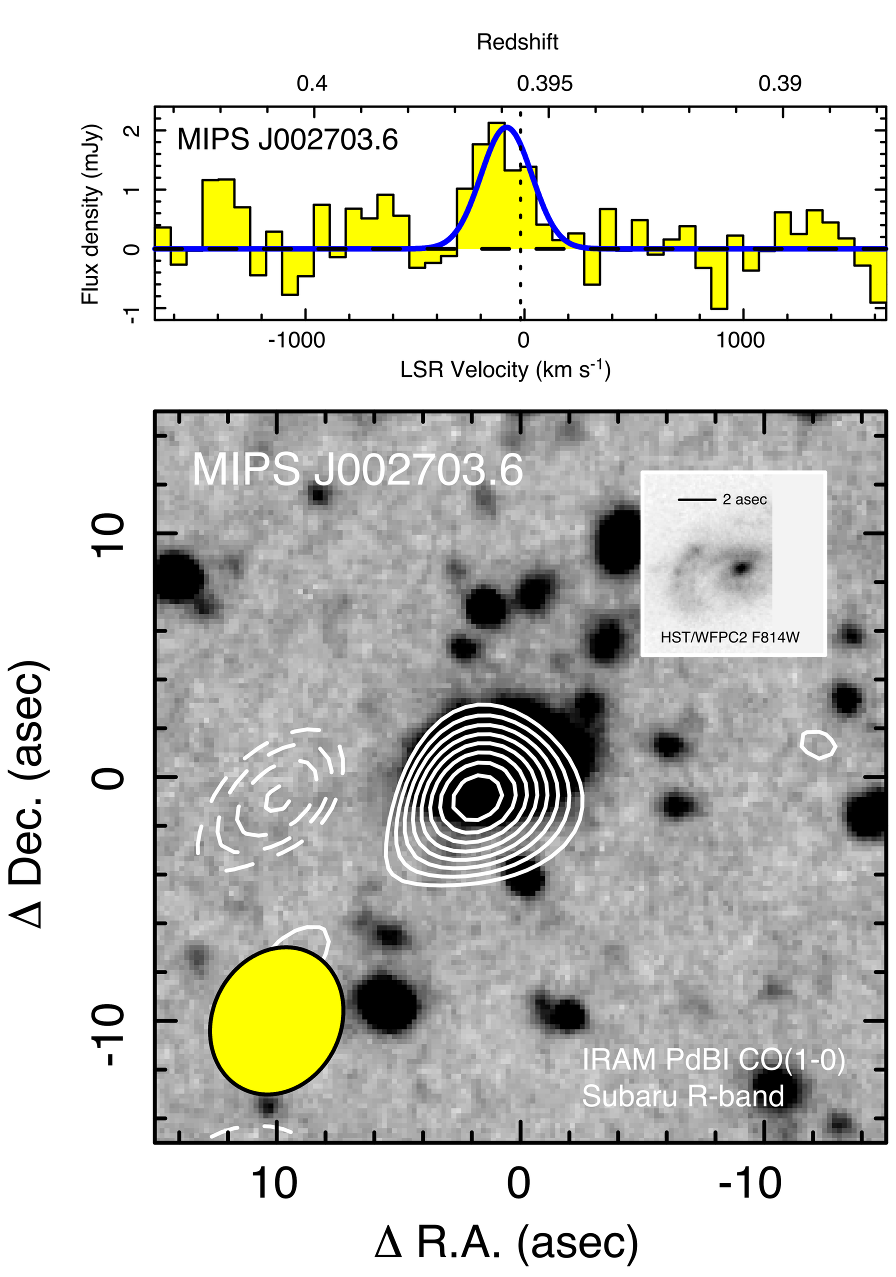
Evolution of the molecular gas fraction of star-forming galaxies since z∼2

Abridged from Geach et al. (2011), submitted

James E. Geach[1], *Ian Smail*[2], *Sean M. Moran*[3], *Lauren A. MacArthur*[4], *Claudia del P. Lagos*[2] *& Alastair C. Edge*[2]
[1]McGill University [2]ICC, Durham University [3]Johns Hopkins University [4]HIA / University of Victoria

Abstract We present IRAM Plateau de Bure interferometric detections of CO ($J = 1 \rightarrow 0$) emission from a 24μm-selected sample of star-forming galaxies at $z = 0.4$. The galaxies have PAH 7.7μm-derived star formation rates of SFR∼30–60 $M_\odot$ yr^{-1} and stellar masses $M_\star \sim 10^{11} M_\odot$. The CO ($J = 1 \rightarrow 0$) luminosities of the galaxies imply that the discs still contain a large reservoir of molecular gas, contributing ∼20% of the baryonic mass, but have star-formation 'efficiencies' similar to local quiescent discs and gas-dominated discs at $z \sim 1.5$–2. We reveal evidence that the average molecular gas fraction has undergone strong evolution since $z \sim 2$, with $f_{\rm gas} \propto (1+z)^{\sim 2\pm 0.5}$. The evolution of $f_{\rm gas}$ encodes fundamental information about the relative depletion/replenishment of molecular fuel in galaxies, and is expected to be a strong function of halo mass. We show that the latest predictions for the evolution of the molecular gas fraction in semi-analytic models of galaxy formation within a ΛCDM Universe are supported by these new observations.

Observing cool (<50 K) molecular hydrogen is difficult; the molecule has no permanent electric dipole and so at all redshifts one must rely on tracer molecular emission. Unfortunately, the majority of molecular gas studies at high-z have focused on the most active systems (generally sub-millimeter selected galaxies and quasars), and so comparatively little is known about the evolution of the molecular gas properties of the more common, but less active population. In this work we present new IRAM Plateau de Bure interferometric observations of a sample of 24μm-selected galaxies (LIRGs) in the rich cluster Cl 0024+16 at $z = 0.395$ (see Geach et al. 2009). These galaxies bridge the gap between quiescent, local spirals and luminous, high-redshift starbursts and discs. Figure 1 summarises our main result.



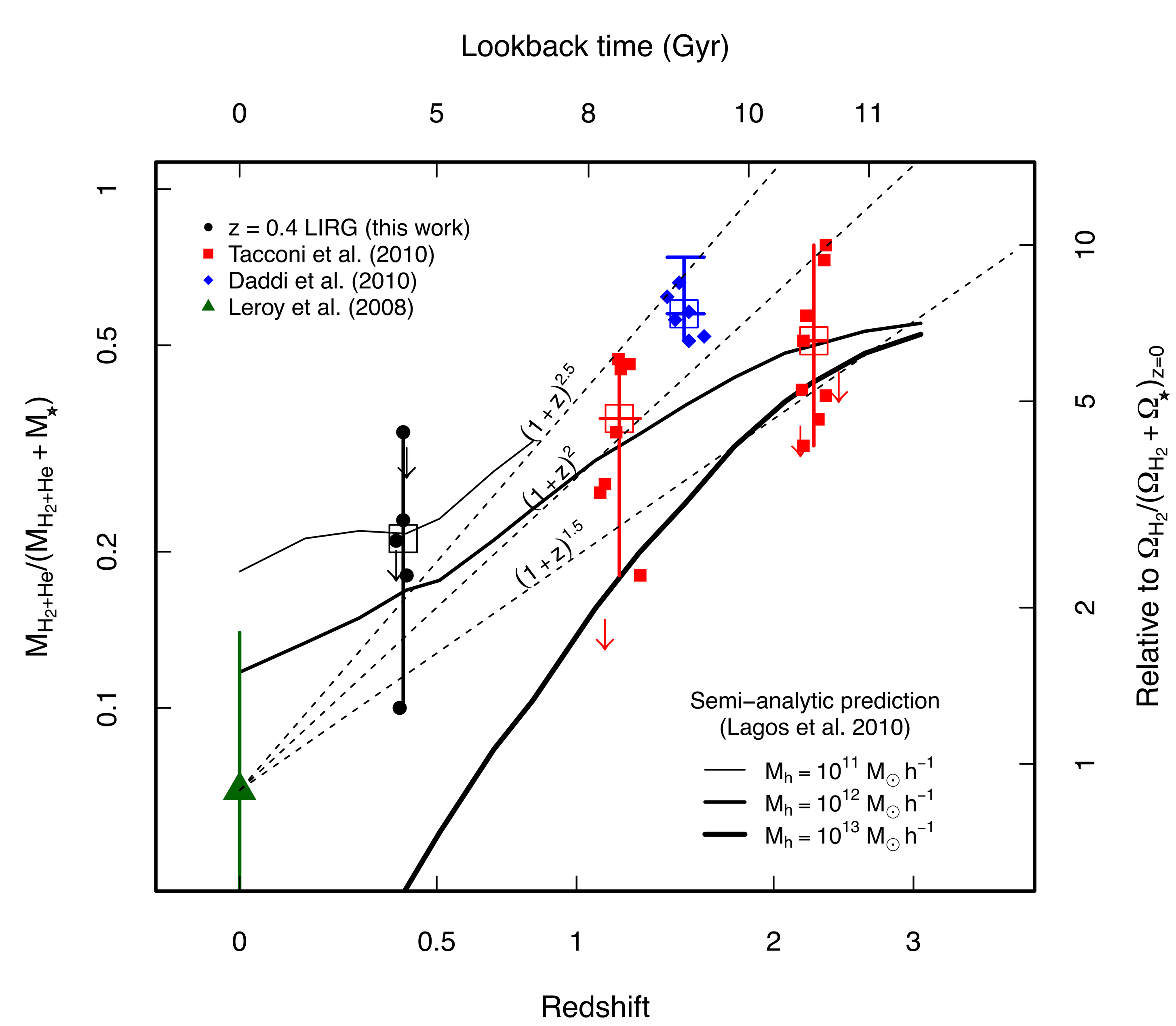


Fig. 1. *(left)* Example of a velocity integrated, clean CO ($J = 1 \rightarrow 0$) line emission map (shown as contours at levels of $\geq 2 \times$ r.m.s.) overlaid on a Subaru SuprimeCam R-band image centred on a target LIRG (ellipse indicates the beam size and shape). (*top*) the 3 mm spectrum extracted from the peak of the integrated line emission map. *(right)* Evolution of the molecular gas fraction in $M_\star > 10^{10} M_\odot$ galaxies. We compare our $z = 0.4$ results with the high-z discs of Daddi et al. (2010) and Tacconi et al. (2010), and the $z \sim 0$ sample of Leroy et al. (2008). On average, there has been a pronounced decline in $f_{\rm gas}$ over cosmic time, following $(1+z)^{\sim 2\pm 0.5}$. The evolution is predicted to be halo-dependent, and is a balance between the cooling of fresh material onto the discs, and on-going star-formation and feedback. For comparison, we show the average gas fraction in galaxies with $M_\star > 10^{10} M_\odot$ in different halos as a function of epoch from the latest semi-analytic predictions for the evolution of molecular gas (Lagos et al. 2010).

References Daddi et al. 2010, ApJ, 713, 686, Geach et al., 2009, MN, 395, L62, Lagos et al., 2010, astro-ph/1011.5506, Leroy et al., 2008, AJ, 136, 2782, Tacconi et al., 2010, Nature, 463, 781