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The contribution of starbursts and normal galaxies to IR luminosity functions and the molecular gas content of the Universe at $z < 2$

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Abstract. We present a parameter-less approach capable of predicting the shape of the infrared luminosity function at redshifts $z \leq 2$. It relies on three observables: (1) the redshift evolution of the stellar mass function for star-forming galaxies, (2) the evolution of the specific star formation rate of main-sequence galaxies, and (3) the double-Gaussian decomposition of the specific star formation rate distribution at fixed stellar mass into the contributions (assumed to be redshift- and mass-invariant) from main-sequence and starburst activity.
Using this self-consistent and simple framework, we identify the contributions of main-sequence and starburst activity to the global infrared luminosity function and find a constant or only weakly redshift-dependent contribution (8–14%) of starbursts to the star formation rate density at $z \leq 2$. Over the same redshift range, we also infer the evolution of the cosmic abundance of molecular gas in star-forming galaxies, based on the relations between star formation rate and molecular gas mass followed by normal and starburst galaxies.

1. Introduction

Star-forming galaxies (SFGs) at both high and low redshift are a mixture of (1) "normal" SFGs obeying a tight relation – the "galaxy main sequence" – between star formation rate (SFR) and stellar mass $M_\star$ (e.g. Brinchmann et al. 2004; Daddi et al. 2007), and (2) "starbursts" with a strong excess in specific SFR (sSFR) compared to typical galaxies on the SFR-$M_\star$ main sequence.
Distributions of $M_\star$ and SFR describe galaxy populations at a very basic level. The stellar mass function (MF) of SFGs is well-fitted by a Schechter function (e.g., Ilbert et al. 2010), whereas their infrared (IR) luminosity function (LF, a proxy for the SFR distribution) is generally parameterized as a double exponential or power law function (e.g., Le Floc'h et al. 2005; Magnelli et al., 2009). A plausible explanation of this difference is the occurrence of burst-like and "normal" star formation (SF) activity among SFGs. The evolving shape of IR LFs hence implicitly contains information on the relative importance of the two modes of SF in the past.
Here we discuss how the contribution of main-sequence and starburst galaxies to IR LFs (and thus to the SFR density) can be disentangled and use this information to reconstruct the molecular gas history of the Universe.

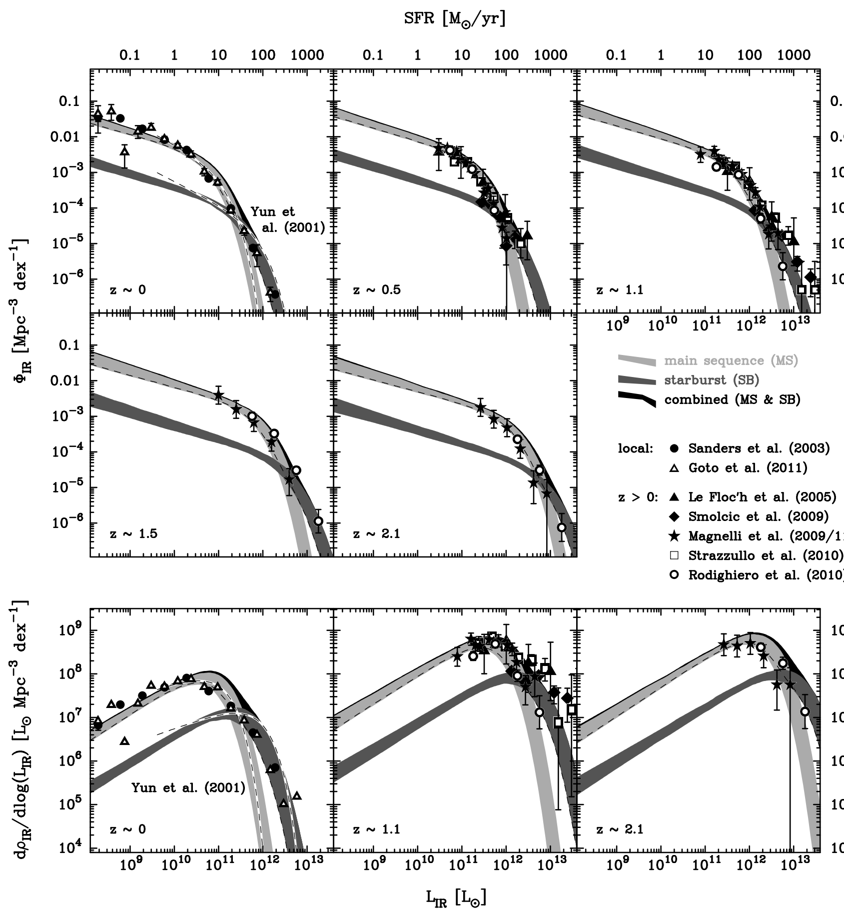

Figure 1. *Top*: Predicted contribution of normal (light grey) and burst-like (dark grey) star formation to IR LFs (SFR distributions; conversion between SFR and $L_{\rm IR}$ following Kennicutt 1998) at $z < 2$. Literature measurements are overlaid (see legend for authorship key). *Bottom*: Predicted IR luminosity density distributions.

2. Method

• *A simple model for the prediction of IR LFs*: The redshift evolution of the average sSFR in main-sequence galaxies out to $z \sim 2$ (e.g., Elbaz et al. 2011; Karim et al. 2011) can be combined with the evolution of the stellar MF of SFGs to predict the shape of the IR LF if the distribution of sSFR at fixed stellar mass in known. Based on the results of Rodighiero et al. (2011) for SFGs at $zsim2$, we approximate this distribution by a double-Gaussian function (identified as being due to main-sequence and burst-like SF activity, respectively; see Sargent et al. 2012 for details and a discussion of the underlying assumptions). The mapping of the stellar MF to an IR LF is effectively a convolution of the MF and a variable double-Gaussian kernel with (i) normalization fixed by the shape

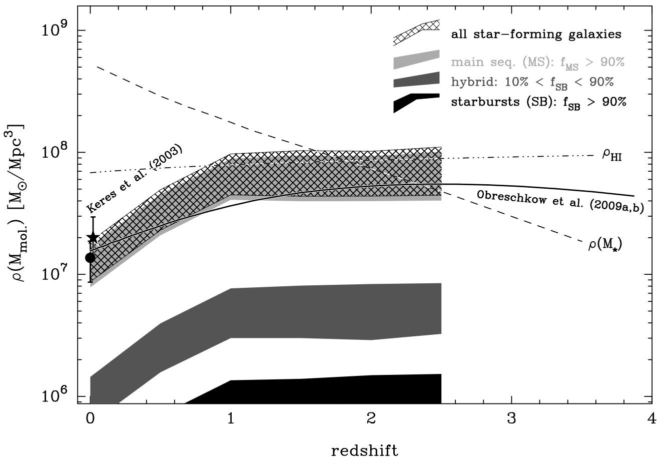

Figure 2. Inferred evolution of the comoving cosmic molecular gas density at $0 < z < 2.5$, contributed by SFGs dominated by normal, by burst-like SF activity or by a mixture of both SF modes (hatched curve – total SFG population). Dashed line: evolution of the stellar mass density (e.g. Fontana et al. 2006); dash-dotted line: evolution of cosmic HI abundance (Bauermeister et al. 2010); black, thin curve: simulation-based predictions (Obreshkow et al. 2009). The $z = 0$ measurements from Obreshkow et al. (2009; dot) and Keres et al. (2003; star) are also shown.

of the MF and (ii) main-sequence peak position that – given the redshift – is uniquely determined by the position of the SF main sequence in the (s)SFR vs. $M_\star$ plane. Thanks to our decomposition, we can then also identify the individual contribution of normal and burst-like SF activity to the IR LF (see Fig. 1).

• *The molecular gas history of the Universe*: The well-constrained evolution at $z < 2.5$ of stellar MF and sSFR of SFGs and our decomposition of the SFR distribution at fixed $M_\star$ into components due to normal and burst-like SFR activity provides a powerful framework for the prediction of cosmological observables, e.g. the evolution of molecular gas reservoirs in normal and starburst galaxies (Sargent et al. 2012, in prep.). One of the main discoveries that recently gave rise to the notion of "bimodal" SF is that "normal" galaxies at low and high redshift convert their molecular gas into stars with an approximately 10-fold lower efficiency than starburst galaxies (cf. Daddi et al. 2010b; Genzel et al. 2010). The two populations follow parallel, slightly supralinear relations between SFR and molecular mass ($M_{\rm mol}$). We use these integrated Kennicutt-Schmidt relations to convert the SFR-distributions in Fig. 1 into mass functions for the molecular gas component of SFGs experiencing either normal and burst-like SF activity. The redshift-dependent molecular gas MFs can then be integrated to infer the cosmic abundance of molecular gas (Fig. 2).

3. Results and discussion

In Fig. 1 we show that the evolution of the stellar MF and of the IR LF (i.e. of the SFR distribution) of SFGs at $z < 2$ is self-consistent (see also Bell et al. 2007) and that starburst galaxies are the dominant factor shaping the bright end of the IR LFs. We find (cf. Sargent et al. 2012) that the fractional contribution of starburst activity to the cosmic SFR density (8–14%) is only weakly redshift-dependent at $z < 2$. We also reproduce the well-known fact that most local ULIRGs are starbursts (e.g., Sanders & Mirabel 1996). At $z > 0.9$, the majority of ULIRGs are main-sequence galaxies. Importantly, however, their high SFR ($>100\,M_{\odot}$) is not triggered by merging as in most local ULIRGs but is a secular process linked to large gas reservoirs in high-z disks (e.g., Daddi et al. 2010a, Tacconi et al. 2010, Geach et al. 2011). Local and distant ULIRGs are *intrinsically different objects* for which direct comparisons should be avoided.
Fig. 2 illustrates the rapid growth of molecular gas reservoirs in SFGs. We infer that most of this 10-fold increase takes place at $z < 1$ and that it is entirely dominated by the molecular gas fuelling "secular" SF activity in main-sequence galaxies. By $z \sim 2$, the comoving stellar and molecular mass content of the Universe are predicted to become equal, in good agreement with the molecular gas fractions of ∼50% measured in $z \sim 2$ disks (e.g., Daddi et al. 2010a; Tacconi et al. 2010).

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