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The Scaling of Star Formation: from Molecular Clouds to Galaxies

Daniela Calzetti

Department of Astronomy
University of Massachusetts
710 North Pleasant Street
Amhest, MA 01003, USA
email: calzetti@astro.umass.edu

Abstract. This is a review of the extant literature and recent work on the scaling relation(s) that link the gas content of galaxies to the measured star formation rates. A diverse array of observing techniques and underlying physical assumptions characterize the determination of these relations at different scales, that range from the tens of parsec sizes of molecular clouds to the tens of kpc sizes of whole galaxies. Different techniques and measurements, and a variety of strategies, have been used by many authors to compare the scaling relations, both within and across galaxies. Although the picture is far from final, the past decade has seen tremendous progress in this field, and more progress is expected over the next several years.

Keywords. galaxies: star formation – galaxies: ISM – ISM:clouds

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1. Introduction

The studies that link star formation to its fuel, the gas, are at the foundation of all investigations of the evolution of galaxies across cosmic times. The early hypothesis by Schmidt (1959) of a correlation between star formation rate (SFR) and gas volume densities has evolved over the years to use the surface densities of both the SFR and the gas: $\Sigma_{SFR}/(M_{\odot}\ yr^{-1}\ kpc^{-2}) \propto [\Sigma_{gas}/(M_{\odot}\ pc^{-2})]^{\gamma}$, in order to employ only observable quantities and remove the (uncertain) measurement of the thickness of the emitting regions (e.g., Kennicutt 1989, 1998). Alternate, non–exclusive, formulations introduce dynamical timescales τ_{dyn}: $\Sigma_{SFR} = \epsilon_{ff}[\Sigma_{gas}/\tau_{dyn}]$ (e.g. Kennicutt 1998; Kennicutt, & Evans 2012), where ϵ_{ff} is the efficiency of star formation, i.e., the rate of conversion of gas to stars over one dynamical timescale. The gas/SFR ratio expresses the timescale over which the gas will be exhausted is star formation proceed at the same rate, thus defining a depletion timescale: $\tau_{dep} = \Sigma_{gas}/\Sigma_{SFR} = \tau_{dyn}/\epsilon_{ff}$. Following common practice, I will term the relation between SFR and gas surface densities the 'Schmidt–Kennicutt Law', or SK Law for short.

Advances in both space and ground facilities and instrumentation have opened a new era for the investigation of the scaling laws of star formation, pushing the frontier both in time, towards higher redshifts, and in space, towards smaller and smaller scales within galaxies. High angular resolution and/or deep measurements of both the dust–obscured and unobscured SFRs have been secured by space facilities like the Galaxy Evolution Explorer in the ultraviolet (UV), the Hubble Space Telescope in the UV–to–nearIR, and the Spitzer Space Telescope and the Herschel Space Observatory in the infrared, in concert with ground–based optical and nearIR observations of the nebular line emission from galaxies. Ground–based radio, millimeter, and sub–mm facilities and the Herschel Space Observatory have secured the HI, CO and dust continuum observations needed to trace the gas (and dust) emission.

In this review, I briefly summarize the basic results of the past ∼decade of investigations, with specific emphasis on the intermediate scales within nearby galaxies, i.e., the scales that are in–between the whole galaxy and the giant molecular clouds (GMCs), and range from a few hundred pc to several kpc. These scales are here referred to as 'sub–galactic', while measurements of whole galaxies are termed 'global'. In the nearby Universe, the study of sub–galactic scales has most benefitted from the facilities briefly described above. Because of the extensive literature on the subject, this review is inevitably incomplete. Omissions are unintentional.

2. The Global Relation

The general picture that has emerged since the first systematic analysis of local galaxies (Kennicutt 1989) is that more actively star forming galaxies convert gas into stars at a higher rate than less active galaxies. This continues to be supported by more recent data, both at low (Kennicutt 1998; Kennicutt, & Evans 2012) and high redshift (Daddi, *et al.* 2010a; Genzel, *et al.* 2010; Santini, *et al.* 2014). The fundamental relation between SFR density and gas density of galaxies has been variously interpreted as a non–linearity between Σ_{SFR} and Σ_{gas} ($\gamma > 1$, e.g., Kennicutt, & Evans 2012; Cormier, *et al.* 2014) or a decrease in the depletion timescale τ_{dep} for increasing SFR density or specific SFR, sSFR=SFR/Mass$_{stars}$ (e.g., Saintonge, *et al.* 2011; Tacconi, *et al.* 2013; Genzel, *et al.* 2014, see, also, Linda Tacconi's contribution to this Conference).

One of the recurring questions when measuring the Global SK Law is whether Σ_{gas} should be calculated including only the molecular (star–forming) component or the sum of all gas, the main contributors typically being neutral atomic and molecular (including CO–dark molecular gas, e.g., Wolfire, Hollenbach, & McKee 2010; Langer, *et al.* 2014). There is not necessarily a unique answer to this question, and it may depend on the actual details of the question. To the extent that the main question is: what is the relation between SFR and the gas reservoir?, the search for an answer should likely include *all* gas components. Although the atomic gas traced by HI does not participate directly in the formation of stars, the existence of a density boundary for HI, Σ_{HI} ∼10 $M_\odot$ pc^{-2} (e.g., Kennicutt, *et al.* 2007), suggests that HI converts into H_2 above this density value (Krumholz, McKee, & Tumlinson 2009). If HI replenishes the molecular gas reservoir depleted by star formation and to the extent that a galaxy can be considered an isolated system on the timescales relevant for star formation (⩽100 Myr), HI ought to be included in calculations of the gas reservoir of a galaxy when deriving the Global SK Law (Boissier, *et al.* 2003). This is likely less of an issue at high redshift, where current evidence suggests that the molecular fraction in galaxies is higher than in local galaxies (Daddi, *et al.* 2010b; Tacconi, *et al.* 2013).

The higher rate of gas–to–stars conversion in more active galaxies can be re-interpreted as a change in the dynamical timescale relevant for the conversion of gas to stars, at fixed efficiency ϵ_{ff}; since the dynamical timescale decreases as the star formation rate increases, the relation between Σ_{SFR} and Σ_{gas}/τ_{dyn} becomes linear (e.g., Kennicutt 1998; Daddi, *et al.* 2010a; Genzel, *et al.* 2010; Krumholz, Dekel, & McKee 2012). However, there is currently no agreement on what timescale to use for the SK Law, whether the orbital, free–fall, and/or crossing time, and why (Kennicutt, & Evans 2012). The value of the efficiency of star formation, ϵ_{ff}, which is around a few percent, is also another parameter that has not been explained physically, so far. Finally, there is some evidence for the existence of two regimes for the Global SK Law, one for 'normal star–forming' galaxies and one for 'starburst' galaxies (Daddi, *et al.* 2010a; Genzel, *et al.* 2010), but the dichotomy represented by the two regimes may be driven, at least in part, by the choice of the CO–to–H_2 factor (Narayanan, *et al.* 2011). Thus, despite much progress in this area, many questions still remain open.

3. Down to the Scales of GMCs

Zooming into galaxies can offer better understanding of the physical underpinning of the SK Law, since we can approach the region sizes where star formation occurs. Star formation is more closely related to GMCs than to the more diffuse gas (as traced by HI), and it has become customary to represent the Sub–Galactic SK Law via a relation between Σ_{SFR} and Σ_{H2}, rather than Σ_{HI+H2} (e.g., Kennicutt, *et al.* 2007; Bigiel, *et al.* 2008, , and many others). Furthermore, recent investigations suggest that, within GMCs, star formation is closely associated with the dense molecular gas (A_V >7 mag), with a linear relation between SFR and $M_{gas,dense}$ (e.g., Lada, *et al.* 2012, 2013, see, also, the review by Charlie Lada at this Conference).

Independently of the gas phase that we decide to relate to star formation, the fundamental question remains: how are the different gas phases (loosely separated according to increasing gas density) interconnected, and how does this interconnection lead to the observed SFRs? This question is still unanswered.

The results on the SK Law of GMCs are difficult to relate to those of whole galaxies, because moving up in scale does not translate into a simple rescaling of quantities. The locus of GMCs in the Σ_{SFR}–Σ_{H2} plane is one–to–two orders of magnitude higher than the locus occupied by galaxies and sub–galactic regions (e.g., Heiderman, *et al.* 2010; Gutermuth, *et al.* 2011). Most of the area of galaxies is not occupied by GMCs and their associated star formation: the GMCs covering factor hovers around 5%–15% in local star–forming galaxies, with large variations from system to system (Leroy, *et al.* 2009). However, the covering factor alone does not account for the discrepancy between the GMC–scale SK Law and the Global SK Law. Large fractions of CO–emitting diffuse molecular gas need to be invoked, in order to move the GMC–scale SK Law to higher gas surface densities, while keeping the SFR surface density at low values (Heiderman, *et al.* 2010). Alternatively, the two Laws (GMCs and Global) may originate from different physical mechanisms, with the Global SK Law determined by stellar and supernova feedback, and the GMC–scale SK Law dominated by local processes, such as turbulence–regulated gravitational collapse (Faucher–Giguère, Quataert & Hopkins 2013, see, also the review by Phil Hopkins at this Conference). Thus, the relation between star formation in GMCs and in galaxies as a whole is far from trivial. The SK Law at intermediate (≈kpc) scales may provide insights on the link between the two.

4. The Sub–Galactic Relations

Extensive literature exists on the Sub–Galactic SK Law, where investigators have used a variety of approaches for the treatment of both the data and the statistics, with analyses that include both radial profiles and galaxy region bins, and covering the full spatial range between ∼200 pc and ∼2 kpc (a highly incomplete list includes: Heyer, *et al.* 2004; Kennicutt, *et al.* 2007; Bigiel, *et al.* 2008; Blanc, *et al.* 2009; Verley, *et al.* 2010; Liu, *et al.* 2011; Momose, *et al.* 2013; Shetty, *et al.* 2014). One common characteristic to these studies is the general lack of agreement on what the shape of the Sub–Galactic SK Law is, specifically in regard to the value of γ, that ranges from ~ 0.6 to ~ 1.8. For $\gamma \geqslant 1$, the value of γ carries information about the physical process(es) responsible for the conversion of gas into stars. Thus, determining whether a single value exists among galaxies and what this value is for sub–galactic regions has become an important quest.

Conversely, studies that find a sub–linear ($\gamma < 1$) Sub–Galactic SK Law require the introduction of components unrelated to star–formation, such as CO–emitting diffuse molecular gas (e.g. Shetty, Clark, & Klessen 2014).

At this point in time, it may still be difficult to establish whether a universal Sub–Galactic SK Law exists, and whether it can be used as a conduit for relating the GMC–scale to the Global SK Laws. The reason is the many biases and spurious effects that can be introduced in the measurement of either the SFR and/or the gas. The following list attempts at conveying the variety of such effects:

• kpc–size 'bins' within galaxies are not isolated systems, not even on the timescales of star formation. This affects measurements of Σ_{SFR}. Ionizing photons leak out of HII regions, at the 30%–60% level (e.g. Thilker, *et al.* 2002), and ionize gas up to a kpc from the point of origin; measurements of faint Hα cannot be readily converted to a SFR because of this effect. While the UV emission from evolved (>100 Myr) stellar populations and the mid–IR emission from the dust they heat only accounts for ≈20%–30% of the total emission from a galaxy (Johnson, *et al.* 2013; Leroy, *et al.* 2012), these numbers do not capture the effect of the clustering of star formation on Sub–Galactic measurements. Clustered star formation disperses in the field, e.g., from the spiral arms into the inter arm regions, in ∼100–300 Myr, or less (Crocker, *et al.* 2014), which produces the redder UV colors of the field relative to those of star–forming regions. This affects popular SFR indicators based on UV, IR, and other stellar continuum or dust emission bands. For reference, a galactic region with stellar populations in the age range 100 Myr–10 Gyr produces enough UV+IR emission to mimic (in unresolved conditions) star formation with values $\Sigma_{SFR}(UV + IR) \sim$1–6$\times10^{-3}$ M$_\odot$ yr^{-1} kpc^{-2}, for star formation with an e–folding time of 5 Gyr and for constant star formation, respectively, using typical mean stellar densities (Barden, *et al.* 2005). Yet, this region contains no current star formation. Its main effect will be to bias measurements of faint star forming regions by providing a spurious 'pedestal' or 'excess' to their SFRs (Liu, *et al.* 2011), together with an overall scatter due to stellar population content variations among bins.

• Measurements of gas surface density are non–trivial. Although there is agreement in the literature that on Sub–Galactic scales star formation is better correlated with molecular gas, the tools to determine Σ_{H2} have both strengths and weaknesses. The most common approach, to measure H_2 via CO line emission can be biased by: (1) the dependency of the CO–to–H_2 conversion factor on metallicity, gas temperature, and turbulence (Bolatto, Wolfire, & Leroy 2013); (2) the variation of the ratio among different CO transitions within a galaxy (e.g., Koda, *et al.* 2012) and the fact that higher transitions trace smaller fractions of the molecular gas (e.g, Rigopoulou, *et al.* 2013); (3) presence of CO-dark, star–forming H_2; and (4) presence of CO-emitting, non–star–forming, diffuse H_2. The other popular approach, that uses a combination of dust and HI maps to derive the H_2 distribution can be affected by: (1) variations, at the level of 2X, in the dust surface densities, due to choice of fit parameters in the dust emission modeling (e.g., Kirkpatrick, *et al.* 2014); (2) presence of sub–mm excess in the dust emission, which affects estimates of the largest, by mass, dust component (Galametz, *et al.* 2014); and (3) the potential super–linear dependency of the dust–to–gas ratio on metallicity (Rémy–Ruyer, *et al.* 2014). While most of these problems affect both the Sub–Galactic and the Global SK Laws, local variations of conditions within a galaxy can exacerbate the impact on the Sub-Galactic SK Law (Koda, *et al.* 2012; Sandstrom, *et al.* 2013).

• The timescale of the association between star formation and gas clouds is likely short. As young stellar structures evolve, the gas clouds from which they formed dissolves, on scales as short as ∼20–30 Myr (Kawamura, *et al.* 2009). When coupled with the dispersal of star formation and the low covering factor of molecular clouds (see

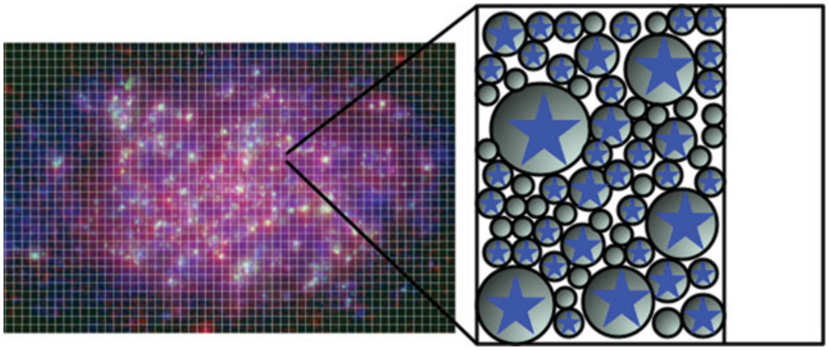

Figure 1. Schematic representation of the simulations by Calzetti, Liu & Koda (2012). **(Left)**: The nearby galaxy NGC7793 is shown in a three–color representation with a grid overlaid. The grid represents the 'blind selection' of galactic regions, discussed in section 5. **(Right)**: Molecular clouds (grey circles) populate each region (bin), with a cloud mass distribution that follows observed trends and limits. A maximum cloud mass of 3×10^7 $M_\odot$ ($R_{cloud,max}$ ~300 pc) is adopted in the simulations. The empty region to the right of the bin is a schematic for a covering factor <1. Clouds are populated with star formation (blue stars) according to a pre–selected star formation law. Monte Carlo simulations are used to model a range of physical and geometric conditions in the regions.

above), this suggests that measurements of the Sub–Galactic SK Law are subject to significant effects of stochastic (random) sampling when the level of star formation is low, Σ_{SFR} <a few$\times10^{-3}$ $M_\odot$ yr^{-1} kpc^{-2}, or when the bins are small, roughly <300 pc.

5. Measuring the Sub-Galactic Relations

There are basically two approaches that have been used to derive the Sub-Galactic SK Law in external galaxies: (1) measure it in regions where star formation is present, using a number of tracers; and (2) divide a galaxy into spatial bins and use all bins for the analysis. The first approach introduces an a–priori selection on the regions to be used, but avoids most of the problems linked to biased measures, which have been detailed in the previous section. The second approach, far more popular than the first, uses a blind selection method for the galactic regions, which avoids a–priori selections, but is subject to biases in the measurements of SFR and gas.

The impact of some of the biases listed in the previous section can be modeled using Monte Carlo simulations of the expected conditions in blindly selected galaxy regions (Calzetti, Liu & Koda 2012). Figure 1 shows a cartoon schematic of a simulated region, which we will call a bin. The simulations include a range of input star formation laws (parametrized by the power law $\beta = 1$,1.5,2), cloud mass functions, cloud covering distributions, and bin sizes, and produce, as outputs, the slope γ_{H2} and the scatter σ_{H2} about the best fit line of the Sub–Galactic SK Law as a function of bin size. This enables us to explore the effects of adding/subtracting a background to the stellar light distribution (to mimic the contribution of the light from evolved stars to measurements Σ_{SFR}), of gas thresholds to star formation, of different statistical estimators (bi–sector fit, bi–linear regression fit), and of adding noise, scatter, and data censoring.

Figure 2 shows the recovered γ_{H2} and σ_{H2} for a default model that includes a simple relation between SFR and H_2, with no additions of thresholds or backgrounds. The general trend is that both γ_{H2} and σ_{H2} decrease for increasing bin size, and they tend to converge to unity and to zero, respectively, independently of the input star formation power law, as parametrized by β. This is an effect of how the cloud mass distribution populates the

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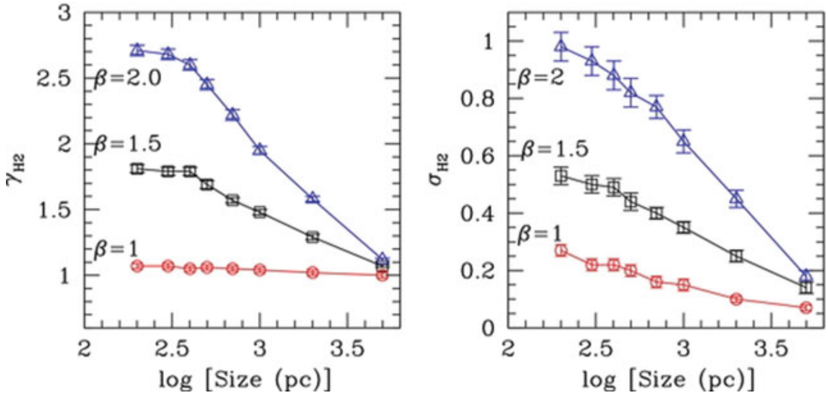

Figure 2. The recovered slope γ_{H2} of the SK Law (left), and scatter σ_{H2} about the best fit line (right) as a function of bin size, for the baseline Monte Carlo model in Calzetti, Liu & Koda (2012). The input star formation law has slope parametrized by β ((β=1, 1.5, 2). The recovered slope and the scatter are always dependent on the bin size, except for the case of the slope when β=1. For $\beta > 1$, the transition between $\gamma_{H2} > \beta$ and $\gamma_{H2} < \beta$ occurs at the bin size corresponding to the transition between a stochastically sampled and a fully sampled cloud mass function. The latter situation converges towards a pure 'cloud counting' regime, where the input star formation law does not or only minimally impact the recovered slope.

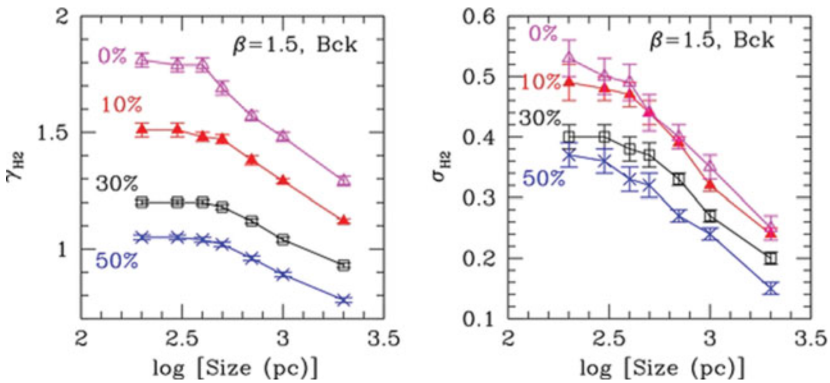

Figure 3. The recovered slope γ_{H2} of the SK Law (left), and scatter σ_{H2} about the best fit line (right) as a function of bin size, for the input star formation law with $\beta = 1.5$, and a range of background levels added to the SFRs. This simulates a situation in which the light used in the measurement of the SFR receives a contribution from evolved (unrelated to the star formation) stellar populations. The indicated fractions are the fraction of the background relative to the total. Sub–linear slopes are recovered for a 50% background contribution.

bin, changing from being stochastically sampled at small bin sizes to be fully sampled at large bin sizes, effectively 'counting clouds' in the latter regime. The convergence of γ_{H2} and σ_{H2} to 1 and 0, respectively, occurs at smaller bin sizes than those shown in Figure 2 for smaller values of the maximum cloud size, i.e., for $R_{cloud,max}$ <300 pc. The trends observed in Figure 2 are similar to the observational ones obtained by Liu, *et al.* (2011), who analyzed the Sub–Galactic SK Law of two nearby galaxies as a function of region size.

Presence of a background added to the stellar light tracing the SFR also affects the recovered γ_{H2} (Figure 3), by lowering its values and pushing them towards unity or sub–unity for increasing background values. At 1 kpc, $\gamma_{H2} < 1$ for a 50% contamination by background light. A similar trend is observed for the scatter σ_{H2} about the best fit line.

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The trends become more marked, with the decrease being steeper for both quantities, if $R_{cloud,max}$ <300 pc.

6. Conclusions

The connection between the scaling laws of star formation of whole galaxies and of GMCs remains elusive, despite much progress on the measurements of the SK Law at all scales (and at many redshifts) over the past ∼decade. The intermediate scales represented by the ∼kpc regions in galaxies may offer an opportunity to link the two SK Laws (or establish that they cannot be linked), but many potential biases affect the measurements of SFR and gas densities in regions that cannot be considered 'isolated'.

'Blind' region selections, like those employed by many studies, should be avoided, in favor of identifying areas of current star formation, which will mitigate the biases on SFR density derivations. If blind region selection cannot be avoided, careful attention should be devoted to regions with gas surface densities with Σ_{gas} <100-200 $M_\odot$ pc^{-2}, i.e., the surface densities typical of normal star–forming galaxies in the local Universe. These are divided between the 'stochastic' regime (Σ_{gas} <5-10 $M_\odot$ pc^{-2}) and the 'cloud counting' regime. One avenue that can be explored to overcome some of the biases and limitations is to perform measurements at a range of scales, which can be used, together with simulations, to disentangle the many effects contributing to the measured values of the slope γ_{H2} of the SK Law and the scatter σ_{H2} of the data about the best fit. These effects include, in addition to the 'true' law of star formation, contamination of SFRs by background light, non-star–forming gas, etc.. Combining high–angular–resolution data on both SFR and gas, by using the synergy between HST (and, in the future, JWST) and ALMA, will enable covering the full range of scales from kpc down to those of GMCs, and finally link the scaling laws of star formation at all scales.

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References

Barden M., Rix H. W., Somerville R. S., *et al.* 2005, *ApJ*, 635, 959
Blanc G., Heiderman A., Gebhardt K., *et al.* 2009, *ApJ*, 704, 842
Bigiel F., Leroy A., Fabian F., *et al.* 2008, *AJ*, 136, 2846
Boissier S., Prantzos N., Boselli A., *et al.* 2003, *MNRAS*, 346, 1215
Bolatto A. D., Wolfire M., & Leroy A. K. 2013, *ARA&A*, 51, 207
Calzetti D., Liu G., & Koda J. 2012, *ApJ*, 752, 98
Cormier D., Madden S. C., Lebouteiller V., *et al.* 2014, *A&A*, 564A, 121
Crocker A. F., Chandar R., Calzetti D., *et al.* 2014, submitted
Daddi E., Elbaz D., Walter F., *et al.* 2010a, *ApJ*, 714, L118
Daddi E., Bournaud F., Walter F., *et al.* 2010b, *ApJ*, 713, 686
Faucher–Giguère C.–A., Quataert E., & Hopkins P. F. 2013, *MNRAS*, 433, 1970
Galametz M., Albrecht M., Kennicutt R., *et al.* 2014, *MNRAS*, 439, 2542
Genzel R., Tacconi L. J., Gracia-Carpio J., *et al.* 2010, *MNRAS*, 407, 2091
Genzel R., Tacconi L. J., Lutz D., *et al.* 2014, (astroph/1409.1171)
Gutermuth R. A., Pipher J. L., Megeath S. T., *et al.* 2011, *ApJ*, 739, 84
Heiderman A., Evans N. J., Allen L. E., *et al.* 2010, *ApJ*, 723, 1019

Heyer M. H., Corbelli E., Schneider S. E., & Young J. S. 2004, *ApJ*, 602, 723
Johnson B. D., Weisz D. R., Dalcanton J. J., *et al.* 2013, *ApJ*, 772, 8
Kawamura A., Mizuno Y., Minamidani T., *et al.* 2009, *ApJS*, 184, 1
Kennicutt R. C. Jr., 1989, *ApJ*, 344, 685
Kennicutt R. C. Jr., 1998, *ApJ*, 498, 541
Kennicutt R. C., Calzetti D., Walter F., *et al.* 2007, *ApJ*, 671, 333
Kennicutt R. C., Evans N. J. 2012, *ARA&A*, 50, 531
Kirkpatrick A., Calzetti D., Kennicutt R., *et al.* 2014, *ApJ*, 789, 130
Koda J., Scoville N., Hasegawa T., *et al.* 2012, *ApJ*, 761, 41
Krumholz M. R., McKee C. F., & Tumlinson J. 2009, *ApJ*, 693, 216
Krumholz M. R., Dekel A., & McKee C. F. 2012, *ApJ*, 745, 69
Lada C. J., Forbrich J., Lombardi M., & Alves J. F. 2012, *ApJ*, 745, 19
Lada C. J., Forbrich J., Roman–Zuniga C., *et al.* 2013, *ApJ*, 778, 133
Langer W. D., Velusamy T., Pineda J. L., *et al.* 2014, *A&A*, 561A, 122
Leroy A. K., Walter F., Bigiel F., *et al.* 2009, *AJ*, 137, 4670
Leroy A. K., Bigiel F., de Blok W. J. G.., *et al.* 2012, *AJ*, 144, 3
Liu G., Koda J., Calzetti D., *et al.* 2011, *ApJ*, 735, 63
Momose R., Koda J., Kennicutt R. C., *et al.* 2013, *ApJ*, 772, L13
Narayanan D.., Krumholz M., Ostriker E. C., & Hernquist L. 2011, *MNRAS*, 418, 664
Rémy–Ruyer A., Madden S. C., Galliano F., *et al.* 2014, *A&A*, 536A, 31
Rigopoulou D., Hurley P. D., Swinyard B. M., *et al.* 2013, *MNRAS*, 434, 2051
Sandstrom K. M., Leroy A. K., Walter F., *et al.* 2013, *ApJ*, 777, 5
Santini D., Maiolino R., Magnelli B., *et al.* 2014, *A&A*, 562A, 30
Saintonge A., Kauffmann G., Wang J., *et al.* 2011, *MNRAS*, 415, 61
Shetty R., Kelly B. C., Rahman N., *et al.* 2014a, *MNRAS*, 437, L61
Shetty R., Clark P. C., & Klessen R. S. 2014b, *MNRAS*, 442, 2208
Schmidt M., 1959, *ApJ*, 129, 243
Tacconi L. J., Neri R., Genzel R., *et al.* 2013, *ApJ*, 768, 74
Thilker D. A., Walterbos R. A. M.., Braun R., & Hoopes C. G. 2002, *AJ*, 124, 3118
Verley S.., Corbelli E., Giovanardi C., & Hunt L. 2010, *A&A*, 510A, 64
Wolfire M. G., Hollenbach D., & McKee C. F. 2010, *ApJ*, 716, 1191