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Star Formation in Molecular Clouds?

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Abstract. Using studies of nearby star formation with Spitzer, I will argue that star formation is restricted to dense cores within molecular clouds. The nature of these dense cores and their connection to star formation will be discussed. Their distribution over masses and over the cloud is similar to that of stars, and their efficiency of forming stars is much higher than that of the whole cloud. Moving to regions forming more massive stars, we find that the mass distribution of the dense clumps is similar to that of OB associations. The infrared luminosity per unit mass of dense gas is high and comparable to that seen in starburst galaxies. The relation between star formation and dense gas appears to be linear. Understanding the Kennicutt-Schmidt law requires an understanding of what controls the conversion of gas into the dense entities where stars actually form.

1. Introduction

The image that comes to mind when we talk about star formation across disciplinary lines is that of the "sight-challenged" villagers and the elephant. Each feels a different part of the elephant and comes to different conclusions about what it is. Discussions of star formation within the Milky Way use language unfamiliar to those who work on star formation in other galaxies and vice versa. If we are to progress, we need to find a common language.

Studies of low mass star formation in nearby (typically within 500 pc) clouds can speak in detail about the distribution of star formation, the timescales for various phases, and the current efficiency in stellar mass per cloud mass. Detailed, predictive theoretical models exist for the formation of individual stars (e.g., Shu et al. 1987). There is a strong focus on detailed studies of the flow of material from envelope to disk to star and on the connection to planet formation (e.g., many articles in Reipurth et al. 2007). We can also provide observational constraints on the origin of the initial mass function. However, these studies are not directly relevant to star formation on galactic scales because low-mass star formation is not observable at large distances.

Regions forming more massive stars begin to show up at about 440 pc (Hirota et al. 2007) in the Orion complex but most lie at distances of kpc, with the most impressive being in the Galactic ring, located about 5 kpc from the center of the Milky Way (Clemens et al. 1988). For the most part, we are really talking about formation of clusters of stars, including both high and low mass stars, though most forming clusters do not survive (Lada & Lada 2003). Our knowledge of these regions is much less detailed, owing to the lack of spatial resolution, and theoretical predictions are less well developed. Considerable theoretical progress is being made, but there are fundamental disagreements on some issues (cf. Krumholz et al. 2005, Bonnell & Bate 2006, Martel et al. 2006). For most of the distant regions, we do not separate individual stars, but rather we characterize the star formation in terms of surrogates, such as the far-infrared luminosity ($L_{\rm IR}$) and the mass of molecular material. While less detailed, these crude measures are more compatible with what can be done in other galaxies.

Discussion of star formation in other galaxies speaks nearly exclusively in terms of "Schmidt Laws". The original version compared the scale heights of young stars and the HI gas and concluded that the star formation rate is proportional to the square of the *volume* density (Schmidt 1959). Were this to be done today, recognizing that star formation is restricted to molecular gas, one would probably infer a linear relationship. However, *surface* density is more amenable to study in other galaxies and modern versions find relations between the surface densities of star formation and gas (Kennicutt 1998). A power law above a threshold provides a remarkably good fit:

$$\Sigma(SF)(\mathrm{M}_\odot\ \mathrm{yr}^{-1}\mathrm{kpc}^{-2}) = (2.5 \pm 0.7) \times 10^{-4} (\Sigma(gas)/1\mathrm{M}_\odot \mathrm{pc}^{-2})^{1.4 \pm 0.15}$$

over a wide range of galaxy types and star formation rates. Several explanations have been offered for the value of the exponent (Elmegreen & Scalo 2004, Krumholz & McKee 2005, Shu et al. 2007). Models of galaxy formation and evolution generally use a Kennicutt-Schmidt relation to simulate star formation, which is treated as "sub-grid physics."

To return to the elephant analogy, each villager feels a different part of the elephant, but also speaks a different language, which is only partly understood, and often misinterpreted, by the others. But the need for communication is great as rapid progress is occurring in studies of massive star formation in our galaxy. At the same time, studies of galaxy formation are progressing rapidly, including both archaeological studies of the oldest stars and direct look-back studies of high-z luminous starbursts. Can we find a common language?

I will summarize recent progress in studies of both local, low-mass and clustered, high-mass star formation in our Galaxy, and then I will discuss some connections that can be made.

2. Low-mass Star Formation in Nearby Clouds

For convenience, I will focus here on recent results from the *Spitzer* legacy project, "From Molecular Cores to Planet-Forming Disks", known as "Cores to Disks" or c2d (Evans 2003). In particular, I will concentrate on studies of five large nearby clouds. For three of these clouds (Perseus, Serpens, and Ophiuchus), we have complementary information on the dust emission at 1 mm using Bolocam (Enoch et al. 2006, Young et al. 2006, Enoch et al. 2007) and molecular line emission (Ridge et al. 2006). These studies provide the first complete coverage of molecular clouds in tracers of gas, dense cores, and young stellar (or substellar) objects (YSOs) down to luminosities of about 0.01 $\mathrm{L}_\odot$.

Comparison of the CO and ^{13}CO maps with the Bolocam maps shows that the dense ($n > 2 \times 10^4$ cm^{-3}) cores traced by dust continuum emission at millimeter wavelengths are distributed very non-uniformly over the cloud. Dense cores are highly clustered, and many lie along filaments traced by ^{13}CO. The dense cores strongly prefer regions of high overall extinction, with 75% of dense cores found within extinction contours that contain only 0.1 to 0.3 of the total cloud mass (Enoch et al. 2007). Comparison of the dense core distribution to that of YSOs shows a strong correlation, especially for the early stages of star formation. The dense cores are clearly the sites of star formation; most of the cloud is completely inactive.

Until spectral types are available for more of the YSOs, we cannot construct IMFs for the clouds, but all data so far are consistent with a typical IMF. The core mass distribution for *starless* cores, averaging over all 3 clouds, is remarkably consistent with the usual IMF, but shifted to larger masses by a factor < 4, suggesting that the IMF is set by the core mass distribution with an efficiency $> 25\%$ (Enoch et al. in prep.). Similar conclusions have been reached by Alves et al. (2007) using extinction mapping to trace cores; their method produces less uncertain masses but probes lower densities on average. Of course, the similarity of the IMF and the core mass distribution could be fortuitous if cores of different masses have different lifetimes (Clark et al. 2007).

We define the actual efficiency of star formation as the fraction of the mass that ends up in stars (or substellar objects):

$$\epsilon_\star = M_\star/(M_\star + M_{\rm gas}) \approx M_\star/M_{\rm gas}.$$

The *final* efficiency, after the gas is consumed or dissipated, is impossible to determine directly since the gas lifetime vastly exceeds human lifetimes, but we can constrain it. In practice we measure the *current* efficiency using the current mass in stars and in gas. To get a star formation rate ($\dot{M}_\star$), we assume a mean stellar mass of 0.5 $M_\odot$ (consistent with actual determinations in one cloud, Alcalà et al. in prep.), and a timescale of 2 Myr (essentially the half-life of infrared excesses that the c2d observations are sensitive to). It is possible for these nearby regions to separate the efficiency, as defined above, from the question of the *speed* of star formation. We define the timescale for gas depletion, as in extragalactic studies:

$$t_{dep} = M(gas)/\dot{M}_\star,$$

and the speed is $1/t_{dep}$. Krumholz & Tan (2007) define the speed as

$$SFR_{\rm ff} = t_{\rm ff}/t_{\rm dep} = \dot{M}_\star t_{\rm ff}/M(gas).$$

This is the speed ($1/t_{dep}$) normalized to the maximum likely speed ($1/t_{\rm ff}$), or the star formation rate normalized to the maximum possible in a free fall time.

The preliminary results for these quantities for the five large clouds studied by c2d are summarized here. The total mass in YSOs is about 2% to 4% of the cloud mass (e.g., Harvey et al. 2007, Evans et al. in prep.) consistent with earlier conclusions that star formation is inefficient. The total mass in dense cores is only 1% to 4% of the total cloud mass included in the $A_V = 2$ contour. Low star formation efficiency begins with inefficient core formation. The values of $\dot{M}_\star$ range from 6.0 to 71 $M_\odot$/Myr, a significant range. Star formation is slow: the depletion timescales for the whole molecular clouds are t_{dep} = 50–90 Myr, much longer than most estimates of cloud lifetimes of 5–10 Myr. While further star formation is likely, the final efficiencies are likely to remain low. In contrast, the depletion times for dense cores, the actual sites of star formation, are 0.6–3.5 Myr, and masses in dense cores are similar to current masses in YSOs. Star formation is fast and efficient *in dense gas*.

What about the speed relative to that obtained from assuming free fall? In calculating SFR_{ff}, we use the mean density of the relevant unit to calculate the free fall time. The SFR_{ff} is 0.02 to 0.03 for the cloud as a whole, consistent with long-standing arguments against efficient star formation at the free-fall rate (e.g., Zuckerman & Evans 1974). Considering the clump that is forming a cluster, the SFR_{ff} increases to 0.1 to 0.3, but if we use the mean density of an individual dense core, the SFR_{ff} is only 0.03 to 0.12. Star formation remains "slow" compared to a free fall time. This slowness cannot be blamed entirely on a slow prestellar phase; comparison of the numbers of dense, starless (prestellar) cores to the numbers of protostellar cores yields lifetimes of a few free-fall times once the density exceeds about 2×10^4 cm^{-3} (Enoch et al. in prep).

Does the surface density relation (Kennicutt 1998) have any relevance to local star formation? This one is hard to test locally because of incompleteness, but we can make a rough estimate. With a local gas surface density of 6.5 M$_\odot$ pc^{-2} (L. Blitz, pers. comm.), of which about 85% is HI (Levine et al. 2006, Dame 1993), the Kennicutt relation would predict $\Sigma(SF) = 3.4 \times 10^{-3}$ M$_\odot$ yr^{-1} kpc^{-2}. Lada & Lada (2003) estimate that embedded clusters contribute, to within a factor of 3, $\Sigma(SF) = 3 \times 10^{-3}$ M$_\odot$ yr^{-1} kpc^{-2} within a radius of 0.5 kpc. This is surely an underestimate until we have a more complete census of all clouds within the local area, but it is already remarkably close to the prediction. A more extensive study of this topic can be found in Blitz & Rosolowsky (2006). It is interesting to note that the low-mass star formation in the clouds studied by the c2d project would not be apparent to the usual tracers used in extragalactic studies, with the possible exception of $L_{\rm IR}$.

The lessons we should take from these very detailed studies of nearby clouds are as follows. The fundamental units of star formation are dense cores, not molecular clouds, per se (hence the question mark in the title). The cores are not located randomly over cloud faces, but are concentrated in clumps, which are forming clusters, and filaments, which tend to form smaller aggregates. The core mass distribution *may* determine the IMF. Star formation in molecular clouds is very inefficient (2–4%), but quite efficient in dense cores ($> 25\%$). Star formation is slow in terms of a free-fall time, especially for the cloud as a whole, but somewhat faster in terms of a free-fall time (and much faster in absolute terms) in dense cores.

3. Massive, Clustered Star Formation

With the exception of a few, relatively nearby regions of massive, clustered star formation, such as the Orion region (e.g., Hillenbrand 1997, Lada & Lada 2003, Allen et al. 2007), we do not have such detailed information on stellar IMF, ages, efficiencies, etc. Instead we accept cruder measures, but these provide a bridge to star formation in other galaxies. Theories are not well developed yet, but progress is being made, as discussed at the meeting by Bonnell, Dobbs, and Krumholz.

There have been a number of surveys for dense gas, but they have all been directed toward sign-posts of star formation, such as water masers (Plume et al. 1992) or *IRAS* sources (Sridharan et al. 2002; Beuther et al. 2002). An unbiased survey of 1 mm continuum emission now underway using Bolocam will provide a more complete census (Williams et al. 2007) and deeper surveys with SCUBA-2 and far-infrared surveys with Herschel will follow. We should soon have a much more complete picture of star formation sites in the Milky Way.

For now, I will focus on results from the survey toward water masers (Plume et al. 1992), which has been followed up by many other studies obtaining gas densities from multitransition CS observations (Plume et al. 1997), images of dust emission at 350 μm (Mueller et al. 2002), maps of CS $J = 5-4$ emission (Shirley et al. 2003), and maps of HCN emission (Wu et al. 2005). While these references call the objects "dense cores", I will adopt the convention of McKee and co-workers (e.g., Krumholz & Tan 2007) and refer to them as dense *clumps*. The dense clumps are the sites of cluster formation and we reserve the term core to refer to the structure that forms one or a few stars.

The dense clumps can be fitted to power law density profiles with exponents very similar to those of dense cores forming low mass stars, but the density, measured at the same radius is typically 100 times higher and the linewidths are typically 16 times wider. Some show evidence in the line profiles for inward motions (Wu & Evans 2003), similar to those seen in some low mass cores. In general, they are scaled up versions of low-mass dense cores. This point is important, as some authors use "clump" to mean something less dense than a core. Massive, dense clumps are *denser* than the low mass cores. The clumps within them are presumably even denser, but they have been hard to separate cleanly.

The mass function of the dense clumps is steeper that that of molecular clouds or of less dense clumps traced by CO isotopes (Shirley et al. 2003), but it is incomplete below about 1000 $M_\odot$. Above that level, it is similar to the distribution of the total masses of OB associations (Massey et al. 1995; McKee & Williams 1997). These dense clumps are very likely to be the sites where clusters and OB associations form. However, it has been difficult to study the forming stars themselves because of the heavy extinction and large distances. The GLIMPSE legacy project (Benjamin et al. 2003) using the IRAC instrument on *Spitzer* is revealing clusters in some of these, but the strong diffuse emission in the IRAC bands makes it difficult to extract detailed information on the stellar content (Nordhaus et al. in prep).

Our observational measures are the luminosity in a molecular line or in dust continuum at long wavelengths, which are tracers of the mass of dense gas, and the bolometric luminosity measured by integrating over the full spectrum of dust emission. The line luminosities of tracers of dense gas, in particular CS and HCN, trace very well the virial mass of dense gas (e.g., Wu et al. in prep.). The integrated infrared luminosity ($L_{\rm IR}$) traces the star formation rate ($\dot{M}_\star$) given enough time for the IMF to be reasonably sampled (Krumholz & Tan 2007). Both these measures are subject to fluctuations about mean values of at least a factor of 3. Despite the variations, $L_{\rm IR}$ correlates well with $L_{\rm Mol}$ or $M_{\rm vir}$.

Without a detailed census of the stellar content, we cannot compute the star formation efficiency in the same sense ($\epsilon_\star$) as we could for low mass star formation, but the similarity of the mass function to that of OB associations suggests reasonably high efficiency in the dense gas.

We will use an efficiency measure common in the extragalactic context as the star formation rate per unit mass of gas ("ϵ" $= \dot{M}_\star/M(gas)$. Note that this "efficiency" is really the speed ($1/t_{dep}$) unnormalized to the free fall time. In observational terms, this is measured by $L_{\rm IR}/L_{\rm Mol}$. As for low mass star formation, the "ϵ" is very low for molecular clouds as a whole, but much higher for dense gas (e.g., a factor of 30 higher in one study, Mueller et al. 2002). Krumholz & Tan (2007) have argued that star formation is also slow relative to a free-fall time (SFR_{ff}), though again there is some evidence that SFR_{ff} is higher in the densest gas, probed for example by the CS $J = 5 - 4$ transition.

These massive dense cores provide the connection point between detailed studies of star formation in the Milky Way and extragalactic star formation.

4. Star Formation in Galaxies

Since we seek a connection between studies of star formation in our Galaxy and extragalactic star formation, we will focus on studies using common tracers. In dusty galaxies, the star formation rate is traced by $L_{\rm IR}$. This is basically a calorimetric method: the dust absorbs all the energy from young stars and re-radiates in the infrared. The advantage is that there is no need for uncertain extinction corrections, which are needed for ultraviolet or Hα measures of star formation. However, one is assuming that *all* the light is indeed absorbed, so some star formation can be missed (this problem can apparently be alleviated by combining infrared and Hα observations, as described by Calzetti at this meeting). Also, a calorimeter measures any heat input, so heating by older stars or an AGN can confuse matters. In practice, this method is applied only to systems where star formation overwhelms the heating by older stars. Assessing the contribution of AGNs can be trickier, especially for high-z systems. A common calibration, based on a continuous burst model is that

$$\dot{M}_\star({\rm M_\odot\ yr^{-1}}) = 1.7 \times 10^{-10} L_{\rm IR}({\rm L_\odot})$$

(Kennicutt 1998), with an averaging time of 10 to 100 Myr. This number may vary by a factor of at least 2 depending on the star formation rate and age of a starburst (see Krumholz & Tan 2007).

How does $L_{\rm IR}$ correlate with various tracers of gas? If CO is used to trace the molecular gas, the relation is strongly non-linear. For CO, the "ϵ" increases by a factor of 100 as $L_{\rm IR}$ rises from 10^{10} to 10^{14} $\rm L_\odot$ (Solomon & Vanden Bout 2005). Even higher "ϵ" may be observed in high-z submillimeter galaxies (Greve et al. 2005).

If the $L_{\rm IR}$ versus $L_{\rm Mol}$ plot is made using HCN $J = 1 - 0$, instead of CO, the correlation is better, the scatter is less, and the relation is *linear* (Gao & Solomon 2004a, Gao & Solomon 2004b). In this case, the "ϵ" is constant over more than 3 orders of magnitude in $L_{\rm Mol}$. The HCN line is sensitive to relatively dense gas, which reminds us that it was only the dense molecular gas that is involved in star formation in well-studied local molecular clouds.

In order to compare directly the situation in local clouds to that in starburst galaxies, Wu et al. (2005) surveyed the HCN $J = 1 - 0$ line in Galactic clumps.

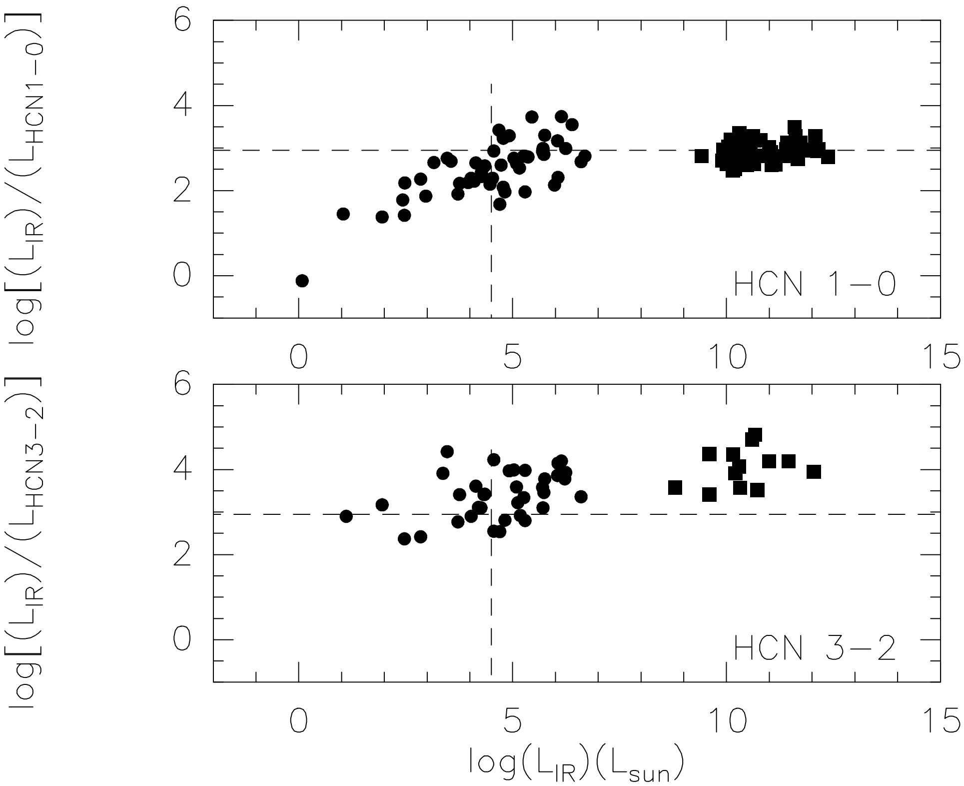

Figure 1. Correlations between the distance-independent ratio $L_{\rm IR}/L_{\rm Mol}$ vs. $L_{\rm IR}$ for HCN $J = 1 - 0$ amd HCN $J = 3 - 2$. The squares are HCN $J = 1 - 0$ observations of galaxies (Gao & Solomon 2004a) in the first panel, and HCN 3-2 observations of galaxies (Paglione et al. 1997) in the second panel. The circles are the equivalent data for massive dense clumps in our Galaxy. The horizontal dashed line in the top plot indicates the average $L_{\rm IR}/L_{\rm HCN}$ ratio for galaxies; the vertical dashed line in the top plot shows the cutoff at $L_{\rm IR} = 10^{4.5}{\rm L}_{\odot}$. These two lines are also shown in the bottom plot to indicate the relative shifts of $L_{\rm IR}/L_{\rm Mol}$ between HCN $J = 1 - 0$ and HCN $J = 3 - 2$.

The results showed that, above a threshold in $L_{\rm Mol}$ or $L_{\rm IR}$, the Galactic clumps fit a linear relation between $L_{\rm IR}$ and $L_{\rm Mol}$, essentially identical to that of the starburst galaxies. Above the threshold in $L_{\rm IR}$ of about $10^{4.5}$ ${\rm L}_{\odot}$, the "efficiency," $L_{\rm IR}/L_{\rm Mol}$, is very similar in the clumps to that in starbursts (Fig. 1). Below the threshold, $L_{\rm IR}/L_{\rm Mol}$ drops rapidly with decreasing $L_{\rm IR}$. While data on the HCN $J = 3 - 2$ line are scarce for galaxies, the currently available data tell a similar story, but with a higher ratio of $L_{\rm IR}/L_{\rm Mol}$ (Fig. 1). A higher ratio is not surprising because the HCN $J = 3 - 2$ line traces still denser gas.

HCN is not the only dense gas tracer. Many other tracers, including CS and HCO^+ have been used in studies of dense gas in our Galaxy. Graciá-Carpio et al. (2006) recently suggested that HCO^+ could be a better tracer in galaxies, but Papadopoulos (2007) came to the opposite conclusion and noted the need for more observations of higher J transitions to constrain the conditions in the dense gas. A recent multitransition study of CS, HCN, and HCO^+ in two local ULIRGs (Greve et al. 2006) found many similarities to the properties of dense clumps in the Galaxy. They concluded that, for the transitions they studied, HCO^+, HCN, and CS probe progressively denser gas.

5. An Emerging Picture

The comparisons in the last section suggest that local studies of massive star formation can indeed provide insights into starbursts. Qualitatively, a modest starburst can happen if a galaxy has a lot of molecular gas, with some fraction of it being dense. For an extreme starburst, a large fraction of the molecular gas must be dense. At the extreme, the entire ISM might look like the dense, cluster-forming clumps in our Galaxy.

Quantitatively, we offer some "Schmidt laws" (Wu et al. (2005):

$$\dot{M}_\star(\mathrm{M}_\odot\ \mathrm{yr}^{-1}) = 1.4 \times 10^{-7} L_{\mathrm{HCN}}(\mathrm{K\ km\ s}^{-1}\ \mathrm{pc}^2)$$

$$\dot{M}_\star(\mathrm{M}_\odot\ \mathrm{yr}^{-1}) = 1.2 \times 10^{-8} M(dense)(\mathrm{M}_\odot)$$

where L_{HCN} is the monochromatic line luminosity of the HCN $J = 1-0$ line in observer's units, and we have assumed that $\dot{M}_\star = 2.0 \times 10^{-10} L_{\mathrm{IR}}$ and $M(dense)(\mathrm{M}_\odot) = 7 L_{\mathrm{HCN}}$ (K km s^{-1} pc^{-2}) (Wu et al. 2005). While these are not yet of practical use, *CARMA* and *ALMA* will be supplying much more observational data on the lines in the coming years. In the meantime, we should try to understand the relationship between these *linear* relations for dense gas and the non-linear relations for less dense gas.

First, we should ask why $L_{\mathrm{IR}}/L_{\mathrm{HCN}}$ is constant from $L_{\mathrm{IR}} = 10^{4.5}$ to 10^{13} $\mathrm{L}_\odot$, but drops sharply for lower L_{IR}. At first glance, the constancy is quite puzzling for Galactic clumps even if the star formation rate is linear with the amount of dense gas because one would expect the mass of the most massive star to increase with the number of stars formed and the stellar luminosity is a non-linear function of the stellar mass. Thus, one might expect L_{IR} to increase non-linearly with $M(dense)$. In fact, it does exactly that *below* the threshold of $L_{\mathrm{IR}} \sim 10^{4.5}$ $\mathrm{L}_\odot$. This is a clue. Wu et al. (2005) proposed that there is a "basic unit" of massive clustered star formation. For clumps below the mass of the basic unit, the IMF is not fully sampled and L_{IR} increases non-linearly with $M(dense)$. Once the mass exceeds the threshold, the IMF is fairly well sampled. Further increases in mass produce more stars but no further change in $L_{\mathrm{IR}}/M(dense)$. In this picture, the difference between star formation in Galactic molecular clouds, normal galaxies, starbursts, and ULIRGS is simply how many such basic units (or how much dense gas) they contain. To be concrete, a L_{IR} of 10^5 $\mathrm{L}_\odot$ corresponds to a stellar mass of about 30 to 40 $\mathrm{L}_\odot$. The basic unit contains 300 to 1000 $\mathrm{M}_\odot$ of dense ($n > 10^5$ cm^{-3}) gas. This picture also explains why the scatter in $L_{\mathrm{IR}}/L_{\mathrm{HCN}}$ is greater in the Galactic clumps than in galaxies: the most massive star formed will be subject to stochastic fluctuations, which can produce order of magnitude fluctuations in the ratio. These tend to average out for a whole galaxy.

Second, we can ask why $L_{\rm IR}/L_{\rm CO}$ increases with $L_{\rm IR}$. While CO traces the overall mass in Galactic clouds, it fails completely to trace the mass in dense clumps and cores. This failure is not surprising as CO is optically thick and thermalized easily. CO does not trace the gas that is relevant to star formation. Roughly speaking $L_{\rm HCN}/L_{\rm CO}$ provides an estimate of the fraction of dense gas, as long as that fraction is not too large. Indeed, this ratio increases with $L_{\rm IR}$, as expected in this picture (Gao & Solomon 2004a).

6. Future Directions

Further studies are needed in both the Galactic and extragalactic context. Systematic, unbiased surveys of the Galactic plane for dense clumps will remove the biases in the samples used so far and provide a much larger data set. Already the Bolocam Galactic Plane Survey has found thousands of clumps (Williams et al. 2007) and deeper surveys are on the way. With large samples in different environments, we can begin to understand the dependence of the relations on chemistry, metallicity, environment, etc. Extragalactic studies should test the relations at lower $L_{\rm IR}$, aided by the tremendous sensitivity of *ALMA*. Further studies of the very luminous end will also be important, and higher J lines of dense gas tracers can be studied in many more sources.

We also need to understand the non-linear Kennicutt relations and their relationship to the linear relations for dense gas. Theories need to explain *both* relations. It is important to realize that the gas surface density, which appears in the Kennicutt relations, is two steps removed from the actual star forming entities: dense clumps and cores. We need to understand how the large-scale surface density controls the formation of molecular clouds and what controls the formation of dense clumps and cores within those clouds. The first step may be best studied with high resolution observations of other galaxies and detailed comparison to simulations with sufficient resolution to separate individual molecular clouds. The second step, from molecular clouds to dense clumps and cores, will be hard to study in other galaxies because of resolution issues, though insights may be available from studies of other galaxies to see how $L_{\rm HCN}/L_{\rm CO}$, for example, depends on conditions. For the most part, though, we need to study the formation of dense cores from molecular clouds with more unbiased and complete studies of molecular clouds in our Galaxy.

I will close by thanking the organizers for providing a forum that allowed some of us touching different parts of the elephant to struggle at least toward a common language.

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