Connecting Dense Gas Tracers of Star Formation in our Galaxy to High-z Star Formation

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ABSTRACT

Observations have revealed prodigious amounts of star formation in starburst galaxies as traced by dust and molecular emission, even at large redshifts. Recent work shows that for both nearby spiral galaxies and distant starbursts, the global star formation rate, as indicated by the infrared luminosity, has a tight and almost linear correlation with the amount of dense gas as traced by the luminosity of HCN. Our surveys of Galactic dense cores in HCN 1-0 and 3-2 emission show that this correlation continues to a much smaller scale, with nearly the same ratio of infrared luminosity to HCN luminosity found over 7 orders of magnitude in L_{IR}, with a lower cutoff around $10^{4.5}$ L_{O} of infrared luminosity. The linear correlation suggests that we may understand distant star formation in terms of the known properties of local star-forming regions. We propose a model in which the basic unit of star formation is a dense core, similar to those studied in our Galaxy; this model may explain both the correlation and the luminosity cutoff.

INTRODUCTION

Star formation in the Milky Way is dominated by massive star formation (Lada & Lada 2003), which occurs at very dense, turbulent molecular cores that are well traced by molecular dense gas tracers like CS (Plume et al. 1992, 1997; Shirley et al. 2003) and HCN (Wu & Evans 2003). Recent work shows that the luminosity of HCN (1-0) has a tighter correlation with Infrared luminosity than CO (1-0), who traces only low density gas. The L_{IR}-L'_{HCN} correlation is linear for both nearby normal galaxies and remote ultra-luminous infrared galaxies (ULIRGs) (Solomon et al. 1992, Gao & Solomon 2004a,b), suggesting a power index N of Schmidt law (Σ_{SFR}=AΣ^{N}_{gas}) of Unity, different from those derived from CO observations. (e.g., Kennicutt 1998). Gao and Solomon (2004a) therefore argue that both normal galaxies and starbursts should have the same star formation rate per amount of dense gas. Maps of HCN for the Galactic dense cores will test this correlation on the Galactic scale, and provide a possible way to connect star formation in our Galaxy to more distant, even to high-z, star formation.

OBSERVATIONS & RESULTS

Observations with HCN 1-0 on galactic dense cores were made at Five College Radio Astronomy Observatory (FCRAO) in April 2004, December 2004 and Feb 2005. HCN 3-2 maps of these cores were obtained at Caltech Submillimeter Observatory (CSO) in 2002 to 2004. Derived infrared luminosity L_{IR} and line luminosity L'_{HCN} for these cores were plotted in Fig. 1 to compare with data of galaxies (Gao & Solomon 2004a). We added CO data on Galactic dense cores, galaxies, high-z Early Universe Molecular Emissions Line Galaxies (EMGs), and a limited sample of HCN 3-2 data on galaxies, with references shown in Fig.1. To cancel the distant square factor in such a huge scale range, we present the correlation of distance independent ratio L_{IR}/ L'_{Mol} vs. L_{IR} and L'_{Mol} in Fig. 2.

Fig. 1 and Fig. 2 show that the linear correlation between L_{IR} and L'_{HCN} continues to Galactic scales, with nearly the same ratio of L_{IR}/ L'_{HCN} for over 7 orders of magnitude in L_{IR}, utill a lower cutoff occurs around $10^{4.5}$ L_{O} of L_{IR}, or $10^{1.5}$ K km pc^2 of $L'_{HCN1\text{-}0}$. The slope of the equivalent correlation for CO, however, increases significantly in the same luminosity range.

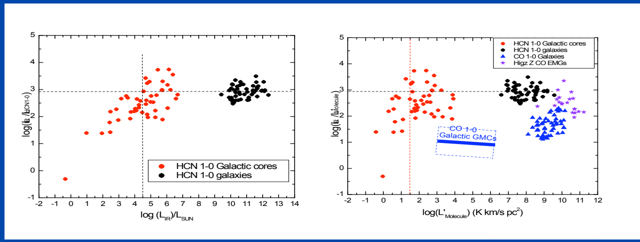

Figure 2. A plot of log L(IR)/L´(Mol. Em.) vs. L´(Mol.Em.), showing that the ratio of L_{IR}/ L'_{HCN} remains constant from remote ULIRGs to Galactic cores with a lower cutoff, while L_{IR}/ L'_{CO} increase dramatically in the same range.

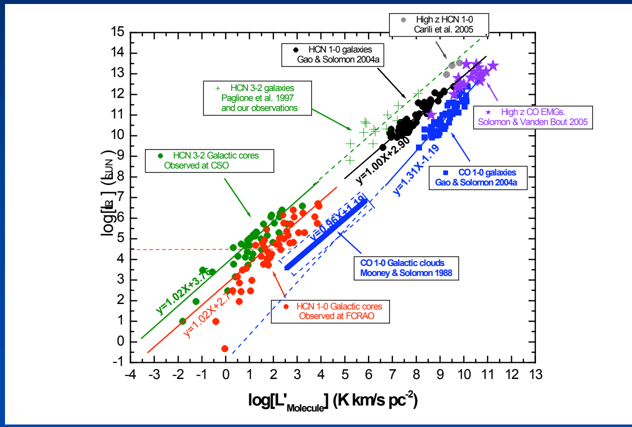

Figure 1. Correlation of log L_{IR} with log L´(Molecular Line Emission). The almost linear correlation of L_{IR}-L'_{HCN} is valid over 7 orders of magnitude with a lower cutoff.

A Model for Star Formation in Galaxies

The L_{IR}-L'_{HCN} correlation is almost linear over 7 orders of magnitude in luminosity from Galactic dense cores to remote starburst galaxies, indicating that star formation may follow a very simple relationship when the appropriate tracers are used (Wu et al. 2005). One key question is that why L_{IR} can linear increase with L'_{HCN} given some IMF (as L_{IR} nearly trace the luminosity and L'_{HCN} trace the mass of dense gas)? And then what break this to cause a lower cutoff? To answer these questions, We propose a model that a basic unit of cluster formation exists. For M_{dense} less than the mass of this unit, L_{IR}/ M_{dense}(or L_{IR}/L'_{HCN}) rises rapidly With M_{dense} , as higher mass stars can form. For M_{dense} greater than the mass of this unit, the IMF is reasonably sampled and further increases in mass produce more units, but no further change in L_{IR}/ M_{dense}. The basic unit corresponds to the cores in the cutoff region in the L_{IR}-L'_{HCN} plot, with a L_{IR} around 10^5 L_{O}. If we suppose that larger scale cluster formation is built up by adding more and more such units, then the linear correlation between the total L_{IR} and M_{dense} is a natural result. In that case, the only difference between star formation on different scales and in different environments--big clusters, normal galaxies, massive ULIRGs--is just how many such cores they contain.

Discussion

Only 3 detections have been made for the high-z EMGs with HCN 1-0, as shown in Fig. 1. They lie above the fitted L_{IR}-L'_{HCN} line of galaxies. But if we can remove the L_{IR} contribution from AGN heated dust, they may drop back to this correlation (Solomon et al. 2003), indicating the simple star formation law may still work there. However, any discussion about these high-z galaxies should be with caution, due to the too limited sample and many complexities.

The L_{IR}-L'_{CO} correlation can keep roughly linear for Galactic clouds and normal spirals but not for starbursts, showing CO is not a good star formation tracer for starbursts. CO can be used to trace star formation rate in the Galaxy may due to that dense cores only occupy a negligible fraction of the mass, and the fraction of dense gas in the overall cloud stays roughly constant. But this is not the case in starbursts, where a much higher fraction of mass is in dense gas.

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