Molecular gas in strongly interacting galaxies: II. Global properties of the sample

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Received ______________; accepted ______________

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ABSTRACT

We have collected CO data on a sample of 95 strongly interacting galaxies (SIG) and on comparison samples of 59 weakly interacting and 69 isolated spiral galaxies. The statistical analysis of the samples shows that the SIGs, especially the colliding and merging systems, have higher CO luminosity (per unit optical area or luminosity) than isolated spiral galaxies. If this excess is interpreted as excess H_2, then we find no significant difference in the molecular to atomic gas mass ratio between the samples; this indicates that the excess molecular gas is not due to conversion of HI to H_2 or to the removal of HI gas from the galaxies by interaction. Another possible interpretation of the excess CO luminosity and of the normal gas ratio is that the CO-to-H_2 conversion factor is lower in SIGs than in isolated starbursting galaxies. In agreement with previous studies, we find that the star formation rate (estimated by the far infrared luminosity) is higher in the SIGs than in the isolated galaxies. The star formation efficiency (measured by the ratio of far infrared luminosity to inferred molecular gas mass) is higher than average in the mergers and colliding systems only. Our results are in agreement with a scenario in which gravitational interaction produces intense star formation which becomes highly efficient in the late stages of evolution.

Subject headings: galaxies: interacting—galaxies: ISM: molecules : ISM: galaxies — starburst

1. Introduction

The influence of gravitational perturbations on spiral galaxies has drawn much attention in recent years. Galaxy collisions and mergers can have a dramatic impact upon the morphology and subsequent dynamical evolution of galaxies. Interactions are thought to be the major cause of the extensive starburst phenomenon seen at high redshift (e.g. Ivison et al. 2000; Scoville 2000). In the local universe, starbursts induced by galaxy interactions are believed to be the major source of the tremendous energy output from the so called ultra-luminous IRAS galaxies (ULIRGs). Indeed, virtually all the ULIRGs with $L_{IR} > 10^{12}\,\mathrm{L}_\odot$ are found to be mergers (Sanders et al. 1991). The star formation activity indicators such as $H\alpha$ and far-infrared and radio continuum emission all point to a higher level of star formation activity in interacting galaxies (IG's) compared to isolated spiral galaxies (ISG's) (e.g, Kennicutt et al. 1987; Xu & Sulentic 1991; Hummel et al. 1990; Bushouse 1987, 1988).

Molecular clouds are the birth places for star formation. Previous CO surveys of external galaxies have established a close correlation between the CO luminosity and the total far infrared (FIR) luminosity (c.f. Young & Scoville 1991). If this correlation holds for IG's, their FIR enhancement would suggest excess CO emission in IGs compared to ISG's. This prediction seemed to be confirmed by some CO studies of external galaxies which reported that the M_{H_2}/L_B ratio is enhanced in IGs compared to isolated galaxies (Solomon 1988; Young 1996; Brains, 1993; Combes et al. 1994). However, most previous studies were based on a relatively small sample and the interacting systems were often selected according to their IRAS flux, which biases these studies toward gas-rich galaxies. The reason for this selection is the relatively low sensitivity of millimeter radio telescopes which made it difficult to detect the CO emission in a large number of gas-poor galaxies within a reasonable observing time. Nevertheless, the CO data for individual interacting systems has been accumulating in the literature over the years. Ironically, interacting systems in the southern hemisphere are studied more systematically and more comprehensively than the IGs in the northern sky (e.g., Combes et al. 1994; Horellou & Booth 1997).

We have conducted observations with the NRAO 12m telescope and the IRAM 30m telescope (Zhu et al. 1999, Paper I), and by combining these data with those obtained by other investigators, we have compiled a large CO database comprising a complete optically-selected sample of strongly interacting galaxies (SIGs) in the northern hemisphere. Here we focus our study on SIGs for mainly two reasons: (1) SIGs can be easily identified with minimal error because they exhibit obvious disturbances in morphology and most of them have close companions (except for mergers); (2) the number of SIGs is relatively small in the local universe so we can observe and sample them completely. Our sample contains 154 IGs (including 95 SIGs) and covers different galaxy progenitor types, interaction phases, and encounter geometries. This enables us to arrive at a statistically meaningful conclusion on the influence of galaxy interaction on the molecular gas properties and induced star formation activity.

This is the second paper in a series devoted to a statistical analysis of the molecular gas properties in IGs. Our goal is to make clear whether the CO emission is enhanced in IGs and whether the enhanced star formation activity in IGs is due to a higher abundance of molecular gas or to a higher star formation efficiency. In Paper I we presented most of the CO data obtained by us. In this paper, we combine the available CO, HI and IRAS data in the literature for our sample galaxies and conduct an analysis of the CO, HI and FIR properties, including a comparison between SIGs and ISGs.

2. The sample

2.1. A complete SIG sample in the northern sky

The complete sample of SIGs was compiled from the UGC (Nilson 1973), ARP catalog (Arp 1966) and the *Catalogue of Isolated Pairs of Galaxies in the Northern Sky* (CPG) (Karachentsev 1972). Bushouse (1986) has identified all the SIGs from galaxies that have been labeled as disturbed, distorted, or with bridges or warped disks in the UGC. By searching the *Third Reference Catalogue of Bright Galaxies* (RC3) (de Vaucouleurs 1991), we obtained the optical (blue) magnitude for each galaxy in Bushouse's complete sample. Then all systems with at least one member brighter than $B_T = 14.5$ were chosen, yielding 164 systems. The ARP catalog contains 338 systems, but it also includes some elliptical galaxies, isolated peculiar galaxies, and some galaxies in the southern sky. The CPG contains 1206 galaxies in 603 isolated pairs (including elliptical galaxy pairs) and is complete to $m_{pg} = 15.0$ (Stocke 1977). Its selection criteria exclude compact group members and also under-sample merger types. For our purpose, only the spiral pairs were selected from the CPG. These three sources overlap with one another and together they cover most of the field IGs in the northern sky (DEC $> -2°$). In order to select our SIG sample, we further inspected all the optical images from the Digitized Sky Survey and classified these systems according to the following criteria:

- IG1: Weakly interacting galaxies (WIG's), including all the interacting galaxies with component separation $> 1.5\ D_{25}$ and with little or no morphology disturbance. Here D_{25} is the diameter of the larger component in the pair, using the brightness contour $B_T = 25$ mag arcsec^{-2}.

- IG2: Galaxies with component separation $< 1.5\ D_{25}$ showing obvious morphology disturbances. Those with strong morphology disturbances but with a component separation up to 2 D_{25} were also included.

- IG3: Galaxies in projected contact with their companions and with severe morphological disturbances, i.e. colliding galaxies. We also include in this category the so called "ring galaxies" which are believed to be the remnants of a head-on collision.

- IG4: Merging systems, with a single amorphous body but double nucleus, and a pair of remnant tidal tails.

- IG5: Late-stage mergers, with one or two tidal tails but only a single nucleus.

In this paper SIGs are defined as those in classes IG2–IG4. Since our main interest is the SIGs, detailed classifications for the SIGs are given and all the paired galaxies not belonging to SIGs were put into the WIG group (IG1) for comparison. The very late-stage mergers were put into another group (IG5) because galaxies of this type should have consumed most of their gas and thus there should be no significant CO enhancement. The very late-stage mergers can be easily confused with isolated elliptical galaxies, so only those that have some tidal features such as tails were retained in the sample.

Finally, our sample galaxies were selected according to the following criteria:

- (1) must be a SIG (IG2–IG4)

- (2) at least one member in the interacting system is brighter than $B_T = 14.5$

- (3) declination DEC$> -2°$.

Our final sample of SIGs contains 126 galaxies in 92 systems. This is by far the most complete sample of SIGs in the northern sky with DEC $> -2°$. Table 1 lists the general properties of our sample galaxies and their IG type. It is ordered by interaction type (IG), and, within the type, by right ascension (RA). The names are in cols. 1, 2 and 3, the interaction type (IG) in col 4, the coordinates (RA and DEC) in cols. 5 and 6, the optical radial velocity (cz, in km s^{-1}) in col. 7, the corrected blue apparent magnitude (B_T^0) in col. 8, the apparent diameter (D_{25} in arcmin.) in col. 9, the minor axis (r_b, in arcmin.) in col. 10 and the morphological type in col. 11. The data are from RC3.

To evaluate the completeness of our sample, we searched the literature for any obvious SIGs with $B < 14.5$ that had not been included in our sample, and none were found. For example, Dahari (1985) compiled 209 peculiar galaxies with $B < 14.4$ from the *Atlas and Catalog of Interacting Galaxies* (Vorontsov-Velyaminov 1959, 1977). He also divided his sample galaxies into six interaction classes (IAC). All IAC3-IAC6 galaxies in Dahari's sample were inspected, and it was found that all the IAC4 to IAC6 galaxies had already been included in our sample. All the IAC1, IAC2 and some IAC3 galaxies were not included because their morphology distortion is not strong. Although the decision to call an individual system "strongly interacting" is a subjective one, the IGs with close components and severe morphology disturbance are easy to identify and their chance of being missed by the UGC, ARP or CPG catalogue is small. Hence our SIG sample should be essentially complete for paired galaxies. Most of the IGs in compact groups were not included because they are not included in either the UGC or the CPG.

The only source of confusion in classifying the galaxies may be in the merger types. For some mergers it is difficult to tell whether they contain double nuclei. To distinguish between IG4 and IG5, use was made of the work by Keel & Wu (1995) who listed the number of nuclei and tails for a sample of disk-disk merger remnants in the local universe. We also used near IR images available in the literature (*e.g.* Stanford & Bushouse 1991; Bushouse & Stanford 1992). It is possible that some IG4 mergers have been mis-classified as IG5 if their double nucleus has not been detected. However, this should not seriously affect our statistical study since the number of such ambiguous cases is very limited.

In summary, our SIG sample contains most of the strongly interacting systems in the northern sky. This sample is selected strictly according to optical brightness and morphology, and without any *a priori* knowledge of the gas content or FIR emission level. Thus it is unbiased and ideal for studying the molecular gas properties of IGs.

2.2. The control sample

The control sample of isolated spiral galaxies was obtained from the FCRAO CO survey made by Young et al. (1996), which is the most homogeneous sample for nearby spiral galaxies. Since the IGs are generally more luminous than the ISGs in the FCRAO sample (Young et al. 1995), only the more luminous ($L_B > 2 \times 10^9\,\mathrm{L}_\odot$) spiral galaxies were selected for the control sample. We also excluded the galaxies belonging to the Virgo cluster. The final control sample comprises 69 galaxies. Figure 1a shows the distribution of M_B for the SIG and control samples. The average L_B of the SIG sample is $2.7 \times 10^{10}\,\mathrm{L}_\odot$, which is about 1.8 times higher than that of the control sample. This is primarily because the SIG sample as a whole is biased towards more distant, and hence more luminous, galaxies, since there are relatively few SIGs nearby. Moreover, some merging systems include emission from more than one galaxy.

Figure 1b compares the morphological types of the SIG and control samples. There are many more Sbc and Sc galaxies in the control sample than in the SIG sample, where the galaxies are more uniformly distributed among all types. It is not surprising that there are many Irr and Peculiar galaxies in the SIG sample. Furthermore, about 20% of the SIGs, especially the merging systems, have a morphology so distorted that they cannot be classified as any specific Hubble type. These spiral galaxies, which are designated S?, are not shown in the figure. Since the primary concern is with the distorted galaxies, we have not attempted to compare the morphology distributions of these two samples, nor did we compare any parameters that are sensitive to galaxy morphology.

3. CO fluxes and molecular gas masses

Since our earlier results on 80 interacting galaxies were reported in Paper I (Zhu et al. 1999), another 30 galaxies were observed with NRAO 12m in March, May, and June 1999. The observing procedures used are identical to that outlined in Paper I. Another 66 galaxies with good CO measurements were obtained from the literature. In addition, all the available CO data for weak IGs (IG1) and late stage mergers (IG5) were collected providing a consistent CO data set for all types of IGs suitable for the statistical study.

In order to make comparisons between the IG sample and the ISG sample of Young et al. (1995), we derived the global CO flux and the inferred total mass of the molecular gas M_{H_2} using the same method as that of Young et al. (1995) (see also Paper I). For all the galaxies larger than twice the telescope beam, several measurements along the major axis were made and the global flux was derived with a Gaussian or exponential brightness distribution model which best fit the data. For galaxies only slightly larger than the telescope beam, measurements were made at a single position only and an exponential model was used to derive the integrated flux from the observed flux. Similar procedures were applied to the galaxies observed by other investigators to derive the global CO fluxes. There are a total of 92 SIGs for which the total CO flux is derived consistently.

In Paper I it was shown that the uncertainty in the global fluxes derived in this way are usually less than 40%, and the data taken by the IRAM 30 telescope and the NRAO 12m telescope are generally consistent with each other after correcting for the flux outside the telescope beam. Uncertainties for the data in the literature are more difficult to estimate. Some galaxies, especially the typical interacting galaxies such as ARP220, IC883 have been observed by different groups. Higher priority was given to data with high S/N ratio and with larger beam sizes compared to the source.

The total M_{H_2} may be derived from the global CO(1-0) flux by assuming a standard

Galactic CO-to-H_2 conversion factor, (*i.e.* the X factor = $N(H_2)/I_{CO}$). However, there is strong observational evidence that the X factor is significantly different from one galaxy to another (e.g Crawford et al. 1985; Stacey et al. 1991; Solomon et al. 1997; Downes & Solomon 1998; Wilson et al. 1995), and a radial variation of more than a factor of 10 has been reported in our Galaxy (Sodroski et al. 1995). Recent studies of the molecular gas in ULIRGs have shown that the M_{H_2}/L_{CO} ratio may be 3-5 times lower in the centers of these galaxies than in the Galactic molecular clouds (Solomon et al. 1997; Downes & Solomon 1998). Hence the application of the standard X factor leads to significant overestimates of the M_{H_2} in these galaxies. There is also a physical basis for such a variation in the X factor, since the CO flux per unit mass of molecular gas is expected to be a function of gas kinetic temperature, density, and chemical composition (*cf.* Young 1991; Wilson et al. 1995). In particular, it has been shown to increase strongly with decreasing metallicity (Israel 2000), which is consistent with the tenfold increase outward in our Galaxy (Sodroski et al. 1995). Accordingly, we introduce a parameter H_2^* to distinguish the H_2 content derived from the standard conversion factor from the actual H_2 content, bearing in mind that it is in reality a reflection of the CO flux rather than a precise measure of the mass of molecular gas. The total H_2^* mass may be derived from the CO fluxes using the conversion factor $X = N(H_2^*)/Ico = 2.8 \times 10^{20} cm^{-2}[Kkms^{-1}]^{-1}$ (Bloemen et al. 1986). Kenney & Young (1989) have shown that this value of the conversion factor leads to H_2^* masses in solar units given by $M_{H_2^*} = 1.1 \times 10^4 D^2 S_{CO}$, where D is the distance in Mpc and S_{CO} is the CO flux in Jy km s^{-1}.

Tables 2 and 3 lists the interacting galaxies with CO measurements made by us (Table 2) or available in the literature (Table 3). For consistency, the global masses $M_{H_2^*}$ based on CO measurements in the literature were re-determined using Young's method as described above. We list not only the SIGs (IG2 – IG4), but also the available data for weak IGs (IG1) and late stage mergers (IG5), in order to provide a comparison sample of weakly interacting systems. A total of 154 IGs are listed in Tables 2 and 3, including 95 SIGs, 44 IG1 and 15 IG5 galaxies. Out of the 126 SIGs in the complete SIG sample (Table 1), 75% of them have CO data available (including non-detections).

4. HI fluxes and IRAS flux densities

HI fluxes for the galaxies in our sample have been taken from the RC3 and the catalogue of Huchtmeier & Richter (1989), or from Bushouse (1987) and Davis & Seaquist (1981). Since it has been shown that a significant amount of atomic gas in IGs may have been dragged out of the optical disk along the tidal tails (Hibbard et al. 1999, 2000), we preferentially selected measurements of the global HI flux made using telescopes with a larger beam size, such as the NRAO 92m telescope. We also gave most weight to the more recent and more sensitive measurements.

The mass of HI is given by:

$$M_{HI} = 2.36 \times 10^5 D^2 S(HI) \tag{1}$$

where D is the distance in Mpc and $S(HI)$ is the HI flux in Jy km s^{-1}. The global HI fluxes and the derived atomic gas masses are listed in Table 4. The uncertainties in these values are approximately 30-40%.

The infrared luminosities (in solar units) integrated from 1 to 500 μm are based on IRAS flux densities at 60 and 100 μm, denoted as S_{60} and S_{100}, and were computed using the formula given by Lonsdale et al. (1985):

$$L(IR) = 3.94 \times 10^5 D^2 [2.58 S_{60} + S_{100}], \tag{2}$$

where S_{60} and S_{100} are In Jy.

Xu and Sulentic (1991) and Bushouse (1988) have re-processed the IRAS data and have derived the IRAS flux densities for their sample galaxies. Their data were used when available. Other data have been obtained from the NED database. The IRAS 60 and 100 μm flux densities and the derived L_{IR} for the CO sample SIGs are given in Table 4.

Since the resolution is not high enough to resolve the interacting galaxies, except for a few widely separated pairs of type IG1, all the IRAS measurements are totals for each system, as are most of the HI fluxes. Therefore there is only one entry in Table 4 for most paired systems.

5. Comparison with isolated spiral galaxies

Table 5 lists the statistical properties of all the interacting and isolated galaxies in our samples. The mean properties were determined using the KMESTM program in the package ASURV Rev 1.2 (see LaValley et al. 1992 and references therein). This program computes the Kaplan-Meier estimator (Kaplan & Meier 1958) of a randomly censored distribution allowing for the non-detections in the sample. The second row for each ratio in Table 5 lists the median properties. These two statistical properties have different advantages. The median is less sensitive than the means to a few extreme values in the sample. However, unlike the mean, it is impossible to estimate the uncertainties in the median. Knowing the uncertainties allows us to test the statistical significance of any difference between the samples. Therefore we based our discussion mainly on the mean values. However both the mean and median properties point to the same trend.

The galaxies in the SIG sample on average have a higher L_B and larger physical size. In order to compare the gas content of galaxies between the two samples, we need to eliminate the effect of the size. This can be achieved by normalizing the molecular gas mass $M_{H_2^*}$ by the optical lumminosity or by the optical area of the galaxy. We adopt the same normalized quantities as Casoli (1998), namely the $M_{H_2^*}/L_B$ and $M_{H_2^*}/D_{25}^2$ ratios.

5.1. The $M_{H_2^*}/L_B$ ratio

Figure 2 shows the distributions of the $M_{H_2^*}/L_B$ ratio for the two samples. Most of the normal spirals have a $M_{H_2^*}/L_B$ ratio smaller than 0.3. M82 and NGC1055 are the only two galaxies in Young's sample with a $M_{H_2^*}/L_B$ ratio higher than 0.31, but they are not really isolated galaxies. M82 is gravitationally interacting with M81, and N1055 is about 130 kpc from NGC 1068. Therefore essentially no strictly isolated galaxies have been found to possess a $M_{H_2^*}/L_B$ ratio higher than 0.31. On the other hand, high ratios of $M_{H_2^*}/L_B$ are frequently seen in IGs and mergers. Merger remnants such as ARP220 have $M_{H_2^*}/L_B$ ratios as high as 1.1. The average $M_{H_2^*}/L_B$ ratio of the SIG sample is 0.22, which is 1.7 times higher than that of the ISG sample.

The high $M_{H_2^*}/L_B$ ratios suggest that SIGs, especially the colliding and merging systems, have more molecular gas than isolated spirals. However, Perea et al. (1997) have argued that the relation between L_B and $M_{H_2^*}$ is not linear, indicating that normalizing the mass by L_B does not completely remove the size effect. To evaluate the latter, we plot $M_{H_2^*}$ against L_B in Fig. 3. The merging systems (IG3 and IG4) are shown as solid circles and IG2 systems are shown as open circles while stars represent the isolated spirals in the control sample. The values of $logL_B$ range from 9.6 to 11. A linear regression applied to the ISG sample, using the ASURV V1.2 BIVAR method which takes into account the upper limits, yields

$$logM_{H_2^*} = (1.30 \pm 0.10) logL_B - (4.04 \pm 0.98) \quad (3)$$

This fit is indicated by a dashed line in Fig. 3. This line fits the ISG and IG2 systems reasonally well, but fails to fit the merging systems. Examining the deviation of each galaxy from the dashed line and applying a Peto-Prentice generalized Wilcoxon test (using the ASURV package) for each subsample, we found that the merger type (IG3 + IG4) has a residual significantly different from zero with a confidence level of 96%. Not surprisingly, the residual for the IG2 subsample and the ISG control sample does not significantly deviate from zero. Hence the high $M_{H_2^*}/L_B$ ratios in merging galaxies are significant and cannot be accounted for by the size effect. The fact that no isolated galaxies are found in the high $M_{H_2^*}/L_B$ regime strongly suggests that the high $M_{H_2^*}/L_B$ ratio is the result of strong galaxy interactions. However, not every interacting or merging system is associated with a high $M_{H_2^*}/L_B$ ratio.

5.2. The $M_{H_2^*}/D_{25}^2$ ratio

Another way to eliminate the size effect is normalization by the optical surface area of the galaxies. The mean and median values of $M_{H_2^*}/D_{25}^2$ for the SIG sample as well as for the individual IG subsamples are given in Table 5. The result is similar to that from normalization by L_B. The average $M_{H_2^*}/D_{25}^2$ ratio is about twice as high in SIGs. The most significant differences come from the merger types. A two-sample Wilcoxon test shows that the IG3 and IG4 subsamples have a mean $M_{H_2^*}/D_{25}^2$ ratio significantly higher than that of the ISGs with a confidence level of 99%, while the confidence level drops to 94% for the IG2 subsample. The histogram in Fig. 4 shows that the $M_{H_2^*}/D_{25}^2$ distribution for the SIG sample is more populated at the higher end, though the dispersion is also larger in the SIG sample.

Figure 5 shows a plot of $M_{H_2^*}$ versus D_{25}^2 for the subsample of IG2 (open circles), merger type (solid circles) and ISGs (stars). A linear regression fit to the isolated galaxy sample (dashed line) yields

$$log M_{H_2^*} = (1.81 \pm 0.24) log D_{25} + (6.85 \pm 0.32) \quad (4)$$

or

$$log M_{H_2^*} = (0.91 \pm 0.12) log D_{25}^2 + (6.85 \pm 0.32) \quad (5)$$

This relation is similar to that derived by Casoli (1998) from a sample of more than 500 isolated galaxies. From this we can see that the relation between $M_{H_2^*}$ and D_{25} is consistent with a linear one and that the ratio $M_{H_2^*}/D_{25}^2$ should completely remove the size effect. Therefore, the high $M_{H_2^*}/D_{25}^2$ ratio for IG3 and IG4 is obviously not due to their larger size.

On Fig. 5 we can also see that the dashed line which best fits the ISG sample fails to fit the SIG sample. Statistical tests show that the residuals are significantly different from zero value at the confidence level of 99% and 95% for the merger type and IG2 subsamples, respectively.

Due to the morphology distortion in virtually all SIGs, the size (D_{25}) may have a large uncertainty. However, one is more likely to overestimate D_{25} of a disturbed disk, and thus underestimate the $M_{H_2^*}/D_{25}^2$ ratio. Even if the errors on D_{25} were random, this should not result in a higher average $M_{H_2^*}/D_{25}^2$ ratio for SIGs. Therefore the high $M_{H_2^*}/D_{25}^2$ ratio in some SIGs must be genuine and indicates an CO enhancement as a result of galaxy interaction.

Casoli (1998) showed that the $M_{H_2^*}/D_{25}^2$ ratio depends on the Hubble type, with the Sa, Sb and Sbc types containing $\sim$ 6 times more molecular gas than late-type spirals and Irr galaxies. If a galaxy sample includes a majority of Sa-Sbc galaxies, it would have a higher than normal average $M_{H_2^*}/D_{25}^2$ ratio. However this is not the case for our SIG sample. In Figure 1b we have shown that the SIG sample is not overpopulated with Sa-Sbc galaxies compared to the control sample.

In summary, both the $M_{H_2^*}/L_B$ and $M_{H_2^*}/D_{25}^2$ ratios suggest either an enhancement in molecular gas content or in the luminous efficiency of CO for some SIGs, especially for IG3 and IG4. The choice between these two options will depend on careful modeling of a number of individual systems.

6. Molecular versus atomic gas

Assuming $M_{H_2^*}$ represents the actual molecular mass M_{H_2} , we may compare the total masses of molecular and atomic gases in our samples, in order to investigate the possibility that some systems are enriched in molecular gas, either by phase conversion of HI to H_2, or by removal of HI from the system by tidal forces.

Figure 6 shows the distributions of the $M_{H_2^*}/M_{HI}$ ratio for the SIG and ISG samples. Both samples peak at $M_{H_2^*}/M_{HI} \sim 1$ and there is no significant difference between them. The average $M_{H_2^*}/M_{HI}$ ratio for SIGs is only 1.3 times higher than that of the ISG sample (Table 5). The merger type subsample has a higher $M_{H_2^*}/M_{HI}$ mean value, but this is not statistically significant, as the confidence level is only 83%.

Table 5 shows that the M_{HI}/L_B ratios of the SIGs and ISG samples are similar. This means that the high $M_{H_2^*}/M_{HI}$ ratios in some systems corresponds to an enhancement of $M_{H_2^*}$ rather than to a depletion of M_{HI}. This is a different conclusion from that derived for the IRAS-selected IG sample (*e.g.* Martin et al. 1991), which shows a depletion of HI gas for the ULIRGs. This result also indicates that the single-dish HI data do not systematically underestimate the HI gas even for the late-stage mergers (IG3 and IG4) which could have a significant amount of HI gas ejected from the galaxy disks by tidal forces (*e.g.* Hibbard et al. 1999).

Figure 7 shows plots of $M_{H_2^*}/L_B$ versus M_{HI}/L_B for the SIGs. No correlation is found between these two quantities (correlation coefficient = 0.23). This provides no support for the idea that the CO enhancement corresponds to a phase conversion from HI to H_2 as there is no anti-correlation between $M_{H_2^*}/L_B$ and M_{HI}/L_B .

Figure 8a shows that $M_{H_2^*}/M_{HI}$ is correlated with $M_{H_2^*}/L_B$ for the SIGs with a correlation coefficient of 0.76, confirming that the high $M_{H_2^*}/M_{HI}$ ratios in some systems are due to an excess of molecular gas rather than to a deficiency of atomic gas. In contrast, there is almost no correlation between $M_{H_2^*}/M_{HI}$ and $M_{H_2^*}/L_B$ for the ISG sample (correlation coefficient = 0.33) (see Fig. 8b). Therefore the extremes in the $M_{H_2^*}/M_{HI}$ ratio in normal galaxies may reflect variations in the richness of atomic, rather than molecular gas. The fact that the $M_{H_2^*}/M_{HI}$ – $M_{H_2^*}/L_B$ correlation is only seen in SIGs indicates that the observed enhancement in CO emission is a an effect of galaxy interactions on the properties of the ISM.

Casoli et al. (1998), using a hybrid sample of more than 500 spiral galaxies, reported an average $M_{H_2^*}/M_{HI}$ ratio of 0.2-0.34, which is not only one magnitude lower than that of our SIG sample, but also much lower than that reported by Young et al. (1996). They argued that Young's sample contains more FIR-bright and optically bright galaxies, while their own sample contains more dwarf galaxies. They also showed that $M_{H_2^*}/M_{HI}$ is weakly correlated with L_B, suggesting that there might be a size effect for the high $M_{H_2^*}/M_{HI}$ ratio in more luminous galaxies. However, this correlation is very weak in Casoli's sample. We also plot log($M_{H_2^*}/M_{HI}$) versus $log(L_B)$ for the ISG control sample in Fig. 9, and see virtually no correlation between $M_{H_2^*}/M_{HI}$ and L_B. Hence there is no evidence that the high $M_{H_2^*}/M_{HI}$ ratio in SIGs is the result of a size effect.

7. Dependence of statistical properties on interaction type and separation

Table 5 gives the statistical properties of each IG subsample and Fig. 12 presents these properties graphically. Both show that the average $M_{H_2^*}/L_B$, $M_{H_2^*}/D_{25}^2$, $M_{H_2^*}/M_{HI}$, L_{IR}/L_B, L_{IR}/M_{GAS^*} and S_{60}/S_{100} ratios all systematically increase with interaction strength. Here M_{GAS^*} is defined as $M_{H_2^*} + M_{HI}$.

7.1. The star formation rate

The FIR luminosity L_{IR} of a galaxy is a good measure of its global star formation rate (SFR) (see Kennicutt 1998 and references therein). The FIR emission is mainly the energy reradiated by dust that has been heated by young massive stars in star forming regions.

There is a well established correlation between FIR and CO emission for both spiral and interacting galaxies (Young et al. 1996 and references therein). In agreement with previous studies, we find a good correlation between L_{IR}/L_B and $M_{H_2^*}/L_B$ for both the interacting (Fig. 10) and isolated galaxy samples. The average L_{IR}/L_B ratio is about twice as high in SIGs than in ISGs (Table 5), suggesting a higher star formation rate.

Although the IG3 and IG4 subsamples include a relatively small number of systems and there may be errors in our IG type classification, both subsamples show significant enhancement in the FIR and CO emission. If we group IG3 and IG4 into a merging-system category, this class forms a larger subsample that is not affected by errors in classification between the two subsamples. Therefore, it is safe to say that merging systems have an enhancement in CO and FIR luminosity. We have also performed the same statistical analysis for an enlarged IG3 and IG4 subsample by including all the known merging systems in the southern sky such as NGC1614, ARP236, NGC4038/39, NGC7592, NGC7252, and the conclusion remains the same.

The variations in the L_{IR}/L_B and $M_{H_2^*}/L_B$ ratios within each IG subsample are quite large however. For example, in several IG4 systems the $M_{H_2^*}/L_B$ ratio is as low as 0.02 (for NGC3239) and as high as 1.09 (for ARP220). Thus not every merging process produces a CO and FIR enhancement.

NGC3239 is an example of a merger with low $M_{H_2^*}/L_B$. It is a small galaxy with L_B less than $10^{10}\,\mathrm{L}_{\odot}$; it is rich in HI, but has little H_2^*. Thus the merging of dwarf galaxies may not produce a CO enhancement. Another example is NGC4194, which is classified as IG5 because it has only one nucleus. However, it has FIR and CO properties similar to most IG4 galaxies. It may be at a stage later than ARP220 but still earlier than most of the other IG5 galaxies. Starburst activity is still quite dramatic in these systems because the gas has not yet been consumed, even though the nuclei have merged.

Figure 11 shows the correlation between L_{IR}/L_B and $M_{H_2^*}/M_{HI}$ for the merger type subsample (solid circles), IG2 (open circles) and ISG sample (stars). This correlation is strong for the merger type subsample, but very weak for IG2 and ISGs. This suggests that molecular gas-rich mergers are more likely to have a high SFR, but the tidal force may not be strong enough in interacting pairs (IG2) to trigger a high level of star formation even if there is plenty of molecular gas available in the system.

7.2. The star formation efficiency

If $M_{H_2^*}$ is indicative of the true mass of molecular gas, then the $L_{IR}/M_{H_2^*}$ ratio can be used as an indicator of the star formation efficiency (SFE) which is the number of newly formed stars per unit mass of molecular gas. This ratio is not significantly enhanced for strongly interacting pairs (IG2 and IG3) compared to the weak tidal types (IG1). Only mergers (IG4 and IG5) have a significantly higher SFE. In the case of IG5 this is mostly due to the depletion of molecular gas at a late stage of merging rather than to a high L_{IR} emission. Only mergers (IG4 and IG5) have a higher SFE than ISGs by a factor of ~ 2. Therefore the high SFR in most SIGs is mainly due to more molecular gas available to fuel the gas.

7.3. The dependence on projected separation

The projected separation is also a statistical indicator of the interaction strength. Figure 13 shows the relationship between Sep/D_{25} and several derived quantities of the interacting systems, where Sep/D_{25} is the pair separation normalized by the primary's diameter D_{25} . We see a weak correlation between Sep/D_{25} and L_{IR}/M_{GAS^*} , L_{IR}/L_B , $L_{IR}/M_{H_2^*}$, S_{60}/S_{100} and $M_{H_2^*}/L_B$, but there are almost no correlations between Sep/D_{25} and M_{HI}/L_B , $M_{H_2^*}/M_{HI}$. In all cases, the scatter is quite large. This is not surprising, because the projected pair separation is not a measure of the true linear separation. Sep/D_{25} provides only a lower limit on the true separation due to projection effects, and it also depends on the evolutionary stage of the encountering pair. Therefore, the IG classification according to the disturbed morphology may be a better measure of the interaction strength. Nevertheless, the correlation between Sep/D_{25} and L_{IR}/L_B or L_{IR}/M_{GAS^*} confirms the results found by other investigators that closer interactions increase the chances of producing enhanced star formation and hence more FIR emission. The M_{HI}/L_B ratio is not anti-correlated with

Sep/D_{25} , and provides no evidence for conversion of atomic gas to molecular gas along the merging sequence.

8. Discussion: More molecular gas in SIGs?

Here we return to the issue of whether the quantity $M_{H_2^*}$ truly represents the mass of molecular gas. As shown in the previous sections, SIGs on average have higher $M_{H_2^*}/L_B$ and $M_{H_2^*}/D_{25}^2$ ratios than ISGs, which suggests that SIGs have more molecular gas than ISGs. However, as discussed in section 6, there is no evidence for HI depletion in SIGs. HI appears deficient in the late-stage mergers (IG5) only. If the extra molecular gas is not produced by conversion of HI to H_2, where does it come from? There is a priori no reason why galaxies about to interact initially have more than average amounts of molecular gas. It is thus necessary to examine whether the global CO flux or the X factor of the SIGs have been overestimated before stating that SIGs have more molecular gas than average.

It is unlikely that the excess CO emission seen in SIGs is caused by a significant overestimate of the derived global CO flux. As discussed in Paper I, if the molecular gas is more centrally distributed in SIGs, the global CO flux might be overestimated to some degree when a correction factor is applied to take into account emission outside the beam. However this correction factor is small for most of the sample. Thus any overestimate should be less than 40%, and therefore cannot account for all of the CO enhancement in most SIGs. Also there are a number of SIGs, such as ARP220, ARP193, and UGC8874 that have been resolved by interferometers, and the derived $M_{H_2^*}/L_B$ and $M_{H_2^*}/D_{25}^2$ ratios are still significantly higher than those of normal ISGs. Thus the CO enhancement is real, and the question is then indeed whether the X factor is larger in SIGs, or whether there is really more $M_{H_2^*}$ in SIGs than in ISGs.

Figure 10 shows that $M_{H_2^*}/L_B$ is strongly correlated with the SFR indicator L_{IR}/L_B , and thus many of the galaxies with high $M_{H_2^*}/L_B$ are FIR-luminous systems. If their X factor is on average reduced by a factor of two, the resulting average $M_{H_2^*}/L_B$ and $M_{H_2^*}/M_{HI}$ for SIGs would become comparable to that of ISGs. Thus the higher $M_{H_2^*}/L_B$ ratio in the SIG sample may be the result of the dependence of the X factor on physical and/or chemical conditions in the clouds. From Table 5 we can see S_{60}/S_{100} is slightly higher in SIGs than in ISGs, suggesting a higher dust temperature in SIGs. However, this increment is marginal. In particular, there is no significant correlation between $M_{H_2^*}/L_B$ and S_{60}/S_{100} indicating a weak dependence at best of the X factor on temperature.

We have further investigated this issue in a detailed case study of the nearest prototype colliding pair NGC4038/9, in which we can obtain relatively high resolution multi-transition data from both ^{12}CO and ^{13}CO to get a better estimate of the physical parameters and the molecular gas mass (Zhu et al. in preparation). We found that the ^{12}CO is "over luminous" with respect to its H_2 mass, based on modeling the CO emission with a Large Velocity Gradient (LVG) model. The derived X factor in this system is approximately one order of magnitude lower than the conventional value if the Galactic [H_2/CO] ratio is assumed. Furthermore, according to the LVG model, there is an excessive velocity gradient within the molecular clouds, considerably exceeding that for virialized clouds. Thus the excess CO emission in many SIGs may be the result of a large velocity dispersion, which could increase the radiative efficiency and luminosity of the CO emitting gas. High resolution interferometer data shows that some high $M_{H_2^*}/L_B$ mergers, such as ARP220 and ARP299, have relatively broad spectral profiles within the central 1 kpc region, indicating a large velocity gradient (*e.g.* Casoli *et al.* 1999; Downes & Solomon 1998; Scoville *et al.* 1997; Aalto *et al.* 1997; Gao *et al.* 1997). However, we caution that these observations may not relate directly to the velocity dispersion inferred from an LVG analysis since the latter refers to conditions localized within the molecular clouds. In any event, a lower than normal X

factor may very well be the cause of the excess CO emission in these systems.

9. Summary

We have compiled a complete sample of strongly interacting galaxies in the northern sky which contains 126 galaxies in 92 systems. CO data have been collected for 75% of these systems including non-detections (for the subsamples IG3 and IG4 the coverage is more than 90%). In deriving estimates of the molecular gas mass from the CO luminosity using the traditional Galactic X factor, we have introduced the parameter $M_{H_2^*}$ to represent the H_2 mass in order to emphasize that it is a direct reflection of the CO luminoity. The principal findings are as follows:

(1) Mergers (IG4) and colliding systems (IG3) on average have significantly higher $M_{H_2^*}/L_B$ and $M_{H_2^*}/D_{25}^2$ ratios than normal spiral galaxies. If the CO-to-H_2 conversion factor is the same for all types of galaxies, the enhancement in the CO emission indicates more molecular gas in merging galaxies.

(2) Strongly interacting pairs (IG2) on average have $M_{H_2^*}/L_B$ and $M_{H_2^*}/D_{25}^2$ ratios comparable to those of ISGs. But there are still some peculiar IG2 systems that show evidence of enhanced CO emission. The $M_{H_2^*}/L_B$ and $M_{H_2^*}/D_{25}^2$ ratios are correlated with interaction strengths.

(3) There is no evidence that enhanced H_2 content in SIGs is produced by the conversion of atomic gas to molecular gas. Note that this result may be the strongest argument to date that the enhancement is most readily accounted for by a significantly higher value of the X factor in SIGs.

(4) The high L_{IR}/L_B ratios seen in most interacting pairs, especially those involved in only mild to moderate strength interactions (groups IG2 and IG3), appears to be due to an

enhancement in the amount of molecular gas available to fuel star formation, rather than an increase in the SFE (a conventional X factor is assumed). Only in the most strongly interacting and merging systems (IG4) does it appear that the SFE is enhanced, indicating that the strong tidal forces experienced by these systems affects the process of star formation. This enhancement would be even more pronounced if $M_{H_2^*}$ is an overestimate of the true molecular mass.

(5) The primary issue now is whether molecular masses can be reliably estimated for interacting and star-forming galaxies using a universal X factor. The possibility exists that this approach yields a significant overestimate. Future effort will have to concentrate on deriving more precise estimates of the molecular mass, and on understanding the origin of the suspected enhancement in CO luminosity for these systems.

10. Acknowledgements

This research was supported by a research grant to E.R.S. from the Natural Sciences and Engineering Research Council of Canada.

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Figure Captions

Figure 1a: Distribution of the M_B for the SIG sample (upper panel) and the control sample (lower panel).

Figure 1b: Hubble type distribution of the SIG sample (upper panel) and the control sample (lower panel).

Figure 2: Histogram of the $M_{H_2^*}/L_B$ ratio for the SIG sample (upper panel) and the control sample (lower panel).

Figure 3: Correlation between $M_{H_2^*}$ and L_B. Solid circles are merger types (IG3+IG4) and open circles are IG2 and starts are for isolated galaxies in Young's sample.

Figure 4: Histogram of the $M_{H_2^*}/D_{25}^2$ ratio for the SIG sample (upper panel) and the control sample (lower panel).

Figure 5: Correlation between $M_{H_2^*}$ and D_{25}. Solid circles are mergers (IG3+IG4), open circles are IG2 and starts are isolated galaxies in Young's sample.

Figure 6: Histogram of the $M_{H_2^*}/M_{HI}$ ratio for the SIG sample (upper panel) and the control sample (lower panel).

Figure 7: Relation between M_{HI}/L_B and $M_{H_2^*}/L_B$ for the SIG sample.

Figure 8: Relation between $M_{H_2^*}/M_{HI}$ and $M_{H_2^*}/L_B$ for (a) the SIG sample; (b) the control sample.

Figure 9: Relation between $M_{H_2^*}/M_{HI}$ and L_B for the SIG sample.

Figure 10: Relation between L_{IR}/L_B and $M_{H_2^*}/L_B$ for the SIG sample.

Figure 11: Relation between L_{IR}/L_B and $M_{H_2^*}/M_{HI}$ for the SIG sample and the control sample. Solid circles represent mergers (IG3+IG4), open circles represent IG2, and stars

represent ISGs.

Figure 12: Relation between statistics properties and IG types.

Figure 13: Relation between statistics properties and pair separation Sep/D_{25}.

Table 1. SIG Sample

Name (1)	Other Name (2)	ARP (3)	IG (4)	R.A. (5)	DEC (6)	cz (7)	B_T^0 (8)	D_{25} (9)	r_b (10)	Hubble Type (11)
NGC317A	UGC593		2	00 54 49.8	+ 43 31 51	5293	14.60	1.4	1.3	S?
NGC317B	UGC594		2	00 54 51.2	+ 43 31 19	5334	12.80	1.1	0.5	SB?
UGC816			2	01 13 24.3	+ 46 29 01	5188	13.16	1.9	0.9	S?
UGC01449		126	2	01 55 31.1	+ 02 50 35	5555	13.58	1.2	0.7	SBm pec
UGC1555		290	2	02 01 02.0	+ 14 28 08	3648	13.78	1.5	0.8	S0
UGC1556		290	2	02 01 07.4	+ 14 30 00	3534	13.05	2.8	1.4	S0-
NGC0935	UGC1937	276	2	02 25 23.1	+ 19 22 35	4142	12.93	1.7	1.1	Scd:
NGC1633	UGC3125		2	04 37 27.3	+ 07 15 09	4989	13.73	1.0	0.9	SAB(s)ab
UGC3706N			2	07 06 09.0	+ 47 59 41	6090	14.10	0.4	0.2	Sa
UGC3706S			2	07 06 10.3	+ 47 59 21	6090	14.10	0.4	0.2	Sa
NGC2744	UGC4757		2	09 01 49.4	+ 18 39 25	3428	13.55	1.7	1.1	SBab(s) pec:
NGC2798		283	2	09 14 09.5	+ 42 12 37	1739	12.48	2.6	1.0	SB(s)a pec
NGC2799		283	2	09 14 18.1	+ 42 12 15	1755	13.72	1.9	0.5	SB(s)m?
NGC2820	UGC4961		2	09 17 43.7	+ 64 28 16	1579	11.73	4.1	0.5	SBc(s) pec sp
UGC5304			2	09 50 30.1	+ 08 06 08	12308	13.98	1.1	0.9	S?
NGC3226	UGC5617	94	2	10 20 43.6	+ 20 09 07	1322	12.45	3.2	2.8	E2: pec
NGC3227	UGC5620	94	2	10 20 47.6	+ 20 07 00	1157	11.18	5.4	3.6	SAB(s)a pec
UGC5643	NGC 3212	181	2	10 23 12.1	+ 80 04 42	9769	13.73	1.5	1.1	SB?
UGC05832		291	2	10 40 09.6	+ 13 43 18	1216	13.58	1.1	1.0	SB?
NGC3395	UGC5931	270	2	10 47 02.3	+ 33 14 45	1620	12.09	2.1	1.2	SAB(rs)cd pec
NGC3396	UGC5935	270	2	10 47 09.0	+ 33 15 16	1625	12.32	3.1	1.2	IBm pec
UGC5984			2	10 49 29.6	+ 30 19 26	10423	14.10	1.9	1.2	S?
NGC3561N	UGC6224N	105	2	11 08 31.3	+ 28 59 03	8549	14.40	0.7	0.7	SA(r)a pec

Table 1—Continued

Name (1)	Other Name (2)	ARP (3)	IG (4)	R.A. (5)	DEC (6)	cz (7)	B_T^0 (8)	D_{25} (9)	r_b (10)	Hubble Type (11)
NGC3561S	UGC6224S	105	2	11 08 31.5	+ 28 58 07	8811	14.40	0.9	0.9	$S0^0$: pec
NGC3786		294	2	11 37 04.7	+ 32 11 13	2723	12.97	2.2	1.3	SAB(rs)a pec
NGC3788		294	2	11 37 06.4	+ 32 12 35	2699	12.80	2.1	0.7	SAB(rs)ab pec
NGC3808	UGC6643		2	11 38 07.9	+ 22 42 18	7078	13.66	1.7	0.9	SAB(rs)c: pec
UGC6854	KGC307A		2	11 50 9.7	+ 02 01 10	6128	14.06	1.0	0.9	SB(rs)bc pec
UGC6865		62	2	11 51 02.1	+ 43 43 53	5886	13.96	1.1	0.4	SB
NGC3985	UGC6921		2	11 54 06.8	+ 48 36 44	950	12.89	1.3	0.8	SB(s)m:
NGC3994		313	2	11 55 01.5	+ 32 33 26	3096	13.18	1.0	0.6	SA(r)c pec?
NGC3995	UGC6944	313	2	11 55 09.9	+ 32 34 20	3254	12.32	2.8	1.0	SA(m)pec
NGC4211N	UGC7277N	106	2	12 13 04.4	+ 28 27 20	6599	14.30	1.0	1.0	S0/a pec
NGC4211S	UGC7277S	106	2	12 13 05.8	+ 28 26 51	6670	15.20	1.4	1.4	S0/a pec
NGC4435	UGC7575	120	2	12 25 08.6	+ 13 21 23	781	11.61	2.8	2.0	$SB(s)0^0$
NGC4438	UGC7574	120	2	12 25 13.5	+ 13 17 11	69	10.49	8.5	3.2	SA(s)0/a pec
NGC4485		269	2	12 28 05.5	+ 41 58 35	493	12.22	2.3	1.6	IB(s)m pec
NGC4490		269	2	12 28 10.5	+ 41 54 56	578	9.81	6.3	3.1	SB(s)0+? sp
NGC4496A	UGC7668A		2	12 29 06.2	+ 04 12 56	1730	11.78	4.0	3.2	SBm(rs)
UGC7905S	UGC7905S		2	12 41 31.9	+ 55 10 11	4933	13.97	1.0	0.6	Pec
UGC7905N	UGC7905N		2	12 41 33.4	+ 55 10 44	4875	13.97	0.0	1.0	S? pec
NGC4676A	UGC7938	242	2	12 43 44.2	+ 31 00 23	6613	14.10	2.3	0.7	S0 pec?
NGC4676B	UGC7939	242	2	12 43 45.3	+ 30 59 51	6607	14.70	2.2	0.8	SB(s)0/a pec
NGC4809		277	2	12 52 18.0	+ 02 55 27	915	14.04	1.7	0.7	Im pec
NGC4810		277	2	12 52 18.2	+ 02 54 40	876	14.75	0.8	0.5	Im pec
UGC8335			2	13 13 41.8	+ 62 23 16	9243	14.10	0.9	0.8	S?

Table 1—Continued

Name	Other Name	ARP	IG	R.A.	DEC	cz	B_T^0	D_{25}	r_b	Hubble Type
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
UGC8357S			2	13 15 25.1	- 00 02 56	9944	13.84	1.2	0.5	SB(s)b pec?
NGC5257	UGC8641	240	2	13 37 19.7	+ 01 05 40	6798	13.05	1.8	0.9	Sb? pec
NGC5258	UGC8645	240	2	13 37 24.7	+ 01 05 10	6784	13.19	1.7	1.1	Sb? pec
NGC5278	UGC8677	239	2	13 39 47.2	+ 55 55 19	7541	13.4	1.3	1.0	SA(s)b? pec
NGC5279	UGC8678	239	2	13 39 51.8	+ 55 55 29	7580	–	0.6	0.4	SB(s)a pec
NGC5331S	UGC8774S		2	13 49 43.6	+ 02 20 53	9906	14.85	1.1	0.7	Sb pec?
NGC5331N	UGC8774N		2	13 49 43.7	+ 02 21 17	9906	13.83	1.1	0.7	Sb pec?
NGC5394	UGC8898	84	2	13 56 25.2	+ 37 41 51	3427	13.29	1.7	1.0	SB(s)b pec
NGC5395	UGC8900	84	2	13 56 29.7	+ 37 40 05	3487	12.01	2.9	1.5	SA(s)b pec
NGC5410	UGC8931		2	13 58 49.9	+ 41 13 40	3738	13.53	1.5	0.8	SB?
NGC5421N	UGC8941N	111	2	13 59 30.0	+ 34 04 10	7889	14.10	1.2	0.9	SB?
NGC5421S	UGC8941S		2	13 59 30.9	+ 34 03 45	7868	15.00	1.2	0.9	E
UGC8972	KPG411B		2	14 01 12.0	+ 11 37 03	11338	14.14	1.2	0.7	Sb
UGC8973	KPG411A		2	14 01 12.0	+ 11 38 00	11629	14.15	1.2	0.6	Sb
UGC9098W	KPG415A		2	14 10 30.4	+ 45 55 32	8387	14.2	0.45	0.3	Sb
UGC9098E	KPG415B		2	14 10 33.1	+ 45 55 32	8303	14.3	1.0	0.4	Sb
NGC5544	UGC9142	199	2	14 14 56.5	+ 36 48 11	3077	13.2	1.0	1.0	(R)SB(rs)0/a
NGC5545	UGC9143	199	2	14 14 59.5	+ 36 48 25	3071	–	1.3	0.4	(R)SB(rs)0/a
UGC9221	KPG425A		2	14 21 34.9	+ 34 14 06	3860	14.38	0.8	0.7	S?
UGC9222	KPG425B		2	14 21 38.9	+ 34 14 35	3539	14.42	0.9	0.3	S0/a
NGC5613		178	2	14 21 59.7	+ 35 07 08	8746	–	1.0	0.8	(R)SAB(r)0+
NGC5614	UGC9226	178	2	14 22 01.1	+ 35 05 04	3892	12.37	2.5	2.0	SA(r)ab pec
NGC5679		274	2	14 32 38.7	+ 05 34 40	8654	–	1.1	0.7	Sb

Table 1—Continued

Name (1)	Other Name (2)	ARP (3)	IG (4)	R.A. (5)	DEC (6)	cz (7)	B_T^0 (8)	D_{25} (9)	r_b (10)	Hubble Type (11)
UGC9622			2	14 55 04.0	+ 19 52 16	4833	13.68	1.2	0.8	S?
NGC5953	UGC9903	91	2	15 32 13.2	+ 15 21 40	1965	13.0	1.6	1.3	SAa: pec
NGC5954	UGC9904	91	2	15 32 15.7	+ 15 22 10	1959	13.1	1.3	0.6	SAB(rs)cd pec
UGC10770			2	17 12 27.4	+ 59 23 23	1108	–	1.2	0.6	Im pec
ARP311		311	2	17 26 31.4	+ 58 31 32	7928	14.18	0.9	0.7	Sab?
UGC10923			2	17 36 22.7	+ 86 46 39	7721	13.70	1.2	0.7	S?
NGC6636	UGC11221		2	18 22 03.5	+ 66 35 23	4226	–	2.2	0.4	S?
NGC6745	UGC11391		2	19 00 03.4	+ 40 40 20	4545	–	1.4	0.7	S?
UGC11657			2	20 57 11.7	- 02 04 57	5836	14.10	1.1	1.1	Pec
UGC11658			2	20 57 12.8	- 02 04 07	5843	13.90	1.4	0.9	SAB(rs)a pec?
NGC7253A	UGC11984	278	2	22 17 08.6	+ 29 08 48	4583	13.3	1.7	0.5	SB?
NGC7253B	UGC11985	278	2	22 17 11.3	+ 29 08 06	4493	13.3	1.6	0.5	SB?
UGC12011A			2	22 20 45.5	+ 30 40 15	6715	14.0	0.3	0.2	Sb
UGC12011B			2	22 20 48.0	+ 30 40 18	6702	14.0	0.2	0.2	Sa
NGC7550		99	2	23 12 46.8	+ 18 41 25	5101	13.11	1.4	1.2	SA0-
UGC12856		262	2	23 54 11.9	+ 16 32 09	1777	13.80	1.6	1.0	IB(s)m
NGC7805	UGC12908	112	2	23 58 52.7	+ 31 09 20	4850	13.90	1.2	0.9	SAB0^0: pec
NGC7806	UGC12911	112	2	23 58 56.4	+ 31 09 51	4768	13.88	1.1	0.8	SA(rs)bc? pec
UGC5615N			2	10 20 36.6	+ 53 21 38	9586	13.8	0.8	0.7	Sb
UGC5615S			2	10 20 37.0	+ 53 21 05	10028	13.5	0.7	0.5	Sb
UGC9618b		302	2	14 54 48.1	+ 24 48 21	9776	15.1	0.6	0.6	Sc
UGC9618a		302	2	14 54 48.6	+ 24 49 02	10094	14.2	0.9	0.3	Sb
UGC1720			3	02 11 28.8	+ 04 56 33	9061	14.16	0.8	0.6	I?

Table 1—Continued

Name (1)	Other Name (2)	ARP (3)	IG (4)	R.A. (5)	DEC (6)	cz (7)	B_T^0 (8)	D_{25} (9)	r_b (10)	Hubble Type (11)
ARP145		145	3	02 20 00.3	+ 41 08 35	5425	13.61	1.5	1.3	Ring B
NGC1143	UGC2388	118	3	02 52 36.2	- 00 22 47	8459	14.06	0.9	0.8	SAB0-:pec/Rng
NGC1144	UGC2389	118	3	02 52 38.5	- 00 23 07	8647	13.21	1.1	0.7	Im pec/Ring B
UGC03730		141	3	07 08 12.1	+ 73 33 58	2709	12.88	2.8	1.5	Ring
UGC3829			3	07 20 28.5	+ 33 32 24	4028	13.40	1.0	0.8	S?
UGC3852	KPG135A		3	07 23 38.5	+ 72 13 50	3605	13.82	0.8	0.6	I?
NGC2444		143	3	07 43 30.6	+ 39 09 24	4048	13.91	1.2	0.8	Ring A
NGC2445	UGC4017	143	3	07 43 32.3	+ 39 08 25	4002	13.58	1.4	1.1	Ring B
NGC2936	UGC5130	142	3	09 35 08.5	+ 02 59 11	6989	13.75	2.1	0.7	I, Ring B
NGC2937	UGC5131	142	3	09 35 09.3	+ 02 58 23	6839	14.41	1.3	1.1	E, Ring A
ARP299	UGC6471/72	299	3	11 25 44.2	+ 58 50 23	3033	11.85	2.0	1.5	IBm pec
UGC6767	KPG301A		3	11 45 00.0	+ 57 55 00	9223	13.90	0.4	0.3	Sb
NGC4410A	UGC7535		3	12 23 55.8	+ 09 17 48	7219	14.01	1.3	0.8	Sab? pec
NGC4922	UGC8135		3	12 59 00.2	+ 29 34 36	7071	13.60	1.8	1.3	I0 pec
NGC5514	UGC9102		3	14 11 10.6	+ 07 53 32	7300	13.19	2.2	1.1	SA
NGC5929	UGC9851	90	3	15 24 18.3	+ 41 50 43	2561	–	1.0	0.9	SAB(s)bc I-II
NGC5930	UGC9852	90	3	15 24 20.6	+ 41 51 05	2672	12.56	1.7	0.9	Sab: pec
NGC6621	UGC11175	81	3	18 13 14.5	+ 68 20 15	6284	13.40	2.1	0.8	Sb: pec
NGC7714	UGC12699	284	3	23 33 41.2	+ 01 52 42	2799	12.62	1.9	1.4	SB:(s)b? pec
UGC12914			3	23 59 04.1	+ 23 12 23	4371	12.51	2.3	1.3	(R)Scd(r):pec
UGC12915			3	23 59 08.6	+ 23 12 59	4336	13.01	1.5	0.5	S?
NGC0520		157	4	01 21 59.4	+ 03 32 13	2217	11.97	4.5	1.8	S pec
NGC0523	UGC979	158	4	01 22 29.9	+ 33 45 53	4750	12.60	2.5	0.7	Pec

Table 1—Continued

Name (1)	Other Name (2)	ARP (3)	IG (4)	R.A. (5)	DEC (6)	cz (7)	B_T^0 (8)	D_{25} (9)	r_b (10)	Hubble Type (11)
NGC2623	UGC4509	243	4	08 35 25.3	+ 25 55 35	5535	13.19	2.4	0.7	P: Trip Coll
NGC3239		263	4	10 22 23.3	+ 17 24 50	753	11.54	5.0	3.3	Ib(s)m pec
NGC3303	UGC5773	192	4	10 34 17.9	+ 18 23 48	6165	14.00	3.0	2.1	Pec
Mrk231	UGC8058		4	12 54 05.0	+ 57 08 38	12642	13.97	1.3	1.0	SA(rs)c?:pec
ARP193		193	4	13 18 17.0	+ 34 24 04	6892	14.29	1.5	1.1	Im: pec
NGC5256	UGC8632		4	13 36 14.9	+ 48 31 47	8353	13.90	0.4	0.3	Compact pec
NGC5860	UGC9717		4	15 04 44.4	+ 42 50 00	5398	14.20	0.7	0.7	S?
ARP220		220	4	15 32 47.3	+ 23 40 06	5434	13.55	1.5	1.2	S?
NGC6052	UGC10182	209	4	16 03 01.3	+ 20 40 43	4716	13.40	0.9	0.7	Sc
NGC6090	UGC10267		4	16 10 24.0	+ 52 35 00	8785	13.89	1.7	0.7	S0?
NGC6240	UGC10592		4	16 50 27.8	+ 02 28 58	7339	13.17	2.1	1.1	I0:pec

Note. — (1) The most common name (2) Other Name (3) ARP number (4) IG type as defined in §2.1 (5) R.A. (1950) (6) DEC (1950) (7) Optical radial velocity cz from RC3 (8) B_T^0 (9) D_{25} in arcmin 10) r_b in arcmin (11) Hubble Type

Table 2. CO Data and Derived Quantities for IGs Observed by Us

Name	D	S_{CO}	$\log(L_B)$	$\log(M_{H_2^*})$	$M_{H_2^*}/L_B$	$\log\,[\frac{M(H_2^*)}{D_{25}^2}]$	IG type
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ARP205	18.9	96	9.95	8.58	0.04	5.60	1
UGC0717	148.6	28	10.96	9.83	0.07	6.21	1
UGC0365	63.6	240	10.84	10.03	0.15	6.66	1
UGC1063	78.0	48	10.48	9.51	0.11	6.79	1
UGC1810	102.4	64	11.05	9.87	0.07	6.24	1
UGC4264	53.8	66	10.60	9.32	0.05	6.14	1
UGC5265	22.9	<23	9.47	<8.12	<0.04	<6.32	1
UGC5269	22.9	30	9.76	8.24	0.03	5.67	1
UGC5600	39.5	43	9.73	8.87	0.14	6.45	1
UGC5609	39.5	<31	9.69	<8.69	<0.10	<6.38	1
UGC8529	39.2	367	10.24	9.79	0.36	7.17	1
UGC10033	45.3	89	10.44	9.30	0.07	6.60	1
UGC11137	32.5	90	10.29	9.02	0.05	6.56	1
UGC11414	103.1	<31	10.94	<9.56	<0.04	<6.52	1
UGC11695	130.9	104	10.80	10.29	0.31	6.84	1
UGC12066	77.2	37	10.44	9.38	0.09	6.60	1
UGC12456	67.8	31	10.64	9.23	0.04	6.31	1
UGC12457	67.8	215	10.75	10.00	0.18	6.55	1
ARP126N	74.5	69	10.50	9.63	0.13	6.80	2
ARP126S	74.5	45	10.74	9.43	0.05	7.36	2
ARP262N	25.8	<53	9.42	< 8.59	< 0.15	< 6.43	2
ARP308N	72.6	<63	10.71	< 9.55	< 0.07	< 6.15	2
ARP308S	72.6	<41	10.76	< 9.39	< 0.04	< 6.50	2
ARP311	108.5	48	10.59	9.79	0.16	6.89	2
UGC0593	73.2	<14	10.08	<8.91	<0.07	<5.97	2

Table 2—Continued

Name	D	S_{CO}	$\log(L_B)$	$\log(M_{H_2^*})$	$M_{H_2^*}/L_B$	$\log\,[\frac{M(H_2^*)}{D_{25}^2}]$	IG type
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
UGC0594	73.2	208	10.80	10.09	0.19	7.35	2
UGC0813	70.2	63	10.40	9.52	0.13	6.76	2
UGC0816	70.2	161	10.64	9.96	0.21	6.76	2
UGC3706N	80.8	12	10.37	8.94	0.04	6.99	2
UGC3706S	80.8	10	10.37	8.86	0.03	6.91	2
UGC5304	154.1	14	10.98	9.56	0.04	6.18	2
UGC5931	21.4	99	10.01	8.69	0.05	6.47	2
UGC5935	21.4	112	9.93	8.76	0.07	6.18	2
UGC5984	138.6	46	10.84	9.99	0.14	6.22	2
UGC6643	93.8	62	10.67	9.78	0.13	6.45	2
UGC6865	78.4	154	10.40	10.02	0.42	7.22	2
UGC7277N	88.3	<9	10.36	<8.88	<0.03	<6.07	2
UGC7277S	88.3	47	10.01	9.61	0.40	6.43	2
UGC7905N	67.0	<40	10.26	<9.30	<0.11	<8.11	2
UGC7905S	67.0	<24	10.26	<9.07	<0.07	<6.49	2
UGC8357S	132.6	122	10.90	10.37	0.30	0.00	2
UGC8677	102.6	76	10.85	9.94	0.12	6.70	2
UGC8774N	133.8	70	11.00	10.23	0.17	7.75	2
UGC8774S	133.8	151	10.42	10.39	0.93	7.74	2
UGC8898	46.9	201	10.21	9.68	0.29	6.96	2
UGC8900	46.9	548	10.74	10.13	0.25	6.93	2
UGC8931	51.1	<43	10.20	<9.09	<0.08	<6.40	2
UGC8941N	106.0	93	10.60	10.06	0.29	6.92	2
UGC8941S	106.0	7	10.24	8.94	0.05	5.80	2
UGC9142	42.3	40	10.16	8.90	0.05	6.72	2

Table 2—Continued

Name	D	S_{CO}	$\log(L_B)$	$\log(M_{H_2^*})$	$M_{H_2^*}/L_B$	$\log\,[\frac{M(H_2^*)}{D_{25}^2}]$	IG type
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
UGC9226	52.9	490	10.69	10.18	0.31	7.01	2
UGC9903	27.1	365	9.86	9.47	0.41	7.27	2
UGC9904	27.1	73	9.82	8.77	0.09	6.75	2
UGC10923	105.4	129	10.76	10.20	0.28	7.07	2
UGC11657	79.8	<9	10.35	<8.80	<0.03	<5.99	2
UGC11658	79.8	25	10.44	9.24	0.06	6.22	2
UGC11984	63.8	180	10.48	9.91	0.27	6.91	2
UGC11985	63.8	47	10.47	9.31	0.07	6.38	2
UGC12011A	89.5	<15	10.50	< 9.12	<0.04	<7.34	2
UGC12011B	89.5	<15	10.50	< 9.12	<0.04	<7.69	2
UGC12908	66.6	<36	10.29	< 9.25	<0.09	<6.51	2
UGC12911	66.6	46	10.28	9.34	0.12	6.69	2
ARP141	37.8	<56	10.19	< 8.94	< 0.06	< 5.97	3
ARP142S	90.3	<45	10.33	< 9.60	< 0.19	< 6.13	3
ARP142N	90.3	335	10.65	10.49	0.68	7.41	3
ARP90	37.4	148	10.31	9.36	0.11	6.82	3
UGC11175	86.2	255	10.70	10.32	0.41	6.88	3
UGC12914	60.4	420	10.75	10.23	0.30	7.01	3
UGC12915	60.4	381	10.55	10.18	0.43	7.34	3
UGC3829	53.3	92	10.29	9.46	0.15	7.08	3
UGC3852	49.4	23	10.05	8.79	0.06	6.67	3
UGC7535	95.7	<34	10.55	<9.53	<0.10	<6.42	3
UGC9102	97.4	111	10.89	10.06	0.15	6.47	3
NGC3239	8.9	< 66	9.47	<7.76	<0.02	<5.54	4
UGC5773	81.9	<7	10.42	<8.71	<0.02	<6.40	4

Table 2—Continued

Name	D	S_{CO}	$\log(L_B)$	$\log(M_{H_2^*})$	$M_{H_2^*}/L_B$	$\log\left[\frac{M(H_2^*)}{D_{25}^2}\right]$	IG type
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
UGC0979	65.5	90	10.78	9.63	0.07	6.27	4
UGC9717	73.7	37	10.25	9.34	0.12	6.99	4
ARP137	41.9	<49	9.95	<8.98	<0.11	<6.80	5
ARP162	18.3	<75	9.97	<8.44	<0.03	<5.90	5
ARP165	66.3	<64	10.65	<9.49	<0.07	<6.41	5
NGC3509	101.2	91	11.09	10.01	0.08	6.43	5
NGC3921	79.1	80	10.83	9.74	0.08	6.37	5
ARP164	71.3	<54	10.65	< 9.48	< 0.07	< 6.29	5
ARP222	25.3	<157	10.49	< 9.04	< 0.04	< 5.97	5
ARP223	47.5	<49	10.65	< 9.08	< 0.03	< 6.08	5

Note. — Col.(1) Galaxy name. Col.(2) Distance in Mpc, computed using the mean optical radial velocity of each system from Table 1 and assuming $H_0 = 75$ km s^{-1} Mpc^{-1}. Col.(3) Global CO flux, in units of Jy km/sec. Corrections for flux outside the telescope beam are applied. Upper limits are 3 σ. Col.(4) Logarithm of the blue luminosity in units of $L_\odot$, computed from values of B_T^0 in Table 1 and assuming $M_{B_\odot} = +5.48$. Col.(5) Logarithm of the global molecular gas mass in the units of $M_\odot$, computed using $M_{H_2^*} = 1.1\times10^4 D^2 S_{CO}$. Col.(6) Ratio of the global molecular gas mass to the blue luminosity in the units of $L_\odot/M_\odot$. Col.(7) Logarithm of the ratio of the global molecular gas mass to the optical area D_{25}^2 in units of $M_\odot$/kpc^2. The optical area is computed using the D_{25} from Table 1. Col.(8) IG type as defined in §2.1.

Table 3. CO Data for IGs in the Literature

Name (1)	D (2)	S_{CO} (3)	$\log(L_B)$ (4)	$\log(M_{H_2^*})$ (5)	$M_{H_2^*}/L_B$ (6)	$\log\,[\frac{M(H_2^*)}{D_{25}}]$ (7)	IG type (8)	Reference (9)
ARP295a	91.5	43	10.47	9.60	0.13	6.19	1	16
ARP295b	91.5	89	10.81	9.91	0.13	7.15	1	16
NGC1055	13.3	2800	10.15	9.74	0.38	6.85	1	15
NGC2276	32.1	800	10.51	9.96	0.28	7.25	1	15
NGC3169	14.6	1300	10.14	9.48	0.22	6.83	1	15
NGC3718	13.3	<315	9.96	<8.79	<0.06	<5.82	1	15
NGC3800	43.1	200	10.39	9.61	0.17	6.81	1	5
NGC3893	13.0	540	10.15	9.00	0.07	6.61	1	15
NGC4017	45.8	83	10.31	9.28	0.09	6.52	1	3
NGC4298	14.5	660	9.87	9.18	0.21	6.85	1	15
NGC4302	14.1	620	9.95	9.13	0.15	6.43	1	15
NGC4567	29.5	500	10.42	9.68	0.18	6.17	1	15
NGC4568	29.4	1050	10.66	10.00	0.22	6.12	1	15
NGC4647	18.2	600	9.99	9.34	0.22	6.67	1	15
NGC5000	75.1	60	10.57	9.57	0.10	6.60	1	3
NGC5194	6.4	9450	10.34	9.63	0.20	7.01	1	15
NGC5195	6.4	240	9.64	8.03	0.02	6.03	1	15
NGC6285	74.7	83	10.36	9.71	0.22	7.12	1	9
NGC6286	74.7	290	10.31	10.25	0.86	7.35	1	9
NGC7603	119.7	249	10.91	10.59	0.48	7.16	1	8
NGC7674	118.8	350	10.90	10.74	0.69	7.51	1	15
NGC7771	59.3	805	10.74	10.49	0.57	7.24	1	13
UGC480W	151.2	160	11.36	10.60	0.17	6.97	1	2

Table 3—Continued

Name	D	S_{CO}	$\log(L_B)$	$\log(M_{H_2^*})$	$M_{H_2^*}/L_B$	$\log\,[\frac{M(H_2^*)}{D_{25}}]$	IG type	Reference
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
UGC3031	62.3	<28	9.94	<9.08	<0.14	<6.15	1	2
UGC3032	62.2	<36	10.12	< 9.19	<0.12	<6.59	1	2
UGC4718	41.7	<48	9.99	<8.96	<0.09	<6.50	1	2
UGC4744	31.8	55	9.84	8.79	0.09	6.70	1	2
ARP302a	132.0	332	10.94	10.08	0.78	7.73	2	9
ARP302b	132.0	59	10.58	10.94	0.32	7.33	2	9
NGC0935	56.3	170	10.52	9.77	0.18	6.88	2	5
NGC2798	23.2	440	9.93	9.42	0.31	6.91	2	15
NGC2799	23.9	60	9.46	8.58	0.13	6.29	2	15
NGC2820	22.2	100	10.19	8.73	0.03	5.89	2	15
NGC3226	16.6	<135	9.65	<8.62	<0.09	<6.24	2	15
NGC3227	14.4	1418	10.04	9.51	0.30	6.80	2	10
NGC3786	36.2	157	10.12	9.35	0.17	6.62	2	10
NGC3788	36.2	<49	10.18	8.84	0.046	<6.16	2	10
NGC3995	43.4	55	10.54	9.06	0.03	5.96	2	3
NGC4438	13.3	357	10.63	9.61	0.10	5.81	2	6
NGC4490	10.9	480	10.11	8.56	0.03	6.43	2	15
NGC4676A	88.5	71	10.45	9.79	0.22	6.24	2	3
NGC4676B	88.2	51	10.20	9.64	0.27	6.14	2	3
UGC4757	44.4	<55	10.07	<9.08	<0.10	<6.39	2	2
UGC6224N	117.1	125	10.57	10.28	0.51	7.52	2	2
UGC8335E	124.1	51	10.74	9.93	0.16	7.28	2	2
UGC8641	90.1	258	10.88	10.36	0.30	7.01	2	2

Table 3—Continued

Name	D	S_{CO}	$\log(L_B)$	$\log(M_{H_2^*})$	$M_{H_2^*}/L_B$	$\log\left[\frac{M(H_2^*)}{D_{25}}\right]$	IG type	Reference
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
UGC8645	89.6	296	10.82	10.42	0.39	7.12	2	2
ARP143	53.6	95	10.22	9.48	0.18	6.80	3	10
ARP145	69.0	44	10.43	9.36	0.09	6.41	3	10
ARP299	42.1	900	10.69	10.23	0.36	7.45	3	15
NGC1144	115.3	318	11.03	10.67	0.43	7.53	3	9
NGC5929	35.8	104	10.14	9.17	0.11	7.13	3	10
NGC6090	119.4	200	10.79	10.50	0.51	6.91	3	15
NGC7714	39.0	130	10.33	9.34	0.10	6.67	3	15
UGC1720	121.3	88	10.70	10.15	0.29	7.25	3	2
UGC8135	94.7	107	10.22	10.02	0.63	6.63	3	2
ARP193	92.5	220	10.40	10.32	0.83	7.10	4	15
ARP220	73.5	556	10.48	10.52	1.09	7.51	4	4
Mrk 231	165.7	100	11.04	10.48	0.28	6.65	4	15
NGC520	30.3	1260	10.53	10.10	0.37	6.91	4	15
NGC5256	111.4	210	10.73	10.46	0.54	8.23	4	15
NGC6052	64.3	190	10.44	9.94	0.31	7.49	4	11
NGC6240	101.3	313	10.88	10.55	0.46	6.93	4	4
NGC828	71.6	430	10.87	10.38	0.33	6.82	5	12
NGC2623	72.9	170	10.64	10.00	0.23	6.53	5	15
NGC3310	13.9	140	10.10	8.47	0.02	6.30	5	15
NGC3597	46.8	141	10.20	9.53	0.22	6.70	5	14
NGC3656	39.6	162	10.09	9.45	0.23	6.92	5	14
NGC4194	34.5	251	10.12	9.52	0.25	7.00	5	4

Table 3—Continued

Name	D	S_{CO}	$\log(L_B)$	$\log(M_{H_2^*})$	$M_{H_2^*}/L_B$	$\log\,[\frac{M(H_2^*)}{D_{25}}]$	IG type	Reference
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

Note. — Col.(1) Galaxy name. Col.(2) Distance in Mpc, computed using the mean optical radial velocity of each system from Table 1 and assuming H_0 = 75 km s^{-1} Mpc^{-1}. Col.(3) Global CO flux, in units of Jy km/sec. Corrections for flux outside the telescope beam are applied. Upper limits are 3 σ. Col.(4) Logarithm of the blue luminosity in units of $L_\odot$, computed from values of B_T^0 in Table 1 and assuming $M_{B_\odot} = +5.48$. Col.(5) Logarithm of the global molecular gas mass in the units of $M_\odot$, computed using $M_{H_2^*} = 1.1 \times 10^4 D^2 S_{CO}$. Col.(6) Ratio of the global molecular gas mass to the blue luminosity in the units of $L_\odot/M_\odot$. Col.(7) Logarithm of the ratio of the global molecular gas mass to the optical area D_{25}^2 in units of $M_\odot$/kpc^2. The optical area is computed using the D_{25} from Table 1. Col.(8) IG type as defined in §2.1. Col.(9) Reference for the CO data.

References. — (1) Braine et al. 1993; (2) Bushouse et al. 1999; (3) Casoli et al. 1996 ; (4) Casoli et al. 1992; (5) Chini et al. 1996; (6) Combes et al. 1988; (7) Dupraz et al. 1990; (8) Elfhag et al. 1996; (9) Gao 1997; (10) Maiolino et al. 1997; (11) Sage 1993; (12) Sanders et al. 1991; (13) Solomon et al. 1988; (14) Wiklind et al. 1995 (15) Young et al. 1996; (16) Hibbard 1995.

Table 4. Global Quantities for Interacting Systems

Name	IG	Sep/D_{25}	S_{CO}	HI	S_{60}	S_{100}	$\log(L_B)$	$\log(M_{H_2^*})$	$\log(M_{HI})$	$\log(L_{IR})$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
ARP205	1	–	96	64.80	5.87	10.65	9.95	8.58	9.74	9.56
NGC2276	1	2.60	800	24.50	14.20	29.80	10.56	10.02	9.84	10.49
NGC3169	1	1.53	1300	96.00	8.06	22.16	10.10	9.45	9.65	9.52
NGC3718	1	1.48	<315	151.10	0.78	3.42	10.05	<8.79	9.88	8.66
NGC3800	1	0.65	200	4.80	–	–	10.39	9.61	9.32	–
NGC4017	1	3.23	83	25.80	1.89	5.41	10.31	9.28	10.11	9.93
NGC4298/302	1	0.42	1280	64.00	5.74	24.03	10.15	9.40	9.43	9.43
NGC4647	1	0.63	600	8.20	5.63	16.69	9.72	9.07	8.54	9.34
NGC5000	1	–	60	5.79	0.96	2.39	10.57	9.57	9.89	10.03
NGC5194	1	0.42	9690	220.00	84.48	233.32	10.42	9.64	9.33	9.86
NGC6285/6	1	1.15	373	–	9.50	23.32	10.64	10.36	–	11.02
NGC7603	1	–	249	6.80	0.85	2.04	10.91	10.59	10.36	10.38
NGC7674	1	1.99	350	7.38	5.56	8.79	10.91	10.75	10.40	11.12
NGC7771	1	2.22	805	15.20	20.15	46.64	10.75	10.50	10.11	11.15
UGC0365	1	0.14	240	10.10	3.00	–	10.84	10.03	9.98	–
UGC0717	1	1.38	28	0.68	0.45	1.60	10.96	9.83	9.55	10.38
UGC1063	1	1.12	48	–	1.48	3.73	10.48	9.51	–	10.26
UGC1810	1	0.08	64	16.03	2.00	–	11.05	9.87	10.60	–
UGC3031/2	1	0.77	<64	2.42	0.35	0.93	10.34	<9.44	9.34	9.44
UGC4264	1	0.70	66	25.30	3.14	6.61	10.60	9.32	10.24	10.22
UGC4718	1	0.30	<48	16.70	1.97	2.71	9.99	<8.96	9.84	9.73
UGC4744	1	0.64	55	15.90	1.22	3.33	9.85	8.79	9.58	9.41
UGC480W	1	0.94	160	1.93	1.69	4.00	11.36	10.61	10.02	10.88

Table 4—Continued

Name (1)	IG (2)	Sep/D_{25} (3)	S_{CO} (4)	HI (5)	S_{60} (6)	S_{100} (7)	$\log(L_B)$ (8)	$\log(M_{H_2^*})$ (9)	$\log(M_{HI})$ (10)	$\log(L_{IR})$ (11)
UGC5265	1	2.29	<23	30.20	2.27	4.54	9.46	<8.12	9.57	9.33
UGC5269	1	0.95	30	18.80	2.27	4.54	9.76	8.24	9.37	9.33
UGC5600	1	0.94	43	10.30	3.46	14.96	9.73	8.87	9.58	10.17
UGC5609	1	1.02	<31	11.40	2.00	–	9.69	<8.69	9.59	–
UGC8529	1	2.27	367	3.88	6.91	13.57	10.24	9.79	9.15	10.28
UGC8929S	1	0.91	6	–	0.47	0.71	10.40	8.91	–	9.97
UGC10033	1	0.89	89	20.20	4.43	8.05	10.44	9.30	9.99	10.20
UGC11137	1	–	90	11.89	2.55	6.25	10.29	9.02	9.47	9.73
UGC11414	1	1.12	<31	–	7.38	11.36	10.94	<9.56	–	11.10
UGC11695	1	0.90	104	6.99	0.56	1.12	10.80	10.29	10.45	10.24
UGC12066	1	0.20	37	11.90	1.10	2.37	10.44	9.38	10.22	10.09
UGC12457	1	1.80	215	4.57	1.73	4.79	10.75	10.04	9.70	10.22
ARP262	2	0.50	<53	–	0.32	<1.10	9.42	<8.73	–	<8.84
ARP126	2	0.35	114	9.53	4.80	8.22	11.04	9.84	10.10	10.65
ARP302	2	0.77	391	4.66	6.94	15.52	11.10	10.90	10.31	11.39
ARP311	2	–	48	–	0.04	0.19	10.59	9.79	–	9.13
NGC0935	2	0.62	170	18.20	4.41	11.72	10.52	9.77	10.13	10.46
NGC2798/9	2	0.60	500	9.60	22.55	28.28	10.03	9.46	9.07	10.25
NGC2820	2	0.49	100	58.50	4.07	10.43	10.19	8.73	9.83	9.61
NGC3226/7	2	0.40	1508	23.14	8.60	17.98	10.19	9.54	9.05	9.51
NGC3786	2	0.63	157	15.40	–	–	10.45	9.35	9.68	–
NGC3788	2	0.66	< 49	12.91	3.00	–	10.18	<8.84	9.59	–
NGC3995	2	0.71	55	46.40	7.57	14.27	10.54	9.06	10.31	10.40

Table 4—Continued

Name (1)	IG (2)	Sep/D_{25} (3)	S_{CO} (4)	HI (5)	S_{60} (6)	S_{100} (7)	$\log(L_B)$ (8)	$\log(M_{H_2^*})$ (9)	$\log(M_{HI})$ (10)	$\log(L_{IR})$ (11)
NGC4438	2	0.52	357	10.20	4.24	12.46	10.44	8.84	8.63	9.21
NGC4490	2	0.78	480	335.00	46.94	78.37	10.34	8.80	9.97	9.97
NGC4567/8	2	0.13	1550	33.30	21.00	55.93	10.86	9.48	9.15	9.89
NGC4676	2	0.25	122	6.68	2.81	5.12	10.64	10.02	10.09	10.58
UGC4757	2	–	<55	9.54	1.45	2.65	10.07	<9.08	9.65	9.70
NGC5929	2	0.46	104	3.10	9.22	13.68	10.14	9.17	8.97	10.27
UGC0594	2	0.52	208	6.90	9.02	13.54	10.80	10.09	9.94	10.89
UGC0813/6	2	0.46	224	10.50	2.74	6.53	10.84	10.10	10.10	10.44
UGC3706	2	0.97	22	1.61	0.34	0.62	10.67	9.20	9.39	9.58
UGC5304	2	0.53	14	–	0.98	1.60	10.98	9.56	–	10.58
UGC5931/5	2	0.40	211	37.80	10.29	17.43	10.27	9.02	9.61	9.89
UGC5984	2	0.60	46	2.66	0.15	0.77	10.84	9.99	10.08	9.94
UGC6224	2	1.33	125	1.65	4.30	7.80	10.57	10.27	9.73	11.01
UGC6643	2	0.61	62	1.12	3.36	6.24	10.67	9.78	9.37	10.71
UGC6865	2	0.53	154	8.04	2.45	5.77	10.40	10.02	10.07	10.46
UGC7277S	2	0.58	47	1.22	0.66	1.03	10.01	9.61	9.36	9.93
UGC7905	2	0.59	<64	7.58	2.18	2.92	10.56	<9.50	9.90	10.18
UGC8335	2	0.67	119	1.20	10.66	11.80	10.74	10.30	9.64	11.38
UGC8357S	2	0.82	122	–	2.87	4.39	10.90	10.37	–	10.91
UGC8641/5	2	0.73	554	8.97	9.39	19.42	11.15	10.69	10.23	11.14
UGC8677	2	0.40	76	1.71	1.86	4.70	10.85	9.94	9.63	10.59
UGC8774	2	0.86	221	5.23	5.63	10.75	11.10	10.73	10.43	11.34
UGC8898/900	2	0.65	749	51.40	9.92	19.16	10.85	10.27	10.44	10.60

Table 4—Continued

Name	IG	Sep/D_{25}	S_{CO}	HI	S_{60}	S_{100}	$\log(L_B)$	$\log(M_{H_2^*})$	$\log(M_{HI})$	$\log(L_{IR})$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
UGC8931	2	0.73	<43	11.90	0.75	2.34	10.20	<9.09	9.87	9.64
UGC8941	2	0.26	100	2.22	0.82	1.69	10.76	10.09	9.77	10.22
UGC9142	2	0.52	40	4.03	0.82	1.82	10.16	8.90	9.23	9.44
UGC9226	2	0.38	490	4.20	1.48	5.50	10.69	10.18	9.44	10.01
UGC9903/4	2	0.49	438	9.70	11.58	20.51	10.14	9.55	9.23	10.16
UGC10923	2	0.60	129	4.33	4.95	10.01	10.76	10.20	10.06	11.00
UGC11657/8	2	0.66	9	7.24	1.09	1.18	10.70	8.80	10.04	10.00
UGC11984/5	2	0.40	227	7.79	6.70	12.90	10.77	10.00	9.86	10.67
UGC12011	2	1.09	<30	1.47	1.50	2.37	10.80	<9.42	9.44	10.29
UGC12911	2	0.77	46	12.69	0.38	0.81	10.28	9.34	10.12	9.49
ARP141	3	–	<56	10.68	0.19	0.81	10.19	<8.94	9.53	<8.83
ARP142N	3	0.64	335	–	2.00	4.70	11.03	10.49	–	10.51
ARP143	3	0.69	95	14.07	3.25	6.08	10.22	9.48	9.98	10.21
ARP145	3	0.43	44	1.55	0.77	1.39	10.43	9.36	9.24	9.80
ARP299	3	0.20	900	16.10	120.81	115.33	10.69	10.23	9.81	11.46
ARP90	3	0.27	148	4.10	9.42	13.80	10.31	9.36	9.13	10.32
NGC1143/4	3	0.32	318	2.83	5.43	11.53	11.03	10.67	9.95	11.12
NGC7714	3	1.04	130	26.00	11.22	11.66	10.33	9.34	9.97	10.38
UGC11175	3	0.32	255	9.04	6.60	11.61	10.70	10.32	10.20	10.92
UGC12914/5	3	0.48	1012	15.30	6.13	13.25	10.96	10.61	10.12	10.62
UGC1720	3	0.25	88	2.96	5.32	8.15	10.69	10.15	10.01	11.10
UGC3829	3	–	92	2.30	7.15	8.48	10.29	9.46	9.19	10.48
UGC3852	3	0.27	23	9.50	2.34	3.15	10.05	8.79	9.74	9.94

Table 4—Continued

Name (1)	IG (2)	Sep/D_{25} (3)	S_{CO} (4)	HI (5)	S_{60} (6)	S_{100} (7)	$\log(L_B)$ (8)	$\log(M_{H_2^*})$ (9)	$\log(M_{HI})$ (10)	$\log(L_{IR})$ (11)
UGC7535	3	0.25	<34	0.74	3.00	–	10.55	<9.53	9.20	–
UGC8135	3	0.20	107	0.70	5.73	7.54	10.71	10.02	9.17	10.89
UGC9102	3	0.13	111	1.27	1.39	2.16	10.89	10.06	9.45	10.33
ARP193	4	0.11	220	1.30	16.46	24.72	10.40	10.32	9.42	11.35
ARP220	4	0.14	556	3.80	107.43	119.34	10.48	10.52	9.69	11.92
Mrk231	4	0.03	100	3.10	9.14	13.69	11.04	10.48	10.30	11.60
NGC0520	4	0.14	1260	38.80	31.70	47.32	10.54	10.10	9.92	10.67
NGC2623	4	0.07	170	3.90	24.02	26.08	10.62	9.98	9.67	11.25
NGC3239	4	0.13	66	79.50	4.09	6.32	9.48	7.76	9.17	8.72
NGC5256	4	0.40	210	–	7.19	10.76	10.73	10.46	–	11.16
NGC6052	4	–	190	10.10	7.04	10.96	10.44	9.94	9.99	10.67
NGC6240	4	0.08	313	4.18	22.80	27.03	10.88	10.55	10.01	11.54
UGC5773	4	0.39	< 7	1.79	0.34	1.05	10.42	<8.71	9.45	9.71
UGC9717	4	0.46	37	–	1.64	3.02	10.25	9.34	–	10.19
UGC979	4	–	90	16.57	2.00	4.57	10.78	9.63	10.22	10.21
UGC10267	4	0.08	179	5.29	6.48	9.42	10.79	10.45	10.25	11.16
ARP137	5	–	<49	1.60	–	–	9.95	<8.98	8.82	–
ARP162	5	–	<75	1.01	0.19	<0.91	9.97	<8.44	7.90	<8.27
ARP164	5	–	<54	<3.00	–	–	10.65	<9.47	<9.54	–
ARP165	5	–	<64	–	–	–	10.65	<9.49	–	–
NGC0828	5	–	430	13.87	11.58	25.50	10.87	10.38	10.22	11.05
NGC3310	5	–	140	63.06	34.91	45.24	10.12	8.49	9.48	10.03
NGC3509	5	–	91	8.70	1.09	3.41	11.09	10.01	10.32	10.40

Table 4—Continued

Name	IG	Sep/D_{25}	S_{CO}	HI	S_{60}	S_{100}	$\log(L_B)$	$\log(M_{H_2^*})$	$\log(M_{HI})$	$\log(L_{IR})$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
NGC3597	5	–	141	–	13.14	16.54	10.20	9.53	–	10.64
NGC3656	5	–	162	4.90	2.47	5.27	10.09	9.45	9.26	9.86
NGC3921	5	–	80	5.65	0.77	1.23	10.83	9.74	9.92	9.90
NGC4194	5	–	251	9.20	23.79	25.38	10.12	9.52	9.41	10.61
NGC7252	5	–	82	5.42	3.97	7.19	10.82	9.57	9.72	10.45

Note. — Col.(1) Galaxy name. Col.(2) IG type as defined in §2.1. Col.(3) Pair separations *Sep* normalized by the primary's diameter D_{25}. Col.(4) Total CO flux for the whole system, in units of Jy km/sec. For close pairs the sum of the two galaxies are used. Upper limits are 3 σ. Col.(5) HI flux for the system, in units of Jy km/sec. Col.(6) FIR flux at 60 μm, in units of Jy. Col.(7) FIR flux at 100 μm, in units of Jy. Col.(8) Logarithm of the total blue luminosity in units of $L_\odot$, computed from values of B_T^0 in Table 1 and assuming $M_{B_\odot} = +5.48$. For pairs this is the sum of both galaxies. Col.(9) Logarithm of the global molecular gas mass in the units of $M_\odot$, computed using $M_{H_2^*} = 1.1 \times 10^4 D^2 S_{CO}$. Col.(10)Logarithm of the global HI mass in the units of $M_\odot$, computed using $M_{HI} = 2.36 \times 10^5 D^2 S_{HI}$. Col.(11) Logarithm of FIR luminosity, computed from the 60 μm and 100 μm flux densities using $L_{IR} = 3.94 \times 10^5 D^2 [2.58 S_{60} + S_{100}]$

Table 5. Mean and Median Properties of IG subsamples

Quanty[a]	IG0	IG1	IG2	IG3	IG4	IG5	SIG
N[b]	59	42	61	18	13	11	92
D (Mpc)	23.9 ± 1.0	54.6 ± 6.8	71.9 ± 5.8	71.8 ± 7.2	81.5 ±10.9	54.6 ± 8.0	73.3 ± 7.6
$logL_B$ ($L_\odot$)	10.18 ± 0.04	10.31 ± 0.07	10.38 ± 0.05	10.52 ± 0.06	10.53 ± 0.11	10.45 ± 0.14	10.43 ± 0.04
Size (Kpc)	23.69 ± 1.31	29.60 ± 2.28	27.80 ± 1.83	33.12 ± 3.38	37.60 ± 6.29	33.30 ± 6.28	30.30 ± 1.67
$M_{H_2^*}/L_B$	0.13 ± 0.01	0.18 ± 0.03	0.19 ± 0.02	0.23 ± 0.04	0.37 ± 0.08	0.11 ± 0.03	0.22 ± 0.02
$(M_\odot/L_\odot)$	0.12	0.13	0.14	0.21	0.31	0.08	0.15
$M_{H_2^*}/D_{25}^2$	5.29 ± 0.46	6.10 ± 1.03	8.35 ± 1.50	10.73 ± 2.38	22.42 ±12.14	4.20 ± 1.01	10.71 ± 2.04
$(M_\odot/Kpc^2)$	4.04	3.54	5.03	6.39	8.02	2.96	5.44
$M_{H_2^*}/M_{HI}$	1.34 ± 0.20	1.12 ± 0.21	1.31 ± 0.21	2.18 ± 0.52	2.28 ± 0.80	1.23 ± 0.32	1.72 ± 0.22
	0.81	0.66	0.89	1.68	1.51	1.27	1.36
$L_{IR}/M_{H_2^*}$	4.34 ± 0.63	5.65 ± 1.24	5.51 ± 0.71	6.53 ± 1.32	9.76 ± 1.75	9.76 ± 3.85	6.54 ± 0.63
$(M_\odot/L_\odot)$	3.30	3.80	4.14	5.54	9.11	6.09	4.97
L_{IR}/L_B	0.54 ± 0.12	0.66 ± 0.12	0.80 ± 0.13	1.31 ± 0.37	4.53 ± 2.05	1.18 ± 0.41	1.62 ± 0.43
	0.41	0.38	0.55	1.01	2.37	0.70	0.87
L_{IR}/M_{GAS^*}[c]	1.90 ± 0.29	1.13 ± 0.16	2.24 ± 0.33	3.57 ± 0.89	6.39 ± 1.98	2.70 ± 0.81	3.26 ± 0.47
$(L_\odot/M_\odot)$	1.48	0.86	1.46	2.19	3.18	2.71	2.09
M_{GAS^*}/L_B	0.30 ± 0.03	0.50 ± 0.05	0.39 ± 0.03	0.39 ± 0.06	0.58 ± 0.09	0.27 ± 0.05	0.43 ± 0.03
$(M_\odot/L_\odot)$	0.31	0.45	0.37	0.48	0.59	0.25	0.44
M_{HI}/L_B	0.19 ± 0.02	0.35 ± 0.05	0.21 ± 0.03	0.18 ± 0.05	0.22 ± 0.04	0.14 ± 0.03	0.21 ± 0.02
$(L_\odot/M_\odot)$	0.15	0.29	0.16	0.08	0.18	0.15	0.16
S_{60}/S_{100}[d]	0.43 ± 0.02	0.43 ± 0.02	0.53 ± 0.05	0.64 ± 0.07	0.66 ± 0.05	0.52 ± 0.11	0.58 ± 0.02
	0.42	0.41	0.53	0.64	0.67	0.55	0.55

[a] Each ratio has two rows, the first is the mean value and the second is the median. The errors in the means are the 1σ uncertainties.

[b] N is the number of sytems in the subsample.

[c] M_{GAS^*} is the total mass of the HI and H_2^* gas.

[d] S_{60} and S_{100} are the IRAX flux densities at 60 and 100 μm.