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A STUDY OF CO EMISSION FROM TWO Scd GALAXIES: IC 342 AND NGC 6946

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ABSTRACT

In a search for CO emission from an inhomogeneous sample of late-type galaxies, CO emission was detected in two: IC 342 and NGC 6946. Partial mapping of these nearly face-on galaxies shows that the CO emission peaks sharply at the nuclei but is present at a detectable level over most of the disks out to 8–10 kpc.

A look at all galaxies studied in CO to date reveals (1) a tendency for galaxies with nuclear minima in their H I surface densities to have nuclear maxima in their H_2 surface densities, and (2) no marked tendency, within the present sample, for the presence or abundance of molecular gas in spirals to be correlated with Hubble type.

Subject headings: galaxies: individual — galaxies: structure — interstellar: molecules

I. INTRODUCTION

Emission from the CO molecule, which has provided abundant information on dark clouds, regions of star formation, and the structure of our Galaxy, has recently been detected in external galaxies (Rickard *et al.* 1975). Because the spatial resolution presently attainable in CO observations is as small as 1′, one now has the ability to study the molecular gas component of nearby external galaxies in some detail. CO observations of external galaxies can provide a direct picture of the large-scale distribution of the molecular gas, and a measure of the molecular gas content. CO emission can also serve as a tracer of regions of star formation, since, as deduced from studies in our Galaxy, star formation is intimately associated with molecular clouds and dark clouds.

Carbon monoxide has previously been detected in several external galaxies in searches of nearby galaxies and galaxies with strong infrared emission (e.g., Rickard *et al.* 1977; Combes *et al.* 1977; Huggins *et al.* 1975). As late-type galaxies have the highest neutral atomic hydrogen content (Roberts 1972), and because it is believed that late-type galaxies have a more uniform rate of star formation than early-type galaxies (Searle, Sargent, and Bagnuolo 1973), we selected a sample of late-type galaxies, including irregular, Sc, Scd, and compact blue galaxies, for a search of CO emission. We have also included galaxies for which aperture synthesis observations of H I have been made.

We detected CO emission from two Scd galaxies, IC 342 and NGC 6946. We have also partially mapped the CO emission from these nearly face-on galaxies.

IC 342 and NGC 6946 are both relatively nearby, but are probably not members of the local group (Yahil, Tammann, and Sandage 1977). Both galaxies have been mapped at 21 cm, and both were found to have extensive H I envelopes (Rogstad, Shostak, and Rots 1973, hereafter RSR). IC 342 has a large apparent diameter, but because of its low surface brightness, and because it has a low galactic latitude (~11°), it has not been studied optically as much as other nearby spirals. The surface brightness of NGC 6946 is much higher. It is displayed in the *Atlas of Peculiar Galaxies* (Arp 1966) because of the asymmetry in brightness of the spiral arms.

The observations are described in § II. In § III we present the results of the partial mapping of the galaxies and the negative results of our survey. In § IV we examine the molecular gas components of the nuclear regions and disks separately and consider the correlations of CO emission with the other observable activities.

II. OBSERVATIONS

The observations were made with the NRAO[1] 11 m telescope at Kitt Peak during 1976 June and October. One channel of the dual-channel cooled mixer receiver was used. The receiver output was split and fed into two 256-channel filter banks, one with filter widths and separations of 1 MHz (corresponding to a velocity resolution of 2.6 km s^{-1} at the CO frequency of 115.2712 GHz), and the other with 500 kHz filters (1.3 km s^{-1}). The spectra were obtained by switching the telescope at 30 s intervals between on- and off-source positions separated by 15′ in azimuth (30′ in the case of IC 342). The intensities of spectra were calibrated with a chopper wheel, following the procedure of Ulich and Haas (1976), and are presented in terms of beam-diluted brightness temperature, T_A^*, which has been corrected for atmospheric absorption and telescopic losses.

The pointing of the telescope was checked by periodically observing Mars, Jupiter, or Saturn. The results indicate that the pointing was accurate to within

[1] The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

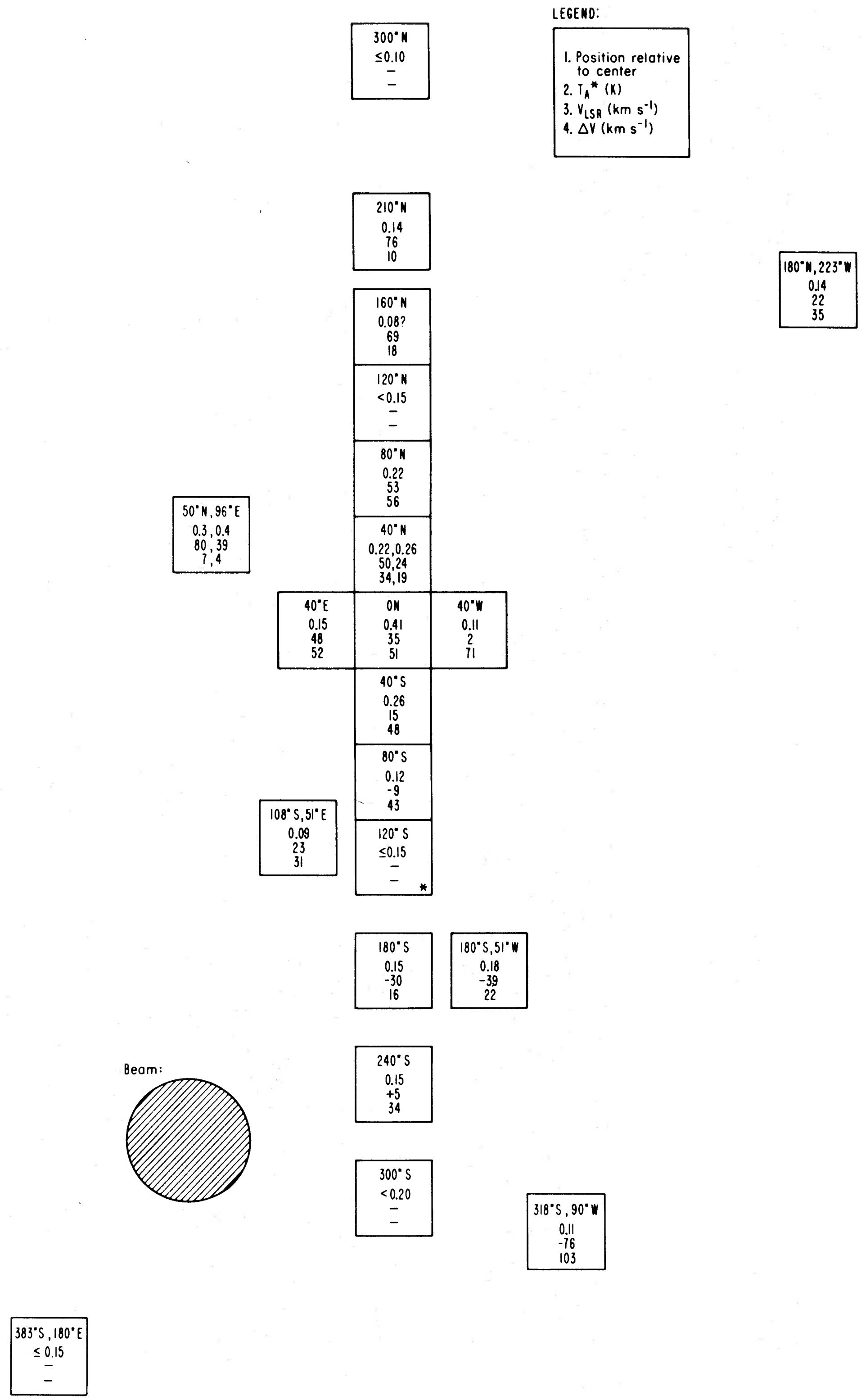

FIG. 2.—A summary of the observed line parameters (or upper limits) at the positions corresponding to the circles in Fig. 1

$\pm 15''$. This is about one-fourth of the telescope resolution, which is 65″. With distances of 10.1 and 4.5 Mpc for NGC 6946 and IC 342, respectively (Sandage and Tammann 1974), 1′ corresponds to 2.9 and 1.3 kpc, respectively.

The CO emission from NGC 6946 and IC 342 is possibly subject to interference from galactic CO because of the low systemic velocities of these galaxies (40 and 25 km s^{-1}, respectively). Indeed, weak, narrow CO emission at $V_{LSR} \sim 0$ km s^{-1} was detected in some off-source positions for IC 342. This problem was eliminated to a level of $\sim$0.1 K by the use of a positive azimuth offset for the off position. Except possibly for emission near $\sim$0 km s^{-1}, we feel that our results are free from galactic interference.

III. RESULTS

a) *IC 342*

We essentially made a strip map through the nucleus of IC 342 plus several other selected positions. The 21 positions where we searched for CO emission are denoted by circles superposed on a photograph of the galaxy in Figure 1 (Plate 31). The angular size of each circle is 65″, which is the half-power beamwidth of the 11 m telescope. Figure 2 gives the line parameters (or upper limits) for each position searched, and Figure 3 gives a sample of the CO spectra obtained at some of the positions.

CO emission was detected at many positions out to a projected distance of 7.2 kpc from the nucleus. The emission is strongest at the nuclear position and drops off abruptly in all directions. An inspection of Figure 1 will show that the 65″ beam can spatially resolve the large-scale structure of the galaxy, such as the arm and interarm regions. However, our strip map indicates that the CO intensity does not vary much over the disk. This lack of clear correlation with the arm and interarm regions is perhaps understandable because the spiral arms and dust lanes in IC 342 are themselves not well defined.

Aside from the east-west positions astride the nucleus, the positions not in the north-south strip were chosen to coincide with optically prominent H II regions. CO emission was detected at all of these positions, with the exception of the most southeastern point, which coincides with a foreground star. Thus, CO emission is detected at positions coinciding with a prominent dust lane, a large H II region, or a complex of H II regions. Where CO is not detected, such features are not prominent. This is consistent with the known association of CO emission with dust clouds and regions of star formation in our Galaxy. Also, we note an asymmetry in the nuclear regions: positions 40″ to the north and south of the nucleus display significantly more intense CO emission than positions 40″ to the east and west. This asymmetry may be related to the dust lanes which are aligned along the inner spiral arms for a great distance and which may be followed almost all the way into the nucleus. In the inner 1 kpc, these dust lanes are present to the north and south of the nucleus.

The radial velocities of almost all the detected CO emission are consistent with the velocity field of H I in IC 342 determined by RSR, implying that the molecular gas shares the same galactic rotation as the atomic gas. The one possible exception is the point at 240″ south, which shows CO emission at a radial

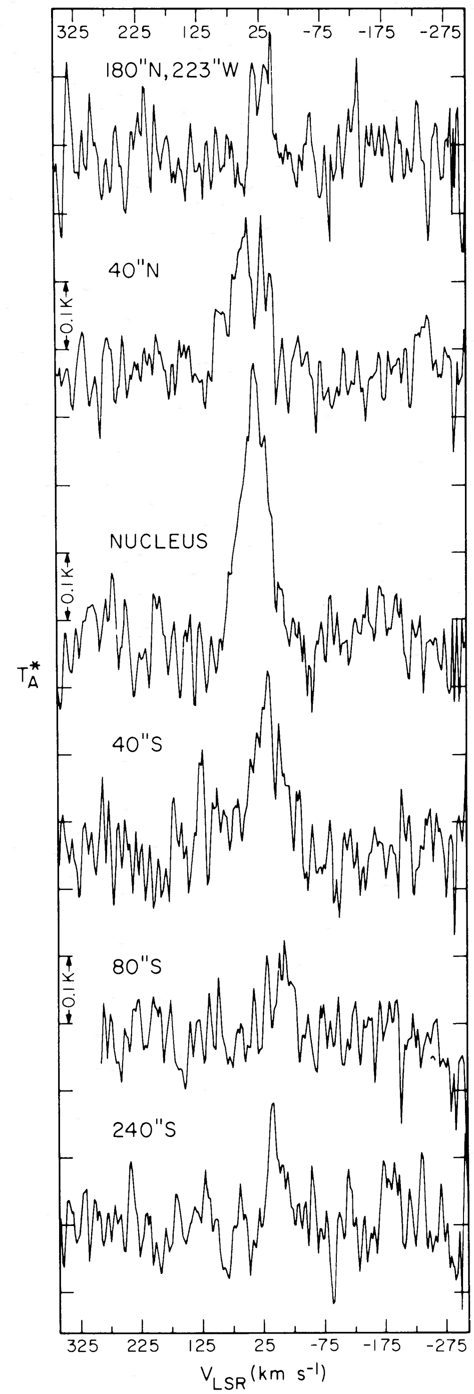

FIG. 3.—A sample of the CO spectra observed at various positions in IC 342. The offsets in arcsec from the nucleus are given next to each spectrum.

velocity greater than 35 km s^{-1} higher than expected from the H I velocity field.

The half-power line width of the CO emission at the nuclear position ($\sim$50 km s^{-1}) is the narrowest yet found for CO in any galactic nucleus. This is primarily due to the fact that IC 342 is being viewed almost face-on. With an inclination angle of 25° $\pm$ 5° for the plane of IC 342, as suggested by RSR, pure galactic rotation could account for the line width observed at the nuclear region. However, since the line width does not change significantly out to 1.5 kpc from the nucleus, some random or noncircular motion must contribute to the observed line widths. This may also imply that the inclination angle of IC 342 could be smaller than 25°, as suggested by Ables (1972). The observed line width also poses an upper limit of $\sim$50 km s^{-1} to the velocity dispersion of molecular clouds perpendicular to the galactic plane near the nucleus.

b) NGC 6946

Twenty-five positions in NGC 6946 were searched for CO emission, covering almost an entire quadrant of this nearly face-on galaxy. Figure 4 (Plate 32) shows these positions as circles, representing the beam of the 11 m telescope, superposed on a photograph of this galaxy. It is more difficult to resolve individual structures in NGC 6946 than was the case with IC 342 because NGC 6946 is twice as distant.

The CO emission from the nucleus of NGC 6946 has a lower intensity and a much wider line width than that from the nucleus of IC 342. This is most likely due to the larger inclination angle of NGC 6946 (30° $\pm$ 5°; RSR) and the lower linear resolution of the telescope beam at the distance of the NGC 6946. If the CO clouds in the nuclear regions of NGC 6946 and IC 342 have comparable sizes, then the absolute intensity of the CO emission from the nucleus of NGC 6946 is higher than that from IC 342.

The observed line parameters for NGC 6946 (Fig. 5) reveal that CO is detected out to at least 9.5 kpc from the center. The line width of the CO emission at most of the positions in the disk is quite narrow ($\sim$15–30 km s^{-1}), indicating that individual giant molecular clouds instead of an ensemble of smaller clouds may dominate the emission. This is because the velocity dispersion of small clouds distributed in a region of size $\sim$3 kpc covered by each telescope beam is likely to be larger than the velocity dispersion within one or a few giant molecular clouds.

The quadrant of NGC 6946 which was mapped contains the prominent optical arm which led Arp to place this galaxy in his *Atlas of Peculiar Galaxies* (1966). The CO observations indicate that there is certainly no lack of cloud material with which to form stars in this region, but that there is no simple correlation between the optical activity and the presence of CO emission. Wherever CO was detected H II regions can be seen in the beam (Fig. 4), but, on the other hand, at

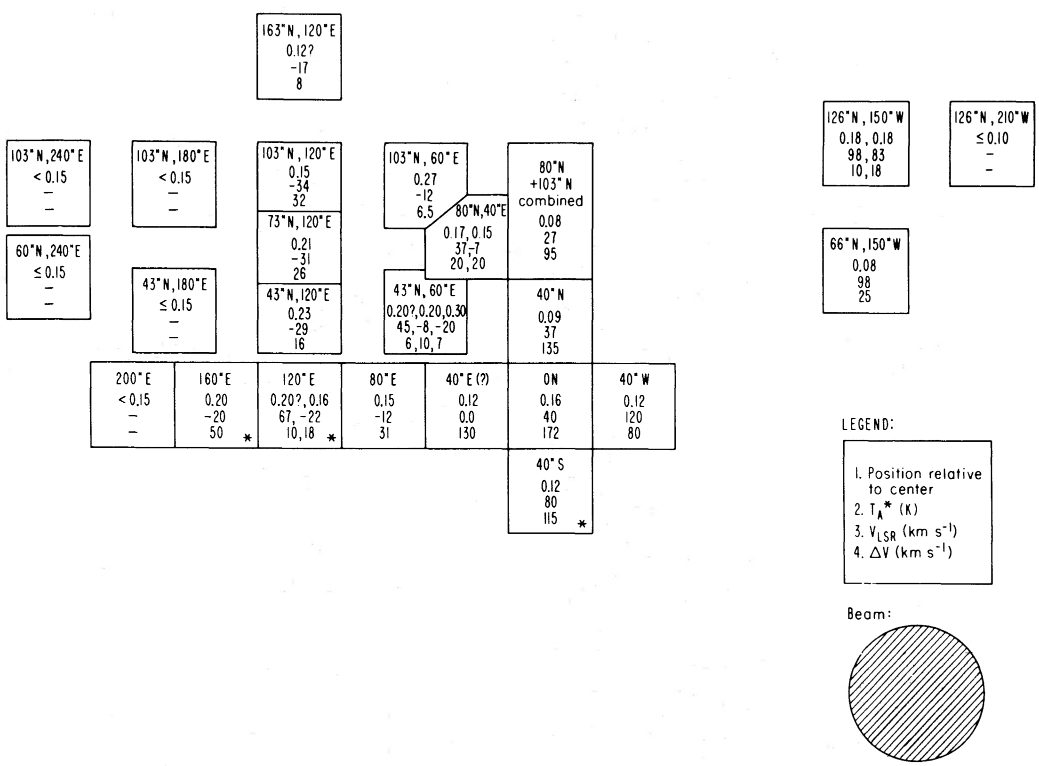

FIG. 5.—The observed line parameters (or upper limits) at the positions marked by circles in Fig. 4

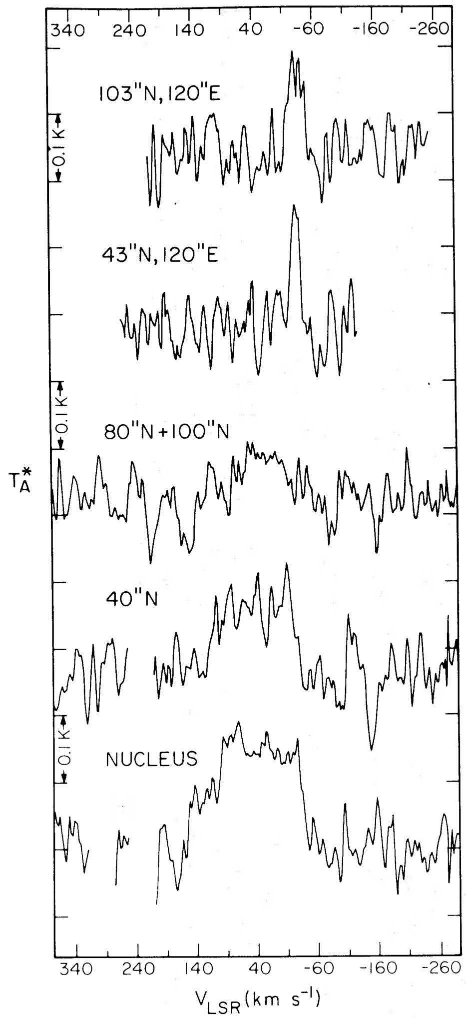

FIG. 6.—A sample of the CO spectra obtained from various positions in NGC 6946.

the positions (103″ N, 180″ E) and (60″ N, 240″ E) no CO was detected despite the presence of prominent H II complexes in the beam. However, the upper limits at these positions are not very small, so such non-detections are not significant.

Of particular interest are the three positions (103″ N, 120″ E), (73″ N, 120″ E), and (43″ N, 120″ E) (see Fig. 5). These positions lie along a line segment which starts on the brightest part of the optically prominent arm (an H II complex), and trails behind the arm perpendicular to it (Fig. 6). The CO lines at all three positions have similar radial velocity and integrated intensity. This indicates that for ~ 3 kpc the CO emission does change significantly, and the change in the CO radial velocity is only about 5 km s^{-1}, whereas the change in radial velocity across these three positions due to galactic rotation should be about 20 km s^{-1} (as judged by the H I velocity field measured by RSR). These results suggest that we are seeing one huge molecular cloud complex—one more extensive than any known in our own Galaxy and one almost certainly associated with the unusual optical activity in the prominent arm. More refined measurements are needed to confirm this possibility.

Supporting evidence for the unusual nature of this molecular cloud complex comes from Westerbork radio continuum observations of van der Kruit, Allen, and Rots (1977) which indicate the presence of a giant H II complex (complex C in their notation) adjacent to this molecular complex. This H II complex C is quite dense ($N_e \sim 10^4$ cm^{-3}), contains a very large H II mass ($\sim 5 \times 10^7 M_{\odot}$), and requires almost 10^3 O5 stars to account for the ionization observed.

c) *Negative Results*

Nineteen other galaxies were searched for CO emission, with no detection. The coordinates used for telescope pointing, the radial velocity adopted, and the upper limit to the CO emission intensity are summarized in Table 1. With the exception of a few spirals, most of these galaxies are irregulars. For the irregular galaxies, the positions used are generally at the centroid of the optical extent of the galaxies. Since all the irregular galaxies observed are larger than 65″ (the 11 m telescope beam), the absence of CO emission in this search may merely reflect the fact that molecular clouds are not found at the centroids of the galaxies. For the Scd galaxies, the positions are those of the nucleus.

IV. DISCUSSION

Surveys of CO in the plane of our Galaxy have indicated that between 300 pc and 4 kpc from the center the surface density of molecular material is relatively low (see Gordon and Burton 1976). Most molecular clouds are apparently concentrated either within 300 pc from the center or in an annulus between 4 and 7 kpc from the nucleus. Whether the galactic distribution of molecular clouds is truly axisymmetric or whether instead the data reflect the presence or absence of spiral arms in the directions observed ($l = -5°$ to $+90°$) can best be answered by direct observations of external galaxies that may be similar to our own. Unfortunately, our observations of NGC 6946 and IC 342 are still too limited to answer this question definitively. Plotting the integrated intensity of CO as a function of galactocentric distance, one finds from our limited data only a weak and insignificant indication that the CO emission intensity passes through a minimum within several kpc of the nuclei. This is in marked contrast with the situation in our Galaxy, where the observations imply that the minimum is very pronounced. More complete observations are definitely needed.

From the observed CO profiles, one may estimate the amount of molecular gas present in IC 342 and NGC 6946. We do this by assuming that the disks of these galaxies contain "standard clouds" which have the mean characteristics of clouds in our own galactic disk: a diameter of ~ 5 pc, a CO brightness temperature of 14 K, an internal velocity dispersion of 2.5 km

TABLE 1

SUMMARY OF NEGATIVE RESULTS

Name	α(1950)	δ(1950)	V_0 (km s^{-1})	T_A*(3 σ) K	Type	Note
IC 10	$00^h17^m43^s.0$	+59°00′17″	−346	0.2	Irr	
	00 17 28.2	+59 02 00	−346	0.13	...	Position of N(H I) minimum
NGC 628	01 34 01.0	+15 31 38	+670	0.3	Sc	
Mrk 71	07 23 24.0	+69 17 33	+350	0.12	Irr	
NGC 2403	07 32 01.0	+65 42 56	+128	0.13	Scd	
Mrk 86	08 09 43.0	+46 08 33	+350	0.25	Irr	
M 82 (NGC 3034)	09 51 49.0	+69 55 18	+246	0.15	Irr	Only $C^{18}O$ searched
Sex B	09 57 23.0	+05 34 07	+295	0.20	Irr	
NGC 3077	09 59 21.4	+68 58 31	+10	0.10	Irr	
	09 59 35.2	+68 58 00	+10	0.20	...	Position of N(H I) minimum
	10 00 11.1	+68 57 07	+10	0.20	...	Position of N(H I) maximum
Sex A	10 08 30.0	−04 26 47	+321	0.13	Irr	
IC 2574	10 24 47.9	+68 40 20	+46	0.18	Irr	
	10 24 36.9	+69 40 30	+46	0.16	...	
NGC 3556	11 08 36.0	+55 56 39	+820	0.13	Scd	
Mrk 178	11 30 44.9	+49 30 43	+256	0.20	Irr	
NGC 4258	12 16 29.1	+47 35 01	+465	0.18	Sbc	
NGC 4449	12 25 47.0	+44 22 20	+380	0.20	Irr	
DDO 154	12 51 38.9	+27 25 06	+378	0.13	Irr	
I Zw 87	14 22 48.0	+44 44 59	+153	0.10	Irr	
DDO 204	16 14 49.0	+47 10 00	+715	0.16	Irr	
DDO 210	20 44 08.0	−13 02 00	−131	0.25	Irr	
DDO 216	23 26 04.0	+14 28 00	−179	0.30	Irr	
WLM	23 59 23.0	−15 44 06	−123	0.25	Irr	

s^{-1}, and an optical depth of 5 in the $J = 1 \rightarrow 0$ CO line (Burton and Gordon 1976). The surface densities of molecular gas that we derive in this manner are not very sensitive to exactly what kind of reasonable standard cloud is assumed. The surface mass densities are, of course, directly proportional to the assumed value of the [CO]/[H_2] abundance ratio. We assume, following Gordon and Burton (1976), that the value of this ratio is 6×10^{-5}, implying that 10% of the cosmic abundance of carbon is in the form of CO and thus that the mean density of H_2 molecules in the standard cloud is 520 cm^{-3}. This density agrees with the independent estimate of 670 cm^{-3} made by Scoville and Solomon (1975). Throughout this discussion we make one further assumption—that no shadowing of one cloud by another at the same velocity is taking place (the optical depth estimate presumably takes this effect into account).

Applying these assumptions to the disk of NGC 6946, we estimate that there are, on the average, 6.7×10^4 standard clouds in each beam, which yields a smoothed-out surface density of molecular clouds of $\sim 16\ M_\odot$ pc^{-2}. This is somewhat greater than the mean surface density of molecular gas in our Galaxy between 3 and 8 kpc from the center, about 4 $M_\odot$ pc^{-2} (Gordon and Burton 1976). Since both studies assume the same value for the [CO]/[H_2] ratio, the comparison is apt. If all quadrants of NGC 6946 are similar, then the total molecular mass in the disk ($\varpi > 3$ kpc) is estimated to be $2.8 \times 10^9\ M_\odot$.

Different assumptions are made for the nuclear regions. We assume that the nuclei contain standard galactic center molecular clouds with the following characteristics: diameter, 20 pc; CO brightness temperature, 20 K; internal velocity dispersion, 10 km s^{-1}; and optical depth in the $J = 1 \rightarrow 0$ CO transition, 20. Choosing the same [CO]/[H_2] ratio (and we caution that this ratio could be much larger in the nucleus than in the disk), one finds that the mean H_2 density in the assumed nuclear clouds is 740 cm^{-3}. The observation of the nuclear position of NGC 6946 implies that 13% of the beam is filled with CO clouds. The mean surface density of molecular material within $\varpi = 1500$ pc is estimated to be 63 $M_\odot$ pc^{-2}, which gives a total molecular cloud mass near the nucleus of $5 \times 10^8\ M_\odot$. The total galactic mass of molecular material in NGC 6946 is then $\sim 3.7 \times 10^9\ M_\odot$, which is about twice the mass of molecular clouds in our own Galaxy (Scoville and Solomon 1975; Gordon and Burton 1976). Because the same assumptions went into all estimates, we believe that although the values of the estimated masses may be quite uncertain (reflecting primarily the uncertainty in the CO/H_2 ratio), the relative masses may be significant.

The observations of IC 342 are not yet complete enough to allow a reliable estimate of the gross properties of the galactic H_2 distribution, but it appears that the mean surface density of H_2 within $\varpi = 8$ kpc in the disk is smaller than that in NGC 6946 by about a factor of 2. For the nuclear region ($\varpi \leq 700$ pc), we make the same assumptions as were made for NGC 6946, and find a mean surface density of 50 $M_\odot$ pc^{-2} and a total molecular cloud mass in the nuclear region of $8 \times 10^7\ M_\odot$. That this is so much smaller than the nuclear mass of NGC 6946 is primarily due to the different sizes defined for the nuclear regions, which in turn is due to the different resolutions that the 65″ telescope beam has at the different distances of these two galaxies. We estimate the total mass of H_2 molecules in IC 342 to be $2 \times 10^9\ M_\odot$, which is about the same as has been estimated for our Galaxy by Scoville and Solomon (1975) and Gordon and Burton (1976). The detections of significant CO emission at positions centered 80″ north and south of the nucleus of IC 342 (corresponding to 1750 pc) contrasts with the apparent situation in our Galaxy. Very little molecular gas has been detected between $\varpi = 1$ and 4 kpc in the Galaxy (see Oort 1977). The positions centered 80″ north and south of the nucleus of IC 342 appear to have at least a factor of 5 higher surface density of H_2 than has been found in the Galaxy.

The estimated H_2 masses for NGC 6946 and IC 342 are much less than the total H I masses determined by RSR (21 and $15 \times 10^9 M_{\odot}$, respectively), primarily because the H I surface density in both galaxies remains high out to very large galactocentric distances ($\varpi =$ 25–30 kpc). The fraction of total gas in molecular form is about the same in both galaxies, being $\sim 15\%$. This contrasts sharply with our own Galaxy, in which the masses of H_2 and H I ($2.6 \times 10^9 M_{\odot}$; Baker and Burton 1975) appear to be about equal. Since the total H_2 masses are about the same, the difference is due to the much smaller H I mass of our Galaxy. The contrast with our Galaxy is further made evident by a comparison of surface density ratios: at an average point in the range 3 kpc $\leq \varpi \leq$ 8 kpc in NGC 6946 or IC 342, the H I surface mass density is equal to that of H_2, whereas in our Galaxy, the (H I/H_2) ratio averages about 0.25 in this region (Gordon and Burton 1976).

The 21 cm H I surface density maps of IC 342 and NGC 6946 both show a definite minimum or "hole" centered on the galactic nuclei (RSR). This phenomenon is common to the majority of spiral galaxies which have been mapped at 21 cm with sufficient resolution. We propose that, in most cases, the 21cm minimum in spiral galaxies is due to the interior gas having become primarily molecular rather than to an actual minimum in the overall gas density. For NGC 6946 and IC 342, we estimate from the H I maps of RSR that the masses of molecular gas derived above are enough (by a factor of 2) to compensate for the H I minima, so that the total surface density of hydrogen gas (H + H_2) either remains approximately constant across the nuclear region, or reaches a mild maximum there. These remarks, of course, refer to a picture which is smoothed to our limited spatial resolution. At this stage, we cannot address the possibility that the total surface density of gas might peak sharply at the galactic nucleus in the form of molecular clouds and go through a pronounced annular minimum within 1 or 2 kpc of the nucleus.

Similar considerations applied to the CO observations of NGC 253, NGC 5236, and M51 (Rickard *et al.* 1977) suggest that, despite H I holes at the nuclei of these galaxies, the total hydrogen surface densities do not have minima at the nuclei. For those galaxies such as M31 and M81 which have nuclear H I minima, but only upper limits on CO emission at their nuclear positions (Rickard *et al.* 1977; Combes *et al.* 1977), the limit on the H_2 surface density is not yet sensitive enough to be inconsistent with the hypothesis that all nuclear H I minima in spiral galaxies are compensated by H_2 maxima.

It is noteworthy that, in some spiral galaxies, CO peaks strongly at the nucleus, whereas in others (such as M31, M33, M81, and M101) CO is not present at a detectable level in the nuclei, although it may be detectable in the disks (Combes *et al.* 1977; Rickard *et al.* 1977). In the present sample, these tendencies show no obvious correlation with galaxy type. We suggest a preliminary division of spiral galaxies into two types based solely upon their molecular cloud content: (I) those with dominant CO emission from the nucleus, and (II) those with dominant, although weak, CO emission from the disk. There is conceivably a third class of spirals which have no CO emission at all, but present observations are too incomplete to determine whether such a class is present. This division should be reflected in other characteristics of galaxies, such as the intensity of infrared emission from dust (see Rickard *et al.* 1977), the level of star-formation activity (see below), and possibly the level of nuclear activity as evidenced by large, noncircular motions of gas or the presence of a strong nuclear radio source. Such characteristics of our suggested division seem to be borne out by the present sample of galaxies observed in CO.

Rickard, Turner, and Palmer (1977) have noted an apparent correlation between the presence of strong CO emission from the nuclear regions of spiral galaxies and the brightness of the continuum emission from their disks. Their treatment includes our CO results for IC 342 and NGC 6946, so the reader is referred to their paper for details. The correlation presumably arises because the abundant molecular clouds throughout the galaxy give rise to a relatively high rate of recent star formation, which in turn gives rise to a relatively enhanced level of supernova activity. The supernovae provide a relatively high density of cosmic rays in the galactic disks, which are responsible for the relatively high intensity of synchrotron emission observed there.

V. CONCLUSIONS

The distribution of CO emission in the two Scd galaxies IC 342 and NGC 6946 has been partially determined. The total mass of molecular clouds is estimated to be 1 and 2 times, respectively, the molecular mass in our own Galaxy. The CO surface density peaks at the nuclei of these two galaxies and falls off to a fairly constant value in the disks. At $\varpi >$ 8–10 kpc, CO emission falls to an undetectable level. More complete mapping is needed to determine whether nonaxisymmetric details exist in the CO distributions. In particular, the suggestion of an anomalously giant molecular cloud complex near the bright optical arm of NGC 6946 needs to be reexamined.

Previously noted correlations of CO surface density with nuclear 10 μm luminosity and with intensity of nonthermal continuum emission from the disk are upheld by the observations of IC 342 and NGC 6946. We note a further correlation of nuclear CO emission with the presence of a nuclear minimum in the surface density of atomic hydrogen. It appears that in the majority of spiral galaxies, if not all, the total surface density of gas does not go through a minimum at the nucleus.

In the sample of CO–emitting galaxies studied to date, there is no obvious correlation of galaxy type with molecular cloud content or large-scale molecular cloud morphology. However, one can separate these galaxies into two types: (I) those with the dominant CO emission emanating from the nucleus, and (II) those with some disk emission of CO, but with no comparable emission from the nucleus.

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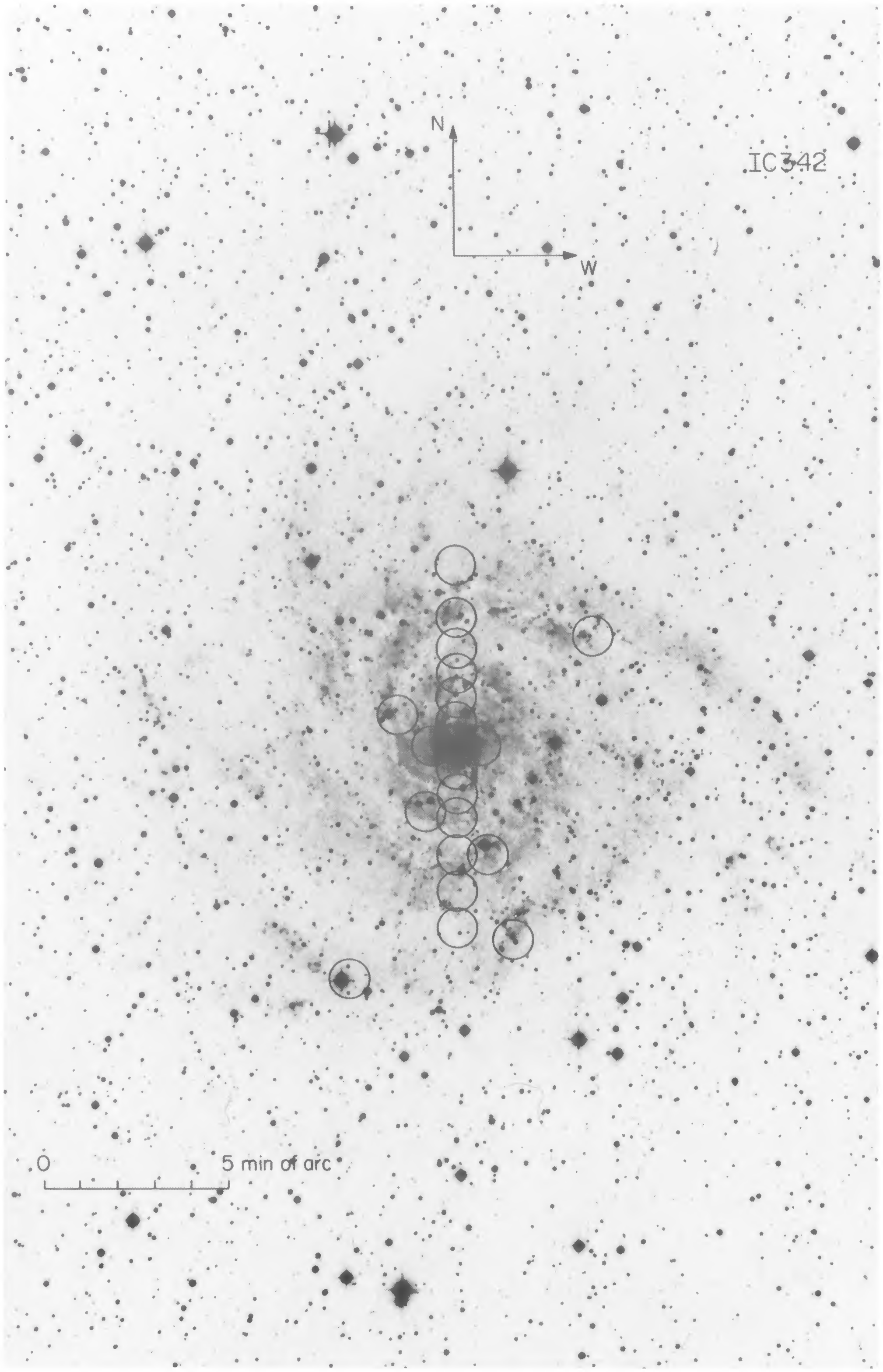

FIG. 1.—A print of IC 342, from a plate kindly provided by Dr. H. C. Arp. The circles, representing the 65″ FWHP of the telescope beam, mark the positions of the galaxy at which observations were made.

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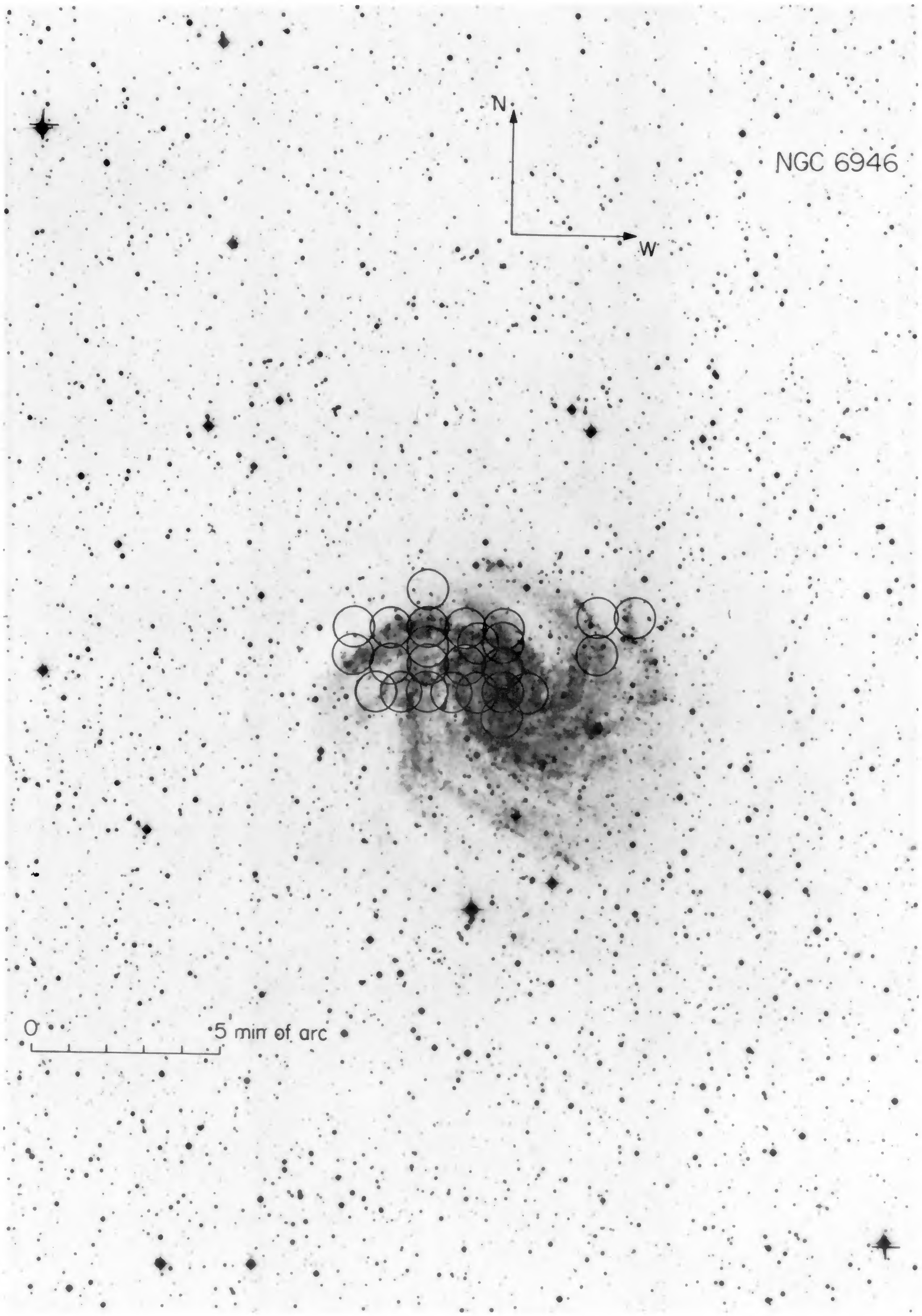

FIG. 4.—A print of NGC 6946, from a plate kindly provided by Dr. H. C. Arp. The circles, representing the telescope beam, denote the positions of the galaxy at which observations were made.

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