MOLECULAR STRUCTURES OF OTHER GALAXIES COMPARED TO THAT OF THE GALAXY

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NUCLEAR SOURCES

Of the eleven galaxies with detected CO emission, eight have bright nuclear CO sources: M82, NGC 253, M51, NGC 5236, NGC 1068, Maffei 2 (Rickard et al. 1977a,b), NGC 6946, and IC 342 (Morris and Lo 1978). Two have disk-population CO sources and no detectable nuclear source (M31 and M81, Combes et al. 1977a), and one has no obvious nucleus (LMC, Huggins, et al. 1975). Nuclear maxima thus appear to be the rule for galaxies with extensive molecular components, and such a peak is also seen in our Galaxy (e.g., Bania 1977). In Figure 1, I compare the CO data for the nuclei of M82 and M31 with spectra of the Galactic nucleus as it would be seen at their respective distances. (The Galactic spectra were synthesized from the date of Bania [1977], and assume a uniform z-distribution of 30 pc width.) The Galaxy is roughly intermediate, being about one-fifth the intensity of M82 and more than six times the intensity of M31.

After reasonable assumptions, one infers molecular hydrogen surface densities (corrected to face-on values) for the nuclear sources in the range 40-90 $M_\odot/pc^2$ and total H_2 masses $\sim 10^9$ $M_\odot$ (Rickard et al. 1977a, Morris and Lo 1978). These mass estimates are within a factor of two of those obtained from 390μ, 540μ, and 1 mm observations (Hildebrand et al. 1977, Elias et al. 1978). The ^{12}CO optical depths must thus be $\lesssim 5$, consistent with present upper limits for ^{13}CO emission. The velocity structures of several sources suggest strong non-circular motions, and Rickard et al. (1977a) make a direct comparison of models for M82 and the Galactic center. The inferred kinetic energies of expansion are quite similar, although other gauges of nuclear activity (e.g., infrared luminosity) differ by orders of magnitude.

OH is seen in absorption against the strong nuclear continuum sources in M82, NGC 253, NGC 4945, and NGC 5128 (Weliachew 1971, Whiteoak and Gardner 1973, Gardner and Whiteoak 1975, 1976, Nguyen-Q-Rieu et al. 1976). The total velocity widths of the absorption features in

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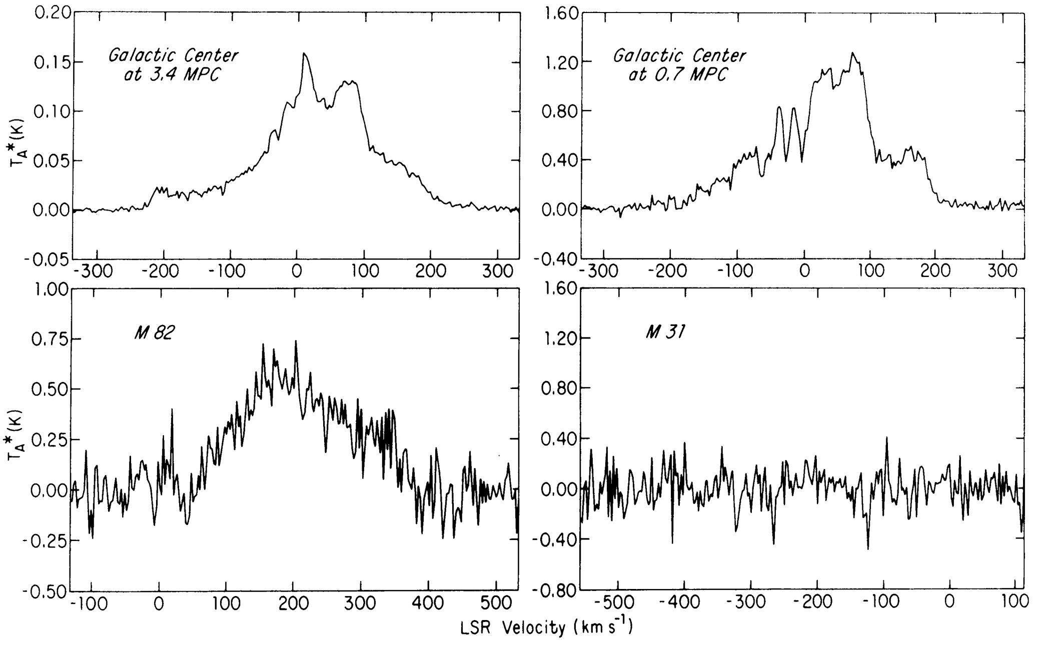

Figure 1. Comparison of CO data for M82 and M31 with synthetic spectra of the Galactic nucleus placed at their respective distances.

M82 and NGC 253 are comparable to the widths of the CO emission features, although the absorption arises from a more narrowly defined region of the galaxy. This also supports the inference of non-circular motions in these sources. Observations of the satellite transitions in NGC 253 and NGC 4945 (Gardner and Whiteoak 1975, Whiteoak and Gardner 1975) show strong hyperfine anomalies, which can be explained by the transport of intense infrared radiation from the nucleus through the OH. The same effect is seen in the Galactic center (Whiteoak and Gardner 1976a).

Also seen in the central molecular sources are HCN emission (Rickard et al. 1977c), H_2CO absorption (Gardner and Whiteoak 1974), and maser emission from H_2O (Lépine and Dos Santos 1977) and OH (Gardner and Whiteoak 1975, Nguyen-Q-Rieu et al. 1976). The OH masers are particularly remarkable, being 10 to 100 times as strong as Galactic masers, and strongest at 1667 MHz, rather than 1665 MHz. They may be amplifying the strong nuclear continuum sources.

DISK SOURCES

Some (but apparently not all) galaxies with bright nuclear CO sources also have detectable CO emission from extended disk components. The radii of the observable disks range from 6 to 10 kpc (Rickard et al. 1977b, Morris and Lo 1978, Rickard et al. 1978). When the data are averaged over azimuth, the resulting radial variation is generally a fairly smooth decline with the suggestion of a plateau for radii > 6 kpc, of intensity ∿ 25% of the peak intensity. The implied H_2 surface densities, 10 to 20 $M_\odot/pc^2$, are about twice the mean for the Galactic molecular annulus (Gordon and Burton 1976). There is no evidence for a trough or discontinuity in the radial distribution akin to that at 3-4 kpc in our Galaxy, linked by Gordon (1978) to the inner Lindblad resonance. However, the effect of the coarse angular resolution may be significant here.

Morris and Lo (1978) note that when the inferred H_2 distributions in NGC 6946 and IC 342 are combined with 21-cm data, the total gas density is roughly constant over the inner regions. They then argue that the 21-cm minima in the centers of many spiral galaxies arise from the conversion of atomic to molecular hydrogen. However, there are several cases of galaxies with nuclear HI minima and no compensating molecular sources (e.g., M31). Also there are cases of galaxies with similar H_2 distributions but quite different 21-cm distributions (e.g., NGC 6946 and M51).

H_2O and H_2CO have also been detected specifically towards disk-population sources. Churchwell et al. (1977) and Huchtmeier et al. (1978) have detected H_2O masers associated with several HII regions in M33 and IC 342. The source luminosities are in the range of the stronger Galactic H_2O masers (0.01 $L_\odot$ to $\sim$ 1 $L_\odot$), but a meaningful comparison with the Galactic luminosity distribution cannot be made yet. Whiteoak and Gardner (1976b) reported H_2CO absorption towards N159, in the LMC.

SPIRAL STRUCTURE

Do the molecular components of spiral galaxies themselves show any spiral structure? At present, this question reduces to asking whether there is any evidence for a preferential association of CO emission with spiral structure. One would expect an affirmative answer because of the association of bright Galactic CO sources with HII complexes, which are the sharp delineators of spiral patterns in other galaxies, and because of indirect evidence for such structure in our Galaxy (Roberts and Burton 1977). Unfortunately, present evidence is not compelling.

Combes et al. (1977b) searched for CO emission along the major axis and southern spiral arms of M31. From their detection statistics, they inferred that CO emission was present only on the inner sides of the 21-cm spiral arms within the mean corotation radius--as expected in density-wave models. However, Emerson (1978) has disagreed with this conclusion, noting that the HI distribution on the SW side is too irregular to allow a simple comparison with the under-sampled CO data, and that the CO data do not cover the outer edges of the smoother NE HI arms.

Some of the structure in extended CO disks of galaxies like NGC 6946 and M51 can be associated with particular features of the optical spiral patterns. But global spiral structure is not yet evident in the CO data.

REFERENCES

Bania, T. M.: 1977, Astrophys. J. 216, pp. 381-404.
Churchwell, E., Witzel, A., Huchtmeier, W., Pauliny-Toth, I., Roland, J. and Sieber, W.: 1977, Astron. Astrophys. 54, pp. 969-971.

Combes, F., Encrenaz, P. J., Lucas, R., and Weliachew, L.: 1977a, Astron. Astrophys. 55 pp. 311-314.
Combes, F., Encrenaz, P. J., Lucas, R., and Weliachew, L.: 1978, Astron. Astrophys. 61, pp. L7-L9.
Elias, J. H., Ennis, D. J., Gezari, D. Y., Hauser, M. G., Houck, J. R., Lo, K. Y., Matthews, K., Nadeau, D., Neugebauer, G., Werner, M. W., and Westbrook, W. E.: 1978, Astrophys. J. 220, pp. 25-41.
Emerson, D. T.: 1978, Astron. Astrophys. 63, pp. L29-L30.
Gardner, F. F., and Whiteoak, J. B.: 1974, Nature 247, pp. 526-527.
Gardner, F. F., and Whiteoak, J. B.:1975, M.N.R.A.S., 173, pp. 77P-81P.
Gardner, F. F., and Whiteoak, J. B.: 1976, Proc. Astron. Soc. Aust. 3, pp. 63-65.
Gordon, M. A.: 1978, Astrophys. J. 222, pp. 100-102.
Gordon, M. A., and Burton, W. B.: 1976, Astrophys. J. 208, pp. 346-353.
Hildebrand, R. H., Whitcomb, S. E., Winston, R., Steining, R. F., Harper, D. A., and Moseley, S. H.:1977, Astrophys. J. 216, pp. 698-7C
Huchtmeier, W., Witzel, A., Kuhr, H., Pauliny-Toth, I., and Roland, J.: 1978, Astron. Astrophys. 64, pp. L21-L24.
Huggins, P. J., Gillespie, A. R., Phillips, T. G., Gardner, F. F., and Knowles, S.: 1975, M.N.R.A.S. 173, pp. 69P-71P.
Lépine, J.R.D., and Dos Santos, P. M.: 1977, Nature 270, p. 501.
Morris, M., and Lo, K. Y.: 1978, Astrophys. J., in press.
Nguyen-Q-Rieu, Mebold, U., Winnberg, A., Guibert, J., and Booth, R.: 1976, Astron. Astrophys. 52, pp. 467-469.
Rickard, L. J, Palmer, P., and Turner, B. E.: 1978, in preparation.
Rickard, L. J, Palmer, P., Morris, M., Turner, B. E., and Zuckerman, B.: 1978a, Astrophys. J. 213, pp. 673-695.
Rickard, L. J, Palmer, P., Turner, B. E., Morris, M., and Zuckerman, B.: 1977c, Astrophys. J. 214, pp. 390-393.
Rickard, L. J, Turner, B. E., and Palmer, P.: 1977b, Astrophys. J. (Letters) 218, pp. L51-L55.
Roberts, W. W., and Burton, W. B.: 1977, in "Topics in Interstellar Matter", H. van, Woerden (ed.), Reidel, Dordrecht, pp. 195-205.
Weliachew, L.: 1971, Astrophys. J. (Letters) 167, pp. L47-L52.
Whiteoak, J. B., and Gardner, F. F.: 1973, Astrophys. Lett. 15, pp. 211-215.
Whiteoak, J. B., and Gardner, F. F.: 1975, Astrophys. J. (Letters) 195, pp. L81-L84.
Whiteoak, J. B., and Gardner, F. F.: 1976a, M.N.R.A.S. 174, pp. 627-636.
Whiteoak, J. B., and Gardner, F. F.: 1976b, M.N.R.A.S. 174, pp. 51P-52P.

DISCUSSION

van der Hulst: I have the impression that CO has been detected in primarily late type galaxies. If so, is this a real effect or is this due to observational selection?

Rickard: It is true that the galaxies with bright nuclear CO sources are mainly of Hubble type Sc. However, NGC 1068 is Sb; and M31 and M81, for which only disk-population sources are reported, are Sb also. I think that the present differences in the detection statistics for different Hubble types are not significant.