A COMPLETE CO SURVEY OF M31

T. M. DAME[1], E. KOPER[2], F. ISRAEL[2], and P. THADDEUS[1]

[1] *Harvard-Smithsonian*
Center for Astrophysics
60 Garden Street
Cambridge, Mass. 01238

[2] *Leiden Observatory*
P.O. Box 9513
2300 RA Leiden
The Netherlands

ABSTRACT. The 1.2 m telescope at the Center for Astrophysics is being used to carry out the first complete CO survey of M31. To date, the entire galaxy out to a radius of at least 15 kpc — well beyond the optical disk and H I ring — has been observed every half-beamwidth (4.5'), with ~1 hr of integration per point yielding an rms of 20 mK in 1.3 km s^{-1} channels. Like H I and other Population I tracers, molecular clouds in M31 are mainly concentrated in a broad ring with a radius of ~10 kpc, but beyond the peak of the ring molecular gas falls off more sharply than atomic gas. On the assumption of a standard Galactic value for the conversion of CO emission to H_2 mass, the average molecular surface density at the peak of the ring is ~1 $M_\odot$ pc^{-2} and the total molecular mass of M31 is ~3 x 10^8 $M_\odot$. The survey will be essentially repeated during the coming year to improve the signal-to-noise.

1. Introduction

M31, as the nearest external spiral galaxy, is an important target for observations in CO, yet the combination of its large angular size and weak lines make such observations fairly difficult. Although the global properties of M31 have been extensively studied in H I (e.g., Unwin, 1980) and in the IRAS bands (Walterbos and Schwering, 1987), previously only a modest fraction of its disk has been surveyed in CO (e.g., Ryden and Stark, 1986) and much less in any other interstellar molecule.

2. Observations

The 1.2 m telescope at the Center for Astrophysics is well suited for carrying out a complete CO survey of M31. Its SIS receiver, with a noise temperature of 70 K (SSB), is among the most sensitive in the world at the CO frequency, and its beamwidth, 8.7', is comparable to that of the largest steerable antennas at 21 cm while also large enough for a complete survey of M31 to be feasible in just one or two years. The spectrometer used for the survey, a 256 channel

F. Combes and F. Casoli (eds.), Dynamics of Galaxies and Their Molecular Cloud Distributions, 23–26.

filter bank with a velocity resolution of 1.3 km s^{-1} and a total bandwidth of 332 km s^{-1}, has adequate spectral coverage for the wide lines observed in M31.

Because the beam of this instrument at the CO frequency is essentially the same as that of the Bonn 100 m antenna at 21 cm, we observed on the same

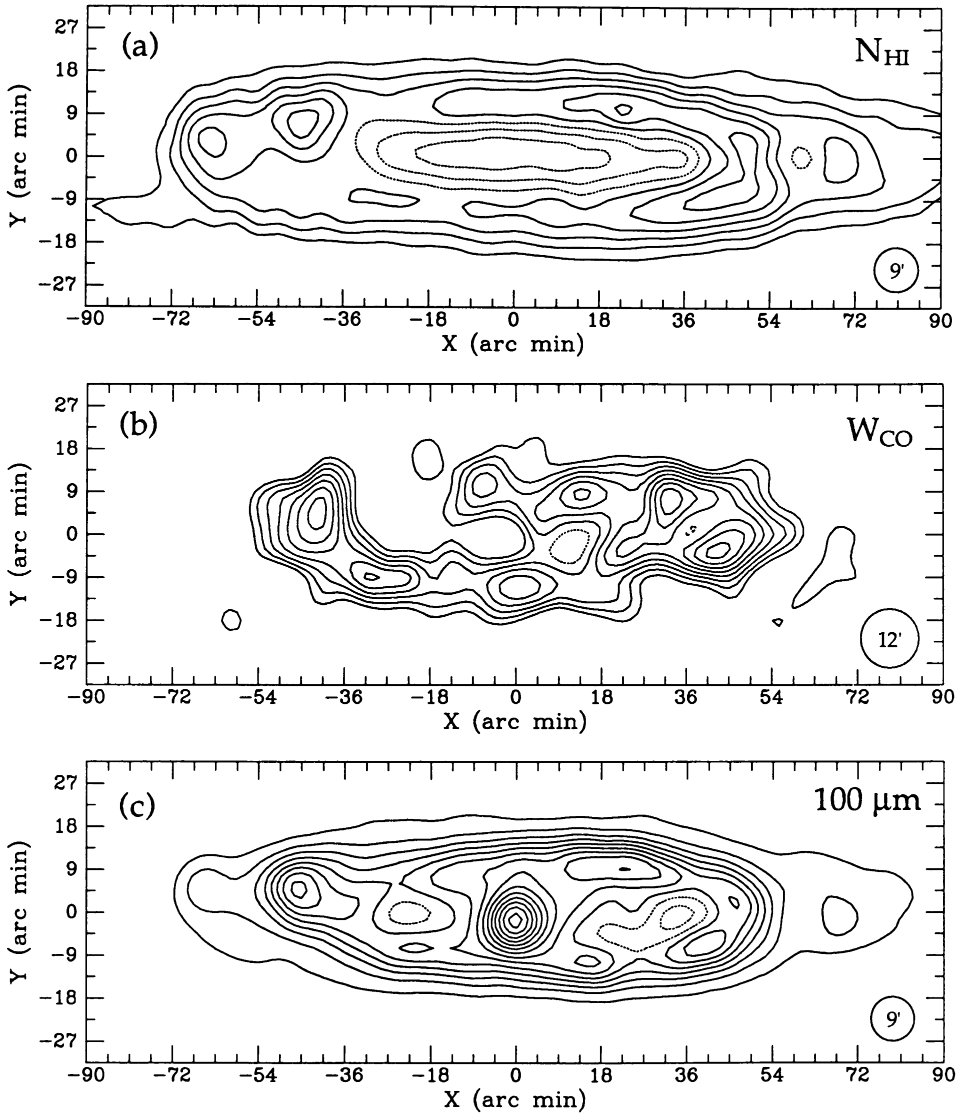

Figure 1. Comparison of gas tracers in M31. X and Y are Baade-Arp offsets from $\alpha = 0^h\,40^m$ $\delta = 41°$ along and perpendicular to the major axis, at p.a. 38°. *(a)* H I column density from the 21 cm survey of Cram *et al.* (1980). Contours are from 5 by 2.5 x 10^{20} cm^{-2}. *(b)* Velocity-integrated CO intensity spatially smoothed to 12'. Contours are from 0.3 by 0.1 K km s^{-1}. *(c)* IRAS 100 μm emission spatially smoothed to 9'. Contours are from 1.8 by 1.8 MJy sr^{-1}.

Baade-Arp grid (4.5' spacing) as the Bonn 21 cm survey of Cram, Roberts, and Whitehurst (1980). In terms of spatial coverage the CO survey is nearly complete, the 345 points observed fully sampling the galaxy beyond a radius of 15 kpc, but in terms of integration time the survey is only half complete. During the winter of 1990-91, we plan to double the average integration time per point, from 1 hr to 2, to decrease the rms noise per channel from the current 20 mK to 14 mK.

3. Results

Our velocity-integrated CO map of M31 is compared in Figure 1 to similar maps at 21 cm and 100 µm. The CO lines detected are very weak (peak $T_A < 30$ mK), but since the emission is quite extended in both solid angle and velocity, the signal-to-noise in Figure 1*b*, which has been integrated over a velocity window typically 100 km s^{-1} wide and smoothed to an angular resolution of 12', is fairly high: the lowest contour is at about the 3 σ level.

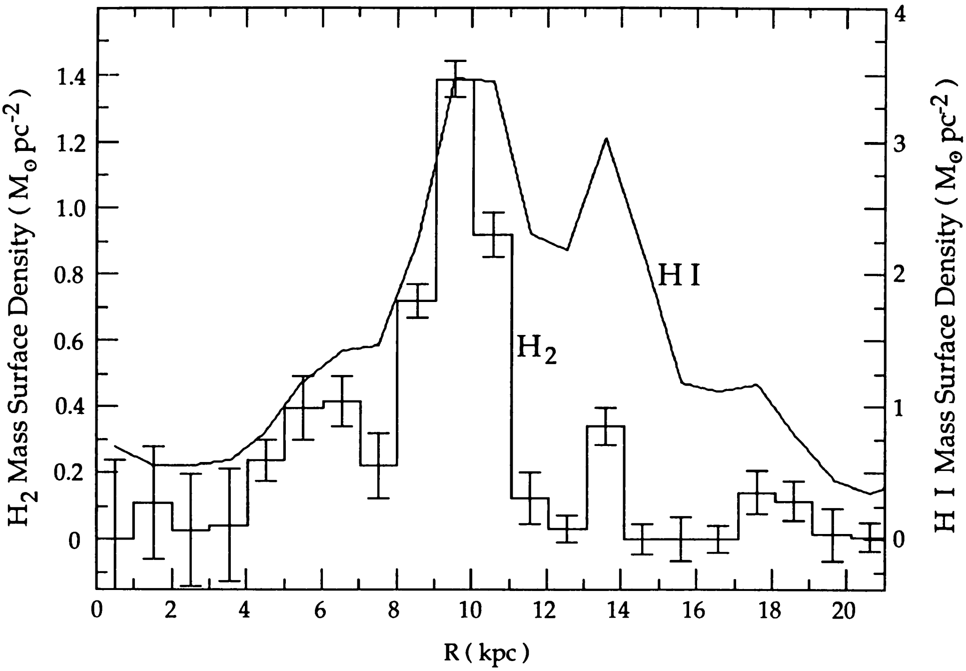

Figure 2. Radial distribution of atomic and molecular mass surface densities in M31, derived from unsmoothed versions of Figs. 1*a* and 1*b*, respectively, using an iterative rectification scheme (Lucy, 1974). Molecular column densities were derived using $N(H_2)/W_{CO} = 2.3 \times 10^{20}$ cm^{-2} K^{-1} km^{-1} s (Strong *et al.* 1988) and assuming a distance of 690 pc and an inclination of 77° for M31. The error bars represent the instrumental noise in each bin.

The Population I ring at ~10 kpc is evident at all three wavelengths, as are a number of smaller features within the ring. Characteristically, the CO emission appears more clumped and of higher contrast than the 21 cm emission. For example, a weak point in the 21 cm and 100 μm rings near (X,Y) = (–27', 9') appears of much higher contrast in CO. Two of the more intense regions in the velocity-integrated CO map were observed previously with the Bell Laboratories 7 m antenna, but a third intense region centered near (40.5, –4.5) is mapped for the first time by our survey.

Even at the current noise level, our CO survey can be used to determine the average radial distribution of molecules in M31. The poor angular resolution of the survey along the minor axis of M31 — more than 7 kpc — precludes a simple radial binning of the data, so we have instead fit an axisymmetric model to the velocity-integrated CO emission using an iterative rectification scheme (Lucy, 1974). For comparison, and as a check on the procedure, the same model was fit to the velocity-integrated 21 cm emission from the Bonn survey; the results of both fits are shown in Figure 2. The H I radial distribution agrees well with that derived from a simple radial binning of higher resolution 21 cm data by Unwin (1980).

The comparison in Figure 2 is particularly interesting because the curves were derived in exactly the same way from CO and 21 cm observations of the same points at the same angular resolution. Both curves show a smooth increase to a peak near 10 kpc and a possible secondary peak near 13 kpc; the main difference between them is the much sharper drop in the H_2 density beyond 10 kpc. Using the standard Galactic value of the molecular mass calibration, we derive an average molecular surface density near the peak of the M31 molecular ring of ~1 $M_\odot$ pc^{-2}, about 2.5 times less than the atomic surface density there, and a total H_2 mass for M31 of ~3 x 10^8 $M_\odot$, more than an order of magnitude less than the total atomic mass (3.9 x 10^9 $M_\odot$; Cram *et al.* 1980).

A central problem posed by these results is why M31 and the Milky Way, two spiral galaxies with comparable amounts of atomic gas, appear so different in CO. While the "molecular ring" of the Milky Way can more accurately be described as an exponential disk with a hole inside ~3.5 kpc and a very strong central peak, the CO emission in M31 appears more truly ring-like, peaking twice as far from the center and showing no detectable emission at the center. Further, the average CO intensity at the peak of the molecular ring in M31 is only comparable to that in the solar neighborhood, and therefore about 6 times less than at the peak of our so-called molecular ring.

4. References

Cram, T. R., Roberts, M. S., and Whitehurst, R. N. 1980, *Astr. Ap. Suppl.*, **40**, 215.
Lucy, L. B. 1974, *A. J.*, **79**, 745.
Ryden, B. S., and Stark, A. A. 1986, *Ap. J.*, **305**, 823.
Strong, A. W., Bloemen, J. B. G. M., Dame, T. M., Grenier, I. A., Hermsen, W., Lebrun, F., Nyman, L.-Å., Pollock, A. M. T., and Thaddeus, P. 1988, *Astr. Ap.*, **207**, 1.
Unwin, S. C. 1980, *M.N.R.A.S.*, **192**, 243.
Walterbos, R. A. M., and Schwering, P. B. W. 1987, *Astr. Ap.*, **180**, 27.