CO Distributions in Southern S0 Galaxies

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Abstract. With the SEST, we have observed 7 S0 galaxies at 2.6 mm, and detected CO emission in five. Observing four offset positions per galaxy at $\geq 40''$ from the center, we find significantly extended CO emission in almost all cases. The (lower limits to) H_2 masses of several times 10^8 $M_\odot$ amount to 0.2–0.3 times the HI mass in 4 or 5 galaxies.

1. Introduction

While most S0 galaxies appear to have used up their supply of gas, a minority contain sizable amounts of atomic hydrogen (Wardle and Knapp 1986). Van Driel (1987) and collaborators have mapped the distribution of HI in gas-rich early-type galaxies at Westerbork. The gas in S0's often lies in outer rings of radius $R \sim 2R_{25}$, sometimes also in an inner ring at $R \sim 0.5R_{25}$. The HI distribution in S0/a galaxies resembles the filled disks of spirals. Barred S0 and S0/a galaxies have outer rings of HI at 1.0–1.5 R_{25} and deep, central depressions (van Driel and van Woerden 1989).

Surveys of CO emission from S0 galaxies have been made by Thronson *et al.* (1989), Sage and Wrobel (1989), and Wiklind and Henkel (1989). In these single dish studies (beamwidths of 20–50″), generally one position per galaxy was measured. Maps of CO emission are required to provide the distributions of the molecular gas. Together with the HI distributions, they should inform us about the origin and evolution of the gas in S0 galaxies. We have therefore undertaken a study of CO *distributions* in southern S0 galaxies. We selected for observation galaxies with HI detections (Reif *et al.* 1982) and/or IRAS detections at 60 and 100 μm (Lonsdale *et al.* 1985).

2. Observations

We have used the 15-meter Swedish-ESO Submillimeter Telescope (SEST) at La Silla (Chile) for 74 hours in November 1988 to measure the ^{12}CO line emission at 2.6 mm in 7 galaxies (Table 1). The half-power beamwidth was 43″, with a main beam efficiency of 0.71. The spectrometer provided 722 channels in a bandwidth of 500 MHz = 1300 km s^{-1}. Our spectra were smoothed over 10 channels, giving a velocity resolution of 18 km s^{-1}. The single-sideband system temperature was 600–700 K, after correction to above the atmosphere. Integration times of typically 2 hours per position gave us an rms noise of ~5 mK in our 10 channel averages.

In the distant polar-ring galaxy, A0136-0801 (van Gorkom *et al.* 1987), we observed only the center, without detection. In the other 6 galaxies, we observed the center and 3 or 4 offset positions (Table 1) placed either along one axis (NGC 1291, 1326, and 2217), or at ±40″ on orthogonal axes (IC 1830, NGC 7233); in IC 5063, two offset positions lie on the dust lane (Danziger *et al.* 1981). Clearly, 4 offsets per galaxy do not yet provide a complete map of CO emission.

Observed antenna temperatures (T_A^*) were converted to flux densities per beam, S_{CO}, via

$$S_{CO}(\mathrm{Jy}) = 28.3\,T_A^*(\mathrm{K})/f \qquad (1)$$

which was derived from

$$S_{CO} = 2k\lambda^{-2}\,T_A^*\,\Omega_{mb}/(\eta_{mb}f)$$

where η_{mb} = main beam efficiency = 0.71, and Ω_{mb} = main beam solid angle = 4.9×10^{-8} sterad, and the quantity f, called the "correction factor for source-beam coupling" (Thronson *et al.* 1989) or "fraction of emission observed" (Kenney 1987), depends on the distribution relative to the beam. It is 1.00 for a point source at the beam center, and 0.72 for a flat distribution. We have used f = 0.72 for nondetections, giving upper limits to the CO flux, and f = 1.00 for detections, giving lower limits to the CO flux because of incomplete mapping.

3. Results

Table 1 summarizes our preliminary results. Column 3 gives the profile integrals for the central position and for the sum of all observed positions. Column 4 shows the distance, Δ, to the galaxy (as calculated from the HI velocity and $H_o = 100$), and the HI mass from van Gorkom *et al.* (1987), Danziger *et al.* (1981), or Reif *et al.* (1982). Column 5 gives the H_2 mass and the $M(H_2)/M(HI)$ ratio. H_2 masses were calculated

Table 1

Preliminary Results

Name D_{25} (arcmin)	Offsets $\Delta\alpha \cos\delta$, $\Delta\delta$ (arcmin)	$\int S_{CO}\,dV$: center (Jy km/s) "total"	Distance (Mpc) M(HI) (10^8 $M_\odot$)	M(H_2) (10^8 $M_\odot$) M(H_2)/M(HI)	$\langle I_1 \rangle / I_0$ R_1 (kpc)	notes
A 0136-0801	centre only	≤ 100 (3σ)	55 8.3	≤ 33 (3σ) ≤ 4.0		
IC 1830 1.8±0.2	4: ±0.67, 0.00 0.00,±0.67	$\geq 33 \pm 9$ $>108 \pm 55$	12.7 11.4±1.8	$>1.9 \pm 1.0$ $>0.17 \pm 0.09$	0.6±0.5 2.5	
NGC 1291 10.5±0.8	3: +1.00, 0.00 +2.00, 0.00 +4.00, 0.00	$\geq 44 \pm 12$ $>34 \pm 31$	6.9 8.1±0.7	$\geq 0.23 \pm 0.06$ $\geq 0.029 \pm 0.008$	(−0.2±0.4) 2.0	
NGC 1326 4.0±0.6	4: ±0.65,±0.15 ±1.30,±0.30	$\geq 78 \pm 11$ $>184 \pm 38$	12.2 14.0±1.6	$>3.0 \pm 0.6$ $>0.22 \pm 0.05$	0.6±0.2 2.4	a
NGC 2217 4.8±0.5	4: ±1.00, 0.00 ±2.00, 0.00	$\geq 44 \pm 14$ b $>120 \pm 32$	13.8 11.9±0.9	$>2.5 \pm 0.7$ $>0.21 \pm 0.06$	? 4.0	b
IC 5063 1.9±0.7	4: ±0.63,±0.14 ±0.27,∓0.58	≤ 47 (3σ) $>62 \pm 24$	33.0 25	$>7.4 \pm 2.9$ $>0.29 \pm 0.12$	? 6.4	c
NGC 7233 2.2±0.5	4: ±0.48,∓0.45 ±0.45,±0.48	$\geq 56 \pm 12$ $>79 \pm 38$	18.9 $\leq 19.6 \pm 2.8$	$>3.1 \pm 1.5$ $>0.16 \pm 0.08$	0.1±0.2 3.7	d

Notes

a Detections (50±12 and 39±11 Jy km/s) at 40″ in P.A. 77° and 257°.

b No detection at center; quoted detection is at 60″ east.

c *No detection. Two offset positions on dust lane.*

d HI detection from group of galaxies.

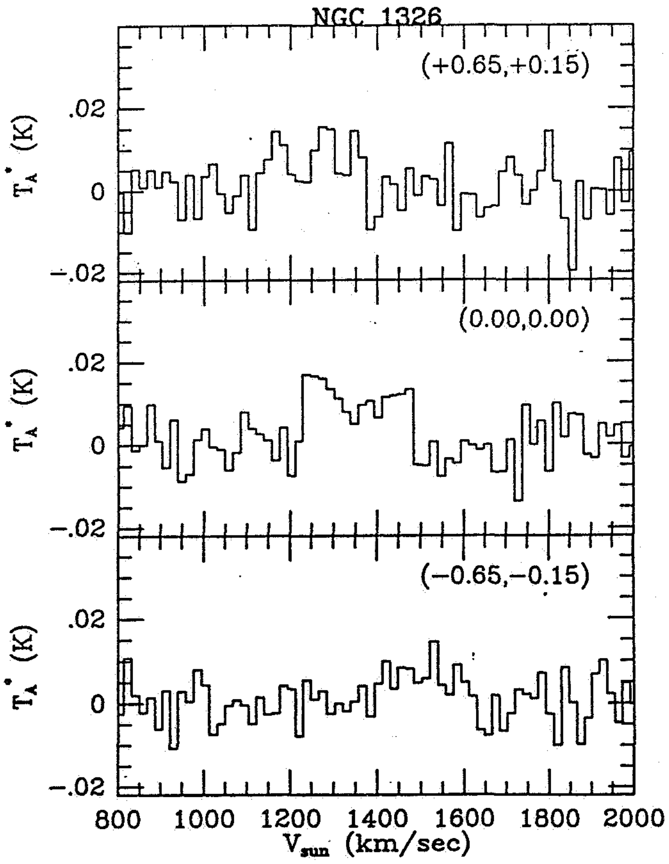

Figure 1: Profiles of ^{12}CO emission from NGC 1326 at the center and 2 offset positions ($\Delta\alpha \cos\delta$ and $\Delta\delta$ given in arcmin).

from the "total" profile integrals (sum of all observed positions) via

$$M(H_2)\,(\mathrm{M}_\odot) = 1.1 \times 10^4[\Delta(\mathrm{Mpc})]^2 \int S_{CO}\,dV\,(\mathrm{Jy\ km\ s^{-1}}) \tag{2}$$

Column 6 gives the ratio of the average profile integral $\langle \mathrm{I}_1 \rangle$ at the first offsets to the central integral I_0, and the offset distance, R_1.

We have central detections above 3σ in four galaxies: NGC 1291, 1326, and 7233, and IC 1830, and a non-central 3σ detection in NGC 2217. The other two galaxies were not detected. The "total" profiles obtained by adding 3 or 4 offset positions to the central position have a much higher noise level, but also more signal; hence the CO distributions must generally be extended. Although the "total" profile integrals exceed 3σ only in NGC 1326 and NGC 2217, we consider these integrals in general a better approximation to the total CO emission than the central integral (except in NGC 1291). However, we emphasize that these "totals" are based on incomplete maps, and thus provide lower limits to the CO emission only.

The calculation of H_2 mass from CO emission, using the formula (2) as in Thronson *et al.* , assumes the same H_2/CO ratio as in our galaxy. The ratios of molecular to atomic hydrogen mass are of order 0.2–0.3 in most cases, which is lower than in many spiral galaxies (Young, this conference). In NGC 1291, the H_2/HI ratio may be an order of magnitude lower, but in this big galaxy the map is very incomplete.

In NGC 1326 the CO distribution is clearly extended, with the two offset positions at $\pm 40''$ from the center having well-detected CO emission. Preliminary calculations indicate that both central and offset profiles can be well fit by a model having the CO concentrated in a narrow ring at $20''$ (=1.2 kpc) radius and rotating at $225 \sin i$ km s^{-1}. In IC 1830 and NGC 7233, the average offset emission $\langle \mathrm{I}_1 \rangle$ and its ratio to I_0 were estimated from the difference between total and central profiles, but here the ratios $\langle \mathrm{I}_1 \rangle / \mathrm{I}_0$ remain inconclusive.

Our present results represent only a first step towards our goal. A good determination of CO distributions requires more sensitive observations. In addition, for both the distributions and the total amount of molecular gas, more complete maps are required. There is an urgent need for feed arrays on millimeter telescopes.

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