ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

JULY **1996**, PAGE 47

Astron. Astrophys. Suppl. Ser. **118,** 47-57 (1996)

Dust and CO emission in normal spirals.*,** I. The data

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Received August 25; accepted November 25, 1995

Abstract. — We present 1300 μm continuum observations and measurements of the CO (1−0) and (2−1) emission from the inner regions of 98 normal galaxies. The spatial resolution ranges from 11″ to 45″. The sources come from a complete FIR selected sample of 138 inactive spirals with an optical diameter $D_{25} \leq 180''$.

Key words: galaxies: abundances — galaxies: interstellar matter — galaxies: spiral — radio continuum: galaxies — radio lines: galaxies

1. Introduction

The total gas content of a galaxy plays a fundamental role for the global star formation. For a thorough investigation of this problem we have compiled a sample of non-active spirals, taken from Fullmer & Lonsdale (1989). We included all spirals which have optical sizes $\leq 180''$ and 100 μm fluxes ≥ 10 Jy. We omitted *Hubble* types S0 and SB as well as clearly active systems. In this way we obtained a complete FIR–flux limited sample of 138 spirals.

As part of this study, we want to derive observationally the amount of molecular gas. The distribution of the total mass as traced by dust emission, i.e. including also atomic hydrogen, and its concentration towards the nucleus was investigated by Chini et al. (1995) for a sub-sample of the present data set. Other related quantities of interest are the conversion factor between CO and H_2, the dust-to-gas ratio and the mass absorption coefficient of dust at 1300 μm. Because of the intrinsic uncertainties of the various gas tracers, we measure the galaxies both in the dust continuum at 1300 μm and in the (1−0) and (2−1) lines of CO. Obtaining data from different telescopes, i.e. at different spatial resolution, allows us to compare both methods with identical or at least similar beams. In the following, we present the 1300 μm photometry of the central (11″, 24″, 70″) regions and show the CO spectra at various resolutions (12″, 24″, 45″) for 98 galaxies. Furthermore, we list the line parameters of the CO (1−0) and (2−1) transitions. The data will be discussed elsewhere (Chini & Krügel, in prep.).

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*Based on observations collected at ESO, La Silla, Chile and at IRAM, Pico Veleta, Spain

**Tables 1 and 2 also available in electronic form at CDS via ftp 150.79.120.5

2. Observations

Due to the fact that our dust continuum observations have to be interpreted in the context of *IRAS* data we took the positions from Fullmer & Lonsdale (1989). Having high quality flux measurements at all four wavelengths, the FIR positions generally agree with the optical positions of the galaxies. Nevertheless, it cannot be excluded that in particular the high resolution IRAM data miss some fraction of the central emission. The pointing accuracy of about 5″ at SEST (Swedish ESO Submillimeter Telescope) and 3″ at IRAM introduces another error when comparing masses derived from dust and CO.

2.1. *1300 μm continuum*

Most of the continuum observations were made between 1991 and 1993 at the SEST on La Silla, Chile. We used the 1300 μm facility bolometer with a beamsize of 24″ (HPBW); the beam separation was always 70″ in azimuth, which ensured that the reference beam was free of contamination from flux in the outer parts of the galaxy. Further details of the observing procedure are described by Chini et al. (1995). In general we observed only the central 24″ region; for 32 objects we enlarged the coverage to roughly 70″ (see also Chini et al. 1995) by observing a grid of up to 7 points. Additional data for 38 galaxies come from the IRAM 30 m telescope obtained over the same period.

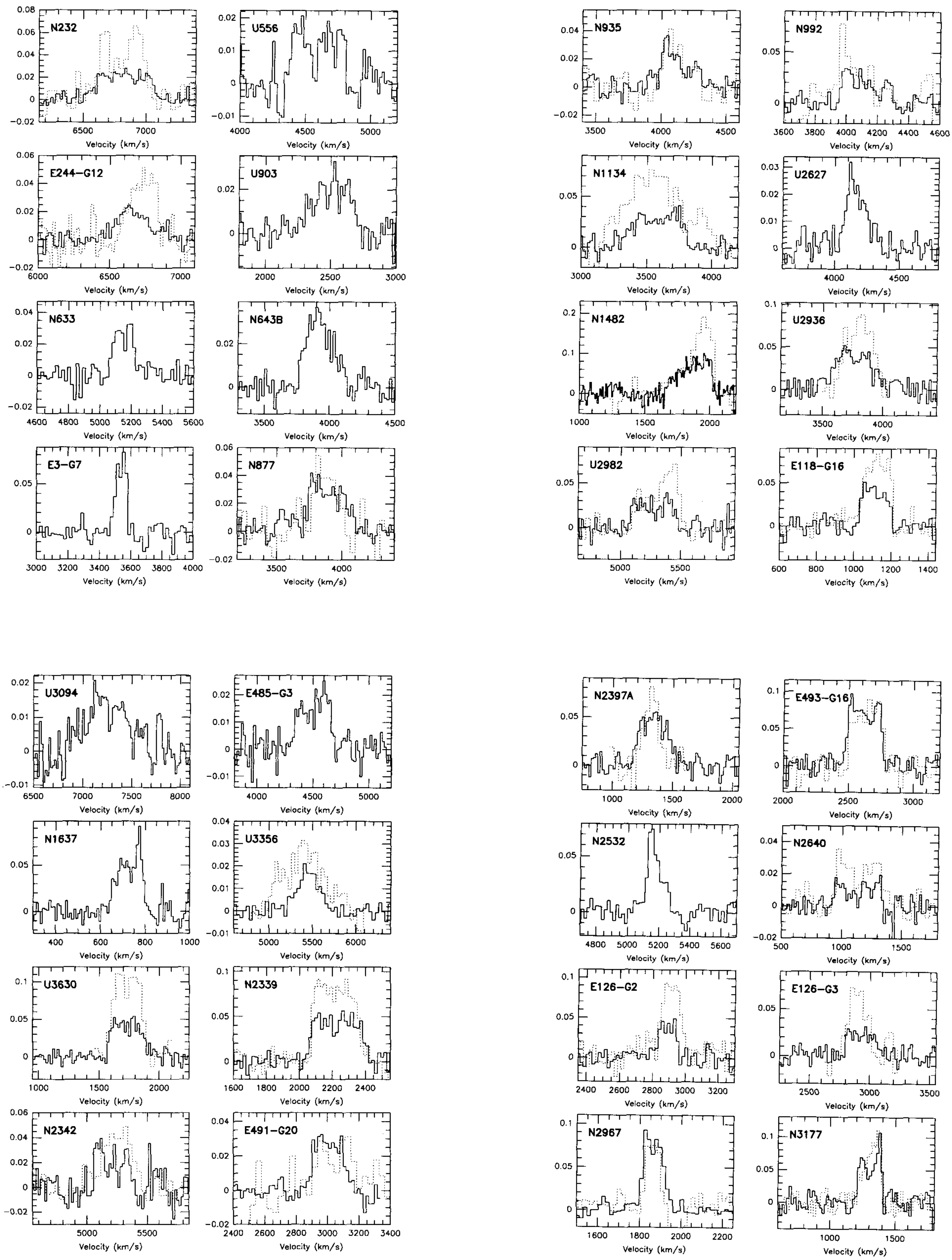
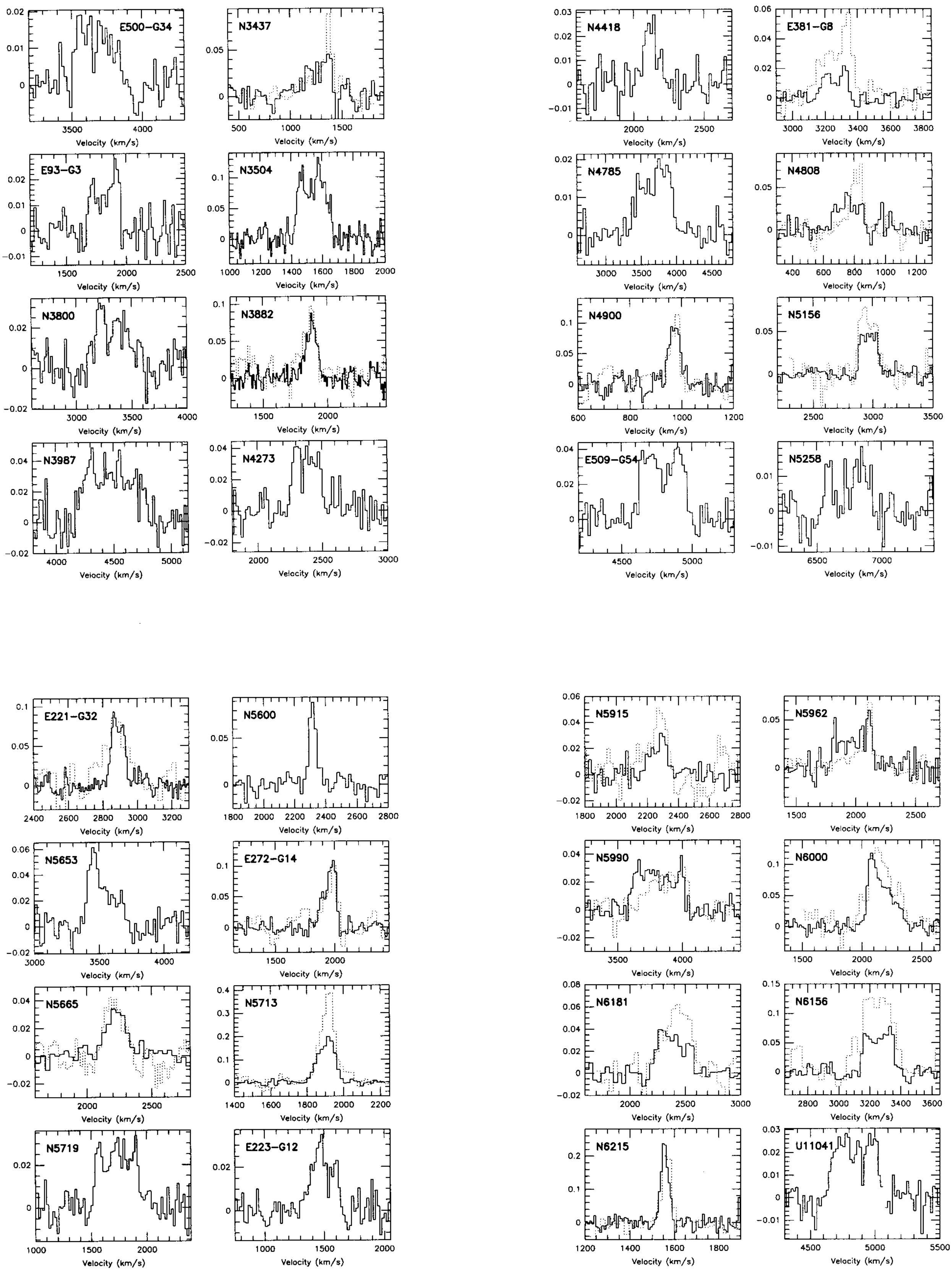


Fig. 1. CO spectra from SEST of the (1–0) line (*solid*, 45″ HPBW) and the (2–1) line (*dotted*, 24″ HPBW). Ordinate gives $T_{\rm mb}$ in K



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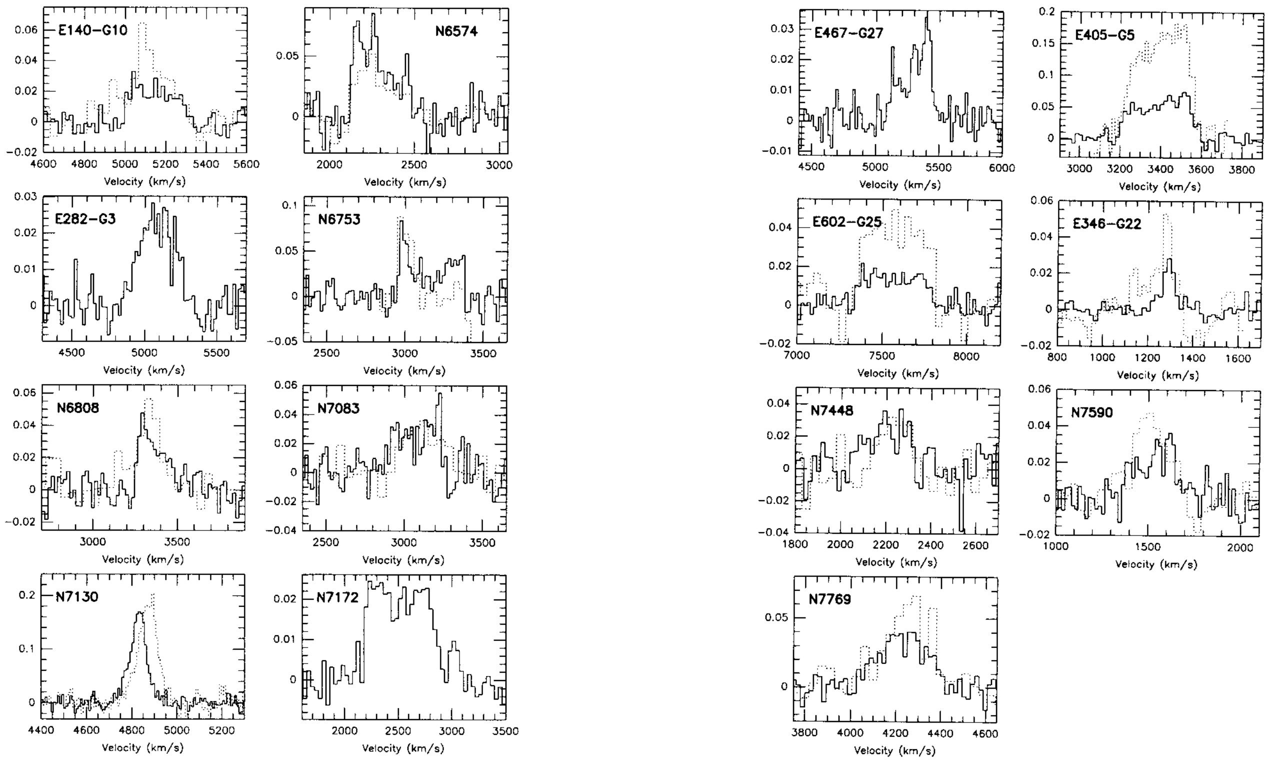

Fig. 1. continued

There the spatial resolution was 11″; for comparison purposes the beam separation was left at 70″.

2.2. *CO lines*

Most of the line observations were performed at the SEST during five observing sessions, partly as backup programs, from 1992 to 1994. Receiver temperatures were typically around 300 K ((1−0) line) and 400 K ((2−1) line), the system temperatures about a factor of 1.5 higher. Integration times varied between half an hour and three hours per line. The beam width was 45″ in the CO (1−0) line and 24″ in the (2−1) transition; the beam separation was 11′45″ in azimuth. We assumed main beam efficiencies of 0.71 and 0.51 appropriate for point sources at 115 and 230 GHz, respectively.

Two observing sessions were made at the IRAM 30 m dish in May 1991 and October 1995 using the 3 mm and 1 mm SIS receivers to observe the CO (1−0) and (2−1) lines simultaneously; the corresponding beam sizes were 12″ and 24″. To stabilize the baseline, we wobbled the secondary at 0.5 Hz with an amplitude of ± 120″. System temperatures varied between 700 and 1200 K. The adopted main beam efficiency was 0.68 at 115 GHz and 0.41 at 230 GHz.

3. Results

Table 1 gives the most common names of the objects and the observed positions (Fullmer & Lonsdale 1989). In case of a CO detection, we adopted a distance from conversion of the velocity assuming $H_0 = 75$ km s^{-1} Mpc^{-1}; otherwise it was taken from the literature; for 10 objects no value could be found. The 1300 μm flux densities within an 11″, 24″ and ≈ 70″ area are listed together with their statistical 1σ uncertainties.

Figure 1 shows the spectra taken at SEST, Fig. 2 those taken at IRAM. For better comparison, in each frame the (1−0) and (2−1) transitions are superimposed. In Fig. 3 we plot the (1−0) line from IRAM and the (2−1) line from SEST, both observed with the same spatial resolution of 24″. In all figures only linear baselines were subtracted. The signal–to–noise in the spectra amounts typically to uncertainties in the line area of 10%. Table 2 lists all galaxies and the parameters from Gaussian fits. Central velocity v and line width dv are in km s^{-1}, $T_{\rm mb}$ in mK. In case the spectrum is fit by two Gaussians, the parameters of both components are listed. Furthermore, we have calculated $I(2-1)/I(1-0)$, the ratio of the integrated intensities. In the column labeled **24″**, the (1−0) line comes from

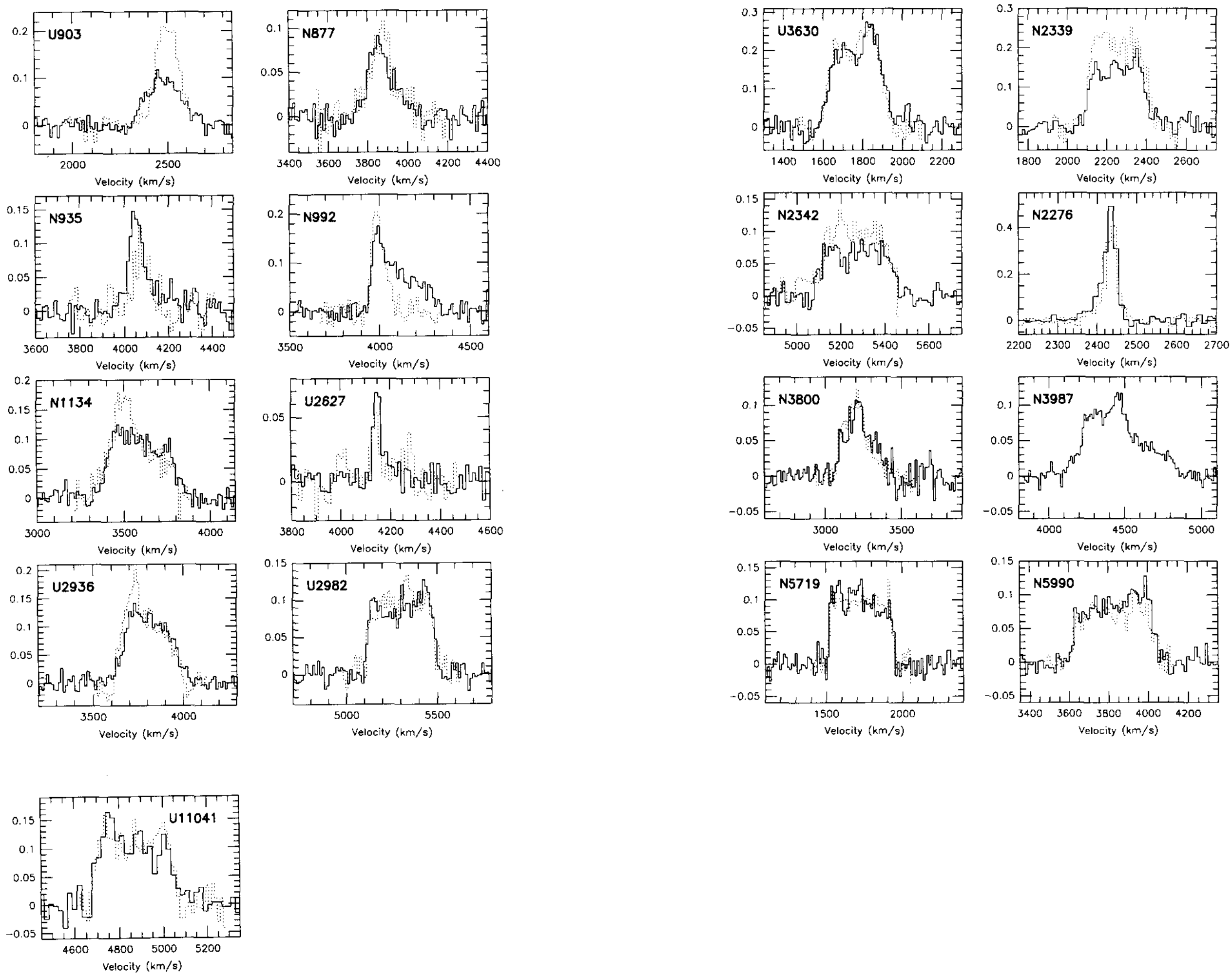

Fig. 2. CO spectra from IRAM 30 m of the (1−0) line (*solid*, 24″ HPBW) and the (2−1) line (*dotted*, 12″ HPBW). Ordinate gives $T_{\rm mb}$ in K

the 30 m telescope, the other from SEST; thus, both lines have the same spatial resolution. In the column **SEST**, observations refer to 45″ in the (1−0) transition and 24″ in (2−1); no attempt was made to account for the different beam sizes.

There are several recently published surveys of millimeter CO emission in external galaxies (e.g. Stark et al. (1987), 100″ (HPBW); Verter (1987), 100″; Solomon & Sage (1988), 45″; Tinney et al. (1990), 60″; Sanders et al. (1991), 60″; Braine et al. (1993), 12 and 24″; Young et al. (1995), 45″; Elfhag et al. (1996), 33 and 44″). Because the spatial resolution is partly different from ours and because line parameters are not given in all the above mentioned surveys, a comparison of the pure observational data is usually difficult. Comparing our study with the FCRAO Extragalactic CO Survey (Young et al. 1995), one finds 15 common galaxies observed in the CO (1−0) line in a 45″ beam; the agreement of the line parameters is in general very good.

16 objects in our sample have also been observed by Elfhag et al. (1996) in the CO (1−0) transition, 10 of them even at SEST, 6 at Onsala. At SEST, Elfhag et al. did not detect NGC 232 and E93–G3 because they searched at other velocities; their failure to detect NGC 1637 cannot be explained. In 6 of the remaining objects the agreement is reasonable considering the noisiness of the spectra. However, for NGC 1482, although ours and their spectrum is of good quality and the observing positions are identical, the line profiles differ and there is a discrepancy of 50% in the integrated intensity; we do not have an explanation.

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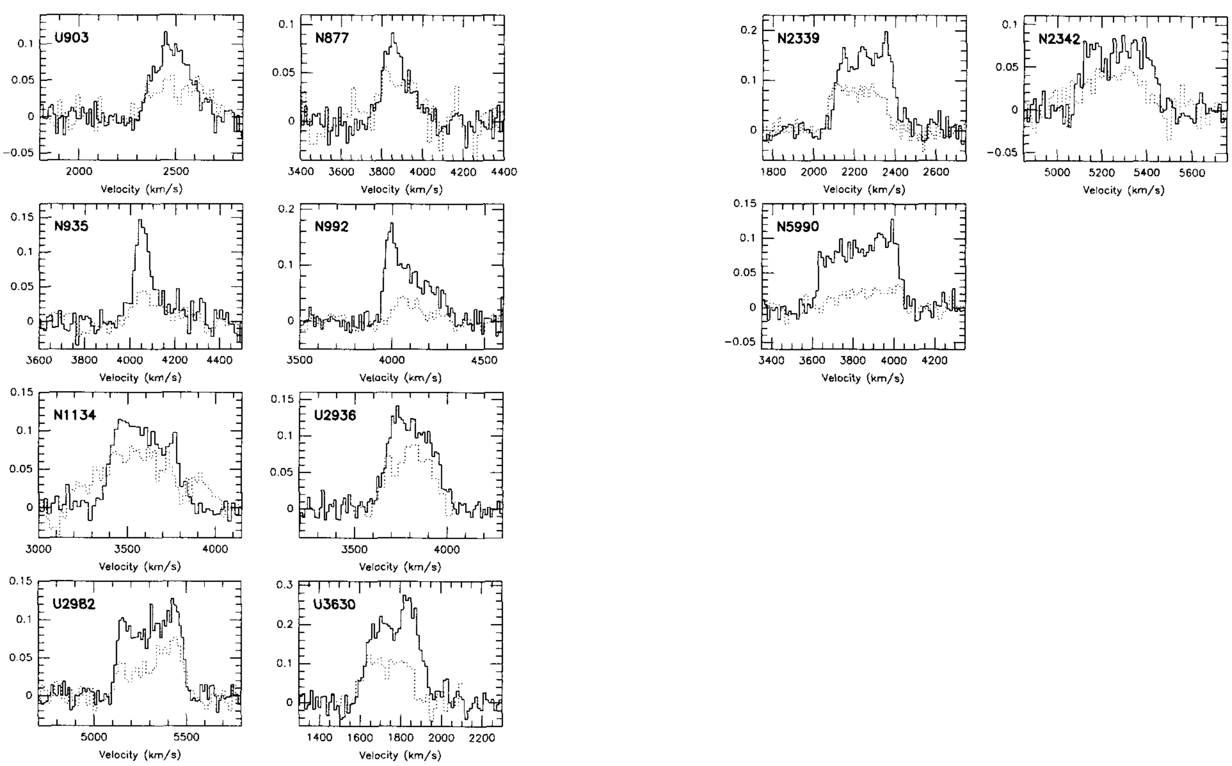

Fig. 3. Spectra of CO (2–1) from SEST (*dotted*) and of CO (1–0) from IRAM 30m (*solid*). Both refer to the same resolution of 24″. Ordinate gives $T_{\rm mb}$ in K

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Table 1. Dust emission in normal spirals

Name	*RA* [1950]	*Dec* [1950]	*D* [Mpc]	$S_{1300\ \mu m}$ [mJy] MRT 11″	SEST 24″	SEST 70″
NGC 0232	00 40 17.5	−23 50 02	90.9		30.3 ± 4.0	48 ± 5.7
UGC 00556	00 52 07.8	+28 58 27	61.2		14.3 ± 5.4	
E244-G12	01 15 56.9	−44 43 26	88.7		21.6 ± 3.7	
UGC 00903	01 19 06.6	+17 19 52	33.4		38.5 ± 5.8	
NGC 0633	01 34 11.1	−37 34 28	67.9			
NGC 0643	01 38 25.3	−75 15 45	52.9		29.4 ± 7.0	
E 3-G 7	02 03 08.6	−84 13 40	45.5		27.6 ± 6.6	
NGC 0834	02 08 00.3	+37 25 55	64.7	19.3 ± 3.4		
NGC 0877	02 15 15.2	+14 18 37	51.7	14.0 ± 4.2	27.0 ± 5.3	105 ± 12.3
NGC 0935	02 25 23.9	+19 22 22	54.5		21.4 ± 5.6	
NGC 0992	02 34 35.8	+20 53 06	54.7		14.7 ± 4.2	
NGC 1134	02 50 57.1	+12 48 42	48.0	21.3 ± 6.7	43.9 ± 9.0	142 ± 16.7
UGC 02627	03 13 55.7	+31 23 16	55.4	11.4 ± 3.1	1.1 ± 8.4	
NGC 1482	03 52 25.8	−20 38 54	25.2		72.3 ± 8.2	143 ± 15.7
UGC 02936	04 00 12.3	+01 49 39	49.9		26.5 ± 5.8	80 ± 11.5
UGC 02982	04 09 43.3	+05 25 12	70.0	13.1 ± 1.8	39.6 ± 5.1	55 ± 11.8
E118-G16	04 15 36.0	−60 19 40	14.9		20.8 ± 3.7	
UGC 03094	04 32 38.3	+19 04 07	98.8		38.1 ± 9.0	
E485-G 3	04 37 00.9	−24 16 52	60.3		14.5 ± 3.7	
NGC 1637	04 38 57.2	−02 57 12	9.5			
UGC 03356	05 44 15.9	+17 32 42	72.6		15.7 ± 17.2	
UGC 03490	06 30 38.8	+12 05 52		41.6 ± 1.3	137 ± 9.1	428 ± 31.3
UGC 03630	06 58 27.4	+01 58 57	23.3	16.2 ± 2.0	27.2 ± 5.6	81 ± 13.4
NGC 2339	07 05 24.9	+18 51 36	30.0	19.4 ± 2.4	35.3 ± 5.9	138 ± 13.6
NGC 2342	07 06 20.5	+20 43 04	69.3	11.9 ± 4.0	44.0 ± 8.8	103 ± 15.9
E491-G20	07 07 46.5	−27 29 14	40.1		26.2 ± 5.0	
NGC 2276	07 10 11.5	+85 50 53	32.3	17.6 ± 4.8		
NGC 2397	07 21 29.6	−68 54 17	17.8		35.4 ± 6.1	94 ± 12.9
E493-G16	07 46 39.0	−26 07 11	34.7		26.1 ± 5.1	
E494-G 1	07 53 00.1	−25 13 33			34.9 ± 4.4	60 ± 9.4
NGC 2532	08 07 04.1	+34 06 17	68.8	7.1 ± 8.9		
E430-N22	08 07 37.0	−28 58 28			32.5 ± 5.6	91 ± 9.6
NGC 2640	08 36 05.1	−54 56 51	14.0		42.9 ± 6.1	
E126-G 2	09 12 15.8	−60 34 56	38.5		33.1 ± 5.9	
E126-G 3	09 13 23.6	−60 13 35	39.0		13.0 ± 4.5	
E 91-G16	09 36 57.5	−63 15 37			21.3 ± 5.6	
E 61-G11	09 37 32.4	−69 51 56			25.4 ± 7.9	
NGC 2967	09 39 29.3	+00 33 58	27.3	−0.2 ± 3.0		
NGC 3067	09 55 26.1	+32 36 32	19.0	11.9 ± 1.9		
NGC 3177	10 13 48.6	+21 22 24	17.3	18.6 ± 2.0		
E500-G34	10 22 10.0	−23 17 59	48.8			
NGC 3437	10 49 52.8	+23 12 04	15.1	10.6 ± 1.5		
E264-G57	10 56 44.8	−43 10 18			26.3 ± 4.4	
E 93-G 3	10 57 33.0	−66 03 54	24.5			
NGC 3504	11 00 28.5	+28 14 27	20.7	22.0 ± 1.7		
NGC 3800	11 37 37.6	+15 37 08	44.0	15.4 ± 2.1		
NGC 3882	11 43 36.9	−56 06 32	25.1		40.3 ± 7.7	116 ± 15.1
NGC 3987	11 54 46.2	+25 28 24	59.4	23.3 ± 2.8		
NGC 4041	11 59 38.8	+62 24 53	17.9	18.7 ± 4.5		
NGC 4273	12 17 22.3	+05 37 17	31.7	11.9 ± 2.6		

Table 1. continued

Name	RA [1950]	Dec [1950]	D [Mpc]	$S_{1300\ \mu m}$ [mJy] MRT 11″	SEST 24″	SEST 70″
NGC 4418	12 24 22.1	−00 36 14	28.3			
NGC 4575	12 35 09.0	−40 15 48	70.0		30.1 ± 6.6	
E381-G 8	12 38 10.2	−36 28 52	43.7		16.9 ± 3.7	
NGC 4785	12 50 36.7	−48 28 46	49.8			
NGC 4808	12 53 15.9	+04 34 32	8.9			
NGC 4900	12 58 05.8	+02 46 12	12.0			
NGC 5156	13 25 41.4	−48 39 31	39.6			
E509-G54	13 30 07.9	−23 57 04	65.7		10.1 ± 4.2	
NGC 5258	13 37 22.2	+01 05 13	90.3			
NGC 5480	14 04 30.4	+50 57 46	26.9	10.7 ± 3.6		
E221-G32	14 08 53.3	−49 09 22	38.5		21.6 ± 7.8	
NGC 5600	14 21 25.8	+14 51 53	30.9	5.6 ± 7.2		
NGC 5653	14 28 00.2	+31 26 17	46.7			
E272-G14	14 28 27.2	−43 11 55	25.3		55.5 ± 8.4	146 ± 22.0
NGC 5665	14 29 57.4	+08 17 59	29.7	25.0 ± 15.4		
E272-G23	14 36 55.4	−44 06 14			23.1 ± 7.8	
NGC 5713	14 37 37.1	−00 04 34	25.4	17.1 ± 1.4	79.4 ± 12.0	158 ± 19.9
NGC 5719	14 38 22.6	−00 06 19	23.2	24.3 ± 4.0	32.5 ± 9.5	
NGC 5786	14 55 40.3	−41 48 51			40.6 ± 10.7	
E223-G12	15 05 49.9	−52 21 54	19.7		45.1 ± 10.3	
NGC 5915	15 34 13.8	+16 46 16	26.0	8.1 ± 2.0	39.7 ± 7.1	
NGC 5990	15 43 44.7	+02 34 11	50.7	13.1 ± 3.0	19.9 ± 5.9	
NGC 6000	15 46 44.1	−29 14 08	29.3	42.7 ± 3.9	60.6 ± 7.8	122 ± 12.8
NGC 6181	16 30 10.1	+19 55 49	31.6	8.4 ± 4.0	19.7 ± 4.8	
NGC 6156	16 30 28.2	−60 30 55	43.5		42.1 ± 5.6	163 ± 16.7
NGC 6215	16 46 47.2	−58 54 32	20.7		35.8 ± 3.8	128 ± 12.1
UGC 11041	17 53 04.5	+34 46 59	64.7	22.5 ± 3.4	16.3 ± 12.1	
E140-IG10	18 09 20.2	−57 44 28	68.7		35.2 ± 5.2	82 ± 11.2
NGC 6574	18 09 35.1	+14 58 05	29.3	30.7 ± 5.4	41.9 ± 7.1	134 ± 15.7
E282-G 3	18 57 28.1	−45 23 05	67.7		29.5 ± 7.4	49 ± 9.8
NGC 6753	19 07 11.5	−57 07 57	42.0		44.6 ± 4.8	124 ± 10.8
NGC 6796	19 20 50.8	+61 02 53	31.6	15.3 ± 3.5		
NGC 6808	19 38 30.8	−70 45 02	44.6		20.5 ± 4.0	37 ± 0
NGC 6824	19 42 36.3	+55 59 18	47.8	17.3 ± 2.9		
M+04-48-2	20 26 26.3	+25 33 53		14.3 ± 3.4	38.6 ± 9.0	81 ± 12.9
NGC 6918	20 27 15.4	−47 38 33	24.0		18.7 ± 5.4	45 ± 8.0
E286-G35	21 00 52.5	−43 47 32			25.4 ± 4.2	
NGC 7083	21 31 50.0	−64 07 33	41.1		22.4 ± 5.2	77 ± 10.1
NGC 7130	21 45 19.7	−35 11 04	64.4		32.9 ± 4.3	101 ± 10.5
NGC 7172	21 59 07.0	−32 06 42	34.3		34.2 ± 6.4	48 ± 7.7
E467-G27	22 11 49.6	−27 42 51	70.0		17.9 ± 5.5	38 ± 8.9
E405-G 5	22 13 12.9	−37 05 39	45.3		48.5 ± 3.9	185 ± 15.8
E602-G25	22 28 42.8	−19 17 31	101	22.0 ± 6.4	24.9 ± 4.2	
E346-G22	22 56 39.3	−37 58 18	17.2		11.4 ± 3.8	78 ± 10.6
NGC 7448	22 57 34.4	+15 42 48	29.4	11.8 ± 1.8	32.9 ± 7.0	90 ± 12.3
NGC 7590	23 16 09.7	−42 30 48	20.7		16.5 ± 3.3	86 ± 12.7
NGC 7769	23 48 31.0	+19 52 18	56.9			

Table 2. CO emission in normal spirals

Name	CO (1 – 0)						CO (2 – 1)						$I^{(2-1)}_{(1-0)}$	
	MRT (24″)			SEST (45″)			MRT (12″)			SEST (24″)			24″	SEST
	v	dv	T_{mb}	v	dv	T_{mb}	v	dv	T_{mb}	v	dv	T_{mb}		
NGC 0232				6814	433	25				6667	88	65		1.52
										6901	183	60		
UGC 00556				4595	373	15								
E244-G12				6658	275	21				6741	201	67		1.63
UGC 00903	2417	133	47	2395	220	15	2500	138	220	2433	174	44		1.81
	2514	189	80	2580	202	21				2625	145	40		
NGC 0633				5152	141	30								
NGC 0643				3917	226	33								
E003-G07				3539	74	80								
NGC 0877	3862	143	80	3870	342	32	3871	132	92	3865	213	46		0.90
NGC 0935	4055	86	135	4084	256	25	4078	82	87	4085	172	41		1.12
NGC 0992	3991	67	131	3998	60	30	3992	78	204	3977	41	61		1.81
	4118	245	83	4131	233	20				4007	295	31		
NGC 1134	3482	169	107	3489	277	29	3504	189	166	3539	471	71		2.63
	3687	236	89	3720	144	32	3715	151	68					
UGC 02627	4150	35	72	4159	179	24	4143	34	52					
NGC 1482				1887	259	84				1938	183	184		1.55
UGC 02936	3721	130	106	3644	136	21	3719	119	164	3792	226	82		1.58
	3869	193	104	3792	338	37	3865	165	101					1.58
UGC 02982	5192	148	94	5182	185	30	5188	140	84	5209	178	35		1.87
	5395	168	116	5392	110	34	5369	205	117	5413	148	74		
E118-G16				1107	130	49				1121	144	86		1.93
UGC 03094				7239	482	15								1.03
E485-G03				4523	305	19								
NGC 1637				732	124	60								
UGC 03356				5453	285	18				5385	397	20		1.60
UGC 03630	1692	125	203	1629	85	40	1678	109	216	1663	110	111	0.46	2.17
	1841	129	257	1776	199	46	1825	133	269	1804	117	113		
NGC 2339	2162	123	134	2122	113	49	2172	126	240	2121	88	79	0.52	1.59
	2320	164	170	2295	173	51	2328	149	217	2265	179	80		
NGC 2342	5149	92	69	5186	265	25	5202	175	115	5248	262	47	0.52	1.88
	5325	204	82				5367	118	94					
E491-G20				3003	192	32				3063	299	24		2.06
NGC 2276	2440	36	470				2440	31	430					
NGC 2397				1337	251	54				1315	121	76		0.75
E493-G16				2568	170	87				2648	214	88		0.82
				2719	71	82								
NGC 2532				5163	102	65								
NGC 2640				985	106	15				1001	115	31		2.45
				1229	169	14				1243	237	25		
E126-G02				2886	116	44				2909	126	95		2.37
E126-G03				2928	245	26				2893	165	73		1.92
NGC 2967				1828	34	90				1839	31	74		0.58
				1887	69	82				1879	35	77		
NGC 3177				1256	93	67				1305	127	81		1.19
				1370	56	97				1374	37	93		
E500-G34				3655	278	15								
NGC 3437				1207	221	27				1305	312	25		1.26
				1365	77	41				1382	46	84		
E093-G03				1841	225	18								
NGC 3504				1465	60	100								
				1580	119	110								

Table 2. continued

Name	CO (1 − 0)						CO (2 − 1)						$I\frac{(2-1)}{(1-0)}$	
	MRT (24″)			SEST (45″)			MRT (12″)			SEST (24″)			24″	SEST
	v	dv	T_{mb}	v	dv	T_{mb}	v	dv	T_{mb}	v	dv	T_{mb}		
NGC 3800	3216	206	91	3217	84	30	3197	174	104					
				3397	222	22								
NGC 3882				1879	100	73				1864	123	82		1.43
NGC 3987	4350	350	100	4470	455	36								
NGC 4273				2380	225	37								
NGC 4418				2123	112	25								
E381-G08				3216	82	17				3228	170	31		3.10
				3318	46	23				3343	59	52		
NGC 4785				3714	504	17								
NGC 4808				759	165	35				819	86	72		1.06
NGC 4900				972	51	97				976	35	108		0.77
NGC 5156				2968	145	52				2956	160	75		1.58
E509-G54				4705	153	40								
				4898	114	41								
NGC 5258				6787	279	11								
E221-G32				2885	85	87				2876	90	93		1.62
NGC 5600				2317	50	92								
NGC 5653				3451	88	55								
				3586	178	25								
E272-G14				1965	108	100				1981	98	95		0.86
NGC 5665				2227	177	34				2211	169	45		1.30
NGC 5713				1909	104	191				1915	95	376		1.79
NGC 5719	1730	400	100	1743	361	28	1730	400	95					
E223-G12				1478	205	27								
NGC 5915				2277	122	27				2272	139	51		2.15
NGC 5962				2004	340	35				2110	80	65		0.44
NGC 5990	3760	232	91	3798	350	28	3750	202	83	3886	295	26	0.31	0.80
	3961	134	100				3950	143	84					
NGC 6000				2136	212	94				2154	250	117		1.46
NGC 6181				2373	275	37				2429	237	58		1.37
NGC 6156				3263	182	71				3249	213	136		2.19
NGC 6215				1556	40	236				1565	44	235		1.09
UGC 11041	4700	90	122	4772	202	27	4695	107	128					
	4863	260	110	4979	102	26	4887	200	131					
E140-G10				5044	68	24				5103	299	49		
				5182	183	21								
NGC 6574				2250	236	62				2246	188	47		0.67
E282-G03				5083	269	25								
NGC 6753				2990	64	73				2998	90	95		0.53
				3247	255	33								
NGC 6808				3348	176	34				3330	140	55		1.36
NGC 7083				3187	70	66				3120	251	34		0.86
				3304	107	75								
NGC 7130				4830	85	163				4872	96	187		1.30
NGC 7172				2289	216	22								
				2659	439	23								
E467-G27				5386	132	28								
				5200	212	14								
E405-G05				3296	166	51				3350	216	151		2.61
				3480	150	70				3500	111	137		
E602-G25				7462	215	17				7495	208	42		2.47
				7698	165	15				7706	164	40		

Table 2. continued

Name	CO (1 − 0)						CO (2 − 1)						$I\frac{(2-1)}{(1-0)}$	
	MRT (24″)			SEST (45″)			MRT (12″)			SEST (24″)			24″	SEST
	v	dv	T_{mb}	v	dv	T_{mb}	v	dv	T_{mb}	v	dv	T_{mb}		
E346-G22				1292	56	28				1260	159	41		4.14
NGC 7448				2205	205	27				2237	139	37		0.92
NGC 7590				1553	259	26				1507	205	45		1.37
NGC 7769				4232	245	38				4261	226	58		1.42