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An optically directed HI search for new dwarf members of the M 81 group

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Abstract. We present a search for neutral hydrogen (HI) emission from optically identified dwarf galaxy candidates in the larger M 81 group area. Of 136 candidates, 68 galaxies have been detected (this corresponds to a detection rate of $\sim$ 49%). Most of the detected galaxies are background objects and fail to be classified as dwarfs. Many known dwarfs in the M 81 group have been detected, but no new members have been discovered.

Key words: galaxies: irregular — radio lines: galaxies — galaxies: M 81 — galaxies clusters M 81 group

1. Introduction

1.1. Searching for dwarf galaxies

Until very recently, the Las Campanas surveys of the Virgo cluster (Binggeli et al. 1985) and the Fornax cluster (Ferguson 1989) were about the only galaxy catalogs complete down to low luminosities. The Local Group and the catalog of nearby galaxies (Kraan-Korteweg & Tammann 1979; KKT) are easily affected by incompleteness (e.g., Irwin et al. 1990), especially in the zone of avoidance (e.g., Kraan-Korteweg et al. 1994; Huchtmeier et al. 1995; McCall & Buta 1995; Huchtmeier et al. 1997). Studies of nearby groups of galaxies were usually confined to only a small part of the sky and, due to the groups' small distances, are not sensitivity limited.

Recently, Côté (1995) has surveyed the nearby Sculptor and Centaurus groups, and discovered nine new dwarf members. This adds support to the notion that the census of nearby galaxies, particularly low surface brightness galaxies, is far from complete (e.g., Shade & Ferguson 1994).

There are several good reasons to look for more nearby dwarf galaxies. The first, obvious reason is to improve completeness of the sample of nearby galaxies (e.g., KKT) for the luminosity function of the "field sample".

A second goal is a study of group dynamics. HI spectra provide the only practical method for obtaining radial velocities of the very low surface brightness galaxies. A large population of dwarf galaxies with known radial velocities will allow a new estimate of the mass distribution of the M 81 group. The finding of Bothun et al. (1987) that a previously cataloged dwarf galaxy in the Virgo cluster is indeed a massive low surface brightness background galaxy stresses both the need for radial velocity measurements in such studies and the opportunity for important serendipitous discoveries.

A further motivation is to find additional very low mass galaxies. Without velocity information it is impossible to distinguish between truly low mass galaxies and low surface brightness background galaxies. HI line-widths give an additional clue to discriminate against higher mass systems. Skillman et al. (1988, 1989a,b) have shown that extremely low mass galaxies hold the most promise for finding regions of near-primordial abundances. Follow-up CCD H-alpha imaging of the most promising candidates can then lead to the identification of HII regions for chemical abundance studies. The lowest mass galaxies are also important for helping to determine the trend of mass-to-light ratio with total luminosity (Côté 1995).

1.2. The M 81 Group

In his review of nearby groups of galaxies, de Vaucouleurs (1975) identified the M 81 group as the second closest group to ours at a distance of 2.5 Mpc. Modern Cepheid distance measurements of M 81 place it at a distance of 3.6 Mpc (Madore et al. 1993). de Vaucouleurs noted that the precise extent of the M 81 group was not well determined, as it appeared that other nearby galaxies (e.g., NGC 2403, NGC 2366, NGC 4236) could be outlying members of the M 81 group, which, itself, might be a condensation in a larger "cloud". Geller & Huchra (1983) identified the M 81 group

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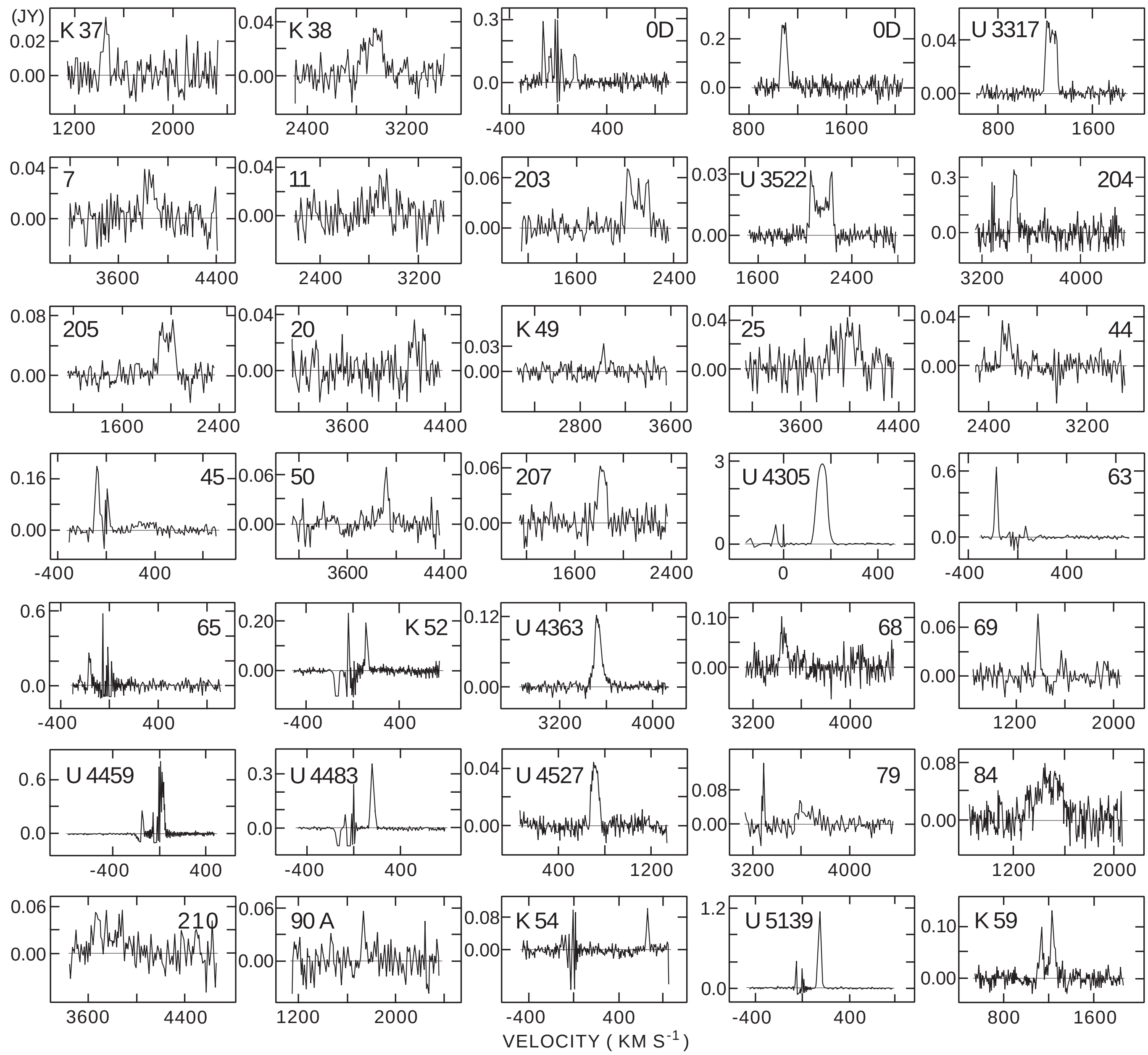

Fig. 1. a) H I profiles of the detected galaxies as seen with the 100-m radio telescope at Effelsberg which has a half power beam width of 9.3′ at 21-cm wavelength. As local HI is observed all over the sky our (ON – OFF) observing procedure produces the difference of the local emission between the source and the reference position at local velocities around zero km s^{-1}

(their group No. 52) among the bright galaxies contained in the CfA catalog as a smaller, more concentrated distribution than de Vaucouleurs.

Tully (1988) produced a catalog of galaxies judged to be reasonably complete out to ∼ 25 Mpc. Using this catalog, Tully (1987) identified groups (thought to be gravitationally bound and virialized entities), associations, and clouds. From his analysis, the M 81 group is found to be more extended (in agreement with de Vaucouleurs original definition) and lying in the Coma – Sculptor Cloud, which contains many familiar nearby groups (M 81, the Local Group, the Sculptor Group, and the Centaurus Group).

Given the extended nature of the M 81 group, it was clear that a successful search would need to cover a large area of the sky. There are several catalogs containing optical information on M 81 dwarf galaxies; we have used the catalogs by Karachentseva (1968), Börngen et al. & Karachentseva (1982) and Börngen et al. (1982) who list 39 faint probable members of the M 81 group excluding the known bright galaxies that usually are taken to identify this group (e.g., de Vaucouleurs 1975). These dwarf

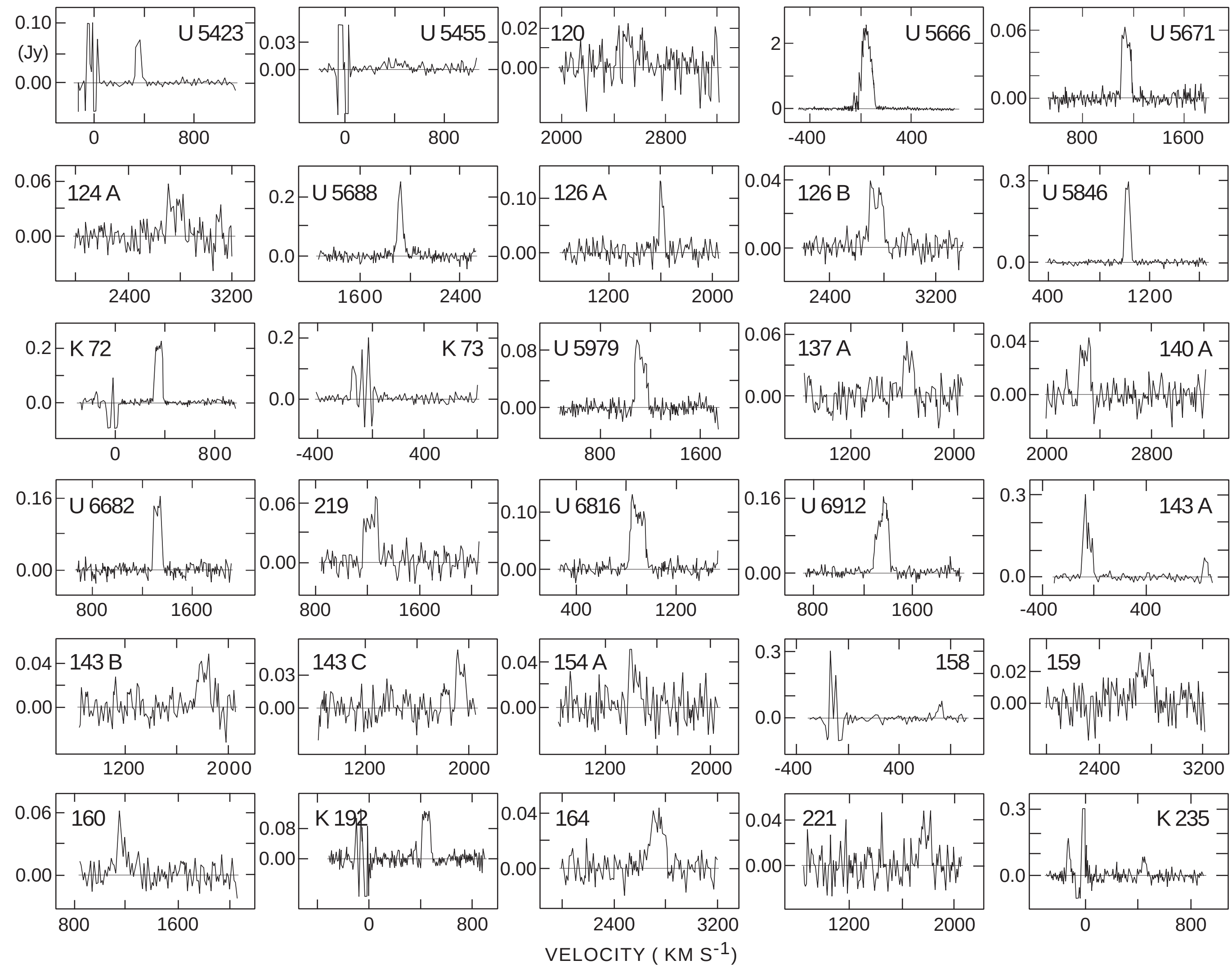

Fig. 1. b) H I profiles of the detected galaxies as seen with the 100-m radio telescope at Effelsberg which has a half power beam width of 9.3′ at 21-cm wavelength. As local HI is observed all over the sky our (ON − OFF) observing procedure produces the difference of the local emission between the source and the reference position at local velocities around zero $\mathrm{km\,s^{-1}}$

galaxies have been further classified concerning probable membership by Karachentseva et al. (1985). Lo et al. (1986) conducted a deep IIIa-J survey of the M 81 group covering 36 fields using the 48 inch Palomar Schmidt. After visually searching the plates for low surface brightness objects, 137 candidate dwarf galaxies were detected of which 57 were judged to be group members. We composed a search list from the above named catalogs, which amounts to 136 candidate dwarf galaxies roughly in the range $65^\circ \leq$ Dec. $\leq 80^\circ$ and $7^{\mathrm{h}}\ 30^{\mathrm{m}} \leq$ R.A. $\leq 13^{\mathrm{h}}$. Most of these dwarfs have crude visual magnitudes of 17 to 19 mag (absolute magnitudes of -11 to -9 at the distance of the M 81 group), diameters around 1 arcmin or less, and classifications of type Im with a few E type or spheroidals (Börngen spheroidals were not detected in HI). A few galaxies are very close to brighter galaxies of this sample. This confusion could not be resolved as most probably the detections are due to the brighter galaxies.

2. New Effelsberg HI observations

Observations were performed in 1987/88 and 1991 using the 100 m radio telescope at Effelsberg which has a half power beam width of 9.3 arcmin for the 21 cm HI line. A FET receiver in the first run and a HEMT receiver in the latter run yielded a total system noise of 60 K and 30 K respectively. The total power mode was applied observing an on-source position followed by an empty reference field which was subtracted from the former in order to reduce instrumental effects. Pointing is believed to be about ±15 arcsec rms Some of the optical positions are not known to better than 1 arcmin. However, this is small compared to the telescope beam of 9 arcmin. Galaxies with optical velocities were observed with a velocity range of 1250 km s^{-1} (with a resolution of 6 km s^{-1}). The radial velocity range of the M 81 group overlaps with velocities of local hydrogen. This "confusion" essentially could not be solved. Fainter signals adjacent to the range of velocities of local hydrogen were checked by both frequency modulation and rudimentary mapping. All such features which were suspected to be due to galaxies were found to be extended considerably larger compared to known extended haloes and to show velocity gradients different to what one would expect from a rotating galaxy. Therefore they were considered to be local emission.

We aimed for a detection limit of 10^6 solar masses in HI at the distance of M 81. For comparison, the dwarf M 81 dwA (Lo & Sargent 1979) has an HI flux of 4.2 Jy km s^{-1} (line width of 22 km s^{-1}) which corresponds to 7.2 10^6 solar masses.

In order to identify background galaxies, a larger range of radial velocities had to be searched. The 1024 channel autocorrelator was split into four banks of 256 channels using a bandwidth of 6.25 MHz each resulting in a resolution of 6 km s^{-1} and a velocity coverage from -400 km s^{-1} to 4000 km s^{-1}. Galaxies not detected in this velocity range were searched at higher radial velocities. In Fig. 2 we present the HI profiles of 65 of the 68 detected galaxies. All emission features at negative radial velocities fall into the range of local HI, only two cases are shown in Table 1 (objects 63 and 65), not shown are 211, K63, and 223. In Table 1 we present the observational data: the galaxy's name in Col. 1 (where a bare number refers to the catalog of Lo et al., a K to that of Karachentseva, and a BK to the catalog of Börngen et al.) is followed by the 1950 position used for the observation (Col. 2), the galaxy type follows in Col. 3. H I data: the integrated HI flux (Col. 4) in Jy km s^{-1} is followed by the peak flux and the rms noise in Col. 5. The H I velocity (Col. 6) and the linewidths at 50%, 25%, and 20% of the peak (Col. 7) are followed by comments (Col. 8). A colon (:) in Col. 7 marks a rather uncertain value.

Recently van Driel et al. (1997, A.A. submitted) searched for HI emission in 23 dwarfs in the area around M 81; they detected three background galaxies (UGC 4998, Kar 1N, and UGC 5658) and improved the existing upper limits.

The typical rms noise was in the range 0.003 to 0.01 K; assuming line widths of 15 or 30 km s^{-1} (which are typical for small dwarf galaxies) and three times the rms noise this corresponds to an HI line integral of 0.1 to 0.6 Jy km s^{-1} or to 0.3 to 1.8 10^6 solar masses of HI at the distance of the M 81 group (3.6 Mpc). This represents a detection limit much better than needed for the M 81dwA system. However this galaxy remains at the lower end of the HI fluxes of the detected objects. 68 galaxies (a detection rate of 49%) were detected; most of which are background objects. Figure 2 shows the radial velocity distribution of these galaxies which is like that of a magnitude limited sample of galaxies rather than that of a group of galaxies at a certain distance.

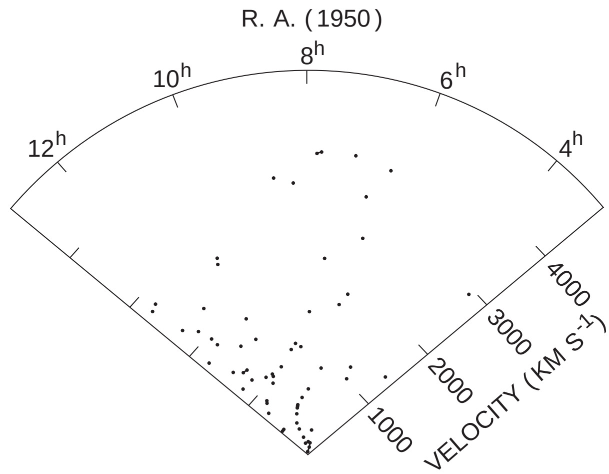

Fig. 2. The detected galaxies are plotted as a function of right ascension and radial velocity in this cone diagram. Only the very center ($v \leq 300$ km s^{-1}) is the M 81 group

3. The M 81 group galaxies

In Fig. 2 we present a cone diagram for the detected galaxies. Summed over the declination range 65 to 80 degrees the galaxies are displayed in R.A. versus radial velocity. Only the very center of this plot ($v \leq 300$ km s^{-1}) represents the M 81 group. This cone diagram does not show a complete sample of galaxies, hence this diagram does not necessarily document the structure of the nearby universe. It is evident from this figure that all newly detected galaxies are far more distant than the M 81 group.

Galactic hydrogen in the foreground roughly covers a velocity range of -150 to 50 km s^{-1}. About one third of the known M 81 group members have radial velocities in this interval. Therefore we probably miss a number of galaxies in this velocity interval due to confusion with the strong foreground emission of Galactic hydrogen.

4. Conclusions

This survey of dwarf galaxies in the M 81 group area revealed:

1) a detection rate of 49%, most of which are background galaxies relative to the M 81 group, and

2) no new HI rich dwarfs in the M 81 group. With the detection limit in mind, this result is unexpected. HI-observations of the Centaurus and Sculptor groups (Côté 1995) yielded 9 new HI rich dwarf members around those groups with a detection limit of about 10^7 solar masses.

While it is true that the velocity range covered by local neutral hydrogen prohibits detection of faint galaxies within this range, we would still expect at least a dozen or so dwarf galaxies to be detectable in the M 81 group if it had a luminosity function similar to that of the Centaurus and Sculptor groups. The undetected galaxies might be either low surface brightness galaxies in the background or dwarf ellipticals in the M 81 group itself.

In their study on dwarf galaxies Binggeli et al. (1990) concluded that "dwarf galaxies obey a morphology-density relation like the giants", and "dEs prefer strongly dense environments on all scales". Hence the different dwarf population of the Centaurus and Sculptor groups on one side and the M 81 group on the other side might just be documenting the large variety in the population of groups.

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Table 1. Observed parameters

Galaxy name	position (1950.0) R.A. Dec.	type	HI flux [Jy km s^{-1}]	S_{max} [mJy]	HI-velocity	HI-linewidths [km s^{-1}]	comment
K37	03 29 00 57 55		1.2	25±8	1452±6	88 97 99	
K38	03 29 00 68 12		3.5	33±8	2969±5	208 330 354	
OC	05 18 48 73 16	Irr		±10			UGC 3297, multiple
201	05 19 00 76 24			±8			diffuse
OD	05 23 18 72 25	Irr	11.7	224±8	1089±1	52 69 71	extremely diffuse
UGC 3317	05 27 30 73 42	Irr	12.5	124±8	1240±1	110 119 121	DDO 38
202	05 53 06 68 33			±10			
5	06 11 06 74 50	Irr		±10			smooth
7	06 22 00 70 48	Irr	2.3	50±11	3860±3	97 105 125	
7A	06 22 00 82 54	S/Irr		±11			UGC 3461
10	06 38 36 80 10	S/Irr		± 8			
11	06 38 42 63 46	Irr	2.4	50±11	2900±15	67 71 72	
203	06 40 54 84 57		6.3	66±8	2134± 5	203 210 213	diffuse
UGC 3522	06 41 00 84 58	S/pec	9.0	75±7	2132±5	201 212 216	
204	06 45 36 61 40		4.2	100±6	3450±2	45 55 57	UGC 3545
205	06 52 36 61 15		7.1	75±8	1970±2	140 142 146	
18	06 59 12 64 08			±17			
20	07 01 00 66 01	Irr	2.8	32 ±8	4174±5	109 148 149	
K49	07 02 42 71 57			±5			
22	07 03 06 78 30			±11			UGC 3671
23	07 03 12 65 22	Irr		±8			
25	07 06 36 59 20	Irr	4.9	33±7	3968±15	250:	
28	07 10 36 65 03	Irr		±12			
31	07 16 48 67 12	Irr		±11			
33	07 19 30 60 15	Irr		±17			
38	07 23 18 60 59	Irr		±12			
42	07 25 48 65 29	Irr		±8			
44	07 29 36 73 04	Irr	1.3	30±6	2592±4	78 91 92	
45	07 30 54 60 35	Irr	2.7	25±5	300±10	138 171 193	
46	07 34 42 59 20	S		±8			
50	07 47 42 73 36		0.8	25±6	3982±4	99 101 122	
207	07 58 18 86 17		3.4	58±8	1850±2	58 76 78	
UGC 4305	08 14 06 70 52	Irr	168.1	3104±20	160±1	53 67 70	DDO 50, HoII
63	08 14 12 63 05	Irr	11.7	590±8	-180±1	19 28 30	DDO 71
64	08 16 06 65 51	S/Irr		±8			
65	08 16 18 66 18		4.3	224±35	-154±5	42 44 49	
K52	08 18 42 71 12	Irr	4.2	200±3	112±5	19 30 36	M81dwA
UGC 4363	08 19 18 74 36	SBc	9.2	133±7	3529±10	64 95 105	DDO 51
68	08 19 42 74 31	Irr	3.7	83±11	3450±5	50 70 80	
69	08 21 42 79 00	Irr	2.1	75±8	1399±6	24 32 34	
70	08 23 00 72 26	Irr		±12			DDO 53
73	08 32 06 69 58	Irr	13.0	380±8	159±1	32 47 50	UGC 4483
75	08 36 42 69 53	S		±11			
UGC 4527	08 38 00 77 06	Irr	3.2	48±4	720±3	72 140 150	
208	08 40 54 78 43			±17			UGC 4563/4566
79	08 41 30 78 43	Irr	3.9	44±8	3634±5	117 128 158:	
82	08 44 36 73 38	Irr		±22			
84	08 47 30 78 27		10.4	66±7	1476±6	187 276 293	
210	08 50 48 58 40		6.1	190±12	-172±1	33 38 39	
			6.2	55±13	3753±9	238 258 263	
K53	08 50 48 72 12			±5			diffuse
211	08 53 18 60 57		10.4	280±8	-175±1	33 47 48	diffuse
212	08 59 06 79 06			±25			very diffuse
213	09 02 24 59 33			±12			
89	09 09 00 60 12			±11			
90A	09 17 30 85 32	S/Irr	1.8	50±7	1730±5	28 48 49	
K54	09 17 36 75 57 00		2.4	120±15	659±1	15 27 30	
U4998	09 20 48 68 37 00			±6			
93A	09 24 00 86 18	Irr		±8			diffuse
UGC 5139	09 36 00 71 35	Irr	38.7	1235±13	143±1	29 40 44	DDO 63, HoI, K57

Table 1. continued

Galaxy name	position (1950.0) R.A. Dec.	type	HI flux [Jy km s^{-1}]	$S_{\max}$ [mJy]	HI-velocity	HI-linewidths [km s^{-1}]	comment
97	09 36 24 58 46	S		±12			
1N	09 41 00 69 37 12		4.2	85±6	571±2	53 69 75	
101	09 43 18 71 28	Irr		±8			diffuse
BK2	09 43 43 69 30 24			±6			
103	09 46 06 67 45			±12			
K59	09 47 06 72 19		8.4	108±5	1181±3	140 168 171	
BK3	09 49 42 69 12 24			±11			
215	09 52 30 58 31			±11			
108	09 56 30 63 27			±12			
BK4	09 59 56 68 25 18			±11			
BK5	10 00 44 68 29 54			±8			
UGC5423	10 01 25 70 36 27		3.4	76±5	350±3	47 58 60	
K63	10 01 36 66 46		4.2	133±3	-126±5	27 43 50	
K64	10 02 12 68 03			±10			
UGC 5455	10 04 54 70 53	Irr	1.7	17±3	428±8	142 182 184	K66
117	10 17 36 71 21			±11			
UGC 5612	10 20 06 71 08	SB		±6			DDO 77
120	10 22 48 67 54		1.8	19±7	2550±9	210 240 255	
U5658	10 23 54 71 29		1.2	37±7	1126±1		
UGC 5666	10 24 48 68 40	S	184	2880±36	57±2	77 91 95	DDO 81
123	10 25 06 63 25	Irr		±11			
UGC 5671	10 25 18 67 04	Irr	4.6	68±5	1136±2	70 91 94	K69
124A	10 26 30 74 30	S	3.6	60±8	2820±4	120 129 132	
UGC 5688	10 26 36 70 19	SBm	13.0	266±15	1920±2	46 61 76	DDO 80
126A	10 27 30 78 04	Irr	3.5	100±6	1624±2	38 45 50	UGC 5701
126	10 28 48 70 53			±8			DDO 82
126B	10 30 30 79 24	SB	3.2	42±5	2748±4	102 124 127	UGC 5728 126B
BK6	10 31 02 66 16 12			±6			
127A	10 39 00 57 21	Irr		±12			diffuse
UGC 5846	10 41 12 60 38	Irr	15.1	324±8	1022±1	48 59 62	DDO 86
128	10 41 24 73 10	S		±8			
A1045+65	10 45 30 65 02			±6			
129	10 46 06 65 00	Irr		±12			UGC 5932
K72	10 46 18 65 49	Irr	15.4	245±9	340±1	66 76 79	DDO 87
BK7	10 47 07 65 22 24			±6			
A1047+65	10 47 12 65 00			±6			
K73	10 48 48 69 56		2.7	108±5	-132±6	27 35 37	
UGC 5979	10 49 12 68 14	Irr	7.4	100±9	1116±2	90 106 109	
134	10 49 54 69 48	Irr		±12			diffuse
A1050+65	10 50 30 65 31			±7			
BK8	10 51 06 65 28 12			±7			
K74	10 59 01 70 32 06	Irr		±8			
137A	11 04 12 61 48	Irr	4.1	52±11	1673±5	76 88 90	
216	11 14 48 68 04			±17			
138	11 19 12 69 25	S/Irr		±17			UGC 6381
138B	11 24 36 79 16	pec		±4			UGC 6456
217	11 24 42 79 53			±8			
218	11 31 06 76 38			±12			
140	11 31 30 74 31			±17			
140A	11 32 36 57 05		1.7	42±12	2317±2	84 86 89	
UGC 6682	11 40 30 59 23		10.9	174±12	1326±1	68 81 83	
219	11 46 12 57 41		4.1	66±11	1200±4	100 112 113	
UGC 6816	11 48 06 56 44		13.8	137±9	888±2	116 136 139	
UGC 6912	11 53 36 58 29		15.5	178±9	1347±1	91 127 130	
K84	11 54 30 56 33			±8			
143A	11 56 54 57 22		2.3	71±8	849±2	35 44 46	
143B	11 57 00 85 26		3.2	52±8	1841±5	100 110 118	
143C	11 58 00 79 08		4.0	48±13	1966±4	91 101 104	UGC 6996
148	12 10 18 69 13			±12			
150	12 11 30 59 50			±8			
154A	12 17 42 75 27		1.9	42±12	1421±3	86 95 97	

Table 1. continued

Galaxy name	position (1950.0) R.A. Dec.	type	HI flux [Jy km s^{-1}]	$S_{\rm max}$ [mJy]	HI-velocity	HI-linewidths [km s^{-1}]	comment
156	12 22 42 61 22		5.1	75±10	709±2	70 80 83	
158	12 24 24 62 40		2.0	80±12	711±2	34 40 41	UGC 7544
159	12 31 54 64 50		2.2	28±7	2780±9	132 141 156	UGC 7730
160	12 32 24 73 56		1.8	33±8	1190±3	56 160 165	
K162	12 33 00 58 40			±17			
162	12 34 48 74 32			±12			
K192	12 41 36 54 14		5.8	108±17	445±1	66 75 77	
164	12 42 00 64 05		2.6	46±13	2770±3	113 150 174:	
K195	12 42 10 71 03 46			±17			
167	12 43 24 63 18			±8			
168	12 46 00 60 33			±17			
221	12 47 24 78 39		1.9	25±5	1760±10	86 95 101	
222	12 47 54 80 16			±13			
170	12 49 00 78 40			±4			UGC 7995
223	13 22 24 74 38		8.1	183±4	-55±5	79 93 95	
176	13 29 06 79 04			±4			
K235	17 01 24 70 20		4.0	150±12	-134±6	26 36 39	
			1	75±12	440±10	40 42 45	