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H I observations of galaxies in the Virgo and Coma clusters

W. van Driel[1], **D. Ragaigne**[1,2], **A. Boselli**[3], **J. Donas**[3], **and G. Gavazzi**[4]

[1] Unité Scientifique Nançay, USR CNRS B704, Observatoire de Paris, 5 place Jules Janssen, F-92195 Meudon, France
[2] DAEC, UMR CNRS 8631, Observatoire de Meudon, 5 place Jules Janssen, F-92195 Meudon, France
[3] Laboratoire d'Astronomie Spatiale, BP. 8, Traverse du Siphon, F-13376 Marseille Cedex 12, France
[4] Universita degli Studi di Milano, Dipartimento di Fisica, Sezione Astrofisica, Via Celoria 16, I-20133 Milano, Italy

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Abstract. A total of 44 galaxies in the direction of the Virgo and Coma/Abell 1367 Clusters have been observed in the H I line at Nançay, 17 of which were clearly detected. These observations were obtained in order to complete the H I database for a large, optically selected, sample of galaxies in these two regions. Surveys in these regions at other wavelengths (UV, visible, near-, mid- and far-infrared, radio continuum) have been recently completed or are still underway.

Key words: galaxies: distances and redshifts — galaxies: general — galaxies: ISM — radio lines: galaxies

1. Introduction – the $z = 0$ galaxy sample

The physical properties observed in galaxies at different redshifts, pose strong observational constraints to models of galaxy formation and galaxy evolution. Hierachical and monolithic models predict different evolutions of star formation activity and hydrogen content of the Universe (Steidel et al. 1999; Pei & Fall 1995), and of the properties of individual galaxies and their inter-relationships. In this framework, the study of galaxies at $z = 0$ naturally plays a principal role since the small distance of the targets makes the aquisition and the interpretation of spectro-photometric data more accurate and easier than for high-redshift objects.

An exhaustive study of the phenomenology of galaxies at $z = 0$ can be done only through the use of a multifrequency analysis (UV, visible, Hα infrared, H I and CO), which is crucial for understanding the physical processes responsible for the emission at different wavelengths, as well as through the establishment of a sufficiently large, "unbiased" sample, crucial once the general properties of galaxies have been derived from the statistical analysis of a given sample, since different selection criteria can bring about opposite results. Statistical analyses can only yield strong observational constraints when the sample selection biases are known and understood.

The importance of acquiring a well-defined local reference sample of galaxies, which is both complete at various wavelengths as well as of sufficiently large size is evident. It enables statistical analyses which study the phenomenology of galaxies of different type and luminosity; construct a reference sample for studies at higher redshifts; test the prediction of chemo-spectrophotometric evolution models; study environmental effects; understand the properties of the ISM such as the gas-to-dust ratio; and study the relationship between the activity of star formation and the gas content in galaxies.

It is evident that H I line data are crucial for the analysis of all these points; not only because they can be used to determine the H I gas mass, but also since they can provide us with a dynamical measurement through the linewidth.

Working towards the acquisition of a full reference sample of galaxies, priority was given to two well-defined regions of the sky, the Virgo Cluster and the Coma/A1367 supercluster region, since:

- A number of surveys at other wavelengths are either completed or under way: UV at 2000 Å (Donas et al. 1995, and references therein), visible (Binggeli et al. 1985; Gavazzi & Boselli 1996; Boselli et al. in preparation), near-infrared (Gavazzi et al. 1996a,b, 2000; Boselli et al. 1997a, 2000), mid-infrared (Boselli et al. 1998), far-infrared (IRAS catalogues), radio continuum (Gavazzi & Boselli 1999a,b), CO line data (Casoli et al. 1991; Boselli et al. 1995, 1997b; Kenney & Young 1988), Hα data (Gavazzi et al. 1998; Boselli et al. in preparation);

- Their proximity allows the determination of accurate morphological classifications, expecially in Virgo, and the observation of low-luminosity galaxies ($M_b = -16$) at most of the above mentioned wavelengths;

Send offprint requests to: W. van Driel,
e-mail: Wim.vanDriel@obspm.fr

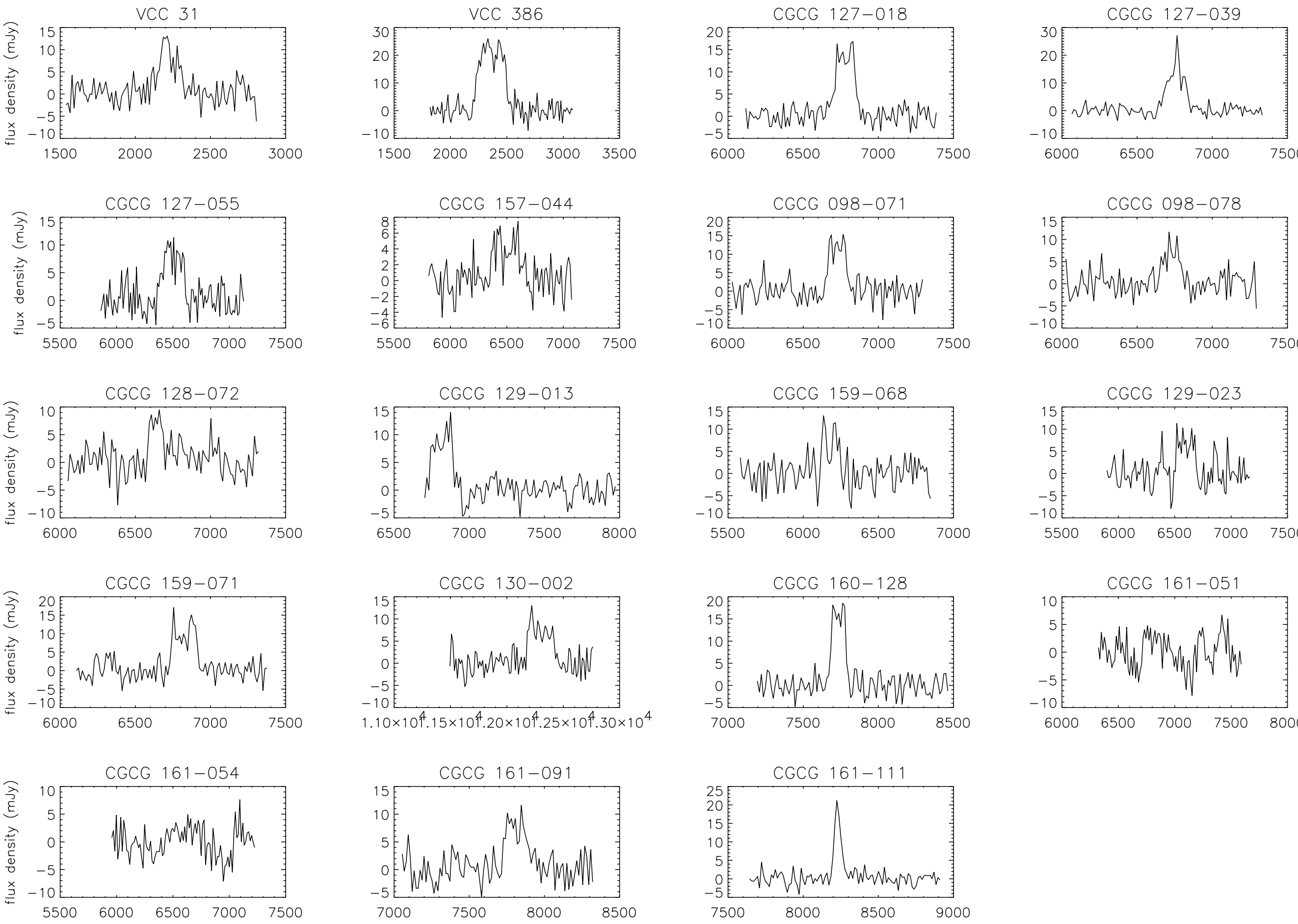

Fig. 1. Nançay 21-cm H I line spectra of all detections and marginal detections. Velocity resolution is 15.8 $\mathrm{km\,s^{-1}}$, radial velocities are according to the radio convention

- They span a large range in local galaxy density since they include rich clusters (Coma, A1367, Virgo), compact and loose groups, pairs and interacting galaxies and several isolated objects, and thus present ideal reference for environmental studies (Gavazzi et al. 1999a);

- Distance biases are minimized since isolated and cluster galaxies in the Coma/A1367 supercluster are all at the same distance, while Virgo galaxies are at the cluster distance (Gavazzi et al. 1999b);

- These two regions will be surveyed by the GALEX far-UV satellite (Martin et al. 1999). Given their proximity, the UV detection rate among the star forming objects belonging to the Virgo or the Coma/A1367 supercluster is expected to be high enough to construct a significant UV-selected sample, suitable for statistical analyses.

2. Sample selection

Whilst these two regions have previously been surveyed in H I (Gavazzi 1987; Hoffman et al. 1996, and reference therein), H I data are still lacking for many galaxies. The present project is aimed at completing the H I observations of galaxies with available redshift measurements. The inclusion of galaxies detected in the UV (at 2000 Å) was meant as a first step towards the construction of a UV-selected galaxy sample complete in H I. Most of these are early types (E/S0), but with blue colors, and our aim was to see whether H I is present in them.

- Sample 1: Virgo cluster: 8 spirals from the VCC catalogue (Binggeli et al. 1985), 6 brighter than $B_{\rm T} = 15$ and 3 of $B_{\rm T} \sim 16$, as well as 5 early-type galaxies;

- Sample 2: Coma/A1367 supercluster: 25 galaxies, practically all spirals brighter than $B_{\rm T} = 15.7$, and 6 galaxies detected in the UV.

Basic optical data for the galaxies observed in H I are listed in Table 1. The coordinates listed were used as the actual pointing centres for the Nançay radio telescope observations. Morphological types were taken from the on-line LEDA and NED databases; blue apparent magnitudes, $B_{\rm T}$, isophotal blue diameters, D_{25}, and optical velocities and their uncertainties, $V_{\rm opt}$, were taken from the mean data catalogued in LEDA.

3. Observations

The Nançay telescope is a meridian transit-type instrument of the Kraus/Ohio State design, consisting of a fixed spherical mirror, 300 m long and 35 m high, a tiltable flat mirror (200 × 40 m), and a focal carriage moving along a 90 m long curved rail track, which allows the tracking of a source on the celestial equator for about 1 hour. Located in the centre of France, it can reach declinations as low as −39°. It has an effective collecting area of about 7000 m^2 (equivalent to a 94-m diameter parabolic dish). Due to the elongated mirror geometry, at 21-cm wavelength it has a half-power beam width of $3\farcm6$ E−W × 22′ N−S for the range of declinations covered in this work (E. Gérard, private comm.; see also Matthews & van Driel 2000). Typical system temperatures were ∼40 K for our project. For a technical description of the telescope and the general methods for data handling and reduction see, e.g., Theureau et al. (1998) and references therein.

Our observations were made throughout the period between December 1998 and October 1999, using a total of about 150 hours of telescope time. We obtained our observations in total power (position-switching) mode using consecutive pairs of two-minute on- and two-minute off-source integrations. Off-source integrations were taken at approximately $2^{\rm m}$ E of the target position. The autocorrelator was divided into two pairs of cross-polarized receiver banks, each with 512 channels and a 6.4 MHz bandpass. This yielded a channel spacing of 2.64 $\rm km\,s^{-1}$ and an effective velocity resolution of ∼3.3 $\rm km\,s^{-1}$, which was smoothed to a channel separation of 13.2 and a velocity resolution of 15.8 $\rm km\,s^{-1}$ during the data reduction, in order to search for faint features. The centre frequencies of the two banks were set to the known redshifted H I frequency of the target.

We reduced our H I spectra using the standard Nançay spectral line reduction packages available at the Nançay site. With this software we subtracted baselines (generally third order polynomials), averaged the two receiver polarizations, and applied a declination-dependent conversion factor to convert from units of $T_{\rm sys}$ to flux density in mJy. The $T_{\rm sys}$-to-mJy conversion factor is determined via a standard calibration relation established by the Nançay staff through regular monitoring of strong continuum sources. This procedure yields a calibration accuracy of ∼15%. In addition, we applied a flux scaling factor of 1.26 to our spectra based on statistical comparisons (see Matthews et al. 1998; Matthews & van Driel 2000) of Nançay data of samples of late-type spirals with past observations of these galaxies made at Nançay and elsewhere.

4. Results

The reduced Nançay H I spectra are shown in Fig. 1 for the 19 detected and marginal objects only. Radial velocities, $V_{\rm HI}$, integrated line fluxes, $I_{\rm HI}$, velocity widths at 50% and 20% of peak maximum, W_{50} and W_{20}, and rms noise levels of our new spectra were measured using standard Nançay reduction software for galaxy observations. The H I profile parameters are listed in Table 1. The upper limits are 3σ values for flat-topped profiles with a width of 250 $\rm km\,s^{-1}$, a representative value for the W_{20} width of the detected profiles.

With the Nançay radio telescope, a 100 m-class instrument, 17 out of the 44 galaxies were clearly detected (39% detection rate). In order to get a significantly higher detection rate, observations are required with, e.g., the renovated Nançay telescope (van Driel et al. 1997) (expected to come on-line in September 2000), or with the larger Arecibo telescope. We intend to pursue the acquisition of H I data with these instruments, both as pointed observations and as a blind H I line survey (e.g., Kraan-Korteweg et al. 1998) of the Virgo cluster area.

All galaxies detected in H I have $M_{\rm HI}/L_B$ ratios of ∼0.3 − 0.8 $M_\odot/L_{\odot,B}$, like the average values for Sb-Sm type spirals (Roberts & Haynes 1994). Our results show that the UV flux measured at 2000 Å allows a reliable estimate of the H I line flux of galaxies and hence of their detectability in H I. Of the 6 Coma cluster UV-bright objects (CGCG 097–083, 098–071, 098–078, 160–128, 161–091 and 161–111), 5 were detected in H I. Most of these are classified as spirals, and one as elliptical.

4.1. Notes on individual galaxies

We searched the vicinity of the target objects for nearby spiral galaxies which could potentially give rise to confusion in those Nançay H I profiles where line emission was detected. We used the online NED and LEDA databases, in an area of $5\farcm5$ × 30′ ($\alpha \times \Delta$) round the pointing centre, i.e. about 1.5 times the HPBW, as well as optical images extracted from the Digitized Sky Survey.

VCC 31: the galaxy and its surroundings were mapped in H I at Arecibo (Van Zee et al. 1995), and no extended H I emission was found around the object; Arecibo profile parameters are $V = 2240$ $\rm km\,s^{-1}$, $I_{\rm HI} = 1.53$ Jy $\rm km\,s^{-1}$ and $W_{20} = 132$ $\rm km\,s^{-1}$. The object was also detected in the present survey.

Table 1. Basic data for the sample galaxies

Ident.	R.A. (1950.0)	Dec.	Morphol. NED	LEDA	$B_{\rm T}$ mag	D_{25} $'$	$V_{\rm opt}$ km s^{-1}	err km s^{-1}	$V_{\rm HI}$ km s^{-1}	$I_{\rm HI}$ Jy km s^{-1}	W_{50} km s^{-1}	W_{20} km s^{-1}	$M_{\rm HI}/L_B$ $M_\odot/L_{\odot,B}$	rms mJy
Virgo cluster galaxies														
VCC 1	12 05 46.8	13 57 42	S0	S0/a	14.8	0.55	2266	60		<2.2			<0.29	3.0
VCC 31	12 08 23.4	09 29 48			15.0	0.33	2215	60	2251	2.12	142	312	0.32	3.2
VCC 99	12 11 28.9	07 00 04	Sa	Sab	14.9	0.94	2444	60		<2.5			<0.35	3.3
VCC 234	12 14 52.6	06 58 04	SA	S0/a	13.0	2.63	2275	70		<1.8			<0.04	2.4
VCC 358	12 17 02.5	06 07 27	SB	S0/a	13.7	0.91	2637	51		<8.1			<0.37	10.8
VCC 386	12 17 30.5	05 37 07	SAB	SBa	14.9	0.95	2504	51	2380	7.33	268	287	0.82	3.7
VCC 781	12 22 42.6	12 59 30	S0	E/S0	14.7	0.91	-213	39		<2.6			<0.30	3.5
VCC 951	12 24 22.2	11 56 42	dE,N	E/S0	14.2	1.17	2072	40		<2.2			<0.17	3.0
VCC 1174	12 26 45.8	10 12 46	BCD		15.8	0.24	11840							2.5
VCC 1237	12 27 19.5	14 08 38			16.1	0.58	-335	60		<4.0			<1.67	5.3
VCC 1327	12 28 25.9	12 32 50	E	E	13.3	0.95	374	151		<4.5			<0.14	6.0
VCC 1348	12 28 43.9	12 36 28	dE	E/S0	15.8	0.58	1968	259	basel.					
VCC 1491	12 30 42.4	13 08 00	dE	So	15.2	0.89	1811	60		<2.0			<0.38	2.7
Coma cluster/A1367 galaxies														
CGCG 127-018	11 37 08.2	22 57 46	Sb	Sbc	15.1	0.69	6935	9	6938	2.67	133	209	0.45	2.4
CGCG 127-039	11 40 54.9	23 17 23	Sbc	Sc	15.1	0.58	6880		6919	2.79	42	167	0.46	2.1
CGCG 097-083	11 40 55.7	19 54 20	Sab		15.2	0.78	13102	30		<2.8			<0.51	3.7
CGCG 127-055	11 44 11.3	21 32 57	SAa		14.9	0.33	6665	74	6656	2.12	185	250	0.28	3.2
CGCG 157-044	11 48 48.0	27 03 45	Pec	Sb	15.5	0.71	6610	60	6628	1.45	244	317	0.36	2.5
CGCG 127-138	11 59 21.8	21 01 34			15.5		7210	339		<2.0			<0.49	2.7
CGCG 098-067	12 06 07.3	18 14 04	Comp		15.7	0.21	7610	172		<2.9			<0.85	4.0
CGCG 098-071	12 07 02.5	18 05 21	Irr	SBbc	15.1	0.89	6840	40	6881	2.12	123	156	0.36	3.7
CGCG 098-078	12 08 05.2	18 08 54	E		15.4	0.48	6824	45	6872	1.21	119	156	0.69	3.2
CGCG 128-057	12 11 50.3	22 27 55	E?		15.6		6998	174		<2.6			<0.69	3.5
CGCG 099-002	12 15 23.8	18 40 37	E?		16.9	0.22	7681	108		<2.1			<1.85	2.8
CGCG 128-072	12 15 36.8	24 57 58	Pec	Sc	15.5	0.63	6792	25	6848	1.41	215	373:	0.35	3.4
CGCG 129-004	12 27 19.1	22 38 54	S		15.6	0.63	6847	71		<2.9			<0.82	3.9
CGCG 129-013	12 35 38.5	22 58 21	Sm	SBbc	15.4	0.89	7550	60	6962	1.43	171		0.33	2.5
CGCG 159-048	12 37 44.5	31 27 06	S	SBab	15.4	0.59	7086	60		<2.9			<0.63	3.9
CGCG 159-058	12 40 21.0	26 54 48	E	S0/a	15.6	0.62	6746	71		<2.7			<0.70	3.6
CGCG 159-064	12 41 36.7	29 10 27	S	Sc	15.6	0.71	7265	60		<3.3			<0.86	4.4
CGCG 159-068	12 42 17.1	28 09 54	SBc	Sc	15.4	0.91	6374	60	6313	1.04	122	182	0.23	3.8
CGCG 129-023	12 42 50.2	21 48 31	S	Sc	15.6	0.59	6706	60	6746	1.37	171	248	0.35	3.9
CGCG 159-071	12 43 17.0	29 42 22	S	SBc	15.5	0.87	6924	60	6985	2.35	166	188	0.56	3.1
CGCG 159-097	12 49 40.6	27 17 52	Comp	Sa	15.5	0.43	6670	203		<1.6			<0.41	2.2
CGCG 160-012	12 52 23.1	30 48 58	S	Sc	15.7	0.63	6323	34		<2.2			<0.68	3.0
CGCG 130-002	12 54 26.4	22 38 41	Sc	Sc	15.5	0.55	6529	60	6663	2.31	244	256	0.58	3.0
CGCG 130-003	12 57 20.3	22 04 55	Sb	Sb	15.1	0.59	7094	60		<1.3			<0.22	1.8
CGCG 160-128	13 01 58.9	29 04 43	Sb	Sbc	15.1	0.74	8049	46	7940	2.20	100	122	0.36	2.8
CGCG 160-169	13 12 19.1	30 15 43	S0		15.4	0.79	6960	60		<2.2			<0.50	2.9
CGCG 161-048	13 23 38.4	31 52 38	Sa	Sab	14.9	0.85	7280	60		<1.9			<0.27	2.6
CGCG 161-051	13 24 24.0	30 46 00	E		15.8	0.33	7150	60	6993:	1.47:	235:		0.46:	3.6
CGCG 161-054	13 24 44.1	31 14 07	S0	Sb	15.4	0.65	6767	60	6760:	1.84:	335:		0.39:	3.2
CGCG 161-091	13 35 19.2	29 03 22		Sc	15.4	0.62	7918	60	8011	1.59	151	186	0.35	3.1
CGCG 161-111	13 37 25.0	28 01 48	S	Sb	15.5	0.47	8540	106	8460	1.35	48	78	0.33	2.1

VCC 234 (= NGC 4241): reported (Magri 1994) as detected in H I at Arecibo (V = 2237 km s^{-1}, $I_{\rm HI}$ = 9.0 Jy km s^{-1}, W_{50} = 359 km s^{-1}), but not detected in the present survey ($I_{\rm HI}$ < 1.8 Jy km s^{-1}) nor at Effelsberg ($I_{\rm HI}$ < 6.0 Jy km s^{-1}, Huchtmeier & Richter 1986b).

VCC 358 (= UGC 7364): detected in H I at Arecibo (Magri 1994); V = 2633 km s^{-1}, $I_{\rm HI}$ = 9.0 Jy km s^{-1}, but not detected ($I_{\rm HI}$ < 6.0 Jy km s^{-1}) at Effelsberg (Huchtmeier & Richter 1986b). Though our raw spectra show strong baseline curvature due to the proximity of NGC 4261, a large elliptical galaxy with a 21 cm continuum flux density of 19 Jy, such a strong H I profile should have been detected. After fitting a 6th order baseline, our H polarization spectrum has an rms of 11 mJy.

VCC 386 (= NGC 4277): our H I profile appears to be heavily confused by nearby (1$'$.9 separation) 12.4 mag SBc spiral NGC 4273, which has been observed at Arecibo with a 3$'$.6 HPBW, with the following results: V = 2386, W_{50} = 280 km s^{-1}, W_{20} = 298 km s^{-1} and $I_{\rm HI}$ = 12.8 Jy km s^{-1} (Davis & Seaquist 1983; Helou et al. 1987; Magri 1994; Mirabel & Sanders 1988). Our H I detection appears to be of NGC 4273, given the optical velocities of NGC 4273 (2347 ± 55 km s^{-1}) and VCC 386 (2504 ± 51 km s^{-1}) and the Arecibo profile parameters.

VCC 781 (= IC 3303): not detected in 21 cm line synthesis observations at Westerbork (Kotanyi 1981) with an rms noise of 2.5 mJy per synthesized beam, 21$''$ × 118 ($\alpha \times \delta$).

VCC 951 (= IC 3358): not detected in H I at Green Bank (Fisher & Tully 1981), upper limit 11 Jy km s^{-1}, nor in the present survey ($I_{\rm HI} < 2.2$ Jy km s^{-1}).

VCC 1174 (= VIII Zw 187): an optical redshift of 11,840 km s^{-1} was measured (Gavazzi et al., in prep) for this object after the completion of the present survey. This high redshift is far outside the velocity search ranges of our Nançay observations as well as of the Arecibo observations of Hoffman et al. (see Huchtmeier & Richter 1989).

VCC 1327 (= UGC 7658) and 1348 (= IC 3443): our raw H I profiles, all show that very strong baseline curvature is due to the proximity of M 87, a large elliptical galaxy with a 21 cm continuum flux density of 220 Jy. After fitting a 6th order baseline, the VCC 1327 spectrum has an rms of 6 mJy. The VCC 1348 spectra could not be fitted succesfully even with such a high-order polynomial, and strong ripples (of the order 50 mJy amplitude) remained in the spectra. VCC 1327 was not detected at Effelsberg (Huchtmeier & Richter 1986a), with an rms of 31 mJy.

VCC 1491 (= IC 3486): not detected in H I at Effelsberg by Huchtmeier & Richter (1986a, 1986b), who list the object (erroneously) as IC 3492; upper limit $I_{\rm HI} < 8.3$ Jy km s^{-1}. The upper limit in the present survey is 2.0 Jy km s^{-1}.

CGCG 098–071: another galaxy was found within the Nançay search area: CGCG 098–73, a 0$'$.8 diameter $B_{\rm T}$ 16.0 mag Sbc spiral, 2$'$.9 N of the target galaxy at $V = 6439$ km s^{-1}, 400 km s^{-1} lower than the optical velocity of the target galaxy.

CGCG 098–078 (= Mrk 758): this is the only galaxy classified as elliptical in whose direction H I was detected in our survey, which would imply a high $M_{\rm HI}/L_B$ ratio of 0.7 $M_\odot/L_{\odot,B}$ if all the gas were to reside in the galaxy. It is not a classical, gas-poor elliptical, though, it is a Markarian type UV-excess object and one of the strongest Hα line emitters (EW$_{\rm H\alpha}$ = 82 Å) in a survey of Coma cluster galaxies (Gavazzi et al. 1998a). The Hα emission is almost completely nuclear, and Gavazzi et al. speculated that this may be due to gravitational interaction with a nearby galaxy (see below). The H I profile has a central velocity of 6872 km s^{-1} and a FWHM of 119 km s^{-1}. The optical redshift of CGCG 98–78 as listed in the LEDA database, 6824 ± 45 km s^{-1}, is only 47 km s^{-1} lower than the H I value, and is based on two optical measurements (Denisyuk & Lipovetskii 1983; Lipovetskii & Stepanyan 1986). Another galaxy was found within the Nançay search area, well within the beam: CGCG 098–81, a 1$'$.1 diameter $B_{\rm T}$ 15.2 spiral of type Sa [NED]/Sc [LEDA], 1$'$.4 N−E of the target galaxy at an optical redshift of 7177 ± 132 km s^{-1} (Gavazzi et al. 1999a), i.e., 305 km s^{-1} higher than the central velocity of our H I profile. In conclusion, the detected H I is quite probably associated with the targeted galaxy, which is not a true elliptical, however.

CGCG 127–18: detected (Gavazzi 1987) in H I at Arecibo ($V = 2633$ km s^{-1}, $W_{20} = (162)$ km s^{-1}), where poor pointing conditions due to mechanical failure did not allow the measurement of other profile parameters.

CGCG 129–13: the H I velocity is 588 km s^{-1} lower than the optical. The 6 hours of H I observations were accumulated over 7 days in July and October 1999, and the H I signal is present in all observations, so it appears to be real and not due to radio interference. THe optical velocity is based on a single measurement by Tifft & Gregory (1988), who note that their spectrum is very faint and that consequently no error on the redshift could be given. Our search for nearby galaxies has not shown an object which may cause confusion in the H I data.

CGCG 130–003 (= IC 841): not detected in the CO(1−0) line (Boselli et al. 1995), with a 3σ upper limit for a 300 km s^{-1} broad profile to its H_2 mass of 1.0 10^9 $M_\odot$ (for $D = 71.5$ Mpc), and not detected in the present H I survey, with an upper limit to its H I mass of 1.6 10^9 $M_\odot$.

CGCG 160–128 (= KUG 1301+290): weak detection in the CO(1−0) line (Boselli et al. 1997b), H_2 mass of 4 10^8 $M_\odot$ (for $D = 69$ Mpc) and a FWHM of 349 km s^{-1} (no CO line velocity was reported), and detected in the present H I survey, $M_{\rm HI} = 2.6$ 10^9 $M_\odot$.

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