

The H_I content of early-type galaxies from the ALFALFA survey

II. The case of low density environments

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ABSTRACT

Aims. We present the analysis of the H_I content of a sample of early-type galaxies (ETGs) in low-density environments (LDEs) using the data set provided by the Arecibo Legacy Fast ALFA (ALFALFA) survey. We compare their properties to the sample in the Virgo cluster that we studied in a previous paper (di Serego Alighieri et al. 2007, A&A, 474, 851, Paper I). Our aim is both to investigate how the cool interstellar medium (ISM) of these systems depends on the galaxy mass and the environment and to relate the properties of the neutral hydrogen to the warm phases of the ISM.

Methods. We have selected a sample of 62 nearby ETGs ($V < 3000 \text{ km s}^{-1}$) in an area of the sky where the ALFALFA data are already available ($8^{\circ} < \text{RA} < 16^{\circ}$, $4^{\circ} < \text{Dec} < 16^{\circ}$), avoiding the region of the Virgo cluster. Among these, 39 have absolute B magnitudes fainter than $M_B = -17$.

Results. Fifteen out of 62 galaxies have been firmly detected with ALFALFA (~25%). Five additional galaxies show a weaker H_I emission ($S/N \sim 4$) and they will need deeper observations to be confirmed. Eight objects had 21-cm measurements reported in the literature. One by one comparison with the available material confirms, as expected, that ALFALFA data are, with rare exceptions, of equal or better quality than the best spectra previously obtained for these objects. All together, our analysis doubles the number of known gas-rich ETGs in this area. The H_I detection rate is 44% in luminous ETGs ($M_B < -17$) and 13% in dwarf ETGs ($M_B > -17$). In both cases it is 10 times higher than that of the Virgo cluster. The presence of gas can be related to a recent star formation activity: 60% of all ETGs with H_I have optical emission line ratios typical of star-forming galaxies and blue colours suggesting the presence of young stellar populations, especially in the dwarf subsample.

Conclusions. We show that the H_I detection rate of ETGs depends both on the environment and mass. The fraction of early-type systems with neutral hydrogen is higher in more massive objects when compared to early-type dwarfs. The ETGs in LDEs seem to have more heterogeneous properties than their Virgo cluster counterparts, since they are able to retain a cold interstellar gas component and to support star formation activity even at recent epochs.

Key words. galaxies: elliptical and lenticular, cD – galaxies: evolution – galaxies: ISM

1. Introduction

In the monolithic scenario (Larson 1974; Chiosi & Carraro 2002), early-type galaxies (ETGs) form in a single, short, and highly efficient burst of star formation at high redshift ($z > 3$) followed by a more quiescent evolution until today as the residual gas flows into the nuclear region of the galaxy. In this model, the bulk of the stellar population was formed at early epochs and ETGs appear today as gas-poor systems dominated by an old stellar population. On the other hand, hierarchical structure formation scenarios suggest that ETGs seen today in clusters have followed different evolutionary paths compared to the galaxies in LDEs (Governato et al. 1999), which are still undergoing hierarchical assembly and therefore are expected to be on average younger with more heterogeneous properties (Schweizer & Seitzer 1992; Barnes 1997). Larson et al. (1980) first pointed out that field ellipticals may have experienced a more extended star formation history with respect to their cluster counterparts. Rose et al. (1994) found an intermediate-age population in

E/S0 galaxies in LDEs, suggesting a wider spread in the epochs of major star formation activity. Spectroscopic observations of 26 ETGs located in voids (Wegner & Grogin 2008) indicate that even though there is a range of old (>9 Gyr) and young (<5 Gyr) systems, there appears to be a greater proportion of young galaxies in voids than in clusters.

The finding of gaseous structures, such as rings and discs, mostly in ETG field galaxies, can give further indication that merging events with gas-rich objects are taking place today in LDEs (see review by Schweizer et al. 1990). Detailed studies of nearby ETGs have shown that a fraction of them contains neutral hydrogen (Sanders 1980; Knapp et al. 1985; Huchtmeier 1994) and they can host extended H_I structures around them (Oosterloo et al. 2007), accompanied in some cases by traces of ongoing or recent star formation (Sadler et al. 2000; Serra et al. 2007; Hau et al. 2008).

The presence of neutral hydrogen in ETGs may be explained as the consequence of a recent accretion of a gas-rich satellite or of a merging process between similar-size galaxies

(Knapp et al. 1985; van Driel & van Woerden 1991; Barnes 2002). Simulations show that spheroidal galaxies with extended gaseous discs can form in spiral mergers (Barnes 2002; Burkert & Naab 2004), as the result of the subsequent infall of the HI from the tidal tails to the main merging remnant. This process can rebuild the gaseous disc on the timescale of few Gyr leading to an elliptical or a S0 galaxy with an extended gaseous component (Hibbard & Mihos 1995).

An alternative scenario foresees that the gas is accreted from the intergalactic medium via a “cold mode”, where the gas cools along filamentary structures without being shock-heated to the virial temperature of the halo ($T \sim 10^5$ K; Kereš et al. 2005; Macciò et al. 2006).

When the HI distribution is mapped at high resolution, gas-rich ETGs show regular HI structures appearing as low column density ($<5 \times 10^{20} \text{ cm}^{-2}$) discs or rings in rotation (van Driel & van Woerden 1991; Oosterloo et al. 2007). The regular kinematics of these structures suggests that they are relatively old and long-lived (a few Gyr). HI tails or clouds offset from the optical counterpart are also found in some systems (Morganti et al. 2006; Oosterloo et al. 2007) which is indicative of recent interactions or of a gas accretion process.

Nonetheless, the rate of detection of neutral hydrogen in nearby ETGs varies broadly depending on the depth of observations and the choice of the sample (Sadler et al. 2002; Morganti et al. 2006; di Serego Alighieri et al. 2007). It is well known that the HI content of late-type galaxies in dense cluster decreases when compared to systems of the same morphological type in lower density regions (Giovanardi et al. 1983a; Haynes & Giovanelli 1986; Solanes et al. 2001). But how does the HI content of ETGs vary with the environment? Variations in the detection rate of HI in ETGs have already been noticed in previous studies (Haynes & Giovanelli 1980; Giovanardi et al. 1983b; Huchtmeier 1994; Oosterloo et al. 2007), confirming that the probability of finding ETGs with gas is higher in lower density environments. The HI Parkes All-Sky Survey (HIPASS; Meyer et al. 2004) in the southern hemisphere provides a large database at 21-cm which has been recently used to study the HI content of 2500 nearby ETGs (E and S0) extracted from the RC3 catalog (de Vaucouleurs et al. 1991). HIPASS detected HI with a rate of 6% for elliptical and 13% for S0 galaxies (Sadler et al. 2002). However this preliminary analysis of the HIPASS data is plagued by confusion, since 30%–50% of the HI detected ellipticals have more than one neighbor with similar optical velocity within the 15' Parkes beam, and no distinction between different environments has been analysed or discussed. These results suggest the need for a systematic attempt to determine the HI properties of ETGs with a better spatial resolution, extending this analysis to a more uniform sample of galaxies in different environments.

In Paper I we have used data from the ALFALFA survey (Giovanelli et al. 2005, 2007), an ongoing blind survey at 21-cm performed with the Arecibo telescope, to start a more uniform and systematic study of the HI content of ETGs, by analysing it in the Virgo cluster. The advantage of using ALFALFA with respect to a previous blind HI survey such as HIPASS is twofold: its higher sensitivity and the smaller beam size which reduces the possibility of confusing the HI detections. We have defined an optical sample of 457 ETG, extracted from the Virgo Cluster Catalog (VCC Binggeli et al. 1985), which are brighter than the VCC completeness limit at $B_T = 18.0$. We have correlated this optical sample with the catalog of detected HI sources from ALFALFA. Only 9 out of 457 ETGs (roughly 2%) are detected

in HI, with the majority of ETGs with gas having peculiar morphologies and being located in the outer regions of the cluster.

Here we extend our analysis to a low density sample of ETGs, to compare the HI detection rate in different environments.

The paper is organised as follows: in Sect. 2 we describe the sample selection, in Sect. 3 we give an overview of the results, presenting the 21-cm detections, and their optical properties. In Sect. 4 we discuss the role of the environment on the HI detection rate of ETGs, and the evidence of recent star forming activity in the sample, and in Sect. 5 we present our conclusions.

2. Sample selection

The strategy we have followed in this study is the same as in Paper I for the Virgo cluster. We define a-priori an optical sample of ETGs within a definite radial velocity limit, which we then search for HI, using the ALFALFA survey.

The selection of a LDE optical sample of ETGs as similar as possible to the Virgo one, in terms of luminosity distribution, and possibly complete to a faint limiting magnitude is the crucial point of this work. For this aim we have used the Sloan Digital Sky Survey (SDSS; York et al. 2000; Stoughton et al. 2002) which provides a homogeneous data set of galaxies with both photometric and spectroscopic measurements in different environments: from voids to groups and rich clusters. Spectra are taken only for a subset of objects, the so called main spectroscopic sample, consisting of galaxies with r -band magnitudes $r < 17.77$ and r -band half-light surface brightnesses $\mu_{50} \leq 24.5 \text{ mag arcsec}^{-2}$ (Strauss et al. 2002).

First we selected all the objects in the seventh data release (DR7, Abazajian & Sloan Digital Sky Survey 2008) within the sky region where ALFALFA data are currently available with the same cut in radial velocity as in Paper I, i.e.

- $V < 3000 \text{ km s}^{-1}$;
- $8^{\text{h}} < \text{RA} < 16^{\text{h}}$, avoiding the region of the Virgo cluster between 12^{h} and 13^{h} ;
- $4^{\circ} < \text{Dec} < 16^{\circ}$.

The criterium on the radial velocity was imposed to reach a comparable HI mass detection limit to the one of Paper I. After this preliminary selection we obtained 307 galaxies of all morphological types.

Bernardi et al. (2005) defined a set of criteria to separate early and late-type galaxies in the SDSS database from the value of two outputs by the SDSS pipeline, the spectroscopic parameter $e\text{class}$ and the photometric parameter fracDev_r ¹: early-type morphologies are defined by choosing $e\text{class} < 0$ and $\text{fracDev}_r > 0.8$. Applying both these cuts we obtained only 4 galaxies. However we realised that this method was not appropriate for our aims. The use of fracDev_r would prevent to select early-type dwarfs, because their light profiles are generally fitted by an exponential law (Ferguson & Binggeli 1994), while the choice of $e\text{class} < 0$ would have automatically excluded ETGs with emission line spectra, a possibility that cannot be rejected a-priori, especially for our interest in gas-rich ETGs. Moreover, because the aperture of a SDSS spectroscopic fiber (3'') samples only the inner parts of nearby galaxies, we found that, using this criterium on its own, the bulges of some nearby late-type galaxies were mistakenly selected as early-type objects. Therefore we

¹ $e\text{class}$ is a spectroscopic parameter giving the spectral type from a principal component analysis, while fracDev_r measures the fraction of light profile that is fitted by a de Vaucoulers law.

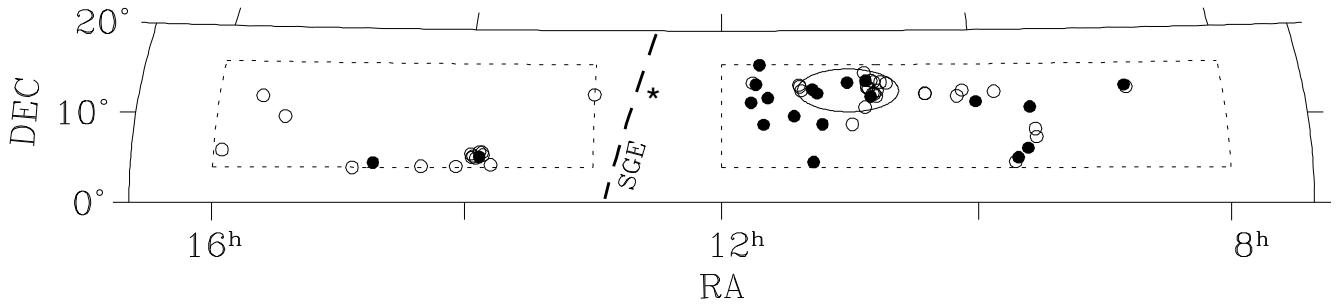


Fig. 1. The sky distribution of the selected sample of ETGs in Right Ascension and Declination. Filled dots correspond to galaxies detected at 21-cm, while empty dots show gas-poor ETGs. The ellipse indicates the area of the Leo group. The star between the two regions where we have defined our sample gives the position of M 87, while the thick dashed line traces the super galactic plane.

examined by visual inspection the SDSS multi-colour images of the 307 galaxies and classified 50 of them as early-type (E and S0).

The completeness of the main spectroscopic sample depends on the magnitude (Strauss et al. 2002). The main source of incompleteness is due to blending with saturated stars, an effect which is more significant for brighter and larger galaxies. According to Strauss et al. (2002), at bright magnitudes ($r < 15$) only 5% of the galaxies in the Zwicky catalog are missed, while from comparison with visual inspections of all objects brighter than $r = 18$ over 22 deg 2 of sky, the completeness of the sample is above 99%.

To remedy the incompleteness of the SDSS spectroscopic sample at bright magnitudes, we have looked for ETGs with $V < 3000 \text{ km s}^{-1}$ in the RC3 catalog (de Vaucouleurs et al. 1991) and in the Nasa/IPAC Extragalactic Database (NED), and we found that some galaxies had been missed by our selection from the SDSS database. From the RC3 we added 10 bright ETGs, excluded by the SDSS spectroscopic target selection algorithm. From NED we found also one faint dwarf (LeG 14) whose r -band magnitude is fainter than the limit of the main sample ($r < 17.77$), and Leo I, which was not included in the SDSS spectroscopic sample because it is resolved.

Thus we have built an apparent magnitude limited and bound in redshift sample of ETGs in LDEs which is complete down to the r -band magnitude $r < 17.77$ (Strauss et al. 2002). Our final list of targets is composed of 62 objects, 34 ellipticals and 28 S0s. For the galaxies in common with the RC3 catalog (de Vaucouleurs et al. 1991) we have adopted the RC3 morphological classification. 39 objects have absolute magnitudes $M_B > -17$, and they can be considered as dwarf ETGs.

Figure 1 shows the sky distribution of the galaxy sample and the regions we have selected, which also include the Leo group; in Table 1 the main observational parameters of our targets are displayed. The columns are as follows:

Column (1). The name of the galaxy.

Column (2). The absolute B magnitude of the galaxy. B apparent total magnitudes have been derived from the RC3 when available, otherwise they have been calculated from the model² r, g magnitudes derived from the SDSS database and converted to the Johnson system using the following relation

² The model magnitude (*modelmag*) in the SDSS database is defined as the total magnitude calculated by using the de Vaucouleurs or exponential model that best fits the galaxy profile in the r band.

$B = g + 0.17 + 0.47 \times (g - r)$ (Smith et al. 2002). A correction to the g magnitudes, $\Delta g = 1 - \exp[-0.11(g - 17)]$, has been applied to compensate for the overestimate of the local sky flux near bright large galaxies performed by the SDSS photometric pipeline (Mandelbaum et al. 2005).

Column (3). The optical heliocentric velocity of the galaxy extracted from NED in km s^{-1} .

Column (4). Heliocentric velocity of the HI detections, measured as the midpoint of the 50% level of the peak flux density.

Column (5). Velocity width of the HI line profile, measured at half peak value. More details on the way it has been estimated can be found in Giovanelli et al. (2007).

Column (6). Integrated flux density F of the source in Jy km s^{-1} and its estimated uncertainty. For non-detections, upper limits on the flux density have been derived by measuring the rms of the integrated spectrum, obtained over a region of $5' \times 5'$ around the optical position. The flux value has then been calculated for a $S/N = 5$ and a velocity width of 200 km s^{-1} if $M_B < -17$ or 80 km s^{-1} if $M_B > -17$.

Column (7). The HI mass (and upper limits for non-detections) in units of $10^7 M_\odot$, obtained using the standard equation $M_{\text{HI}} = 2.35 \times 10^5 d_{\text{Mpc}}^2 F$ where d_{Mpc} is the assumed distance in Mpc.

Column (8). Logarithm in base 10 of the HI mass-to-stellar light ratio in solar units (and upper limits for non-detections).

Column (9). Distance modulus. For 12 objects (labeled with a star) direct distance measurements are available from various indicators such as the tip of the red giant branch, surface brightness fluctuations, supernovae, planetary nebulae, and they have been taken from Tully et al. (2008) and NED³. For the other galaxies we have adopted the Hubble flow distance moduli calculated in NED, based on the local velocity field given in Mould et al. (2000), assuming $H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$. The corresponding distances range between 230 kpc (Leo I) and 47 Mpc (2MASX11460404+1134529).

Column (10). $\text{H}\alpha$ equivalent width in Angstrom, derived from the SDSS spectra. The $\text{H}\alpha$ equivalent width of

³ <http://nedwww.ipac.caltech.edu/level5/NED1D/>

Table 1. The sample of early-type galaxies selected in this work and their main parameters.

ID	M_B	V_{opt}	V_{HI}	ΔV_{50}	F	M_{HI}	$\log \frac{M_{\text{HI}}}{L_B}$	$m - M$	$\text{H}\alpha$	T	Code
	mag	km s ⁻¹	km s ⁻¹	km s ⁻¹	Jy km s ⁻¹	$10^7 M_\odot$		mag	Å		
UGC 4590	-17.26	1901	—	208	<0.65	<13.3	<-0.97	32.17	11.3	-1	—
UGC 4599	-19.07	2072	2071 ± 1	148	35.34 ± 0.09	850.5	0.11	32.53	-0.01	-2	a
SDSS J093155.94+073210.3	-14.30	2217	—	83	<0.42	<11.7	<0.16	32.49	-1.7	-2	—
SDSS J093208.81+082810.8	-14.41	2340	—	83	<0.46	<14.3	<0.20	32.60	-3.6	-5	—
MRK 0706	-17.56	2489	2501 ± 7	61	0.64 ± 0.06	22.5	-0.86	32.73	123.0	-1	b
SDSS J093608.59+061525.4	-15.66	2424	2413 ± 11	127	0.60 ± 0.06	19.7	-0.16	32.66	21.1	-1	b
NGC 2962	-20.08	1959	1958 ± 1	414	4.22 ± 0.12	112.7	-1.17	*32.64	—	-1	a
SDSS J094218.94+044121.8	-13.67	2036	—	83	<0.50	<12.1	<0.42	32.31	0.5	-5	—
SDSS J095036.25+124832.7	-14.49	1335	—	83	<0.41	<4.8	<-0.31	31.54	9.3	-5	—
CGCG064-021	-18.48	2822	2676 ± 9	36	0.30 ± 0.07	13.1	-1.47	32.96	-1.0	-5	c
CGCG064-055	-17.92	2789	—	210	<0.68	<30.2	<-0.88	32.99	20.7	-5	—
LeoI	-11.00	229	—	82	<0.51	$<6.3 \times 10^{-4}$	<-2.79	*21.80	—	-5	—
SDSS J102326.34+123542.5	-14.49	2739	—	84	<0.44	<18.9	<0.29	32.96	-1.9	-5	—
SDSS J102339.36+123725.6	-15.16	2723	—	83	<0.42	<18.0	<-0.001	32.95	23.4	-5	—
SDSS J104140.97+134929.6	-14.34	1271	—	83	<0.45	<5.4	<-0.20	31.57	1.0	-5	—
SDSS J104435.28+135622.7	-12.20	633	—	82	<0.50	<0.5	<-0.37	28.91	-1.7	-5	—
LeG14 ^a	-11.75	886	—	82	<0.45	<1.5	<0.27	30.34	—	-2	—
LeG17 ^a	-14.07	1013	—	83	<0.33	<1.9	<-0.54	30.95	-1.1	-2	—
NGC 3377 ^a	-19.18	684	—	207	<0.63	<1.9	<-2.59	*30.25	—	-5	—
NGC 3379 ^a	-20.03	897	—	207	<0.59	<1.7	<-2.98	*30.21	-1.2	-5	—
NGC 3384 ^a	-19.57	733	—	82	<0.35	<1.1	<-2.97	*30.32	—	-3	—
CGCG066-026 ^a	-13.10	541	—	82	<0.43	<0.3	<-1.01	28.54	-1.4	-5	—
SDSS J104926.70+121528.0	-14.43	1321	1338 ± 12	47	0.31 ± 0.08	4.1	-0.35	31.87	102.6	-5	c
UGC 5944	-15.15	1073	—	83	<0.35	<1.0	<-1.25	*30.22	-1.1	-5	—
NGC 3412 ^a	-18.93	853	—	207	<0.56	<1.7	<-2.54	*30.27	—	-2	—
SDSS J105101.51+132000.5	-11.97	656	—	82	<0.37	<0.4	<-0.40	29.12	-2.7	-5	—
SDSS J105131.35+140653.2	-11.34	832	816 ± 9	32	0.22 ± 0.05	0.5	0.01	29.87	-10.6	-5	c
SDSS J105204.79+150149.7	-12.47	828	—	82	<0.47	<1.1	<-0.12	29.87	-1.3	-5	—
SDSS J105219.51+110235.6	-13.45	824	—	82	<0.43	<0.9	<-0.60	29.75	-2.4	-5	—
UGC 6062	-19.31	2629	—	209	<0.73	<30.5	<-1.43	32.92	-1.2	-1	—
NGC 3489 ^a	-19.26	692	692 ± 2	107	0.86 ± 0.06	2.6	-2.48	*30.41	—	-1	a
IC 676	-19.42	1414	1421 ± 2	176	1.33 ± 0.07	21.9	-1.62	32.12	33.6	-1	a
SDSS J111445.02+123851.7 ^a	-10.86	582	629 ± 3	44	0.62 ± 0.04	0.4	0.03	28.36	5.5	-5	a
IC 2684	-12.42	648	590 ± 2	25	0.57 ± 0.03	0.4	-0.52	28.79	2.3	-5	a
SDSS J111701.18+043944.2	-13.40	1446	1441 ± 24	96	0.30 ± 0.07	4.8	0.13	31.90	5.2	-5	c
SDSS J112224.02+125846.4	-11.54	626	—	82	<0.40	<0.3	<-0.38	28.49	-2.7	-1	—
IC 2782	-14.44	860	—	82	<0.44	<0.8	<-1.08	29.69	-1.5	-5	—
IC 2787	-13.33	708	—	82	<0.37	<0.3	<-1.00	28.96	-2.2	-5	—
IC 692	-17.31	1157	1156 ± 3	52	3.59 ± 0.06	37.2	-0.55	31.61	8.9	-5	a
NGC 3773	-17.31	987	983 ± 3	90	3.06 ± 0.06	8.7	-1.18	30.21	63.6	-2	a
IC 719	-17.87	1849	1848 ± 18	231	4.08 ± 0.10	53.9	-0.61	*31.87	1.1	-2	a
UGC 6655	-13.66	748	750 ± 3	55	1.26 ± 0.07	1.0	-0.66	28.81	121.7	-1	a
2MASX J11434609+1342273	-16.58	2920	2926 ± 10	42	0.22 ± 0.05	11.2	-0.77	33.14	102.2	-2	c
SDSS J114516.18+135221.2	-14.56	2957	—	84	<0.37	<19.1	<0.27	33.16	-1.5	-1	—
2MASX J11460404+1134529	-17.89	2977	2922 ± 14	168	0.72 ± 0.06	37.8	-0.77	33.17	75.0	-1	b
NGC 4880	-18.36	1377	—	200	<0.63	<2.9	<-2.08	30.71	-1.6	-1	—
SDSS J134757.45+041850.6	-12.01	954	—	83	<0.49	<2.4	<0.38	30.79	-1.6	-5	—
SDSS J135142.91+052647.4	-15.77	1241	—	83	<0.46	<5.9	<-0.73	31.85	-1.1	-1	—
MAPS-NGPO_559_1243538	-13.83	977	—	83	<0.43	<2.3	<-0.36	30.91	17.6	-1	—
UGC 8799	-14.42	1132	—	83	<0.49	<2.0	<-0.65	*30.61	-1.1	-5	—
NGC 5338	-17.17	804	803 ± 3	135	0.57 ± 0.06	2.2	-1.72	*30.54	24.9	-2	a
SDSS J135502.70+050525.2	-15.13	1396	—	83	<0.49	<7.6	<-0.36	32.05	-1.4	-5	—
SDSS J135621.31+051944.2	-14.54	1395	—	83	<0.45	<7.0	<-0.16	32.05	-1.2	-5	—
CGCG046-013	-16.41	1516	—	83	<0.50	<8.6	<-0.82	32.17	-1.5	-5	—
SDSS J135723.57+053425.2	-15.01	1055	—	83	<0.45	<3.7	<-0.62	31.36	0.6	-5	—
UGC 8986	-17.78	1232	—	207	<0.70	<8.5	<-1.37	31.78	-1.2	-2	—
SDSS J142043.54+040837.0	-15.03	1704	—	83	<0.43	<8.6	<0.27	32.34	3.5	-2	—
SDSS J144329.18+043153.4	-15.81	1745	1716 ± 2	74	1.36 ± 0.06	28.6	-0.06	32.38	13.5	-5	a
NGC 5770	-18.41	1454	—	200	<0.63	<5.4	<-1.83	*31.39	—	-2	—
SDSS J152655.37+094657.5	-13.96	1858	—	83	<0.41	<7.7	<0.11	32.26	0.2	-5	—
IC 1131	-18.05	2017	—	200	<0.63	<18.0	<-1.16	32.71	—	-5	—
NGC 6014	-20.04	2491	—	200	<0.63	<25.4	<-1.80	33.08	—	-2	—

^a Leo group member.

NGC 3773 has been taken from Gavazzi et al. (in preparation), because it is not included in the SDSS spectroscopic sample.

Column (11). Morphological type of the galaxies in the sample. $T = -5$ refers to ellipticals, and $T = -3, -2, -1$ correspond to S0 galaxies.

Column (12). The code of the HI detections. Given that the signal threshold in the ALFALFA catalog is $S/N > 6.5$ for $\Delta V < 400 \text{ km s}^{-1}$ (Saintonge 2007), we define with code *a* firm detections with S/N above the adopted ALFALFA threshold, code *b* denotes reliable detections with a lower signal-to-noise ratio ($5 < S/N < 6.5$) which have an optical counterpart with a similar redshift, while code *c* refers to possible detections which need to be corroborated with deeper observations.

3. Results

3.1. HI properties

For each galaxy we have analysed the ALFALFA grids searching for 21-cm emission. We found 15 good quality detections out of 62 galaxies ($\sim 25\%$; code *a* and *b*), while five additional candidate sources have lower S/N (~ 4) and they will need deeper observations to be confirmed (code *c*).

15 objects of our sample of 62, have been previously observed at 21-cm. In particular, 6 out of our 15 detections had previous measurements, and the spectra we obtain are in good agreement with those in the literature. Upon inspection of the published spectra we find ours to be of comparable or better quality with the exception of NGC 3489 (Bregman et al. 1992), IC 719 (Giovanardi et al. 1983b), and NGC 5701 (Duprie & Schneider 1996), which are instead of sensitivity higher than ours. Two others have been previously detected but with a marked disagreement with our data; this is the case of UGC 4599 (Theureau et al. 2007; Rosenberg & Schneider 2000), and of IC 676 (Davoust & Contini 2004). In both cases our data are definitely of superior quality. As for the undetected ones, 2 objects have in the literature HI limits worse than those here provided (NGC 3379, 5770), while for NGC 3377 (Knapp et al. 1979), NGC 3412 and NGC 4880 (Sage & Welch 2006) the published limits are lower than ours. We do not confirm the dubious detection of NGC 6014 of comparable sensitivity to ours (Lewis 1983). Finally, Sage & Welch (2006) report a 21-cm detection of NGC 3384 ($M_{\text{HI}} = 1.8 \times 10^6 M_{\odot}$) at a level well below our detection limit.

In total we added 7 new 21-cm detections and, possibly, 5 more sources (code *c*), doubling (at least) the number of ETGs with neutral hydrogen in this region of the sky.

The spectra of all the HI detections (including the dubious ones) are shown in Fig. 2. The atomic gas is regularly rotating in UGC 4599 and NGC 2962, as indicated by the double horn profiles. Four galaxies (UGC 4599, NGC 2962, IC 719, and SDSS J111445.02+123851.7) have gas-rich neighbours to which they appear to be connected by a HI bridge, and their contour maps are displayed in Fig. 3. The maps of UGC 4599, NGC 2962 and IC 719 show that the gas extends far beyond the optical disc in these objects. Here we discuss the HI properties of some of the most interesting 21-cm detections.

UGC 4599. It is the galaxy with the highest HI mass of the sample ($M_{\text{HI}} = 7.6 \times 10^9 M_{\odot}$). The gaseous distribution is very extended ($\sim 100 \text{ kpc}$) and in rotation as indicated by the double horn 21-cm profile. It belongs to the compact group No. 79

in the Updated Zwicky Catalog (UZC; Focardi & Kelm 2002). From the ALFALFA cube one can see a possible companion also detected at 21-cm (CGCG061-011) with $V_{\text{hel}} = 2087 \text{ km s}^{-1}$ (Fig. 3). In a few channels there is evidence for HI emission in the region between the two galaxies which connects to the disc of UGC 4599, although this feature is not visible in Fig. 3.

NGC 2962. The HI emission appears to be connected to that of the galaxy SDSS J094056.3+050240.5, being located at a projected distance of about 8 arcmin ($\sim 80 \text{ kpc}$; see Fig. 3). In the Lyon Group of Galaxies catalog (Garcia 1993) it belongs to the group No. 178 whose brightest member is NGC 2966. From the ALFALFA data, within a box of 1.5 degrees in RA and Dec and a radial velocity range of $\pm 250 \text{ km s}^{-1}$, there are 8 systems which are detected at 21-cm. The rotating HI structure shows the largest velocity width of the sample ($\Delta V_{50} = 415 \text{ km s}^{-1}$).

NGC 3489. This lenticular galaxy belongs to the Leo Group, but it is in between the two subgroups defined by M 66 and M 96. It is among the faintest detection with one of the lowest HI masses ($2 \times 10^7 M_{\odot}$). The HI structure is not resolved by the Arecibo beam thus it is not shown in Fig. 3.

SDSS J111445.02+123851.7 A dwarf galaxy in the M 66 subgroup of Leo. The 21-cm emission (Fig. 3) extends to the north towards the brighter companion NGC 3593 ($V_{\text{hel}} = 628 \text{ km s}^{-1}$; at a projected distance of 10 arcmin/30 kpc), a S0a galaxy with two counterrotating stellar discs of different scale length and surface brightness (Bertola et al. 1996). The smaller and less massive one corotates with the HI gaseous disc, contrary to the more massive stellar disc. The accretion of a gas-rich satellite is addressed as a possible mechanism to explain the double structure of NGC 3593 (Pizzella et al. 1999).

IC 719. It is a S0 galaxy fairly isolated. It shows only one companion (IC 718; $V_{\text{hel}} = 1860 \text{ km s}^{-1}$) to which it seems to be connected by a HI bridge (see Fig. 3).

3.2. HI content vs. B band luminosity

The SDSS database provides u, g, r, z, i photometry for all the galaxies of our sample, including those for which spectroscopic information is not available. As mentioned in Sect. 2, B apparent magnitudes have been taken from the RC3 for the galaxies included in this catalog, otherwise they have been computed from the dereddened SDSS photometry using the relation from Smith et al. (2002). Figure 4 displays the absolute magnitude distribution of all the galaxies, compared to those detected at 21-cm (filled histogram). The five code *c* detections are also shown. Given that our sample is complete down to $r < 17.7$ we can evaluate what is the completeness magnitude limit in M_B . The $B - r$ colour distribution of these galaxies ranges between 0.4 and 1.4 and the maximum distance modulus is $m - M = 33.18$; this implies that the sample we have selected is at least complete down to $M_B = -15$.

A large fraction of the observed luminous ($M_B < -17$) early-type systems (10 out of 23, 44%) contain neutral hydrogen. At fainter magnitudes ($M_B > -17$) we find 5 out 39 gas-rich dwarfs (13%, not taking into account the uncertain detections), although the incompleteness of the sample becomes important for $M_B > -15$. The detection rate per magnitude bin peaks at $M_B = -17$ (60%), and then it drops at magnitudes fainter than $M_B = -16$.

Other studies in the field find similar high HI detection rates in ETGs, however the difference with a dense environment like Virgo is striking. In Paper I we found that only 2 out of 55 galaxies brighter than $M_B = -17$ have neutral hydrogen (about 4%). The fraction of luminous ETG with HI in LDEs is 10 times higher than in Virgo. However the three brightest ellipticals of

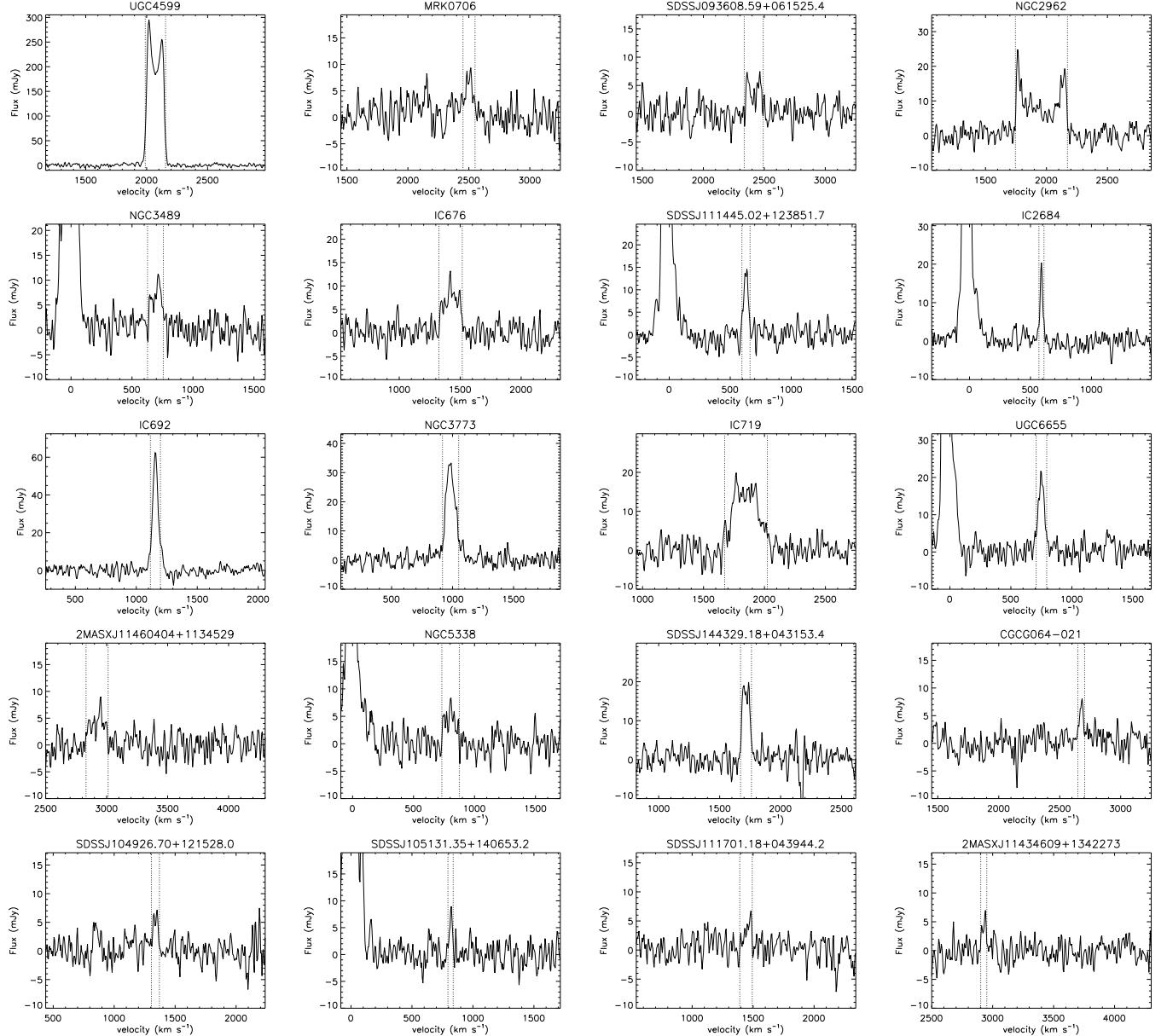


Fig. 2. 21-cm spectra of the ETGs with HI emission. The last five spectra correspond to the uncertain detections (code *c* in Table 1).

the LDE sample (NGC 3377, NGC 3379 and NGC 3384) do not show HI emission down to the sensitivity limit of the ALFALFA data set (see Table 1). On the fainter side of the distribution, the HI detection rate for dwarf ETGs in LDEs is almost ten times higher than in Virgo where we found only 7 gas-rich early-type dwarfs out of 407 (1.7%, see Paper I).

3.3. The M_{HI}/L_B distribution of the sample

In Fig. 5 we compare the gas-mass-to-light ratios of the LDE and Virgo cluster samples displayed as a function of the absolute B magnitude. The HI mass-to-light-ratios (M_{HI}/L_B) for the LDE sample range between 3×10^{-3} (NGC 3489) and 1.3 in solar units (UGC 4599 which shows an unusually high M_{HI}/L_B for a S0 galaxy). Non detections are indicated with their upper limits on M_{HI}/L_B . As one can notice from Fig. 5 there is a spread in the HI content of the luminous ETGs ($M_B < -17$), and the

M_{HI}/L_B ratios of the sample do not seem to be correlated with the luminosity, at least at brighter magnitudes, as it is generally found in other morphological types (Verheijen & Sancisi 2001; Gavazzi et al. 2008). This could give an indication that gas-rich luminous objects have recently accreted gas either via merging or from the IGM as it has been suggested in previous works (Knapp et al. 1985). The figure clearly shows the difference with respect to Virgo, where only two objects with $M_B < -17$ have been detected at 21-cm, and the only HI detected luminous elliptical (M 86) has a very low M_{HI}/L_B ratio.

From the M_{HI}/L_B distribution of the sample we can check whether we are finding a “peculiar” set of galaxies with a higher gas content than what is usually expected for these morphological types. The median M_{HI}/L_B for ellipticals and S0s in the Uppsala General Catalog (UGC) is 0.04 (Roberts & Haynes 1994). For the luminous galaxies in our LDE sample we find $M_{\text{HI}}/L_B = 0.07$, which is roughly comparable to the UGC. On the other hand, the dwarf ellipticals/spheroidals detected with ALFALFA have a median gas-mass-to-stellar light ratio,

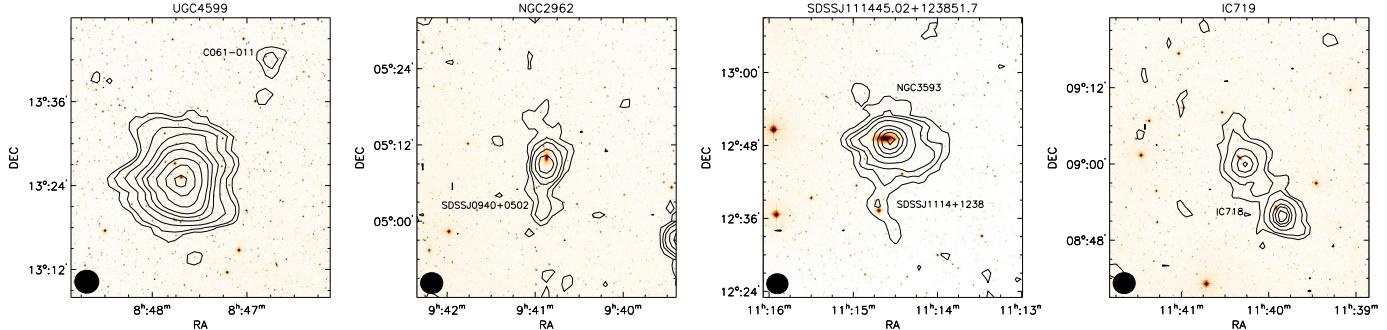


Fig. 3. Contour maps of the ETGs with the brightest and most extended HI emission. The lowest contour level of the maps is at $6 \times 10^{18} \text{ cm}^{-2}$, while the peak column density ranges between $5 \times 10^{19} \text{ cm}^{-2}$ and $3 \times 10^{20} \text{ cm}^{-2}$. For these galaxies the Arecibo beam ($\sim 4'$), which is shown at the bottom left corner of each map, corresponds to a projected linear size which varies between 11 kpc and 40 kpc.

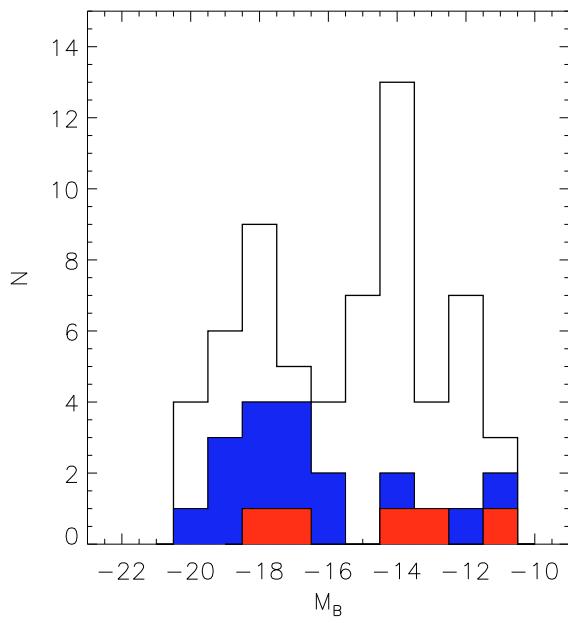


Fig. 4. The absolute magnitude distribution of the ETGs detected at 21-cm (filled histogram), compared to the total number of galaxies in our sample. The 5 uncertain HI detections are shown in red (light grey).

$M_{\text{HI}}/L_B = 0.9$, which is more similar to those of dwarf irregulars ($M_{\text{HI}}/L_B \lesssim 1$). In the Local Group, for example, the dE galaxies NGC 205 and NGC 185 have both $M_{\text{HI}}/L_B = 0.001 M_\odot/L_\odot$ (Mateo 1998), while early-type dwarfs in the Sculptor group with HI masses around $10^5 M_\odot$, exhibit M_{HI}/L_B ratios between 0.08 and 0.2 (Bouchard et al. 2005). The lack of low luminosity galaxies with low relative gas content is probably a selection effect due to the smaller volume that the ALFALFA sensitivity allows for these systems at a given M_{HI}/L_B ratio, as shown in Fig. 5.

3.4. Optical emission lines and colours

To check whether we can find traces of a recent star formation activity and/or differences in the stellar population in our sample of ETGs, we have looked for optical emission lines in the SDSS spectroscopic database and we have analysed the optical colours provided by the SDSS photometric database.

Different ionising mechanisms can produce emission line spectra in galaxies, however the use of diagnostic diagrams

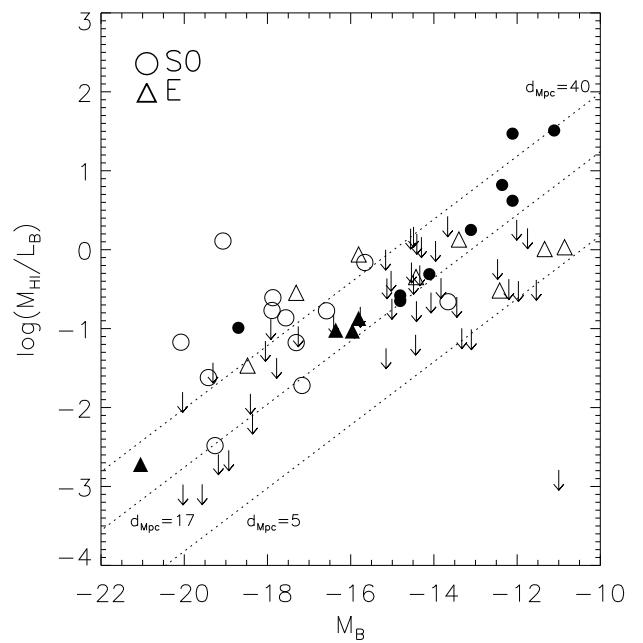


Fig. 5. The gas mass-to-light ratio versus the absolute magnitude of the LDE sample (open symbols) compared to the Virgo one analysed in Paper I (filled symbols). Arrows indicate the upper limits for the galaxies non-detected at 21-cm. The dotted lines show the 5σ ALFALFA detection limits at three different distances ($d = 5, 17, 40$ Mpc), assuming a rms of 2 mJy, and a velocity width of 80 km s^{-1} .

(Baldwin et al. 1981; Veilleux & Osterbrock 1987), for given values of the emission line ratios $[\text{OIII}]_{5007}/\text{H}\beta$ and $[\text{NII}]_{6583}/\text{H}\alpha$, allows to distinguish the spectra of normal star forming (SF) systems from those with an active galactic nuclei (AGN), such as Seyfert galaxies and low-ionization nuclear emission regions (LINERs) (Kewley et al. 2001; Kauffmann et al. 2003; Stasińska et al. 2006).

We have extracted from the SDSS database the fluxes of the four lines $\text{H}\beta$, $[\text{OIII}]_{5007}$, $\text{H}\alpha$ and $[\text{NII}]_{6583}$ (Table 2) and their ratios are shown in Figure 6. For the 12 galaxies without SDSS spectra we have used the values reported in the literature when emission lines had been observed, as in NGC 2962 (Gallagher et al. 2005), NGC 3489 (Ho et al. 1997) and NGC 3773 (Moustakas & Kennicutt 2006). The solid and dashed lines in the figure define the region of the diagram below which SF galaxies can be found, according to Stasinska et al. (2006) and

Table 2. $u - r$ colour and emission-line fluxes of the galaxies with ionised gas. The horizontal line divides HI detections from non-detections. For the objects not included in the SDSS spectroscopic sample, the fluxes have been taken from the values reported in the literature. The references are indicated in the last column and they correspond to: 1. SDSS (Strauss et al. 2002); 2. Gallagher et al. (2005); 3. Ho et al. (1997); 4. Moustakas & Kennicutt (2006).

ID	$u - r$	$H\beta$ $10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2}$	O[III]_{5007} $10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2}$	$\text{H}\alpha$ $10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2}$	N[II]_{6583} $10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2}$	Ref.
MRK 0706	1.62	2671 ± 37	5035 ± 62	10850 ± 125	1981 ± 30	1
SDSS J093608.59+061525.4	1.41	74 ± 4	151 ± 6	347 ± 7	57 ± 4	1
NGC 2962	2.85	–	–	20	130	2
SDSS J104926.70+121528.0	1.02	260 ± 8	892 ± 14	857 ± 14	40 ± 4	1
NGC 3489	3.73	1488	4367	3235	4302	3
IC 676	2.00	589 ± 17	175 ± 16	4071 ± 57	1921 ± 34	1
SDSS J111445.02+123851.7	1.27	1.5 ± 1.3	10 ± 3	19 ± 2	3.0 ± 2	1
IC 692	1.23	165 ± 21	563 ± 23	753 ± 9	120 ± 11	1
2MASX J11434609+1342273	1.89	832 ± 14	641 ± 11	4187 ± 53	1286 ± 17	1
NGC 3773	1.13	$(271 \pm 11) \times 10^2$	$(355 \pm 15) \times 10^2$	$(879 \pm 35) \times 10^2$	$(157 \pm 7) \times 10^2$	4
UGC 6655	1.28	1635 ± 31	5352 ± 96	5563 ± 67	515 ± 12	1
2MASX J11460404+1134529	1.22	1135 ± 20	3294 ± 43	4294 ± 47	424 ± 12	1
NGC 5338	1.91	407 ± 15	531 ± 18	2742 ± 19	893 ± 21	1
SDSS J144329.18+043153.4	1.68	9 ± 2	16 ± 2	41 ± 2	5 ± 1	1
UGC 4590	2.23	48 ± 5	16 ± 5	507 ± 11	176 ± 9	1
SDSS J095036.25+124832.7	1.64	9 ± 5	25 ± 5	92 ± 3	17 ± 3	1
CGCG064-055	1.34	200 ± 11	2714 ± 42	1810 ± 17	1507 ± 34	1
SDSS J102339.36+123725.6	1.85	17 ± 3	33 ± 4	94 ± 3	18 ± 3	1
MAPS-NGPO_559_1243538	1.82	28 ± 4	72 ± 5	124 ± 3	11 ± 3	1

Kauffmann et al. (2003) respectively. 10 out of the 15 certain 21-cm detections fall in the SF region of the diagram (67%). As regards the remaining five galaxies, line ratios of NGC 3489 indicate that this is a Seyfert galaxy (Ho et al. 1997), while the other four have no clearly detected [OIII] emission lines. Particularly, the spectrum of NGC 2962 does not show neither [OIII]₅₀₀₇ nor H β emission lines (Gallagher et al. 2005), as well as IC 719, thus we do not display these objects in Fig. 6, even though the [NII]₆₅₈₃/H α ratio would place them in the AGN region of the diagram. The SDSS spectrum of IC 2684 shows low S/N H α , and [NII] emission lines, thus it is difficult to draw any conclusions on the position of this galaxy in the diagnostic diagram. Finally, the spectrum of UGC 4599, which is the galaxy with the highest HI mass, has no emission lines, but for the latter galaxy one has to take into account that the SDSS spectrum is sampling only its inner 3'' region, while the multi-colours image shows a blue ring where SF is probably occurring at about 30'' from the centre. Two of the five uncertain HI sources (SDSS J104926.70+121528.0 and 2MASX J11434609+1342273) have emission line ratios typical of HII regions.

It is interesting to note the presence of four ETGs non detected at 21-cm in the SF area of the diagram (UGC 4590, SDSS J102339.36+123725.6, MAPS-NGPO_559_1243538 and SDSS J095036.25+124832.7). The spectrum of CGCG064-055 instead appears to be typical of a Seyfert galaxy.

$g - r$ versus $u - g$ colour-colour diagrams are used to separate between early and late-type morphology in the SDSS (Strateva et al. 2001; Lamareille et al. 2006) and the boundary between the two classes of galaxies is set at $u - r = 2.2$ (Strateva et al. 2001). In Fig. 6 we display the $u - r$ colours of the galaxies with emission lines. One can notice that all the systems detected at 21-cm falling in the SF region have blue colours ($u - r < 2$), more similar to those of later morphological types (Lamareille et al. 2006); the bluer the galaxy the greater the [OIII]₅₀₀₇/H β ratio. As regards the ETGs non detected at 21-cm in the SF

region, they also have colours bluer than $u - r = 2$, except for UGC 4590, whose spectrum shows weak [OIII] emission lines. The remaining galaxies outside the SF region both with or without HI such as NGC 3489, CGCG064-055 and NGC 2962 (not shown in the plot) have all colours $u - r > 2.2$ typical of early-type morphologies.

4. Discussion

4.1. The role of the environment

The aim of our study was to assess the extent to which the neutral hydrogen content of ETGs can be affected by the environment. In this paper we have selected a uniform set of galaxies which are members of groups (both small and more populated such as Leo), or evolve in relative isolation, and we have compared it to a rich cluster like Virgo (Paper I).

The reduced HI content of early-type systems in Virgo is remarkable when compared to the LDE sample. The percentage of galaxies detected at 21-cm is 10 times higher in regions of low intergalactic density both for luminous and dwarf ETGs, confirming that the impact of the environment on the gaseous content of galaxies is fundamental.

Several factors may concur to the higher detection rate of HI in LDEs. Contrary to clusters, groups have low velocity dispersions and crossing times smaller than the Hubble time, so that interactions and mergers are more likely to occur (Mamon 2007). The lack of an intragroup hot medium and the low relative velocities imply that the role of ram pressure stripping (Gunn & Gott 1972) is reduced in LDEs. On the other hand, luminous ETGs in Virgo are primarily confined to the central regions of the cluster and are strongly concentrated around M 87 (Binggeli et al. 1987), where mechanisms such as ram-pressure, or turbulent/viscous stripping (Nulsen 1982) and tidal interactions (Moore et al. 1996) are more efficient at removing the gas from a galaxy.

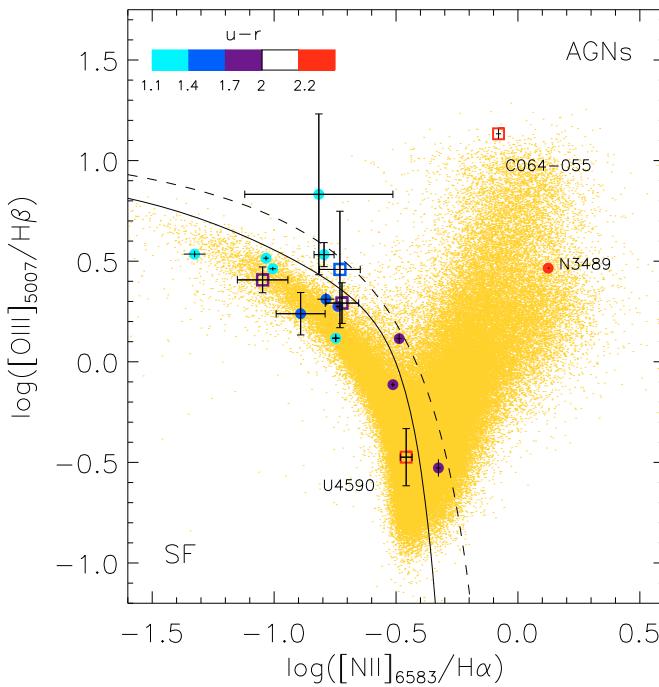


Fig. 6. The $[\text{NII}]_{6583}/\text{H}\alpha$ vs. $[\text{OIII}]_{5007}/\text{H}\beta$ line ratios for the galaxies in our sample with emission line spectra. Filled circles correspond to galaxies with HI, and open squares to 21-cm non-detections. The bar at the top left corner of the plot shows the range of the $u - r$ colour of the galaxies. The curved lines represent the demarcation between SF systems and AGNs according to Stasińska et al. (2006) (solid line) and Kauffmann et al. (2003) (dashed line). The small gray dots give the distribution of the SDSS DR5 sample of Stasińska et al. (2008), clearly showing that galaxies occupy two well defined regions where AGNs (Seyferts and LINERs on the righthand side) can be distinguished from SF galaxies (the so-called “left wing of the seagull”).

Another explanation for the paucity of gas-rich luminous ETGs in Virgo compared to the LDE case, may be the relatively short evaporation time for a cold gas cloud embedded in a hot intracluster medium. Following McKee & Cowie (1977) we estimate that the evaporation time due to heat conduction for a cloud of ~ 500 pc radius and $n \sim 1 \text{ cm}^{-3}$ density, embedded in a hot plasma with properties typical of Virgo (Ghizzardi et al. 2004) is around few times 10^8 yr (for conductivity at the Spitzer’s value). Within this scheme the paucity of HI detections of bright cluster ETGs compared to lower density environments derives from the dearth of HI rich dwarfs to be cannibalized. Within 6° from M 87, we estimate from the VCC (Binggeli et al. 1985) an average density of gas-rich dwarfs $n_{\text{HI}}^d \simeq 10 \text{ gal Mpc}^{-3}$ with a velocity dispersion $\sigma \simeq 700 \text{ km s}^{-1}$. If we fix a cross section diameter of 100 kpc for the capture by a giant member, this implies an impact rate of $\sim 5.3 \times 10^{-2} \text{ Gyr}^{-1}$. That is, in each bright ETG, the time between collisions/capture of a HI rich dwarf amounts to ~ 19 Gyr. Given, as said before, a survival time of the neutral gas of $\sim 6 \times 10^8$ Myr, this gives an expected detection rate around 3%, in agreement with the observed one.

Finally an important role in evaporating HI clouds could be also played by the possible presence of a hot ISM in luminous ETGs. At this stage, unfortunately, we can derive little information about the relation between the cool and hot ISM for the LDE sample, since the overlap with X-ray datasets is very small. Few objects have been observed, but no evidence of a hot ISM has been reported in any of them to relatively low levels

(O’ Sullivan et al. 2001; David et al. 2006), with the exception of NGC 3379, where a small amount of hot gas is detected in an outflow phase (Trinchieri et al. 2008). A more systematic analysis of the effects of a hot plasma on the HI content of ETGs in different environments will be presented in a subsequent work (Grossi et al., in prep.).

4.2. Star formation in LDE ETGs

Warm ionised gas is considered a reliable tracer of star formation activity in spiral galaxies, but in E and S0 galaxies other ionising sources such as AGNs or old stars (post asymptotic giant branch stars or low mass core helium-burning stars) can produce emission line spectra (di Serego Alighieri et al. 1990; Trinchieri & di Serego Alighieri 1991; Binette et al. 1994). The presence of ionised gas is quite common in ETGs (Sarzi et al. 2006), particularly Falcón-Barroso et al. (2006) find that emission lines are slightly more frequent in S0s (83%) than in ellipticals (66%). In general, line ratios in ETGs, especially in the more luminous ones, are typical of LINERs (Phillips et al. 1986; Filippenko 2003; Serra et al. 2008).

We find that 40% of the ETGs in our sample have H α equivalent widths (EWs) greater than 1 Å, indicating the presence of ionised gas (see Table 1). This fraction is lower than what is generally found in other samples of ETGs.

Searching for optical emission lines other than H α we find that 30% of our ETGs have spectra with H β , [OIII] and [NII] in emission. The majority of them lie in the SF side of the diagnostic diagram displayed in Fig. 6, the so-called “left wing of the seagull” (Stasińska et al. 2006). The upper side of the left wing corresponds to low metallicity SF galaxies, while more massive and metal-rich galaxies populate the bottom of the SF region. Objects move to the right of the left wing as the metallicity increases. Combining the presence of the optical lines with the colours from the SDSS photometry, 12 out of 20 ETGs with neutral hydrogen (60% if we include code *c* detections) appear to show traces of ongoing SF activity. The colours of the galaxies in the SF region are predominantly blue and particularly they are bluer than $u - r = 2.2$, values that are more similar to those of later type morphologies. Thus a significant fraction of the ETGs with gas seems to be forming stars.

If we exclude IC 676, all the gas-rich ETGs in the SF region are either low luminosity or dwarf ETGs with $M_B > -18$. Evidence of ongoing star formation activity is not unusual in the central regions of low luminosity ETGs (Sadler et al. 2000). Semi-analytic models expect that low luminosity ellipticals and field ellipticals may have experienced more extended star formation histories or could have been formed in later mergers (Khochfar & Burkert 2001).

Even though star formation could be the dominant source of ionisation in the ETGs of our sample with optical emission line spectra, one has to consider that the diagnostic diagram does not allow to unambiguously distinguish whether the gas is ionised by massive young stars or hot old stars (Stasińska et al. 2008; Kniazev et al. 2008), and a further analysis of the UV colours is needed to disentangle this issue.

Finally 35% of the firm HI detection galaxies (or 40% if one includes the code *c* objects) do not present emission lines in their optical spectra, or do not have line ratios typical of HII regions. A possible explanation could be that star formation has now faded, but it occurred in a recent past (< 1 Gyr). Indeed some of these gas-rich galaxies have relatively blue colours for their morphological type (such as IC 2684 with $u - r = 2$). Alternatively,

the lack of SF activity in ETGs with gas could be due to the too low column densities of the observed gaseous structures in their sample (at most a few times 10^{20} cm^{-2}), which would not allow to trigger star formation on a large scale. Thus it is possible that, even if ETGs host a gaseous component, only in some of them the conditions for star formation are attained and the gas converted into stars. If this does not occur, the gaseous discs and rings could survive for several Gyr (Morganti et al. 2006; Oosterloo et al. 2007).

5. Conclusions

To better understand the environmental effects on the evolutionary path of ETGs, after having studied the HI content of a sample in a dense cluster like Virgo (Paper I) here we have used the ALFALFA data set to make a similar analysis on a LDE sample to identify any differences in the ISM and stellar properties of such galaxies. Using the SDSS database we have built an apparent magnitude limited sample of 62 ETGs with radial velocity below 3000 km s^{-1} which is complete down to $r < 17.77 \text{ mag}$.

Our main results are:

- The HI detection rate of luminous ETGs in LDEs is 44%, 10 times higher with respect to what we found in the Virgo cluster. The three brightest ellipticals (the Leo group members NGC 3377, NGC 3379 and NGC 3384) do not appear to have a gaseous component down to the 5σ detection limit of $M_{\text{HI}} \sim 2 \times 10^7 (\Delta V/200 \text{ km s}^{-1})^{\frac{1}{2}} (d/11 \text{ Mpc}) M_{\odot}$. In agreement with previous studies (Giovanardi et al. 1983b) we confirm that the probability of finding S0 galaxies with gas is higher in LDEs compared to a rich cluster like Virgo. The non-detection of ellipticals brighter than $M_B < -20$ at 21-cm prevents to make any comparison of their HI properties between different environments.
- The HI detection rate lowers to 13% when one considers only the early-type dwarfs of the sample. The gas content of the dwarfs ($M_{\text{HI}}/L_B > 0.2$) appears to be greater than typical values usually found in dE/dS0 morphological types. The fraction of gas-rich dwarf ETGs in LDEs is about 10 times higher than the Virgo cluster.
- The presence of HI in LDE ETGs is possibly the result of recent minor or major merging of gas-rich companions. We find that $\sim 25\%$ of the galaxies with HI emission do also appear to have gas-rich companions. However we cannot exclude that, given the less “hostile” environment where such galaxies are evolving in, with gas removal mechanisms being less effective, some of them may have been able to retain their original gas content compared to their cluster counterparts.
- From the analysis of the emission line ratios of these galaxies we find that 60% of the ETGs with gas show traces of ongoing star formation and colours suggesting the presence of young stellar population ($u - r < 2$). The presence of gas seems to be related to a recent star formation activity in a significant fraction of the gas-rich ETGs. In some ETGs, particularly the massive ones, the gas could be ionised by hot old stars.
- Gas-rich ETGs without traces of recent star formation are also found. They may have not experienced any recent merging/interaction event and they have been passively evolving because the surface densities of their HI discs are too low for star formation to occur. Alternatively we cannot exclude that they may have got their gas from IGM accretion, a process

which not necessarily may trigger star forming activity in the galaxy (Morganti et al. 2006; Oosterloo et al. 2007).

- Few ETGs non detected with ALFALFA show emission line spectra of star forming galaxies, and colours indicative of young stellar populations. Deeper 21-cm observations are needed to set stronger constraint on the HI content of these galaxies.

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