AMIGA: HI CONTENT OF THE MOST ISOLATED GALAXIES

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INTRODUCTION

We present an analysis of the atomic gas (HI) properties for a large sample of isolated galaxies. It includes nearly 800 isolated galaxies, members of the Catalogue of Isolated Galaxies (CIG, Karachentseva 1973). Since the number of objects in our sample is much larger than any HI data compilation of really isolated galaxies presented before, we will be able to improve substantially the statistical studies done up to now. The data have been obtained both from the bibliography and by our own observations, done by means of the Nançay, Effelsberg, Arecibo and GBT radio-telescopes.

The here presented goals of our HI study are the following:

• Construction of a statistically meaningful template for the HI content as a function of LB, Ø and morphology, extending the earlier valuable HI survey for N=324 galaxies (Haynes & Giovanelli 1984). We double the sample size and improve the quality of the lower sensitivity measures used in the earlier work, allowing a better quantification of properties for all subsamples (e.g. attending to morphological type). In this study only really isolated galaxies (the CIG sample after revision, N=893) have been taken into account (aprox. 230 were really isolated in the sample published by Haynes & Giovanelli 1984).

• HI study of early type isolated galaxies. The presence of gas in early type galaxies is usually attributed to accretion from a nearby companion (cf. Huchtmeier, 1994) or to minor/major merger events (e.g. Morganti et al. 1997; Balcells et al. 2001). A subsample of 16 HI rich early type galaxies has been found in the CIG sample. Since the here proposed galaxies are selected based on isolation criteria the above interpretation is not straightforward. Are they really early type galaxies? Are they the definition of a primordial early-type?

AMIGA PROJECT

Analysing the Interstellar Medium of Isolated GAlaxies

• A definition of "isolated galaxy" is needed before one can properly assess the history and properties of peculiar ones.

• We are constructing the first complete unbiased control sample of the most isolated galaxies of the northern sky (Verdes-Montenegro et al 2001, 2002, Leon & Verdes-Montenegro 2003) to serve as a template in the study of star formation and galaxy evolution in denser environments.

• Our goal is to compare and quantify the properties of different phases of the interstellar medium in this sample, as well as the level of star formation, both relevant parameters in the internal evolution of galaxies and strongly conditioned by the environment.

• To achieve this goal we are building a multiwavelength database for this sample to compare and quantify the properties of different phases of the ISM. Our source list is based on the Catalog of Isolated Galaxies (1051 galaxies) and our sample contains ~900 galaxies

OBSERVATIONS AND COMPILATION OF DATA

The sample used in the HI study is composed by those isolated galaxies catalogued after revision as isolated. We have HI data for nearly 750 galaxies, coming both from archival data and/or observed by us at several radiotelescopes. Seventy percent of them are firm detections, 6 % marginal detections and 24 % upper limits. New redshifts have been found for 12 galaxies without any previous measurements. In Fig. 1 are shown the number of observed galaxies for a given morphological type (red histogram), the galaxies detected (green, code=0), upper limits (blue, code=1) and marginal detections. As expected, the number of galaxies not detected increases for early types.

• Compilation of data: HI data for almost 400 galaxies were obtained from a search in the literature, looking for the individual papers cited in the RC3 (de Vaucouleurs et al. 1991), the HI catalog (Huchtmeier & Richter 1989) and the Hyperleda catalog (Paturel et al. 2003). Almost 50 articles have been used in the compilation, extracting all HI parameters that were avalaible. Once all the data were collected from the bibliography for a given galaxy, we proceeded to select the best data by taking into account the beam attenuation and the quality of the profiles as main selection criteria. For those galaxies whose spectra were included in their respective articles (80% aproximately), we proceeded to digitilize their profiles. Digitalizations of the selected profiles allowed us to calculate the parameters by the same reduction program as for our own observations, homogenizing in this way the HI data for the whole sample. 80% of the 352 galaxies had a difference lower than 20 % in the integrated flux, being the rest mainly marginal detections or profiles with bad baselines.

• Observations: We have splitted the rest of galaxies in the HI sample to be observed at several telescopes based on their sensitivity of the radiotelescope and the distance, declination, size and morphology of the galaxies. HI observations were performed in total power mode, substracting an empty field from the target field (ON-OFF).The two channel in all Hemt-receiver considered was used to observe both polarizations that were added after baseline substraction. In total more than 300 galaxies have been already observed by means of 110x100m GBT, 304m Arecibo, 200x35m Nançay and 100m Effelsberg with some overlap to compare calibration errors between them. Table 1 lists the number of galaxies observed in each telescope, as well as the velocity resolution obtained and the bandwidth. Eighty percent of the observed profiles have resolution better than 15 km/s after smoothing.

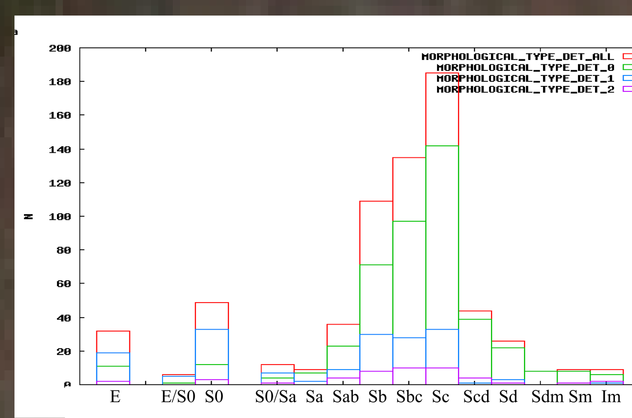

Fig. 1. Histogram showing the number of galaxies observed for a given morphological type (red), the detected galaxies (green, code=0), upper limits (blue, code=1) and marginal detections (violet, code=2)

Radio-telescope	Observed gal.	% detected gal.	Resolution (km/s)	Bandwidth (km/s)	HPBW (arcmin)
304m Arecibo	34	70%	0.67/2.7	1400/5550	3.4
200x35m Nançay	134	30%	2.57	10550	3.6x21
110x100m GBT	51	94%	1.2/2.5	1220/2500	9.0
100m Effelsberg	186	67%	5.24	1200	9.3

Table 1. Selected information for the observations

HI RICH EARLY TYPE ISOLATED GALAXIES (HI RICH ETIG)

Most of early type galaxies are usually gas-poor but occasionally some of them possess a considerable amount of gas. The presence of HI in these galaxies is connected in most cases with their environment. As a result of the interaction, morphological irregularities are found, like optical shells, isophote twists (Marcum et al. 2004) or outer HI ring-like distribution (Duprie & Schneider 1996). Mechanisms to form these HI rich ETIG could be minor mergers or major mergers. Abnormality in the B-V color almost always means a signature of recent SF frequently associated with dynamical events (Marcum et al 2004). The median B-V color for early type galaxies is 0.9, and those significantly bluer than 0.1 mag (3 sigma) when compared with this color could be hosts of a recent massive SF. Therefore we could find blue ellipticals lacking morphological peculiarities 1-2 Gyr after a merger-induced starburst. Another indicator of a past merger is the total luminosity of the galaxy. The prediction of the brightness for a merged group association of galaxies (i.e. compact groups) is MB < -21.75 (Marcum 2004).

Around 35 % of the ETIG in the HI sample coming from CIG have been detected in HI (16 galaxies). In Fig. 2 we show a composition of their optical images from POSSII, 2MASS plates or from SDSS if available (Abazajian et al. 2004, AJ, in press). Some relevant information has been listed in Table 2: CIG number, velocity, HI mass, width of the HI profile at 20% of the maximum, optical and infrared luminosity, and finally some comments about the availability of any CO or FIR data, which can indicate presence of SF. In Table 2 we can see that the blue luminosities are spread through a large range of luminosities(8.5-10.5). Additionally, plates of the HI detected ETIG from POSSII and SDSS have been revised in order to check for any distortion in their morphologies and for the search of any close companion in interaction with the primary galaxy. Six of our early type galaxies were found in SDSS fields: CIG 332, 338, 393, 481, 483 and 582. We have searched for (B-V)o colors for the entire sample of ETIG as well, and found that CIG 393 and 481 are bluer than expected ((B-V)o = 0.5 and 0.7 respectively), and therefore they are likely candidates to have accreted any companion (but not to be a merged compact group, since in both cases the MB is higher than the higher limit indicated above).

We notice that at least 8 of the 16 HI profiles present a typical double horn in the HI profile, characteristic of a gas disk, indicating probably a recent minor merger with a gas rich galaxy.

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Fig 3. Histogram showing available colors (B-V)o for the CIG sample. In white for all morphological types, in filled red bins the early-type galaxies, and in green non-filled bins specifically the ellipticals . The location of the bluer ellipticals (with (B-V) lower than 0.9) is also shown

CIG	T	Vel (km/s)	M_HI log(Msun)	W_HI (km/s)	Lb log(Lsun)	Lfir log(Lsun)	DET_Lfir	Comments
~~14~~	~~E~~	~~5237~~	~~9.00~~	~~409~~	~~10.24~~	~~10.50~~	~~Y~~	~~-Perturbed and likely to be in minor interaction.~~
120	E	6682	9.62	434	10.43	10.73	N	-Detected in IRAS S60, 100 but not in 25). Double horn and wide HI profile. Shell present?. projected dwarf galaxies candidates in 2MASS
332	S0	4309	9.27	339	10.14	10.57	Y	-Detected in CO (own observation). Detected in IRAS (25, 60 and 100). Weak interaction, isophote twist in 2Mass-J. Few projected dwarf galaxies.
338	S0	3494	9.18	160	9.93	9.78	N	-Not detected in CO (own obs.). Detected in IRAS (25, 60 but not in 100). Weak interaction, isophote twist in 2Mass-J. Few projected dwarf galaxies.
393	E	3011	8.36	159	9.68	10.45	Y	-Not detected in CO (own obs.). Detected in IRAS (25, 60 and 100). Double horn in HI profile . HII galaxy, with a high ratio S60/S100 (HII+AGN?). Elongated nucleus.
481	S0	1508	8.25	305	9.57	10.54	Y	-Detected in CO (Wiklind & Henkel 1989). Detected in IRAS (25, 60 and 100). Double horn with asymmetry in HI profile. Huge elliptical with numerous projected dwarf satellites visible. Dust lanes.
483	S0	6710	9.43	426	10.50	10.43	Y	-Detected in IRAS (60, 100 but not in 25). Weak interaction . Asymmetric profile in HI profile. Several projected dwarf galaxies. Low S60/S100 ratio
501	S0	6498	9.60	297	10.04	-	-	-Double horn in HI profile.
503	S0	1059	7.33	237	9.02	9.39	Y	-Detected in IRAS (60, 100 but not in S25). Dust lanes. Noisy HI profile.
555	E	1106	7.65	134	8.53	8.93	N	
582	E	9998	10.51	478	10.35	10.74	N	-Detected in IRAS (25 but not 60 and 100). Slight asymmetry in 2Mass-J. Weak interaction. Dust lanes.
811	E/S0	7872	9.32	306	10.36	10.46	Y	-Detected in IRAS (60, 100 but not in 25).
824	E	5340	8.71	277	10.07	9.96	N	-Centre of the galaxy perturbed in the optical image.
870	E	6292	9.22	168	10.29	11.24	Y	-Detected in IRAS (25, 60 and 100). with a high ratio S60/S100 (HII+AGN?). Tidal tails, companion?
895	E	4847	9.22	267	9.72	10.60	N	-Detected in IRAS (60, 100 but not in 25). Marginal detection in CO (own obs.).
1015	S0	4437	10.13	185	10.41	10.02	Y	-Detected in CO (own obs.). Detected in IRAS (60, 100 but not in 25). high ratio S60/S100, high SF in the centre.

Table 2. Morphological type (E or S0), HI, LB and Lfir data for the ETIG. In the comments information about SF and environment is given.

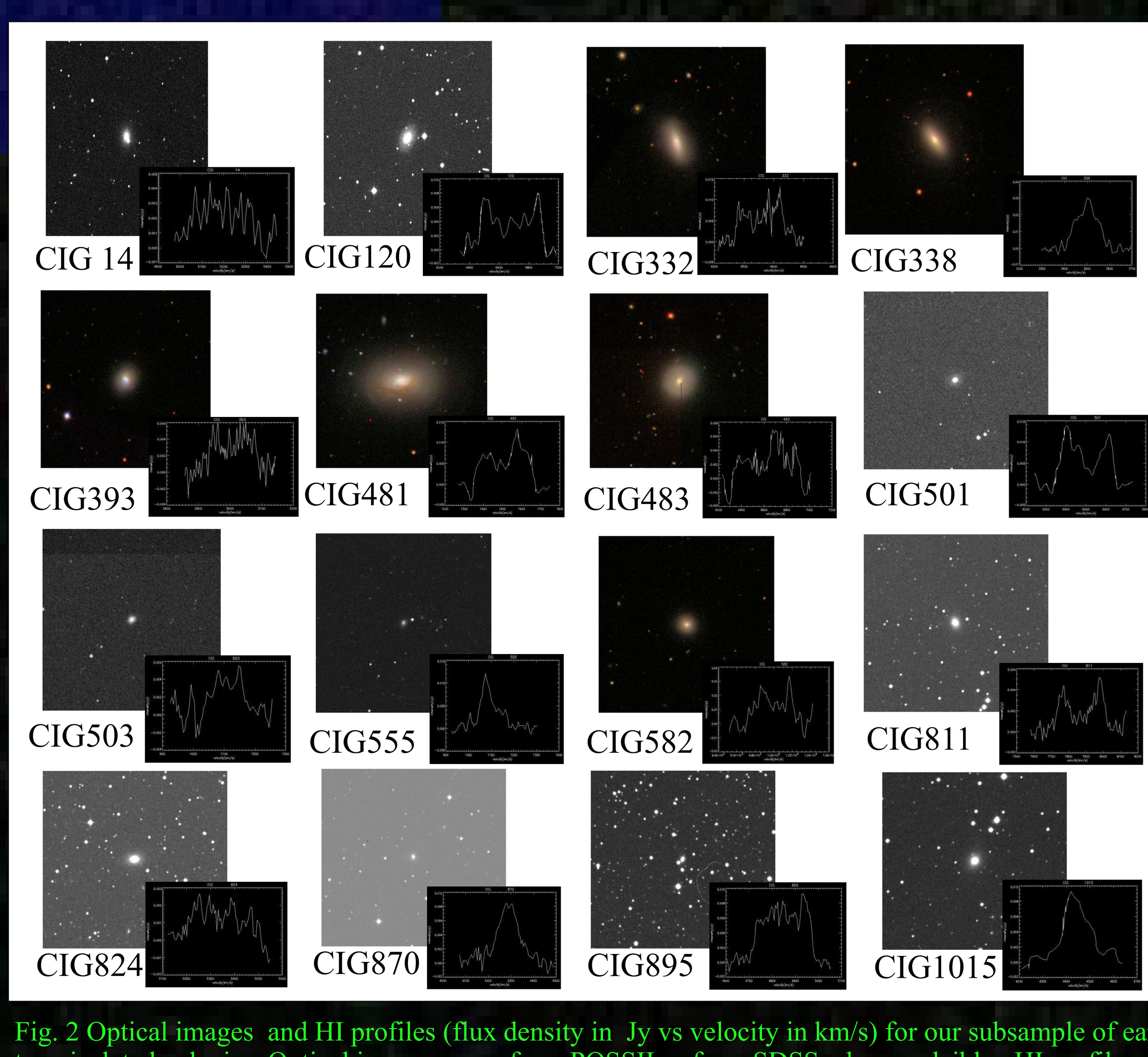

Fig. 2 Optical images and HI profiles (flux density in Jy vs velocity in km/s) for our subsample of early type isolated galaxies. Optical images come from POSSII or from SDSS when avalaible. HI profiles come from own observations, except for CIG1015 (Haynes & Giovanelli 1984)

THE CIG REFINED SAMPLE

Karachentseva (1973) compiled the Catalog of Isolated Galaxies (CIG) which includes 1050 galaxies. We use the CIG as our starting point because it has a number of strengths:

• Isolation: The CIG sample was assembled with the requirement that no similar sized galaxies with diameter d (between 1/4 and 4 times diameter D of the CIG galaxy) lie within 20d. It is immediately seen that this criterion is superior to one with a fixed isolation in terms of the diameter of the CIG galaxy in question. However it is also clear that dwarf companions are not excluded. This is the familiar compromise between seeking isolation and avoiding the background of distant unrelated galaxies. Using the publicly available images of POSS-I plates (as well as POSS-II plates for some fields) a revision of the isolation degree of CIG galaxies has been done.(see poster "AMIGA: The influence of the environment on the most isolated galaxies", Verley et al).

• Complementarity: This CIG is complemented by catalogs of galaxy pairs (Karachentsev 1972), triplets (Karachentseva et al. 1979) and compact groups (Hickson 1982; largely quartets).

• Morphology: All morphological types are found in the CIG including a significant local supercluster dwarf population. The CIG sample is large enough to permit discrimination on the basis of galaxy type (Sulentic et al, in prep.).

• Depth: The CIG samples a large enough volume of space to allow us to sample the majority of the optical luminosity function (OLF).

• Positions: Leon & Verdes-Montenegro (2003) revised positions for the 1051 CIG galaxies, using SExtractor to the Digitized Sky Survey CIG fields with a spatial resolution of 1.2" and an accuracy of 0.05". They visually checked the resulting positions for 143 galaxies and had to recompute the assigned positions due to irregular morphologies or the presence of bright stars, finding differences between the older and newer coordinates of up to 44.5" arcsec with a mean value of 1.8".

HI CONTENT AS A FUNCTION OF LB, DIAMETER AND MORPHOLOGY

The main aim of this study is to establish reference relationships between the HI mass, blue luminosity, size and type for the given HI sample of isolated galaxies that can serve as standard references of normalcy to galaxies in denser environments. This will be an improvement of similar studies (i.e. Haynes & Giovanelli 1984 (HG84) and Solanes et al 1996), since we will be able to study these issues as a function of isolation in an analytical way through isolation coefficients (see poster "AMIGA: The influence of the environment on the most isolated galaxies", Verley et al).

-Distribution of the HI mass: we present in Fig. 4 histograms showing the distribution of the HI mass for 1)all morphological types, 2) HI mass binned in early, late and irregular types. We can see that we contribute to better sample lower blue luminosity regions and early and irregular types (green histogram) with respect to HG84 (red histogram superposed).

-HI mass-LB and HI mass- D^2 relationships: are shown in Fig. 5. Standard errors are comparable between both fits (green and red solid lines for our data and HG84 respectively), but our sample contains just isolated galaxies after revision, reducing in this way the effect of deviations coming from HI rich dwarfs, etc. We have used survival analysis and therefore upper limits (yellow triangles in the plot) have been considered. The coefficients of the fits are the following:

$\log(M_{HI}) = 2.3 + 0.72 \log(L_B)$ s.e.e=0.44, our sample
$\log(M_{HI}) = 2.9+0.66 \log(L_B)$ s.e.e=0.36, for HG84

$\log(M_{HI}) = 7.0+ 0.85 \log(D^2)$ s.e.e=0.33, our sample
$\log(M_{HI}) = 7.1+0.88 \log(D^2)$ s.e.e=0.23, for HG84

Fig 4. Histograms showing the distribution of the HI content as a function of the morphological type. In green the distribution of MHI for detected galaxies in our sample (nearly 475 galaxies) and in red the same for the sample in HG84. From top to bottom and from left to right: 1) distributions for all the types, 2) for early types, 3) for late types and 4) for irregulars.

Fig 5. Relationships between the HI mass and the blue luminosity (top), and the HI mass with respect to the squared linear optical diameter (bottom). Red crosses indicate data points from galaxies detected in HI, blue squares are marginal detections and yellow triangles are upper limits, all from our HI sample data points. The green solid line is the regression line, fit to all our data points through survival analysis. The red line represents the fit done in HG84 to the set of all their detected galaxies. The standard error of the estimate (s.e.e.) are indicated on the upper left side of each figure.

ONGOING AND FUTURE WORK

- We will analyse recent observations that we have recently performed at the VLA to study asymmetries of 10 very isolated galaxies with extremely HI asymmetric profiles .

-We will use the here presented reference sample to revise HI deficiencies in denser environments (e.g. HCGs, Verdes-Montenegro et al 2001).

-We will perform multiwavelength observations in order to better characterize our HI rich early type candidates.