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ALFALFA: an Exploration of the $z = 0$ HI Universe

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Summary. — The Arecibo Legacy Fast ALFA (ALFALFA) Survey is a program aimed at obtaining a census of HI-bearing objects over a cosmologically significant volume of the local Universe. It will cover 7074 square degrees of the high latitude sky accessible with the Arecibo 305m telescope, using the 7-beam feed L-band feed array (ALFA). Started in February 2005, as of Summer of 2007 survey observations are 44% complete. ALFALFA offers an improvement of about one order of magnitude in sensitivity, 4 times the angular resolution, 3 times the spectral resolution, and 1.6 times the total bandwidth of HIPASS. Although it will cover only one quarter the sky solid angle surveyed by HIPASS, ALFALFA will detect approximately six times as many sources, with a median depth of 110 Mpc. Preliminary results of ALFALFA are presented, with emphasis on those related with the Virgo cluster.

1. – Introduction

Baryons make up about 4.5% of the mass/energy budget of the Universe, and only 1/6 of its matter density. At $z = 0$ the vast majority of baryons are thought to exist in the form of coronal and intergalactic gas, at temperatures $> 10^5$ K; Ω_{stars} is a tiny 0.0027 and $\Omega_{cold\ gas}$ an even smaller 0.0008, of which a bit over half is neutral Hydrogen [1]. This unimpressive budgetary datum could well prompt the question: why do we care about HI? Several reasons for caring are relevant to the purview of this conference. First, HI is easy to detect at 21 cm wavelength, most of the emission originates in optically thin regions and cold gas masses are reliably measured; the abundance of cold gas is a reliable indicator of star forming potential for an extragalactic system. Second, the distribution of HI, which extends farther out than other easily detectable components in a galaxy, makes it an excellent tracer of the large–scale dynamics of its host. Third, scaling relations of disks, such as that between luminosity and rotational width, make HI measurements good cosmological tools: for example in the measurement of $H_\circ$, peculiar velocities, the convergence depth of the Universe and the local matter density field. Fourth, because of its distribution at relatively large galactocentric distances, HI is vulnerable to external influences and thus constitutes a good tracer of tidal interactions, mergers and other environmental effects. Fifth, it can be the dominant brayonic component in low mass galaxies and thus help provide a reliable census of low mass systems in the galactic hierarchy. Hence, ALFALFA.

2. – What is ALFALFA?

Wide angle surveys of the extragalactic HI sky became possible with the advent of multifeed front–end systems at L–band. The first such system with spectroscopic capability was installed on the 64 m Parkes telescope in Australia, and has produced the excellent results of the HIPASS survey [2]. The 1990s upgrade of the Arecibo telescope optics made it possible for that telescope to host feed arrays, as proposed by [3]. Eventually a 7-beam radio "camera", named ALFA (Arecibo L–band Feed Array), became operational enabling large–scale mapping projects with the great sensitivity of the 305–m telescope.

ALFALFA will map the extragalactic HI emission at $cz < 18000$ km s^{-1} over 7074 deg^2. Exploiting the large collecting area of the Arecibo antenna and its relatively small beam size ($\sim 3.5'$), ALFALFA will be eight times more sensitive than HIPASS with $\sim$four times better angular resolution. The combination of sensitivity and angular resolution allows dramatically improved ability in determining the position of HI sources, a detail of paramount importance in the identification of source counterparts at other wavelengths. Furthermore, its spectral backend provides 3 times better spectral resolution (5.3 km s^{-1} at $z = 0$) and over 1.4 times more bandwidth. These advantages offer new opportunities to explore the extragalactic HI sky. A comparison of ALFALFA and other past and current HI surveys is given in Table 1. Data taking for ALFALFA was initiated in February 2005 and, in the practical context of time allocation at a widely used, multidisciplinary national facility, completion of the full survey is projected to require a total of 6 years.

Some of the main science goals to be addressed by ALFALFA which are of special relevance to these proceedings include: (i) the determination and environmental variance of the HI mass function, especially at its faint end and its impact on the abundance of low mass halos; (ii) the large–scale structure characteristics of HI sources, their impact on the "void problem" and metallicity issues; (iii) providing a blind survey for HI tidal remnants and "cold accretion"; (iv) determining a direct characterization of the HI diameter function; (v) the ALFALFA survey area includes ~ 2000 continuum sources with fluxes sufficiently large to make useful measurements of HI optical depth, and hence to provide a low z link with DLA absorbers.

The minimum integration time per beam in seconds t_s necessary for ALFA to detect an HI source of HI mass M_{HI}, width W_{kms}, at a distance D_{Mpc} is

$$t_s \simeq 0.25\Big(\frac{M_{HI}}{10^6 M_\odot}\Big)^{-2}(D_{Mpc})^4\Big(\frac{W_{kms}}{100}\Big)^{\gamma}, \tag{1}$$

where the exponent $\gamma \simeq 1$ for $W_{kms} < 300$ km s^{-1}and increases to $\gamma \simeq 2$ for sources of larger width. Thus the depth of the survey, i.e. the maximum distance at which a given HI mass can be detected, increases only as $t_s^{1/4}$. A corollary of this scaling law is the fact that, once M_{HI} is detectable at an astrophysically satisfactory distance, it is more advantageous to maximize the survey solid angle than to increase the depth of the survey through longer dwell times. In passing, we note that the t_s required to detect a given M_{HI} at a given distance decreases as the 4th power of the telescope diameter: Arecibo offers a tremendous advantage because of its huge primary reflector. The effective integration

Table I. – *Comparison of Blind HI Surveys*

Survey	Beam ($'$)	Area (deg^2)	res (km s^{-1})	rms^a	V$_{med}$ (km s^{-1})	N$_{det}$	Ref
AHISS	3.3	13	16	0.7	4800	65	[b]
ADBS	3.3	430	34	3.3	3300	265	[c]
WSRT	49.	1800	17	18	4000	155	[d]
HIPASS	15.	30000	18	13	2800	5000	[e,f]
HI-ZOA	15.	1840	18	13	2800	110	[g]
HIDEEP	15.	32	18	3.2	5000	129	[h]
HIJASS	12.	1115	18	13	[i]	222	[i]
J-Virgo	12.	32	18	4	1900	31	[j]
AGES	3.5	200	11	0.7	12000		[k]
ALFALFA	3.5	7074	11	1.7	7800	>25000	[l]

[a] mJy per beam uniformly referred at 18 km s^{-1} resolution; [b] Zwaan *et al.* (1997, *ApJ* 490, 173); [c] Rosenberg & Schneider (2000, *ApJSS* 130, 177); [d] Braun *et al.* (2003, *AAp* 406, 829); [e] Meyer *et al.* (2004, *MNRAS* 350, 1195); [f] Wong *et al.* (2006, *MNRAS* 371, 1855); [g] Henning *et al.* (2000, *AJ* 119, 2696); [h] Minchin *et al.* (2003, *MNRAS* 346, 787); [i] Lang *et al.* (2003, *MNRAS* 342, 738), HIJASS has a gap in velocity coverage between 4500-7500 km s^{-1}, caused by RFI; [j] Davies *et al.* (2004, *MNRAS* 349, 922); [k] Minchin *et al.* (2007, *IAU 233*, 227); [l] Giovanelli *et al.* (2007, *AJ* 133, 2569).

time per beam area of ALFALFA is of order of 40 sec, which yields a minimum detectable HI mass of 2×10^7 $M_\odot$ at the distance of the Virgo cluster and in a catalog of sources with a median $cz \sim 7800$ km s^{-1}. As of mid–2007, 44% of the survey solid angle has been fully mapped. Further details on the design and progress of the survey can be seen in [4] and at the URL *http://egg.astro.cornell.edu/alfalfa*. ALFALFA is an open collaboration. Anybody with a legitimate scientific interest and willing to participate in the development of the survey can join. Access to cataloged survey products can be obtained at *http://arecibo.tc.cornell.edu/hiarchive/alfalfa* and survey progress, guidelines for joining and other details can be obtained at *http://egg.astro.cornell.edu/alfalfa*.

Two catalogs of HI sources extracted from 3-D spectral data cubes have been accepted for publication in 2007 [5] [6], and several others are in preparation. As of Summer of 2007, more than 5000 HI sources have been identified, over a solid angle representing 15% of the total ALFALFA survey. Figure 1 shows those sources in the framework of two wedge plots, corresponding to contiguous declination strips. While the two strips are non-overlapping, repeatability of the large scale features bears witness to the correlation scale in the galaxy distribution. Note that, due to the impact of local RFI, ALFALFA is effectively blind in the redshift range cz ∼15000 to 16000 km s^{-1}.

Figure 2 shows a HI mass vs. distance diagram of the HI sources in Figure 1. Two smooth lines are overplotted, identifying respectively the completeness limit (dotted) and the detection limit (dashed) for sources of 200 km s^{-1}linewidth for the HIPASS survey. This diagram dramatically illustrates the improvement ALFALFA represents, over previous surveys. The median redshift of the catalog is ∼7800 km s^{-1} and its distribution reflects the known local large scale structure. See Haynes' presentation in

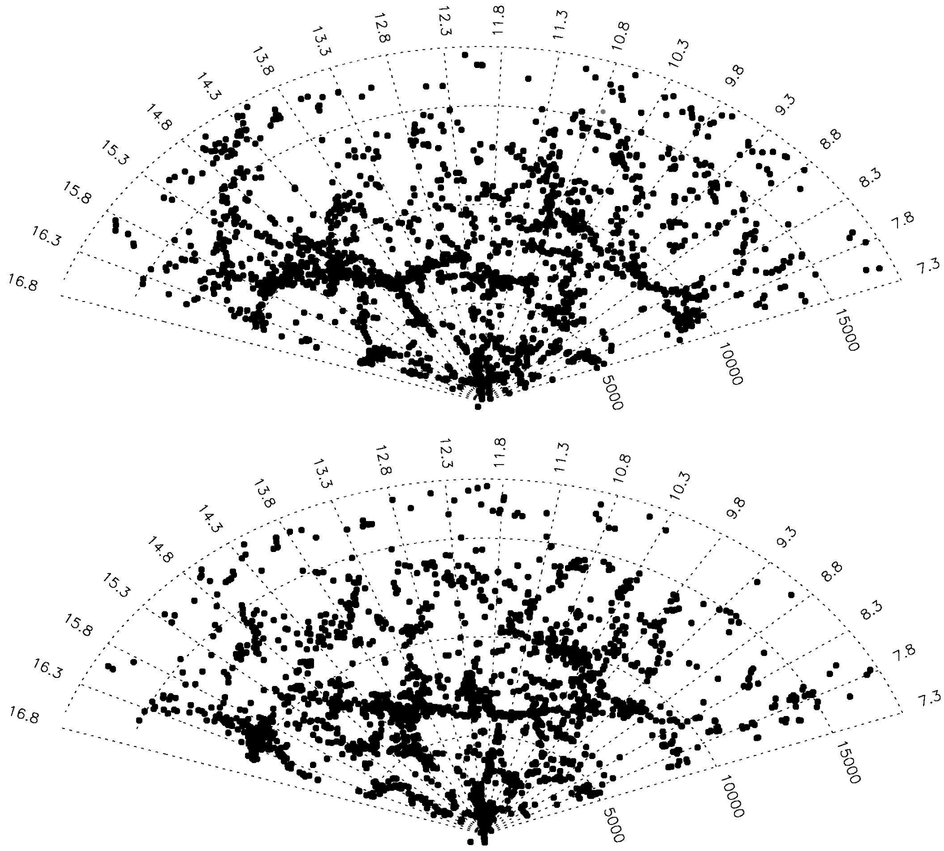

Fig. 1. – Wedge plots of HI sources detected by ALFALFA. Both figures cover the same range in R.A.=[7.5^h–16.5^h]; the upper diagram corresponds to 2657 sources in the region Dec=[12°–16°], whilee the lower one refers to 2580 sources in the contiguous region Dec=[8°–12°]. Together, they represents 15% of the ALFALFA survey. Note that due to RFI, ALFALFA is effectively blind in the redshift range between approximately 15000 and 16000 km s^{-1}.

these proceedings for a discussion of the impact of these observations on the faint end of the HI mass function.

For the same set of sources, the top panel on the right of Fig. 2 displays S/N vs. velocity width, while the bottom panel displays the flux integral vs. velocity width. The quality of the ALFALFA signal extraction is apparent: the S/N of detections exhibits no significant bias with respect to velocity width. Spectroscopic HI surveys are not single flux limited. The flux limit rises as $W^{1/2}$ for low velocity widths, changing to a linear rise for the wider line profiles. Such a transition is observed near $\log W \simeq 2.5$. The ALFALFA flux limit is ~ 0.25 Jy km s^{-1} for narrow lines, rising near 1 Jy km s^{-1} for the broadest ones.

The positional accuracy of HI sources is a very important survey parameter, especially in the identification of HI sources with sources at other wavelengths. The quality of the

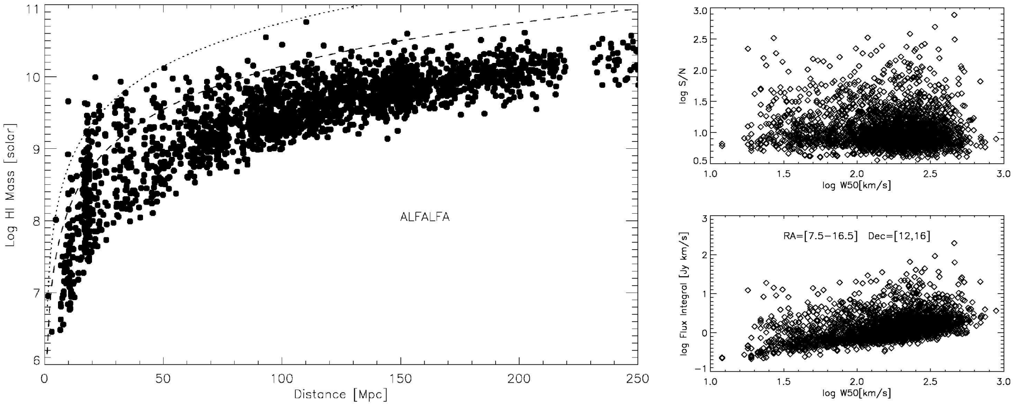

Fig. 2. – **Left:** Spänhauer plot HI sources in the region R.A.=[7.5^h–16.5^h], Dec=[12°–16°]. The two smooth lines identify the completeness limit (dotted) and the detection limit (dashed) for sources of 200 km s^{-1} linewidth for the HIPASS survey. Note that due to rfi, ALFALFA is effectively blind in the redshift range between approximately 15000 and 16000 km s^{-1}. **Right:** Signal–to–noise ratio vs. velocity width (top) and Flux integral vs. velocity width for the galaxies in the left–hand panel.

positional centroiding of a source depends roughly linearly on source S/N and inversely on the telescope beam angular size. Consider, for example, a source barely detected by HIPASS at S/N$\simeq$ 6.5. The error box of its positioning will have a radius of approximately 2.5'. The same source can be detected by ALFALFA with $S/N \simeq 50$; as the Arecibo beam is about 4 times smaller than that of Parkes, the positional error box for the ALFALFA observation is $\sim 0.1'$, thus making an optical identification far more reliable. Positional accuracy of ALFALFA sources averages $24''$ ($20''$ median) for all sources with S/N $>$ 6.5 and is $\sim$$17''$ ($14''$ median) for signals S/N $>$ 12.

While in preliminary form, interesting statistical properties are starting to emerge from the ALFALFA data, some of which are illustrated in M. Haynes's presentation in these proceedings. The remainder of this paper is devoted to discussion of HI sources with no obvious optical counterparts in the Virgo cluster region.

3. – VirgoHI21: a Dark Galaxy?

What should we refer to as a "dark galaxy" (perhaps a misnomer)? A dark galaxy would be a starless halo, yet detectable at other than optical wavelengths, possibly in HI or through lensing experiments. Such objects are likely to exist, but hard to find. Within the CDM galaxy formation paradigm, such objects would have relatively low mass, were unable to form stars before re–ionization and either lost their baryons or were prevented from cooling them thereafter, by the IG ionizing flux. Yet we know of low mass galaxies in the Local Group which not only made stars early on, presumably before re–ionization, but they were also capable of retaining cold gas and make stars at later cosmic times. Why then should we not expect the existence of low mass systems that were unable to form stars but have retained baryons and have been able to cool them, as the IG ionizing flux rarefies? We have extremely little observational evidence for the existence of such systems. The SW component of the system known as HI1225+01

[7] has $M_{HI}/L_{opt} > 200$ and exhibits evidence for dynamical independence (a very small amplitude rotation curve) from the NE component, which has an optical counterpart. However, the SW component is not an isolated object and it cannot be excluded that it originated from a high speed tidal encounter of the NE component with a now remote passer–by, as the system lies in the outskirts of the Virgo cluster. In that case the velocity gradients interpreted as a rotation curve may just be tidal. The burden on observers is that of finding isolated systems resembling HI1225+01SW.

VirgoHI21 was discovered at Jodrell Bank, corroborated by Arecibo and WSRT observations ([8] and refs therein). It lies some 100 kpc N of NGC4254, in the NW periphery of the Virgo cluster, projected ~ 1 Mpc from the cluster center and has a relative velocity of more than 1000 km $s^{-1}$with respect to the cluster. Because of its large separation from optical galaxies and the gradient seen in its velocity field, it was interpreted by its discoverers as a dark galaxy. The ALFALFA data suggest a different scenario. The left–hand panel in Figure 3 displays ALFALFA contours of HI flux, superimposed on an optical image, showing a gas streamer extending some 250 kpc N of NGC 4254. The velocity field of the stream, which matches the velocity of NGC4254 to the S, is shown on the center panel of the figure. The observations by the previous group did not reveal the HI stream in its full extent: what they called VirgoHI21 is the bright section of the HI stream extending from $14°41'$ to $14°49'$. The HI mass in the disk of NGC2454 is 4.3×10^9 $M_\odot$ and that associated with the stream is $5.0 \pm 0.6 \times 10^8$ $M_\odot$. One of the driving arguments for the interpretation of VirgoHI21 as an isolated disk galaxy is the gradient seen in the velocity field[8]; ALFALFA data shows that gradient to be just a part of the varying, large–scale velocity field along the stream.

NGC 4254 is a system well known for its prominent $m = 1$ southern spiral arm. It is reasonable to postulate that this special feature is related with the existence of the stream. Note the following:

- NGC 4254 moves at a large velocity with respect to the cluster (> 1000 km s^{-1}) and lies at a projected distance of ~ 1 Mpc from M87.
- The prominent m=1 arm is visible in the gas and in the disk stellar population: gravity, rather than hydro phenomena such as ram pressure, is at work.
- The HI mass in the stream is only $\sim 10\%$ of that in the NGC 4254 disk: the disturbance of NGC 4254 is relatively mild (it would not, in fact be classified as an HI deficient galaxy).
- The velocity field of the stream shows the coupling of the tidal force and the rotation of NGC 4254, which suggests an interesting timing argument:
    1. the stream exhibits memory of a full rotational cycle of the NGC 4254 disk;
    2. from the NGC 4254 VLA map of [9], we can get the present outer radius of the HI disk (18.5 kpc) and the rotational velocity at that radius (150 km s^{-1}); from those we compute a rotation period of $\simeq 800$ Myr.
- Hence we estimate that the tidal encounter which gave rise to the stream initiated some 800 Myr ago, a time comparable with the cluster crossing time. If the interaction resulted from a high speed (of order of 1000 km s^{-1}, the velocity differential between NGC 4254 and the cluster) close encounter with another galaxy and/or the cluster potential, the culprit for the tidal damage would now be ~ 1 Gpc away.

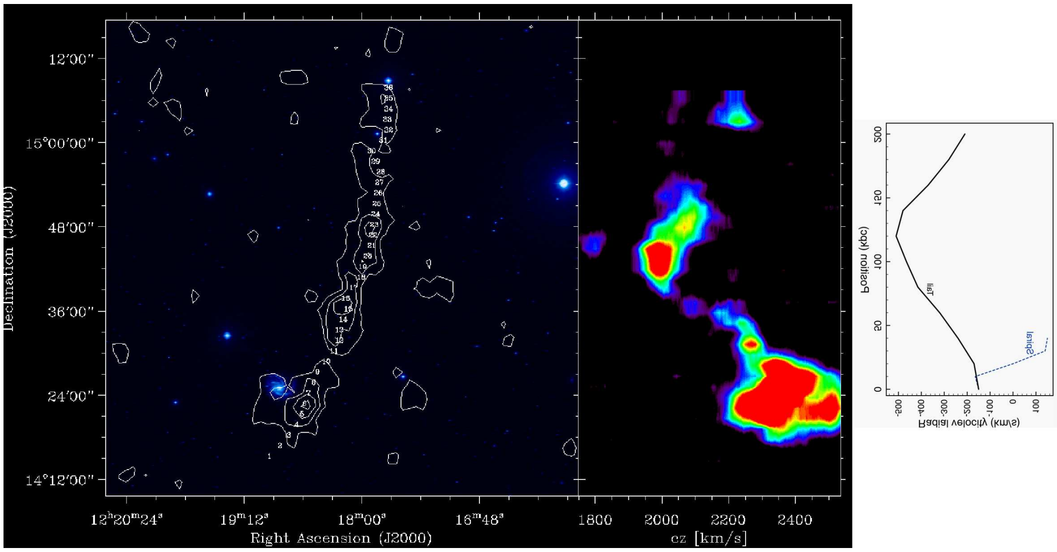

Fig. 3. – *Left*: HI column density contours extracted from the ALFALFA survey dataset, superposed on the SDSS image and centered on the position of Virgo HI21 (Minchin *et al.* 2005a). *Center*: The velocity of the HI emission peak as seen along the ridge of the stream. Note that HI emission from NGC 4254 is excluded from the map to the left, but it is included in the one on the center image. *Right*: Position-velocity line along the stream as modelled by Duc & Burneaud, flipped and scaled to match the two color images. VirgoHI21 was identified as a section of the HI stream extending from 14°41′ to 14°49′.

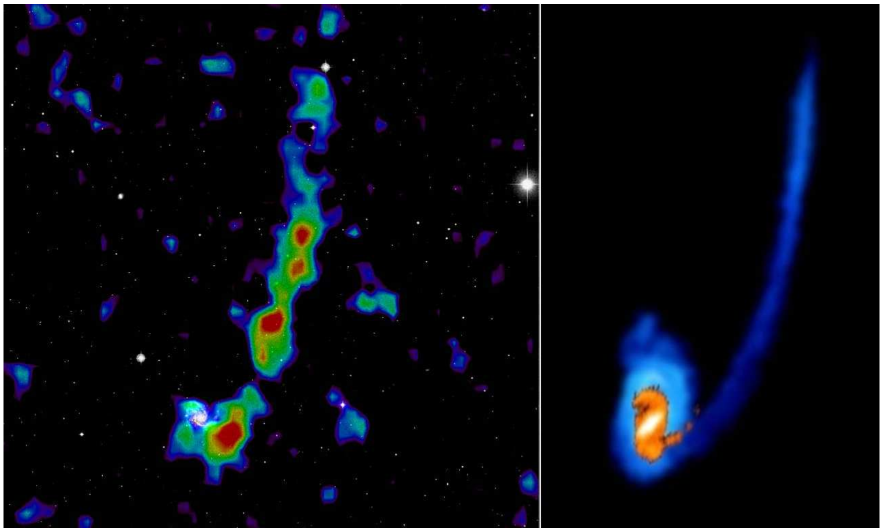

Fig. 4. – *Left*: HI column density contours extracted from the ALFALFA survey dataset, superposed on the SDSS image and centered on the position of Virgo HI21 [8]. *Right*: The stream as modelled by [11]. VirgoHI21 was identified as a section of the HI stream extending from 14°41′ to 14°49′ (see preceding figure).

We conclude that the most reasonable interpretation of the system is that of a relatively mild episode of harassment, resulting from the high speed passage of NGC 4254 through the cluster periphery. These results are discussed in greater detail in [10].

Duc & Bournaud [11] have produced a computer simulation of a high speed encounter of NGC 4254 with another peripheral cluster galaxy. The simulation matches extremely well both the morphology and the velocity field of the stream. A comparison of the model and the ALFALFA data is shown in figures 4 (stream morphology) and 3, right hand panel (position–velocity). The culprit responsible for the harassment of NGC 4254 could now be located far from NGC 4254. The authors of the simulation speculate that, given its location and velocity, the culprit could be M 98 = NGC 4192. ALFALFA finds an extended HI appendage apparently emanating from that galaxy.

The overall evidence for VirgoHI21 to be part of the phenomenology associated with a tidal episode of harassment, rather than an isolated "dark galaxy" is thus quite strong.

4. – The NGC 4532/DDO 137 System

This pair of galaxies is located to the South of the Virgo cluster. The two galaxies are of late type (SmIII/SmIV) and very gas rich. Arecibo observations ([12] and refs. therein) revealed that some of the HI in the system is well beyond the optical disks of the two galaxies. VLA observations[13] confirmed those results. ALFALFA maps expand on both of those results, revealing the presence of cold gas at significantly larger galactocentric distances than previously realized. The left panel of figure 5 covers a solid angle of about 3 deg^2, with a bold solid contour approximately tracing the outer envelope of the HI gas reported by [12]. Within that region, ALFALFA[14] detects an HI mass of 6.2 x 10^9 $M_\odot$, in agreement with previous reports. An additional 1.3 x 10^8 $M_\odot$ is contained within a partially resolved clump $\sim 20'$ west of NGC 4532, labelled 'western clump' (WC). A set of discrete clumps, numbered 1 through 8, outline the ridges of two streams, connected by low column density emission not displayed by the contour plots. They have HI masses varying between 2.5×10^7 and 6.8×10^7 $M_\odot$. Clumps 1, 2, 4, 5 and 8 outline one stream, while clumps 7 and 8 appear to be on a separate stream. The right-hand panel of figure 5 provides an elementary position-velocity map of the system, showing the streamer system apparently emerging from the low velocity side of NGC 4532 (solid contours). No apparent optical counterparts are seen associated with WC and the numbered clumps in the system; the overall HI mass associated with them is about 5 to 7×10^8 $M_\odot$, which is approximately 10% of the galaxy pair's HI mass, a ratio similar to that of the stream–to–galaxy in the NGC 4254 system discussed above. At the Virgo cluster distance, the stream system associated with NGC 4532/DDO 137 extends over 500 kpc. As in the case of NGC 4254, the disturbance is spectacular, but the "damage" caused to the galaxy pair appears to be mild. The size, velocity and other characteristics of the system suggest, again, a galaxy harassment scenario. Modelling of the interaction that may have caused the streams is underway.

5. – A Cloud Complex near NGC 4424

Roughly halfway in the sky between M87 and M49, ALFALFA detects a conspicuous complex of HI clouds, shown in figure 6. The nearest optical galaxy with a velocity near that of the complex is NGC 4424, located some 40' W of the complex center. An optical image of NGC 4424 is shown in figure 6, at its approximate sky location with respect to the cloud complex. The optical image is however enlarged by a factor of 2.5 with respect

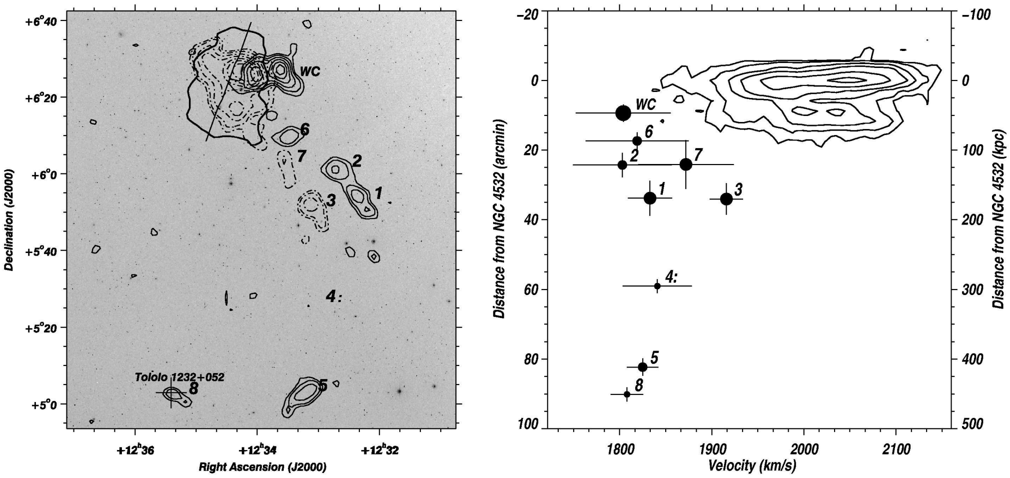

Fig. 5. – *Left*: The bold contour at 0.3 Jy beam^{-1} km s^{-1}, integrated over 1951 - 2139 km s^{-1}, encompasses the approximate area of the HI envelope detected by Hoffman *et al.*(1993). Solid contours show tail emission integrated over 1784 - 1836 km s^{-1}, while dashed contours show emission integrated over 1868 and 1930 km^{-1}. *Right*: Position (radial distance from NGC 4532) as a function of velocity for the NGC 4532/DDO 137 system. The contours follow a locus (the solid line in the left panel) along the major axis of NGC 4532 and through the HI envelope of the pair system.

to the features shown in the HI map. The velocities of the individual clouds are (S to N) 476, 490, 601, 605 and 527 km s^{-1}, and their velocity widths are 48, 66, 45, 257 and 120 km s^{-1}. NGC 4424 has heliocentric velocity of 441 km s^{-1}. At the Virgo cluster distance, the individual clouds in the complex have HI masses between 0.4×10^7 $M_\odot$ (to the SE) and 2×10^8 $M_\odot$. The total HI mass of the complex is $\simeq 5 \times 10^8$ $M_\odot$. The HI mass of NGC 4424 is 1.7×10^8 $M_\odot$. Given its HI mass and optical size, NGC 4424 is very HI deficient ($Def \simeq 1$, corresponding to having lost most of its cold gas[15]).

Stretching over 200 kpc (at the Virgo cluster distance), the cloud complex does not appear to be gravitationally bound. With cloud–to–cloud velocity differences of order of 100 km s^{-1}, the mean cloud separation will double over $\sim$ 1 Gyr. The complex thus appears to be a transient phenomenon. Plausible interpretations of its nature are: (a) detached ISM from a single galaxy, either by ram pressure or tidal forces; (b) group of mini halos falling in the cluster for the first time . The absence of conspicuous (given the velocity widths involved) optical counterparts argues strongly (b). The HI deficiency and other properties of NGC 4424 are is strongly suggestive of environment–driven mechanisms at work, and likelihood of association with the cloud complex. Occam's razor does not favor the idea of a cluster of dark galaxies, albeit the possibility that some of the clumps may give rise to the formation of tidal dwarfs is an attractive hypothesis.

6. – Other Virgo Features

NGC 4192 = M 98 is a galaxy located in the NW periphery of the Virgo cluster, with a negative $cz_\odot = -142$ km s^{-1}) indicative of large relative motion with respect to the cluster itself. A number of HI clouds with velocities between 60 and 100 km s^{-1} are

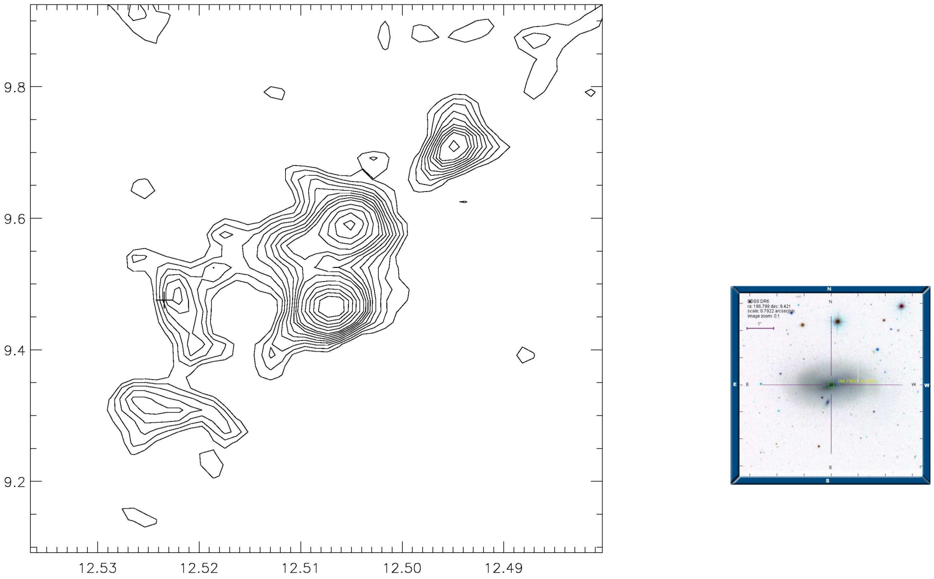

Fig. 6. – Zeroth moment map of an HI cloud complex detected in the vicinity of NGC 4424. The lowest contour plotted corresponds to approximately 0.8 mJy beam^{-1}. An SDSS image of NGC 4424 is shown at its approximate location with respect to the cloud complex, although the optical image is enlarged by a factor of 2.5. The heliocentric velocity of NGC 4424 is 441 km s^{-1}, while those of the clumps in the complex vary between 485 and 609 km s^{-1}.

found in its vicinity, spectrally well separated from Milky Way emission. They would typically be cataloged as High (or Intermediate) Velocity Clouds, perigalactic (or Local Group) dwellers, and most of them may very well be just that. Some of the clouds, however, appear to stream out of M 98, stretching over more than 1°, well matched both spatially and kinematically to the disk of M 98. The characteristics of this system are under close scrutiny. Of particular interest is the fact that [11] suggest that M 98 may be the culprit responsible for the harassment of NGC 4254, observed in the form of the stream VirgoHI21 is a part of.

ALFALFA has detected several other features lacking obvious counterparts, as tabulated in [16]. Figure 7 shows two such examples: the HI sources are unresolved by the Arecibo beam and thus extend fewer than ~ 15 kpc at the Virgo distance, at which their HI masses would be 4×10^7 (left panel) and 8×10^7 $M_\odot$(right panel); the second object may however be part of the M cloud, in the background of the cluster. No clear clues are available as to the nature of these objects. They are sufficiently removed from the cluster center that ram pressure effects are small. While the possibility that they may be primordial remains open, the likelihood is high that they may constitute tidal remnants, the consequence of events such as those discussed in the previous sections.

7. – An Overall HI View of the Virgo Cluster

The HI content and extent of HI disks of galaxies that venture in the inner regions of clusters have been known to be strongly affected([17], [18],[19],[20],[22],[21]). Figure 8 clearly illustrates the matter. About 200 HI sources are detected by ALFALFA in the

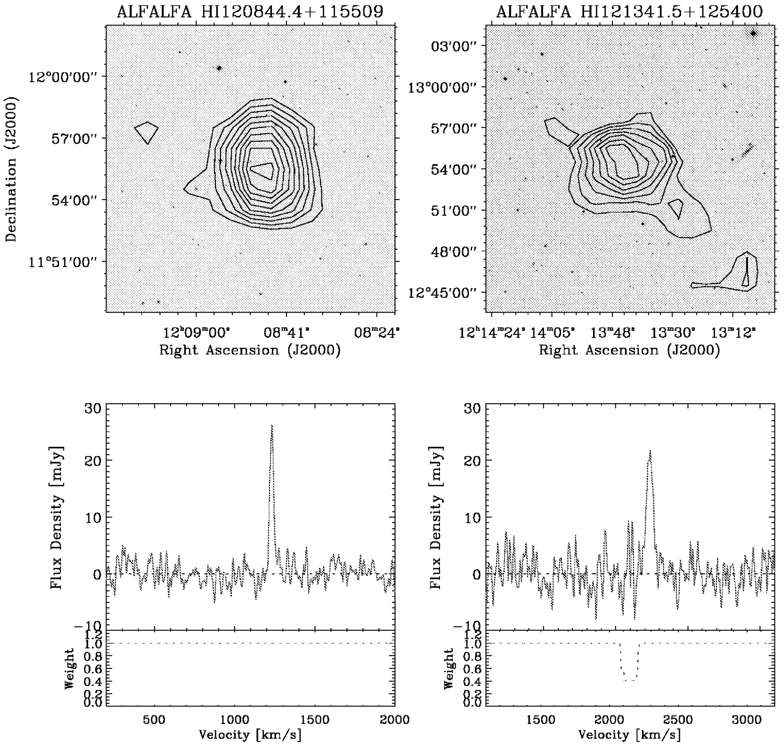

Fig. 7. – HI spectra and contour maps of 2 sources in the Virgo cluster region (see text for details).

Virgo region shown in that graph; they are identified by blue circles, the area of which is proportional to the HI mass, varying between 2×10^7 and 3×10^9 $M_\odot$. The orange–to–red contours represent the intensity of the X–ray emission, as imaged by ROSAT [23]. In HI, the Virgo cluster appears as a ringofo emission surrounding the X–ray emiting IGM. Sources detected in the inner parts of the cluster typically correspond to highly HI deficient galaxies. The red stars in the graph show the locations of HI sources found by ALFALFA not to have obvious optical counterparts. The vast majority of those lie in the outer parts of the cluster and are posssibly remnants of tidal events. With a complete census of the HI sources in the cluster — a goal nearly at hand — and a fair understanding of the cluster structure and dynamics, it will soon be possible to estimate the frequency and longevity of environment driven events in the nearest cluster to us. It is interesting to conclude with the emerging realization that the wealth of optically inert sources found in the vicinity of the cluster does not appear to be matched in other regions for which ALFALFA mapping is becoming complete.

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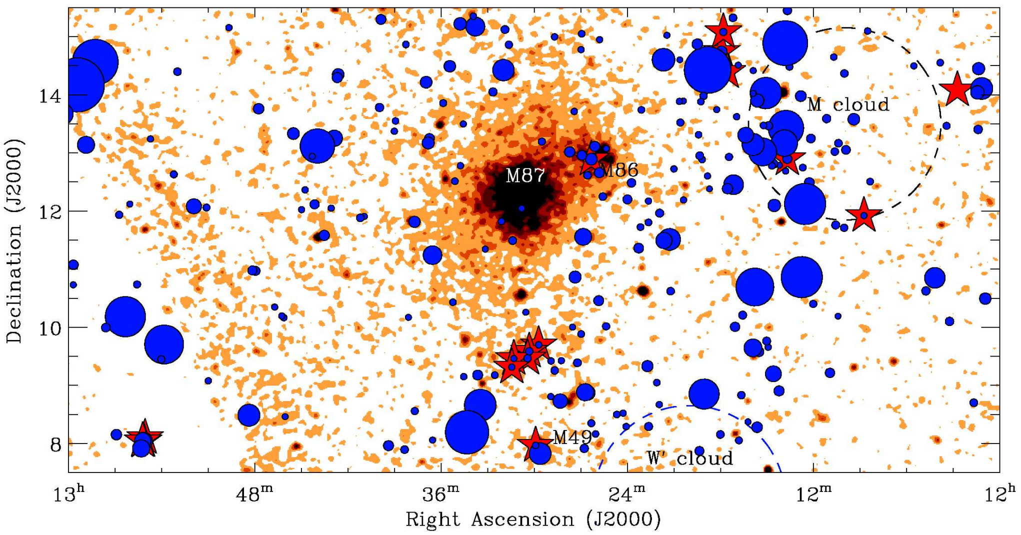

Fig. 8. – Composite of the Virgo cluster: X ray emission (orange), HI sources (blue circles) and HI sources with no obvvious optical counterpart (red stars). See text for details.

REFERENCES

[1] Fukugita M. and Peebles P.J.E., *ApJ*, **616** (2004) 643.
[2] Barnes D.G., Staveley–Smith L., de Blok W.J.G. *et al.*, *MNRAS*, **322** (2001) 486
[3] Kildal P.S., Johansson M., Hagfors T. and Giovanelli R., *IEEE Trans. Anten. Propag.*, **41** (1993) 1019
[4] Giovanelli R., Haynes M.P., Kent B.R. *et al.*, *AJ*, **130** (2005) 2598
[5] Giovanelli R., Haynes M.P., Kent B.R. *et al.*, *AJ*, **133** (2007) 2569
[6] Saintonge A., Giovanelli R., Haynes M.P., *et al.*, *AJ*, (2007) in press and astro–ph/
[7] Chengalur J., Giovanelli R. and Haynes M.P., *AJ*, **109** (1995) 2415
[8] Minchin R.F., Davies J.I., Disney M.J. *et al.*, *ApJ*, (2007) in press and astro-ph/0706.1586
[9] Phookun B., Vogel S.N. and Mundy L.G., *ApJ*, **418** (1993) 113
[10] Haynes M.P., Giovanelli R. and Kent B.R., *ApJL*, **665** (2007) L19
[11] Duc P.–A. and Bournaud F., *ApJ*, (2007) in press and astro-ph/0710.3867
[12] Hoffman G. L., Lu N. Y., Salpeter E. E. *et al.*, *AJ*, **106** (1993) 39
[13] Hoffman G. L., Lu N. Y. and Salpeter E. E., *AJ*, **117** (1999) 811
[14] Koopmann R., Giovanelli R., Haynes M.P. *et al.*, *ApJ*, (2007) submitted
[15] Cortes J.R., Kenney J.D.P. and Hardy E., *AJ*, **131** (2006) 747.
[16] Kent B.R., Giovanelli R., Haynes M.P. *et al.*, *ApJL*, **665** (2007) L15
[17] Chamaraux P., Balkowski C. and Gerard E>, *AA*, **83** (1981) 38
[18] Giovanelli R. and Haynes M.P., *AJ*, **88** (1983) 881
[19] Haynes M.P., Giovanelli R. and Chincarini G., *ARAA*, **22** (1984) 445
[20] Cayatte V., van Gorkom J., Balkowski C. and Kotanyi C., *AJ*, **100** (1990) 604
[21] Solanes J.M., Manrique A., Garcia-Gomez C. *et al.*, *ApJ*, **548** (2001) 97
[22] Chung A., van Gorkom J., Kenney J.D.P. and Vollmer B., *ApJL*, **659** (2007) 115
[23] Snowden S.L., Freyberg M.J., Plucinsky P.P. *et al.*, *ApJ*, **454** (1995) 643