PROCEEDINGS OF SCIENCE

The Arecibo galaxy environment survey - a sensitive survey for neutral hydrogen in the local Universe

R. F. Minchin[∗a], **R. Auld**[b], **L. Cortese**[b], **J. I. Davies**[b], **E. Momjian**[c], **R. Taylor**[b], **B. Catinella**[d], **P. A. Henning**[e], **S. Linder**[f], **E. Muller**[g], **K. L. O'Neil**[h], **J. Rosenberg**[i], **S. Sabatini**[j], **S. E. Schneider**[k], **M. D. Stage**[k], **W. van Driel**[l]

[a] *Arecibo Observatory*
[b] *Cardiff University*
[c] *NRAO Socorro*
[d] *MPIfA Garching*
[e] *University of New Mexico*
[f] *University of Hamburg*
[g] *ATNF*
[h] *NRAO Green Bank*
[i] *George Mason University*
[j] *Osservatorio Astronomico di Roma*
[k] *University of Massachusetts*
[l] *Observatoire de Paris*
E-mail: rminchin@naic.edu, Robbie.Auld@astro.cf.ac.uk, Luca.Cortese@astro.cf.ac.uk, Jonathan.Davies@astro.cf.ac.uk, emomjian@nrao.edu Rhys.Taylor@astro.cf.ac.uk, bcatinel@mpa-garching.mpg.de, henning@cosmos.phys.unm.edu, suzanne.linder@hs.uni-hamburg.de, Erik.Muller@atnf.csiro.au, koneil@gb.nrao.edu, jrosenb4@gmu.edu, sabatini@oa-roma.inaf.it, schneider@astro.umass.edu, mikstage@astro.umass.edu, Wim.vanDriel@obspm.fr

The Arecibo Galaxy Environment Survey (AGES) is covering 200 square degrees of sky in a variety of different environments with a noise level lower than 1 mJy beam^{-1} at a velocity resolution of 10 km s^{-1}. This unprecedented sensitivity for a wide-area neutral hydrogen survey is similar to that expected from a quick (a few seconds per point), all-sky survey with the SKA. AGES thus gives a direct precursor to such an SKA all-sky H I survey. Over half of the sources are not previously catalogued, some of which have no visible counterpart on the digitized sky survey, and even fewer have previous H I or redshift information.

From Planets to Dark Energy: the Modern Radio Universe
October 1-5 2007
The University of Manchester, UK

∗Speaker.

 http://pos.sissa.it/

PoS(MRU)027

1. Introduction

The Arecibo Galaxy Environment Survey (AGES) is a sensitive survey for extragalactic neutral hydrogen (H I) being carried out with the Arecibo L-band Feed Array (ALFA) multibeam system on the 305-m Arecibo telescope[1]. The survey is designed to sample the whole gamut of galaxy environments, ranging from the Local Void through isolated galaxies, galaxy pairs and galaxy groups to galaxy clusters[1].

Thirteen fields have been chosen for the survey, covering a total of 200 square degress. Of these, three five square-degree regions have been fully observed so far: the isolated galaxy NGC 1156[2], the galaxy pair NGC 7332/9[3] and a cut through the Virgo Cluster. Additionally, a five square-degree section of the twenty square-degree field around the spiral-rich cluster Abell 1367 has been completed[4]. While these areas are targeted, AGES also covers a huge 'blind' volume behind (and sometimes in front of) the chosen fields.

The survey so far has been observed with a 100 MHz bandwidth covering approximately 1330 – 1430 MHz. This gives a useful velocity range of around -1500 – 19000 $\mathrm{km\,s^{-1}}$. After Hanning smoothing, the velocity resolution (at $z = 0$) is 10.9 $\mathrm{km\,s^{-1}}$ and the noise is 0.75 mJy $\mathrm{beam^{-1}}$. From early 2008, the bandwidth will be extended to give 300 MHz of good band covering 1525 – 1225 MHz. The top 100 MHz of this is not useful for extragalactic neutral hydrogen surveys but at lower frequencies this will extend the accessible redshift out to $z \simeq 0.15$.

2. AGES and the SKA

As a relatively large-area survey with sub-mJy noise levels, AGES forms a direct precursor to possible quick, all-sky H I surveys with the Square Kilometre Array.

The SKA specification at the H I frequency of 1.4 GHz is for a survey speed with the Wide-Band Feed of 6×10^7 $\mathrm{m^4\ K^{-2}\ deg^2}$ [5]. Arecibo equipped with ALFA has a survey speed of 1.5×10^4 $\mathrm{m^4\ K^{-2}\ deg^2}$, or 4000 times less than the SKA. However, for a large-area survey, only the shorter baselines will be useful. Twenty per cent of the SKA area will be on baselines shorter than 1 km (the SKA 'core'[5]), thus the SKA survey speed is reduced to 2.4×10^6 $\mathrm{m^4\ K^{-2}\ deg^2}$, or 160 times the Arecibo speed. Table 1 gives the sensitivty and survey speed for the SKA 'core and Arecibo for the two Phase 1 and three Phase 2 scenarios considered by [5].

To carry out a survey of an entire hemisphere of sky, or 100$\times$ the AGES area, with the SKA will therefore take a little over 60 per cent of the time needed to carry out AGES with Arecibo. As AGES is expected to take 2000 hours, a similar-sensitivity survey with the SKA (in the Wide-Band Feed scenario) that covers an entire hemisphere will take $\sim$ 1250 hours. This seems a very reasonable investment of time for such a survey.

An all-sky H I survey with the SKA carried out in a reasonable time-frame is therefore likely to have a similar sensitivity to AGES. With maximum baselines of $\sim$ 1 km, the angular resolution will be around 4 times what is achieved with Arecibo, and thus the brightness temperature sensitivity of AGES will be around 16 times higher than the SKA survey, but for many purposes AGES may be considered a direct precursor of such an SKA survey.

[1] The Arecibo Observatory is part of the National Astronomy and Ionosphere Center, which is operated by Cornell University under a cooperative agreement with the National Science Foundation.

Table 1: Sensitivity and survey speed at 1.4 GHz of Arecibo with the ALFA multibeam system and the SKA core (baselines $<$ 1 km) for various scenarios (from [5]).

	Sensitivity (m^2 K^{-1})	Survey Speed (m^4 K^{-2} deg^2)	Speed advantage over Arecibo
Arecibo (ALFA)	920	1.5×10^4	1.0
SKA Phase 1 Core (WBF)	1000	5×10^5	33
SKA Phase 1 Core (WBF+PAF)	550	7.5×10^6	500
Full SKA Core (WBF)	2400	2.4×10^6	160
Full SKA Core (WBF+PAF)	1400	4×10^7	2700
Full SKA Core (WBF+dense AA)	2000	1.6×10^6	110

3. Results and Highlights

The results of AGES indicate the sort of discoveries that will be made in an all-sky SKA H I survey. With AGES only 10 per cent complete and with analysis of the observed fields still under way, the results so far are limited, but already demonstrate the potential of H I surveys at this sensitivity level. Some highlights thrown up by AGES are:

3.1 New Galaxies

Around 60 per cent of the sources found in AGES do not correspond to galaxies in current catalogues. Furthermore, over 80 per cent do not have previous H I data. We have now passed the sensitivity level where most of the sources are completely new discoveries, as opposed to adding new H I data to previously-known sources – which could be done more efficiently with pointed observations.

The new galaxies found in AGES turn up at all redshifts. We are not simply uncovering a population of low surface-brightness, gas-rich dwarf galaxies but are finding new galaxies in approximately equal proportions everywhere we look.

3.2 Very Low Surface Brightness Galaxies

Three per cent of the sources found so far have optical counterparts too dim to be seen on the Digitized Sky Survey[6]. This implies that they have *B*-band surface brightnesses dimmer than 24.5 mag arcsec^{-2}. All of these galaxies have H I masses $> 10^8 M_\odot$ – by their gas mass they are not dwarf galaxies, even if they are by their luminosities. We are currently seeking deep optical imaging of these sources in order to try and identify their counterparts.

3.3 Gas Streams and Clouds

As described in [4], AGES has turned up extended structures in the CGCG 97027 and CGCG 97041 subclusters of Abell 1367. The combined H I mass in these structures is a few times $10^9 M_\odot$, or as much gas as in a reasonable-sized spiral galaxy.

AGES has also discovered that there is an extended H I cloud around NGC 7339 (Fig. 1), with a diameter of around 120 kpc. The cloud extends over the position of the other member of the galaxy pair, NGC 7339 and the total mass is $1.8 \times 10^9 M_\odot$, with around half of this being found more than one Arecibo beamwidth (3.5 arc minutes) from the optical position.

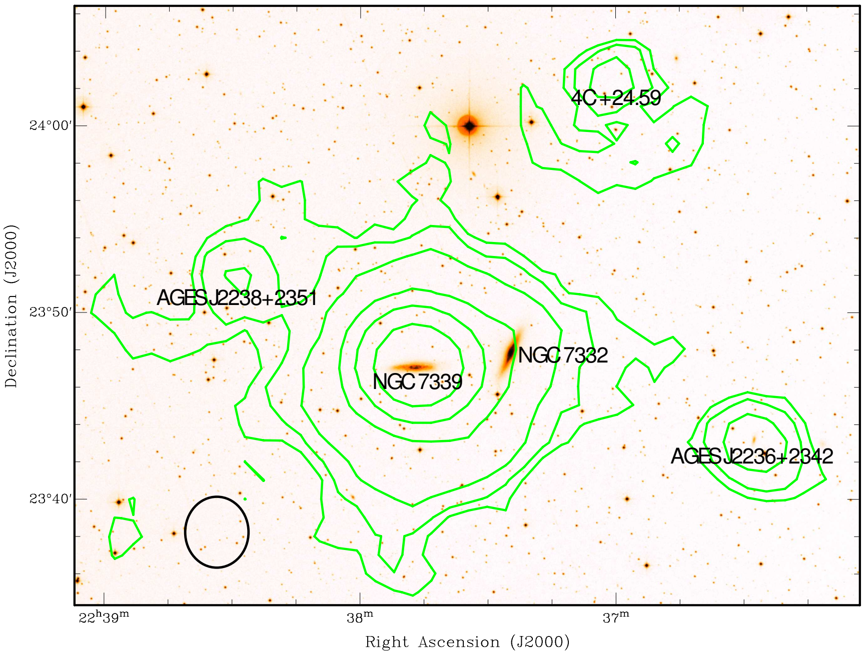

Figure 1: Integrated H I map of the NGC 7332 group overlaid on the digitized sky survey image of the region. Contours are at 2.5, 5, 10, 25, 50 and 100 $\times 10^{18}$ cm^{-2}. The AGES beam size is shown as a black ellipse at the bottom-left.

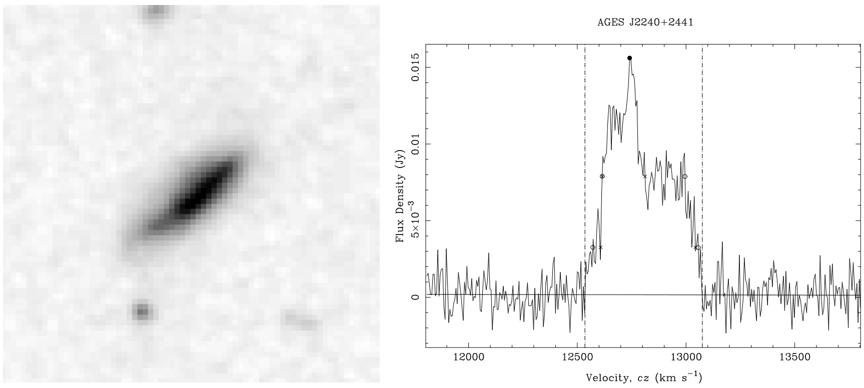

Figure 2: The massive, HI-rich galaxy AGES J2240+2441: DSS2 *B*-band image (left) of a $1.2' \times 1.2'$ centred on the optical position, and the HI spectrum (right).

3.4 Giant Galaxies

Sixteen galaxies have been found so far with $M_{HI} > 10^{10} M_\odot$. Of these, 4 have $M_{HI} > 2 \times 10^{10} M_\odot$ and the most massive, AGES J2240+2441 (PGC 1714044; Fig. 2) has $M_{HI} = 3.3 \times 10^{10} M_\odot$. From LEDA, we find that this galaxy has a very high $M_{HI}/L_B = 2.7 M_\odot/L_\odot$, but from analysing 2MASS images we also find that the galaxy has $M_{HI}/L_H = 0.4 M_\odot/L_\odot$. The discrepancy between the two may be due to high internal extiction.

The galaxy appears to be actively star forming, with an SFR of $20-40 M_\odot$ yr^{-1} from its IRAS and NVSS fluxes. It appears to be a star-bursting galaxy, and its unusual looking H I profile may indicate a recent interaction.

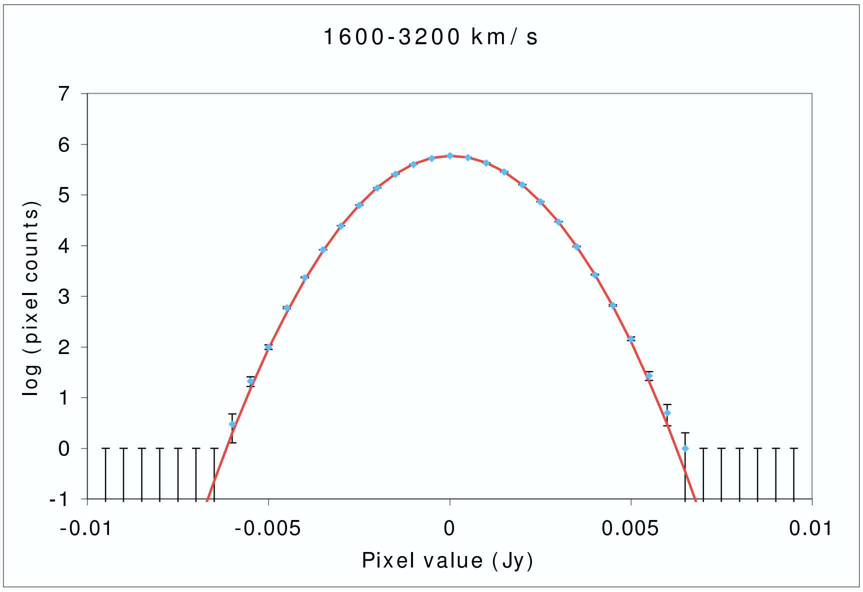

Figure 3: Distribution of pixel fluxes in the void region behind NGC 7332/9 over the redshift range 1600 – 3200 km s^{-1}. The solid line shows the best-fit Gaussian distribution.

3.5 H I Density in Voids

While the main AGES void field, targeted on the Local Void, is yet to be observed, the NGC 7332 field includes the Delphinus, Cygnus and Pegaus Voids which lie over a velocity range of 1500 – 7000 km s^{-1} behind the NGC 7332/9 galaxy pair. One source has been found in this void region, AGES J2235+2337 at a velocity of 5656 km s^{-1}.

We have examined the statistical distribution of fluxes in this region (Fig. 3), looking for excess flux that might be due to small sources that are, individually, below the detection limit. No significant variation from Gaussian noise has been found, allowing us to set (using simple statistics) a 3-σ upper limit on the density from sources of greater than $\sim 10^6 M_\odot$ of $3 \times 10^7 M_\odot$ Mpc^{-3}.

It is possible that this simple analysis would miss a population of sources that, after bandpass-subtraction, were symmetric around zero flux. This does not seem likely as it is, for instance, possible to see RFI (as non-Gaussian wings to the noise distribution) or continuum sources (as positive excesses). However, we are currently carrying out simulations in order to fully understand the effects of the data-reduction process on our limits.

References

[1] Auld R. et al., 2006, MNRAS, 371, 1617

[2] Auld R., 2007, PhD Thesis, Cardiff University

[3] Minchin R. F. et al., 2007, MNRAS, submitted

[4] Cortese L. et al., 2007, MNRAS, accepted

[5] Schilizzi R. T. et al., 2007, “Preliminary Specifications for the Square Kilometre Array v2.4”

[6] Minchin R. F. et al., 2007, in “Dark Galaxies and Missing Baryons”, IAU Symp. 244, in press