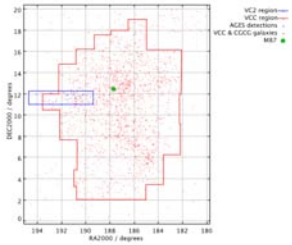
Searching for dark galaxies : the AGES VC2 region

1 The Survey



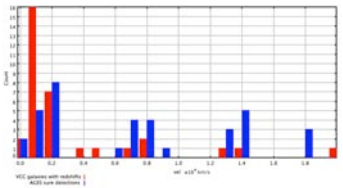
The VC2 strip spans 5x1 degrees of the Virgo Cluster, from the outskirts of the cluster to its interior. The strip covers part of subcluster A while avoiding the strong continuum source M87. 40 hours of observations were taken in January-February 2007 using the ALFA instrument on the Arecibo telescope, reaching a noise level as low as 0.5 mJy. For a 200 km/s velocity width, this gives a sensitivity limit of $6*10^6$ M_{solar} at the Virgo distance (16 Mpc). Currently, 36 definite sources have been found, with an additional 12 requiring follow-up observations.

2 Sample selection

Source extraction is done by visually inspecting the cube and with the automatic extractor Polyfind. A 'sure' source is one that has been found by both methods, an 'uncertain' source has only been found by one. Unless otherwise stated, only sure detections are considered here.

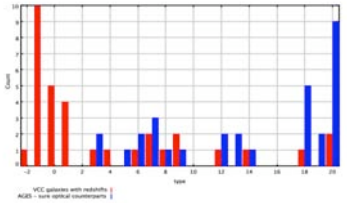
The search for optical counterparts is done via NED and the SDSS. If a galaxy lies within the Arecibo beam and has an available redshift measurement, agreeing with the AGES measurement to within 200 km/s, then it is considered a sure optical counterpart. If there are galaxies visible in the SDSS or a NED search, but with no available redshift measurements, then the object is considered to have a candidate optical counterpart.

3 Large-scale structure



The velocities of VCC galaxies with available redshift measurements are compared with those of the AGES detections. The large-scale structure appears in general agreement with the VCC sample, showing several distinct populations. However, whereas 75% of the optically-selected galaxies with available velocity measurements lie in the Virgo region, only 40% of the AGES detections do the same.

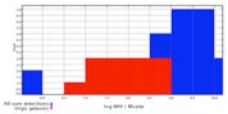
4 Morphologies



The morphological type of VCC galaxies (with available redshift measurements) are here compared to the AGES detections with definite optical counterparts. For non VCC galaxies, morphological type is determined through a NED search. The classification scheme is that used in the VCC, with later-type galaxies being more positive.

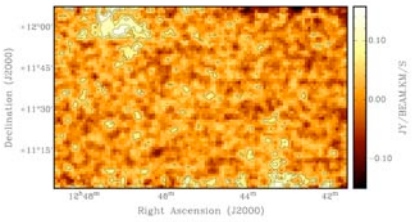
The morphology of the AGES selected sample appears quite different from the VCC selection – AGES having a clear preference for later-type galaxies whereas the opposite is true of the VCC.

5 HI Mass Distribution



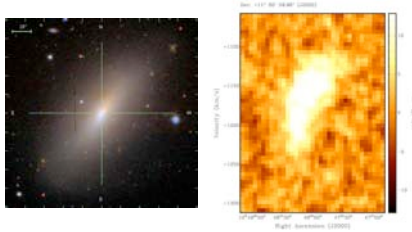
The HI mass distribution of the complete AGES sample. The two lowest mass detections are the high velocity clouds. The gap until > $10^{6.5}$ M_{solar} is below the AGES sensitivity limit at the Virgo distance. A constant distance of 16 Mpc as been assumed for all galaxies within the Virgo velocity range (500<v<3000 km/s), pure Hubble flow is assumed for all galaxies outside it.

6 High Velocity Clouds



Almost all the detections have definite or candidate optical counterparts. Only 2 definite detections undoubtedly have no optical counterparts (but for other possibilities, see panel 9, far right). These are shown above in a moment map integrated over a velocity range of 57 km/s, from 221 to 278 km/s. The lowest contour is at 55 mJy/beam.km/s, increasing in steps of 30 mJy/beam.km/s. Both sources are large enough to be resolved by the Arecibo 3.5' beam. The northernmost source shows clear evidence of structure, whereas the southern source is diffuse. Owing to the relatively low velocity and large angular size, these objects are almost certainly nearby High Velocity Clouds. The northern source has already been detected by ALFALFA.

7 VCC 2066 : A tailed S0



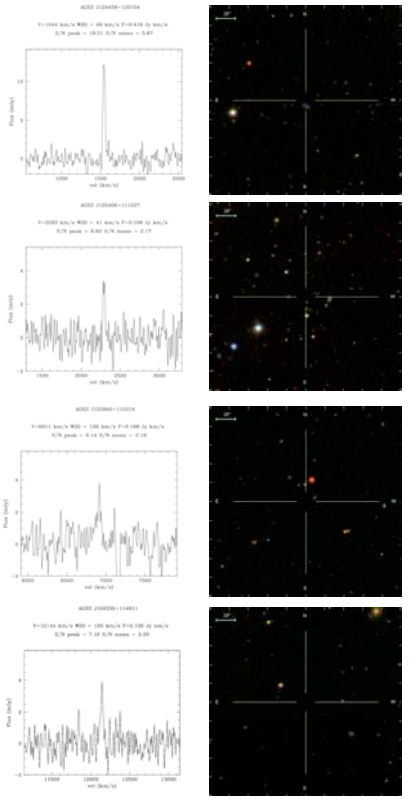
Left : SDSS image of VCC 2066, an apparent early-type galaxy detected with AGES.
Right : RA vs Velocity map of VCC 2066, from AGES.

AGES clearly detects an HI tail extending west from VCC 2066. This object is well-studied and has previous HI observations, in particular, van Driel and van Woerden conducted Westerbork observations in 1989 (A&A p. 317). These showed that the HI tail extends linearly west towards a dwarf irregular (with no redshift measurement), with most of the gas lying outside the galaxy – as is also shown by AGES. They classify it as an unusually blue S0, although in the VCC it is amorphous. They speculate the gas may have been removed by ram-pressure stripping or captured by the S0 during an interaction with another galaxy.

8 VCC 1955

VCC 1955 is classed as a Blue Compact Dwarf in the VCC. Unusually for an AGES detection, it is neither irregular nor shows any obvious signs of spiral structure. It is the only BCD detected in this region, both from AGES and the VCC.

9 The Search for Dark Galaxies



New Virgo Cluster objects not listed in the VCC

In most cases, AGES detections have a clear optical counterpart with a measured optical redshift in good agreement with its HI data. Some, such as those on this panel, are more ambiguous. The HI spectra from AGES is shown against the corresponding SDSS image. None of the detections on this panel have a matching object with a NED search, but some have more probable optical counterparts than others. Only in the case of the High Velocity Clouds (see far left panel) can optical counterparts be completely ruled out, due to the highly extended angular distribution of the HI and lack of any corresponding optical structure.

The majority of galaxies detected by AGES are behind the cluster, and are not listed in the VCC. However these two sure detections are within the Virgo velocity range, but are not listed. The above detection has a very probable dwarf irregular as an optical counterpart, almost exactly at the coordinates from AGES. Strictly speaking it is not a certain counterpart, since no optical redshift data is available. The second detection (below) is more ambiguous in terms of an optical counterpart, but potential objects are visible in the SDSS image.

Dark Galaxy Candidates

Whereas the above detections seem to have possible - if uncertain – optical counterparts, these two detections are even more ambiguous. Without optical redshifts it is impossible to determine if the supposed counterparts really correspond to the HI detections. The top detection has a potential faint galaxy very close to the coordinates from AGES, whereas the nearest candidate for the lower detection is ~1 arcminute away. Note that the second detection, unlike the others, is **not** a sure detection, but a peak signal to noise of over 7 makes it hard to dismiss as spurious. The sure detection has a similar signal to noise.

Whilst those objects within the Virgo Cluster (see above) could perhaps be categorised as dark galaxy candidates, optical counterparts to these detections seem more uncertain. By the nature of dark galaxies they are difficult to find. Any HI detection from them may be weak and require radio follow-up, and optical redshifts are required for any potential galaxies in the Arecibo beam, in order to ensure the HI truly has no optical counterpart. The search so far has therefore been inconclusive : while there are no HI detections without *possible* optical counterparts, we cannot yet be certain those counterparts really correspond to the HI.