The Southern H I Sky Survey

Multibeam Survey Working Group

TAC proposal dated 15/10/99

Abstract

We propose an extragalactic H I survey of the southern sky with the Parkes multibeam instrument. The survey will be sensitive to a volume of $6 \times 10^6 h^{-3}$ Mpc^3 and will contain valuable information on the distribution of galaxies, the power spectrum, the H I mass function, the dynamics of groups and superclusters, the frequency of dwarf galaxies, the space density of giant low-surface-brightness galaxies, and will contain information relevant to a new estimate of the density parameter $\Omega_\circ$. The proposed observations are in a wavelength regime which may be one of the least 'biased' in terms of tracing large-scale structure and will increase the size of existing H I-selected samples (Szomoru et al. 1994; Henning 1995) by two orders of magnitude. We request a total of 3500 hrs over eight observing terms for the southern survey and 1400 hrs for the northern ($\delta > 2^\circ$) extension.

1. Introduction

Virtually all galaxy surveys in the 21cm line of H I have been conducted in a pointed manner (with the notable exception of the work by Henning & Kerr 1989 and Szomoru et al. 1994). In other words, H I has been measured only for galaxies with previously determined positions from optical or IR catalogues. Currently, only $\sim 1000h^{-3}$ Mpc^3, or $\sim 1\%$ of the λ21 cm sky out to $z \sim 0.01$ has been surveyed (see Briggs 1990 for a review).

This has several implications for the status our knowledge of the space distribution and mass function of galaxies in the local Universe. Firstly, the inventory of massive H I-rich objects such as Malin-1 (Bothun et al. 1987), the Virgo protogalaxy (Giovanelli & Haynes 1989) and the Leo ring (Schneider 1989) is based on a few serendipitous discoveries, even though the density and distribution of high mass, low surface brightness galaxies has important implications for theories of galaxy formation (e.g. Hoffman, Silk & Wyse 1992). Briggs (1990) estimates that several thousand supermassive galaxies similar to Malin-1 may remain undetected within a distance of $250h^{-1}$ Mpc. Secondly, the probable increase of H I content in low mass galaxies (Staveley-Smith et al. 1992) points to the existence of a 'sea' of low mass dwarf galaxies, more numerous than L^* galaxies by 1-2 orders of magnitude, and perhaps contributing up to 50% of the H I mass in the Universe at the present epoch. This 'sea' has, at various times, also been postulated to explain damped Lyα population (Tyson & Scalo 1988) and the faint blue galaxy population (Cowie et al. 1991; McGaugh 1994; Gronwald & Koo 1995). Existing single-dish (e.g. Fisher & Tully 1981; Briggs & Rao 1993) and interferometric (e.g. Weinberg et al. 1991) H I observations place some constraints on the distribution of galaxies in the $N_{HI} - M_{HI}$ plane, and have been successful in rejecting extreme hypotheses such as voids being filled with dwarf galaxies and such galaxies contributing significant H I mass to closure density. However, the paucity of H I-selected samples (the blind survey of Henning 1995, with 37 objects, is one of the largest) is such that large parts of parameter space remain unexplored. Even within well-sampled, but atypical, regions such as the Virgo Cluster (Hoffman et al. 1992) little can be said about the space density of the lowest mass objects.

Existing H I observations reveal that the classical density-morphology relation seen in rich clusters (e.g. Dressler 1980) extends to lower density supercluster regions (Giovanelli et al. 1986). That is, the ratio of gas-rich spiral galaxies to early-type galaxies increases as galaxy density decreases. The implication of this is that, in the CDM biasing scenario (Kaiser 1984), gas-rich galaxies are the least biased tracers of the large-scale mass distribution, and therefore the most representative of the underlying mass distribution. This effect is already seen in the IRAS galaxy sample for which the ratio of galaxy overdensity ($\delta\rho_*$) to true overdensity ($\delta\rho$), is lower than for optical samples (Hudson 1993). For studies of the distances and dynamics of galaxies, samples based on gas-rich galaxies will lead to improved values of the density parameter, $\Omega_\circ$.

A new method of constraining $\Omega_\circ$ has recently been described by Dekel & Rees (1994). They suggest that the divergence of the velocity field around voids will give a dynamical lower limit to $\Omega_\circ$ due to the fact that high outflow velocities cannot arise in a low density Universe (if large-scale motions are solely induced by gravity from small initial fluctuations). Their method has the advantage that non-linear corrections are trivial as, for voids, $|\delta\rho/\rho_\circ| \leq 1$. Unfortunately it is difficult, by definition, to find many galaxies in voids. The multibeam survey will help in this regard because the bias factor b will be low, and therefore the void population will be higher than for optical samples. Dekel & Rees (see also Dekel 1994) specifically cite the southern Sculptor void as the most suitable local example.

2. Scientific Goals

The multibeam receiver gives us the opportunity, for the first time, of mapping significant areas of the sky at 21 cm with useful sensitivity. We propose to exploit this capability by mapping the entire southern sky. Such a survey has advantages over deeper surveys over more limited areas: it gives a fairer global view of the 21 cm sky; it allows the study of gas-rich galaxy power spectrum over the widest range of scales; it allows the study of environmental effects on the formation of gas-rich galaxies over the widest range of densities (e.g. Efstathiou 1992); and it is the most efficient way to detect galaxies and measure the H I mass function for a given observing time.

The scientific goals of the proposed survey can be summarized as follows:

- Measure the H I mass function in an unbiased fashion. At present, this is poorly known with both the low-mass and high-mass ends being defined by galaxies with very low optical surface brightness.

- Measure the true space density of the dwarf galaxies with $M_{HI} < 10^8$ $M_\odot$. These galaxies may contribute significantly to the H I mass-density of the Universe, but their numbers are probably better constrained at high redshift through Ly-α observations, than by local observations. If dark-to-luminous mass ratio increases with decreasing luminosity as most current observations suggest (e.g. Broeils 1992), such galaxies may also contribute significantly to $\Omega_\circ$.

- Locate any truly isolated H I clouds. Presently, no H I cloud devoid of star-formation is known to exist, except as a result of an interaction.

- Locate giant low surface brightness galaxies. It has been suggested (e.g. Disney & Phillips 1987) that these may be an important constituent of the Universe. Three other examples of galaxies with H I masses approaching that of Malin-1 ($\sim 10^{11}$ $M_\odot$) have recently been found (e.g. Sprayberry et al. 1993). This small sample, together with the sample of existing galaxies, shows a marked trend for the most massive H I galaxies to have the lowest optical surface brightness, and therefore to be the most under-represented in existing optical samples.

- Measure the spatial distribution of an H I-selected sample; measure its power spectrum; and use an iterative redshift-distance model (c.f. Strauss et al. 1992) to predict the non-Hubble monopole and dipole contributions. Compare with redshift-independent distance estimators to measure $\Omega_\circ$.

3. Southern Survey Parameters

We propose an integration time of 450 s/beam, and propose to map the sky at declinations $\delta \leq 0°$. Approximately 28,000 effective pointings of the multibeam array are required, leading to a total integration time of 3500 hr.

For the requested integration times, the 3-σ detection limit[1] is 25 mJy which, for a galaxy with a velocity width of 200 km s^{-1} , corresponds to an H I mass of 10^6 M$_\odot$ at 1 Mpc and 10^{10} M$_\odot$ at 100 Mpc. The limiting distance for a normal Sc galaxy (in the volume-limited sense) is $45h^{-1}$ Mpc. For a dwarf galaxy with a velocity width of 40 km s^{-1} , the corresponding masses are 2×10^5 M$_\odot$ and 2×10^9 M$_\odot$, respectively. The limiting distance for a 2×10^8 M$_\odot$ dwarf galaxy is 30 Mpc. Massive Malin-1 type objects, and any giant galaxies that fill the $14'.3$ beam, are detectable to the survey limit of $140h^{-1}$ Mpc. We expect to detect in the order of 5000 galaxies.

4. Survey Byproducts

As well as creating an H I catalogue of the local Universe, the proposed survey, like any new survey, will undoubtedly come across unusual galaxies or entirely new classes of galaxy. Besides such 'serendipitous' discoveries, other survey byproducts are likely to include:

- Interacting galaxies: as the IRAS survey demonstrated, interacting galaxies can look dramatically different in regimes other than the optical. Such galaxies are often characterised by tidally induced tails of gas. Such gas tails are important in understanding the nature of galaxy interactions and, in certain cases (Schneider 1989), can accurately probe galactic potentials close to the edge of the dark matter halo.

- Galactic and Magellanic H I: the survey will include low-velocity local H I in its frequency range. Although the velocity resolution for the survey (13 km s^{-1} channel spacing) is too low for normal Galactic work, it will nevertheless produce a quality total column density map of higher angular resolution than previously obtained in the either hemisphere. Some modifications to the on-line observing technique (such as occasional frequency-switched reference spectra), or to the off-line software (such as beam-switched image reconstruction) may be necessary.

- OH megamasers: the proposed frequency range, 1360 to 1420 MHz corresponds to a redshift range for the 1667 MHz OH transition of 0.17 to 0.23. With the proposed survey parameters, we will be able to detect powerful OH megamasers such as IRAS 20100-4156 (Staveley-Smith et al. 1989) with $S/N \sim 10$ in this redshift range. The number of such objects is likely to be low, but line identification should be straightforward unless the 1667/1665 MHz mainline ratio is unusually high.

[1] For the actual HIPASS $6'$ robust gridding function

5. Observation Strategy

To minimise rms noise, and to maximize positional accuracy and baseline stability, we will raster scan the telescope at 1°/min. Scan rates higher than those are not compatible with a 5 s correlator integration period.

6. Data Availability

We will make the H I data available in the form of a data cubes. Data for a region will be released 12 months after the completion of that region. Data for a particular region will be gathered promptly (a few months between start and end).

Assuming that the southern HIPASS observing can be completed in 99SEPT, we propose that all calibrated spectra be available on the web in December 1999.

7. Northern Survey

Given that the Lovell telescope looks likely to be able to observe a substantial part of the northern sky, there are compelling reasons to extend the Parkes survey to its northern limit in order that a full-sky HI survey can be obtained:

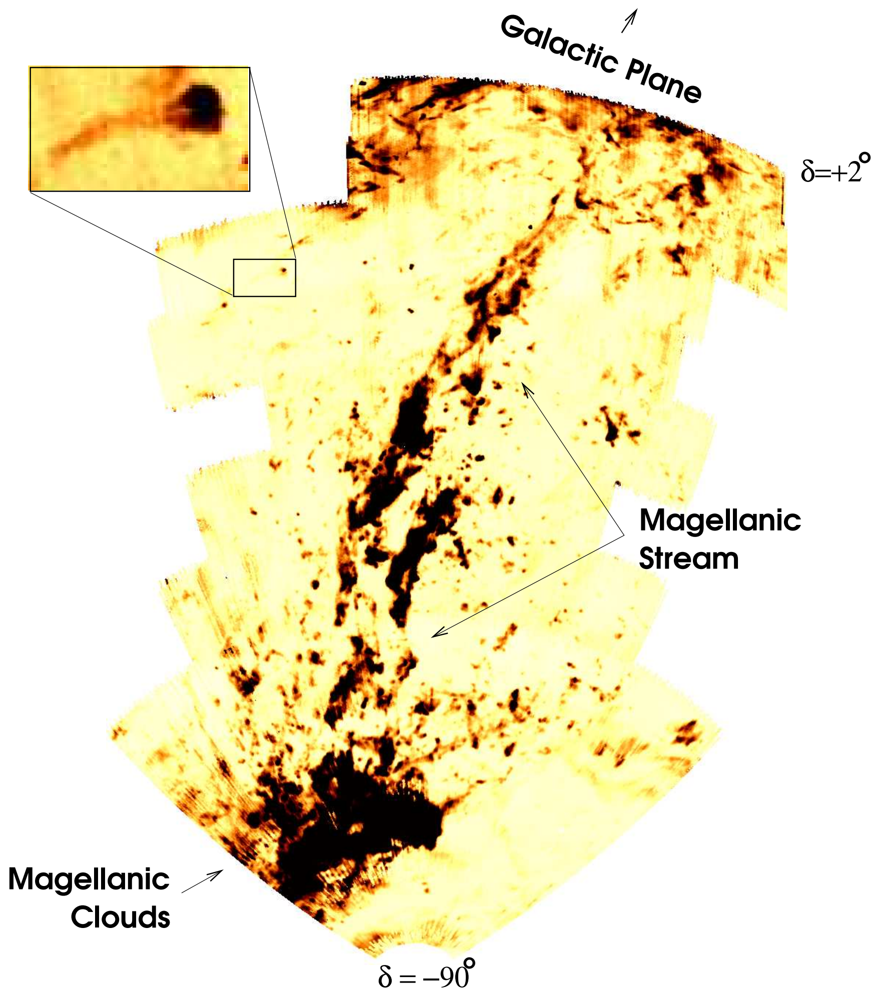

Figure 1: A mosaic of HIPASS data from the SCP to the equator showing the Magellanic Stream (Putman et al.). A comet-like feature, perhaps the result of hydrodynamic interaction with Galactic gas, is highlighted.

- An all-sky HI survey will double the number of galaxies available and therefore better determine the HI mass function. By examining regions of different galaxy density, it will also better define any change of the mass function with environment. More importantly, an all-sky survey is more immune from 'cosmic variance' caused by large-scale clustering, and will therefore better define the HI mass function normalisation.
- The Local Supercluster (centred on the Virgo Cluster at declination 12°) lies mainly in the northern hemisphere. Any attempt to characterize the local Universe ($v < 3000$ km s^{-1}) without including this structure, will of course be unrealistic. The connection between the Virgo S cloud and the southern extension of the Local supercluster is especially interesting.
- The Magellanic Stream, which the HIPASS survey has been successful in characterising (Putman et al. 1998), extends well into the northern hemisphere. As Figure 1 shows, the Stream is well-defined up to the limit of the HIPASS survey. Extension into the north is very desirable as this part of the Stream probably lies closest to the Galaxy and is the most susceptible to interaction with the Galaxy's gaseous halo. To what extent, for example, is the Stream responsible for the HVC population of the Galaxy?

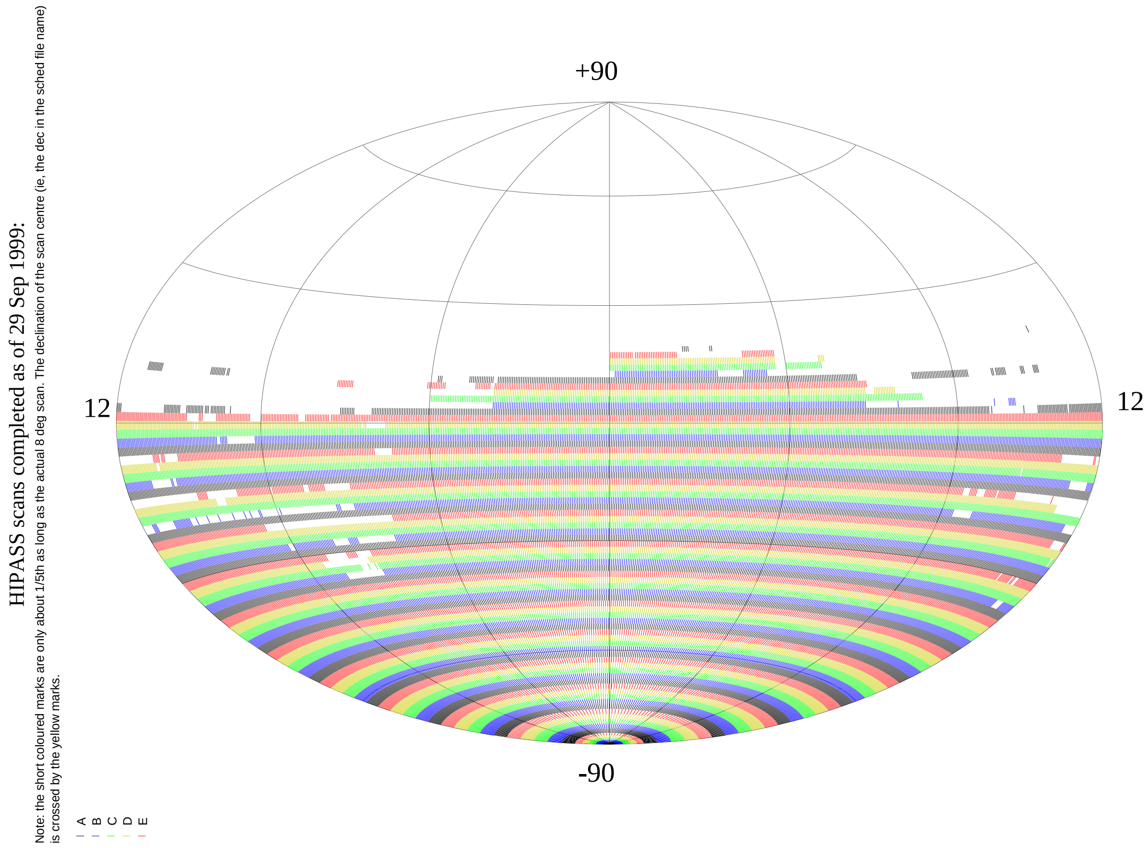

Figure 2: HIPASS survey progress as of September 29, 1999 (Aitoff projection).

8. Progress

As of 1999 September 29, the HIPASS survey is nominally 91% complete (Fig.2) and 306 of the 388 southern cubes have been made. An analysis of the rms noise for HIPASS cubes suggests that few, if any, reobservations will be necessary. Variation in the rms noise level is mainly caused by continuum and strong line sources, particularly near the Galactic Plane. The northern HIPASS extension (for which the TAC has permitted lower-priority scans) is 24% complete.

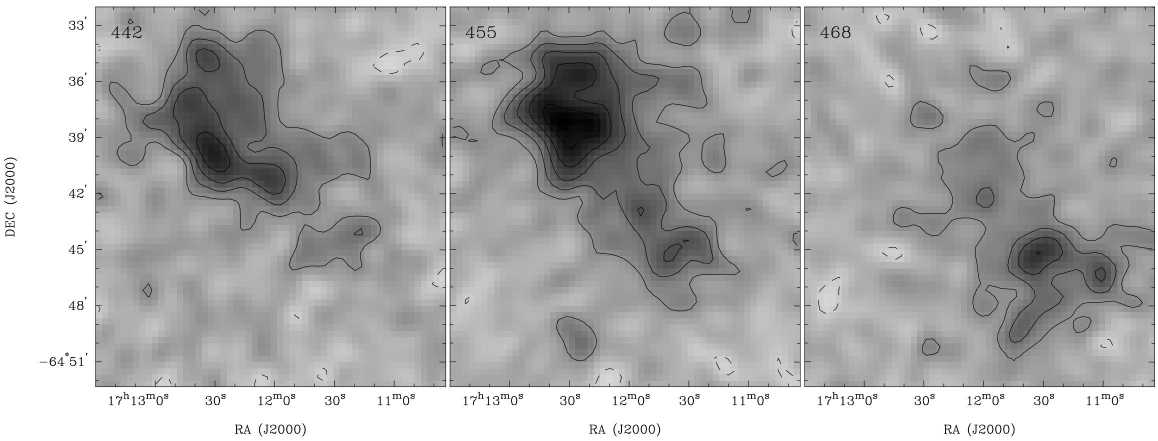

Figure 3: HI channel images for HIPASS 1712-64 which is a nearby, low-mass galaxy without any apparent optical counterpart.

Follow-up ATCA and optical observations have been completed for HIPASS 1712-64, which appears to be the first nearby HIPASS detection, away from regions of Galactic and Magellanic dust obscuration, to have no optical counterpart to very good limits ($B \sim 19$ mag for the CCD data, and $B_\mu \sim 27.5$ mag arcsec^{-2} for the amplified UKST plate material. The results (see Figs 3 and 4) are being prepared by submission by Kilborn et al. (1999).

Most other recent progress has been related to final data reduction, cleaning and simulation algorithms, data release, finalising the observations and data reduction paper (Barnes et al. 1999), and extracting spectral data for the first generation HIPASS catalogues (Barnes and Sadler).

A full list of publications is available from the multibeam web site[2].

References

Bothun, G.D., Impey, C.D., Malin, D.F., and Mould, J.R. 1987, AJ, 94, 23.
Briggs, F.H., 1990, AJ, 100, 999.
Briggs, F.H., & Rao, S., 1993, ApJ, 417, 494
Broeils, A.H., 1992, AA, 256, 19.
Cowie, L.L., Songalia, A., and Hu, E.M., 1991, Nature, 354, 460.
Dekel, A., 1994, ARAA, 32, 371.
Dekel, A., & Rees, M.J., 1994, ApJ, 422, L1.
Disney, M.J., & Phillips, S., 1987, Nature, 329, 203.
Dressler, A., 1980, ApJ, 236, 351.
Efstathiou, G., 1992, MNRAS, 256, 43P.
Fisher, J.R., & Tully, R.B., 1981, ApJS, 47, 139.
Giovanelli, R. & Haynes, M.P., 1989, ApJ, 346, L5

[2]http://www.atnf.csiro.au/research/multibeam/papers/papers.html

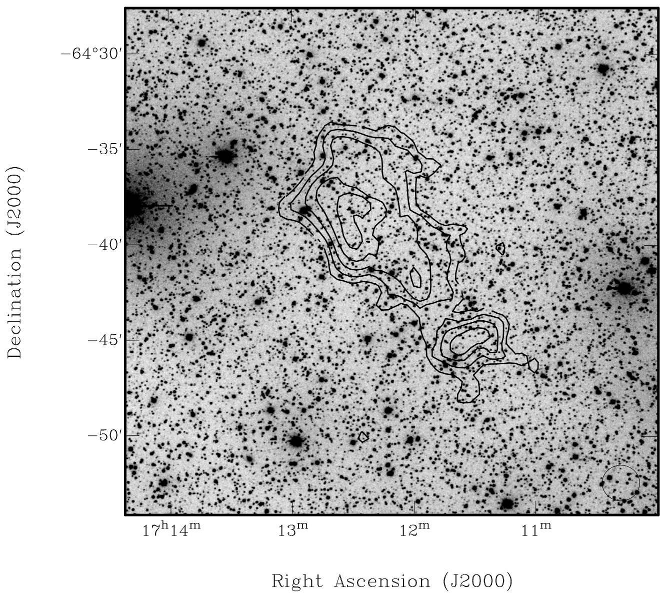

Figure 4: HI column density contours for HIPASS 1712-64 overlayed on a combined CTIO 40-inch B and R image, showing no apparent counterpart. Although the stellar density is moderately high owing to the Galactic latitude of 15°, the extinction is only $E_{(B-V)} = 0.12$ mag.

Giovanelli, R., Haynes, M.P., & Chincarini, G.L., 1986, ApJ, 300, 77.

Gronwald, C., & Koo, D.C., 1995, ApJ, 440, L1.

Henning, P.A. and Kerr, F.J. 1989, ApJ, 347, L1.

Henning, P.A., 1995, ApJ, 450, 578.

Hoffman, G.L., Lu, N.Y., & Salpeter, E.E., 1992, AJ, 104, 2086.

Hoffman, Y., Silk, J. & Wyse, R.F.G., 1992, ApJ, 388, L13

Hudson, M.J., 1993, MNRAS, 265, 43.

Kaiser, N., 1984, ApJ, 284, L9.

Kilborn, V., Staveley-Smith, L. & Webster, R.L. 1998a, Proceedings of the XXXIII Moriond meeting on "Dwarf Galaxies" held in Les Arc, France, March 1998

Kilborn, V., de Blok, E., Staveley-Smith, L. & Webster, R.L. 1998b, Proceedings of IAU Colloquium 171 held in Cardiff, July 1998

Kilborn, V. et al. 1999, Proceedings of 'HI in the Local Universe II', PASA vol.16 no.1

McGaugh, S., 1994, Nature, 367, 538.

Putman, M.E., Gibson, B.K., Staveley-Smith, L., Banks, G., Barnes, D.G., Bhatal, R., Disney, M.J., Ekers, R. D., Freeman, K. C., Haynes, R. F., Henning, P., Jerjen, H., Kilborn, V., Koribalski, B., Knezek, P., Malin, D. F., Mould, J. R., Oosterloo, T., Price, R. M., Ryder, S. D., Sadler, E. M., Stewart, I., Stootman, F., Vaile, R. A., Webster, R. L., Wright, A. E. 1998, Nature, 394, 752

Schneider, S.E., 1989, ApJ, 343, 94

Sprayberry, D., Impey, C.D., Irwin, M.J., McMahon, R.G., & Bothun, G.D., 1993, ApJ, 417, 114.

Staveley-Smith L., Webster R.L., Banks G., Kilborn V., Koribalski B. & Putman M.E. 1998a, Proceedings of ESO/Australia meeting held in Sydney, December 1997

Staveley-Smith L., Kim S., Putman M.E. & Stanimirovic S. 1998b, "Reviews of Modern Astronomy", vol 11, Stars and Galaxies, p.117, Astronomische Gesellschaft

Staveley-Smith, L., Allen, D.A., Chapman, J.M., Norris, R.P., & Whiteoak, J.B., 1989. Nature, 337,

625.
Staveley-Smith, L., Davies, R.D., & Kinman, T.D., 1992. MNRAS, 258, 334.
Strauss, M., Yahil, A., Davis, M., Huchra, J.P., & Fisher, K., 1992, ApJ, 397, 395.
Szomoru, A., Guhathakurta, P., van Gorkom, J.H., Knapen, J.H., Weinberg, D.H. & Fruchter, A.S., 1994, AJ, 108, 491
Tyson, N.D., & Scalo, J.M., 1988, ApJ, 329, 618.
Weinberg, D.H., Szomoru, A., Guhathakurta, P., van Gorkom, J.H. 1991, Ap.J. 372, L13.
Webster, R.L. et al. 1998, Proceedings of IAU Colloquium 171 held in Cardiff, July 1998
Zwaan, M. A., Briggs, F. H., Sprayberry, D., & Sorar, E. 1997, ApJ 490, 173