To appear in 'Imaging at Radio through Submillimeter Wavelengths' (Tucson June 6-9, 1999), eds Mangum & Radford, ASP conf. series

The HI Parkes All-Sky Survey

L. Staveley-Smith, B. S. Koribalski and I. Stewart

Australia Telescope National Facility, CSIRO, PO Box 76, Epping, NSW 1710, Australia

M. E. Putman

Research School of Astronomy and Astrophysics, ANU, Private Bag, Weston Creek, ACT 2611, Australia

V. A. Kilborn and R. L. Webster

School of Physics, University of Melbourne, Parkville, Victoria 3052, Australia

Abstract. The HI Parkes All-Sky Survey (HIPASS) and the southern Zone of Avoidance (ZOA) surveys are nearing completion. In this paper: we describe aspects of the observational, analysis and imaging techniques used, show examples of data cubes and newly-detected galaxies, describe early results on the HI content of the nearby Universe, discuss the Magellanic system, including a recent mosaic of the Magellanic Stream, and discuss galaxies and large-scale structure previously hidden from optical study by dust extinction.

1. Introduction

Deep spectral-line surveys of large-areas of sky have recently been made possible with the advent of powerful spectrometers and multibeam receivers on radio telescopes, coupled with a large increase in the capabilities of computing hardware and software. The HI Parkes[1] All-Sky Survey (HIPASS) is one such survey to have recently benefited from cheap, yet powerful correlator chips (Canaris 1993), a 13-beam receiver (Staveley-Smith et al. 1996), and a new generation of observation and reduction software (Barnes et al. 1998). HIPASS is a survey for neutral hydrogen over the whole southern sky ($\delta < 2°$), and is able to detect normal spiral galaxies at distances[2] of ~ 100 Mpc. HIPASS complements optical surveys in that it easily detects HI-rich galaxies that may be of low optical surface brightness, and also easily penetrates regions of high optical extinction in the Milky Way, increasing our knowledge of the large-scale distribution of matter in the local Universe.

---

[1]The Parkes telescope is part of the Australia Telescope which is funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO.

[2]We assume $H_{\circ}$=75 km s^{-1} Mpc^{-1}.

2. HIPASS techniques and progress

HIPASS consists of 23020 scans with the Parkes telescope, each of length 8° in declination. Fig. 1 shows the sky coverage in November 1999. Most of the southern sky is covered, with parts of a northern extension ($2° < \delta < 26°$) already started. HIPASS covers the Galactic Plane in the southern hemisphere,

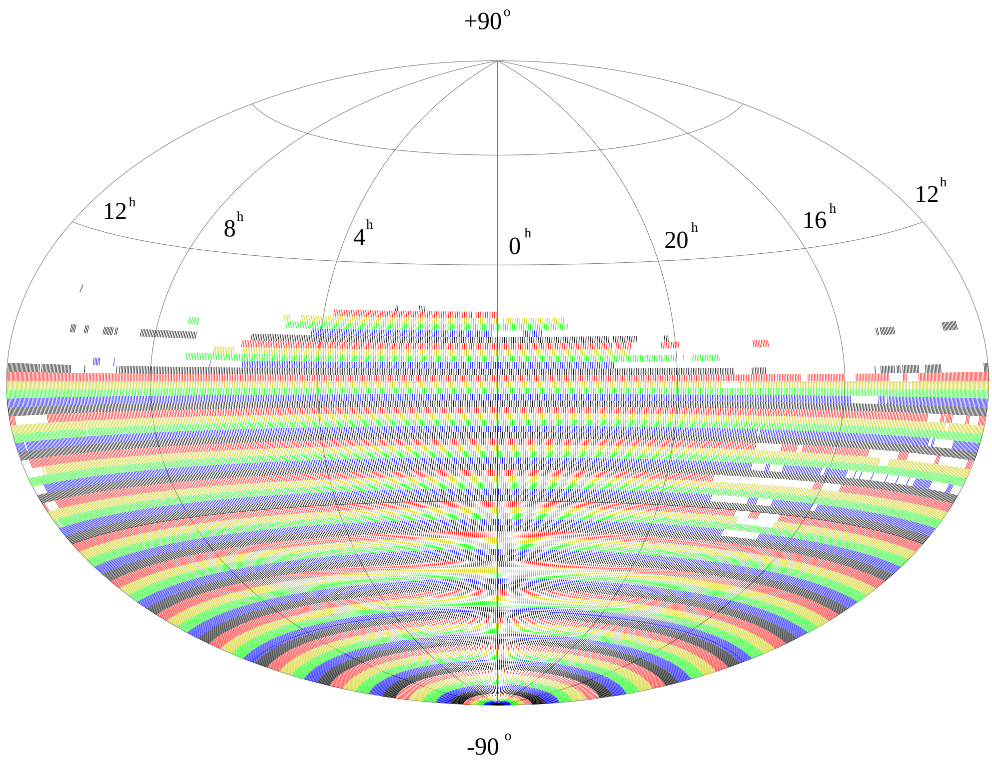

Figure 1. Progress of HIPASS as of November 1999. Each area of sky is covered 5 times, on separate occasions. Nearly 100% of the southern sky has been surveyed, and parts of a northern extension are underway.

but its sensitivity is improved by separate scans at constant Galactic latitude in the range $b = \pm 5°$. This additional Zone of Avoidance (ZOA) survey increases integration times in the Galactic Plane by about a factor of five. The parameters of the dual surveys are summarised in Table 1. The HI mass detection limits are $10^6 d^2_{Mpc}$ M$_\odot$ and $5 \times 10^5 d^2_{Mpc}$ M$_\odot$ for HIPASS and the ZOA survey, respectively.

Data from the survey are position, bandpass and velocity-calibrated in real-time at the telescope using the LiveData package (Barnes 1998), built using the AIPS++ toolkit. Data are archived in single-dish FITS format and, when all data for a particular region has been collected, gridded together to produce data cubes. Because of the volume of data ($\sim$ 0.5 TB), manual inspection of individual spectra is not possible, so a robust gridding procedure is used. Although not optimal in the case of perfect data, it has the advantage of being

Table 1. Summary of the HI Parkes multibeam survey parameters

Parameter	**HIPASS survey**	**ZOA survey**
Sky Coverage	$\delta \leq 2°$	$\ell = 213°$ to $33°$
Integration time per beam	460 s	2100 s
Average system temperature	20 K	25 K
Central beam efficiency	63%	63%
Central FWHP beamwidth	$14.0'$	$14.0'$
Velocity coverage (km s^{-1})	-1200 to 12700	-1200 to 12700
Channel separation	13.2 km s^{-1}	13.2 km s^{-1}
Velocity resolution[a]	18.0 km s^{-1}	18.0 km s^{-1}
3-σ Positional accuracy	$3.0'$	$3.0'$
3-σ detection limit	40 mJy $beam^{-1}$	20 mJy $beam^{-1}$
3-σ HI mass limit[b]	$10^6 d^2_{\rm Mpc} {\rm M}_\odot$	$5 \times 10^5 d^2_{\rm Mpc} {\rm M}_\odot$

[a] After application of on-line Tukey 25% smoothing.
[b] For $\Delta V = 100$ km s^{-1}.

automated and relatively immune to interference and bad data. Each HIPASS data cube covers an $8° \times 8°$ region of sky, with a pixel size of $4'$. An example of a HIPASS cube (H342) can be seen in Fig. 2 which is a peak-voxel representation of the cube spun to an arbitrary angle. Galactic emission, a High Velocity Cloud and several bright NGC galaxies are visible.

3. Faint Galaxies, Mass Function

Cubes such as shown in Fig. 2 also contain many faint galaxies not visible in a crude maximum voxel projection. An example is the galaxy HIPASS J0236-00 shown in Fig. 3. This galaxy is previously uncataloged by NED[3], although the *Digitised Sky Survey* reveals what appears to be a small disk-like system seen edge-on. Optically, the linear diameter of this system is no more than 4 kpc.

Optically faint and low surface-brightness galaxies are common in HIPASS cubes. Do these galaxies contain a significant fraction of the neutral hydrogen in the Universe? Preliminary results suggest not. The HIPASS mass function derived from a small subset of the eventual catalog suggests an HI contribution to closure density $\Omega_{HI} = 2.5 \times 10^{-4}$ (Kilborn, Webster & Staveley-Smith 1999), which is not substantially greater than the HI known to exist in optically-selected galaxies at the present epoch (Rao & Briggs 1993).

[3]The NASA/IPAC Extragalactic Database (NED) is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

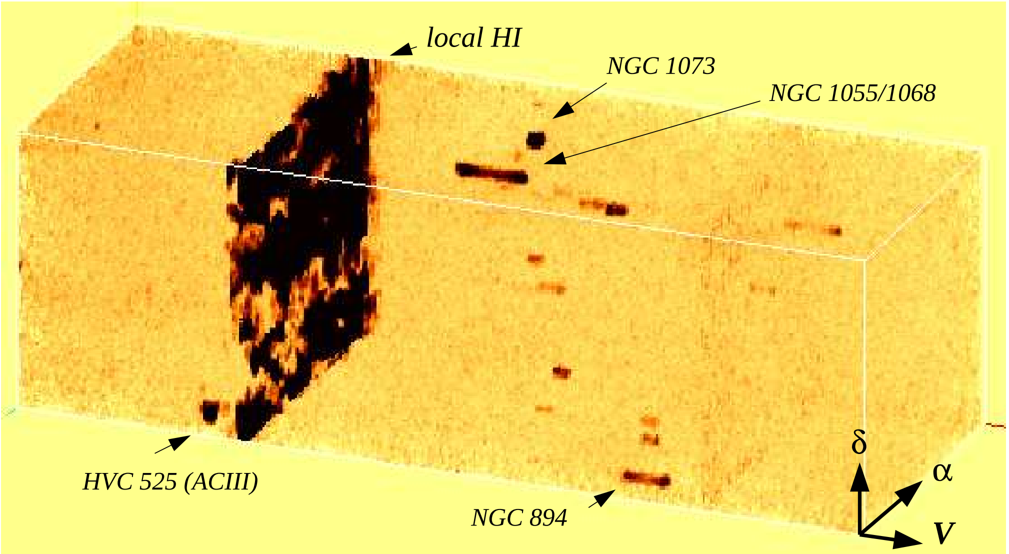

Figure 2. A maximum voxel representation of a third of the HIPASS data cube H342, centered at $\alpha = 02^{\mathrm{h}}37^{\mathrm{m}}$, $\delta = -2^\circ$ (J2000), showing local hydrogen at $v = 0$ (including a negative velocity HVC) and several bright galaxies extended along the velocity axis. The velocity axis goes from -1200 km s^{-1} on the left-hand side to 3500 km s^{-1} on the right-hand side.

The incidence of galaxies with much higher HI mass-to-light ratios than J0236-00 will be quantified as optical identification of HIPASS detections proceeds. The incidence of optically faint, or invisible HI clouds appears, however, to be low, although there are several firm candidates (Kilborn et al. 2000).

4. Magellanic Stream

Although primarily designed as an extragalactic survey, HIPASS nevertheless includes the velocity range occupied by the Magellanic System. Mosaicing of early HIPASS data in the South Celestial Cap quickly lead to the discovery of a Leading Arm to the Magellanic System (Putman et al. 1998). Although individual clouds in the Leading Arm had been previously recognised, the coverage, resolution and sensitivity of HIPASS made it clear that this was a coherent entity attached to the Magellanic Clouds themselves, and not in the foreground as had been previously argued. The significance of this finding is that it implies that the Magellanic System is largely tidal in origin.

The Magellanic Stream is the more obvious manifestation of the tidal influence of the Galaxy on the Magellanic Clouds (Mathewson, Cleary & Murray 1974). It trails behind the Clouds for $\sim 100^\circ$, forming a partial polar ring around the Galaxy. The key to understanding more of the history of the encounter between the Clouds and the Galaxy, and their relationship with the population of HVCs, may lie in studying the structure, distance, kinematics and metallicity

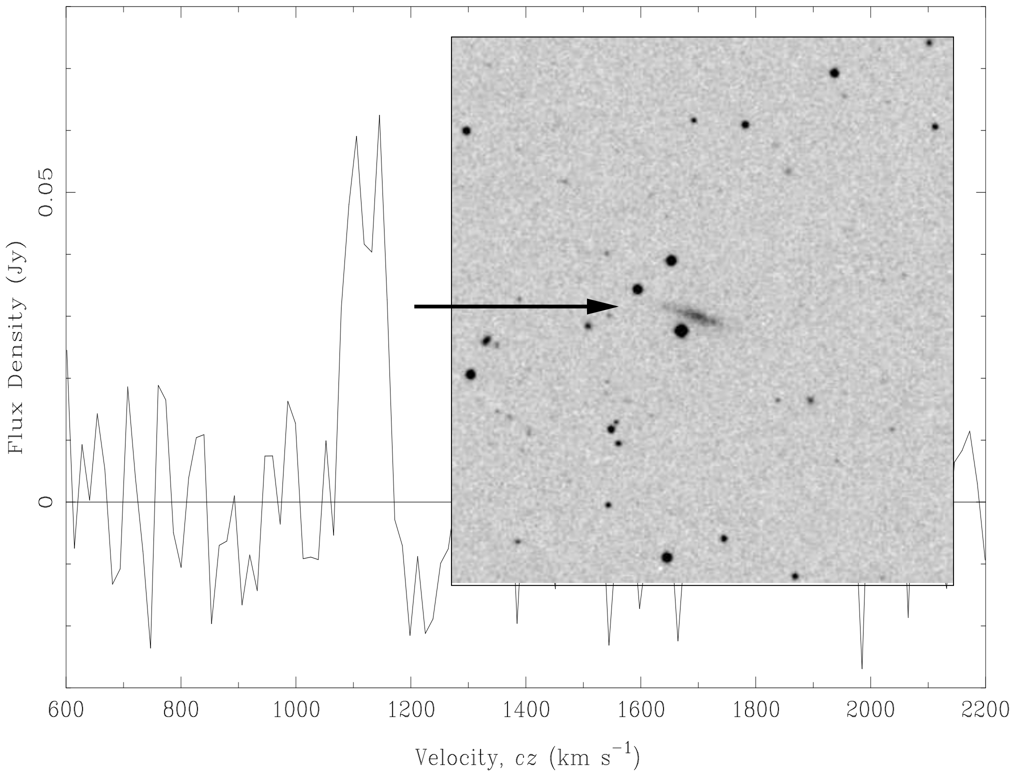

Figure 3. The HI spectrum of HIPASS J0236-00, a previously uncataloged galaxy in cube H342. The inset shows that a likely optical indentification, about an arcminute in diameter, is visible on the *DSS* image.

of the gas in the Stream. A mosaic of HIPASS data, reprocessed to retain low spatial frequencies (removed in normal HIPASS bandpass calibration), is shown in Fig. 4. This mosaic covers the full declination range of the HIPASS data $-90°$ to $+2°$, so covers a substantial fraction of the sky. Several features are readily apparent in Fig. 4: the origin of the Stream near the Small Magellanic Cloud, its overall curvature, and the existence of two parallel streams over much of its length. This bifurcation seems to arise at the origin of the stream near the SMC. The Magellanic Stream goes through zero velocity at the center of Fig. 4 (which is nearly coincident with the South Galactic Pole), so this image includes some Galactic emission. Several Sculptor group galaxies are also visible.

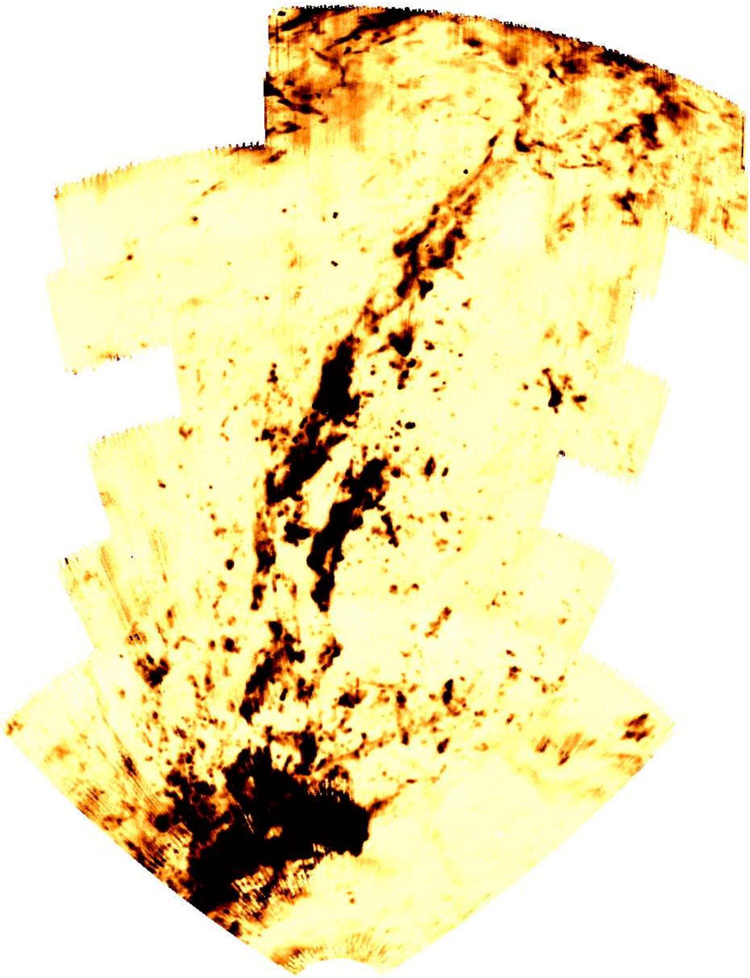

Figure 4. A peak-temperature image of the Magellanic Stream. The Small Magellanic Cloud is at the bottom of the image, and the celestial equator is at the top of the image (Putman 2000).

5. Hidden Galaxies

Depending on wavelength, between 10% and 25% of the extragalactic sky suffers the obscuring effects of our own Galaxy. The southern Milky Way happens to obscure several dynamically important structures and somewhat biases our view of the local Universe. The Local Void and the Centaurus/'Great Attractor' regions in particular lie close to the Galactic Plane. Since the pioneering survey of Kerr & Henning (1987), it has been appreciated that blind HI searches are insensitive to dust obscuration, and are an excellent way to find galaxies in even the deepest layers of extinction.

The multibeam ZOA survey has similarly been successful and has managed to reveal galaxies at Galactic latitudes down to 0°. Shown in Fig. 5 is HIZOA J1532-56 which has an estimated extinction in the blue waveband of 57 magnitudes (Staveley-Smith et al. 1998). This system has an overall size in excess of

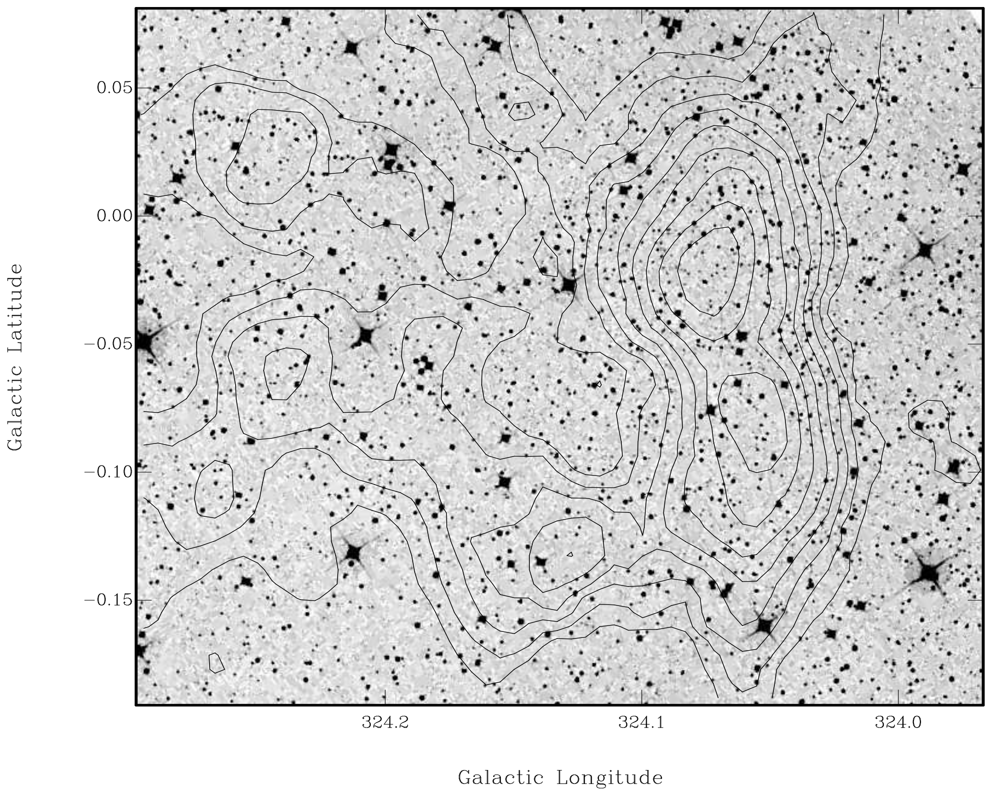

Figure 5. The galaxy HIZOA J1532-56 straddles the Galactic equator, behind an estimated extinction $A_B = 57$ mag. The greyscale is the *DSS* image; the contours are HI column densities from the Australia Telescope Compact Array (Staveley-Smith et al. 1998).

100 kpc, and straddles the Galactic equator. It has similarities with the well-known M81 interacting system. Over 100 other galaxies have also been found in the shallow ZOA survey. Around three-quarters of these were previously unknown. This survey, which is the initial phase of the overall ZOA survey, consists of slightly more than 100 hrs of observing time. The distribution of the shallow-survey galaxies is discussed by Henning et al. (1999) who suggest the existence of a narrow filamentary structure, around 75 Mpc in projection, extending over much of the southern sky. Other structures, including groups and clusters of galaxies may become obvious as survey integration time builds up, and higher velocities are reached.

6. Summary

Using rapid scanning observing techniques, new multibeam receivers and powerful digital correlators, spectral-line surveys of large regions of sky are rapidly overtaking traditional hop-and-dwell observing methods in the wealth of scientific data they reveal. HIPASS is a good example of this. We have used HIPASS data to show the existence of a Leading Arm to the Magellanic System (revealing the tidal nature of its origin); we have been able to find hundreds of previously unrecognised galaxies and quantified, in a preliminary manner, the mass function of HI clouds and galaxies. We have also been able to recognise the existence of galaxies and large-scale structure, obscured from examination at optical and infrared wavelengths by dust.

Further information on HIPASS including the availability of data can be found at www.atnf.csiro.au/research/multibeam.

Acknowledgments. The results summarised in the paper are the result of a joint effort of members of the HIPASS and ZOA teams who are gratefully acknowledged. XRAY in the KARMA package was used to produce Fig.2. Use of Digitised Sky Survey material (UKST/ROE/AAO/STScI) is acknowledged.

References

Barnes D. G. 1998, in ADASS VII, San Francisco:ASP, 32

Barnes D. G, Staveley-Smith L., Ye, T., & Oosterloo, T. 1998, in ADASS VII, San Francisco: ASP, 89

Canaris, J. 1993, in Proceedings of a Workshop on New Generation Digital Correlators, Tucson: NRAO, 117

Henning, P. A., Staveley-Smith, L., Kraan-Korteweg, R. C., & Sadler, E. M. 1999, Publ. Astr. Soc. Australia, 16, 35

Kerr, F. J., & Henning, P. A. 1987, ApJ, 320, 99

Kilborn, V., Webster, R.L., & Staveley-Smith, L. 1999, Publ. Astr. Soc. Australia, 16, 8

Kilborn, V., et al. 2000, AJ, submitted

Mathewson, D. S., Cleary, M. N., & Murray, J. D. 1974, ApJ, 190, 291

Putman, M. E. et al. 1998, Nature, 394, 752

Putman, M. E. 2000, in High-Velocity Clouds, eds van Woerden, H., Schwarz, U., Wakker, B., & de Boer, K., Dordrecht: Kluwer, in press

Rao, S., & Briggs, F. 1993, ApJ, 419, 515

Staveley-Smith L., Juraszek, S., Koribalski, B. S., Ekers, R. D., Green, A. J., Haynes, R. F., Henning, P. A., Kesteven, M. J., Kraan-Korteweg, R. C., Price, R. M., & Sadler, E. M. 1998, AJ, 116, 2717

Staveley-Smith L., Wilson, W. E., Bird, T. S., Disney, M. J., Ekers, R. D., Freeman, K. C., Haynes, R. F., Sinclair, M. W., Vaile, R. A., Webster, R. L., Wright, A. E. 1996, Publ. Astr. Soc. Australia, 13, 243