The HI Parkes Deep Zone of Avoidance Survey

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Abstract. The 64-m Parkes telescope, equipped with the 21-cm multibeam receiver, has completed a sensitive survey (typically 6 mJy beam^{-1} rms) for HI galaxies in the Zone of Avoidance (ZOA) accessible to the telescope, $196° \leq \ell \leq 52°$, and $|b| \leq 5°$. While galaxy candidate inspection is not yet quite complete, and final number not yet determined, the survey has yielded about 1000 galaxies. The data, in the form of three-dimensional datacubes, have been inspected by eye, and candidate lists assembled, and about half have now been checked for reality, and accepted into the final catalog. The distributions on the sky and in redshift space are presented, showing galaxies belonging to previously-known structures, and newly-discovered features. Of the 469 confirmed HI galaxies, 191 have a NIR source within $6'$ in the 2MASS Extended Source Catalog, but the incidence of NIR counterparts is a strong function of longitude: in the low obscuration, low stellar surface density Puppis region, 131 of the 186 HI galaxies have 2MASS counterparts (70%), while in the Galactic bulge region, only 6 of the 155 HI detections have a 2MASS extended source coincident (4%). This is attributable to the HI survey's ability to detect galaxies even in regions of high foreground stellar surface density.

1. Why a 21-cm Survey?

Dedicated searches for galaxies and clusters have been successful in recent years in narrowing the ZOA, and obtaining redshifts, where possible, to map three dimensional large-scale structures at low Galactic latitude (see Kraan-Korteweg & Lahav 2000 for an overview of the various multiwavelength campaigns in the ZOA, and the many contributions in this volume.) Results from the 2 Micron All-Sky Survey (2MASS) have produced an impressive narrowing of the ZOA, particularly away from the Galactic bulge region, and allowed appreciation of low-latitude large-scale structure traced by a homogeneous sample (see contribution from Huchra in this volume.) However, such methods fail in regions of heaviest obscuration, and highest foreground stellar surface density. Fortunately, 21-cm searches for HI-bearing galaxies have been proven to succeed in obscured and confused areas (eg. Kerr & Henning 1987; Kraan-Korteweg et al. 1994; Henning et al. 1998; Henning et al. 2000.)

2. The Survey

2.1. Parameters and Strategy

The multibeam receiver system on the Parkes 64-m telescope, with its large footprint on the sky, allows a sensitive, wide area survey. The ZOA accessible from Parkes, covering $196^\circ \leq \ell \leq 52^\circ$, $|b| \leq 5^\circ$, was observed to quite uniform sensitivity, due to the strategy of observing overlapping strips of constant Galactic latitude (Staveley-Smith et al. 1998; Henning et al. 2000; Donley et al. 2004). The data were bandpass-corrected, Doppler corrected, calibrated and gridded with resulting pixel and beam sizes of $4' \times 4'$, and $15\overset{'}{.}5$, respectively. The observations were done over 27 fields of $(\Delta\ell, \Delta b = 8^\circ, 10^\circ)$. The effective integration time per beam was 2100 s [compare with 450 s per beam integration time of the HI Parkes All Sky Survey (HIPASS; Meyer et al. 2004)]. The correlator bandwidth of 64 MHz, set to cover the velocity range -1200 to 12700 km s^{-1}, provides coverage in the third dimension, thus we speak of the *datacubes*, three-dimensional position-position-velocity representations of the survey data.

Because of the strong HI signal of the Galaxy, which causes spectral ringing, the data were Hanning smoothed, resulting in a velocity resolution of 27.0 km s^{-1}, a significant increase over the channel spacing of 13.2 km s^{-1}. Strong continuum emission was subtracted, although some residual continuum baseline ripple remains where there was particularly strong continuum emission.

2.2. Survey Sensitivity

Over most of the volume surveyed, away from small regions of strong continuum, the noise was about 6 mJy beam^{-1} rms, which compares favorably to the HIPASS noise of 13 mJy beam^{-1}. This noise of 6 mJy beam^{-1} is equivalent to a 5σ HI mass detection limit of 1.4×10^6 $\mathrm{d}^2_{\mathrm{Mpc}}$ $\mathrm{M}_\odot$ (for a galaxy with a linewidth of 200 km s^{-1}). For instance, the survey was sensitive to galaxies with 5×10^9 $\mathrm{M}_\odot$ at 60 Mpc, and 1×10^{10} $\mathrm{M}_\odot$ at 100 Mpc. Thus, the survey was sensitive to normal spirals well beyond the Great Attractor region, and could detect some galaxies beyond 10,000 km s^{-1}. It was also sensitive to very low mass local dwarfs, as well.

2.3. Searching for Galaxies

The 27 datacubes were searched by members of the HI Parkes ZOA Team. The cubes were searched by eye, because experimentation with automatic galaxy detection algorithms indicated that in the complicated region of the ZOA, with regions of increased noise due to continuum sources and Galactic HI, the human eye-brain system is enormously more effective at finding galaxies. Each cube was searched by two, or sometimes three, independent searchers, using the visualization tool `karma KVIEW` (Gooch 1995), producing independent lists of galaxy candidates. Figure 1 shows two slices through one of the datacubes, as a searcher would display and search the data. While the entire velocity range of the data was searched, confusion due to Galactic HI generally prevented the recognition of galaxies within about $|v| \leq 250$ km s^{-1}. In addition, the higher noise at low latitudes near the Galactic Center creates a residual ZOA, but even quite close to the Galactic Center direction we were able to detect galaxies (Fig. 2).

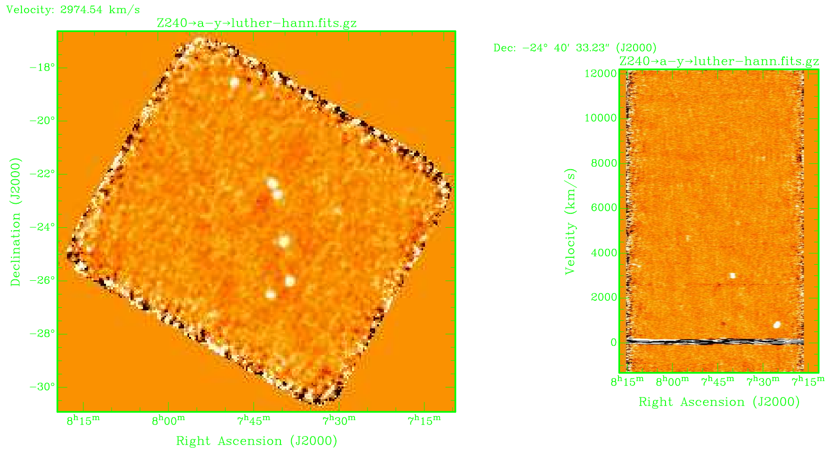

Figure 1. Left panel shows a right ascension – declination plane of a datacube, in a single velocity channel. Several galaxies are visible as white blobs in this rich region. The right panel shows a right ascension – velocity plane, at the declination of one of the galaxies appearing in the left panel. In addition to the extragalactic sources, Galactic HI appears as the strong horizontal feature at zero velocity.

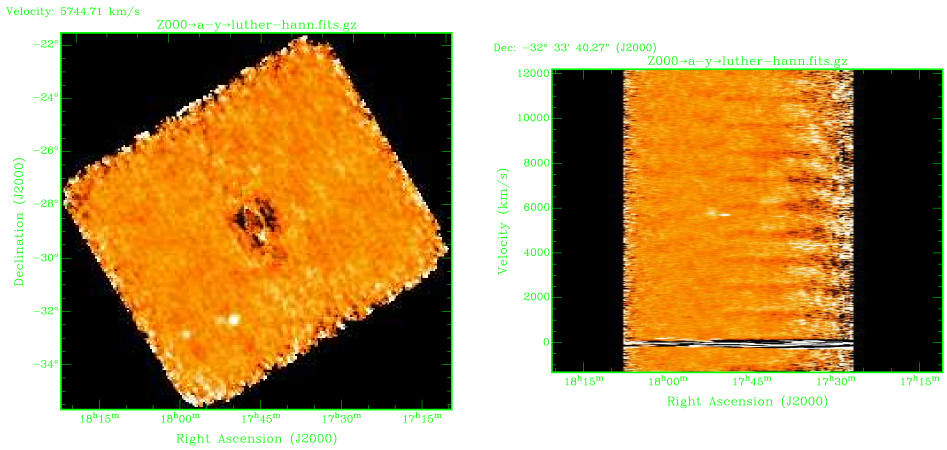

Figure 2. Left panel shows a right ascension – declination slice which contains the Galactic Center, visible as noisy, disturbed data at the center of the map. Note the 3 extragalactic sources visible in this plane. The right panel shows the right ascension – velocity slice through two of the sources at the same declination on the left-hand map. Despite the increased noise, these galaxies are clearly detected within a few degrees of the Galactic Center position itself.

The datacubes have all been searched, and a list of over 1000 galaxy candidates has been produced. To generate a uniformly-selected catalog, all galaxy candidates will be inspected by one person (PAH), who decides if a candidate is to be included in the final catalog. As of writing (June 2004), 16 of the 27 cubes have been inspected by the adjudicator, with 469 candidates accepted. The adjudication is complete over the longitude ranges of 332° to 52°, 236° to 260°, and other isolated longitudes. In the regions $\ell = 36°$ to 52° and 196° to 212° (the "northern extension"), the data are presented by Donley et al. (2004).

3. Distribution of the Detected Galaxies and Candidates

In Figure 3, the upper panel shows the distribution of galaxies in the literature (selected from the LEDA database), and the outline of our survey region in the ZOA. The traditional ZOA is clearly visible as a paucity of galaxies at low Galactic latitude. In the lower panel, with our confirmed galaxies and candidates added in, the ZOA fills in remarkably well, and several large-scale structures are seen to cross the Galactic Plane. The Great Attractor region is seen as an overdensity at $\ell \sim 300° \rightarrow 340°$, the Hydra-Antlia filament at $\ell \sim 280°$ and the Puppis filament crosses at $\ell \sim 240°$. The Local and Sagittarius voids are visible as an underdensity of galaxies at $\ell \sim 350° \rightarrow 52°$.

In velocity space, as shown in Figure 4, quite a number of structures become apparent. The broad overdensity of the Great Attractor is evident at velocity ~ 5000 km s^{-1}. Only a portion of this feature was known from higher-latitude catalogs, and is labelled as part of the Norma supercluster in Figure 5. Galaxies associated with the PKS 1343-601 cluster are also labelled in Figure 5, as is the Puppis cluster, and background void. The filament hinted at, at $\ell \sim 220°$ in Figure 3 becomes clear in the wedge diagram, which we label "Hydra wall and Monoceros extension" in Figure 5.

4. 2MASS Counterparts

Of the 469 confirmed HI galaxies (most others will certainly be real, but the adjudication is not yet complete), there are 191 for which there is a NIR source listed within 6′in the 2MASS Extended Source Catalog. We have not yet examined these NIR sources to check if they are all galaxian, or if some are confused Galactic objects, quite possible at low latitudes. In the longitude range 236° to 260°, there are 186 HI detections, 131 of which have an extended 2MASS counterpart (70%). As we continue to study the HI-selected galaxies, we can investigate the populations of ZOA galaxies uncovered at 21 cm *vs.* at NIR wavelengths. One would expect the HI galaxies to be generally of later type, but this will be quantified better in the future.

In contrast, in the Galactic bulge region, $\ell = 332°$ to 36°, only 6 of the 155 HI detections have a 2MASS extended source within 6′of the HI (4%). The poor performance of the NIR survey in recovering the HI-selected galaxies is due to the extreme stellar confusion in the Galactic bulge. The completeness of the 2MASS survey is a function of stellar survey density, and drops even as far as $\ell \pm 90°$ from the Galactic Center near the Galactic plane.

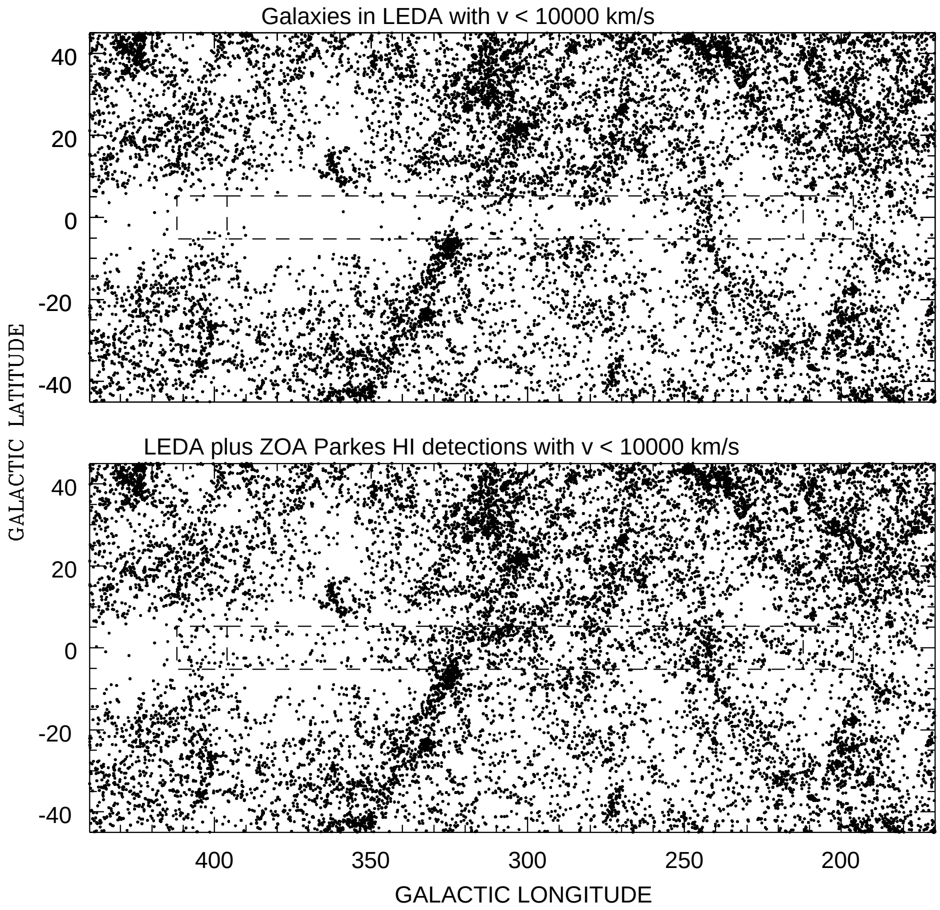

Figure 3. Top panel shows galaxies from the LEDA database with velocities measured within 10000 km s^{-1}. The dashed black lines show the borders of the ZOA search area in the southern hemisphere, and extension to the north. The lower panel adds in the galaxies and candidates uncovered by the HI Parkes Deep ZOA Survey.

5. Ongoing Work

To produce the final catalog of the HI Parkes Deep ZOA Survey, we are working to finish the adjudication of candidates. We then will measure HI parameters, and quantify the selection function *a posteriori*, since this sample has been selected by human eyes. When the full sample is constructed, its HI properties, large-scale structures traced, and NIR counterparts will be investigated. We are also extending the search region with new observations to higher latitudes in the Galactic bulge area, since there the ZOA extends further than $\pm 5°$ from the plane (see Fig. 3.) Finally, we are exploring the possibility of using the new 21-

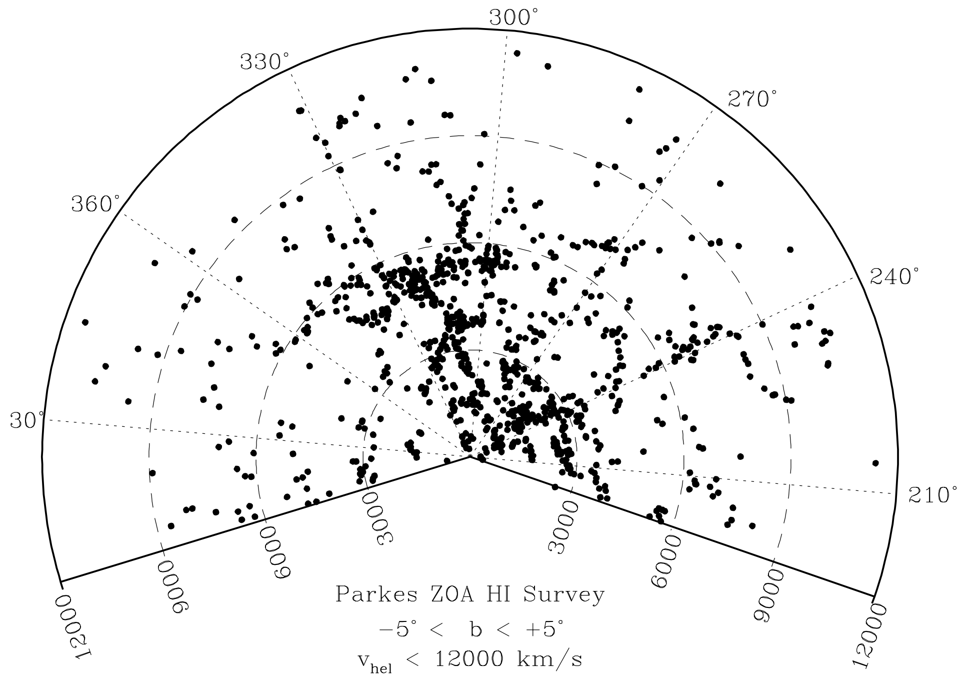

Figure 4. Distribution of HI sources in Galactic longitude and recessional velocity. Note that sources are detected beyond 10000 km s^{-1}. This figure is very similar to Kraan-Korteweg et al.'s Figure 3 to be published in the IAU Symp. Vol. 216, but with some spurious sources in the Local Void area removed. This figure, too, is provisional, until all candidates have been examined, but we expect little qualitative change.

cm multibeam receiver at the Arecibo Observatory to extend our map of hidden HI galaxies and large-scale structures further to the north.

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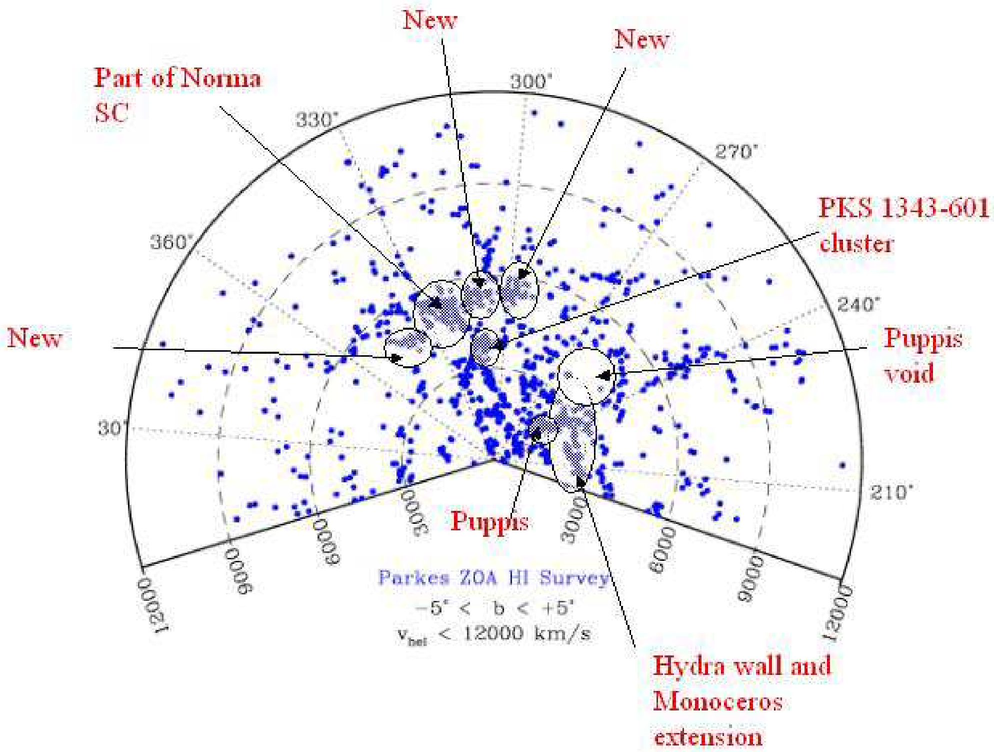

Figure 5. As in Figure 4, but with some new, and previously-indicated large-scale structures labelled.

the conference for science, and for showing us beautiful Cape Town and the Peninsula.

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