An H I survey in the Zone of Avoidance

Multibeam Survey Working Group

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Abstract

We propose to use the Parkes multibeam receiver for a deep H I survey for optically obscured galaxies behind the Galactic Plane. The southern Galactic Plane obscures a part of the sky which is vital for a complete understanding of the distribution and dynamics of nearby galaxies. The Galaxy obscures the southern crossing of the Local Supercluster and its probable connection with the Fornax-Dorado complex. It also obscures the connection between the Hydra-Centaurus supercluster and the Pavo-Indus-Telescopium supercluster. The latter two superclusters appear to dominate the dynamics of galaxies within $70h^{-1}$ Mpc, and appear to be responsible for a large part of velocity of the Local Group of galaxies with respect to the Cosmic Microwave Backround radiation. However, there are large unexplained discrepancies between the observed motions of galaxies, and motions predicted on the basis of the observed galaxy distribution and linear gravity theory. This discrepancy may be due to optical selection effects in the vicinity of the Galactic Plane, or the presence of a large obscured supercluster. On a smaller scale ($\sim 4h^{-1}$ Mpc), the discovery of any large nearby galaxies such as Dwingeloo-1 would also have an impact on timing arguments on which estimates of the mass of the Local Group and the present density of the Universe are based (e.g. Peebles 1994). We propose to observe Galactic latitudes $|b| \leq 5°$ in the longitude range $\ell = 213°$ to $33°$. A total observing time of 1500 hrs is requested. We also propose an extension into the northern hemisphere (longitudes 33° to 56° and 192° to 213°) for which an additional 400 hrs is requested.

1. Introduction

1.1 Nearby Galaxies

Early searches for galaxies obscured by the Galactic Plane were, in part, motivated by the possibility of finding a nearby, obscured M31 (see review of Kerr 1994). Reasons for finding such galaxies in this region include: large-scale vorticity in the early Universe resulting in alignment of spin vectors, or tidal torquing of the Milky Way by a close approach of a companion galaxy. Several nearby galaxies have been discovered behind the Galactic Plane, or 'Zone of Avoidance' (ZOA) already (e.g. Maffei 1 and 2: Maffei 1968; Circinus A: Freeman et al. 1977; Sagittarius dw: Ibata, Gilmore & Irwin 1994; Dwingeloo-1: Kraan-Korteweg et al. 1994), and of the eight apparently brightest galaxies, five lie within the ZOA (Centaurus A, IC 342, Maffei 1 and 2 and NGC 4945) (Kraan-Korteweg 1993).

Knowledge of the distribution and velocities of nearby galaxies is particularly important for mass estimates of the Milky Way and the Local Group of galaxies. These estimates originated with timing argument of Kahn & Woltjer (1959), and have continued to be refined as new data becomes available (e.g. Raychaudhury & Lynden-Bell 1989), with the most detailed predictions presently coming from the 'least-action' results of Peebles (1994). With existing galaxies, knowledge of the Milky Way mass, the Local Group mass, and consequently estimates of the density parameter $\Omega_{\circ}$, are not likely to improve until tangential proper motions are measured for nearby galaxies. However, present calculations are predicated on there being no undiscovered massive galaxies present in the ZOA. The recent discovery of Dwingeloo-1 at $b = -0.1°$ demonstrates that this is not the case. Dwingeloo-1 significantly adds to the estimated mass in the Maffei group of galaxies. Moreover, discovery of new dwarf galaxies, even though they do not change the nature of the solutions (assuming light traces mass), would nevertheless allow for greater constraints to be placed on the allowable family of orbital solutions. One severe problem with present solutions is the predicted orbit of IC 342 which has an observed distance which is much smaller than its predicted distance (Peebles 1994). The fact that IC 342 lies at $b = 11°$ may be significant.

1.2 Distant Galaxies

At some scale, the Universe ought to be homogeneous, and a fair sample of the Universe need not include knowledge of the galaxy distribution in the ZOA. However, this scale appears to lie beyond the redshift range accessible to the Parkes multibeam receiver ($cz = -1000 - 13000$ km s^{-1}). Several large superclusters lie close to, or in, the southern Galactic Plane:

- The Local Supercluster which is predominantly a northern Galactic cap structure at $cz \approx 1500$ km s^{-1} , and is responsible for significantly decelerating the Hubble flow in the Local Universe. The effect of this deceleration on the redshift of the Fornax Cluster has recently been measured by Bureau, Mould & Staveley-Smith (1995). But, there may be a physical connection between the Local Supercluster and the Fornax-Dorado region. This connection is obscured by the Galactic Plane (see Fig.1).
- The Hydra-Centaurus supercluster is one of the most prominent nearby structures. It begins at the Hydra Cluster near the apex of the Local Group's motion with respect to the CMB radiation ($\ell = 270°, b = 27°$), and joins with the Centaurus complex about 30° higher in longitude. The mean velocity is $cz \approx 3000$ km s^{-1} . The peculiar velocities of nearby galaxies appear to indicate an infall, or a bulk flow, towards $\ell \approx 300°$, $b \approx 10°$, which lies within this supercluster (e.g. Lynden-Bell et al. 1988; Staveley-Smith & Davies 1989; Mould et al. 1991). However, the visible mass in the region is insufficient to produce the required acceleration. For example, the dipole in the distribution of IRAS galaxies lies much closer to the CMB dipole (Strauss et al. 1992) than to the direction of bulk motion. There is a possibility that some of the required mass is entirely hidden by the Milky Way. Dressler (1991) was partially successful in looking for the supercluster defining this hidden 'Great Attractor'. He found a coherent structure at $cz = 4500$ km s^{-1} which appeared to extend from behind Centaurus, joining the Pavo-Indus-Telescopium supercluster south of the Plane. More recently, Kraan-Korteweg & Woudt (1994) have recognized the richness of the A3627 cluster at $\ell = 325°, b = -7°$ (see Fig.1). Study of galaxies around this cluster is severely hampered by high optical extinction and foreground confusion.
- The Shapley supercluster, whose core is defined by the clusters A3556, A3558 and A3562, can be regarded as the first 'Great Wall' in the Southern hemisphere. It lies behind the Centaurus supercluster at 14000 km s^{-1} , and may be responsible for between 8% and 30% of the peculiar acceleration of the Local Group (Allen et al. 1990, Scaramella et al. 1991). This supercluster may be one of the reasons why Great Attractor 'back-side infall' has not yet been conclusively measured (Dressler & Faber 1990; Mathewson, Ford & Buchhorn 1992). The centre of this supercluster lies beyond the redshift limit of the proposed survey but high-mass foreground members ought to be detectable.
- Three other regions close to the Galactic Plane which are of interest are: (1) the Puppis cluster which, out to 3000 km s^{-1} , may be second only to Virgo (Lahav 1994).

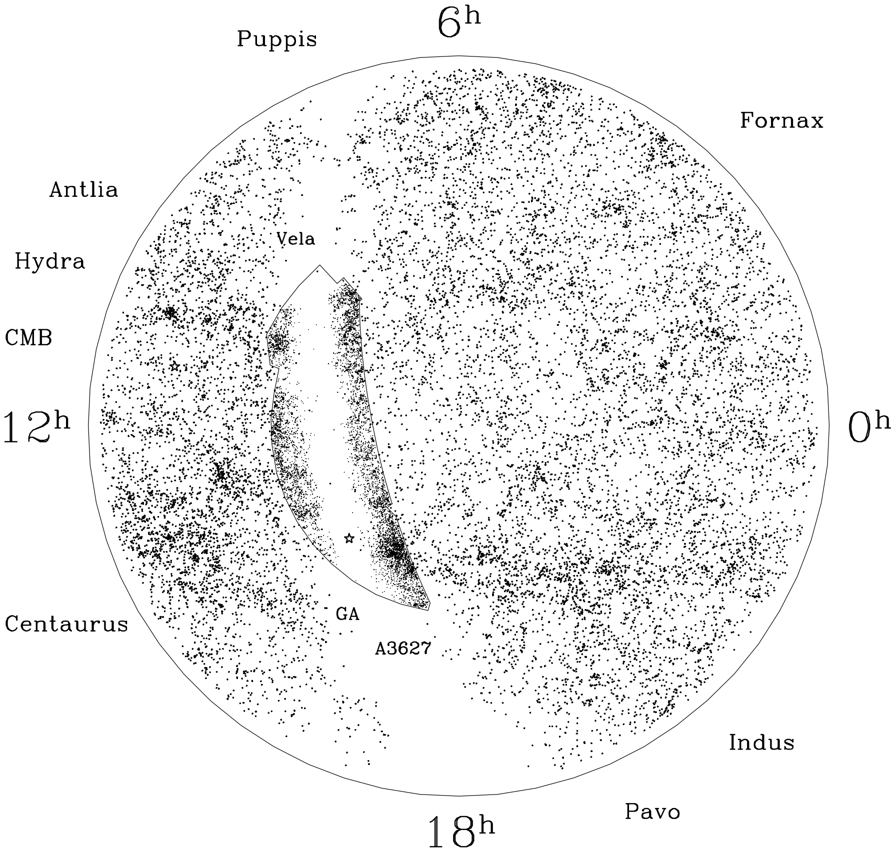

Figure 1: The distribution of optical galaxies near the Galactic Plane found by Kraan-Korteweg et al. (1995) (small or red dots) compared with galaxies from the ESO catalogue (large or blue dots). The empty band is due to obscuration by the Milky Way.

The properties of this region are only inferred by spherical harmonic interpolation across the Plane; (2) the Vela Cluster, which may or may not be an extension of the Hydra/Antlia supercluster (Kraan-Korteweg & Woudt 1994); (3) the Ophiuchus supercluster ($\ell = 0°, b = 8°, cz \approx 8000$ km s^{-1}) (Wakamatsu et al. 1994), which extends around one of the brightest known X-ray clusters (Wakamatsu & Malkan 1981). This supercluster may also be associated with the Sagittarius and Hercules superclusters (Djorgovski et al. 1990; review of Lahav 1994).

For more distant galaxies, the only useful H I ZOA survey has been performed by Kerr & Henning (1987). Although this covered a very small fraction of the sky, it provides the largest H I-selected sample of galaxies to date (37 objects) and places useful limits on the H I mass function (Henning 1995).

2. Scientific Goals

Although galaxies in the latitude range $5° \leq |b| \leq 10°$ suffer high extinction in optical bands, DENIS, the 2μm all-sky survey (2MASS) (Huchra et al. 1994), and the PSC-z extension, based on IR imaging of IRAS galaxy candidates (Saunders et al. 1994) will, in the long term, probably be able to detect many of the higher luminosity galaxies in the velocity range accessible to the Parkes multibeam receiver. However, $|b| \leq 5°$ roughly corresponds to a Galactic H I column density of 5×10^{21} cm^{-2} and an extinction of $A_B = 5$ mag. Below this latitude, the extinction and confusion problem is too severe for any optical or IR-based survey. There are no other surveys we know if which will usefully be able to detect galaxies in this latitude range, except in a few regions of fortuitously low extinction. We therefore propose to concentrate on $|b| \leq 5°$.

An eventual goal of our survey is to combine with redshift surveys of optical, 2MASS, DE-

NIS and IRAS galaxies in order to obtain complete coverage of the southern sky. In order to do this effectively, it is necessary to understand the selection function and the multivariate luminosity function $\Phi(M_{\rm H}, L_{\rm B}, L_{\rm IR}, V_{\rm rot}, \mathbf{r})$ for galaxies (which includes knowledge of any wavelength-dependent bias factors $b = \delta\rho/\rho$). Information about this function is not available within the survey region itself and, ideally, a well-studied control region of comparable size is required. However, we anticipate that the proposed multibeam all-sky survey will contain sufficient information for this goal to be realized.

3. Southern Survey Parameters

We propose an effective integration time of 0.5 hr/beam, and we propose to observe the whole southern Milky Way ($\ell = 213°$ to $33°$, $|b| \leq 5°$). As well as covering the intersection of the Supergalactic Plane with the Galactic Plane which corresponds to the general region of the Great Attractor, this survey covers the obscured Puppis cluster at $\ell = 240°$ (Kraan-Korteweg & Huchtmeier 1992; Yamada et al. 1992), and the Ophiuchus supercluster which lies close to the Galactic Centre (Wakamatsu & Malkan 1981; Wakamatsu et al. 1994).

To obtain the proposed integration time, a total observing time of 1500 hrs is required. The requested LST range is 03:00 to 23:00 hr.

The Galactic Plane survey will have integration times typically six times longer than the proposed all-sky survey, and will therefore achieve a sensitivity increase of 2.4. In the case of a homogeneous distribution function, this will lead to a factor of 3.7 increase in the surface density of galaxies discovered[1], compared with the all-sky survey. However, because of the presence of the 'Great Attractor' region, this will probably be an underestimate. For the requested integration times, the 3-σ detection limit[2] is 10 mJy which, for a galaxy with a velocity width of 200 km s^{-1} , corresponds to an H I mass of 5×10^5 M$_\odot$ at 1 Mpc and 5×10^9 M$_\odot$ at 100 Mpc. The latter H I mass should be compared with the average H I mass of an Sc galaxy in a volume-limited sample, $\sim 2 \times 10^9 h^{-2}$ M$_\odot$ (Staveley-Smith & Davies 1988), or the Schechter mass $M^*_{HI} \approx 2 - 5 \times 10^9 h^{-2}$ M$_\odot$ (Briggs & Rao 1993). Therefore, at a distance of $\sim 80h^{-1}$ Mpc, or almost double the distance of the putative 'Great Attractor', we will be sensitive to relatively normal galaxies. If the overdensity is 1.8, the discovery rate should approach one per pointing of the multibeam array, or a total of ~ 3000 galaxies (although we emphasize that the paucity of extensive blind H I surveys means our knowledge of the H I mass function is poor).

4. Northern Extension

Extension of the ZOA survey into the northern hemisphere has some clear benefits. Although the brightest objects have already been found in the Dwingeloo ZOA survey, nothing is known about the distribution of more distant galaxies at low latitudes except in regions where the extinction is fortuitously low.

The local void, for example, which some authors (e.g. Faber & Burstein 1988) use to explain the discrepancy between the position of maximum CMB temperature, in the Local Group frame, and the putative 'Great Attractor' position, is partly hidden by the Galactic bulge and the Plane. An extension of the ZOA survey into the Northern survey will help determine its true extent. In their dynamical model of the local Universe, Shaya, Tully & Pierce (1992) point out the importance of correctly sampling the low-latitude extragalactic population. For example, they point out that, even with a conservative obscuration correction, the low-latitude IC 342/Maffei group has the greatest gravitational influence on the Local Group..

[1]This also assumes that most galaxies are not resolved by the telescope beam, and that most galaxies lie within the survey redshift limits.

[2]For the actual HIPASS 6′ robust gridding function.

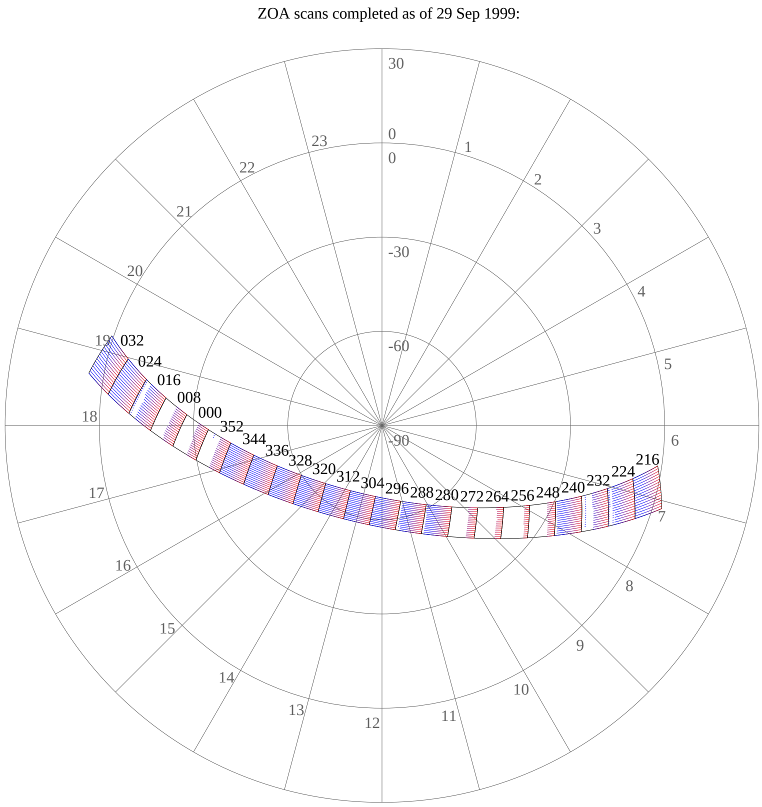

Figure 2: ZOA survey progress as of September 29, 1999.

5. Follow-up Studies

The problems of Galactic extinction mean that IR follow-up observations will challenging, and probably only attempted for a small sample of highly interesting objects. We have requested $I-$band and $K-$band imaging of the shallow survey galaxies. Schröder is currently examining the DENIS catalog at the position of all multibeam-detected galaxies. Follow-up observations with the Compact Array have also been requested for positional and morphological information. Comparison with the MOST 843 MHz Galactic Plane Survey has the potential of giving more accurate positions (sub-arcmin) for large spiral galaxies. This survey already exists in the range $|b| < 1.5°$, and could be extended to $|b| < 5°$ moderately quickly.

6. Data Availability

We will make the H I data available in the form of a data cube. Data will be released on a region-by-region basis 12 months after completion of the observations of a particular region.

7. Progress

The ZOA survey is 76% complete as of 1999 September 29 (see Fig.2). All of the ZoA has been covered with at least five scans and full sensitivity data have been obtained for longitudes 216, 240, 296, 304, 312, 320, 328, 336, 344, 24 and 32 ($\pm 4°$).

Two AJ papers (Staveley-Smith et al. 1998 and Juraszek et al. 1999) are published or submitted. The first describes Multibeam and ATCA observations of three of the largest galaxies discovered so far. The second describes the medium-deep GA survey. A third AJ paper (Henning et al. 1999) on the ZOA shallow survey is about to be submitted (see Fig 3). Eight conference papers are published (Kraan-Korteweg et al. 1998, 1999ab, Henning et al. 1998, 1999, Juraszek 1999ab, Schröder 1999). Current work is concentrating on (a) identifying galaxies at longitudes 304° to 328° (Juraszek et al.); (b) IR (DENIS) and I-band (Curtis Schmidt) identification of shallow

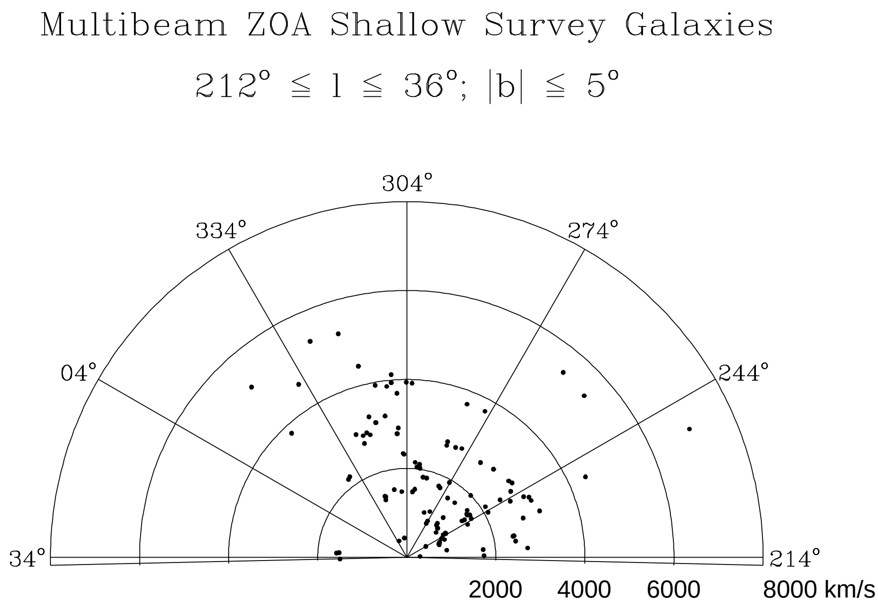

Figure 3: The 110 galaxies found in the ZOA shallow survey (Henning et al. 1999) plotted on a $v-\ell$ polar projection. The Local Void is apparent at the left hand side of the plot.

survey galaxies with DENIS (Schröder et al.).

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