Galaxies behind the deepest extinction layer of the southern Milky Way

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Abstract. About 25% of the optical extragalactic sky is obscured by the dust and stars of our Milky Way. Dynamically important structures might still lie hidden in this zone. Various approaches are presently being employed to uncover the galaxy distribution in this Zone of Avoidance (ZOA). Results as well as the different limitations and selection effects from these multi-wavelengths explorations are being discussed. Galaxies within the innermost part of the Milky Way — typically at a foreground obscuration in the blue of $A_B \gtrsim 5^m$ and $|b| \lesssim \pm 5°$ — remain particularly difficult to uncover except for H I-surveys: the Galaxy is fully transparent at the 21cm line and H I-rich galaxies are easy to trace. We will report here on the first results from the systematic blind H I-search ($v \leq 12700$ km s^{-1}) in the southern Zone of Avoidance which is currently being conducted with the Parkes Multibeam (MB) Receiver.

1 Introduction

To understand the dynamics within the local Universe – the mass distribution and the local velocity field with its peculiar and streaming motions – a detailed map of the 3-dimensional galaxy distribution is highly desirable. However, the dust extinction and confusion with stars in the disk of our Galaxy make this very difficult for ~25% of the sky, and the following questions remain unanswered:

Could a nearby Andromeda-like galaxy have escaped detection to date, hence change our understanding of the internal dynamics and mass derivations of the Local Group (LG), and the present density of the Universe from timing arguments (Peebles 1994)?

Is the dipole in the Cosmic Microwave Background Radiation (direction and amplitude) entirely explained by the gravity on the LG from the irregular mass/galaxy distribution? As the nearest galaxies ($v < 300$ km s^{-1}) generate 20% of the total dipole moment (Kraan-Korteweg 1989) nearby individual galaxies are equally important as massive groups, clusters and voids.

Is the mass overdensity in the Great Attractor (GA) region – postulated from a large-scale systematic flow of galaxies towards $(\ell, b, v) \sim (320°, 0°, 4500\,\mathrm{km\,s^{-1}})$ (Kolatt *et al.* 1995) – in the form of galaxies, hence does light trace mass?

Does the Supergalactic Plane, other superclusters, walls and voids connect across the Milky Way and might other large-scale structures (LSS) have gone undetected due to this 'zone of avoidance'?

2 Multiwavelengths explorations of the southern ZOA

Various approaches are presently being employed to uncover the galaxy distribution in the ZOA: deep optical searches, far-infrared (FIR), near-infrared (NIR) surveys and blind H I searches. All methods produce new results, but all suffer from (different) limitations and selection effects.

OPTICAL: Nearly the whole southern ZOA has been systematically surveyed for highly obscured but still visible galaxies using existing sky surveys (*cf.* Woudt 1998, for a detailed overview). These surveys achieve a considerable reduction of the ZOA and have uncovered distinct LSS unrelated with the foreground extinction. Follow-up redshift observations have revealed a number of dynamically important structures such as *e.g.*, the nearby overdensity in Puppis (Lahav *et al.* 1993) and the massive cluster A3627 at the core of the GA (Kraan-Korteweg *et al.* 1996, *cf.* Fig. 1). Deep optical surveys are not biased with respect to any particular morphological type. However, for foreground extinctions above $A_B \gtrsim 5^m$ (H I-column-densities $N_{HI} \gtrsim 6 \cdot 10^{21}$cm^{-2}), the ZOA remains fully opaque (*cf.* inner contour in Fig. 1). For the southern Milky Way this corresponds roughly to $|b| \lesssim \pm 5°$.

FIR: The IRAS Point-Source Catalog (PSC) has been exploited in the last decade to identify galaxy candidates behind the ZOA. Using different colour selection criteria, galaxy candidates were followed up by HI radio surveys (*e.g.*, Lu *et al.* 1990) or by inspection of plates (*e.g.*, Takata *et al.* 1996). To avoid confusion with Galactic sources, K-band snapshots have proved very efficient (Saunders *et al.* 1994). Confirmed IRAS galaxies can be merged with IRAS galaxy samples outside the ZOA to produce uniform whole-sky samples for LSS studies. But bright spiral and starburst galaxies dominate these samples.

NIR: The recent near infrared (NIR) surveys, 2MASS (Skrutskie *et al.* 1997) and DENIS (Epchtein 1997), provide complementary data. NIR surveys are sensitive to early-type galaxies, are tracers of massive groups and clusters missed in IRAS and H I surveys, have little confusion with Galactic objects and are less affected by absorption than optical surveys.

In a pilot study, we examined the effeciency of uncovering galaxies at high extinctions with DENIS images (*cf.* Schröder *et al.* 1997 & Kraan-Korteweg *et al.* 1998): highly obscured, optically invisible galaxies can indeed be traced to lower latitudes ($|b| \gtrsim 1 - 1\overset{\circ}{.}5$) than deep optical surveys. This is not only of interest in charting early-type galaxies but also with respect to the combination of H I data of heavily obscured spiral galaxies detected in blind H I surveys (cf. below) with NIR data, and therewith the possibility to extend the peculiar velocity field into the ZOA via the NIR Tully – Fisher relation.

H I: In the regions of highest obscuration and infrared confusion the Galaxy is fully transparent to the 21-cm line radiation of neutral hydrogen. H I-rich galaxies can readily be found at lowest latitudes through detection of their redshifted

21-cm emission. Only low-velocity extragalactic sources (blue- and redshifted) within the strong Galactic HI emission will be missed, and – because of baseline ripple – galaxies close to radio continuum sources.

Until recently, radio receivers were not sensitive and efficient enough to attempt large systematic surveys of the ZOA. In a pilot survey with the late 300-ft telescope of Green Bank, Kerr & Henning (1987) surveyed 1.5% of the ZOA and detected 16 new spiral galaxies. Since then a systematic shallow search for nearby, massive galaxies has been completed in the north (Henning *et al.* 1998), yielding five objects including Dwingeloo 1 (Kraan-Korteweg *et al.* 1994).

3 The Parkes Multibeam Survey in the southern ZOA

In March 1997, a systematic blind H I survey began with the Multibeam Receiver (13 beams in the focal plane array) at the 64 m Parkes telescope in the most opaque region of the southern Milky Way ($213° \leq \ell \leq 33°$; $|b| \leq 5°$). The ZOA will be surveyed along constant Galactic latitudes in 23 contiguous fields of length $\Delta\ell = 8°$. The ultimate goal is 25 scans per field where adjacent strips will be offset in latitude by $\Delta b = 1\overset{'}{.}5$ for homogeneous sampling. With a total observing time of 1500h, we will obtain an effective integration time of 25 min/beam with a 3σ detection limit of 15 mJy. Roughly 3000 detections are predicted for the covered velocity range of $-1200 \lesssim v \lesssim 12700\,\mathrm{km\,s^{-1}}$ (Staveley-Smith 1997). This allows the detection of dwarfs with H I-masses as low as $10^6\,\mathrm{M_\odot}$ in the local neighbourhood, and will be sensitive to normal Sc galaxies well beyond the Great Attractor region. As a byproduct, the survey will produce a high resolution integrated column density map of the southern Milky Way and a detailed catalog of high velocity clouds (*cf.* Putnam *et al.* 1998).

3.1 First Results from the Parkes Multibeam survey

At the time of this meeting, the whole southern ZOA survey had been surveyed twice ($\Delta b = 17'$, rms ~ 20 mJy). The cubes of the Hanning smoothed data ($26\,\mathrm{km\,s^{-1}}$ resolution) were inspected visually for 21 of the fields ($220° \leq \ell \leq 4°$) and all galaxy candidates with H I fluxes $\gtrsim 100$ mJy were catalogued.

87 galaxies were uncovered in this way. Four were seen in more than one cube. Though galaxies up to $6500\,\mathrm{km\,s^{-1}}$ were identified, most of the galaxies (80%) are quite local (v< $3500\,\mathrm{km\,s^{-1}}$) due to the (yet) low sensitivity. In the low-extinction Puppis region (*cf.* Fig. 1), a large fraction of the galaxies and their velocities were already known. In the remaining ZOA, about 1/3 have a counterpart in NED or the deep optical surveys.

The distribution of the H I-detected galaxies is shown in the lower panel of Fig. 1. Here we also display the results by Juraszek *et al.* (in prep.) in the GA region. In this high priority area, defined as $310° \leq \ell \leq 330°$, $|b| \leq 10°$, four scans rms (~ 15 mJy) were analyzed and 82 galaxies charted. This area hence probes deeper and finds – not unexpectedly – a peak in the velocity distribution between 3000 and $4500\,\mathrm{km\,s^{-1}}$ in the GA direction. The top panel of Fig. 1

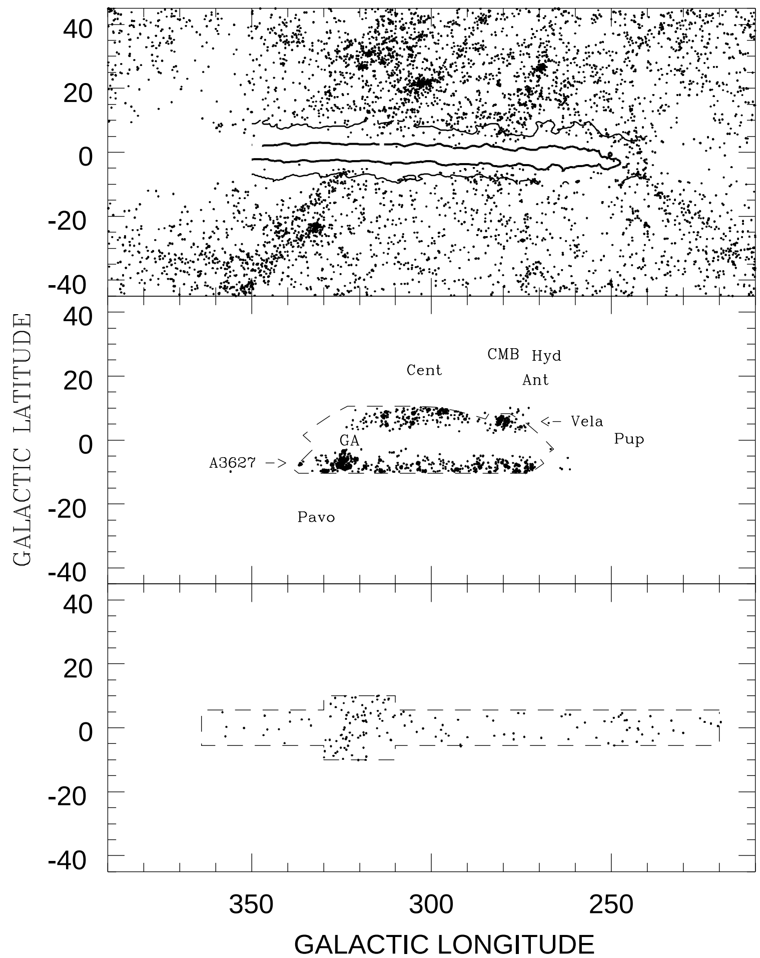

Fig. 1. Galaxies with v<10000 km s^{-1}. Top panel: literature values (LEDA), superimposed are extinction levels A$_B \sim 1\overset{m}{.}5$ and 5^m; middle panel: follow-up redshifts (ESO, SAAO and Parkes) from deep optical ZOA survey with locations of clusters and dynamically important structures; bottom panel: redshifts from shallow MB-ZOA and deeper GA survey in H I with the Parkes radio telescope.

shows the distribution of all galaxies with velocities v $\leq$ 10000 km s^{-1} centered on the southern Milky Way. Note the near full lack of galaxy data for extinction levels A$_B \sim 1\overset{m}{.}5$ (outer contour). The middle panel results from the follow-up observations of the optical galaxy search by Kraan-Korteweg and collaborators. Various new overdensities become apparent at low latitudes. But the innermost part of our Galaxy remains obscured (A$_B \gtrsim 5^m, |b| \lesssim 5°$). Here, the blind H I data (*cf.* lower panel) finally can provide the missing link for LSS studies.

In Fig. 2, the data of Fig. 1 are combined in redshift slices. The achieved

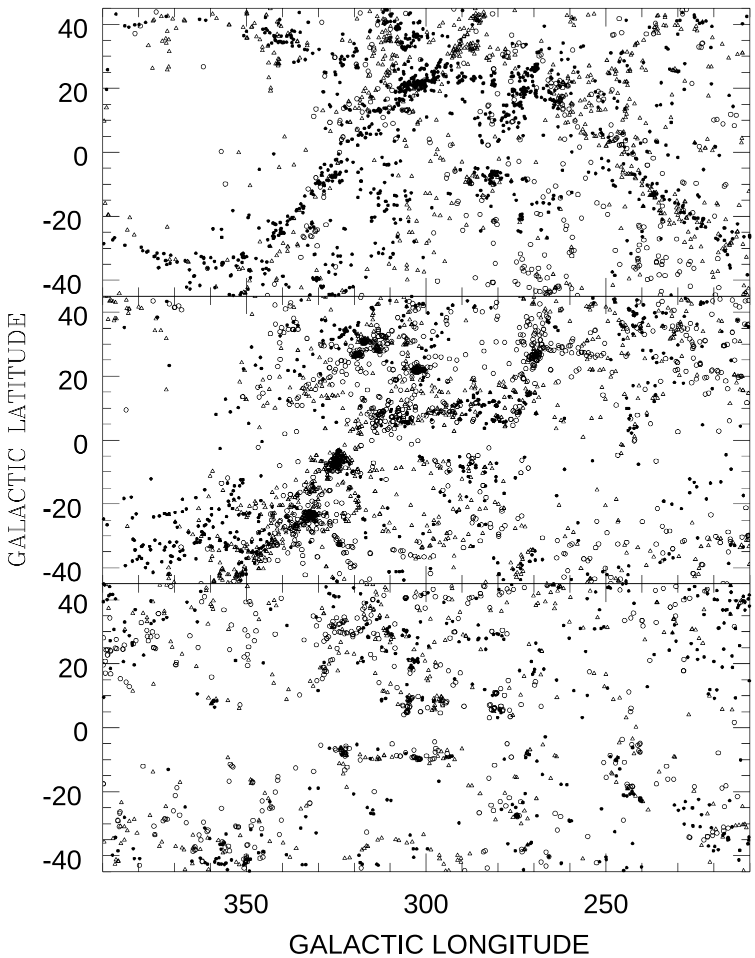

Fig. 2. Redshift slices from data in Fig. 1: 500<v<3500 (top), 3500<v<6500 (middle), 6500<v<9500 $\mathrm{km\,s^{-1}}$ (bottom). The open circles mark the nearest Δv=1000 $\mathrm{km\,s^{-1}}$ slice in a panel, then triangles, then the filled dots the 2 more distant ones.

sensitivity in the current MB H I-survey fills in structures all the way across the ZOA for the upper panel (v $<$ 3500 $\mathrm{km\,s^{-1}}$) for the first time. Note the continuity of the thin filamentary sine-wave-like structure that dominates the whole southern sky, and the prominence of the Local Void. This feature is very different from the thick, foamy Great Wall-like structure, the GA, in the middle panel. With the full sensitivity aimed at with the MB-survey, we will be able to fill in the LSS in the more distant panels of Fig. 2 as well.

ATCA follow-up observations of three very extended ($20'$ to $\gtrsim 1°$), nearby (v $<$ 1500 $\mathrm{km\,s^{-1}}$) sources revealed them to be interesting galaxies/complexes, with unprecedented low H I column densities (*cf.* Staveley-Smith *et al.* 1998).

4 Conclusions

The combination of the complementary multiwavelength surveys allow a new probing of LSS in the 'former' ZOA. The H I surveys are particularly powerful at the lowest latitudes. But future merging of ZOA data with catalogs outside the ZOA will have to be done with care to obtain 'unbiased' whole-sky surveys.

From the sensitivity attained with the first 2 scans of the ZOA MB-survey it can be maintained that no Andromeda or other H I-rich Circinus galaxy is lurking undetected behind the extinction layer of the southern Milky Way.

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