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Large-scale Structures behind the Southern Milky Way from Observations of Partially Obscured Galaxies

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Abstract: We report here on extragalactic large-scale structures uncovered by a deep optical survey for galaxies behind the southern Milky Way. Systematic visual inspection of the ESO/SRC survey revealed over 10 000 previously unknown galaxies in the region $265° \lesssim \ell \lesssim 340°, |b| \lesssim 10°$. With subsequently obtained redshifts of more than 10% of these galaxies, new structures across the Milky Way are unveiled, such as a filament at ~2500 km s^{-1} connecting to the Hydra and Antlia clusters, a shallow extended supercluster in Vela (~6000 km s^{-1}), and a nearby (4882 km s^{-1}), very massive ($\mathcal{M} \sim 2-5 \times 10^{15} \mathcal{M}_\odot$), rich Coma-like cluster which seems to constitute the previously unidentified centre of the Great Attractor.

The innermost part of the Milky Way, where the foreground obscuration in the blue is $A_B \gtrsim 5^{\rm m}$, i.e. where H I-column densities $N_{\rm H\,I} \gtrsim 6 \cdot 10^{21}$cm^{-2}, remains fully opaque. In this approximately 8° wide strip, the forthcoming blind H I survey with the multibeam system at Parkes will provide the only tool to unveil this part of the extragalactic sky.

Keywords: galaxies: distances and redshifts — large-scale structure of Universe — surveys

1 Introduction

The Milky Way obscures about 25% of the extragalactic sky. This severely constrains studies of:

- Large-scale structures, particularly the connectivity of the Supergalactic Plane, other superclusters, walls and voids across the Milky Way.
- The origin of the peculiar motion of the Local Group (LG) with respect to the Cosmic Microwave Background Radiation (CMB). Can the dipole in the CMB be explained by the gravity of the irregular mass/galaxy distribution in the *whole* sky?
- Other streaming motions. Is the predicted mass overdensity, the Great Attractor (GA)—as evidenced in a large-scale systematic flow of galaxies towards $(\ell, b, v) \sim (320°, 0°, 4500$ km s$^{-1})$ (Kolatt, Dekel & Lahav 1995)—in the form of galaxies, hence does light trace mass?
- Individual nearby galaxies. Could a nearby Andromeda-like galaxy lie hidden in the Zone of Avoidance (ZOA)? This is important for the internal dynamics of the LG, as well as mass derivations of the LG and the present density of the Universe from timing arguments (Peebles 1994). Moreover, the gravitational attraction of the nearest galaxies ($v < 300$ km s^{-1}) generates 20% of the total dipole moment (Kraan-Korteweg 1989).

In recent years various groups have initiated projects to unveil the galaxy distribution behind our Milky Way. The methods are manifold [see Balkowski & Kraan-Korteweg (1994) for a review]. Here we describe the results from a deep optical survey for galaxies in the southern Milky Way, a particularly interesting region because of the dipole in the CMB and the infall into the GA, both of which point close to the southern Galactic Plane (see Figure 1).

2 A Deep Optical Galaxy Search in the Southern ZOA

To reduce the ~20°-wide strip of the ZOA, we have embarked on a deep search for partially obscured galaxies, i.e. down to fainter magnitudes and smaller dimensions compared to those in existing catalogues. To date, 50 fields of the ESO/SRC survey have been visually inspected. The surveyed area lies within $265° \lesssim \ell \lesssim 340°, |b| \lesssim 10°$; its borders are outlined in Figure 1. Within the surveyed area of ~1200□°, 10 276 new galaxies with $D \geq 0'.2$ have been identified in addition to the 269 Lauberts galaxies with $D \geq 1'$ within this area (Lauberts 1982). Their distributions are displayed in Figure 1. Details on the search can be found in Kraan-Korteweg & Woudt (1994).

In the mean, the galaxy density is well correlated with the foreground extinction A_B as traced by

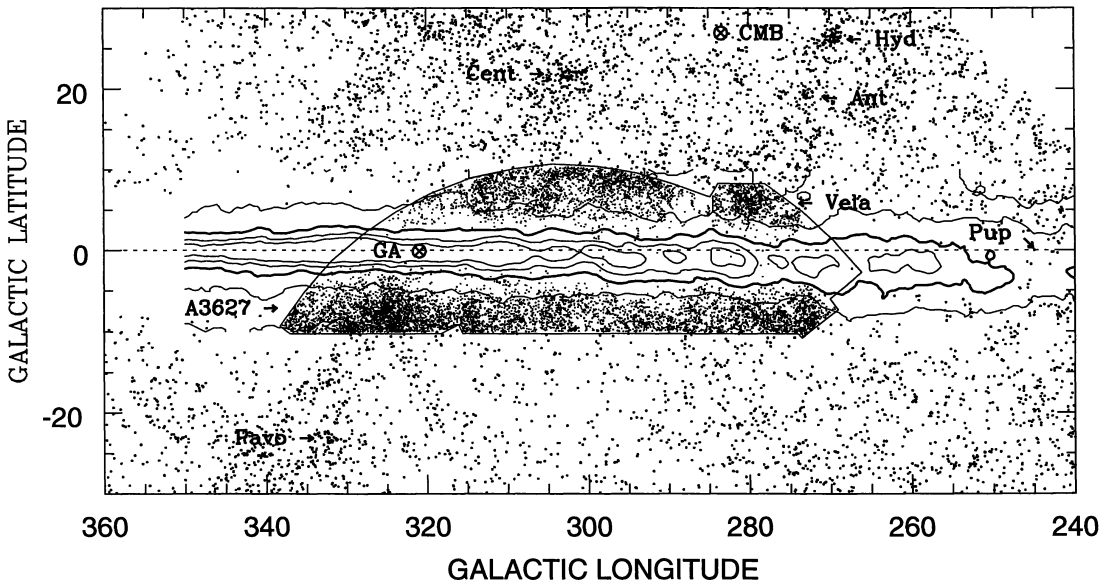

Figure 1—The galaxy distribution from our deep galaxy search ($D \geq 0'.2$) and the Lauberts galaxies ($D \geq 1'$) in Galactic coordinates. The region surveyed to date is outlined. The dipole direction in the CMB, the centre of the GA and the most prominent clusters are marked. The contours mark absorption in the blue of $A_B = 1^m, 2^m.5, 5^m$ (thick contour), $7^m.5$, 10^m as derived from the Galactic H I (Kerr *et al.* 1986), adopting a constant gas-to-dust ratio and the formalism given by Burstein & Heiles (1982).

the H I-column density: for $A_B \gtrsim 5^m$ thick contour, respectively $N_{\rm H\,I} \gtrsim 6 \times 10^{21}$ cm^{-2}, the ZOA remains opaque. Above this band, distinct filaments and round concentrations uncorrelated with the foreground dust can be recognised; these must have their origin in extragalactic large-scale structures. Some of these features seem to align with the known galaxy distribution, for example the filament above the Galactic Plane which points toward the Centaurus cluster, and the filament from the Hydra and Antlia clusters towards the prominent overdensity in Vela. A significant overdensity, centred on the previously identified cluster A3627 (Abell, Corwin & Olowin 1989), is evident within only a few degrees of the predicted centre of the GA. It is the only Abell cluster behind the Milky Way, classified as rich and nearby, and lies within the GA region. Even so, this cluster has received little attention because of the diminishing effects of the foreground obscuration: this cluster at $(\ell, b) = (325°, -7°)$ is hardly obvious in the distribution of Lauberts galaxies and not at all in IRAS samples. However, the galaxies in this overdensity are on average relatively large (just *below* the diameter limit of Lauberts). Lifting the obscuring veil of the Milky Way by correcting the observed properties of the galaxies for the foreground extinction would, in fact, reveal this cluster as the most prominent overdensity in the southern sky.

Redshift measurements are required to map the galaxies in three dimensions. The two-dimensional galaxy distribution alone can be misleading. For instance, the prominent overdensity in Vela was found to be due to a superposition of a nearby (~2500 km s^{-1}) filament connecting to Hydra, a more distant (6000 km s^{-1}) shallow extended supercluster, and a very distant (~16000 km s^{-1}) wall-like structure crossing the ZOA (Kraan-Korteweg et al. 1994).

3 H I Observations of Obscured Galaxies at Parkes

The redshifts of the uncovered galaxies are obtained by three observational approaches: (a) multifibre spectroscopy with OPTOPUS and MEFOS at the 3·6 m telescope of ESO in the densest regions, (b) individual spectroscopy of the brightest galaxies with the 1·9 m telescope of the SAAO, and (c) 21 cm observations of extended low-surface-brightness (LSB) spirals with the 64 m Parkes radio telescope. So far we have obtained 1083 new redshifts in our search area.

An extensive discussion of methods and typical results are given in Kraan-Korteweg et al. (1994). The three observing methods are complementary in galaxy populations, characteristic magnitude and diameter range and the depth of volume they probe. The multifibre spectroscopy gives a good description of clusters and dense groups in the ZOA and traces large-scale structures out to recession velocities of 25 000 km s^{-1}. The SAAO and H I observations cover the bright end of the galaxy distribution and provide a more homogeneous sampling of galaxies out to 10 000 km s^{-1}.

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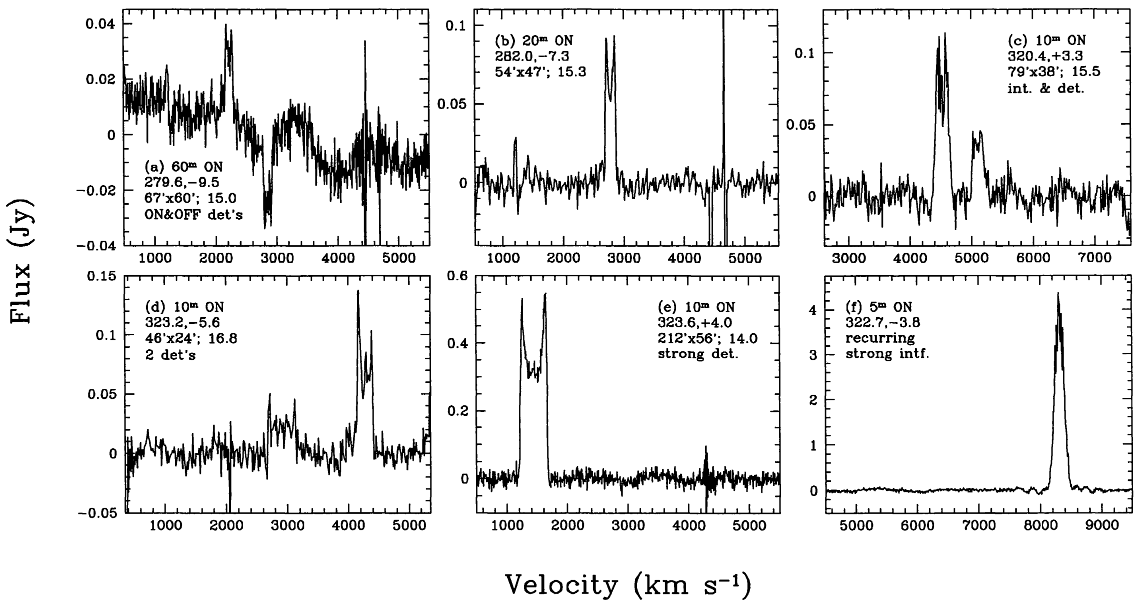

Figure 2—Typical spectra of galaxies in the ZOA obtained with the 64 m Parkes radiotelescope. Integration times (between $5^{\rm min}$ and $60^{\rm min}$), Galactic coordinates, observed (absorbed) diameters (in arcsec) and magnitudes in the blue B_J are indicated. Except for panel (c), all spectra are baseline-subtracted. Regularly appearing interferences of different strengths are found at 1200, 3350, 4700 and 8300 km s^{-1}.

Our H I observations at Parkes have similar sensitivities to the forthcoming blind H I survey with the multibeam (MB) receiver in the ZOA, and therefore merit a more detailed description. These observations are vital in recovering an important fraction of the nearby spiral galaxy population which would otherwise be impossible to map. Although we aimed at complete coverage for the brightest galaxies with optical spectroscopy, a significant fraction of apparent bright galaxies cannot be traced in this manner. In general, this concerns nearby spirals (and also dwarfs) which, seen through a layer of extinction, are extended, very LSB objects.

We have so far observed 345 spiral galaxies without previous redshift estimates at Parkes. Each galaxy was observed in total power mode, with a bandwidth of 32 MHz, using the 1024 channel autocorrelator. We generally integrated 30 minutes ON/30 minutes OFF source. This yielded an rms noise after Hanning smoothing of typically 4 mJy, comparable in sensitivity to the proposed MB ZOA survey. However, we often detected strong galaxies in as little as ten minutes. On the other hand, we sometimes observed a source for an hour to get a sufficient signal-to-noise ratio. We found the sensitivity during the day to be significantly degraded compared to the level achieved at night due to high-amplitude standing waves in the spectrum which precluded detections even with a large number of very short integrations.

In 1993 we generally centred the recession velocity at 3000 km s^{-1} and reobserved some of the non-detections at a central velocity of 7500 km s^{-1} in a second step. This resulted in a detection rate of over 50%. In 1994 and 1995, we used two IFs and offset 512 channels of each polarisation by 22 MHz. This resulted in a velocity coverage of 0–10 000 km s^{-1} with the 32 MHz in one integration. Although the lower frequencies were often badly disturbed by interference around 8300 km s^{-1} (see Figure 2), this increased our detection rate to nearly 80% in 1994! Our observations were considerably less effective in the 1995 run due to a strong increase in recurring interference, part of which was generated locally by the then ongoing tests of the pulsar equipment, a problem that demands careful investigation of the Galactic pulsar survey which will be piggybacked on the MB ZOA survey!

A few examples of typical H I spectra, recurring interference as well as detections at low Galactic latitudes are illustrated in Figure 2. Panels (a) and (b) are pointed observations in the Hydra/Antlia extension, (c)–(f) are observations in the GA region. Panel (a) shows a detection in the ON position as well as a detection in the adjacent $10^{\rm m}.5$ earlier OFF position in the crowded nearby Hydra/Antlia-filament. Panel (b) shows another example of a previously unidentified LSB member of this filament. Note the recurring interference at 1200, 4450 and 4700 km s^{-1}. The interference at 1200 km s^{-1} is found in practically all scans (positive or negative). The final shape often resembles real H I profiles which may be interpreted as erroneous detections. Moreover, detections of weaker real galaxies within that velocity range are impossible.

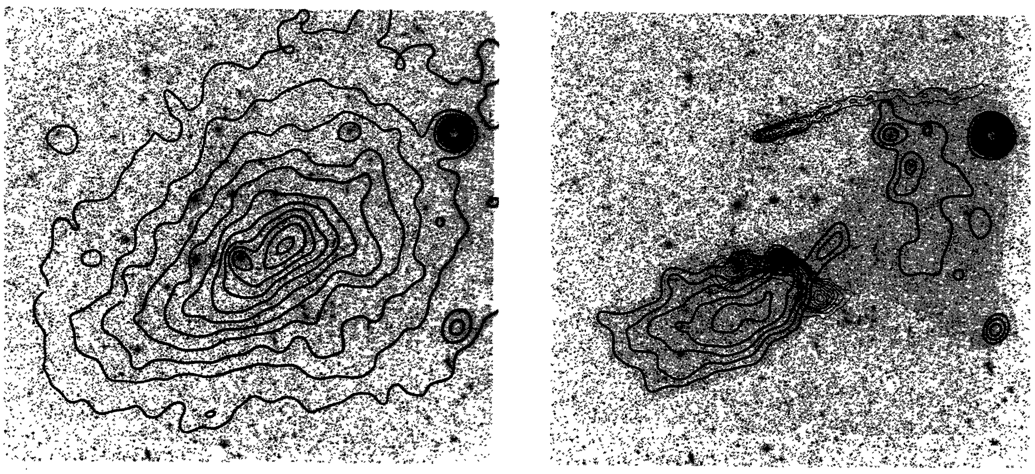

Figure 3—The central part (56′×56′) of the cluster A3627 as reproduced from field 136 of the IIIaJ copy of the ESO/SRC survey. Superimposed in the left panel are the X-ray contours from the ROSAT PSPC observations; the right panel shows the residual X-ray contours after subtraction of a spherical component, and the 843 MHz radio continuum emission of the wide-angle-tail radio galaxy PKS1610–60·8 and the head tail radio source B1610–60·5. The strong X-ray point-source (top right corner), a cluster galaxy, is a Seyfert 1 (Woudt et al. 1996).

Panel (d) shows two detections within one beam in the densely populated GA region, whereas in panel (c) only the feature at 5100 km s^{-1} results from the detection of a massive GA galaxy; the stronger signal at 4450 km s^{-1} is due to interference.

The interference at 8300 km s^{-1} (panel f) constitutes a true problem. Unstable in time and strength, it has perturbed about half of the observations in the higher velocity range. Its strength—sometimes over 10 Jy—causes ringing and baseline wiggles and precludes detections of galaxies in a broad velocity range. This makes an analysis of the detection rate statistics and especially the volume completeness function of the MB ZOA survey extremely hard.

Still, it can be maintained that the H I observations recover obscured galaxies deeper in the obscuration layer than does optical spectroscopy; a natural extension into the fully obscured region will be the MB ZOA survey. The relatively high detection rate of obscured low-latitude galaxies ($5° \lesssim |b| \lesssim 10°$) forecasts quite a high success rate for the MB ZOA survey ($|b| \leq 5°$), with more than one detection per beam in high-density areas (cf. panels a and d in Figure 2).

4 Uncovered Structures and the Cluster Abell 3627

The new redshifts along with published redshifts in adjacent regions provide evidence for the following structures:

The Hydra and Antlia clusters are not isolated clusters, but part of a filamentary structure which can be traced from Hydra through Antlia (see Figure 1), across the Galactic Plane to $(\ell, b) = (283°, -10°)$, thus constituting a major structure in the nearby Universe (>35° at a median recession velocity of only 2800 km s^{-1}). It seems more a filamentary structure, consisting of spiral-rich groups and clusters, than a supercluster.

The prominent galaxy overdensity in Vela is part of a previously unrecognised shallow, large-scale overdensity centred on ~6000 km s^{-1}. The independent predictions of a supercluster at this position and distance by Hoffman (1994) and Saunders et al. (1991) indicate that it could be quite massive.

The redshifts in the cluster A3627 ($\langle v \rangle$ = 4882 km s^{-1} for 131 reduced to date) put this cluster near the centre of the Great Attractor in velocity space. The mass estimate from its velocity dispersion (σ = 903 km s^{-1}) is that of a rich cluster ($5 \times 10^{15}\ \mathcal{M}_\odot$). Its other cluster properties—predominance of early-type galaxies at the centre, its core radius $R_c = 10'.4$ and its central density $N_0 = 800$ gal/□° all are consistent with this being a rich massive cluster (Kraan-Korteweg et al. 1996). It even has, like Coma, two dominant central cD-galaxies (see Figure 3).

Rich massive clusters generally are strong X-ray emitters and were identified early on with the X-ray satellites (Einstein, HEAO, Uhuru). Despite dedicated searches and the fact that the hard X-ray band is hardly affected by H I absorption, A3627 had never been identified in the X-ray region (Jahoda & Mushotzky 1989; Lahav et al. 1989). We therefore studied the ROSAT PSPC data of this cluster (Böhringer et al. 1996) and found that A3627, with an X-ray luminosity of $L_X = 2{\cdot}2 \times 10^{44}$ erg s^{-1}, is in

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fact the sixth-brightest X-ray cluster in the ROSAT All Sky Survey. Moreover, the independent mass estimate from the X-ray data is consistent with the virial mass.

Figure 3 displays the X-ray contours (Böhringer et al. 1996) superimposed on an image of the central part of the cluster. The X-ray provides interesting insight into the cluster morphology. The X-ray centre is offset from the centre of the cluster, the strong radio source PKS1610–60·8, one of the two cD galaxies. The latter coincides with the second central X-ray peak. The X-ray emission is not symmetric but is extended towards the SE (left-bottom) corner. Subtracting a spherical symmetric model leaves a residual component (right panel). This subcluster contains the wide-angle-tail radio galaxy PKS1610–60·8, whose large radio lobes of 8 arcmin (~210 kpc) have a bending angle of 45°. The contours of the radio emission (Jones & McAdam 1992) are drawn onto the X-ray subgroup as well. Note the alignment of the subclump with the radio emission. The redshift data are yet too sparse to allow a kinematical analysis of this cluster, however, the redshifts in the subclump tend to be higher, suggesting that this subgroup is in front of the main cluster and falling towards it.

The emission from the radio galaxy B1610–60·5 (Jones & McAdam 1992) has been drawn onto the right panel of Figure 3 as well. It is one of the longest known head–tail galaxies (26 arcmin, ~710 kpc). The radio emission aligns over nearly its full extent with the third contour of the main X-ray component. The lack of distortion of the radio lobes of both radio galaxies and the compactness of the subclump imply that the suspected merger must be in an early stage. Forthcoming ATCA H I-synthesis observations will allow deeper insight into this cluster.

The cluster A3627 most likely is the previously unidentified core of the Great Attractor overdensity. The mass excess of the GA is presumed to arise within an area of radius of about 20–30 Mpc (Lynden-Bell et al. 1988). This actually matches the emerging picture from our observations quite well. A3627 seems the centre of an apparent 'great wall'-like structure, similar to Coma in the (northern) Great Wall: a broad filament reaches from $(\ell, b, v) = (335°, -25°, \sim 4500\ \mathrm{km\,s^{-1}})$ over the GA region towards $(295°, +5°, \sim 5500\ \mathrm{km\,s^{-1}})$. Whether it merges into the Vela supercluster at $(280°, +6°, \sim 6000\ \mathrm{km\,s^{-1}})$ is not yet certain.

5 Prospects for the Multibeam ZOA Survey

The optical deep galaxy survey has reduced the gap of the ZOA and revealed many interesting extragalactic large-scale structures. However, the innermost part of the southern Milky Way remains fully obscured. Here, the MB ZOA survey will at last allow a view of that area of the extragalactic sky.

The effectiveness of H I observations of partially obscured galaxies at low latitudes substantiates the high expectations for the MB ZOA survey. This survey will trace the structures described above in full detail, and will also delineate the nearby, dynamically important voids. The Hydra–Antlia extension can be followed even across the inner part of the ZOA. An obscured dominant component might still reveal this structure to be a supercluster. The little-studied Vela supercluster can be traced. The mapping of the central part of the GA can be completed, revealing whether it merges with the Vela supercluster or bends back towards the Centaurus clusters. The extent and mass of the nearby Puppis cluster $(245°, 0°, \sim 1500\ \mathrm{km\,s^{-1}}$, Lahav et al. 1993) can be assessed and the extent of the Ophiuchus cluster close to the Galactic bulge at $\sim 8000\ \mathrm{km\,s^{-1}}$ (Wakamatsu et al. 1997, present issue p. 117) and its connections to other superclusters traced. Other important structures not yet apparent from optical surveys can be mapped in the deepest layers of obscuration.

These revelations will all lead to a better understanding of the galaxy distribution, the underlying mass distribution and the dynamics of the local Universe.

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Abell, G., Corwin, H. G., & Olowin, R. P. 1989, ApJSS, 70, 1
Balkowski, C., & Kraan-Korteweg, R. C. (eds) 1996, Unveiling Large-scale Structures Behind the Milky Way, 4th DAEC Meeting, ed. C. Balkowski & R. C. Kraan-Korteweg, ASP 67
Böhringer, H., Neumann, D. M., Schindler, S., & Kraan-Korteweg, R. C. 1996, ApJ, 497, 168
Burstein, D., & Heiles, C. 1982, AJ, 87, 1165
Hoffman, Y. 1994, in Cosmic Velocity Fields, 9th IAP Astrophysics Meeting, ed. F. Bouchet & M. Lachièze-Rey (Gif-sur-Yvette: Editions Frontiéres), 357
Jahoda, K., & Mushotzky, R. F. 1989, ApJ, 346, 638
Jones, P. A., & McAdam, W. B. 1992, ApJSS, 80, 137
Kerr, F. J., Bowers, P. F., Jackson, P. D., & Kerr, M. 1986, AASS, 66, 373
Kolatt, T., Dekel, A., & Lahav, O. 1995, MNRAS, 275, 797
Kraan-Korteweg, R. C. 1989, in Reviews in Modern Astronomy, vol. 2, ed. G. Klare (Berlin: Springer), 119
Kraan-Korteweg, R. C., & Woudt, P. A. 1994, in Unveiling Large-scale Structures behind the Milky Way, 4th DAEC Meeting, ed. C. Balkowski & R. C. Kraan-Korteweg, ASP 67, 89

Kraan-Korteweg, R. C., Cayatte, V., Fairall, A. P., Balkowski, C., & Henning, P. A. 1994, in Unveiling Large-Scale Structures Behind the Milky Way, 4th DAEC Meeting, ed. C. Balkowski & R. C. Kraan-Korteweg, ASP 67, 99
Kraan-Korteweg, R. C., Woudt, P. A., Cayatte, V., Fairall, A. P., Balkowksi, C., & Henning, P. A. 1996, Nature, 379, 519
Lahav, O., Edge, A. C., Fabian, A. C., & Putney, A. 1989, MRNRAS, 238, 881
Lahav, O., Yamada, T., Scharf, C., & Kraan-Korteweg, R. C. 1993, MNRAS, 262, 711
Lauberts, A. 1982, ESO/Uppsala Survey of the ESO (B) Atlas (Garching: ESO)
Lynden-Bell, D., Faber, S. M., Burstein, D., Davies, R. L., Dressler, A., Terlevich, R. J., & Wegner, G. 1988, ApJ, 326, 19
Peebles, P. J. E. 1994, ApJ, 429, 43
Saunders, W., et al. 1991, Nature, 349, 32
Wakamatsu, K., Malkan, M., Parkes, Q. A., & Karoji, H. 1997, PASA, 14, 117
Woudt, P. A., Fairall, A. P., Kraan-Korteweg, R. C., & Cayatte, V., 1997, in preparation

https://doi.org/10.1071/AS97015 Published online by Cambridge University Press