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H I Searches in the Zone of Avoidance: Past and Present (and Future)

P. A. Henning

Institute for Astrophysics, University of New Mexico,
800 Yale Blvd, NE, Albuquerque, NM 87131, USA
henning@tinsley.phys.unm.edu

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Abstract: In the regions of highest optical obscuration and infrared confusion, only 21-cm emission can be used to find galaxies in the Zone of Avoidance. A feasibility study conducted with the 300-ft telescope successfully uncovered galaxies which seem to be consistent with populations of optically-selected low surface brightness galaxies. A complete survey is currently being conducted in the north with the Dwingeloo telescope. The big breakthrough should come in the south, however, with the advent of the Parkes telescope multibeam system.

Keywords: galaxies: distances and redshifts — galaxies: surveys

1 Introduction

Diligent searches in the optical and infrared can narrow the Zone of Avoidance (ZOA) (cf. many contributions in Balkowski & Kraan-Korteweg 1994), but the most opaque regions require searches using the 21 cm line of neutral hydrogen. Unlike the case at other wavelengths, the opacity of the Milky Way is not a problem at 21 cm (except for extragalactic H I emission near zero velocity, which would be masked by local hydrogen). At the lowest latitudes, H I searches are our only option for mapping large-scale structures.

In this contribution, the results of the feasibility study conducted with the 300 ft telescope at Green Bank, and a follow-up study with the Very Large Array, will be reviewed (Kerr & Henning 1987; Henning 1992; Henning 1995.) A complete survey of the northern ZOA to 4000 km s^{-1} with the Dwingeloo telescope is ongoing [with collaborators P. Henning and A. Rivers (UNM), R. C. Kraan-Korteweg (Meudon), A. Loan, O. Lahav and D. Lynden-Bell (Cambridge) and W. B. Burton (Leiden)] and the very exciting prospects for the southern Parkes multibeam survey (principal investigator L. Staveley-Smith (ATNF), with collaborators R. Ekers (ATNF), P. Henning (UNM), R. Kraan-Korteweg (Meudon), A. Green and S. Jurasek (Sydney), and M. Price (ATNF)] will be discussed.

The search method also presents an astrophysical opportunity: the study of a 21 cm-selected sample. Our present concept of a 'normal galaxy' is based mainly on optical catalogues, on infrared compilations, and on relatively small H I searches. Before a full survey of the ZOA is undertaken, it is useful to understand the sorts of objects we will find, how these differ from samples produced by surveys at other wavelengths, and the impact on our optically-prejudiced notion of normal galaxies.

2 The Feasibility Study

The pilot 21 cm survey for galaxies in the ZOA was conducted with the NRAO 300 ft telescope at Green Bank, West Virginia. Five observing sessions during the period 1986–1988 covered 7200 search points. The beam width at 21 cm was about 10′. About 60% of the lines of sight were in the ZOA; the rest were located in regions of low obscuration as a control. The search points were not concentrated in any particular area, but were spread over the sky accessible to the 300 ft. The velocity range covered, −400 to 6800 km s^{-1}, allowed the possibility of discovering new Local Group members, as well as spirals out to several thousand km s^{-1}. The 300 ft telescope was an extremely sensitive instrument, allowing detection of dwarfs over a large volume, and normal spirals to the limit set by the spectrometer bandwidth. A more complete description of the survey method is provided by Henning (1992).

The survey yielded 37 extragalactic objects, and two interesting high negative velocity sources which we believe are associated with our own Galaxy. Only the sample of 37 clearly extragalactic objects will be discussed here. Nineteen of these appear in optical catalogues. As expected, most of the optically-known objects lie at high galactic latitude, but one, NGC 2377, is quite close to the Galactic Plane, at $b = 3°$. This illustrates the patchiness of the foreground obscuration. Of the full sample of 37 galaxies, 19 showed the typical two-horned or flat-topped H I profiles of unresolved spirals, but morphological classifications are shaky due

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to the random placement of the sources in the beam. Our rough classifications were accurate only about half of the time, judging from comparisons with published morphological types of the optically-catalogued objects. Spirals far from the beam centre tend to look one-horned, as do narrow-profile dwarf spirals. Therefore, all further study of the sample was based on follow-up observations with the Very Large Array (VLA) radio interferometer.

Interferometric observations were made for 25 galaxies, including all of the uncatalogued objects and the weaker catalogued ones. The VLA was used in its most compact configuration, providing the highest sensitivity, but not allowing detailed mapping. From these observations, more accurate positions, H I masses, sizes, profile shapes, and linewidths were derived. The galaxies' H I masses range over two orders of magnitude, from 10^8 to 10^{10} $M_\odot$, small dwarfs to massive spirals. The profiles obtained look just like optically-unobscured H I galaxies (Henning 1992). Visual obscuration makes no difference whatsoever to H I.

Armed with accurate positions, we consulted the Infrared Astronomical Satellite (IRAS) Point Source Catalog to investigate any IR counterparts. Twelve of the 37 objects are associated with IR sources of appropriate colour for galaxies. Ten of these are optically catalogued, and the other two appear on the Palomar Sky Survey. Why such a poor IR performance in finding the hidden galaxies? There are two reasons. First, the IR sky is terribly confused at low latitudes, so our sources near the Galactic Plane were masked by Galactic IR emission. Even inspection of the more sensitive IRAS co-adds does not help pick out extragalactic sources at the very lowest latitudes. Second, IRAS is biased against dwarfs and dwarf spirals. The optically-catalogued dwarfs and dwarf spirals in our sample were not listed in the Point Source Catalog, even though they were in regions of low obscuration.

3 Types of Galaxies found at 21 cm

Using the 21 cm line of H I to search for galaxies is a relatively new technique, and it is important to understand the types of objects that will be discovered by large H I blind searches, such as those to be conducted with the multibeam system. Will a 21 cm-selected sample consist of the same types of galaxies as are found in optical- or IR-selected samples, or will they differ? This is especially important to know when comparing studies at different wavelengths in the ZOA, and is also of general astrophysical interest.

Because a large fraction of this H I-selected sample lies in optically opaque regions, we are forced to consider only the H I properties of the sample versus H I properties of optical- and IR-selected comparison samples. For this analysis, the distribution of H I linewidths, a sensitive indicator of galaxy morphological type, is considered. The possible bias against broad-lined galaxies has been considered, and does not appear to be important. A fuller discussion of this analysis has appeared recently (Henning 1995). In summary, the linewidth distribution of the H I-selected sample is statistically indistinguishable from that of the optically-selected sample of dwarf and other low surface brightness galaxies studied by Schneider et al. (1990). So while the H I search did not discover a new class of previously unknown objects, it does turn up galaxies that are difficult to study optically, and are under-represented in optical catalogs and redshift surveys.

A related point for consideration when tracing large-scale structure into the ZOA is that galaxies discovered in H I are drawn from a different population than those found by IRAS, which consist of broader linewidth, relatively massive spirals. These two methods of searching at low latitudes are complementary, and it is important to realise that they use different tracers to map structures.

4 Clustering and Space Density of the H I-selected Sample

We have determined that an H I-selected sample is not made up of high optical surface brightness galaxies, which are the types usually used to trace large-scale structures. Because blind 21 cm searches are rarely done, the relative distributions of H I-selected galaxies versus optical samples are not well known. For our sample, we can ask if the H I galaxies out of the ZOA lie along structures delineated by optically selected samples. In particular, we considered the magnitude-limited CfA redshift survey (Huchra et al. 1983) and a volume-limited survey of dwarf and other low surface brightness galaxies. Analysis by Thuan et al. (1991) indicates that the high and low surface brightness galaxies lie along the same three-dimensional structures. We have eleven H I-selected galaxies in regions covered by these surveys. Each of the eleven lies along structures traced by the high and low surface brightness samples. This result is consistent with the underdensity of H I galaxies in the Local Void, where it lies behind the Milky Way (Henning 1995).

Finally, we consider the space densities of galaxies of various H I masses. In particular, are we missing a large population of low optical surface brightness, H I-rich objects when relying on optical catalogs? To answer this, we have constructed an H I mass function, analogous to optical luminosity functions. Figure 1 (Figure 6 of Henning 1995) shows the number density of galaxies as a function of $M_{\rm H\,I}$, weighted inversely by the volume in which the galaxies could have been detected. Uncertainty is introduced by the presence of large-scale structures in the survey volume, but this effect should be relatively minor

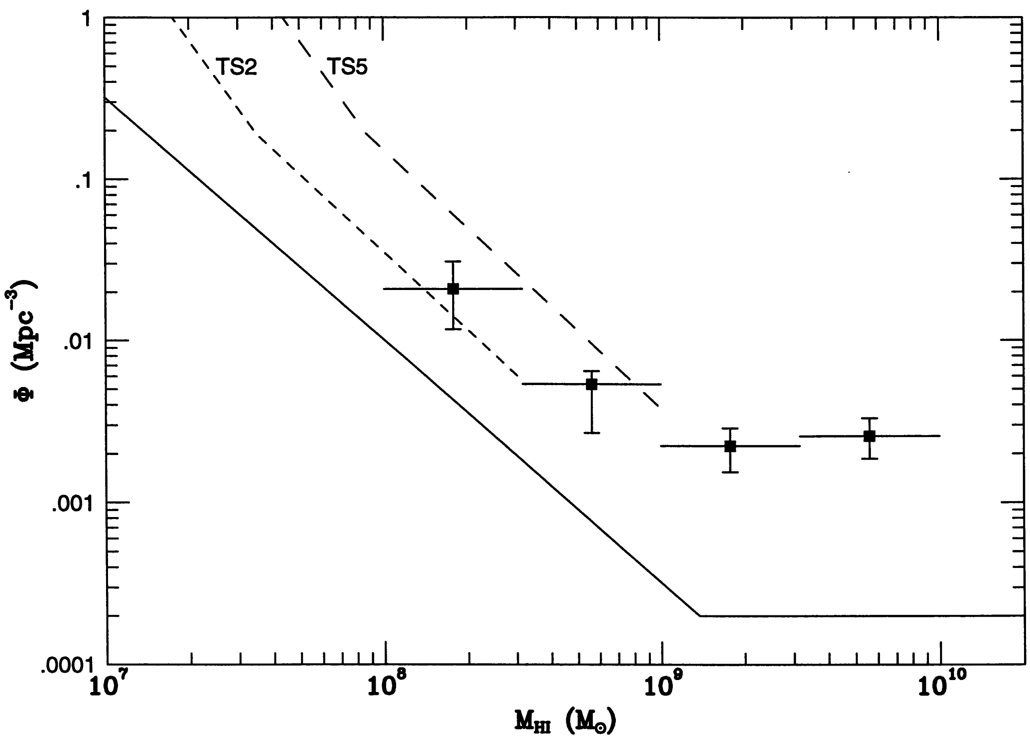

Figure 1—Plotted points represent the observed H I mass function of Henning (1995). The sensitivity of the search is shown by the solid line, and the curves labelled TS2 and TS5 represent the predictions of the model by Tyson & Scalo (1988) discussed in the text.

due to the all-sky distribution of the search points. This function is flat over high $M_{\rm H\,I}$ then shows an upturn at $M_{\rm H\,I} \approx 10^8\ M_\odot$; however, we do not see the large population of very low mass (10^7 to $10^8\ M_\odot$) low surface brightness dwarfs predicted by the model of dwarf galaxy formation developed by Tyson & Scalo (1988). The curves TS2 and TS5 show their predicted number densities of dwarf galaxies with H I column densities of 2×10^{20} cm^{-2} and 5×10^{20} cm^{-2}, following Briggs (1990). Our search sensitivity would have allowed detection of this population. While the number density increases with decreasing mass, low mass objects do not hold the majority of the neutral hydrogen mass. High H I mass objects, with log $M_{\rm H\,I} \geq 9{\cdot}5$, still contain the bulk (60%) of the H I mass. This is consistent with the study of the H I contents of optically selected galaxies by Rao & Briggs (1993). This H I mass function is also consistent with the analysis (Schneider 1996) of the blind survey conducted with the Arecibo telescope by Spitzak (1996). However, compared with his more recent analysis (Schneider 1997, present issue p. 99), in which he applies a larger correction for sensitivity, our H I mass function falls significantly below Schneider's. We note that much of our searching probed the Local Void; further, these small blind surveys conducted to date may all suffer uncertainties due to large-scale structure.

5 Surveys in the North and South

The time is ripe for a full 21 cm survey of the ZOA. There is no other way to map large-scale structure in the regions of highest optical obscuration, and infrared confusion. In the north, the Dwingeloo telescope is surveying the ZOA over the area $30° \leq l \leq 220°; |b| \leq 5°$, out to a redshift of 4000 km s^{-1}. A quick, shallow (5 min/pointing) survey of the entire area has been completed, with the aim of finding very massive and/or nearby galaxies. Three objects were clearly detected, the nearest being the barred spiral dubbed 'Dwingeloo 1', first reported by Kraan-Korteweg et al. (1994). The telescope is currently conducting a deeper survey (1 hr/pointing) of the same area, to uncover normal spirals to the survey redshift limit, and local dwarfs. Figure 2 shows the H I mass detection limit as a function of distance for the deep survey, calculated from the rms noise per pointing of 40 mJy. Extrapolating from the H I mass function derived from the 300 ft survey, and the consistent results from an Arecibo survey (Schneider 1996), we estimate that the Dwingeloo survey will uncover about 100 previously unknown galaxies. New galaxies are being catalogued now, and when obscuration allows, optical follow-up work is being done with the University of New Mexico's 24 in telescope at Capilla Peak, with plans for deeper work with the

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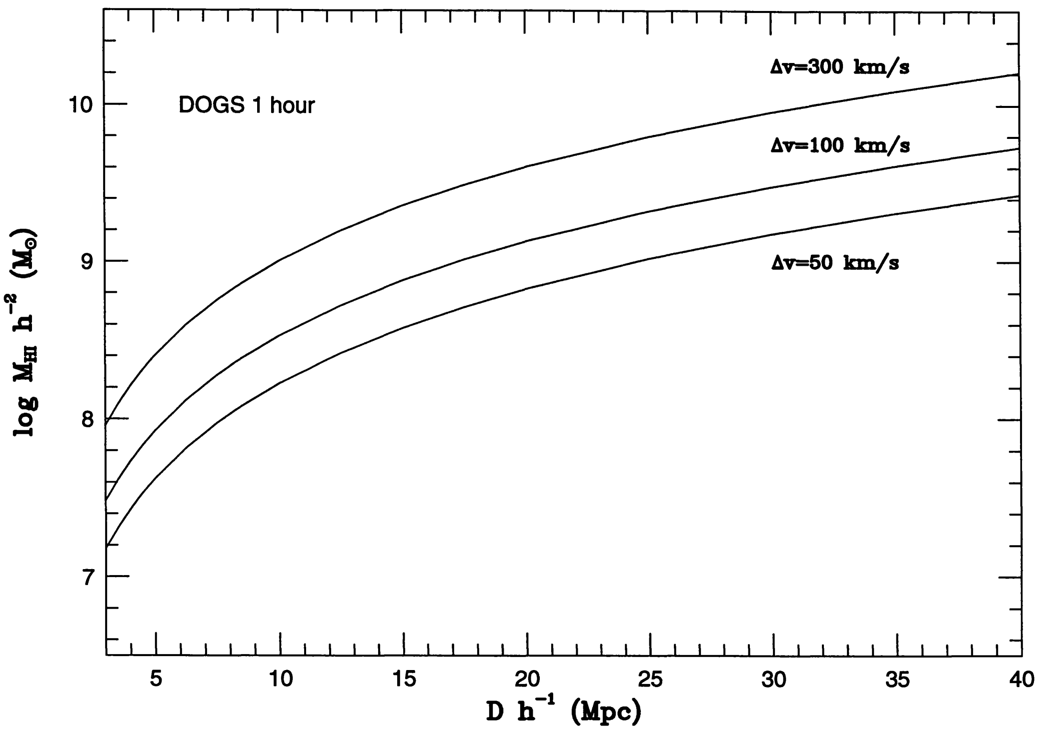

Figure 2—Sensitivity to H I mass as a function of distance of the Dwingeloo Obscured Galaxies Survey for the deep phase (one hour/pointing), for galaxies of three representative linewidths.

3·5 m at Apache Point. When a larger sample has been collected, H I synthesis images will be obtained.

The biggest leap forward will occur in the south, with the advent of the Parkes multibeam system. Previous surveys have struggled to find dozens of galaxies, Dwingeloo will do somewhat better, but the multibeam ZOA survey promises the detection of thousands, owing to the excellent sensitivity and broad velocity coverage. (These estimates are based on H I mass functions derived from relatively tiny samples.) The area covered ($213° \leq l \leq 30°$; $|b| \leq 5°$ with redshift limit of 12 700 km s^{-1}) spans many structures of interest, including the southern crossing of the Local Supercluster, the probable connection between the Hydra Centaurus supercluster and the Pavo–Indus–Telescopium supercluster, and not least of all, the region of the rich cluster A3627 which lies only 9° from the predicted centre of the Great Attractor [see the contribution by Kraan-Korteweg et al. (1997) on p. 15 of this issue for the state of their optical ZOA survey]. The true extent of these and other dynamically important structures, and the presence of any heretofore undiscovered local galaxies, will be uncovered by the multibeam survey.

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