ULTRAVIOLET AND EUV ABSORPTION STUDIES

ABSORPTION LINE STUDIES AND THE
DISTRIBUTION OF NEUTRAL GAS IN THE
LOCAL INTERSTELLAR MEDIUM

Frederick C. Bruhweiler
Department of Physics
Catholic University of America

ABSTRACT

Previous published absorption line studies performed at ultraviolet and visual wavelengths are combined with new ultraviolet data in order to map out the distribution of HI within 150 pc of the Sun. Newly presented data for distances less than 50 pc further support the local cloud model as presented by Bruhweiler (1982). The Sun is embedded, near the edge of a diffuse cloud with total column density of 2 x 10^{19} cm^{-2}. Most observed directions within 50 pc away from the cloud body reveal trace amounts of gas (N)HI) $\sim 10^{18}$ cm-2) presumably arising in the outer skin of the local cloud. At greater distances ($50 \lesssim d \lesssim 150$ pc) most directions show significant absorption with N(HI)>10^{19} cm^{-2}. Two directions, one toward the northern galactic pole (NGP), the other toward β CMa exhibit unusually low HI column densities out to distances of 150-200 pc. However, substantial amounts of gas, N(HI) > 10^{19} cm^{-2}, are seen toward the NGP at greater distances. The implications of these results on astronomy at wavelengths shortward of 912Å are discussed.

1. INTRODUCTION

We shall here concentrate upon reviewing interstellar absorption line data for lines-of-sight $\lesssim$ 150 pc in the local interstellar medium (LISM) acquired at both visual and ultraviolet wavelengths. We will, first, develop a coherent picture for the distribution of neutral hydrogen within the proximity of the Sun, then we will expand this picture, as revealed through interstellar absorption line studies to larger distances. Our principal goal is to sketch out a "broad brush stroke" picture of the distribution of neutral H I. By including new ultraviolet results, some of which are still preliminary, and visual interstellar line data, a more detailed morphology of neutral hydrogen is presented than that presented previously for the local cloud by Bruhweiler (1982) and by Frisch and York (1983) for longer distances.

One of the initial principal reasons for studying the LISM was to probe the so-called "intercloud medium" (ICM). Naturally, only by sampling short lines-of-sight can we hope to examine the typical volume element of the ICM and avoid the unwanted contamination of cloud complexes and H II regions.

Our preceptions of the ICM changed dramatically when ultraviolet observations using the *Copernicus* satellite revealed the ubiquitous presence of interstellar O VI toward O and B stars (Jenkins and Meloy 1974). Instead of a warm ICM with T $\sim$ 10,000 K and n$\sim$0.1 cm^{-3}, these observations were strong evidence for pervasive, hot (T$\sim 10^5$ - 10^6K), low density (n$\sim 10^{-2}$-10^{-3}cm^{-3}) component (or substrate) to the ISM. This conclusion is valid and regardless of whether the OVI predominately arises in cloud interfaces (McKee and Cowie 1977) or in the pervasive hot substrate. Positive O VI detections in four

https://doi.org/10.1017/S0252921100097955 Published online by Cambridge University Press

that N I column densities correlate extremely well with those of H I and is typically deleted by only 0.15 dex where log $(N(NI)/N(HI + 2H_2)) = -4.21$.

Of five white dwarfs sampled with parallaxes indicating distances less than 50 pc, all yield N(H I)$\sim 10^{18}$ cm^{-2} and clearly indicate a dropoff in $\bar{n}$HI for longer lines-of-sight. The values of n(H I) ranged from 0.087 for Sirius B (2.7 pc), the closest white dwarf studied, to 6 x 10^{-3} cm^{-3} for G191-B2B (48 pc), the most distant. These results mesh well with previous *Copernicus* studies of Lα in late-type stars, EUV results (Holberg *et al.* 1981a, 1981b), and backscattering data. The dropoff in H I number density at larger distances implies that the Sun is embedded in a cloud with a spatial extent of 3-4 pc in the directions studied.

B. Mg II toward nearby A and B stars.

Ultraviolet observations of interstellar Mg II in nearby A and B stars has also been used to trace out the distribution of neutral gas about the Sun. Both Copernicus and the IUE have been used to observe the interstellar lines of the Mg II resonance doublet at 2800 A as seen superimposed upon rotationally broadened corresponding stellar features in these stars (Kondo *et al.* 1978; Morgan *et al.* 1978; Frisch 1981; Bruhweiler and Kondo 1982b; Bruhweiler *et al.* 1984). Analysis of high quality Mg II data, where the doublet ratios can adequately define the Mg II curve of growth, provide important constraints on the distribution of this ion. We emphasize that high quality data are essential since Mg II lines in some lines-of-sight are approaching saturation. The Mg II distribution about the Sun is definitely not uniform. In particular, Mg II lines toward α Leo (25 pc) lie close to the linear portion of the curve of growth, while α Gru (20 pc) in the opposite direction in the sky yields N(Mg II) = 6x 10^{+13} cm^{-2}, a column density an order of magnitude larger (Bruhweiler *et al.* 1984; also elsewhere in these proceedings).

Estimates of neutral hydrogen column densities based upon *Copernicus* data (York 1976) are available for two early-type B stars within 50 pc. From the lines of S II, which is like N I and relatively undepleted in the ISM, York found N (H I) = 7 x 10^{+17} cm^{-2} for η UMa (50 pc) and (0.8-1.6) x 10^{+19} cm^{-2} for α Gru (20 pc). Since these stars also have measured Mg II column densities, we can combine these results with the H I column densities for white dwarfs, which are toward other nearby stars with well-measured Mg II column densities, to determine the depletion of magnesium in the gas of the local cloud. We, then, infer that magnesium is depleted by only 0.7 ± 0.2 dex in the gas of the local cloud (Bruhweiler *et al.* 1984). Based upon this Mg depletion we find that the Mg II results of other A and B stars, within 50 pc, in the general direction of $l^{II} = 0°$ imply N(H I) = (1- 2) x 10^{19} cm^{-2}. Directions away from the galactic center indicate N(H I)$\leq 10^{18}$cm^{-2}.

The above combined data indicate that the Sun is embedded in, and near the edge of, a rather diffuse cloud with a total column density of 2 x 10^{+19} cm^{-2}. Interstellar polarization data are also interpreted as supporting this conclusion. A study of stars within 35 pc by Tinbergen (1982) shows detectable polarization only for stars within 20 pc in small "patch" with 30 - 60° total extent located near l = 5°, b = -20°. This patch coincides remarkably well with the bulk of the local cloud as delineated by the

https://doi.org/10.1017/S0252921100097955 Published online by Cambridge University Press

stars with distances $\lesssim$ 100 pc also shows that this component is quite local. This suggested that the typical volume element in the LISM was representative of the hot interstellar substrate.

Studies of the LISM have been elevated to new levels of importance with current plans and discussions about spaceborne observatories with capabilities of sampling wavelength regions shortward of the Lyman limit ($\lambda \lesssim$ 912A). Even trace amounts of absorbing gas could greatly attentuate the radiation from any potential source at these wavelengths. For example, a H I column density of only 10^{18} cm^{-2} corresponds to optical depths of 6.7 and 1 at the Lyman limit and just longward of the ionization edge of He I (504 A), respectively.

II. Distribution of Gas within 5 pc.

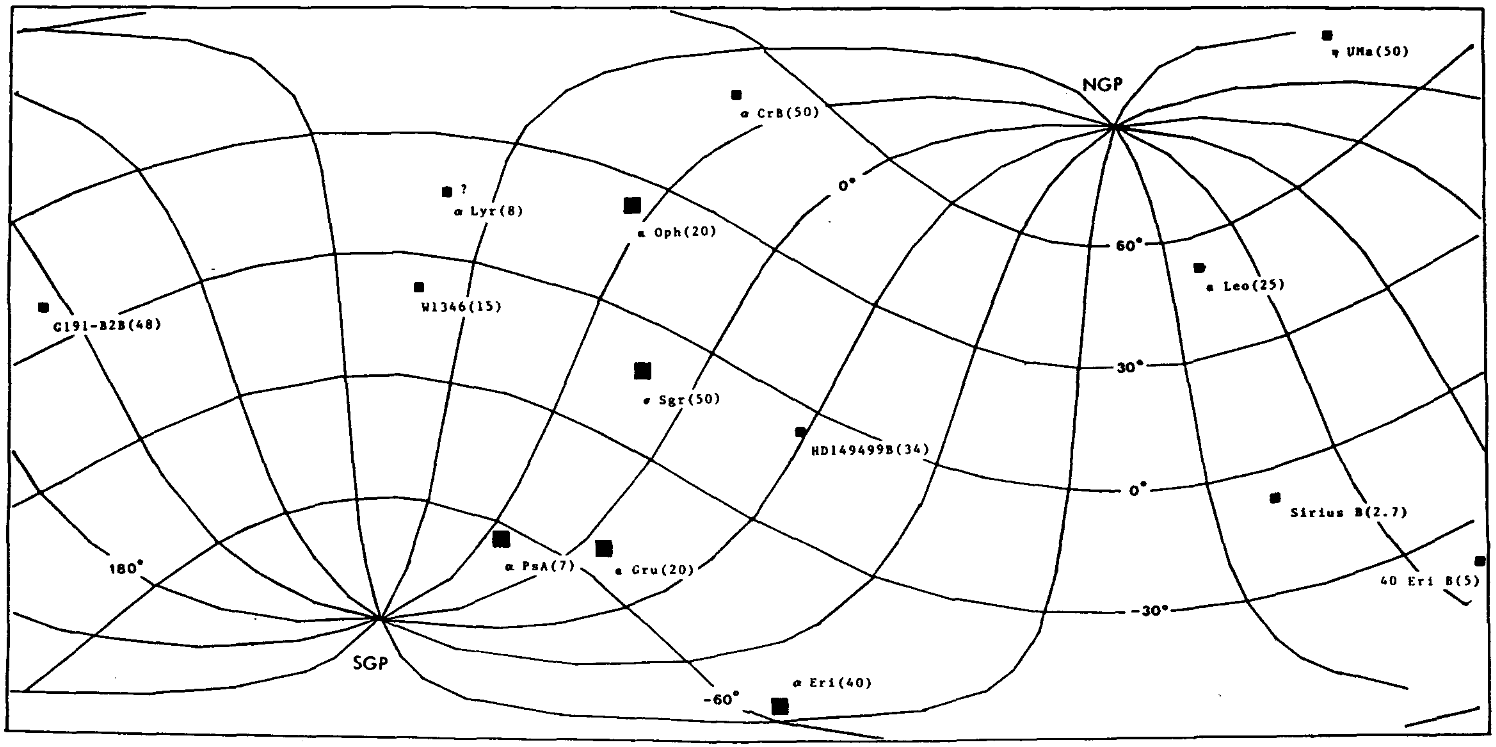
Interstellar absorption line studies for lines-of-sight within 5 pc have been, for the most part, limited to studying H I Lα absorption superimposed upon chromospheric emission profiles in late-type stars (Anderson *et al.* 1978; McClintock *et al.* 1978; and references therein). There is a large degree of uncertainty in the derived H I column density estimates, since these results are very sensitive to profile modeling and the broadening parameter (b). Yet, these results, as a whole, are in relatively good agreement with the H I Lα and He I backscattering results (Bertaux *et al.* 1976; Weller and Meier 1981) and these combined results indicate that the immediate vicinity of the Sun has a average neutral hydrogen number density, $\overline{n(\mathrm{H\ I})}$ $\sim$ 0.04-0.1 cm^{-3}. It is important to mention that the most distant late-type star studied, HR 1099 (33 pc), yielded a very low $\overline{n(\mathrm{H\ I})}$= 0.005 cm^{-3} (Anderson and Weiler 1978), possibly signifying a dropoff in $\overline{n(\mathrm{H\ I})}$ at larger distances.

III. The LISM within 50 pc

A. Ultraviolet observations of nearby hot white dwarfs.

The almost featureless spectra of hot white dwarfs make them ideal backdrops to probe the LISM. Indeed, a serious attempt, within the last few years, has been made to utilize the *International Ultraviolet Explorer* (IUE) to investigate the interstellar lines in these objects. So far, results on five white dwarfs have appeared in the literature (Bruhweiler and Kondo 1981, 1982; Dupree and Raymond 1982), and further detailed results of other nearby white dwarfs should soon follow. The interstellar species detected in the IUE spectra of these white dwarfs include C II, N I, O I, Si II, Fe II, Mg II, and possibly Si III in one line of sight. Interstellar H I is superimposed upon the white dwarf stellar profiles and is unuseable for a direct determination of the H I column density. Thus, we must rely on estimates derived from lines of heavier atomic species.

A good estimate of N(H I) can be derived using the IUE from the N I triplet near 1200 A. Like H I, N I is neutral with an ionization potential (14.5 eV) not too different from that of hydrogen. More importantly, nitrogen appears to exhibit little or no depletion in the interstellar medium. A review of N I and H I *Copernicus* data by Ferlet (1981) shows



BRUHWEILER 1984

LEGEND

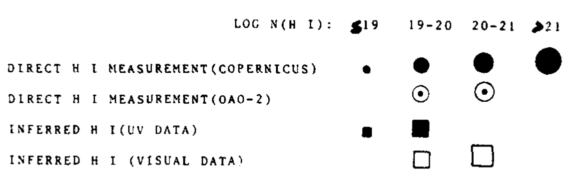


Figure 1. H I Column Densities Toward Stars with d $\lesssim$ 50 pc. The stars with derived H I column densities are displayed in galactic coordinates. The star names are given, and their distances in parsecs are indicated in parentheses. Most stars with small symbols have N(H I)$\sim 10^{18}$ cm^{-2}. The stars, η UMa and 40 Eri B, have N(H I)$< 10^{18}$ cm^{-2}. The white dwarf, HD149499B, has N(H I)$\sim 4\times10^{18}$cm^{-2}. The stars delineating the local cloud have N(H I)$\sim$1-2$\times10^{19}$cm^{-2}, although the path to α Oph may be higher. (Note: The column density estimates come from references cited in text, Results different from published results, such as HD149499B, reflect more complete data. Additional data come from Bruhweiler and Kondo(to be published).

ultraviolet absorption line studies (See Figure 1).

IV. The LISM At Greater Distances: 50 pc< d$\lesssim$ 150 pc.

At ultraviolet wavelengths, perhaps the most extensively analyzed lines-of sight in the LISM, are thos toward α Vir (88 pc; l = 316° b = 51°) and λ Sco (105 pc; l = 352°, b = -2°) (York and Kinahan 1979; York 1983). The *Copernicus* data for α Vir indicate N(H I) = 10^{+19} cm^{-2} with probably an equal amount in H II. Both the neutral and ionized regions have the same velocity within 2 km s^{-1}, and could be in the proximity of α Vir. Although we can not rule out the possibility that the local cloud intersects the path to α Vir, thereby giving rise to the observed 10^{+19} cm^{-2} of H I.

Detailed profile fitting of *Copernicus* data reveal possibly five different interstellar velocity components toward λ Sco. Yet, the overwhelming bulk of the H I (1.7 x 10^{+19} cm^{-2}) is in a component at -32 km s^{-1}. Since λ Sco lies behind the body of the local cloud and the -32 km s^{-1} radial velocity is in accord with what is expected from the local interstellar wind, this component, most assuredly, arises in the local cloud. Comparison of the b-values for various ions indicates that this component is warm, with T $\sim$ 10^{+4} K. Indeed, recent observations of Mg I and Mg II in the local cloud also supports this conclusion (Bruhweiler *et al.* 1984). All the other velocity components appear to be significantly ionized and only one has significant column density (log N(H II) = 18.5-19.3). These components must lie beyond the local cloud.

Interstellar O VI is seen in both α Vir and λ Sco and is most likely formed in thermal conduction fronts associated with the larger column density velocity components.

The *Copernicus* survey of Bohlin, Savage, and Drake (1978) has proved to be an important source of direct measurements of H I column density toward stars in the distance interval 50-150 pc. These H I measurements were supplemented with those determined from OAO-2 data (Savage and Jenkins 1972). Of the 35 stars in common in these two data, the derived H I column densities were in good agreement, generall well within a factor of two. We have combined these UV data with preliminary inferred H I column densities for several hot white dwarfs by Bruhweiler and Kondo in order to more fully map out the H I distribution away from the galactic plane (See Figure 2).

Up to this point, we have not made use of interstellar line studies undertaken at visual wavelengths. The reason for this is that many lines-of-sight within 50 pc exhibit only small traces of absorbing gas with N(H I) < 2x 10^{+19} cm $^{-2}$, which has gone undetected in published studies at visual wavelengths. The *IUE* and *Copernicus* have demonstrated the ability to detect interstellar features of species of abundant, relatively undepleted elements corresponding to H I column densities of a few times 10^{+17} cm^{-2}. Published results for studies undertaken at visual wavelengths indicate detectable amounts of Ca II, Ti II, K I, and Na I in directions where the H I column density is a few times 10^{+19} cm^{-2} (Stokes 1978). Although improved detectors mated with large ground-based telescopes should, in the future, provide smaller detection limits for these species, and more information on directions with lower column density.

Despite the problems for the directions displaying the lowest H I

https://doi.org/10.1017/S0252921100097955 Published online by Cambridge University Press

column densities, very high-signal-to-noise, high-resolution data exist for the visual interstellar lines seen toward many of the early-type stars in the LISM (Stokes1978; Albert 1983; Hobbs 1978 ; Marshall and Hobbs 1972; Hobbs 1969; and references cited therin). These high quality data often show multiple velocity components in the interstellar gas in the same line-of-sight.

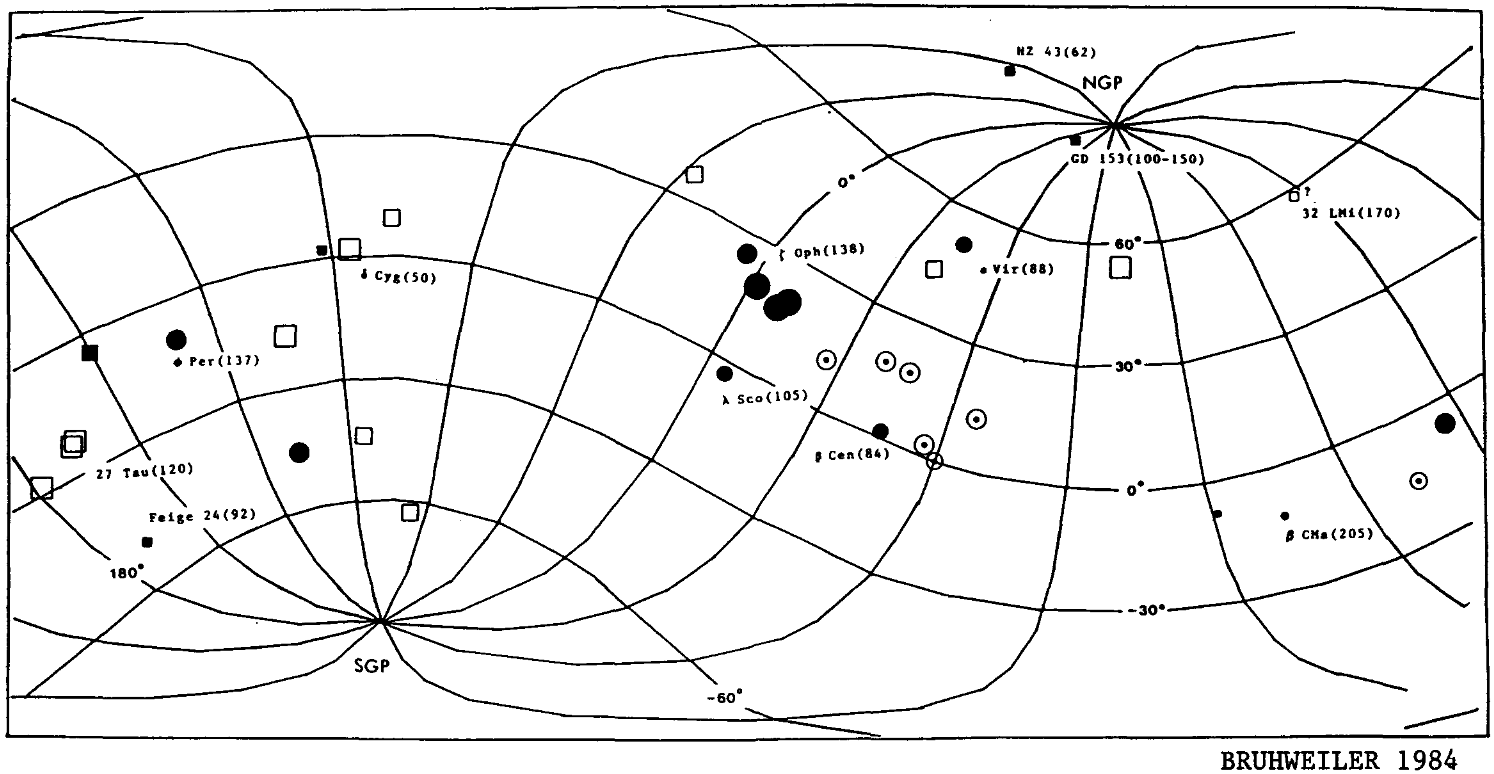
We wish to use the present high signal-to-noise and high-resolution visual data to again, further supplement the ultraviolet data in deriving a more complete map for the H I distribution in the LISM. First, however, we need to calibrate these data with the derived H I column densities obtained at ultraviolet wavelengths. All the visually observed interstellar species in the LISM show some depletion. Moreover, the elemental depletions appear to be variable and seem to be much lower in the low column density clouds of the LISM than in the much longer, higher column density lines-of-sight (York and Kinahan 1979; Hobbs 1978; Bruhweiler and Kondo 1982; York 1983). Therefore, we have taken the average of the relative abundance of Ca II/H I toward σ Sgr and α Vir along with the N(NaI)-N(H I) relation inferred from Hobbs (1978) to obtain estimates or the H I column densities when visual data are only available. We notice a possible tendency for the Na I to give a too high H I column density for stars near to α Vir in the sky and also toward α Oph (20 pc). The Ca II and Na I data indicate N(H I) = $6 \times 10^{+19}$ cm^{-2} toward α Oph. (See also Frisch 1981). However, we consider this as an upper limit based upon the non-detection of cloud shadows with N(H) > $5 \times 10^{+19}$ cm^{-2} in the soft X-ray background in this direction (Fried et al. 1980). We emphasize that it has been long known that the N(Ca II)/N(Na I) ratio can vary dramatically in the ISM. Higher ratios are usually associated with higher velocity gas (shocks), although lower depletions in lower column density clouds might also be expected for both species. In short, our approximation of the H I column densities, based upon Ca II, may be lower limits for higher column density lines-of-sight.

The nearest substantial amount of gas not associated with the local cloud may lie toward δ Cyg (50 pc) where the Na I column density given by Stokes (1978) implies log N(H)=20.3. On the other hand, the observed Ca II features imply N(H) = 1.1×10^{19} cm^{-2}. The foreground white dwarf, W1346 (15 pc), in this direction exhibits an extremely low column density, log N(H I) = 18.0, which probably arises entirely from the outer skin of the local cloud in which the Sun is embedded. We conclude that the bulk of the observed gas toward δ Cyg must reside at greater distances than W1346.

We now turn our discussion to the regions of high column density revealed by the interstellar lines studies as displayed in figure 2.

We, first, point out a region of large column density with N(H) = 10^{+21} cm^{-2} in the constellations Scorpius and Ophiucus (340°<1<30°; 0<d<30)°. This region is behind the local cloud. Both the Copernicus data for λ Sco and soft X-ray indicate this complex is not near, but is at distances greater than 100 pc.

Ultraviolet and visual data indicate absorbing gas with N(H) = 10^{19} - 10^{20} cm^{-2} to higher galactic longitudes and latitudes from the gas complex seen in Scorpus and Ophicus. The stars, 85 Vir, 69 Leo, and α Vir, all with distances on the order of 85 pc show evidence of this gas. This gas may also be linked to that seen in Centaurus as delineated by OAO-2 data in Figure 2.



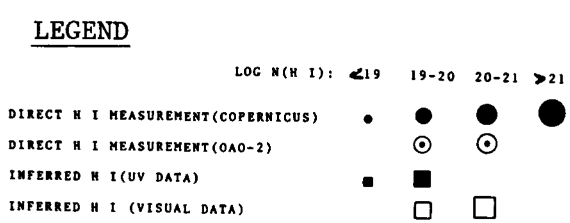


Figure 2. H I Column Densities Toward Stars with $50 \lesssim d \lesssim 150$ pc. (See caption for Fig.1) Most directions exhibit N(H I)>10^{19} cm^{-2}. Two regions, with N(H I) on the order of 10^{18} cm^{-2} (β CMa) or less (GD 153 and HZ 43 toward the NGP), are indicated. Stars at greater distances toward the NGP reveal significant amounts, N(H I) > 10^{19} cm^{-2} (See text.). A low column density measurement for the white dwarf, 2111+49, seems in conflict with that of δ Cyg, a few degrees away in the sky. Yet, uncertianties in distances may make 2111+49 like W1346(Fig. 1), a foreground object to δ Cyg. The column density measured for λ Sco is probably mostly due to the local cloud, which extends no further than 20 pc from the Sun. (Again, see Fig.1.)

Currently, there is no information for stars with shorter pathlengths in this general direction. Thus, we also can not rule out the possibility that some of the observed H I originated in the local cloud. Yet, the absence of soft X-ray cloud shadows in this direction indicates that this gas is at much larger distances.

The *Copernicus* data reveal what appears to be a low column density hole where N(H I)< a few times 10^{18} cm^{-2} extending to distances of at least 200 pc in the direction of β CMA and ε CMa (Bohlin *et al.* 1978; Bruhweiler and Kondo 1981; Frisch and York 1983). The IUE and EUV data also indicate another hole where N(H I) < 10^{18} cm^{-2} up to distances of 100-150 pc toward the north galactic pole (NGP). Evidences for this hole comes from the ultraviolet and EUV data for HZ 43(62 pc), ηUMa (50 pc), GD 153 (100-150 pc) and possibly the visual data for 32 LMi (170 pc).

Near 105° <l<200° and -30°<d< 0°, stars in Taurus, including the Pleadies, and in Perseus indicate a large complex of gas with hydrogen column densities of 10^{21} cm^{-2}.

Another patch of significant absorption can be found in Pegasus (l=90°, d=50°). Both γ Peg and 58 Peg at distances of 160 pc indicate N(H)= 10^{20} cm^{-2}. This gas could be an extension of the complex seen in Taurus and Perseus. Weak or non-detectable features in ψ Aqr (140 pc) could indicate that this gas complex does not extend to more southerly galactic latitudes.

Comparisons with the interstellar reddening results within 100 pc of Perry, Johnston, and Crawford (1982) based upon Strömgren photometry of stars accessible from the northern hemisphere, show good agreement. Notable reddening is only seen in stars with distances greater than 75 pc. This implies that gas complexes with column densities greater than 10^{20} cm^{-2} must lie at distances > 75 pc. The Perry *et al.* results delineate two distinct regions. One is a narrow concentrated arc perpendicular to the galactic plane (30° ≤ l < 45°, -20°< d< 45°). The other is a broad diffuse band near the Milky Way extending from Cepheus through Taurus and Perseus to Orion (90° < l < 205°, - 45 < d < 20°).

V. Other Interstellar Absorption Line Results Relevant to the LISM

Some astronomers have voiced hopes of studying the EUV spectra of nearby extragalactic sources through holes in the neutral hydrogen distribution near the galactic poles. At first glance, the region of unusually low hydrogen column density near the NGP in Figure 2 (i.e. toward HZ 43, GD 153, η UMA) might provide a possible window for extragalactic EUV astronomy. However, observations of objects at greater distances (d ≳ 300 pc) at b > 60° reveal significant column densities of neutral hydrogen. Galactic absorption due to hydrogen at 21-cm has been seen against the continuum of extragalactic radio sources indicating N(H I) ~ 10^{20} cm^{-2}. Also, IUE data for hot stars, especially Feige 86 (l=48°, b=79° and HZ 44 (l=88°, b=79°) show that neutral hydrogen column densities are at least 10^{19} cm^{-2} in these directions. We can not completely rule out the possibility of a substantial hole in the H I distribution toward the NGP. Nonetheless, if a hole exists, its angular size must be quite small. Initial inspection of the 21-cm maps for the polar regions (Burnstein and Heiles 1982) indicate that the chances of finding a hole toward the SGP seems less promising than toward the NGP. Further

https://doi.org/10.1017/S0252921100097955 Published online by Cambridge University Press

studies of the ISM especially toward the SGP are needed to determine the feasibility of doing EUV extragalactic astronomy.

VI. Summary

We have attempted from the ultraviolet and visual interstellar absorption data, to present a picture of the distribution of the neutral hydrogen within 150 pc of the Sun. We will briefly summarize these results for the two distance intervals, $d \lesssim 50$ pc and $50 \lesssim d \lesssim 150$ pc.

A. Distances less than 50 pc.

i. The Sun is embedded in and near the edge of a rather diffuse cloud with a total column density of (1-2) x 10^{+19} cm^{-2} where the H I particle density near the Sun is 0.04 - 0.1 cm^{-3}

ii. The bulk of the cloud can be found toward the galactic center direction over the galactic latitude interval 25° >d >-70°. (Figure 1) Yet the actual spatial extent of the cloud still needs to be better defined.

iii. The backscattering data for H I Lα and He I 584, the observed N(Mg II)/N(mg I) ratios, and derived b-values indicate that the local cloud is warm with T ~ 10^4 K. Although, cooler regions seem to exist (i.e. toward α PsA; Bruhweiler and Kondo 1982b, Bruhweiler *et al.* 1984).

iv. Most directions away from the body of the cloud, which sample only the outer skin of the cloud, indicate rather low H I column densities, on the order of 10^{18} cm^{-2}.

v. The dropoff in H I particle density toward larger distances and the lack of shadows in the soft X-ray background indicate that the local is surrounded by the pervasive, hot 10^6 K, substrate.

B. The interval $50 \lesssim d \lesssim 150$ pc.

i. Significant amounts, N(H I) > 10^{19} cm^{-2}, of gas are found in most directions toward stars with distances greater than 75 pc.

ii. There are two regions, one in the direction of the NGP extending at least 100 - 150 pc, the other in the plane in the direction of β CMa, which have very low H I column density with N(H I) $\lesssim 10^{18}$ cm^{-2}.

iii. The presence of extended regions exhibiting very low H I column density indicate very long mean pathlengths between clouds, much longer than the 12 pc between cloudlets as in the model of McKee and Ostriker (1977). The general picture outlined by McKee and Ostriker may still be valid, but the interstellar absorption line studies of the LISM imply larger, more sparsely spaced clouds.

If the evolution of supershells (Bruhweiler *et al.* 1980; Tomisaka *et al.*

1980) play a significant role in the ISM, then stellar winds and the supernovae from massive stars in OB associations could efficiently evaporate away small clouds and also sweep away the clouds from the central regions of the supershells. This could account for the observed sparse distribution of cloudlets in the LISM.

It is worthwhile to compare these results with the H I 21-cm maps of Colomb et al. (1979). The two large predominant structures, Loop I and the Loop II-III complex, which are centered at galactic longitude 15° and 195°, are found within 150 pc (Spoelstra 1973). These structures could have been formed by supernovae and/or stellar winds (Develaar 1981; Weaver 1978). Estimates indicate that the Sun lies within 130 pc of the center of the 115 pc radius Loop I. This position along with the general direction of the interstellar wind (Weller and Meier 1981; Crutcher 1982) suggests that the local cloud to be a possible shell fragment of the Loop I structure.

In the future, high-resolution, high signal-to-noise observations with the Hubble Space Telescope and ground-based telescopes should not only provide a clearer picture of the morphology of the LISM, but also a better understanding of the physical processes occurring in both the local and general ISM.

References

Albert, C.E. 1983, Ap.J., 272, 509.
Anderson, R.C., Henry, R.C., Moos, H.W., and Linsky, J.L. 1978, Ap.J., 226, 883.
Anderson, R.C., and Weiler, E.J. 1978, Ap.J., 224, 143.
Bertaux, J.L., Blamont, J.E., Tabarie, N., Kurt, W.G., Bowgin, M.D., Smirnov, A.S., and Dementeva, N.N., 1976, Astr. Ap., 46, 16.
Bohlin, R., Savage, B., Drake, J. 1978, Ap.J., 224, 132.
Bruhweiler, F. 1982, Advances in Ultraviolet Astronomy: Four Years of IUE Research, Ed. Y. Kondo, R. Chapman, J. Mead, p. 125.
Bruhweiler, F., Gull, T., Kafateos, M., and Sofia, S. 1980, Ap.J. (Letters), 238, L27.
Bruhweiler, F.C. and Kondo, Y. 1982a, Ap.J., 259, 232.
Bruhweiler, F.C. and Kondo, Y. 1982b, Ap.J., (Letters), 260, L91.
Bruhweiler, F.C. and Kondo, Y. 1981, Ap.J., (Letters), 248, L123.
Bruhweiler, F., Oegerle, W., Weiler, E., Stencel, and Kondo, Y. 1984, Preprint
Burnstein, D. and Heiles, C. 1982, Ap.J., 87, 1165.
Colomb, F.R., Poppel, W.G.L., and Heiles, C. 1979, Astr. Ap., 40, 47.
Crutcher, R.M. 1982, Ap.J., 254, 82.
Davelaar, J.A., Bleeker, J., and Deerenberg, A. 1980, Astr. Ap., 92, 231.
Dickey, J.M., Salpeter, E.E., and Terzian, Y. 1978, Ap.J. Suppl., 36, 77.
Dupree, A.K. and Raymond, J. 1983, Ap.J. (Letters), 263, 63.
Ferlet, R. 1981, Astr. Ap., 98, L1.
Fried, P.M., Nousek, J.A., Sanders, W.T., and Kraushaar, W.L. 1980, Ap.J., 242, 987.
Frisch, P. 1981, Nature, 293, 377.
Frisch, P., and York, D.G. 1983, Ap.J. (Letters).
Hobbs, L.M. 1969, Ap.J., 157, 137.
Hobbs, L.M. 1976, Ap.J., 203, 143.
Holberg, J.B., Sandel, B.R., Forrester, W.T., Broadfoot, A.L., Chipman, H.L., and Barry, D.C. 1981a, Ap.J., 242, L119.
Holberg, J.B. 1981b, Bull. A.A.S., 12, 872.
Jenkins, E.B. and Meloy, D.A. 1974, Ap.J (Letters), 193, L121.
Kondo, Y., Talent, D.L., Barker, E.S., Dufour, R.J., and Modisette, J.L. 1978, Ap.J., 220, L97.
Marshall, L.A., and Hobbs, L.M. 1972, Ap.J., 173, 43.
Martin, E.R., and York, D.G. 1982, Ap.J., 257, 135.
McClintock, W., Henry, R.C., Linsky, J.L., and Moos, H.W. 1978, Ap.J., 225, 465.
McKee, C.F., and Ostriker, J.P. 1977, Ap.J., 218, 148.

https://doi.org/10.1017/S0252921100097955 Published online by Cambridge University Press

Perry, C.L., Johnston, L., and Crawford, D.L. 1982, A.J., 87, 1751.
Savage, B.D. and Jenkins, E.B. 1972, Ap.J., 172, 491.
Spoelstra, T.A.Th. 1973, Astr.Ap., 24, 149.
Stokes, G.M. 1978, Ap.J. Suppl., 36, 115.
Tinbergen, J. 1982, Astr. Ap. 105, 53.
Weller, C.S. and Meier, R.R. 1981, Ap.J., 246, 386.
York, D.G. 1976, Ap.J., 204, 750.
York, D.G. 1983, Ap.J., 264, 172.
York, D.G. and Kinahan 1979, Ap.J., 228, 127.

https://doi.org/10.1017/S0252921100097955 Published online by Cambridge University Press