THE ASTROPHYSICAL JOURNAL, 271:L59–L63, 1983 August 15

SYNTHESIS MAPS OF ULTRAVIOLET OBSERVATIONS OF NEUTRAL INTERSTELLAR GAS[1]

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Received 1983 February 14; accepted 1983 April 21

ABSTRACT

The results of satellite observations of neutral interstellar material in front of 140 stars 10–3000 pc distant are shown projected onto representations of the galactic plane and of a plane passing through the galactic poles. The figures show that the contours of neutral hydrogen in the solar neighborhood asymmetrically surround the Sun, with the 5×10^{18} cm^{-2} contour at $\lesssim 15$ pc in the Sco-Oph direction, but at $\gtrsim 200$ pc in the third quadrant. This neutral gas distribution mirrors the distribution of the nearby B stars associated with the Gould belt. The maps clearly show the directions in which observations at $\lambda < 912$ Å will be most successful.

Subject headings: interstellar: matter — ultraviolet: general

I. INTRODUCTION

Low levels of neutral hydrogen in the line of sight play a severe role in attenuating extreme ultraviolet (EUV) and soft X-ray cosmic radiation. For example, at 500 Å an optical depth of 1 is achieved by $N(\mathrm{H}^0) \sim 5 \times 10^{17}$ cm^{-2}. Consequently, an understanding of the distribution of the first 10^{19} cm^{-2} column density of neutral hydrogen around the Sun is crucial both in planning targets for future observations at $\lambda < 912$ Å and in interpreting the data which already exist on soft X-ray emission. At present, the only way the distribution of clouds with these low column densities can be measured is via satellite-based observations of interstellar absorption lines. Conventional ground-based observations of 21 cm emission from H^0, or of the reddening or polarization of starlight by dust clouds associated with diffuse gas, are relatively insensitive to clouds with $N(\mathrm{H}^0) \lesssim 10^{19}$ cm^{-2}. Furthermore, these types of observations do not directly and unambiguously measure nearby gas. Hence, the best picture that can be formed of low column density, nearby interstellar gas must necessarily be based on satellite observations of interstellar absorption features. Various observational aspects of the nearby interstellar gas have been discussed recently by Adams and Frisch (1977), Vidal-Madjar, Laurent, and Bruston (1978), Frisch (1981), Bruhweiler (1982), and Crutcher (1982).

As a first step in understanding the distribution and characteristics of the interstellar gas around the Sun, we have taken existing *Copernicus* and *International Ultraviolet Explorer* (*IUE*) measurements of neutral hydrogen column densities [i.e., $N(\mathrm{H}^0) + 2N(\mathrm{H}_2)$] for about 140 stars distributed between 10 and 3000 pc from the Sun and plotted these data in several maps in a manner which directly yields estimates of contours of neutral hydrogen column density in the $N(\mathrm{H}) = 5$–500×10^{17} cm^{-2} range. These maps show that low column density neutral hydrogen is asymmetrically distributed around the Sun,with a "hole" in neutral hydrogen located in the third quadrant. These maps provide a useful tool in planning and analyzing EUV and soft X-ray observations and illustrate which regions of the sky are not well observed in the ultraviolet. They also illustrate which regions can be most fruitfully studied for "cloud" versus "intercloud" sight lines. Last, these maps show that the distribution of low column density neutral hydrogen reflects the distribution of the nearby members of the Gould belt.

II. DATA

Data on the hydrogen column densities and stellar distances have been taken from the following sources or references therein: Bohlin, Savage, and Drake (1978, 100 stars); Bohlin *et al.* (1983, 30 stars); Martin (1981, 25 stars); Bruhweiler and Kondo (1982, white dwarfs); Cash, Bowyer, and Lampton (1979, white dwarfs); Anderson *et al.* (1978, α CMi); Anderson and Weiler (1978, HR 1099); McClintock *et al.* (1978, nearby stars); Wallerstein, Silk, and Jenkins (1980, Gum nebula); York (1976, weakly reddened stars); York and Rogerson (1976, weakly reddened stars); Margon *et al.* (1976, HZ 43); Holberg *et al.* (1980, HZ 43); Malina, Bowyer, and Basri (1982, HZ 43); Rogerson *et al.* (1973, nearby stars); and Gry (1983, β CMa). When both H^0 and H_2 measurements are available, $N(\mathrm{H}^0) + 2N(\mathrm{H}_2)$ is

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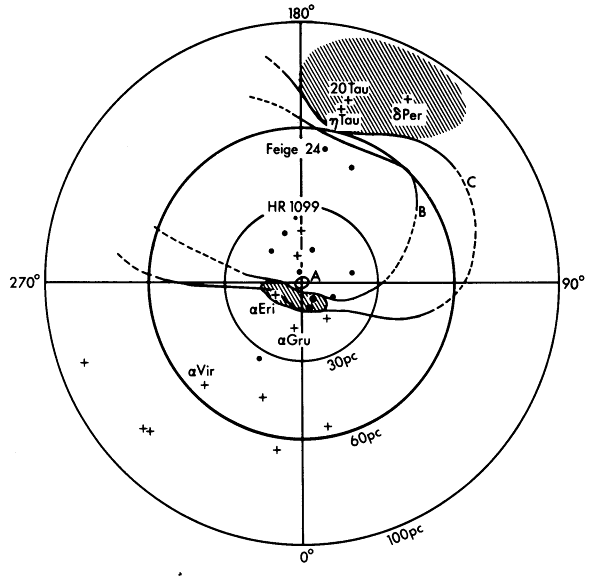

FIG. 1*a*

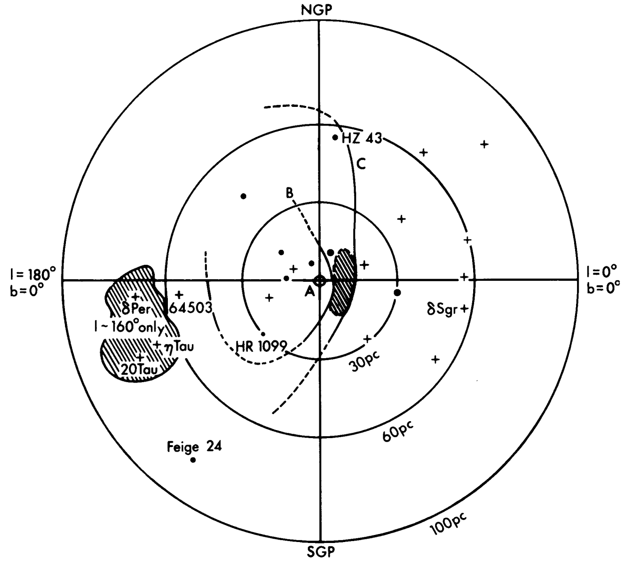

FIG. 1*b*

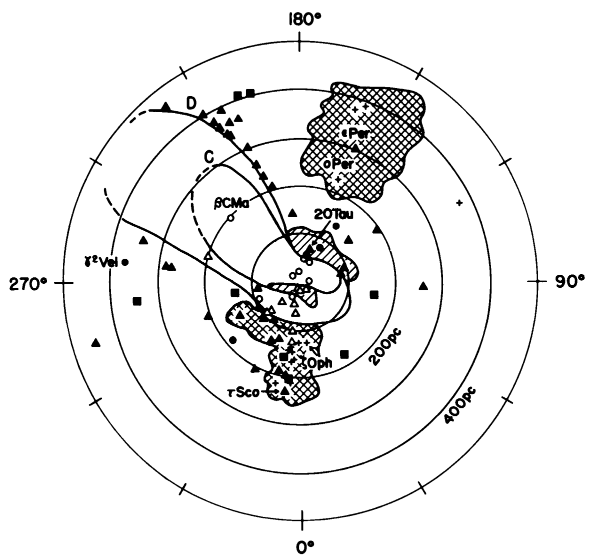

FIG. 1*c*

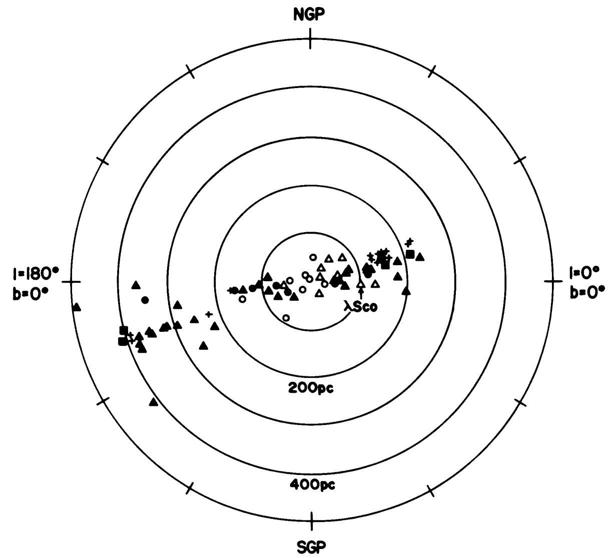

FIG. 1*d*

FIG. 1.—Stars 10–3000 pc away projected onto the galactic plane (*a*, *c*, *e*) and a plane passing through the poles and center-anticenter (*b*, *d*, *f*). (*a* and *b*) Stars 10–100 pc distant; (*c* and *d*): stars 10–500 pc distant; (*e* and *f*): stars 500–3000 pc distant. Stars are coded according to the total amount of foreground neutral hydrogen $N(\mathrm{H}) = N(\mathrm{H}^0) + 2N(\mathrm{H}_2)$. (*a* and *b*) *Small dots*, $N(\mathrm{H}) < 5 \times 10^{17}$ cm^{-2}; *medium dots*, $N(\mathrm{H}) = 5\text{–}25 \times 10^{17}$ cm^{-2}; *large dots*, $N(\mathrm{H}) = 25\text{–}50 \times 10^{17}$ cm^{-2}; *plus signs*, $N(\mathrm{H}) > 5 \times 10^{18}$ cm^{-2}. (*c* and *f*) *Open circles*, $N(\mathrm{H}) < 5 \times 10^{18}$ cm^{-2}; *open triangles*, $N(\mathrm{H}) = 5\text{–}50 \times 10^{18}$ cm^{-2}; *filled circles*, $N(\mathrm{H}) = 5\text{–}10 \times 10^{19}$ cm^{-2}; *filled triangles*, $N(\mathrm{H}) = 1\text{–}5 \times 10^{20}$ cm^{-2}; *filled squares*, $N(\mathrm{H}) = 5\text{–}10 \times 10^{20}$ cm^{-2}; *plus signs*, $N(\mathrm{H}) > 10^{21}$ cm^{-2}. Contour A: $N(\mathrm{H}) \sim 5 \times 10^{17}$ cm^{-2}, drawn assuming that the Sun is immersed in a local cloud with density $n(\mathrm{H}) \sim 0.07$ cm^{-3} (see text); contour B: $N(\mathrm{H}) \sim 25 \times 10^{17}$ cm^{-2}; contour C: $N(\mathrm{H}) \sim 5 \times 10^{18}$ cm^{-2}; contour D: $N(\mathrm{H}) \sim 5 \times 10^{19}$ cm^{-2}; contour E: $N(\mathrm{H}) \sim 5 \times 10^{20}$ cm^{-2}. Contours are dotted where information is scanty. The clouds shown are discussed in the text. Stars located in the intervals $l = 90° \pm 15°$ and $270° \pm 15°$ have been omitted from (*d*) and stars with $|b| > 80°$ are omitted from (*c*) because projection effects confuse the visibility of the "hole." In (*e*) and (*f*) projection effects make some stars appear closer than 500 pc to the origin.

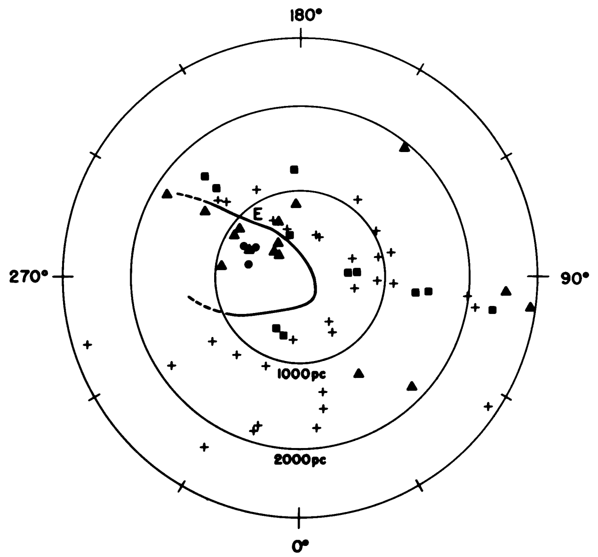

FIG. 1e

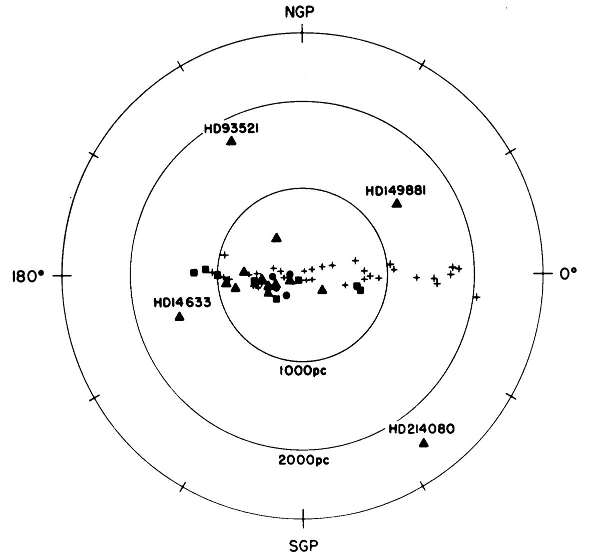

FIG. 1f

plotted. For some of the stars, the amount of neutral material was inferred from either N^0 or Ar^0 data in the source reference. Both species are undepleted in nearby gas and can be used directly to predict $N(H^0)$ (York 1983). Observations of Mg^+ were not used as a basis for determining the amount of neutral interstellar hydrogen because of analysis problems pertaining to the line formation and to abundance and ionization uncertainties.

These data are plotted in Figure 1. The stellar position is projected onto the plane of the figure. Two planes are represented: the galactic plane and a plane passing through the galactic center-anticenter directions and the poles. Each star is coded according to the amount of foreground hydrogen. Such a representation of the data immediately yields the limits on where each contour must fall, i.e., the $N(H) \sim 5 \times 10^{18}$ cm^{-2} contour must be positioned outside of the stars where $N(H) < 5 \times 10^{18}$ cm^{-2} and inside of the stars where $N(H) > 5 \times 10^{18}$ cm^{-2}. This representation of the data is useful in that it yields the hydrogen contours without making any necessarily uncertain assumptions about the location of the cloud parcels in the sight-lines to the targets.

These data are plotted on three scales, with the Sun at the origin for all plots. The innermost contour A on Figures 1a and 1b corresponds to $N(H) \sim 5 \times 10^{17}$ cm^{-2} and is located within 3 pc of the Sun by the assumption that the spatial density of neutral hydrogen around the Sun is $n \sim 0.07$ cm^{-3} (Weller and Meier 1981; Bruhweiler 1982). The remaining contours were drawn according to the locations of the relevant symbols. Contours are dotted where information is scanty. Stars with longitudes $l = 90° \pm 15°$ and $l = 270° \pm 15°$ are omitted from Figure 1d and stars with $|b| > 80°$ are omitted from Figure 1c because they lie in directions almost vertical to the plane of the plot and would serve to confuse the interpretation of these data. Stars with directions nearly perpendicular to the planes of Figures 1e and 1f are not omitted on this scale since stars at $d < 500$ pc, with which they could potentially be confused, are not plotted.

Several stars are exceptions to the contours plotted in Figures 1a and 1b. Two of the exceptions are shown by the plus signs in the anticenter direction at $r < 30$ pc. These are the stars β Gem and α Tau which were reported in McClintock *et al.* (1978) to have highly uncertain interstellar column densities. A third exception is the white dwarf HD 149499B at $l = 330°$ and $r = 34$ pc. This column density was based on N^0 and Si^+ column densities which were derived from absorption lines which were reported to fit the assumed curve of growth poorly (Bruhweiler and Kondo 1982). In Figure 1c the two open triangle stars in the galactic center direction are λ Sco and υ Sco. They have $b \sim 0^0$ and apparently are beneath the main interstellar cloud which is inclined upwards at $b \sim +20°$ along with the Gould belt stars.

Two dust clouds representing Tinbergen's (1982) "patch" (see § III) and the Pleiades dust are drawn schematically in Figure 1a. Figure 1c shows these two clouds and the dust concentrations in the Perseus and Scorpius-Ophiuchus regions.

III. DISCUSSION

The most salient feature of these maps is the asymmetry of the contours with respect to the solar position for column densities down to $\sim 10^{18}$ cm^{-2}. The Sun is displaced from the center of an apparent "hole" in the neutral hydrogen, with the displacement in the sense that the Sco-Oph end of the "hole" is closest to the Sun. The "hole" extends more than 100 pc in the direction of the third quadrant of the Galaxy. A similar asymmetry in the dust distribution has long been recognized from reddening observations of clouds with $E(B - V) > 0.1$ mag, corresponding to $N(\text{H}) > 5 \times 10^{20}$ cm^{-2} (e.g., Lucke 1978). It was also recognized in the H^0 ultraviolet data by Bohlin, Savage, and Drake (1978). These contour maps allow us to locate a rough center for the "hole," at $l \sim 225°$, $b \sim -15°$, and $r \sim 250$ pc and to show explicitly which regions can be studied at $\lambda < 912$ Å without severe attenuation of the radiation. Note that this latitude is not well determined since most of the stars in the third quadrant are at negative latitudes. This position falls remarkably close to the position centroid of 230 nearby (i.e., B2–B3.5) Gould belt main-sequence stars (Stothers and Frogel 1974). It is not unexpected that the neutral interstellar hydrogen distribution mirrors the nearby Gould belt stars since this feature is believed to represent a region of active star formation (Stothers and Frogel 1974).

The Gum nebula is undoubtedly responsible for part of the third quadrant neutral gas minimum. This nebula is a large-diameter Hα emission region (Sivan 1974) of uncertain origin (Wallerstein, Silk, and Jenkins 1980; Reynolds 1976; Weaver, McCray, and Castor 1977) which encompasses the sight lines to the Vela supernova remnant, ζ Pup and γ^2 Vel. It is spherical in appearance, with a diameter of 30°. If it is centered at 460 pc (the distance of γ^2 Vel), then it will yield a neutral gas deficiency between $l = 245°$ and $l = 275°$ for the distance range 370–570 pc.

Another aspect of this asymmetry is that it supports a conclusion by Tinbergen (1982) that there is a "patch" of interstellar material within 35 pc of the Sun in the general direction of the galactic center. This "patch" causes the polarization of starlight in stars as near as 5 pc. The polarization through the "patch" corresponds to $E(B - V) \sim 0.003$ mag, or $N(\text{H}) \sim 1.5 \times 10^{19}$ cm^{-2}. The existence of a cloud of this column density, 5–35 pc from the Sun in the direction of the galactic center, is entirely consistent with the ultraviolet observations shown in Figures 1*a* and 1*b*. The correlation of the local cloud with Tinbergen's patch was first noted by Bruhweiler (1982).

A third striking aspect of these figures is that nearly all of the target sources for the *Copernicus* and *IUE* observations of interstellar gas are stars in the plane of the Gould belt, which in itself is tipped by an angle of $\sim 15°$–$20°$ with respect to the galactic plane (Strothers and Frogel 1974). This concentration of target objects directly reflects the fact that many of the nearby O and early B type stars suitable for observations of ultraviolet interstellar resonance transitions are concentrated in the Gould belt.

It is important to remember when using these maps that the stars chosen as targets for ultraviolet interstellar line studies, especially at greater distances, are relatively unreddened stars which will not have dense concentrations of foreground material. Therefore, relatively large column density clouds, $N(\text{H}) > 10^{21}$ cm^{-2}, may be present but would not appear on these plots. In a future paper (Frisch and York 1983), we will combine reddening and optical line absorption data with the ultraviolet observations to fix the location of the higher column density clouds.

Modeling of soft X-ray emission suggests that there is a substantial amount of X-ray emission from a gas at 10^6 K near the Sun (McCammon *et al.* 1983). According to Figure 1*c*, the $N(\text{H}^0) \sim 5 \times 10^{18}$ cm^{-2} contour is at least 200 pc away for $l \sim 225°$, so the "hole" around the Sun should be optically thin to soft X-rays out to 200 pc in the $l \sim 225°$ direction. However, as pointed out by D. McCammon (private communication), the third quadrant is *not* noticeable as a soft X-ray bright patch. Therefore, the gas temperature in the hole, in this direction, must be cooler than 10^6 K. It will be interesting to make similar maps of the H^+ distribution using, for instance, data on interstellar S^+ to infer $N(\text{H}^+)$. Comparison of such a map and the current maps may shed light on the temperature of the gas in the nearby minimum.

This work is supported by NASA grant NAG-W405 to the University of Chicago. We acknowledge helpful discussions with D. McCammon and S. Bowyer.

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