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A new determination of the local distribution of interstellar Na I

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Abstract. We present galactic maps of the distribution of neutral sodium absorption column density using the newly determined Hipparcos satellite distances for a total of 290 stars lying within 250 pc of the Sun. These maps now replace those originally presented in Welsh et al. (1994). The Local Bubble is now seen to be a neutral gas-free cavity ($n_H < 0.01$ cm^{-3}) with a radius of at least 70 pc in most directions, more than 50% larger in volume than previously determined from Na I absorption data. Additionally, the well-known low-density interstellar tunnel in the direction of the star β CMa is almost twice as wide as previously thought, and the existence of a similarly tenuous interstellar feature has been identified in the galactic direction of Lupus-Norma extending to at least 170 pc. Finally, we note the absence of dense neutral gas out to a distance of at least 100 pc in the direction of galactic longitude l^{II} = 135°.

Key words: ISM: clouds – ISM: atoms – solar neighbourhood

1. Introduction

The Sun is thought to lie at the edge (or just within) a warm (T $\sim$ 7000K) low-density ($n_H \sim 0.1$ cm^{-3}) interstellar cloud that is itself located within a hot (T $\sim 10^6$K) and rarefied ($n_H \sim$ 0.005 cm^{-3}) region of space of approximate dimensions 100 pc called the Local Bubble (Frisch 1995). The origin of this rarefied cavity is still debated, but it seems likely that it was caused by a local supernova event and/or the interaction of the stellar winds from OB stars in the nearby Sco-Cen association. Whether the hot Bubble plasma is in collisional ionization equlibrium or not is still uncertain (Breitschwerdt and Schmutzler 1994).

Although most of the volume in the Local Bubble appears to be filled with hot gas, most of the mass is contained within either warm and partially ionized plasma, or several diffuse interstellar clouds ("fluff") of very low neutral gas density (Frisch 1995). The exact size and shape of the tenous Local Bubble cavity have been much debated. Its dimensions can be determined by either tracing the absence of absorption by neutral interstellar gas, or by determining the extent of the hot emitting Bubble gas. Direct absorption measurements of the interstellar neutral hydrogen column density, N(HI), to stars within 100 pc has generally proven to be problematic due to the observational and instrumental difficulties inherent in measuring hydrogen column densities $< 10^{18}$ cm^{-2}. Therefore other indirect means of determining the extent of the low density local cavity have been used. Paresce (1984) has used both direct and indirect estimates of N(HI) absorption towards 82 stars closer than 250 pc to infer the absence of dense neutral gas out to $\sim$ 100 pc in most galactic directions. Observations of the diffuse soft X-ray background radiation have been modelled by Snowden et al. (1990) to reproduce contours of the observed negative correlation between X-ray intensity and neutral interstellar hydrogen column density out to 300 pc. Similarly, Diamond et al. (1995) have used ROSAT Wide-Field Camera observations of extreme ultraviolet (EUV) sources to model the distribution of inferred neutral hydrogen column densities as a function of distance to 150 pc. Welsh et al. (1994), hereafter Paper 1, have used the observed distribution of interstellar sodium (Na I) absorption within 250 pc of the Sun to infer the contours of neutral gas absorption in the local interstellar medium (LISM). The two interstellar Na I D1 and D2 absorption lines at 5890 Å are believed to be a good tracer of relatively cold (T $<$ 1000K) neutral gas clouds in the general ISM.

All of the above representations of the Local Bubble cavity are dependent on knowledge of the distances towards the respective line-of-sight stellar targets towards which the level of absorption is measured. For stars closer than 20 pc these distances (mostly derived from ground-based parallax measurements) are generally accurate to within 20%, whereas distance estimates for stars beyond 20 pc are of far greater uncertainty. The new distance determination for stars within 300 pc by the Hipparcos satellite (ESA 1997) now allow us to plot the Local Bubble absorption characteristics with much greater certainty. In this Paper, we re-plot the Na I absorption data originally presented in Paper 1 using the newly available Hipparcos stellar distances to investigate the distribution of neutral gas in the LISM. These plots show that the detailed galactic distribution of Na I absorption has changed significantly from that originally presented in Welsh et al. (1994), and that the Local Bubble cavity is some 50% larger than previously thought.

2. Data reduction

Using the original list of Na I column density measurements towards 293 stars lying within $\sim$ 250 pc of the Sun presented in

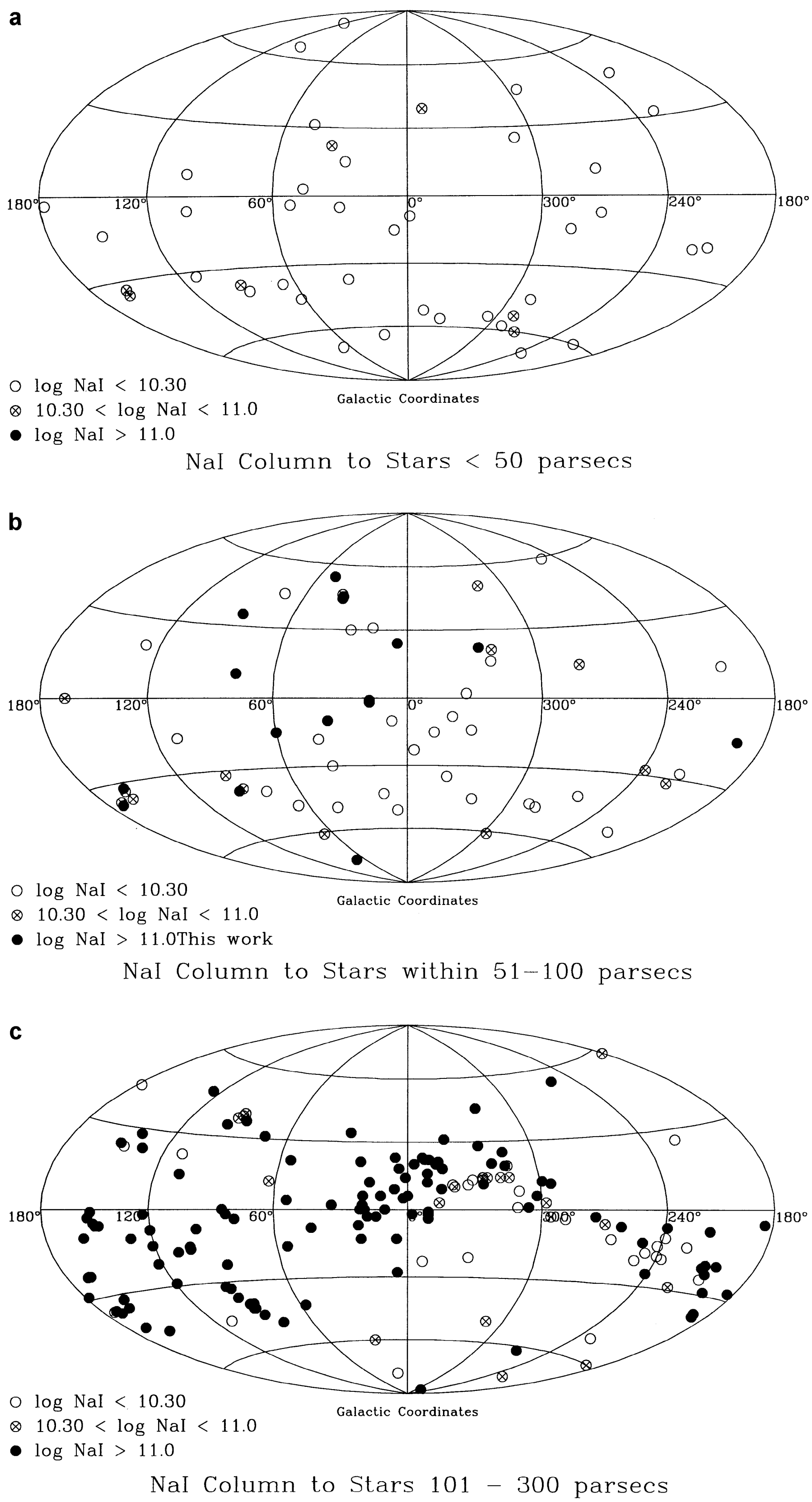

Fig. 1a–c. Plots of the galactic spatial distribution of the total Na I column density for stars with three distance ranges (as determined by Hipparcos): **a** d $<$ 50 pc, **b** d = 51–100 pc, and **c** d $\geq$ 101 pc.

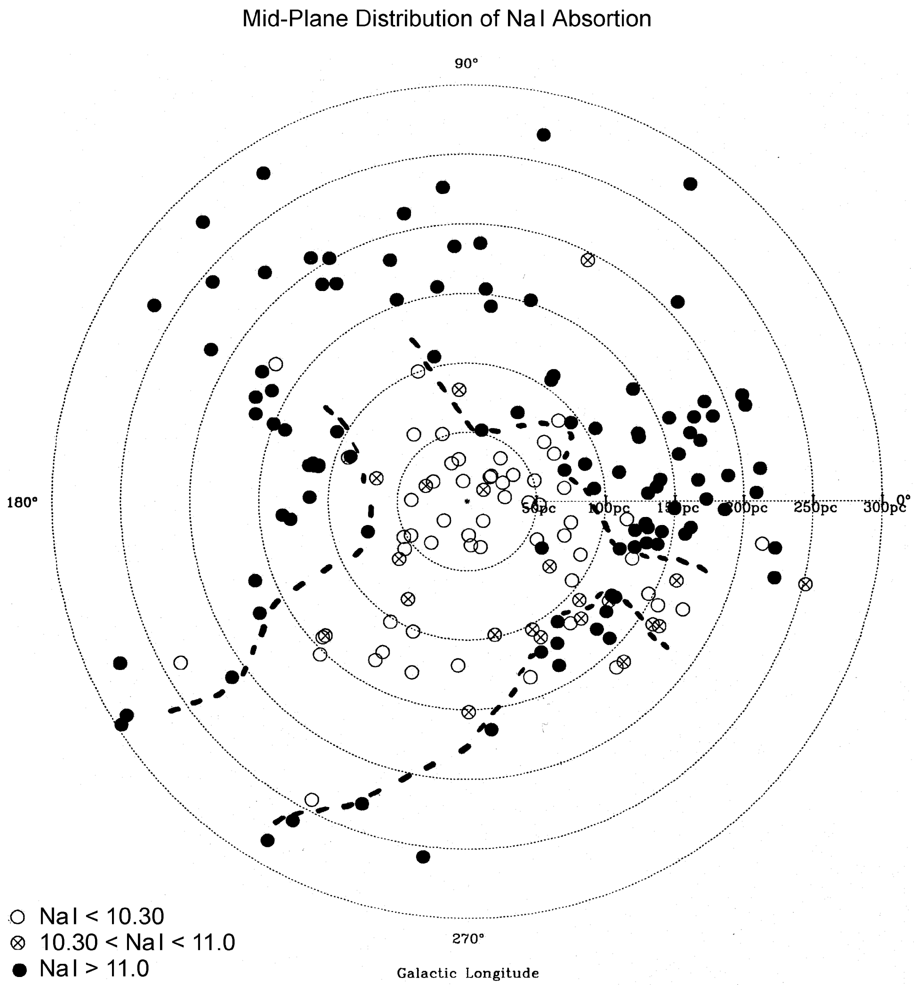

Fig. 2. A polar projection of the line-of-sight Na I column densities presented in Fig. 1 as a function of distance from the Sun and galactic longitude. Only stars with galactic latitude between $-35° < b^{II} < +35°$ are plotted. The dotted line delineates a possible neutral absorption boundary to the Local Bubble cavity.

Paper 1, we have assigned each target with an improved distance estimate using data from the on-line Hipparcos catalog.

If π is the Hipparcos parallax in mas (milli-arcsec), σ_π the standard error on π, and d the distance in pc ($d = 1000/\pi$), the following three criteria were used simultaneously for the selection of stars within 300 pc: $d \leq 300$ pc; $\sigma_\pi/\pi \leq 0.3$; $\sigma_\pi \leq 1.2$.

For the secondary components of multiple star systems, the parallax of the primary was eventually preferred. The final list thus contains 273 stars with distances ≤ 300 pc.

In Figs. 1a–c we plot the galactic distribution of total integrated line-of-sight sodium column density, $N(\text{Na I})_{\text{TOT}}$, as a function of galactic coordinates for stars in three distance groupings: 0–50 pc, 51–100 pc, and 101–300 pc. To remain consistent with the previous presentation of the data in Paper 1, we have plotted the data at three levels of sodium column density i.e. log $N(\text{Na I})_{\text{TOT}} < 10.30$ cm^{-2}, $10.30 < N(\text{Na I})_{\text{TOT}} < 11.0$ cm^{-2} and log $N(\text{Na I})_{\text{TOT}} > 11.0$ cm^{-2}. The astrophysical reasons for the choice of these column density plotting levels are outlined in Paper 1, Sect. 3.1., and are based on the assumption of an empirical relationship between $N(\text{Na I})_{\text{TOT}}$ and that of N(HI).

In addition, in Fig. 2 we show the mid-plane extent of Na I absorption to 300 pc using a polar projection plot of stars whose galactic latitude lies between $-35° < b^{II} < +35°$. This plot is directly comparable to that of Fig. 3 in Paper 1, with the distances being actual and not projected values (see Paper 1 for details).

3. Discussion

3.1. Lines of sight to 50 pc

It is immediately clear from Fig. 1a that in the 43 different galactic directions sampled, the LISM is lacking in any condensations of dense, neutral interstellar gas clouds with most of the lines-of-sight having low values of Na I column density (i.e. log $N(\text{Na I})_{\text{TOT}} < 10.30$ cm^{-2}). Assuming that the corresponding HI neutral column density to these stars is typically log N(HI) < 18.20 cm^{-2} (Lallement et al. 1995), then the average density, n_H, is < 0.01 cm^{-3} throughout the first 50 pc of the Local Bubble. This very low neutral gas density is at least a factor 100 below that observed in the general ISM, and we thus define the Local Bubble as a neutral gas-free region. Our present findings are in contrast to the corresponding plot of Paper 1 in which 5 isolated directions showed appreciable levels of Na I interstellar absorption within 50 pc. The present picture of the LISM in which the first 50 pc is essentially devoid of dense neutral gas in all galactic directions is also in detailed disagreement with the morphology of the LISM presented in both Paresce (1984) and Frisch (1995), who both used pre-Hipparcos stellar distances as the basis of their models. In addition, our current data do not support the presence of any nearby dense interstellar gas clouds in the directions with galactic longitudes, $350° < l^{II} < 10°$, as originally suggested by the optical polarization studies of Tinbergen (1982).

These new plots of the distribution of interstellar Na I absorption are in far better agreement with the findings of both the ROSAT Wide Field Camera (Diamond et al. 1995) and the Extreme Ultraviolet Explorer satellite (Vallerga 1996) in which the galactic distribution of EUV sources is consistent with a neutral gas boundary to the Local Bubble of N(HI) $> 10^{19}$ cm^{-2} at a distance of $\sim$ 70 pc in most directions from the Sun. The EUV data generally infer a mean density in the galactic plane of $\sim$ 0.1 cm^{-3} within the first 20 pc, and beyond this distance the integrated density drops to less than 0.04 cm^{-3} until around 70 pc when the integrated density rises again to $>$ 0.1 cm^{-3}.

Note the presence of at least 7 directions in which tenous (log N(Na I)$_{\rm TOT} \sim$ 10.6 cm^{-2}) neutral interstellar clouds have been detected within 50 pc. These "cloudlets" (often refered to as wisps or interstellar fluff) may well be remnants of the proposed supernova explosion that may have created the Local Bubble several million years ago (Frisch 1995). Clearly, the present number of measurements of Na I absorption in all lines-of-sight $<$ 50 pc (and beyond!) is insufficient to comment further on the very detailed morphology of the LISM, and many more observations of Na I are thus required for future analysis.

3.2. *Lines of sight 51–100 pc*

The new data in Fig. 1b are qualitatively similar to those originally presented in Paper 1. The new Fig. 1b clearly shows the presence of dense neutral gas in $\sim$ 30% of the 58 directions sampled. However note the lack of detections of any appreciable amounts of neutral gas in the galactic quadrant centered around l^{II} = 300°, b^{II} = -30° (see Sect. 3.4). Na I column densities $> 10^{12}$ cm^{-2} (corresponding to N(HI) $\sim 10^{20}$ cm^{-2}) are not encountered until a distance of 70 pc. This is in excellent agreement with the findings of Diamond et al. (1995), and supports the original postulation of Paresce (1984) in which the Local Bubble cavity is bounded by a dense wall of cold neutral gas (clouds) in many galactic directions.

3.3. *Lines of sight 101–300 pc*

The new data of Fig. 1c are very similar to those presented in Paper 1, with the majority of the lines-of-sight sampled generally having values of log N(Na I)$_{\rm TOT} >$ 12.0 cm^{-2}. The main differences between our new data and Paper 1 are best illustrated by the mid-plane absorption characteristics presented in Fig. 2.

3.4. *Mid-plane distribution of Na* I *absorption*

The new mid-plane distribution of Na I absorption for stars with galactic latitude between $-35° < b^{II} < +35°$ is shown in Fig. 2. The dotted line delineates the limits where Na I absorption has a column density of log N(Na I)$_{\rm TOT} <$ 11.0 cm^{-2}. This traces the possible contour of the edge of the Local Bubble cavity, which can be defined as a region deficient in neutral gas such that n$_H <$ 0.01 cm^{-3}. The differences between this plot and the one originally presented in Paper 1 are four-fold. Firstly, the central bubble cavity radius now extends in *all* galactic directions to at least 50 pc, and (more typically) in most directions to a radius of 70 pc. Thus, the central cavity volume is significantly larger (by more than 50%) than previously thought. Secondly, the well-known interstellar tunnel of low density neutral gas in the direction of galactic longitude, l^{II} = 235° towards the star β CMa is almost twice as wide as that originally determined by Welsh (1991). This interstellar feature of extremely low gas density (n $<$ 0.005 cm^{-3}) has typical dimensions of at least 250 pc long by 90 pc wide. Thirdly, the galactic direction towards Lupus-Norma (l^{II} = 330°) is now confirmed as a narrow ($\sim$ 15 pc) interstellar tunnel that extends to a distance of at least 170 pc. Based on the upper limit values of Na I absorption derived for both δ Lup (d = 156 pc) and γ Lup (d = 174 pc) the neutral space density in this interstellar feature is comparable to that of the β CMa tunnel. Further observations of this potentially interesting region are clearly required to define this tunnel's dimensions more accurately. Finally, we note an apparent lack of dense gas in the direction of galactic longitude, l^{II} = 135°. Unfortunately, this direction is not well sampled by the Welsh et al. data, and thus we can presently only tentatively draw a cavity contour that extends to at least 100 pc.

4. Conclusions

We have presented plots of the galactic distribution of Na I interstellar absorption for lines-of-sight $<$ 300 pc using data originally presented in Welsh et al. (1994) together with the newly determined distances of the Hipparcos satellite. Four main differences in the distribution of neutral gas in the LISM have been found. Firstly, no regions of dense neutral absorption (log N(Na I)$_{\rm TOT} >$ 11.0 cm^{-2} have been found for lines-of-sight $<$ 50 pc. This central (neutral gas-free) Local Bubble cavity is typically of radius 70 pc in most galactic directions, and is thus $\sim$ 50% larger than previously thought. Secondly, the extremely low neutral gas density interstellar tunnel towards the star β CMa is almost twice as wide as previously determined, and thirdly a similarly tenous interstellar tunnel feature has been identified in the general direction of Lupus-Norma extending to at least 170 pc. Finally, we tentatively suggest that the galactic direction of l^{II} = 135° is also deficient of neutral gas out to a distance of at least 100 pc.

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