The Structure of the Local Hot Bubble Toward $l = 165°, b = 0°$ Using *IUE* and *ROSAT* Data

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Abstract. The first X-ray-opaque cloud in the direction of Auriga lies at 180 pc. A tenuous cloud, whose distance is derived from *IUE* absorption line studies as well as from an analysis of *ROSAT* data, is *embedded* at 55 pc. The X-ray emitting gas has a temperature of $10^{5.9-6.0}$ K. The pressure is 1.6 10^4 K cm^{-3}.

1 Distance to the Nearest Cloud from *IUE*

The distance to a cloud in the Milky Way is best determined with the help of interstellar absorption lines in the spectra of stars. Stars are selected in the general direction of the cloud, preferably well distributed in distance. The stars in front of the cloud will not show the absorption at the velocity of that cloud, whereas stars behind the cloud will show interstellar absorption at the particular velocity. Alternatively, just the sequence in column density derived from the absorption lines tells about the column density of gas in front of the stars. Knowing the distances of the stars, the cloud distance follows from the absence or presence of the said absorption lines.

IUE spectra were obtained to 6 stars in the direction of Auriga-Perseus and the absorption lines of Fe II are used to determine the column density of absorbing material. Using the depletion factor [Fe/H]$= -6.4$, the equivalent column density $N_{\rm HI}$ can be calculated. Adding data from the literature for other stars in the general direction of $l = 165°$ and $b = 0°$, Lilienthal & de Boer (1991) were able to derive a distance of $\simeq$ 55 pc to the first cloud. Taking further stars from the compilation of Fruscione et al. (1994) shows that as of 180 pc $N_{\rm HI} > 1.6 \cdot 10^{21}$ cm^{-2} . The column density versus distance data in this direction are displayed in Figure 1.

2 X-ray Opacities and X-ray Colours

The interstellar medium (ISM) is a very efficient absorber of soft X-ray photons. The photoelectric absorption cross section of the neutral interstellar medium is roughly $\sigma \sim E^{-3}$. Within the *ROSAT* 1/4 keV energy band the neutral ISM reaches opacity $\tau \simeq 1$ at $N_{\rm HI} = 1 \cdot 10^{20}$ cm^{-2}. Because of the strong energy dependence the 1/4 keV energy band is ideal to search for soft X-ray absorption features caused by thin neutral clouds.

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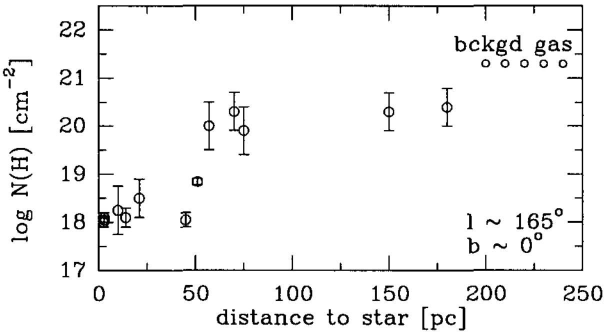

Fig. 1. The column densities $N_{\rm HI}$ toward stars in a small field in the direction of $l = 165°, b = 0°$ are plotted against the distance of the stars. The foreground gas has $N_{\rm HI} \sim 10^{18}$ cm^{-2} . At about 55 pc there is a cloud with $N_{\rm HI} \simeq 10^{20}$ cm^{-2} , then there is little gas beyond until the background gas shows up with $N_{\rm HI} > 2 \cdot 10^{21}$ cm^{-2} at $d \simeq 200$ pc. Data are from Lilienthal & de Boer (1991), Fruscione et al. (1994), and Hartman & Burton (1997)

We can split the *ROSAT* 1/4 keV band into two bands, R1 and R2, to use the maximum energy resolution of the PSPC detector. The R1 ($E \in$ [0.11; 0.2] keV) and R2 ($E \in$ [0.2; 0.28] keV) bands have a significant overlap in their energy response but the difference of the photoelectric absorption cross sections (σ(R1) $\simeq$ 1.4 $\cdot$ σ(R2)) is sufficient to disentangle the composition of the soft X-ray emitting and absorbing matter within the local interstellar medium.

3 Combining X-ray and H I 21-cm Data

We analysed the H I 21-cm line data of the new Leiden/Dwingeloo survey (Hartmann & Burton 1997) as well as a *ROSAT* PSPC observation aimed at α Auriga (HD 34029). In front of this star the absorption line column density is $N_{\rm HI}$ = 1.5-2.0 10^{18} cm^{-2} . The background column density is, as can be seen in the H I 21-cm data, $N_{\rm HI} > 10^{21}$ cm^{-2} , for distances > 200 pc.

The Local Bubble's extent is in general assumed to be of the order of 100 pc. However, the nearest cloud on this line of sight, having low column density, lies at a distance of about 55 pc. Consequently it is likely that the cloud is located inside the Local Bubble and is embedded within the local X-ray emitting plasma.

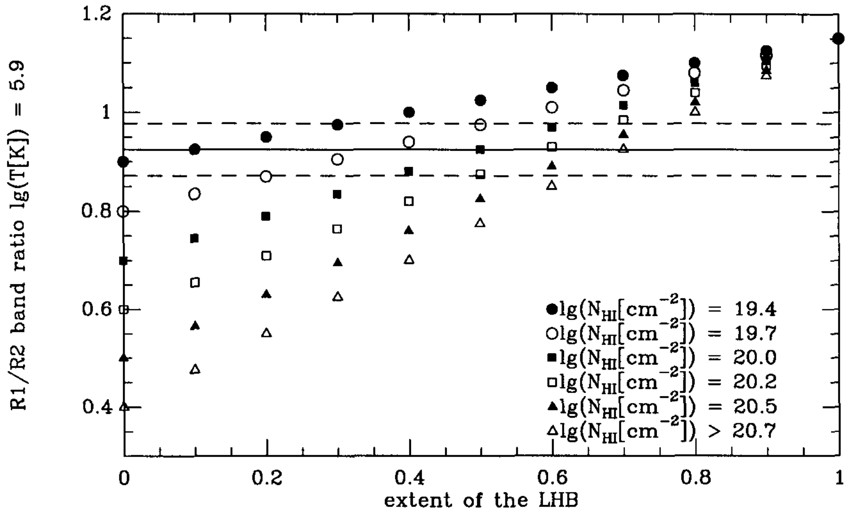

Fig. 2. A plot of the R1/R2 band ratio against the extent of the local bubble (normalised to 1) for a volume of gas at $T = 10^{5.9}$ K in relation to varying amounts of shadowing gas. For a cloud with given column density the shadowing is either strong when the cloud is nearby which leads to a small R1/R2 ratio, or is weak when it is far away resulting in a large R1/R2 ratio. The cloud with $N_{\rm HI} \simeq 1 \cdot 10^{20}$ cm^{-2} (see Fig. 1) fits with the observed R1/R2 ratio for a distance fraction of 0.3–0.4. The solid line marks the mean value of the observed R1/R2 ratio while the dashed lines indicate the 1-σ uncertainty. Since this cloud is at 55 pc (Figure 1) the bubble has an extent of $\simeq$ 180 pc, equal to the distance of the next large column density cloud

4 The Plasma Temperature of the Local Bubble

Within the *ROSAT* PSPC field of view of the pointing in the direction of α Aur we investigated the R1/R2 band ratio at several positions to determine the temperature of the X-ray emitting gas. The observed R1/R2 band ratio is well represented by emission from a plasma of $T = 10^{5.9-6.0}$ K. This temperature is in line with the values derived in different publications about the local X-ray gas.

However, the emission model used assumes *a priori* that there is no soft-X-ray-absorbing interstellar matter distributed along the line-of-sight. The amount of soft X-ray absorbing matter in front of HD 32630 is $N_{\rm HI}$=0.7 to $1.0 \cdot 10^{19}$ cm^{-2} (Fruscione et al. 1994). Correcting for this foreground absorption gives a larger R1/R2 band ratio, because the R1 band photons are attenuated more than the more energetic R2 band photons. In consequence, we have to revise the locally derived plasma temperature to $T = 10^{5.9}$ K.

5 The X-ray Distance to the Cloud

We can additionally use the R1/R2 band ratio to determine the distance of the cloud within the Local Bubble. Using the strong energy dependence of the photoelectric absorption cross section on the X-ray photon energy, the R1/R2 band ratio can discriminate between a thin or a thick cloud localized at the same distance. In Figure 2 we plotted the R1/R2 band ratio as a function of the

distance to such a cloud with a given H I column density. The distance is normalized to 1 which corresponds to the extent of the Local Bubble towards the Auriga – Perseus.

The observed R1/R2 ratio indicates the presence of a thin cloud close by, certainly *within* the Local Bubble. The absorption line data show that beyond 180 pc the column density is larger than $N_{\rm HI} = 1 \cdot 10^{21}\,{\rm cm}^{-2}$. Taking this column density value as the boundary of the Local Bubble, we find *from the analysis of the ROSAT-data* that the cloud is at a distance of 54 – 72 pc. This is in quantitative agreement with the interstellar absorption line measurements (see Fig. 1).

6 Conclusions

The quantitative analysis of the X-ray colours shows that they contain information about the 3-D structure of X-ray emitting and absorbing matter. Furthermore, we demonstrated the usefulness of combined analysis of *IUE* and other absorption line data with *ROSAT* PSPC data.

We could derive physical parameters for the Local Bubble gas such as:
1) an extent of hot gas of about 180 pc in the Perseus – Auriga direction,
2) a local X-ray gas emission measure of $EM \simeq 0.003\,{\rm cm}^{-6}\,{\rm pc}$,
3) a bubble electron density over 180 pc of $n_{\rm e} \simeq 0.004\,{\rm cm}^{-3}$,
4) a pressure within the local X-ray plasma $P_{\rm X-ray-gas} \simeq 16500\,{\rm K\,cm}^{-3}$,
5) an embedded cloud with $N_{\rm HI} = 0.5$ to $1.0 \cdot 10^{20}\ {\rm cm}^{-2}$ at ~ 55 pc,
6) which (with a thickness of 5 pc) has a density of $n({\rm HI}) \sim 5\ {\rm cm}^{-3}$,
7) at (in pressure balance with the X-ray gas) a temperature of ~ 3000 K.

References

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