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# The Interstellar Clouds of Adams and Blaauw Revisited: An HI Absorption Study – II

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**Abstract.** In the preceding paper (Paper I), we presented HI absorption spectra towards radio sources very close to the lines of sight towards twenty five bright stars against which optical absorption spectra had been obtained earlier. In this paper we analyse the results and draw some conclusions.

To summarize briefly, in most cases we found HI absorption at velocities corresponding to the optical absorption features provided one restricted oneself to velocities $\lesssim 10\,\mathrm{km\,s^{-1}}$. At higher velocities we did not detect any HI absorption down to an optical depth limit of 0.1 (except in four cases which we attribute to gas in systematic motion rather than clouds in random motion). After discussing various scenarios, we suggest that this trend should perhaps be understood in terms of the high velocity interstellar clouds being accelerated, heated and ablated by expanding supernova remnants.

*Key words.* ISM: clouds, structure, kinematics and dynamics.

## 1. Introduction

In the preceding paper (Rajagopal, Srinivasan & Dwarakanath 1998; Paper I) we presented the results of a program to obtain the HI absorption profiles towards a selected sample of bright stars. As mentioned there, detailed optical absorption studies exist in the direction of these stars in the lines of NaI and CaII. The motivation for such an observational program was also described in the previous paper. In the present paper, we wish to discuss the results obtained by us. There are two major issues that we wish to address and discuss later:

- Are the properties of interstellar clouds seen in optical absorption the same as those seen in HI emission and absorption in general?
- What is the origin and nature of the faster clouds seen in optical and UV absorption?

Let us elaborate a bit on the first issue. Although the general picture of the ISM that emerged from optical and radio observations, respectively, is the same, viz., clouds in pressure equilibrium with an intercloud medium, it has not been possible to directly compare the inferred properties. Whereas both the column densities and the spin temperatures of the clouds have been estimated from HI observations, there have only

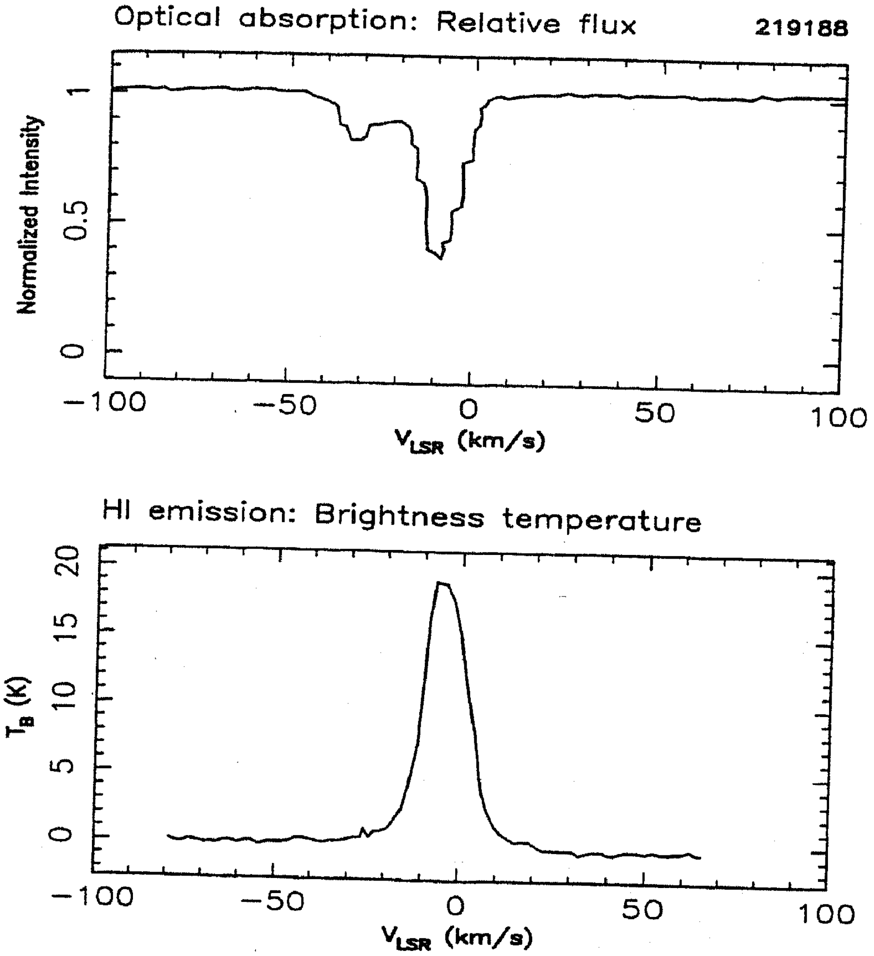

**Figure 1.** Comparison of optical absorption (top) from CaII towards HD219188 (Sembach, Danks and Savage 1993) and HI emission (Habing 1968) in the same direction. The absorption feature at higher velocity is missing in the HI profile.

been indirect and often unreliable estimates for the clouds seen in optical absorption. Our HI absorption measurements, combined with HI emission measurements in the same directions will enable us to directly estimate for the first time the column densities and spin temperatures of the clouds seen in optical absorption.

The second question mentioned above arises as follows. The existence of a *high velocity tail* in the distribution of random velocities of clouds was firmly established by Blaauw (1952) from the data obtained by Adams (1949). As mentioned in Paper I, it was noticed quite early on by Routly and Spitzer (1952) that the faster clouds have a smaller NaI to CaII ratio than the lower velocity clouds. Early HI emission measurements (see Paper I for references) in the direction of the bright O and B stars provided an added twist. Whereas the lower velocity clouds clearly manifested themselves in the HI emission measurements, the higher velocity clouds were not detected. To illustrate this point, we show in Fig. 1 the optical absorption features and the HI emission profiles towards the star HD219188. It may be seen that there is no counterpart in HI emission to the higher velocity optical absorption feature.

In the next two sections (sections 2 and 3) we will discuss the results of our absorption survey presented in Paper I. We shall classify the HI absorption features into two broad classes, viz., "low velocity" and "high velocity". It is of course difficult to define a sharp dividing line between "low" and "high" velocities. But based upon earlier analyses of NaI to CaII ratios, as well as HI emission measurements, we adopt a velocity of the order of $10\,\mathrm{km\,s^{-1}}$ as the dividing line. The main conclusions from our study are summarized in section 4. Section 5 is devoted to a detailed discussion of the nature and origin of the high velocity clouds.

## 2. The low velocity clouds

In this section we discuss the low velocity absorption features (i.e., $v \lesssim 10\,\mathrm{km\,s^{-1}}$). To recall from Paper I, we detected HI absorption in all but four of the twenty four fields we looked at. We will discuss these four unusual fields at the end of the next section.

### 2.1 *Coincident absorption features*

All the lines of sight in our sample show optical absorption from CaII at both low and high velocities. In most of the fields where we have detected HI absorption, they occur at roughly the same velocities as the optical absorption lines for $v \lesssim 10\,\mathrm{km\,s^{-1}}$. Not surprisingly, the HI absorption features have one-to-one correspondence with the HI emission features in the fields for which earlier emission measurements exist. In Table 1 we have listed all the fields with "matching" velocities in optical absorption and HI emission and absorption.

For illustration we have shown in the upper panels of Fig. 2 the HI absorption spectra (optical depth) in three fields; HI optical depth is plotted as a function of $V_{\mathrm{LSR}}$. The arrows indicate the velocities of the optical absorption lines. For comparison, we have shown in the lower panels the HI emission in these 3 fields: the data obtained by Habing (1968) has been digitized and re-plotted. The first field contains the star HD34816. The optical spectrum obtained by Adams (1949) towards this star shows CaII absorption at $-14.0$ and $+4.1\,\mathrm{km\,s^{-1}}$. The HI absorption profile shows a prominent feature at $6\,\mathrm{km\,s^{-1}}$ (we have obtained spectra towards two radio sources in this field but only one of them is shown here). As may be seen from the lower panel, there is a corresponding emission feature at this velocity. As mentioned in Paper I, absorption features in the optical and HI spectra may be taken to be at "matching" velocities provided they are within $\sim 3\,\mathrm{km\,s^{-1}}$ of one another (this window is to account for blending effects in the optical spectra and different corrections adopted for solar motion). In view of this one may conclude that the optical absorption at $+4.1\,\mathrm{km\,s^{-1}}$ and HI emission and absorption at $6\,\mathrm{km\,s^{-1}}$ arise in the same cloud, even though the radio source is $20'$ away from the star.

The second panel pertains to the field containing the star HD42087. In this field also we have two radio sources within the primary beam, and the spectrum towards one of them is shown. The absorption features are clearly seen at $4.4\,\mathrm{km\,s^{-1}}$ and $12.4\,\mathrm{km\,s^{-1}}$, with the latter being much stronger. The HI emission spectrum (shown in the panel below) shows a broad peak centred at $\sim 15\,\mathrm{km\,s^{-1}}$. The absorption feature at $12.4\,\mathrm{km\,s^{-1}}$ may be taken to be the counterpart of the optical absorption at $10.2\,\mathrm{km\,s^{-1}}$. There is no HI absorption at negative velocities corresponding to the other optical absorption lines indicated by the arrows. This may be due to the fact that the two radio sources in the field are $32'$ and $42'$ respectively from the star in

**Table 1.** Summary of coincident low velocities: Column 1 lists the HD number for the field. Columns 2 and 3 give the LSR velocities for the "matching" optical and HI absorption features respectively. Columns 4 and 5 list the optical depth and width for the HI absorption derived from the fitted gaussian. Column 6 lists the spin temperature $T_s$. These values have been derived by using the optical depth from our observations along with the emission brightness temperatures from Habing (1968). Where this was not available we used brightness temperatures from the Leiden-Green Bank survey (Burton 1985). Those fields where emission measurements were not available are marked NA in column 6.

| Field | $V_{\rm lsr}$(opt) | $V_{\rm lsr}$(HI) | $\tau$ | $\Delta V$ | $T_s$ |
|---|---|---|---|---|---|
| | km s$^{-1}$ | km s$^{-1}$ | | km s$^{-1}$ | K |
| 14143–14134 | −10.3 | −11.2 | 0.18 | 11.8 | 283 |
| 14818 | −6.6 | −3.7 | 0.43 | 13.7 | 143 |
| 21278 | −0.2 | 2.8 | 0.18 | 5.1 | 250 |
| 21291 | −7.5 | 7.0 | 0.60 | 6.2 | 180 |
| 24912 | 4.7 | 4.3 | 0.80 | 14.9 | 73 |
| 25558 | 10.1 | 8.1 | 1.13 | 5.6 | 73 |
| 34816 | 4.1 | 6.0 | 1.50 | 3.2 | 45 |
| 41335 | 0.2 | 1.0 | 0.22 | 7.2 | 342 |
| 42087 | 10.2 | 12.4 | 1.26 | 3.5 | 211 |
| 141637 | 0.0 | 0.5 | 1.60 | 8.0 | NA |
| 148184 | 2.2 | 3.4 | 4.90 | 3.4 | 50 |
| 156110 | 0.4 | 2.2 | 0.28 | 7.5 | 102 |
| 159176 | −22.5 | −20.8 | 1.15 | 15.3 | NA |
| 166937 | 5.9 | 5.4 | 1.70 | 5.7 | NA |
| 175754 | 5.9 | 6.8 | 0.35 | 17.7 | 135 |
| 199478 | −2.1, 8.7 | 3.8$^+$ | 0.60 | 11.4 | 121 |
| 212978 | 0.6 | 0.3 | 0.20 | 9.0 | NA |
| 214680 | 0.1 | 1.4 | * | 2.1 | NA |

$^+$The feature is a blend.
$^*$The feature is saturated.

question. Given that the star is at a distance of 1.3 kpc (Paper I, Table 1) it is conceivable that we are not sampling all the gas seen in optical absorption.

The spectra towards HD148184 is shown in panel 3. Again there is good agreement between the HI spectrum and the optical spectrum as far as the lower velocity optical absorption is concerned. As in the previous two cases there is no counterpart of the higher velocity optical absorption in the HI spectrum. These two examples will suffice to illustrate the general trend in Table 1 viz., there is reasonably good agreement at low velocities ($v \lesssim 10\,{\rm km\,s^{-1}}$) between the optical absorption features and the HI spectra.

Returning to Table 1, we have listed the derived optical depths in column 4 and the velocity width of the HI absorption in column 5. In the last column we have given the derived *spin temperatures*. These are obtained by supplementing our HI absorption measurements with brightness temperatures derived from emission measurements (mostly from Habing 1968; and in some cases from Burton 1985). To the best of our knowledge, this is the first direct determination of the temperatures of the interstellar clouds seen in optical absorption. To be precise, the temperature derived by us is the spin temperature which may be taken to be an approximate measure of the kinetic temperature.

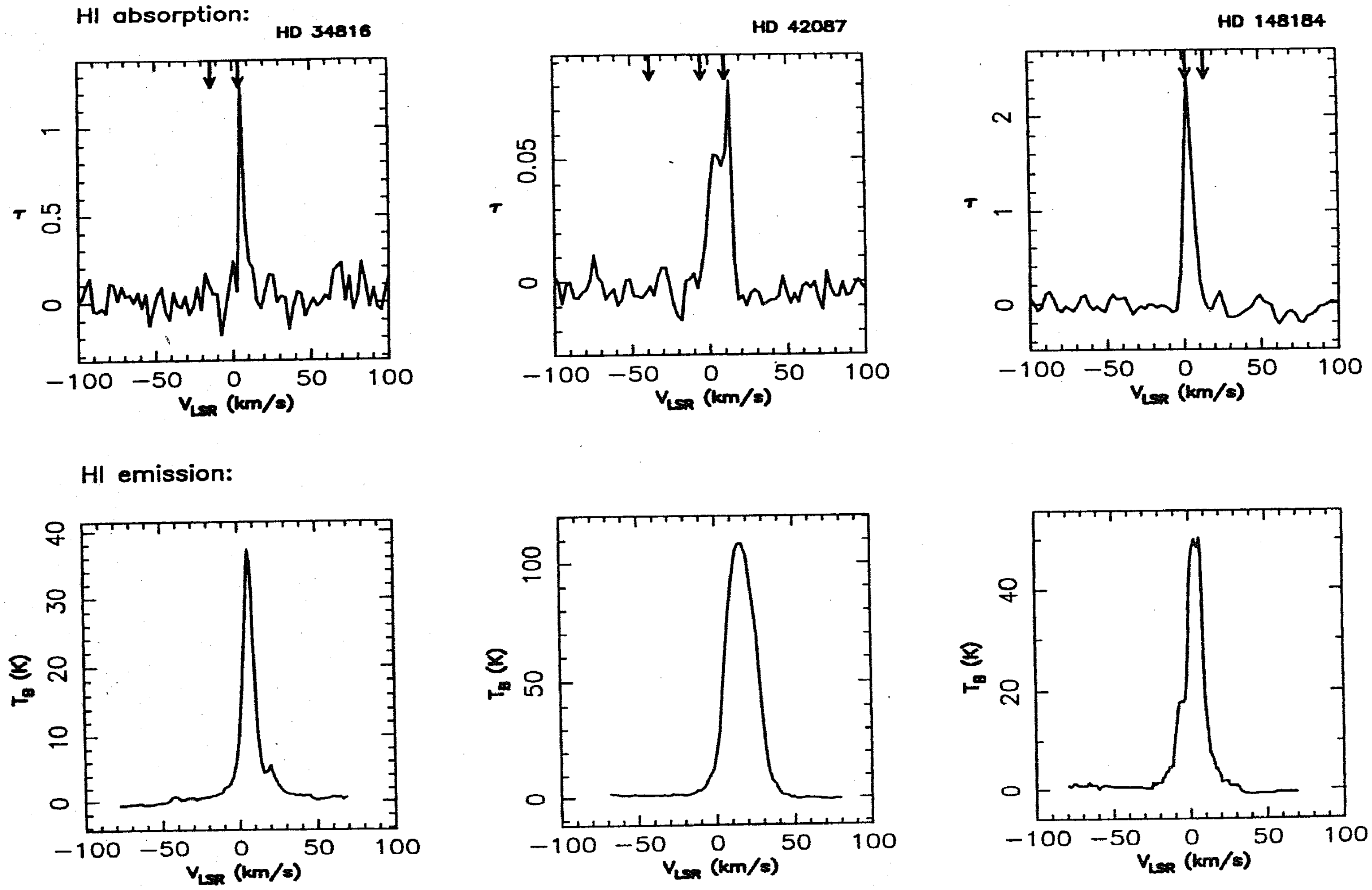

**Figure 2.** HI absorption (top) and emission (bottom) spectra towards three stars demonstrating the correspondence in *low* velocity emission in optical absorption, HI emission and HI absorption. The arrows on the velocity axis of the optical depth plot mark the velocities at which optical absorption is seen. The emission spectra are digitized from Habing (1968).

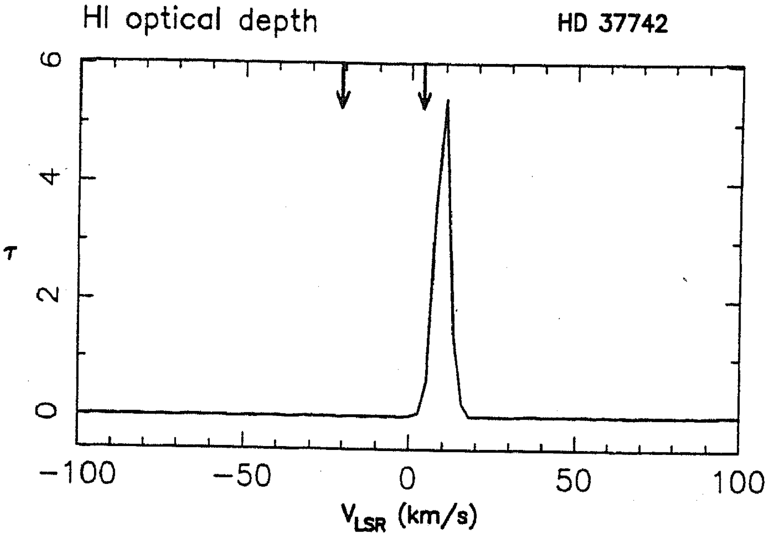

**Figure 3.** Spectrum towards HD37742. The arrows on the velocity axis mark the velocities at which optical absorption is seen.

The correspondence between the optical absorption features and the HI absorption suggests that one is sampling the same clouds in both cases. The derived spin temperatures and velocity widths are consistent with these clouds belonging to the same population as the standard cold diffuse clouds in the raisin-pudding model of the ISM. While it is conceivable that at low velocities one may merely be sampling the local gas (regardless of direction), statistical tests carried out by Habing (1969) suggest that this is unlikely.

### 2.2 *Non-coincident absorption features*

As we have already encountered in the case of HD42087 (see Fig. 2), sometimes there is a mismatch between optical and radio spectrum even at low velocities. We mention two specific cases here.

#### *HD37742*

The HI absorption spectrum obtained by us (Fig. 3) shows a deep absorption feature at 9.5 km s$^{-1}$. There are no other absorption features down to an optical depth limit of 0.03. The optical absorption features are at 3.6 and −21 km s$^{-1}$. Since the radio source is only 12′ away from the star, given the distance estimate of 500 pc to the star the discrepancy between the optical spectrum and the HI absorption spectrum is significant and intriguing. While the gas seen strongly absorbing in HI could be located beyond the star, one is left wondering as to why one does not see the low velocity cloud seen in optical absorption.

#### *HD119608*

The optical absorption spectrum towards this star obtained by Münch and Zirrin (1961) shows two minima at 1.3 and 22.4 km s$^{-1}$. We have obtained HI absorption

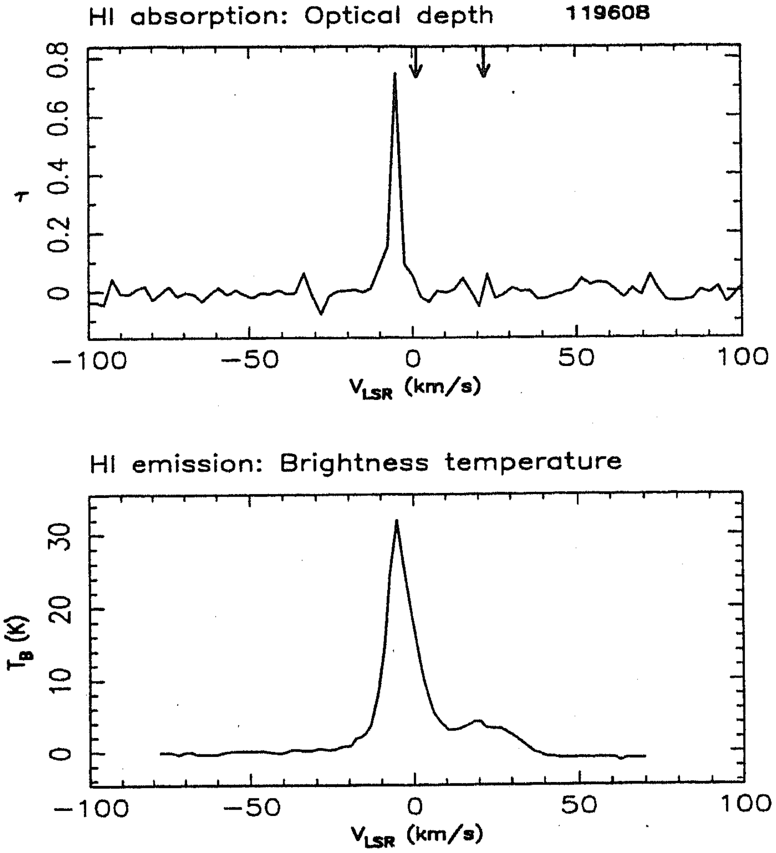

**Figure 4.** HI absorption (top) and emission (bottom) spectra towards HD119608. The arrows mark the velocities at which optical absorption is seen. The emission spectrum is from Habing (1968).

towards two strong radio sources in this field both within 15′ of the star. Both show a deep absorption feature at $-5.4\,\mathrm{km\,s^{-1}}$ (Fig. 4). This agrees with the HI emission feature shown in the lower panel. However the HI emission spectrum also shows a broad feature peaking at $\sim 20\,\mathrm{km\,s^{-1}}$. This is also seen in the more recent measurement of Danly *et al.* (1992). If this feature is indeed to be identified with the optical absorption at $22.4\,\mathrm{km\,s^{-1}}$, then this represents an interesting case where the gas in the line of sight to the star causing optical absorption manifests itself in HI emission but not absorption. This could happen for example if the spin temperature of this gas is sufficiently high as to make the HI optical depth below our detection limit. HD119608 is a high latitude star and one is presumably sampling the halo gas, and warrants a deeper absorption study.

## 3. The high velocity clouds

Although in the previous section, we were primarily concerned with establishing the correspondence between the optical absorption features and the HI absorption spectra at low velocities, we did have occasion to comment on the *absence of HI absorption from the high velocity clouds* [The high velocity clouds we are discussing are those that populate the tail of the velocity distribution obtained by Blaauw (1952) and not those that are commonly referred to as HVCs in the literature]. It turns out that in all

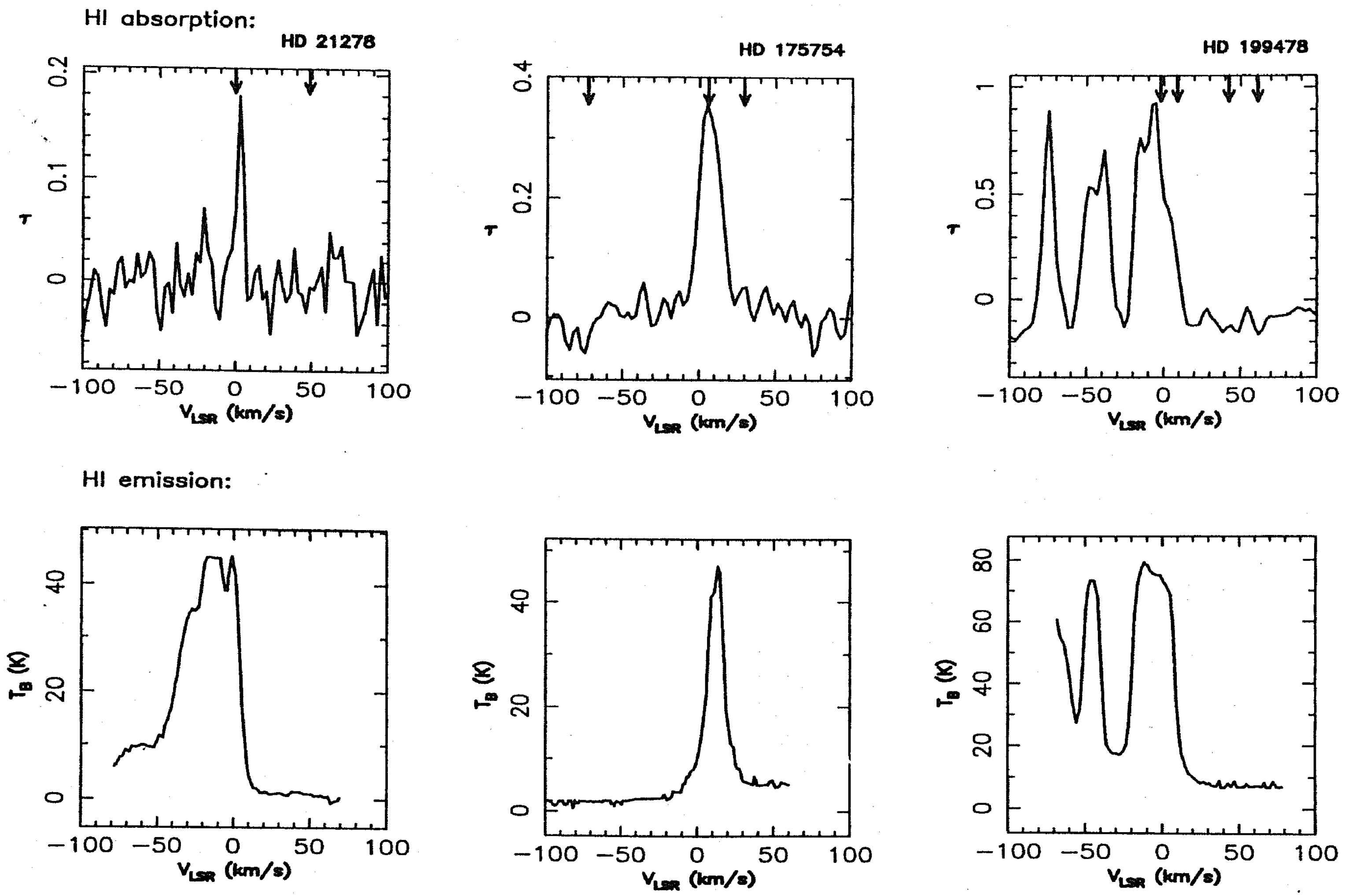

**Figure 5.** HI absorption (top) and emission (bottom) spectra towards three stars showing the lack of HI features corresponding to the high velocity optical absorption. The arrows on the velocity axis of the optical depth plot mark the velocities at which optical absorption is seen. The emission spectrum is from Habing (1968).

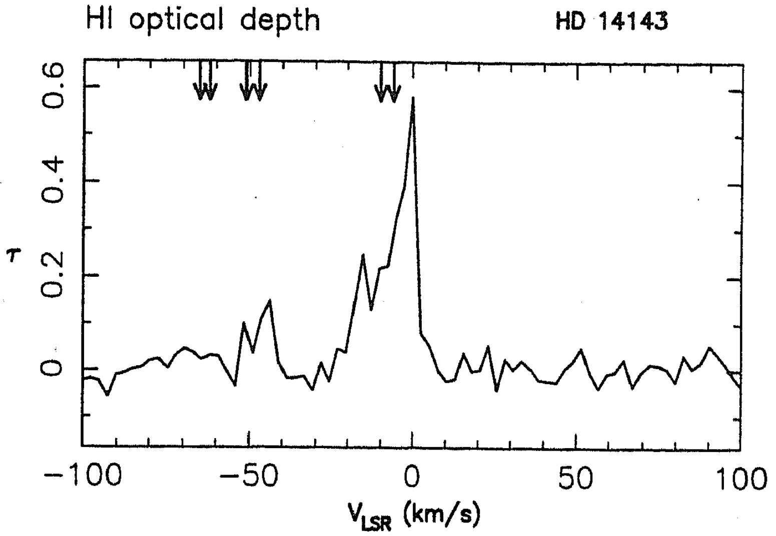

**Figure 6.** HI absorption spectra towards HD14143. The arrows mark the velocities at which optical absorption is seen.

but four cases, we fail to detect HI absorption at velocities corresponding to the high velocity ($\gtrsim 10\,\mathrm{km\,s^{-1}}$) optical absorption lines. To illustrate this generic trend, we have shown some additional examples in Fig. 5. *It may be seen in the figure that the high velocity optical absorption features (indicated by arrows) are not seen in the HI emission spectra either.* A discussion of this will form the major part of section 5.

In only four out of the twenty four lines of sight have we detected HI absorption at velocities $\gtrsim 10\,\mathrm{km\,s^{-1}}$ and which clearly correspond to the optical absorption lines. We discuss these below.

### 3.1 *Coincident absorption features at high velocities*

#### *HD14134, HD14143*

These two stars (in the same field) are members of the *h* and *chi* Persei clusters (Münch 1957). There were three radio sources within our primary beam (all within 10′ of the star). The HI absorption features towards one of them is shown in Fig. 6. The prominent high velocity absorption features towards the three sources are at −52.8, −50.3 and $-46.1\,\mathrm{km\,s^{-1}}$, respectively (Table 1 of Paper I). These should be compared with the optical absorption features towards the two stars in question which are at −46.8 and $-50.8\,\mathrm{km\,s^{-1}}$. Thus there is reasonable coincidence between the optical and HI data. Nevertheless we wish to now point out that the high velocity may not represent random motion but rather systematic motion. While interpreting his pioneering observations Münch (1957) attributed the high velocity features in the optical spectra to anomalous motions in the Perseus arm. Since then it has generally been accepted that there are streaming motions in the Perseus arm with velocities ranging from −10 to $-30\,\mathrm{km\,s^{-1}}$ (Blaauw & Tolbert 1966; Brand & Blitz 1993). For the sake of completeness we have listed in Table 2 the spin temperature of the gas derived by us by combining our measurements with existing HI emission measurements.

**Table 2.** Summary of coincident high velocities: Column 1 gives the HD number of the field. Column 2 lists the *high* velocity optical absorption seen towards the star. Column 3 is the "matching" HI absorption. Columns 4 and 5 give the fitted optical depth and width of the HI absorption features. The spin temperature is listed in column 6. As in the case of the low velocity features, we have used Habing(1968) and the Leiden-Green Bank survey for the emission temperatures needed to compute the spin temperature from the optical depth.

| Field | $V_{\rm lsr}$(optical) | $V_{\rm lsr}$(HI) | $\tau$ | $\Delta V$ | $T_s$ |
|---|---|---|---|---|---|
| | km s$^{-1}$ | km s$^{-1}$ | | km s$^{-1}$ | K |
| 14143–14134 | −50.8 | −50.3 | 0.30 | 10.0 | 96 |
| 21291 | −34.0 | −31.2 | 0.40 | 3.3 | 181 |
| 159176 | −22.5 | −20.8 | 1.15 | 15.2 | NA |

### *HD21291*

The spectrum towards this star near the Perseus arm has a prominent Na D line at a velocity of −34 km s$^{-1}$ (Münch 1957). The HI absorption spectrum shows a feature at −31.2 km s$^{-1}$. The contribution to radial velocity from Galactic rotation can only be $\sim$ 10 km s$^{-1}$, thus indicating significant peculiar motion of the gas. In our opinion one must attribute this to streaming motion of the gas as in the case discussed above. HI emission clearly shows spatially extended gas covering the longitude range from $\sim$ 136° to 141° at the velocity of interest. This strengthens the conclusion that one must not attribute the observed velocity to random motions.

### *HD159176*

There is pronounced optical absorption at −22.5 km s$^{-1}$ which might be identified with the HI absorption seen by us at −20.8 km s$^{-1}$. Given the longitude of 356°, it is difficult to attribute this to Galactic rotation. The measured velocity must correspond either to random velocity or systematic motion.

### *HD166937*

In the case of this star, there is no strict coincidence (within 3 km s$^{-1}$) between the HI and optical absorption at high velocities. However we see two HI absorption features at velocities close to and straddling the optical feature at 41.1 km s$^{-1}$, so we include this field in our list of high velocity coincidences. It may be noted that this star is also close to the Galactic center direction.

## 4. Summary of results

In the preceding section we described the first attempt to directly compare HI absorption with optical absorption features arising in the ISM. We summarize below the main results:

(i) HI absorption measurements were carried out towards twenty four fields. Each field has existing optical absorption spectra towards a bright star. In twenty of these fields we detected HI absorption features.

(ii) In all but four of these twenty fields, the HI absorption features at low velocities ($< 10\,\mathrm{km\,s^{-1}}$) correspond to the optical absorption lines.

(iii) In most cases there is also corresponding HI emission.

(iv) The spin temperatures derived by us for the low velocity gas is consistent with the standard values for the cold diffuse HI clouds.

(v) This lends strong support to the hypothesis that (at least) the low velocity clouds seen in optical absorption belong to the same population as those sampled in extensive HI studies.

(vi) In twenty out of twenty four fields surveyed, we did not detect any HI absorption corresponding to optical absorption at high velocities ($v > 10\,\mathrm{km\,s^{-1}}$). It is unlikely that in all cases this is due to our line of sight not sampling the gas seen in optical absorption; in several cases the line of sight to the radio sources would have sampled this gas even if its linear size was of the order of 1 pc.

(vii) Curiously, the early emission measurements also failed to detect HI gas at high velocities (in these same lines of sight). Given the size of the telescopes used, beam dilution could have accounted for the non-detection if the gas was "clumpy". Our absorption measurements rule this out as a generic explanation.

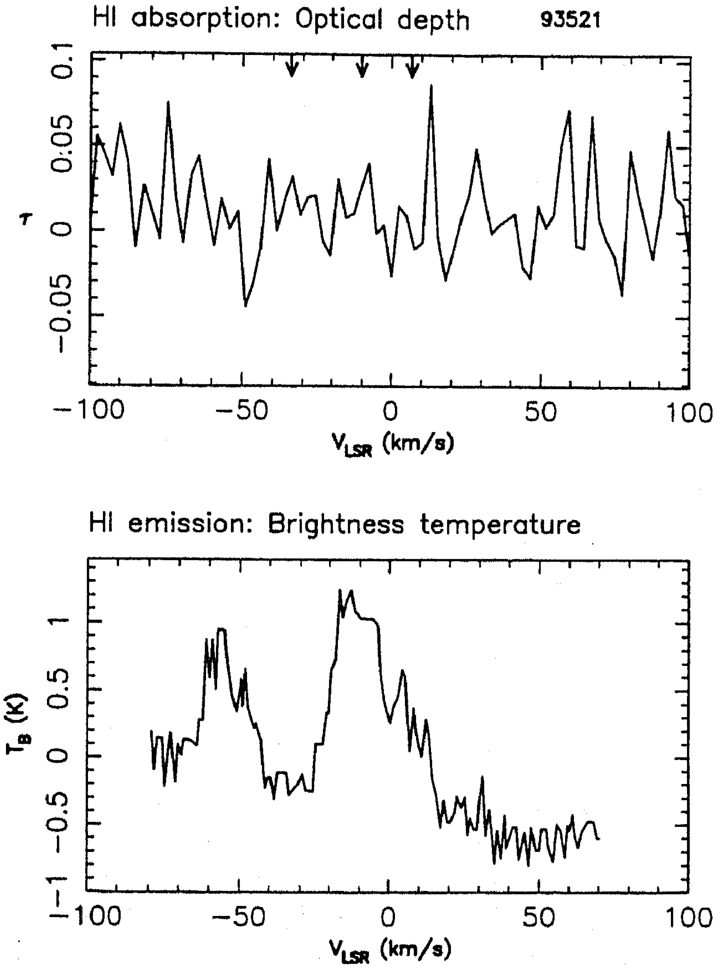

**Figure 7.** HI absorption (top) and emission (bottom) spectra towards HD93521. The arrows plot mark the velocities at which optical absorption is seen. The emission spectrum is from Habing (1968).

More recent and sensitive measurements indicate that the high velocity gas has much smaller column density than the low velocity gas ($N(HI) < 10^{18}\,cm^{-2}$). If this is the case, then it is not difficult to reconcile why we do not see it in absorption since our sensitivity limit was $\tau \gtrsim 0.1$. But then the correlation between high velocity and low column density would have to be explained. We venture to offer some suggestions in the next section.

(viii) *Fields with no HI absorption*: We wish to record that in the fields containing the stars HD38666, HD93521, HD205637 and HD220172 *we did not detect any HI absorption – even at low velocities.* These are all high latitude stars. HI emission spectra also show only weak features. For illustration we show in Fig. 7 the HI absorption and emission spectrum towards HD93521. From very detailed investigations – the case of HD93521 is a good example – it has been concluded that most of the optical absorption arises from warm gas in the halo (detailed references may be found in Spitzer & Fitzpatrick 1993 and Welty, Morton & Hobbs 1996). The fact that we do not see HI absorption is consistent with the interpretation of this gas being warm. Weak HI emission indicates low column density also.

## 5. Discussion

As we have already argued, our absorption measurements, taken together with earlier emission measurements, establishes that the low velocity clouds seen in optical absorption are to be identified with the standard HI clouds—their column densities and spin temperatures match.

But the true nature of the high velocity clouds seen in optical absorption is still unclear. There are two questions to be addressed: (**1**) Do the high velocity clouds belong to a different population, and (**2**) is there a causal connection between their higher velocities and lower column densities? We wish to address these two questions below.

An unambiguous indication that the high velocity clouds may have very different properties compared to their low velocity counterparts comes from an HI absorption study towards the Galactic center (Radhakrishnan & Sarma 1980). Given the statistics of clouds derived from optical studies (8 to 12 per kpc), if the high velocity clouds had optical depths comparable to the low velocity clouds, then an absorption experiment towards the Galactic center should straightaway reveal a velocity distribution similar to the one derived by Blaauw (1952) from Adams' data. The velocity distribution derived by Radhakrishnan and Sarma from precisely such a study did not reveal a pronounced high velocity tail. The velocity dispersion of $5\,km\,s^{-1}$ derived by them was in good agreement with the low velocity component of Blaauw's distribution. Instead of a pronounced high velocity tail seen in optical and UV studies, there was at best a hint of a high velocity population of very weakly absorbing clouds. Even this conclusion has remained controversial (Schwarz, Ekers & Goss 1982).

As for the possible correlation between higher velocities of clouds and lower column densities, fairly conclusive evidence comes from UV absorption studies. Since the UV absorption lines have larger oscillator strengths, they can be used to probe smaller column densities than is possible with optical absorption lines. The analysis of Hobbs (1984) seems to confirm this expectation—in several lines of sight there is more high velocity UV absorption features than in the optical. A more direct inference can be drawn from the work of Martin & York (1982). For the two lines of sight they studied, there is a clear indication of lower column density (N(HI)) at higher velocities.

Over the years, three broad suggestions have been put forward in an attempt to elucidate the nature of the high velocity clouds.

### 5.1 *Circumstellar clouds*

According to an early suggestion due to Schlüter, Schmidt & Stumpf (1953), the high velocity clouds seen in optical absorption are to be identified with circumstellar clouds. This was an attempt to explain the predominance of *negative* velocities in the high velocity absorption features. If the clouds in the vicinity of massive stars are accelerated by the combined effect of stellar winds and radiation from the stars, then in an absorption study against the stars one would detect only those clouds accelerated towards us. A few years later, Oort & Spitzer (1955) developed the well known "rocket mechanism" in which the UV radiation from the star ionizes the near side of the cloud resulting in ablation and consequent acceleration of the cloud. This mechanism will naturally result in the higher velocity clouds having smaller mass and therefore smaller column density. The difficulty with this mechanism, however, is that one will have to invoke another mechanism to explain the large *positive* velocities which are also seen in absorption studies. In view of this we will not dwell any further on this scenario.

### 5.2 *Relic SNRs*

An alternative scenario was advanced by Siluk & Silk (1974). Their suggestion was that the high velocity optical absorption features arise in very old supernova remnants (SNRs) which have lost their identity in the ISM. Their primary objective in advancing this scenario was to explain the high velocity tail of the velocity distribution of optical absorption features. The point was that if the absorption features arise not in interstellar clouds but in SNRs in their very late stages of evolution, then it would result in a power law distribution of velocities; such a distribution according to them provided a good fit to the observations.

While this suggestion is quite attractive, it suffers from two drawbacks: **(1)** The early studies on the evolution of SNRs predicted the formation of very dense shells beyond the radiative phase. Such compressed shells were essential to explain the observed absorption features and the derived column densities. However, more recent studies which take into account the effects of the compressed magnetic field and cosmic ray pressure in the shells suggest that either dense shells do not form or if they do, do not last long enough (Spitzer 1990; Slavin & Cox 1993). **(2)** Given a supernova rate of one per $\sim 50$ years in the Galaxy, the statistics of absorption features requires that the SNRs enter the radiative phase (and as a consequence develop dense shells) when they are still sufficiently small so as not to overlap with one another. This would indeed be the case if the intercloud medium into which the SNRs expand is dense enough ($n \sim 0.1\,\mathrm{cm}^{-3}$). But if a substantial fraction of the ISM is occupied by low density hot gas ($n \sim 0.003\,\mathrm{cm}^{-3}$; $T \sim 5 \times 10^5\,\mathrm{K}$) such as indicated by UV and soft X-ray observations then the supernova bubbles are likely to intersect with one another and perhaps even burst out of the disk of the Galaxy before developing dense shells (Cowie & York 1978). In view of these two drawbacks, we do not favour this suggestion.

### 5.3 *Shocked clouds*

The third possibility is that the high velocity absorption features do arise in interstellar clouds but which have been engulfed and shocked by supernova blast waves. Indeed we feel that this is the most plausible explanation for it has support from several quarters. The earliest evidence that the high velocity gas may be "shocked" came from the Routly-Spitzer effect. The NaI/CaII ratio in the fast clouds was lower (sometimes by several orders of magnitude) than in the slow clouds. The variation in NaI/CaII ratio was primarily attributed to the variable *gas phase abundance* of calcium in these clouds. Due to its relatively high condensation temperature calcium is likely to be trapped in grains. Spitzer has argued that the observed trend in NaI/CaII ratio could be understood if the calcium is released back into the gas phase in the high velocity clouds due to sputtering. This is indeed what one would expect if the interstellar cloud is hit by an external shock, which in turn drives a shock into the clouds (Spitzer 1978). Supernova blast waves are the most likely candidates.

Earlier in this section we referred to an HI absorption study by Radhakrishnan & Sarma towards the Galactic center. While they did not find strong absorption at high velocities they did conclude that there must be a population of weakly absorbing high velocity clouds. Radhakrishnan & Srinivasan (1980) examined this more closely and advanced the view that in order to explain the optical depth profile centered at zero velocity one had to invoke *two distinct velocity distributions*: a standard narrow distribution with a velocity dispersion of $\sim 5\,\mathrm{km\,s^{-1}}$, and a second one with a much higher velocity dispersion of $\sim 35\,\mathrm{km\,s^{-1}}$. While arguing strongly for a high velocity tail, they stressed that the latter distribution must consist of a population of very weakly absorbing clouds. They went on to suggest that this population of weakly absorbing clouds might be those that have been shocked by expanding SNRs; the very process of acceleration by SNRs might have resulted in significant loss of material and heating of the clouds, leading to low HI optical depths.

To conclude this discussion we wish to briefly summarize the expected life history of a cloud hit by a supernova blast wave. The first consequence of a cloud being engulfed by an expanding SNR is that a shock will be driven into the cloud itself resulting in an eventual acceleration of the cloud. The effect of this shock and a secondary shock propagating in the reverse direction after the cloud has been overtaken by the blast wave, is to compress and flatten the cloud. Eventually various instabilities are likely to set in which will fragment the cloud.

The detailed history of the cloud depends upon two important timescales: the time taken for the cloud shock to cross the cloud and the evolutionary timescale of the SNR. If the former is much smaller than the latter, the cloud is likely to be destroyed. However if the reverse is true, then the shocked cloud will survive and be further accelerated as a consequence of the viscous drag of the expanding hot interior. *Clouds accelerated in such a manner will however suffer substantial evaporation due to heat conduction from the hot gas inside the SNR.* Partial fragmentation could further reduce the size of the cloud. For detailed calculation and discussion we refer to McKee & Cowie (1975); Woodward (1976); McKee, Cowie & Ostriker (1978); Cowie, McKee & Ostriker (1981) and a more recent paper by Klein, McKee & Woods (1995).

To summarize the above discussion, in our opinion the shocked cloud scenario has all the ingredients needed to explain the observational trends. In particular it would explain why the high velocity clouds seen so clearly in optical and UV absorption lines do not manifest themselves in HI observations. But this observation is predicated on the conjecture that the higher velocity clouds are not only warmer, but have smaller column densities. There is certainly an indication of this from optical and UV absorption studies. To recall, in UV observations which are sensitive to much smaller column densities than optical studies, the higher velocity absorption features are more pronounced. But it would be desirable to quantify the correlation between velocity and column densities. Reliable column densities are difficult to obtain from optical observations because of blending of lines and also depletion onto grains. The column densities derived from UV observations are also uncertain because of the effects of saturation of the lines. In view of these difficulties it would be rewarding to do a more systematic and much more sensitive HI absorption study, supplemented by emission studies.

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