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High-latitude molecular clouds and near-by OB associations

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Abstract. The Galactic disribution of the high-latitude molecular clouds is considered. It is suggested that the majority of these clouds are clustered in two large shells around the two closest OB associations, Per OB3/Cas-Tau and Sco OB2. The most prominent shell of high-latitude clouds is centred around the Per OB3/ Cas-Tau association which is also at the centre of the Gould's Belt. However, the Per OB3/Cas-Tau group of high-latitude clouds appears as an elliptical shell at nearly right angles to the plane of the Gould's Belt. Its kinematic age ($\sim$ 10 Myr) is much smaller than the expansion age ($\sim$ 35 Myr) of the ring of intertellar matter associated with the Gould's Belt. It is suggested that while, as is generally understood, the larger expanding ring of gas associated with the Gould's Belt was created by stellar winds and supernova explosions of the more massive OB stars of the Per OB3/Cas-Tau association $\sim$ 35 Myr ago, the Per OB3 shell of high-latitude clouds was formed from the back-falling gas as it was swept up by a more recent supernova explosion of an early B type star in Per OB3 $\sim$ 10 Myr ago. More distant OB associations also produce similar shells of clouds at large heights from the Galactic plane having relatively smaller angular sizes due to their greater distances. These can be seen as higher latitude extensions of cloud complexes at lower Galactic latitudes as, for example, in the case of Vela OB2.

Key words: ISM: bubbles – ISM: clouds – Galaxy: open clusters and associations: general – Galaxy: solar neighbourhood

1. Introduction

Molecular clouds are an important constituent of the interstellar medium (ISM) of our Galaxy. They are found to be generally concentrated along the Galactic equator (Lynds 1962; Feitzinger & Stuwe 1984; Hartley et al. 1986). With a relatively small scale height of $\sim$ 75 pc (Sanders et al. 1984; Blitz 1990) perpendicular to the Galactic plane and typical distances within $\sim$ 1 kpc these clouds are to be found at Galactic latitudes within $\sim 10^{\circ}$. In optical surveys (for obscuring dark clouds) only a handful of clouds could be seen at Galactic latitudes $|b| \geq 25^{\circ}$. However, in recent years a number of molecualr clouds at such high Galactic latitudes have been detected, mostly in CO surveys (Blitz et al. 1984; Magnani et al. 1985, hereafter MBM; Keto & Myers 1986; Magnani et al. 1996; Hartmann et al. 1998; Magnani et al. 2000 and references therein).

The high-latitude molecular clouds have CO column densities $\geq 10^{15}$ cm^{-2} and are readily detected in the CO ($J = 1-0$) transition. However, over most of cloud surface, these clouds are characterized by low visual extinctions, making it difficult to identify them on the Palomar Observatory Sky Survey (POSS) plates and similar other optical surveys. Most of the high-latitude clouds are therefore classified as translucent clouds (van Dishoeck et al. 1991). From a literature search, Magnani et al. (1996, hereafter MHS) produced a catalogue of the high-latitude molecular clouds (with galactic latitude $|b| \geq 25^{\circ}$) that contains 120 of these objects. To search for molecular clouds at $|b| \geq 30^{\circ}$ more complete surveys in CO have recently been conducted in the northern Galactic hemisphere (NGH) by Hartmann et al. (1998, hereafter HMT), and in the southern Galactic hemisphere (SGH) by Magnani et al. (2000, hereafter MHHST). The NGH survey by HMT detected CO emission along 26 lines of sight, mostly corresponding to high-latitude clouds already known, and yielded only 2 new molecular clouds. The survey by MHHST found 144 distinct CO emission lines along 133 lines of sight in the SGH. Of these, 58 are new and 75 are associated with 26 previously catalogued high-latitude molecular clouds situated within the survey boundaries. MHS derived a velocity dispersion 5.8 km s^{-1} for the clouds in their catalogue if seven intermediate velocity objects are excluded and 9.9 km s^{-1} otherwise. The scale height and the mean distance of the clouds implied by these velocity dispersions are 124 pc and 150 pc, and 210 pc and 260 pc respectively. For the clouds detected in the recent NGH and SGH surveys MHHST derive a velocity dispersion $\sim$ 7 km s^{-1} leading to the values of $\sim$100 pc and $\sim$140 pc for the scale height and mean distance respectively. Thus the high-latitude clouds are relatively local clouds. Individual clouds range in size from less than $\sim 10^{-1}$ pc to $\sim 10^{1}$ pc and in mass from $\sim 10^{-1}\ M_{\odot}$ to $\sim 10^{3}\ M_{\odot}$, and may contribute $\sim 10\%$ to $\sim 20\%$ by mass to the molecular gas content in the local ISM.

The high-latitude molecular clouds are mostly gravitationally unbound (MBM) and could be in pressure equilibrium with the ISM (Keto & Myers 1986). Distance estimates for these clouds ($\sim 10^{2}$ pc) are similar to the mid-plane distances to the inner edges of the rarefied region in the local ISM called the Local Bubble (e.g., Welsh et al. 1994; Breitschwerdt et al. 1996) that is thought to be produced either by supernova explosions or stellar winds from OB associations. It has also been suggested (e.g., Elmegreen 1988) that the high-latitude clouds could be formed as condensations in swept-up HI shells. The structure of the Local Bubble at high Galactic latitudes is still uncertain. If the high-latitude clouds are indeed associated with the Local Bubble, then a study of the spatial distribution of the high-latitude molecular clouds can also help delineate the boundaries of the Local Bubble.

In this paper we consider the spatial distribution of the high-latitude molecular clouds. In Sect. 2 it is shown that a majority of all the known high-latitude clouds can be assigned to two large shells centred around the two nearest and youngest OB associations, namely the Per OB3/Cas-Tau and the Scorpius-Centaurus (Sco OB2) associations. Sect. 3 discusses the kinematics of the Per OB3/Cas-Tau shell of high-latitude clouds, its expansion and relationship with the Gould's Belt. Similar distributions of clouds extending to large heights from the Galactic plane around other OB associations are also shown. Sect. 4 summarizes our conclusions.

Table 1. List of additional high-latitude clouds

Cloud Identification	$l(^\circ)$	$b(^\circ)$
DCld 004.9-24.6	4.9	-24.6
DCld 008.4-47.1	8.4	-47.1
DCld 009.0-46.5	9.0	-46.5
DCld 010.4-46.6	10.4	-46.6
DCld 010.5-47.1	10.5	-47.1
CB 239	120.61	+24.62
CB 62	120.70	+37.58
L1320	126.65	+24.33
CB 61	127.27	+36.96
L(CDS) 1388	147.49	+50.14
DCld 313.1-28.7	313.1	-28.7
DCld 315.1-29.0	315.1	-29.0
DCld 315.8-27.5	315.8	-27.5
DCld 315.8-27.5	315.8	-27.5
DCld 317.6-28.7	317.6	-28.7
DCld 337.5-35.3	337.5	-35.3
DCld 337.7-35.4	337.7	-35.4
DCld 337.9-35.5	337.9	-35.5
DCld 338.0-26.9	338.0	-26.9
DCld 348.6-50.6	348.6	-50.6
DCld 348.9-46.2	348.9	-46.2

2. The galactic distribution of high-latitude molecular clouds

The MHS catalogue lists 120 high-latitude molecular clouds at Galactic latitudes $|b| \geq 25^\circ$. At Galactic latitudes $|b| \geq 30^\circ$ HMT list 26 detections of CO emission from the NGH survey, while MHHST list detections along 133 lines of sight in the SGH. Some of these detections correspond to clouds in the MHS catalogue, while the others are new. Some MHS clouds in the regions of the NGH and SGH surveys, especially the smaller ones, were missed by the NGH and SGH surveys (MHHST). A few more optically identified clouds with $|b| \geq\sim 25^\circ$, that are not listed in the MHS, HMT and MHHST catalogues, can be found in Lynds (1962), Hartley et al. (1986) and Clemens & Barvainis (1989). Also, the updated version of the Lynds (1962) catalogue, available at CDS, Strasbourg, lists one new cloud at galactic longitude $l = 147.5^\circ$ and latitude $b = +50.1^\circ$. These additional high-latitude clouds from the updated Lynds' catalogue, Hartley et al. (1986) and Clemens & Barvainis (1989) presently lack molecular CO observations, but are likely to be molecular clouds similar to the other high-latitude molecular clouds. These additional high-latitude clouds are listed in Table 1 which gives their designations (L for Lynds clouds, DCld for dark clouds from Hartley et al. (1986), CB for clouds from Clemens & Barvainis (1989) and L(CDS) 1388 for the cloud with running number 1388 in the updated Lynds' catalogue of dark nebulae at CDS) and Galactic coordinates (l and b).

Counting all the CO detections along distinct lines of sight in the NGH and SGH surveys by HMT and MHHST as high-latitude molecular clouds together with MHS clouds not observed or missed by these surveys, and adding the clouds listed in Table 1, we have a total of 260 high-latitude molecular clouds. The Galactic positions of the high-latitude clouds are plotted in Fig. 1. Also shown in Fig. 1 are clouds at lower latitudes ($|b| < 25^\circ$) from the catalogues of Lynds (1962) and Hartley et al. (1986). The Galactic longitude distribution of the high-latitude clouds is rather non uniform. There is a near-total absence of high-latitude clouds in the longitude range $l \sim 240^\circ - 290^\circ$. As pointed out by MHS this may represent a high-latitude analogue of the lower-latitude Local Bubble "tunnel" in the direction of Canis Major (Paresce 1984; Welsh et al. 1994). Also apparent in Fig. 1 are some clusterings of the high-latitude clouds in both northern and the southern Galactic hemispheres. Fig. 2 gives a histogram of the Galactic longitude distribution of the high-latitude clouds. The histogram shows two broad peaks in the distribution. One in the longitude range $l \sim 70^\circ - 200^\circ$ and the other in the range $l \sim 290^\circ - 20^\circ$. The region with $l \sim 20^\circ - 70^\circ$ is relatively poor in the population of high-latitude clouds.

The most prominent feature in the distribution of high-latitude clouds is found in the longitude interval $l \sim 100^\circ - 180^\circ$. The broader peak in the interval $l \sim 70^\circ - 200^\circ$ contains within it a much sharper peak in the range $l \sim 100^\circ - 180^\circ$. This peak, centred at $l \simeq 150^\circ$, consists of 132 high-latitude clouds out of a total of 260 clouds. The second peak in the histogram corresponding to the clustering of high-latitude clouds in the range $l \sim 290^\circ - 20^\circ$ is smaller. But this region of the sky has not been surveyed for high-latitude CO emission as well as the other longitude ranges accessible from observatories in the northern hemisphere. Clouds making up the $l \sim 100^\circ - 180^\circ$ peak in Fig. 2 seem to be distributed in a shell-like structure with an inner cavity that is elliptical in shape and is devoid of clouds even at lower latitudes excepting the dark clouds belonging to the Galactic plane and the Gould's Belt. This is shown schematically in Fig. 3. The positional centre of the elliptical cavity is

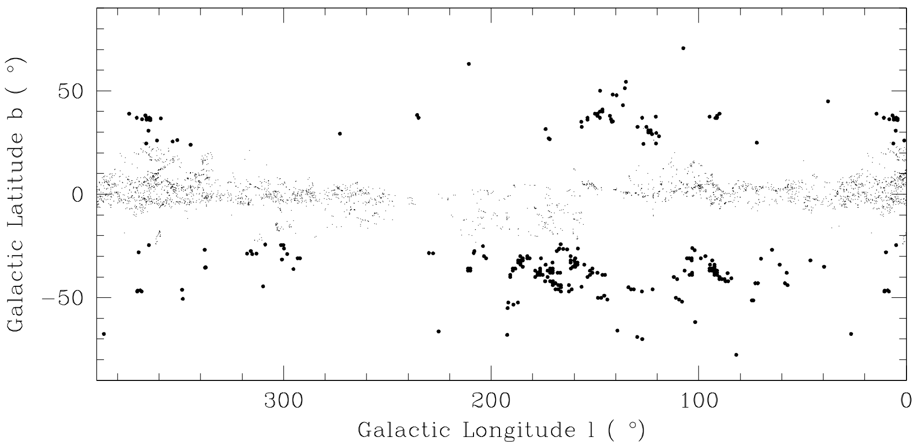

Fig. 1. The Galactic distribution of molecular clouds: The high-latitude clouds are shown by the larger filled symbols, while small dots represent clouds at lower latitudes

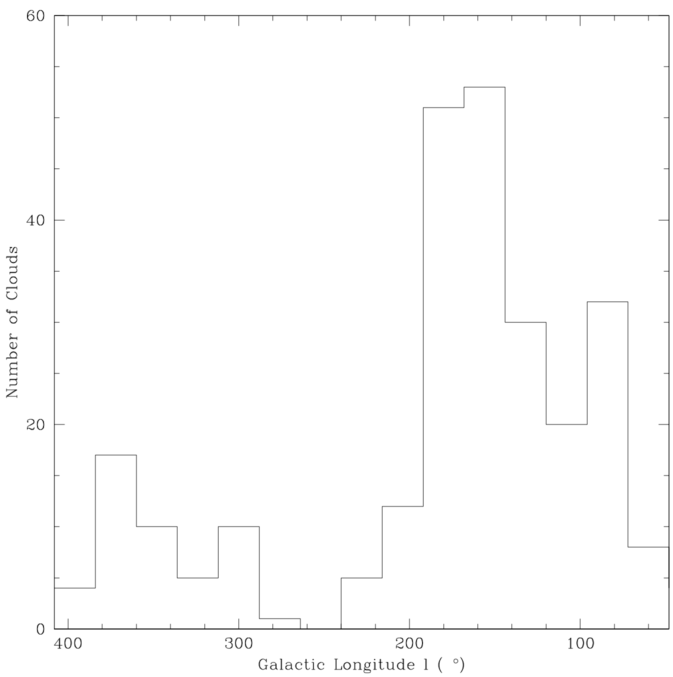

Fig. 2. Histogram shows the distribution of Galactic longitudes of the high-latitude clouds

at $l = 143°$, $b = -5°$. The projected dimensions of the cavity (major axis $\times$ minor axis) are $\sim 90° \times 68°$. The major axis of the ellipse is inclined with the Galactic plane by a large angle ($118°$) and is nearly perpendicular to the plane of the Gould's Belt in this region.

3. OB associations and the high-latitude clouds

If the Local bubble is produced by the action of supernovae and stellar winds from massive stars and the high-latitude clouds are formed as condensations in the swept-up interstellar gas (e.g. Breitschwerdt et al. 1996; Elmegreen 1988), then it would be natural to look for any OB associations in the region of the system of high-latitude clouds identified above. In the longitude range $l \sim 100° - 180°$ and at a distance comparable to the distance estimates ($\sim$ 100–200 pc) for the high-latitude clouds, the only OB association is the large Cassiopeia-Taurus association whose nucleus is the more compact α Per (Per OB3) association. The $Hipparcos$ measurements give a distance of 177 ± 4 pc for the Per OB3 association and, with its $3° \times 3°$ nucleus and a halo of $\sim 10°$, is centred at $l = 147°, b = -7°$ (De Zeeuw et al. 1999). This is very nearly coincident with the positional centre ($l = 143°, b = -5°$) of the elliptical cavity devoid of high-latitude clouds in this region. The much larger Cas-Tau association surrounds the Per OB3 association and its members have distances ranging between ~ 130 pc and 300 pc (De Zeeuw et al. 1999). We suggest here that the elliptical cavity and the surrounding high-latitude clouds are physically related to the Per OB3/Cas-Tau association. Fig. 3 illustrates this relationship, where the Galactic positions of the high-latitude clouds in the $l = 100° - 180°$ range are plotted together with those of the confirmed members of the Per OB3/Cas-Tau association from De Zeeuw et al. (1999). The elliptical cavity within the inner boundary of the shell-like distribution of the clouds is also shown. If the high-latitude clouds in the region considered above are indeed related to the Per OB3/Cas-Tau association, then the mean distance to these clouds can be taken to be the same (~ 180 pc) as that of the OB association, and the linear dimensions of the shell-like structure formed by this group of high-latitude clouds (hereafter Per OB3 shell) are $\sim$ 280 pc $\times$ 200 pc. The mean shell radius is $\sim$120 pc.

3.1. *Kinematics of the clouds in Per OB3 shell*

The mean radial velocity, with respect to the local standard of rest, of the clouds (from radial velocity data in MHS, HMT and MHHST) is -2.15 km s^{-1} and the velocity dispersion is 6.4 km s^{-1}; if the two intermediate velocity clouds near $l = 135°, b = 53°$ with velocities ~ -45 km s^{-1} are excluded. For the Per OB3 member stars (De Zeeuw et al. 1999) the mean radial velocity is -0.7 km s^{-1} and the velocity dispersion is ~ 4.8 km s^{-1}. While a majority of the high-latitude clouds in the range $l = 100° - 180°$ are likely members of the Per OB3 shell, a few clouds (like the intermediate velocity clouds mentioned above) may be unrelated to this group. Some of the clouds with $l \sim 170° \pm 5°, b \sim -40°$ to $-25°$, having radial velocities $\sim +8$

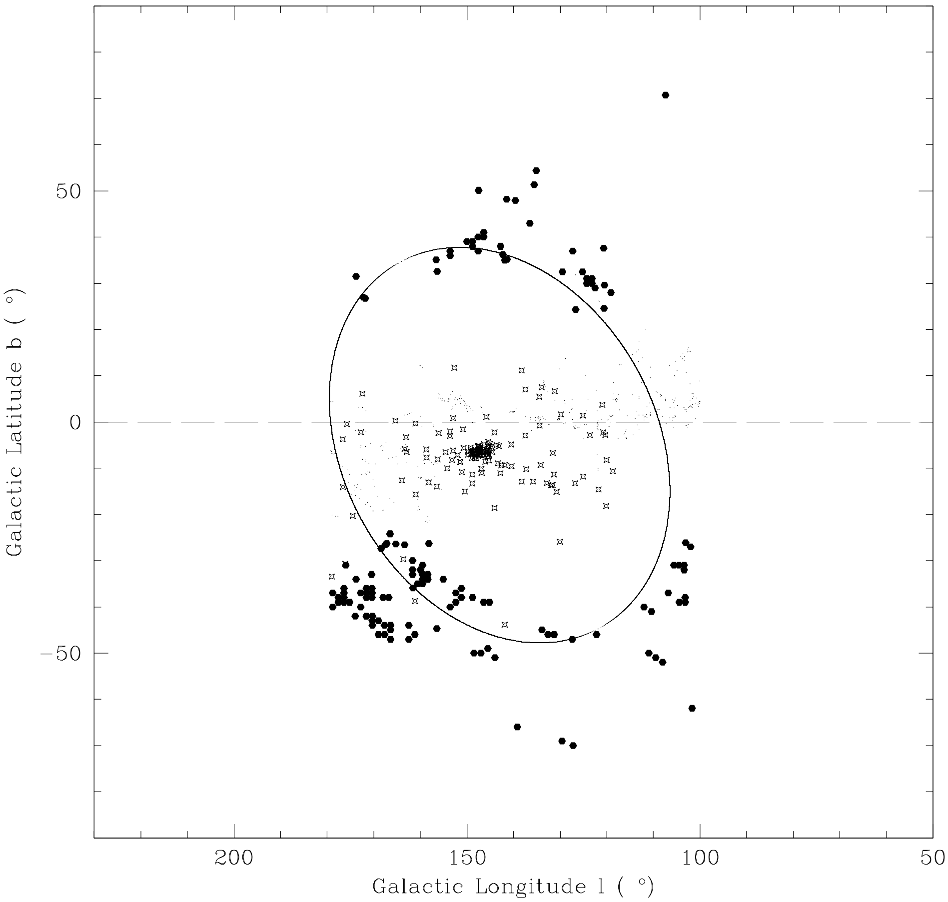

Fig. 3. The shell of high-latitude molecular clouds around the Per OB3/Cas-Tau OB association: The OB stars of the association are shown by open star symbols, lower latitude clouds (mostly belonging to the Gould's Belt) by small dots, and the larger filled symbols represent the high-latitude clouds. An ellipse is schematically fit to the shell-like distribution of the high-latitude clouds and the Galactic equator is drawn as the horizontal line

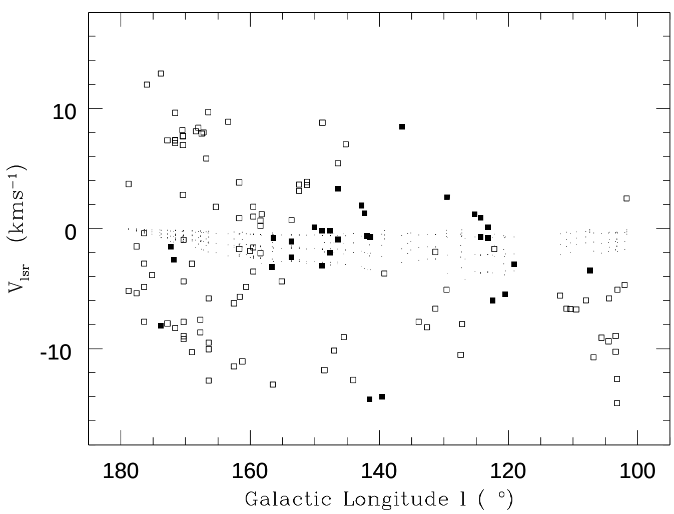

Fig. 4. Plot showing the radial velocity $V_{\rm lsr}$ as a function of Galactic longitude for the Per OB3/Cas-Tau shell of high-latitude clouds. Expected radial velocities due only to the differential Galactic rotation are shown by dots for three values (60, 180 and 300 pc) of distances to the clouds. Filled squares denote clouds with $b > 0$, while open squares represent clouds with $b < 0$

$\rm km\,s^{-1}$, similar to that of the near-by ($l \sim 170°, b \sim -19°$) lower latitude Taurus clouds (Taylor et al. 1987), may possibly be related to the Taurus cloud complex. Also, a few high-latitude clouds (especially in the southern Galactic hemisphere) outside of the longitude range $l = 100° - 180°$ and some clouds at lower latitudes may actually be related to the Per OB3 shell. However, in the present discussion we consider only high-latitude clouds within the range $l = 100° - 180°$ as possible Per OB3 shell members. Fig. 4 shows a plot of the radial velocities of the clouds against the Galactic longitude. The intermediate velocity clouds have been excluded from this plot. Also plotted in Fig. 4 are the radial velocities expected for the clouds at their positions (l, b) due to differential Galactic rotation following the relation

$$V_{\rm lsr}(l) = A.d.sin(2l)cos^2(b)$$

where $A = 17.7\ \rm km\,s^{-1}kpc^{-1}$ is the Oort's constant for $R_\odot = 8.5$ kpc (Clemens 1985) and d is the distance to the cloud. For the estimated mean distance (180 pc) and linear dimensions (mean shell radius $\sim$ 120 pc) for the Per OB3 shell of clouds we have plotted the radial velocities due to differential rotation for three values (60, 180 and 300 pc) of distance d. Measured cloud velocities that fall within or close to the range given by the three sets of points in Fig. 4 can perhaps be ascribed entirely to Galactic differential rotation. It can be seen from Fig. 4 that a large number of clouds have radial velocities much in excess of those expected due to differential Galactic rotation. The large observed velocity dispersion ($\sim 6.4\ \rm km\,s^{-1}$) must be due to large random velocities or systematic motion of the clouds. Some evidence for systematic motions is apparent from Fig. 4.

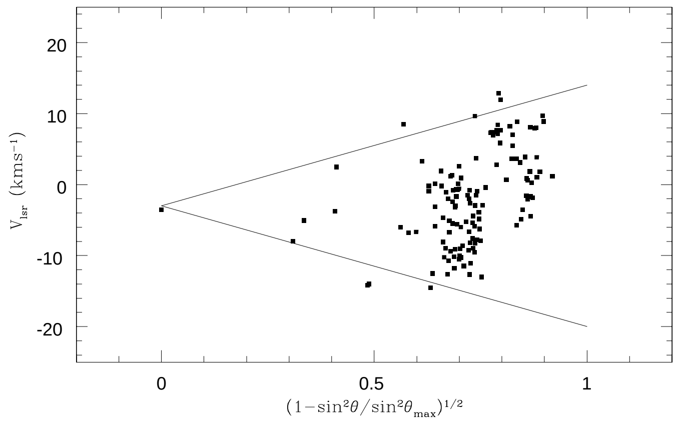

Fig. 5. Expansion of the Per OB3/Cas-Tau shell of high-latitude clouds: The radial velocity $V_{\rm lsr}$ is plotted against $(1 - sin^2\theta/sin^2\theta_{\rm max})^{1/2}$

Clouds in the southern Galactic hemisphere have velocities that are on an average lower (more negative) than those of northern clouds. This difference becomes more pronounced if the southern clouds with $l \sim 165° - 175°$ and velocities ($\sim +8$ km s^{-1}) similar to the Taurus clouds are indeed related to the Taurus cloud complex and are then not members of the Per OB3 shell.

The observed velocity distribution and the shell-like structure formed by the Per OB3 shell of high-latitude clouds can be understood if these clouds formed from an expanding shell of swept-up gas around the Per OB3 association. For an expansion speed of the order of $\sqrt{3}$ times the one-dimensional radial velocity dispersion (6.4 km s^{-1}), i.e. $\sim$ 11 km s^{-1}, and a mean distance ($\sim$ 120 pc) of the clouds from the centre of the Per OB3 association, the kinematic age of the shell can be estimated to be $\sim$ 11 Myr. Expansion from a common centre is also supported by Fig. 5 where the observed radial velocities of the clouds are plotted against $(1 - sin^2\theta/sin^2\theta_{\rm max})^{1/2}$, θ being the angular distance of the cloud from the centre of expansion ($l = 147°, b = -7°$). $\theta_{\rm max}$ ($= 70°$) is the maximum angular separation. If the clouds are distributed in a shell (thin) and expansion velocity is $V_{\rm exp}$, then the observed radial velocity would be given by

$$\mathbf{V}_{\rm lsr} = \mathbf{V_0} \pm \mathbf{V}_{\rm exp} \times (\mathbf{1 - sin^2}\theta/\mathbf{sin^2}\theta_{\rm max})^{\mathbf{1/2}}$$

where V_0 is the systemic velocity of the whole group (see Rajagopal 1997). For a thin-shell distribution the points in the plot would lie along two straight lines as shown in Fig. 5. If the clouds are distributed in a thick shell volume, then the points would lie within the envelope defined by the two lines. It can be seen from Figs. 3 and 5 that most of the clouds lie at projected angular distances $\sim 40° \pm 10°$ from the centre and have radial velocities that are more or less uniformly distributed between the two lines, while there is a relative paucity of clouds with larger angular distances having velocities that fall between the two lines. This may indicate the presence of a thick shell of clouds at $\sim 40° \pm 10°$ from the centre surrounded by a thin shell of much larger angular radius ($\sim 70°$). The fit shown in Fig. 5 (with 95% of the points contained within the envelope defined by the two lines, and a single isolated cloud at $l = 107°$, $b = 71°$ in Fig. 3 not considered for the fit in Fig. 5) for the Per OB3 clouds gives: $V_{\rm exp} = 17$ km s^{-1} and $V_0 = -3$ km s^{-1}. For an outer shell radius of ~ 200 pc corresponding to $\theta_{\rm max} = 70°$ used for the fit shown in Fig. 5, this implies an expansion age ~ 12 Myr. We will adopt an expansion velocity of 15 km s^{-1} and an expansion age of 10 Myr in the following discussion.

It would be interesting to look for other signatures of expanding gas in the Per OB3 shell. From the kinematics of the high-latitude clouds in this region we have estimated an expansion velocity ~ 15 km s^{-1}. At lower latitudes (say $|b| \leq 15°$) evidence for expansion may be present in the Galactic HI surveys (eg. Weaver and Williams 1973, 1974; or the Leiden/Dwingeloo survey: Hartmann & Burton 1997). An expanding shell centred near $l = 147°, b = -7°$ would appear as a small disk of HI emission in measurements made at velocities close to the expansion velocity ~ 15 km s^{-1}, the approaching polar cap at negative velocities and the receding polar cap at positive velocities. Unfortunately, in the Galactic longitude range of the Per OB3 shell the HI gas of the general ISM along the line of sight is approaching us and dominates emission at negative velocities. At positive velocities near ~ 15 km s^{-1} some emission is seen in the Leiden/Dwingeloo survey, but this could also be due partly to HI gas along the line of sight having large velocity dispersion. No clear pronounced disk of emission is evident. It is also possible that the receding part of the shell is much weaker because there might have been too little gas on that side of the Per OB3 association. At larger angular distances (and higher Galactic latitudes) from the centre HI emission would be enhanced in a shell at velocities near zero. Possible existence of such emission may be seen in the Leiden/Dwingeloo HI maps at velocities $\sim 0 \pm 2$ km s^{-1}, although the picture is rather complicated with several HI arcs and filaments superimposed in projection in this region.

3.2. Relationship of Per OB3 shell with the Gould's Belt

The Per OB3/Cas-Tau association is also at the centre of the Gould's Belt (Gould 1874), a flat system of young stars and interstellar matter within ~ 500 pc of the Sun that is tilted by $\sim 18°$ to the Galactic plane. At lower latitudes the interstellar gas related to the Gould's Belt is distributed in an elliptcal ring with semiaxes ~ 360 pc$\times$ 210 pc, while the stellar component is more extended with semiaxes ~ 1000 pc$\times$ 700 pc, and the system is expanding with an expansion age estimated to be $\sim$ 35 Myr (e.g. Olano, 1982; Poppel 1997 and references therein). The Per OB3 shell of high-latitude clouds under consideration here has smaller dimensions (semiaxes ~ 140 pc$\times$ 100 pc) and seems to be nearly at right angles to the plane of the Gould's Belt. Thus, geometrically, the relatively compact Per OB3 association is surrounded by the more dispersed Cas-Tau association, which in turn is surrounded by the shell of high-latitude clouds. These structures, at lower latitudes, reside in the inner cavity of the Gould' Belt that is largely free of diffuse gas and interstellar clouds (e.g. Olano 1982; Ramesh 1994) in an elliptical region with semiaxes ~ 360 pc $\times$ 210 pc.

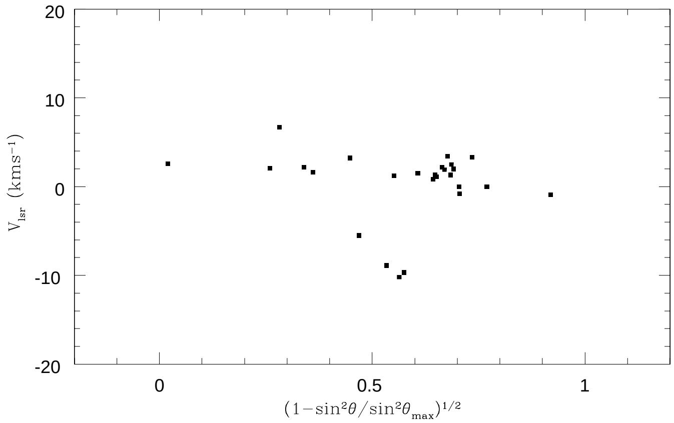

Fig. 6. The radial velocity $V_{\rm lsr}$ is plotted against $(1 - sin^2\theta/sin^2\theta_{\rm max})^{1/2}$ for clouds associated with Sco OB2

The kinematic age of $\sim$ 10 Myr estimated here for the Per OB3 shell of high-latitude clouds is to be compared with the kinematic age of $\sim$ 35 Myr for the expanding system of young stars and interstellar matter associated with the Gould's Belt and the age of $\sim$ 50 Myr for Per OB3 association (Meynet et al. 1993). The shell of high-latitude clouds around Per OB3 is therefore a much younger feature than the ring of expanding interstellar matter associated with the Gould's Belt and the Per OB3/Cas-Tau association. Stellar winds and supernovae from the massive stars of the Cas-Tau association centred around α Per (Per OB3), $\sim$ 35 Myr ago, could have produced the expanding ring of the Gould's Belt (Blaauw 1956; Olano 1982). This event would also have produced shells of gas at high galactic latitudes as two caps that oscillate perpendicular to the galactic plane under the influence of gravity due to matter in the galactic disc (Olano 1982). Half period for the vertical oscillation depends on the mass density in the disc, and is estimated to be $\sim 33 \pm 3$ Myr (e.g. Rampino & Stothers 1984). By now, the material of the two caps would have therefore returned to the Galactic midplane. Also, this material would follow trajectories like in a fountain and is unlikely to show a shell-like pattern (in the Galactic latitude distribution) centred around its point of origin. The Per OB3 shell of high-latitude clouds is perhaps produced by a more recent ($\sim$10 Myr ago) supernova event in the Per OB3 association which swept out the backfalling material of the high-latitude gas-caps belonging to the Gould's Belt expansion event of $\sim$ 35 Myr ago. It is to be noted that the Per OB3/Cas-Tau association still has several stars earlier than spectral type B3 (De Zeeuw et al. 1999) that can explode as supernovae.

3.3. High-latitude clouds associated with other OB associations

The group of high-latitude clouds clustering around $l \sim 290° - 20°$ may similarly be associated with the Sco-Cen OB association (Sco OB2) and originate in the gas shell swept up by stellar winds and supernovae taking place in this young association having sub-groups with ages in the range $\sim$ 5–15 Myr (Blaauw 1991). Unlike Per OB3 association, that has a single centre and a clear shell-like distribution of high-latitude clouds, Sco OB2 has several sub-groups of OB stars (Sco OB2-2: $l \sim 352°, b \sim 20°$, distance ~ 145 pc; Sco OB2-3: $l \sim 328°, b \sim 12°$, distance ~ 140 pc; Sco OB2-4: $l \sim 300°, b \sim 3°$, distance ~ 118 pc; De Zeeuw et al. 1999) with different ages and the shell of the high-latitude clouds is rather ill-defined. However, the system of high-latitude clouds can be seen to envelope the extended OB association.

The system of high-latitude clouds around the Sco OB2 association may also be expected to be expanding. Only 26 of the 44 high-latitude clouds in this poorly surveyed region have radial velocity measurements (MHS, HMT, MHHST). The mean radial velocity is +0.2 km s^{-1} and the velocity dispersion is 4.2 km s^{-1}, which is much larger than that can be expected to arise due to differential Galactic rotation. Fig. 6 shows a plot of radial velocities against $(1-sin^2\theta/sin^2\theta_{\rm max})^{1/2}$ for the Sco OB2 group of high-latitude clouds, θ being the angular distance of the cloud from $l = 328°$, $b = 12°$ representing roughly the centre of this rather extended OB association with several subgroups. In Fig. 6, $\theta_{\rm max}$ = 58°. Unlike the case of the Per OB3 clouds (Fig. 5), no clear evidence for expansion from a common centre is apparent from Fig. 6 for the Sco OB2 clouds. More complete CO line surveys of this region to search for high-latitude molecular clouds and measure their radial velocities would be required to investigate the kinematics of clouds associated with Sco OB2.

A number of high-latitude clouds are also found in the southern Galactic hemisphere in the longitude range $l \sim 180° - 220°$. It is to be noted that some members of the much dispersed Cas-Tau association do extend eastward into this region and may be responsible for the formation of the high-latitude clouds there. However, some of these clouds (especially those at relatively lower latitudes) may be related to the Orion and Taurus cloud complexes. The Galactic dark clouds are generally confined to the Galactic plane within $\sim 10°$. In some directions, however, clouds, other than the local high-latitude clouds being discussed here, can be seen at relatively larger (up to $|b| \sim 20°$) latitudes, often making shell-like structures. These clouds could be physically similar to the local high-latitude clouds, but much farther away. An example is the expanding system of gas and clouds in the Gum-Vela complex (Galactic longitudes in the range $l \sim 250° - 280°$) centred around ($l = 263°, b = -6°$) the Vela OB2 association at a distance of ~ 410 pc (e.g. Sahu 1992; Sridharan 1992; Rajagopal 1997; De Zeeuw et al. 1999). This cloud complex has linear dimensions $\sim$ 210 pc and is expanding with a speed ~ 10 km s^{-1}, similar to the Per OB3 shell of high-latitude clouds. Were the Vela OB2 association as close to us as the Per OB3 association (180 pc), its clouds would be at galactic latitudes as large as $-37°$ compared to the observed $-16.4°$.

Fig. 7 shows the galactic positions of prominent OB associations within ~ 500 pc of the sun (taken from De Zeeuw et al. 1999) together with the clouds of Fig. 1. As disussed earlier the clustering of high-latitude clouds around Per OB3 and Sco OB2 is clear. At relatively lower latitudes also the positional coinci-

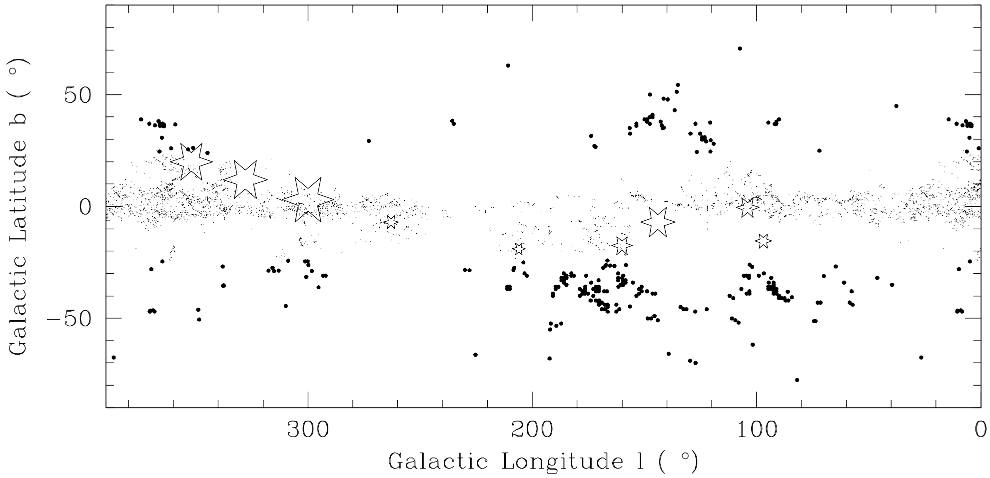

Fig. 7. Prominent OB associations within $\sim$ 500 pc are shown together with the Galactic distribution of molecular clouds of Fig. 1. The OB associations are shown by the large open star shaped symbols whose sizes are in inverse proportion to their distances

dence between OB associations and groups of clouds showing signs of shell-like distribution and extensions to higher latitudes is apparent. This can be seen for the Vela OB2 (as discussed above), Ori OB1 ($l \sim 206°, b \sim -19°$; distance $\sim$ 470 pc), Per OB2 ($l \sim 160°, b \sim -17.5°$; distance $\sim$ 300 pc), Lac OB1 ($l \sim 97°, b \sim -15.5°$; distance $\sim$ 370 pc) and Cep OB6 ($l \sim 104°, b \sim -0.5°$; distance $\sim$ 270 pc) associations. Being more distant than the nearby Sco OB2 and Per OB3 associations, the angular sizes of the shell-like cloud distributions around these OB associations are smaller.

4. Conclusions

In this paper we have considered the Galactic distributions of the positions of the high-latitude molecular clouds and the near-by OB associations. The conclusions can be summarised as follows.

(1) The majority of the high-latitude ($|b| \geq 25°$) clouds are clustered around the two closest OB associations, Per OB3/Cas-tau and Sco OB2.
(2) The system of high-latitude clouds around Per OB3 is distributed in an elliptical shell with semi axes $\sim$ 140 pc $\times$ 100 pc. The shell is oriented nearly perpendicular to the plane of the Gould's Belt. It is expanding at $\sim$ 15 km s^{-1} and has a kinematic age $\sim$ 10 Myr, which is much less than the kinematic age ($\sim$ 35 Myr) for the expanding ring of gas associated with the Gould's Belt. It is suggested that while the primary expanding gas ring of the Gould's Belt was created by the stellar winds and supernova explosions of the more massive OB stars of the Per OB3/ Cas-Tau association $\sim$ 35 Myr ago, the shell of the presently observed high-latitude clouds in this region was produced by a more recent supernova explosion of an early B type star in Per OB3 $\sim$ 10 Myr ago as it swept up the back-falling gas from the earlier events.
(3) More distant OB associations have also produced similar clouds at large heights from the Galactic plane. However, being more distant their angular sizes are smaller; but they can be seen as higher latitude extensions of these cloud complexes closer to the Galactic plane.

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