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Editors' note: The present article which appeared in *Rev. Mexicana Astron. Astrof.* 6, 259-266 (1981) inadvertedly was published with several paragraphs out of order. We present here the correct version.

NEUTRAL HYDROGEN RELATED TO GOULD'S BELT

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RESUMEN

Los perfiles de H I correspondientes a una extensa zona en Ophiuchus, Scorpius y Lupus han sido analizados en componentes gausianas. La zona estudiada se caracteriza por incluir parte de la asociación de Scorpius-Centaurus y del Cinturón de Gould.

Como resultados interesantes cabe destacar que el H I correspondiente a la estructura A de Lindblad (1967) y vinculado al Cinturón de Gould presenta en algunas zonas perturbaciones en las distribuciones de velocidad y de densidad de columna.

SUMMARY

A Gaussian analysis was made of the H I profiles of an extensive region in Ophiuchus, Scorpius and Lupus, which encloses part of the Scorpius-Centaurus Association as well as of Gould's Belt.

We conclude that in some regions the H I related to Lindblad's feature A shows perturbations in the velocity and in the N_H distribution.

Key words: GALAXIES-MILKY WAY – GALAXIES-STRUCTURE

I. INTRODUCTION

The distribution of H I away from the galactic plane includes very extended complexes related to Gould's Belt (Heeschen and Lilley 1954; Davies 1960). On the other hand, Lindblad (1967) performed a Gaussian analysis of the 21-cm line profiles obtained around the direction of the galactic anti-center. One of the features, which he designated "A", had an unusually small velocity dispersion of 2.5 km s^{-1} and a very wide latitude distribution. Although the observations were somewhat restricted in longitude ($\ell \sim 90^\circ - 260^\circ$), Lindblad could explain the entire velocity curve by one single, not too complicated, model. He suggested that feature A constitutes a local expanding cloud with an expansion age of some 6×10^7 years. Further, he pointed out that an extension of the observations might well be desirable, and that the model used should be valid only if the braking forces due to the interaction between the expanding and non-expanding interstellar gas were negligible. He also suggested that the expanding configuration might be related to the expansion of the local group of early-type stars studied by Blaauw (1956) and Bonneau (1964), i.e. with Gould's Belt.

Further evidence to support Lindblad's concept of an expanding elliptical ring of dense H I with the Sun in its interior was given by Hughes and Routledge (1972). Moreover, a study by Lindblad *et al.* (1973) based on new considerably extended 21-cm data, allowed a best fit to the observations by varying the parameters of the original model. Lindblad *et al.* found that feature A covers a very large part of the sky and hence should be present in most 21-cm studies. Further, from kinematic studies of early type stars by Lesh (1968, 1971), Lindblad *et al.* pointed out that the gas forming feature A and the young stars outlining Gould's Belt occupy about the same volume of space in the galactic plane and show the same kinematic behaviour.

Data suitable for picking out feature A were severely lacking in the southern sky between $\ell = 240^\circ - 340^\circ$, i.e. mainly in quadrant IV, despite the fact that the kinematics in this quadrant is very important. While Lindblad's model deals with positive velocities, a model of the local gas derived by Burton and Bania (1974*a*) predicts negative velocities for an observer immersed in a flow pattern of the sort expected by the linear density-wave theory.

Rickard (1975) made a study of interstellar Ca II lines in the Southern Milky Way which led him to

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suppose that Burton and Bania's model was inconsistent with the observational data. Further confirmations of Lindblad's model in quadrant IV arised from the 21-cm studies by Franco and Pöppel (1978) near the galactic center above the galactic plane, and by Morras (1979) in an extended region below the galactic plane covering $\ell = 220° - 325°$. Moreover, Strauss *et al.* (1979), using the data from an extensive survey by Pöppel *et al.* (1979) made a comparative study of optical and radioastronomical data of a section of Gould's Belt for $\ell = 300°$ -12°. Furthermore, large gas complexes at low positive velocities, not always with a symmetrical distribution with respect to the galactic plane, can be seen in the photographic representation of 21-cm data by Colomb *et al.* (1980). It seems that the overall distribution of much of the intermediate latitude gas, with concentrations at $b > 0°$ near $\ell = 0°$ and at $b < 0°$ near $\ell = 180°$, can be explained by the presence of Gould's Belt.

A careful analysis of the stellar kinematics in the local region around the sun may help us to evaluate the spiral structure parameters and to understand the relation between star formation and spiral structure (Lindblad 1980). In this sense, a more comprehensive understanding of the components present in the local interstellar medium seems very desirable. However, as remarked by Lindblad *et al.* (1973), observations that extend with sufficient continuity over a fairly wide interval in latitude are necessary.

In this paper we present results obtained by the authors at the Instituto Argentino de Radioastronomía (IAR).

II. REGIONS AND METHOD

We consider three regions extending over the following limits:

I: $320° \leqslant \ell \leqslant 341°, +7° \leqslant b \leqslant +26°$;

II: $290° \leqslant \ell \leqslant 320°, +3° \leqslant b \leqslant +17°$;

III: $345° \leqslant \ell \leqslant 375° (= 15°), +23° \leqslant b \leqslant +32°$.

Region I contains the Lupus Loop SNR and parts of the Upper Centaurus-Lupus Association. The rest of this association, as well as parts of the Lower Centaurus-Crux Association, are within region II (Blaauw 1964). Finally, region III includes parts of the Upper Scorpius Association, as well as parts of S27, the remarkable H II region surrounding ζ Oph. This very luminous ($M_{bol} \approx -11$) and massive ($M > 80\ M_{\odot}$) star, of spectral type B1 I_a –0 (Wolf and Appenzeller 1979) is a runaway star according to Blaauw (1961). Region III does also contain parts of a very faint and extensive H II region (Number 10 of the list by Sivan 1974).

Strauss *et al.* (1979) made a qualitative plot of the neutral hydrogen associated with Lindblad's feature A (see their Figure 3). However, since they considered only

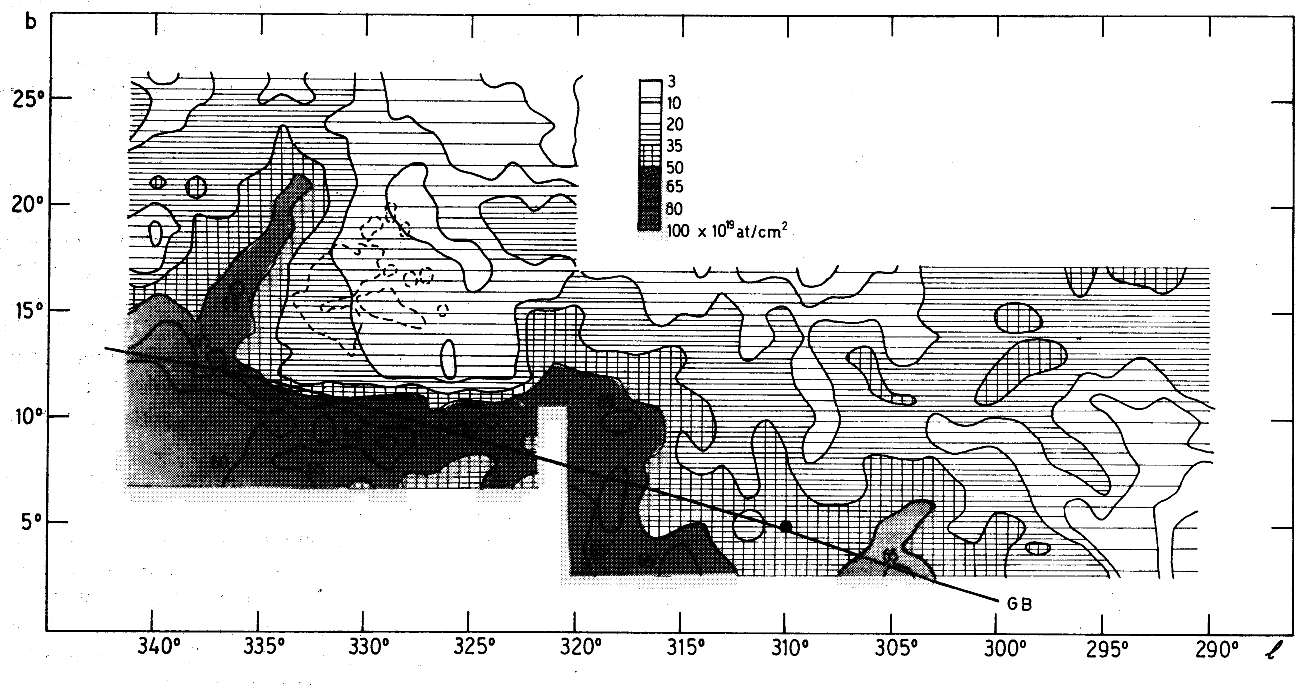

Fig. 1. *a)* $\ell \geqslant 320°$: N_H distribution of component II from Olano and Pöppel (1981*a*). The dashed lines are Milne's (1971) contours observed at 1410 MHz. The full line is the optical equator of Gould's Belt (Stothers and Frogel 1974). *b)* $\ell \leqslant 320°$: N_H distribution of the highest velocity component from Olano (1981).

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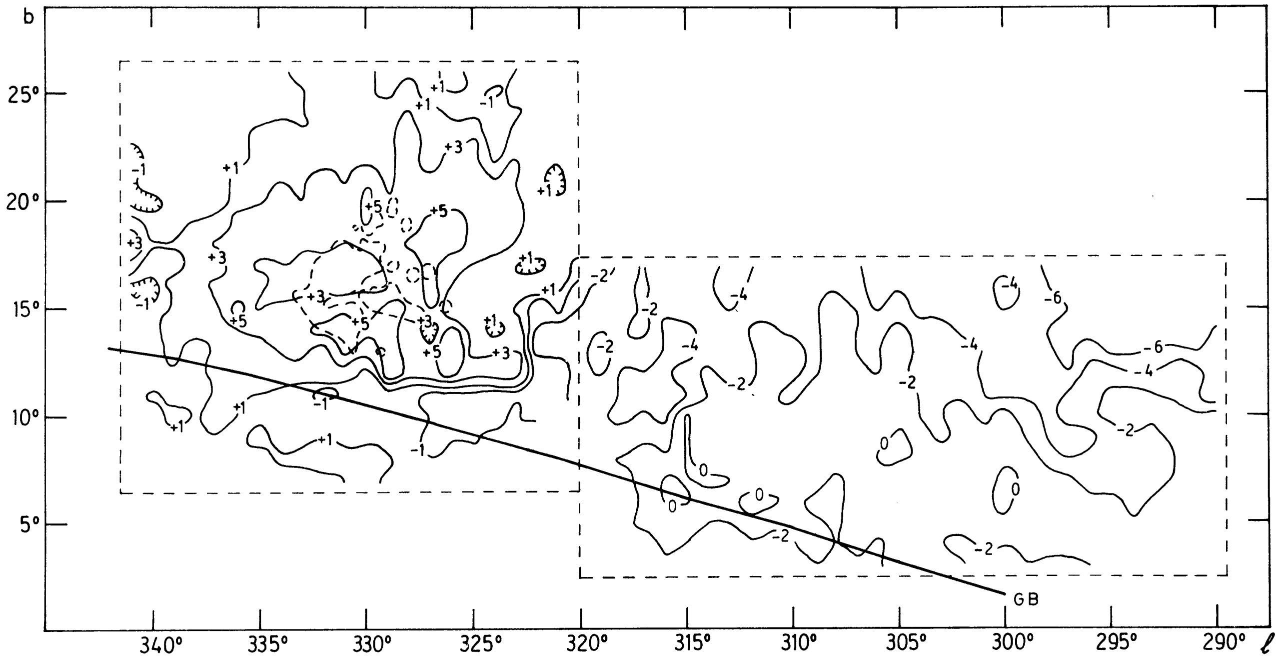

Fig. 2. *a)* $\ell \geqslant 320°$: distribution of the differences between the velocity of component II and V_L, the mean velocity of feature A in km s^{-1} from Olano and Pöppel (1981*a*). *b)* $\ell \leqslant 320°$: distribution of the differences between the velocity of the highest velocity component and V_L from Olano (1981).

the gas moving with the velocity V_L, given by Lindblad *et al.*'s (1973) model, their plot does not consider the cases where Gould's Belt main H I-ridge could be perturbed by a few km s^{-1}. Besides, a more quantitative analysis of the data are highly desirable.

The method which we used for studying gas motions in regions I-III was to make a Gaussian analysis of the H I-profiles. A preliminary inspection of all the observed profiles at latitudes $b \geqslant 18°$ suggested the presence everywhere of a broad Gaussian component. A possible interpretation is that the broad component represents the emission from a diffuse, high-temperature, optically thin intercloud H I-component like that described by Radhakrishnan *et al.* (1972) or Dickey *et al.* (1979). After checking the residual profiles we concluded that subtraction of the broad intercloud component could be a useful method for eliminating a large part of the foreground and background emission. In order to make a quantitative study of the H I associated with Gould's Belt we made a Gaussian analysis of the residual profiles. We are aware of the fact that a Gaussian component analysis implies many serious difficulties: blending, intrinsically non Gaussian contributions, ambiguities regarding the number of components, non-uniqueness of the analysis, etc. (See for example, Kaper *et al.* 1966; Takakubo and van Woerden 1966). In our case, the number of components adopted for each profile was carefully checked by detailed comparisons with several adjacent profiles in order to "trace" the components along ℓ as well as along b. With regard to the accuracy of the fitting, we consider that it is of the same order as the intrinsic errors of the observations.

From the parameters of the Gaussian components we computed formally the N_H-distribution, as if the optical depth τ was low. As usual, at the points where this hypothesis fails, the computed values of N_H can be considered as lower boundaries to the column densities. In what follows we shall consider each region separately.

III. REGION I

This region was analyzed by Olano and Pöppel (1981*a*). We refer to this paper for further details. The observational material belongs to the Atlas by Pöppel *et al.* (1979). The expression adopted for the diffuse intercloud medium was a Gaussian curve:

$$T_G(V) = H \exp\left[-(V-v_G)^2 / 2\sigma^2\right] / \sin b \quad (1)$$

where H is the peak temperature, V, the radial velocity, v_G, its central value, and σ the velocity dispersion. The values $H/\sin b \cong 8°K$, and $\sigma = 12$ km s^{-1} were empirically adopted, while, according to Falgarone and Lequeux (1973), we used

$$v_G(\ell,b) = A \sin 2\ell \cos^2 b \langle |z| \rangle / |\sin b| , \quad (2)$$

A is Oort's first constant of differential rotation and $\langle|z|\rangle = 186$ pc, is the value of the first central moment of the intercloud medium's z-distribution.

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After a careful analysis of the residual profiles, several Gaussian components were distinguished: Ia, Ib, II and III, in order of increasing velocity. Component II, of positive velocity, is the strongest one and it is associated with Gould's Belt. The results of the computation of N_H for component II are given in Figure 1 (for $\ell \geqslant 320^{\circ}$), while the differences between the velocity of component II and the velocity V_L (ℓ) predicted by Lindblad *et al.* are plotted in Figure 2 (for $\ell \geqslant 320^{\circ}$).

This figure shows that the differences are positive, with maxima of $\sim + 7$ km s^{-1}, approximately at the position of the Lupus Loop SNR. The differences decrease with increasing angular distance from the SNR to values $\sim \pm 1$ km s^{-1}. A comparison of both figures shows a rough correlation between low N_H values and high velocity differences on the one hand, and large N_H values and low velocity differences on the other. All these facts are consistent with a strong perturbation of Gould Belt H I-shell by the Lupus Loop SNR.

Furthermore, the other components also subtend wide angles in the sky, have similar velocity dispersions as component II, and their velocity distributions are rather peculiar. A common origin for these clouds is thus suggested. Possibly as fragments blown off from the Gould Belt main H I shell (component II), due to the perturbation produced by the supernova which gave origin to the Lupus Loop.

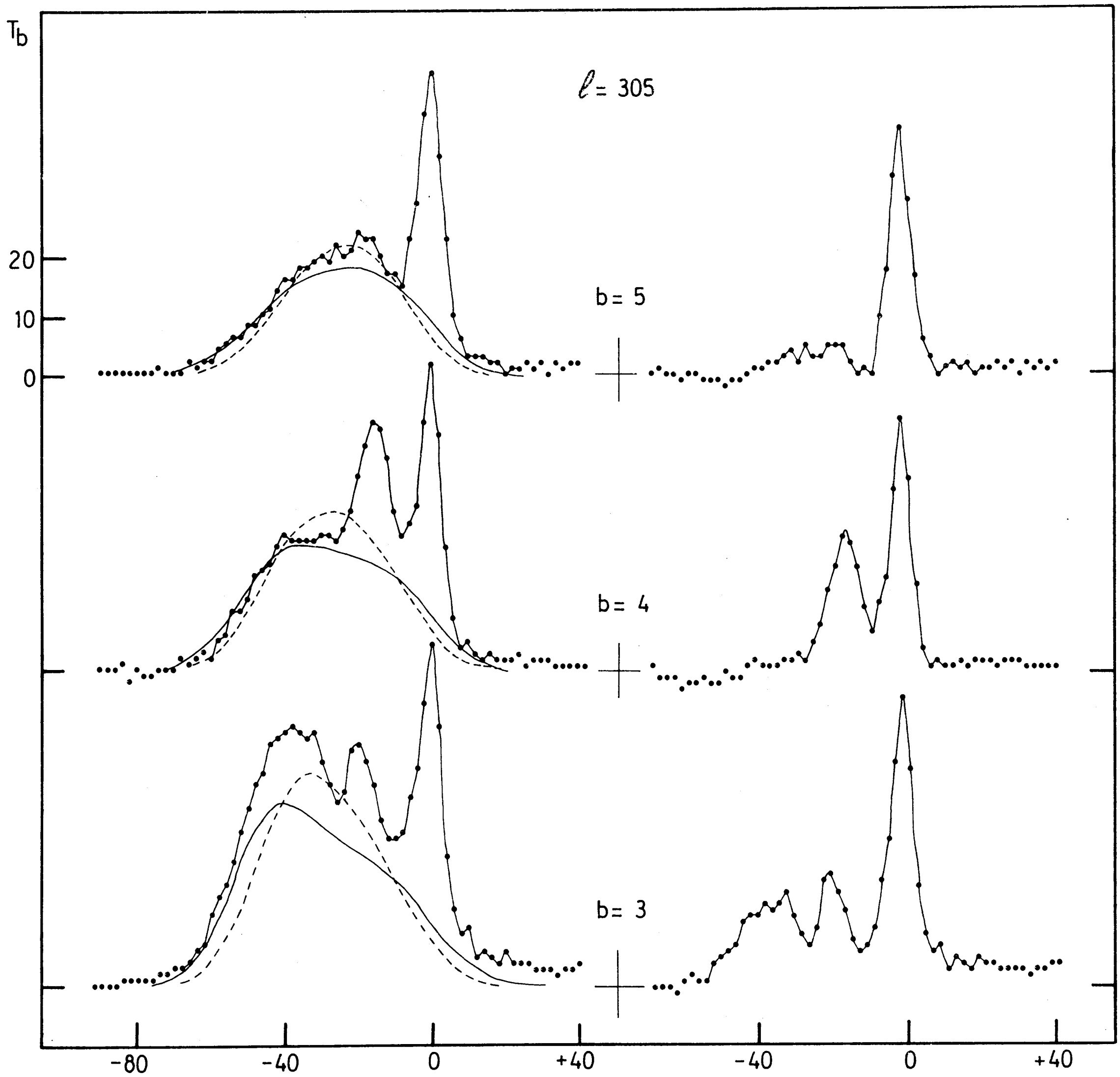

Fig. 3. Hydrogen profiles for $\ell = 305^{\circ}$, $b = 3^{\circ}$, 4° and 5°. On the left: observed profiles (dots), computed profiles for the intercloud medium, for pure circular motions (full line), and for streaming motions as predicted by the density-wave theory (broken line). On the right: residual profiles as obtained using pure circular motions from Olano (1981).

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IV. REGION II

The analysis of region II was performed by Olano (1981) using Pöppel *et al.*'s (1979) observational material. In order to evaluate the diffuse intercloud medium emission, and since region II includes latitudes as low as 3°, synthetic H I-profiles were constructed. A plane-parallel density distribution was assumed, and the following Gaussian distribution was adopted according to Falgarone and Lequeux (1973):

$$n(z) = 0.155 \exp\left[-z^2/2(233\ \mathrm{pc})^2\right]\ \mathrm{cm}^{-3} \qquad (3)$$

Two different velocity fields were considered:

a) Schmidt's (1965) rotation law as given by Contopoulos and Strömgren (1965) in their polynomial approximation.

b) Streaming motions of the sort which the linear density-wave theory suggests with the parameters chosen by Burton and Bania (1974*b*). The differences of the results, however, did not appear to be large. For this reason, the simpler pure circular motions were preferred for computing the synthetic profiles, assuming low optical depth and no absorption due to the clouds.

As an example, the results of computations of synthetic profiles for the intercloud medium, as well as the corresponding residual profiles, are shown in Figures 3 and 4. As can be seen, the synthetic profiles can be well approximated by Gaussian curves for $b \geqslant 10°$.

After subtracting the intercloud-medium's emission from the observed profiles, the residual profiles were analyzed into Gaussian components. Here, we will give only the results for one of the stronger components, namely that of the highest positive velocity. In 90% of

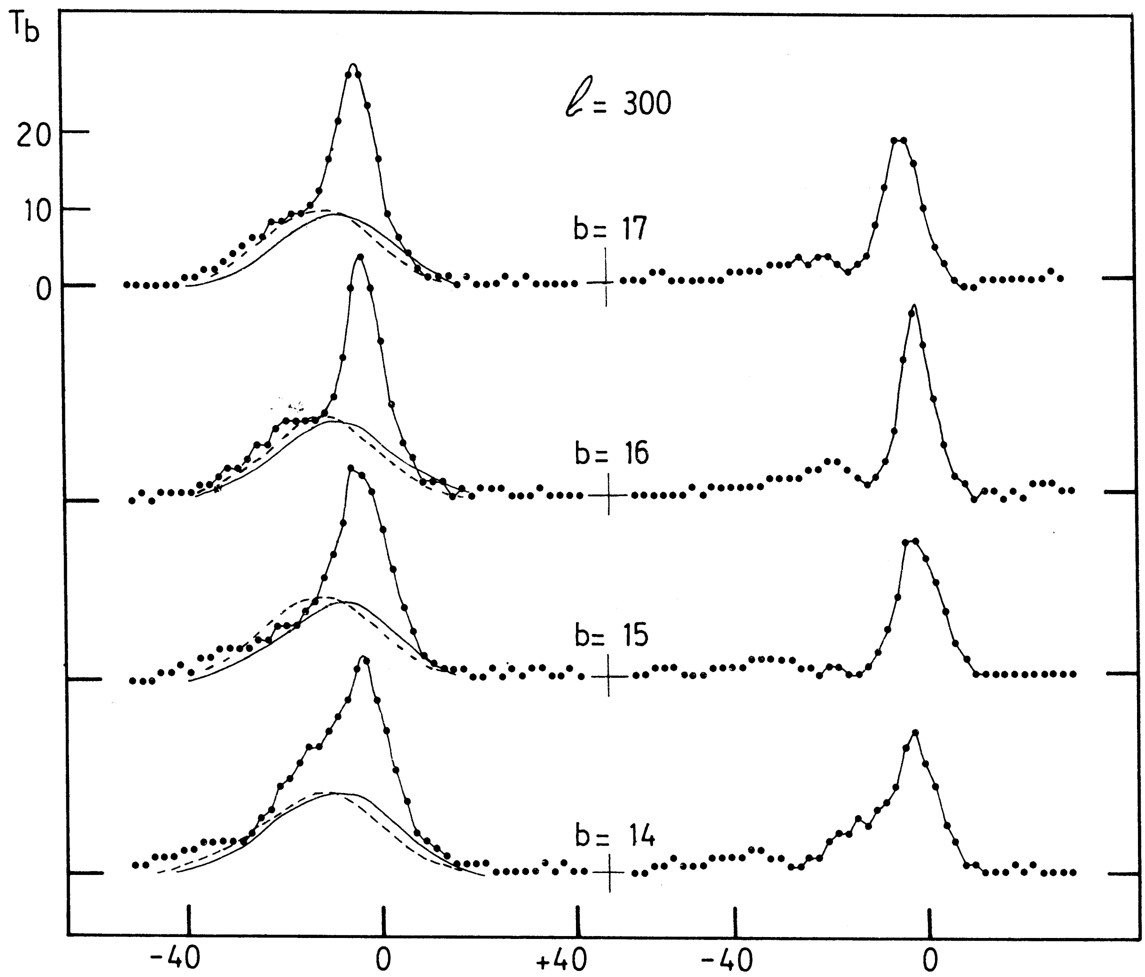

Fig. 4. Same as Figure 3 but for b = 14°, 15°, 16° and 17°.

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the cases this component has no important blending with any other one. Its N_H-distribution is plotted in Figure 1 (for $\ell \leqslant 320°$), while the differences between the component's velocity and V_L are plotted in Figure 2 (for $\ell \leqslant 320°$). As can be seen from Figures 1 and 2 ($\ell \leqslant 320°$), the component seems to be identical with feature A, suggesting a relatively patchy distribution with remarkable gaps around $\ell \sim 311°$ and $\ell \sim 292°$.

V. REGION III

The analysis of this region was done by Cappa de Nicolau and Pöppel (1979, 1981). The observational material was taken from Heiles and Habing's (1974) H I atlas provided by them on magnetic tape. About 60 profiles were observed in order to fill out some of the gaps in the data. These observations were carried out with the 30-m radiotelescope of the IAR, provided by the Carnegie Institution of Washington, constructed in Argentina by members of both institutions, and operated by the staff of the IAR.

As in the case of region I, a Gaussian expression like (1) was used for the intercloud medium emission. The empirically adopted values for H and σ were 1.7 K and 14 km s^{-1} respectively. After subtracting this Gaussian curve from the observed profiles, the residuals were analyzed into Gaussian components.

The Gaussian decomposition is not easy to make: the structure of the profiles is complex so that blending effects are important. It appears that the profiles can be best understood in terms of four strong components of similar dispersions $\sigma \sim 2.5$ km s^{-1}, besides several weak components. We distinguish clearly:

a) a component G, extending more or less over the whole region, with velocities which are generally slightly positive (~ 0 to $+2$ km s^{-1}),

b) a component P of positive velocity (generally in the range +4 to +6 km s^{-1}), which extends predominantly between $\ell = 359°$ and $\ell = 366°$.

c) two weaker components I and I′ of negative velocities, generally in the range ~ -3 to -8 km s^{-1}, which extend prominently only in the range 345° to 360° but with extensive gaps.

However, because of the strong blending effects (particularly at $\ell = 356°$-$365°$), an accurate separation of the components often becomes somewhat ambiguous, and only the general trends can be recognized.

It is interesting to mention that Crutcher (1979) observed the 1667 MHz line of OH toward several dusty patches near ζ Oph. He found two velocity components, at about -0.5 km s^{-1} and $+5$ km s^{-1}. These components may correspond to our components G and P.

We computed formally N_H values assuming low optical depths and without modifying the temperature scale used in Heiles and Habing's tapes. In Figure 5 we show the N_H distribution of component P, while in Figure 6 the resultant N_H-distribution obtained by adding the individual contributions of components G,P,I and I′ are shown. Analogously, in Figure 7 the weighted mean velocity field of the 4 components is reproduced. The results in Figures 6 and 7 should not be very sensitive to the Gaussian decomposition.

As is well known, the positive-velocity ridge related

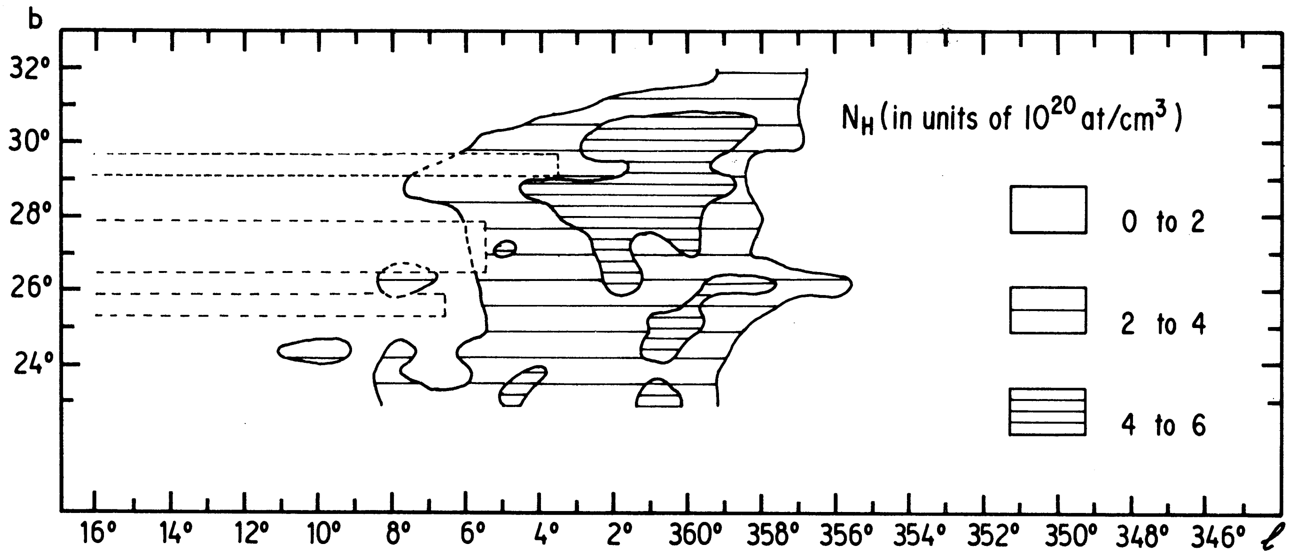

Fig. 5. N_H distribution of component P computed using the data on tape of Heiles and Habing (1974) supplemented with observations made at the IAR from Cappa de Nicolau and Pöppel (1981). The broken lines show gaps in the available data.

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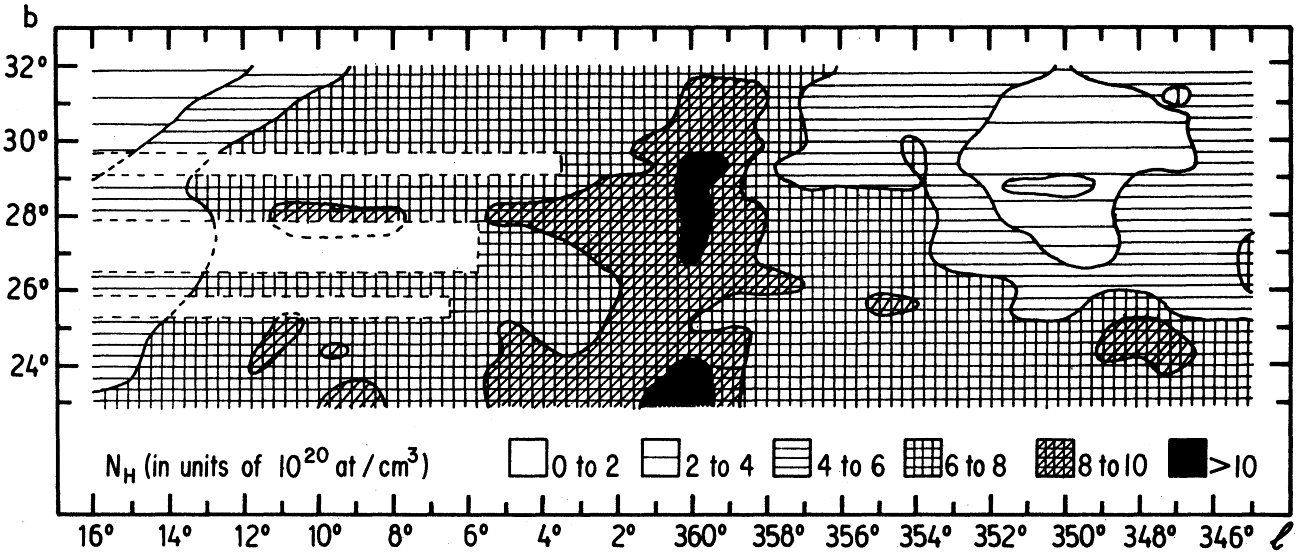

Fig. 6. Same as Figure 5 but for the resultant N_H distribution of components G,P,I, and I'.

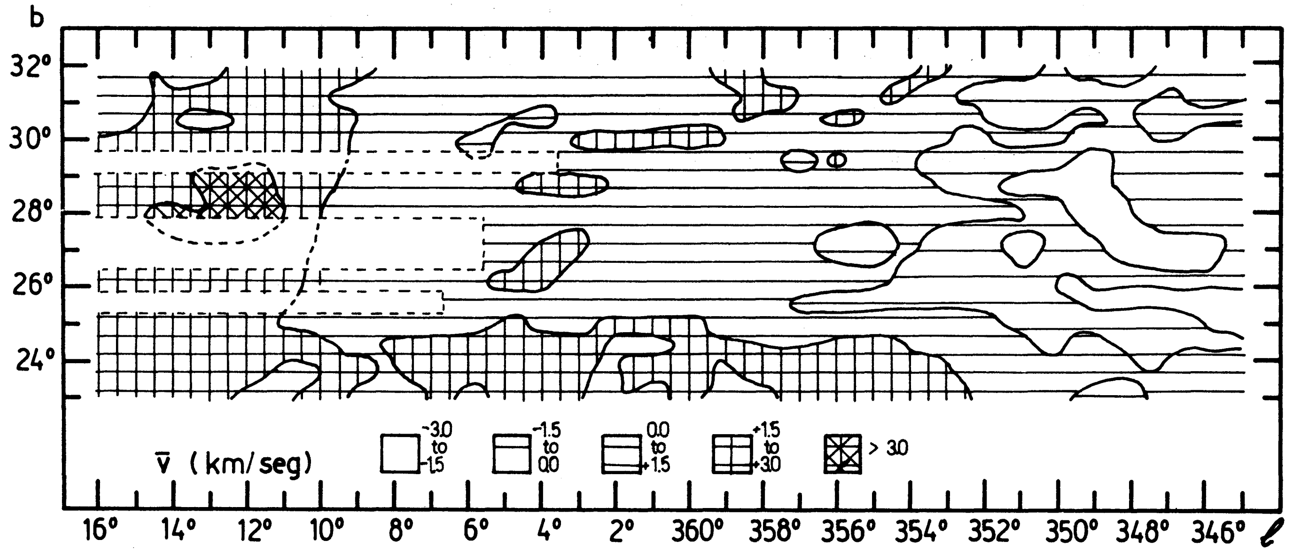

Fig. 7. Same as Figure 5 but for the weighted mean velocity field of the components G,P,I, and I'.

to feature A can be distinguished clearly in region III (see for example Heiles and Habing's 1974 contour plots) and effects due to supernovae could as well be present (Sancisi 1974; Olano and Pöppel 1981*b*). On the other hand, Harten (1971) has pointed out that the radial velocity of feature A tends to become less positive for higher values of | b |.

We therefore conclude that the positive velocity components belong to feature A. An interaction with other H I components, might well be possible like in the case of region II.

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DISCUSSION

Serrano: Como la densidad del gas es tan alta en el Cinturón de Gould, se esperaría que las estrellas O estuvieran concentradas allí, pero esto no sucede. ¿Podrías comentar algo al respecto?
Olano: Quizás no ha transcurrido aún suficiente tiempo como para que las estrellas O se hayan podido formar en la región.
Mirabel: ¿Cuál es la energía que requieren los movimientos anómalos en el Cinturón de Gould?
Olano: La energía total del H I derivada para el caso del Lazo de Lupus es del orden del 3×10^{48} erg si la distancia al remanente de supernova es de 170 pc.

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