NEUTRAL HYDROGEN GAS IN THE TAURUS–ORION REGION OBSERVED WITH A MULTICHANNEL 21 CM LINE RECEIVER

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Summary

A multichannel 21 cm hydrogen line receiver has been developed which is capable of producing a complete line profile in the very short time of 2 min.

To evaluate the large-scale survey potential of the instrument, the Taurus and Orion regions of approximately 3500 square degrees have been observed with a low-resolution ($2 \cdot 8°$ between half-power points) paraboloid.

The results suggest that a single large cloud or connected association of clouds of neutral hydrogen covers most of the region surveyed.

I. Introduction

One of the main limitations in the observation of neutral hydrogen by 21 cm line receivers has been the time required to obtain a single profile; with the typical receivers in current use it is of the order of 2 hr. This has naturally restricted observations to those parts of the sky considered most likely to be rewarding. A new variation of H-line receiver has been developed at the Radiophysics Laboratory, Sydney, in which a complete line profile is observed and recorded in a very short time, at present every 2 min. The receiver is thus particularly suitable for large-scale surveys of the sky. As a preliminary investigation we have surveyed a region, some 3500 square degrees in area, containing the Taurus and Orion complexes. The results suggest that a single large cloud or connected association of clouds of neutral hydrogen covers the greater part of the region.

II. Equipment

The frequency bandwidth accepted by this instrument is divided into 48 separately recorded channels to give a continuous coverage of about $1\frac{1}{2}$ Mc/s, capable of being centred on the natural line frequency ($1420 \cdot 405$ Mc/s) or whatever Doppler-shifted frequency is appropriate to the observed region.

The receiver is of the double-conversion superheterodyne type having $31 \cdot 8$ and $6 \cdot 74$ Mc/s as the intermediate frequencies. By switching, at 385 c/s, the receiver output is arranged to be the difference between radiation from the sky accepted at 1420 Mc/s, the " signal frequency ", and 1424 Mc/s, the " reference frequency ". This latter frequency is believed to be well outside the widest H-line profile. The output of the second I.F. amplifier is passed into 48 double-tuned filters spaced at intervals of 32 kc/s ($\equiv 6 \cdot 8$ km sec^{-1}). The shape of the filter pass bands is approximately Gaussian and their half-power width is 40 kc/s. A second detector is attached to each filter. The detected outputs, containing

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contributions from the two switched frequencies, are passed through audio amplifiers and synchronous detectors for recovery of the wanted portion—the hydrogen line radiation. At this stage the fluctuations are smoothed by the introduction of a time constant of 2 min. A telephone-type uniselector samples each of the synchronous detector outputs once every 2 min. This information is displayed on a Speedomax recorder as a 48-point profile: frequency is the abscissa; H-line aerial temperature the ordinate. No absolute calibration has been made yet and the temperature scale was determined from many comparisons with galactic plane profiles obtained by Muller and Westerhout (1957) at Leiden. The adopted scale may have a small error due to a difference in aerial beamwidths.

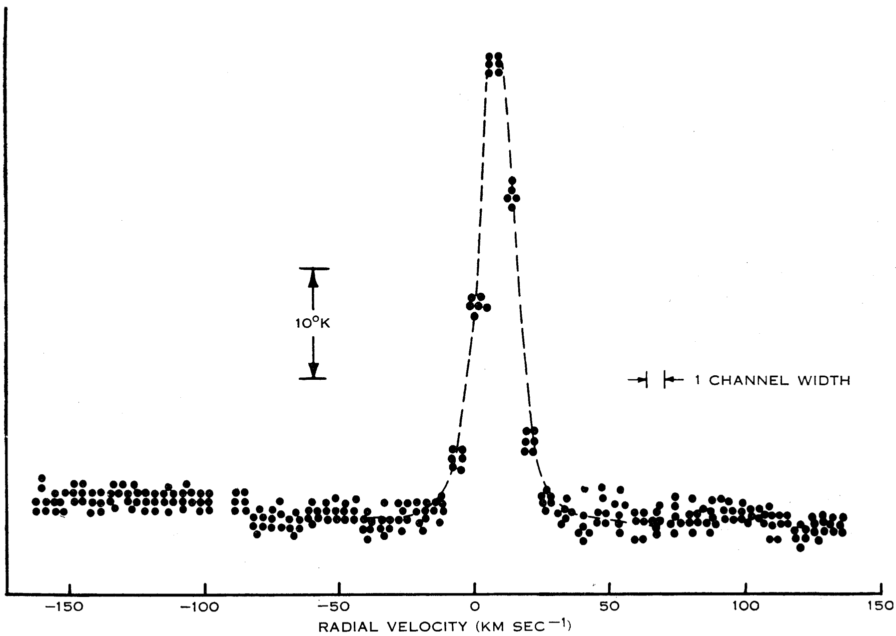

Fig. 1.—Composite H-line profile. The individual points of six successive profiles are plotted. $\delta = +14°$, $\alpha = 03^h\ 49^m$.

A composite profile for a mean position of $03^h\ 49^m$, $+14°$ is given in Figure 1. The individual points of six successively recorded profiles from $03^h\ 44^m$ to $03^h\ 54^m$ have been plotted. The points along the base line illustrate the uncertainty caused by random noise fluctuations superimposed on a small inherent unevenness due to differences from channel to channel. However, it can be seen that a reliable zero level is easily established. The points on the profile show that the r.m.s. noise fluctuations are of the order of 1 °K.

In these initial operations the receiver is connected to a steerable parabolic aerial of beamwidth 2·8° between half-power points. Meridian transit observations are taken on fixed declinations over periods of 24 hr. This means that a low-resolution survey of the entire sky visible at latitude −34° could be made and checked in 3 months of operating time.

III. Observations

The original observations were made at 2° intervals in declination during the early testing period of the receiver. Most of these were repeated 3 months later and good agreement was found between both series. In some cases additional observations have been used to check the expected presence or absence of features.

Nearly all the profiles recorded in this survey were single peaked and appeared to have the same general shape and similar width (at least 3500 profiles were available for inspection). The average half-width of the profiles, calculated from a large randomly selected sample was 19 km sec^{-1} ($\equiv$90 kc/s) with standard deviation 2 km sec^{-1} ($\equiv 9\cdot5$ kc/s). For these reasons peak H-line aerial temperature ($T_{\text{max.}}$) is regarded as a convenient indication of the areas under the profiles and hence of the amounts of hydrogen present.

In addition the combination of conditions enables a direct conversion to be made from $T_{\text{max.}}$ to an approximate value of n_H, the number of hydrogen atoms in a line-of-sight column of 1 cm^2 section.

From the circumstances that 60 °K was the highest recorded aerial temperature and that no profile showed any tendency to flattening, it was inferred that the gas was optically thin at all points in these regions. Thus, the exact calculation of n_H following from Wild (1952) is obtained from the well-known relation,

$$n_H = 1\cdot835\times10^{13}\int_{-\infty}^{\infty} T(v)\mathrm{d}v,$$

where T is the H-line brightness temperature as a function of velocity. A mean profile with the above dimensions was integrated and the factor of proportionality $n_H/T_{\text{max.}}$ was found to be $5\cdot0\times10^{19}$ per °K. Values of n_H calculated from $T_{\text{max.}}$ and by the exact method were compared at a number of points ; the mean error was $\pm$15 per cent. and no errors greater than $\pm$30 per cent. were found.

Contours of peak H-line aerial temperature ($T_{\text{max.}}$), at intervals of $7\cdot5$ °K, are given in Figure 2. Both celestial (1958) and galactic coordinates (Ohlsson) are included. The same distribution in terms of n_H is presented in Figure 4.

To investigate the distribution of radial velocities, more than 350 uniformly distributed velocity values at the profile peaks have been worked out and corrected to the local standard of rest. The probable error involved here is $\pm$1 km sec^{-1}. This represents approximately one velocity per aerial beamwidth over the region of interest. The velocities have been smoothed by taking means over suitable areas, generally 10° by 10°. In each area at least ten velocities were available ; the maximum spread about a mean value is $\pm$3 km sec^{-1} in most cases. The mean velocities in km sec^{-1} are shown in large-print red numbers on about 30 adjacent areas in Figure 2.

IV. Discussion

The outstanding conclusion from the observations is that most of the radiation over a great part of the survey area comes from a single large cloud or connected complex. This follows from two independent lines of evidence ;

from the distribution of the quantity of hydrogen ($T_{\max.}$ contours) and from the distribution of radial velocities.

Firstly, consider the $T_{\max.}$ contours in Figure 2. They show a general decrease from left to right with increasing distance from the galactic plane. Superposed on this general slope are two lateral ridges: a large one in Taurus,

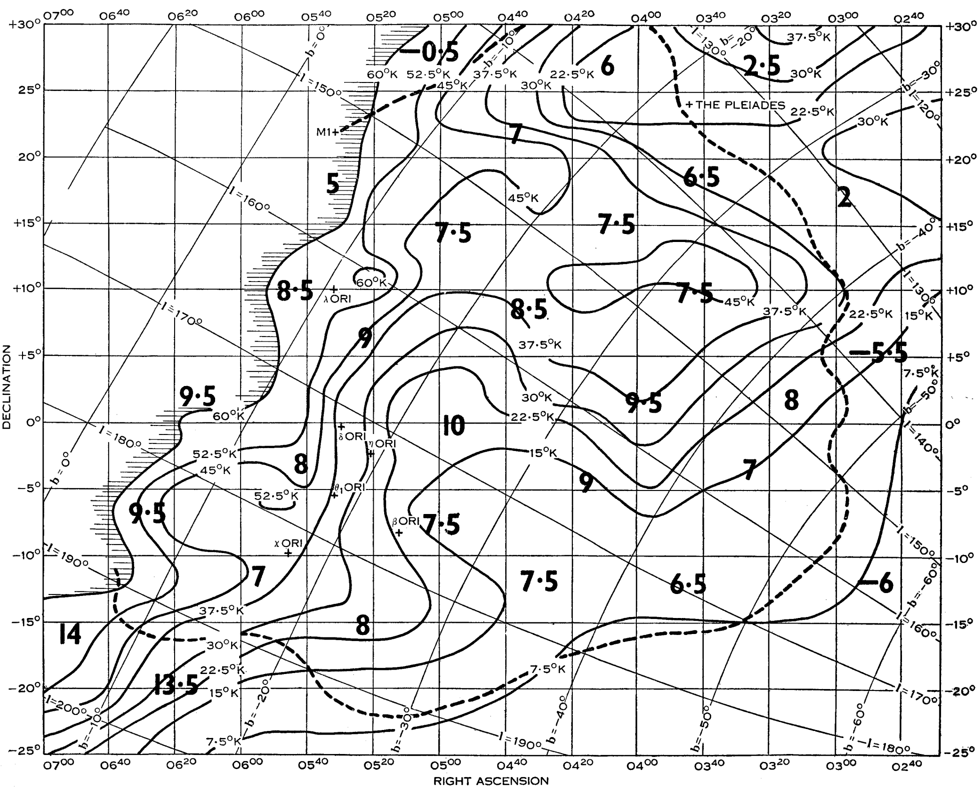

Fig. 2.—The Taurus-Orion neutral hydrogen complex. Contours at intervals of 7·5 °K represent peak H-line temperatures ($T_{\max.}$). The large-print red numbers represent the mean radial velocities in km sec^{-1} over areas usually 10° by 10°. Celestial coordinates: 1958; galactic coordinates: Ohlsson.

longitude 140–160° approximately, extending in latitude from about $b=-10°$ to $b=-45°$, and a smaller one in Orion extending approximately along $l=183°$ from $b=-5°$ to $b=-35°$.

These large-scale features on the contour map must be due to physically associated complexes of hydrogen gas. If the radiation were due to a large number of randomly distributed small clouds the structure would be of the order of size of the aerial beamwidth: 3° instead of 20°.

Even stronger arguments follow from a consideration of velocities. It will be noticed immediately that the velocities over most of Figure 2 lie within a remarkably small range of values: in the region bounded by the dotted line, all but a few lie between $+6\cdot5$ and $+9$ km sec^{-1}, while outside this boundary the velocities change abruptly. The probable association between the two main features of the cloud is again demonstrated by the distribution of these velocities. On both ridges, extending to approximately $b=-40°$, the mean velocities are closely grouped about $7\cdot5$ km sec^{-1}. The central division occupying about 25° in b by 10° in l is one of increasing velocities up to 10 km sec^{-1}. In the outer regions of the cloud (i.e. close to the dotted line in Figure 2) the mean velocities are near $6\cdot5$ km sec^{-1} and suggest a halo of gas surrounding the double feature.

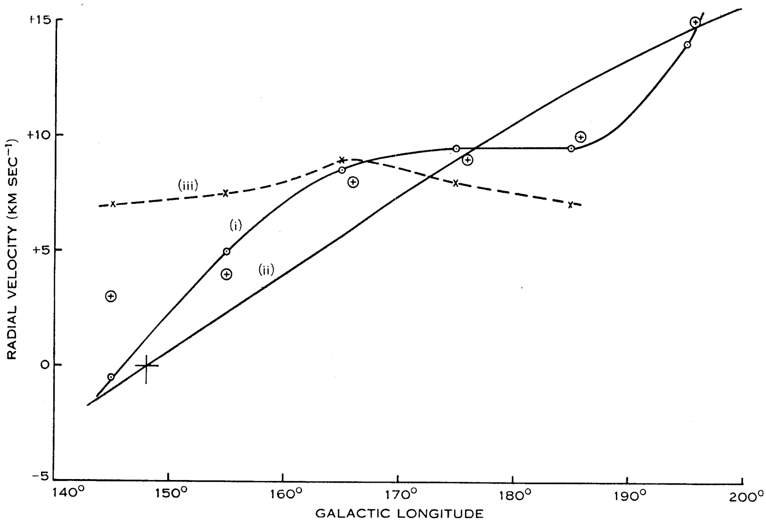

Fig. 3.—Radial velocity as a function of galactic longitude. Curve (i): the mean velocities over 10° longitude intervals between $b=-5°$ and $b=-10°$. Curve (ii): the differential galactic rotational curve through 0 at $l=148°$ and $+14$ km sec^{-1} at $l=193°$. Curve (iii): the mean velocities over 10° longitude intervals between $b=-10°$ and $b=-20°$. Points ⊕ are Leiden velocities at galactic latitude $-7\cdot5°$.

At the low galactic latitudes, the information on amount of hydrogen is cut off at the 60 °K contour. There is evidence in the recordings that parts of the cloud may extend inwards towards the galactic plane but in the vicinity of the 60 °K contour the profiles become complex, and in view of the low aerial resolution no attempt has been made to separate the relevant component.

In examining the effects of differential galactic rotation on the cloud, mean velocities taken over 10° longitude intervals between $b=-5°$ and $b=-10°$ have been plotted against galactic longitude in Figure 3. Incidentally, corresponding peak profile velocities obtained by Muller and Westerhout (1957) along $b=-7\cdot5°$ have been included and show good agreement. Figure 3 also gives the differential galactic rotational curve of best fit with values of 0 at $l=148°$ and $+14$ km sec^{-1} at $l=193°$. The mean observed velocity values $-0\cdot5$ and $+14$ km sec^{-1} may be seen from Figure 2 to represent regions outside the cloud boundary; they are close enough to the rotational curve to indicate that they are determined almost entirely by galactic rotation. On the other hand, the low-latitude velocities inside the cloud boundary lie above the sine curve up to about the mid longitude (175°), then cross it to fall below to a maximum of approximately 3 km sec^{-1} in each case. These curves would suggest, firstly, that the two regions centred on $l=145°$, $b=-7\cdot5°$ and $l=195°$, $b=-7\cdot5°$ belong to background gas rotating as part of the general spiral structure. Its distance is estimated at 430 parsecs after extrapolation from the rotational velocities table of Kwee, Muller, and Westerhout (1954). Secondly, the recorded values of velocity within the cloud boundary could well be the result of a blend of peculiar velocities of the cloud and the velocities of background gas at the 430 parsecs distance. The amount by which the two sets of values would differ falls within a channel width (6·8 km sec^{-1}) of the receiver and the separation of such components would not be detected here.

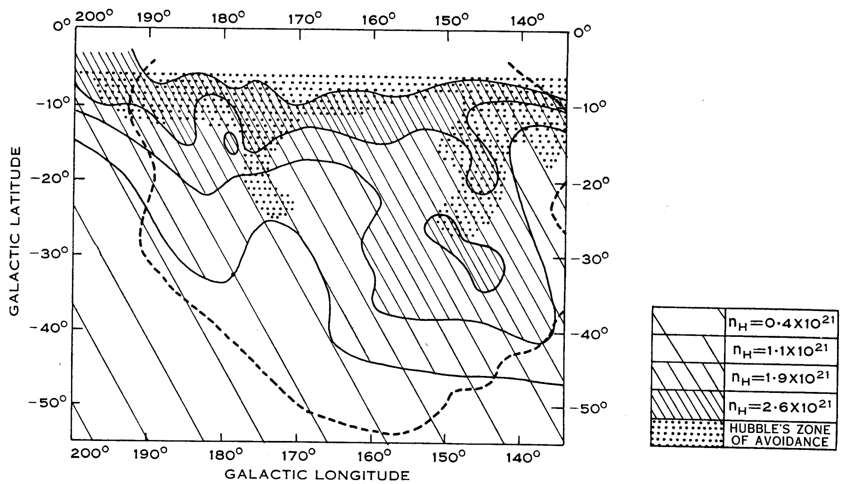

Fig. 4.—The distribution of neutral hydrogen in terms of n_H, the number of hydrogen atoms in a line-of-sight column of 1 cm^2 section, compared with Hubble's Zone of Avoidance in the Taurus-Orion region.

The third curve in Figure 3 in which the velocities of the adjacent regions within the cloud (centred on $b=-15°$) are plotted, illustrates that evidently very little differential galactic rotation occurs across the cloud: say, 1 km sec^{-1} at the most. Reference to Figure 2 will show that the same type of curve exists at all the higher latitudes inside the boundary.

The existence of these extensive regions where the peculiar velocities are predominant and no obvious gradient with longitude exists, would suggest that the cloud is quite close. For example, assuming that the differential galactic rotation across the cloud was 1 km sec^{-1} and that line-of-sight velocities depend on galactic rotational dynamics alone, we should place the cloud at about 20 parsecs from the Sun. The linear dimensions would then be 24 parsecs in l by 20 parsecs in b; assuming a thickness of 25 parsecs an average density would be 23 hydrogen atoms per cm^3.

However, against these considerations is the possibility of the association of the cloud with dust complexes whose distances have long been established. Lilley (1955), using the results of a one-dimensional, 21 cm survey along $l=147°$ and $b=-15°$, has found good correlation between the optical depths of gas and dust. The degree of correspondence can be judged more readily from the two-dimensional evidence of Figure 4. The locations of the dust clouds have been indicated by reproducing Hubble's (1934) Zone of Avoidance for this part of the sky. The double-ridged feature exhibited by the n_H (or $T_{\text{max.}}$) contours coincides partially, particularly at the higher values, with the areas of dust. However, the hydrogen in each ridge covers a considerably larger area than the dust and in the Orion region the centre-line of the main ridge of hydrogen is displaced by almost 10° from the Orion flare of the Avoidance Zone.

If it now be assumed that the association of the dust clouds with the hydrogen cloud be genuine a very different estimate of dimensions and density results. Greenstein (1937) has given a distance of 145 parsecs for the absorbing clouds in Taurus and Orion. At this distance linear dimensions of 175 parsecs in l and 145 parsecs in b could be deduced and for a cloud thickness of 100 parsecs the average density would be 6 hydrogen atoms per cm^3. In making these deductions we have ignored considerations of galactic rotation effects on the cloud; the theoretical galactic rotational velocity gradient expected at 145 parsecs is 0 to $+5$ km sec^{-1}.

V. Conclusion

Our knowledge of the distribution of neutral hydrogen over the sky should include a general survey of the large-scale features as well as detailed studies of special features such as those reported by Menon (1956) and Wade (1957) in the Orion region. The results of this survey demonstrate that in the investigation of the general distribution a low-resolution aerial still has real value when coupled with a receiver capable of producing very many profiles. It would have been a long and difficult task to delineate such a large object as the Taurus-Orion cloud with the frequency-sweeping type of receivers in present use.

VI. Acknowledgments

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