22. MATTER FAR FROM THE GALACTIC PLANE ASSOCIATED WITH SPIRAL ARMS

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Abstract. Neutral hydrogen concentrations were studied in the region between 48° and 200° longitude (new) and +6° and +20° latitude. Gas associated with individual arms beyond the sun has been found up to distances from 1 to 2 kpc from the galactic plane with an average density between 1 and 2% of that in the arm centres. The gas with the highest negative velocities shows a different behaviour. This has no counterpart in the plane, and it shows little or no concentration towards lower latitudes. Contrary to the hydrogen associated with the arms its distribution is highly asymmetrical. It does not seem to exist at negative latitudes. It may be of a similar origin as the high-velocity gas in high galactic latitudes near the sun.

It is of interest to investigate how far spiral arms extend in a direction perpendicular to the galactic plane.

For the part inside the sun's orbit we have Schmidt's (1957) data; he finds that in this whole inner region there is still a density of 2.5% of that in the central disk at $z=560$ pc. In an unpublished investigation based on observations with a much smaller beamwidth W. W. Shane finds for $R=5$ kpc a density of 0.010 cm^{-3} at $z=520$ pc. For $R=7$ kpc this density is reached at $z=600$ pc. This should be compared with an average density in the plane (average of spiral arm and inter arm) of about 0.5 or 0.4, so Shane finds 2 to 2.5% density at $z=520$ and 600 pc, in very good agreement with Schmidt. Simonson has found several discrete features at about 1000 pc from the galactic plane and probably connected with arms within 4 kpc from the centre. They have masses of the order of 10^5 solar masses, and are similar to the clouds previously studied by Gail Smith and by Prata in the same general region.

In this inner region of the Galaxy it is difficult to decide whether such features are associated with specific arms (although this seems likely). The relation between halo features and spiral arms can, however, be observed quite well in the arms beyond the sun. An extensive investigation of the Perseus and outer arms has recently been made in Leiden by Miss Kepner. It covers the region between 48° and 200° longitude and +6° and +20° latitude.

Figure 1a shows three samples of the velocity distribution of hydrogen atoms at intermediate latitudes for the longitude range investigated, which includes the entire region where the Perseus arm is well defined, and a large part of the outer arm. The circles and points plotted give the velocities of well-defined humps, or, sometimes, shoulders in the line profiles. The vertical lines indicate the half widths of the components on the velocity scale. The hatched regions show the velocities of the principal arms in the galactic plane. One can see from this diagram that around the velocities corresponding to these various arms hydrogen is concentrated also at the higher latitudes. Although in the longitudes concerned the entire outer-arm structure is elevated above the average galactic plane, as part of the well-known bending of

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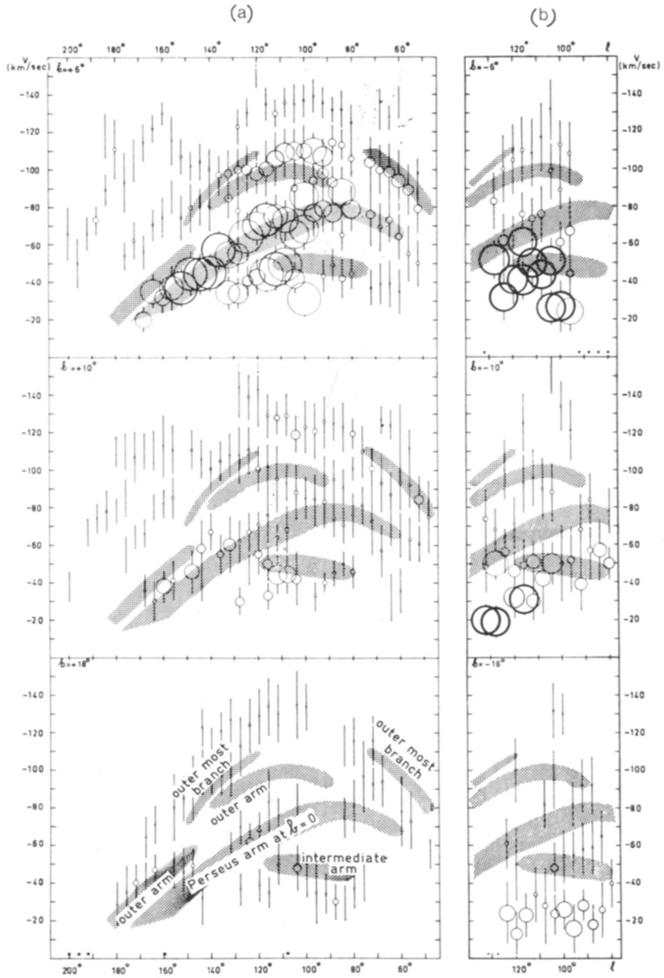

Fig. 1. (a) Three samples of the velocity distribution of hydrogen atoms at intermediate latitude. (b) The same for southern latitudes.

the outer parts of the galactic layer, this effect is small compared with the much higher latitudes considered in this study.

The effect of the clustering of the velocities around the same value at the various latitudes is clearly shown in Figure 2.

With plausible values for the distances to the various arms we find from Miss Kepner's data that in the Perseus arm the average density drops to 1% of the density in the centre of the arm only at z-distances varying between 700 and 2400 pc from the plane of symmetry of the arm, the median being about 1400 pc. In the majority of the longitudes there appears still to be at the latitudes concerned ($+10°$ to $+15°$) an observable concentration near the velocity of the arm.

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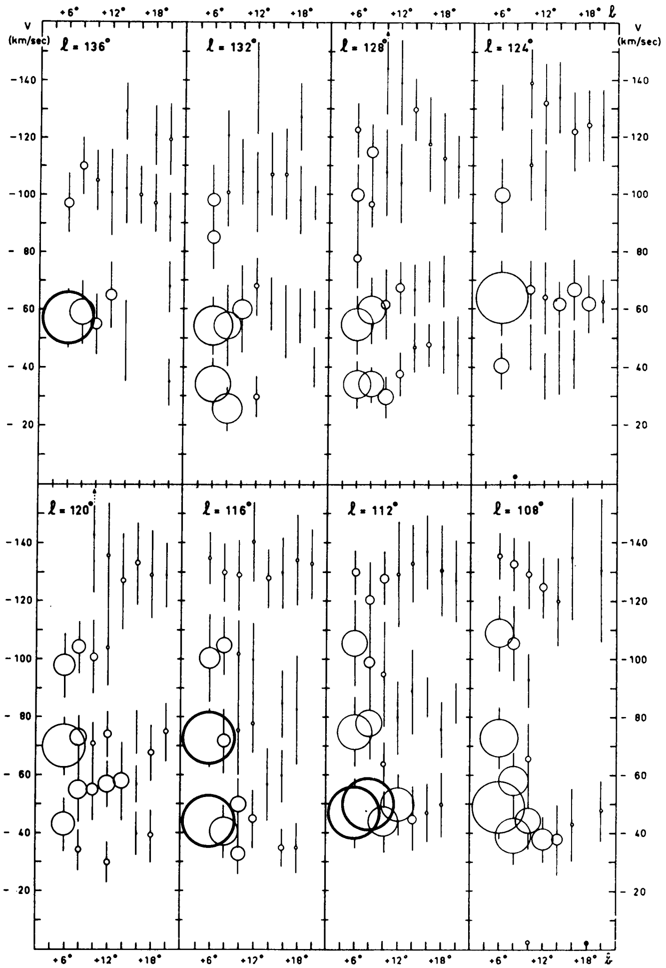

Fig. 2. The effect of clustering of the velocities.

A similar extension to high z-values is found for the outermost branch of the outer arm. Here the density has dropped to about 2% at a distance between 1 and 2 kpc from the plane through the arm.

This is for Northern galactic latitudes. Observations for Southern latitudes are less complete, and have not yet been discussed in detail. A preliminary survey of the data by Mr. Hulsbosch indicates that the extension South of the plane is quite similar to that North of it (Figure 1b).

At the distance of the Perseus arm a star in the galactic plane would need a velocity component perpendicular to the plane of about 55 km s^{-1} for reaching a maximum height of 1400 pc. In order that gaseous filaments could penetrate to such distances their velocity of expulsion from the disk must, of course, be very much higher, because

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of deceleration by the interstellar medium. In fact, they could probably escape from the disk only by an extremely violent event involving very large masses of gas.

One might wonder how under these circumstances the velocities of the gas observed at these heights could still show a distinct clustering around the velocity corresponding to that of the arm in the plane. This must be due to the fact that only the clouds expelled in directions making very large angles with the plane can manage to leave the central layer of gas.

At several positions in Miss Kepner's survey exceptionally high intensities are found, exceeding those in adjacent longitudes by factors from 4 to 10.

Table I shows the most striking examples found in this material.

TABLE I

Positions of high intensity

	l^{II}	b^{II}	v ($km\ s^{-1}$)	z (kpc)	mass H I ($10^6\ M_\odot$)
I	52° to 60°	10° to 12°	−78	3.1	2.0
II	120	8 14	−62	1.1	0.2
	124	14 18			
III	104	14 20	−50	2.1	0.3

The brightness temperatures of these features are between 4° and 5°. Estimates of the H I mass are given in the last column, in units of 10^6 solar masses. It will be seen that the masses are extremely high for matter pushed out to heights between 1 and 3 kpc from the galactic plane.

A similar phenomenon at negative latitudes was discovered long ago by Mrs. Hack and van Woerden, and has been discussed by Blaauw (1962). These authors found two clouds around $l^{II} = 135°$, $b^{II} = -11°$, with velocities of −48 and −26 $km\ s^{-1}$, respectively. They suggested that these masses may have been expelled from the h and χ Persei association, which lies at the same longitude. In that case the mean distance from the plane would be 0.4 kpc, and the total mass $0.18 \times 10^6\ M_\odot$.

In the present material there is an indication of a similar mass concentration at a velocity of about −35 $km\ s^{-1}$ and at longitudes 132° and 128°, latitudes +6° and +8°. However, more observations would be required to see whether or not this is connected with the phenomenon of Van Woerden, Hack and Blaauw.

It seems probable that all the gas at large distances from the plane will be swept down into the central layer in times of the order of a few times 10^7 yr. It must, therefore, be replenished in a similar interval.

It follows that every few times 10^7 yr the interstellar medium must be violently shaken up.

Before concluding this account of the observations in the lower intermediate Northern latitudes I should say a few words about the gas with velocity in excess of the velocities of known spiral arms. The primary incentive to the investigation was to search for such high-velocity gas at large distances from the sun.

It will be noted that over the greater part of the region surveyed there is hydrogen with negative velocity considerably exceeding that of the outermost spiral arms. This gas has a distribution in latitude which is strikingly different from that of the gas which is related to the arms: in the latitude interval studied it shows little if any tendency of concentration towards the lower latitudes. Moreover, this gas is *not* found in *negative* galactic latitudes.

This phenomenon was first discovered and extensively discussed by Habing (1966), who investigated a region from 42° to 142° longitude.

Especially noteworthy in the new survey are the high negative velocities (between -100 and -120 km s^{-1}) in the anticentre region. Can this be an outlying spiral arm whose motion has a radial component of 110 km s^{-1} directed towards the galactic centre, – and which lies far from the galactic plane, on the opposite side of the outer arm studied by Lindblad (1967) which near $l^{II} = 180°$ has a latitude of $-9°$? Or is this high-velocity gas similar to that which has been observed in high galactic latitudes, but here at greater distances from the sun? If the latter interpretation is the correct one it probably applies to all of the hydrogen in the present survey observed at velocities exceeding that of the outermost branch of the outer arm. Much of this might possibly be gas falling from outside into the Perseus arm. The circumstance that the high-velocity gas discussed by Habing and by Miss Kepner shows the same asymmetry with respect to the galactic plane as the high-velocity clouds in high latitudes, both being predominantly observed at positive latitudes, is an indication that we are dealing with the same phenomenon in the two cases.

A full account of Miss Kepner's investigation will appear in *Astronomy and Astrophysics*.

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Discussion

Van Woerden: Oort says that the gas at large distances from the plane will be swept back into the plane in about 30 million years and therefore has to be replaced. Although it is probable (but not at all certain) that in 10^8 or 10^9 years from now there will be similar amounts of gas far from the plane as today, I think there is no reason at all to view the replacement process along lines of detailed balancing. Our galaxy may look different then, at least in detail; we should not consider the gas distribution as an equilibrium configuration.