THE MAGELLANIC STREAM: OBSERVATIONAL CONSIDERATIONS

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GLOBAL CHARACTERISTICS

The Magellanic Stream is an arc of neutral hydrogen which nearly follows a great circle and which contains the Magellanic Clouds - hence its name (Mathewson, Cleary and Murray 1974). This great circle passes within a few degrees of the south galactic pole and lies close to the supergalactic plane. Mathewson and Schwarz (1976) argued that this indicates that the Magellanic Stream and Magellanic Clouds are not bound to the Galaxy. To reinforce this argument, they pointed out that around the supergalactic plane there is a similar systematic variation in the velocities of the Local Group and those of the Stream which may be due to the reflection of the motion of the galactic center if the velocity of rotation of the Sun is 225 km s^{-1}; if it is 290 km s^{-1} then the grounds for this argument would disappear.

THE SECTION BETWEEN THE MAGELLANIC CLOUDS AND THE GALACTIC PLANE AT l=306°

The Magellanic Stream (as first defined) has two sections; the main section is on the south galactic pole side of the Magellanic Clouds and the velocity varies in a systematic manner along its length whilst the other section is comprised of some small clouds scattered between the Magellanic Clouds and the galactic plane which show no systematic velocity variation (Wannier and Wrixon 1972 and Mathewson et al. 1974). Figure 1 shows the results of an HI survey of four of these clouds with the 64-m reflector at Parkes. The clouds 312+1+180 and 306-2+230 have regions with narrow velocity half-widths of about 8 km s^{-1} whilst other parts have much broader half-widths of about 30 km s^{-1}. This two component structure is common in the northern high velocity complexes (c.f. Hulsbosch 1975). It is not found in the main section of the Magellanic Stream where velocity half-widths mostly lie between 20-40 km s^{-1}.

It is interesting that the reflections of 312+1+180 and 306-2+230 in the galactic plane almost coincide with the northern high velocity complexes 131+1-200 and 122+1-197. This may mean that the Sun is moving

W. B. Burton (ed.), The Large-Scale Characteristics of the Galaxy, 547–556.

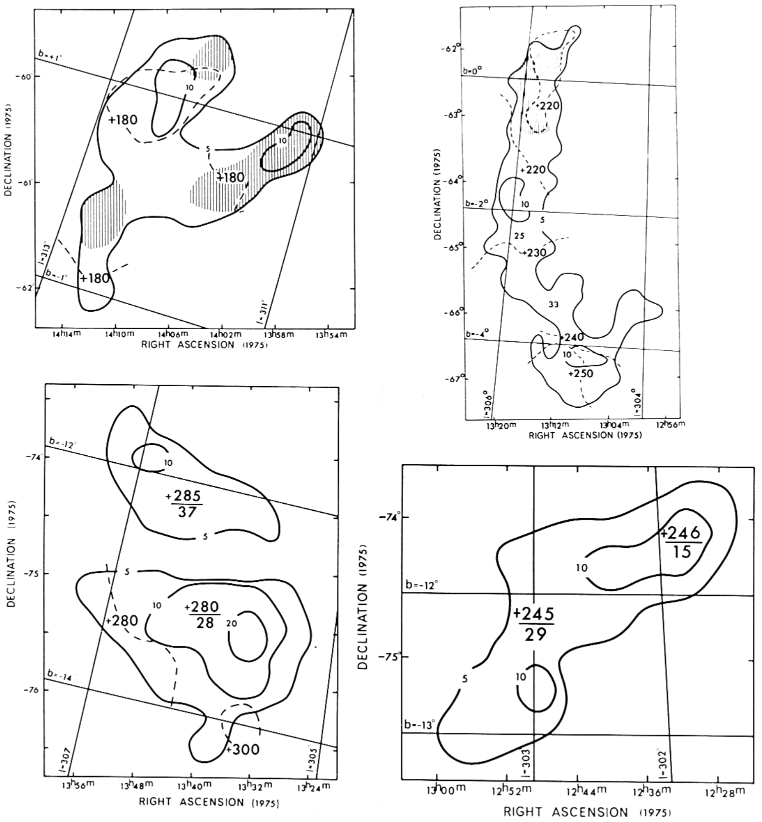

Figure 1. HI surface densities (full lines) of four high velocity clouds between the Magellanic Clouds and the galactic plane observed with the 64-m reflector at Parkes. The contour unit is 10^{19} atoms cm^{-1}. Radial velocity contours are dashed and the contour numbers are V_{LSR} (km s^{-1}). In the bottom two diagrams, the numbers above the lines are regionally representative V_{LSR} whilst those below the lines are velocity half-widths (km s^{-1}). In the top two diagrams, the shaded areas are regions where the velocity half-widths are very narrow, about 10 km s^{-1}.

through an elongated HI complex which is not partaking in galactic rotation. This, together with the two component velocity structure and lack of systematic velocity variation, suggest that this section does not belong to the Magellanic Stream.

A SEARCH FOR OTHER COMPONENTS

Deep plates of the region of the Magellanic Stream reveal nebulosities in some areas. Spectroscopy shows that these must be reflection nebulosities similar to those found by Sandage (1976) at high latitudes and illuminated by the galactic plane. Hα plates taken by Dr. K. H. Elliot with the SRC Schmidt telescope confirm that there are no emission nebulosities associated with the Stream.

Star counts of SRC Schmidt blue plates show no stellar component of the Stream which confirms the negative result from photographic photometry of UBV plates taken with the Uppsala Schmidt telescope. It should be mentioned here that Philip (1976a) claimed to have discovered a blue stellar component of the Magellanic Stream but has since withdrawn his claim as further work showed that the stars were either subdwarfs F-type or white dwarfs (Philip 1976b).

As part of the search program, the region between the LMC and SMC was observed and the stellar wing of the SMC (Westerlund and Glaspey 1971) was found to extend to R.A.03^h15^m. Radial velocity measurements of these stars showed that several were born in regions of HI surface density of only 3×10^{20} atoms cm^{-2} whilst some other regions of higher density had no stellar component. The maximum HI surface density in the Magellanic Stream is 5×10^{20} atoms cm^{-2} at R.A.00^h54^m, Dec.$-49°30'$ (1975.0).

Galaxy counts were made on the SRC Schmidt plates to about 250 galaxies per square degree and an upper limit of 0.2 mag was placed on A_V in the directions of the denser parts of the Stream. However a real decrease in galaxy counts was found in the wing of the SMC as far out as R.A.02^h36^m (HI surface density of 5×10^{20} atoms cm^{-2}) where the absorption was estimated to be 0.3 mag. It is worth pointing out that the dust ridge line lies 40 min of arc to the south of the HI ridge line. This displacement may be produced by radiation pressure of the light from the LMC and SMC on the dust particles (Chiao and Wickramasinghe 1973).

Lynden-Bell (1976) hypothesised on the association between some outlying satellites of the Galaxy and the Magellanic Stream and some northern high velocity HI complexes. Hartwick and Sargent (1978) recently measured radial velocities of these objects and in all cases except Ursa Minor, there were large differences between their velocities and that of the HI. They deduced that no association exists.

Radio continuum observations of the Magellanic Stream at 408 MHz and 1420 MHz using the 64-m reflector show no evidence for emission although the background is irregular which makes an accurate measurement difficult. HI absorption measurements were made using the background continuum radio source at R.A.$00^h39^m48^s$, Dec.$-44°29'16''$ (1950) which allowed a lower limit of 30°K to be placed on the spin temperature of the HI of the Stream in that direction.

To sum up, the Magellanic Stream has only been detected by HI emission measurements. However it would be worthwhile to make UV observations with the IUE around R.A.00^h54^m, Dec.$-49°30'$ (1975.0), the region of maximum HI emission in the Magellanic Stream.

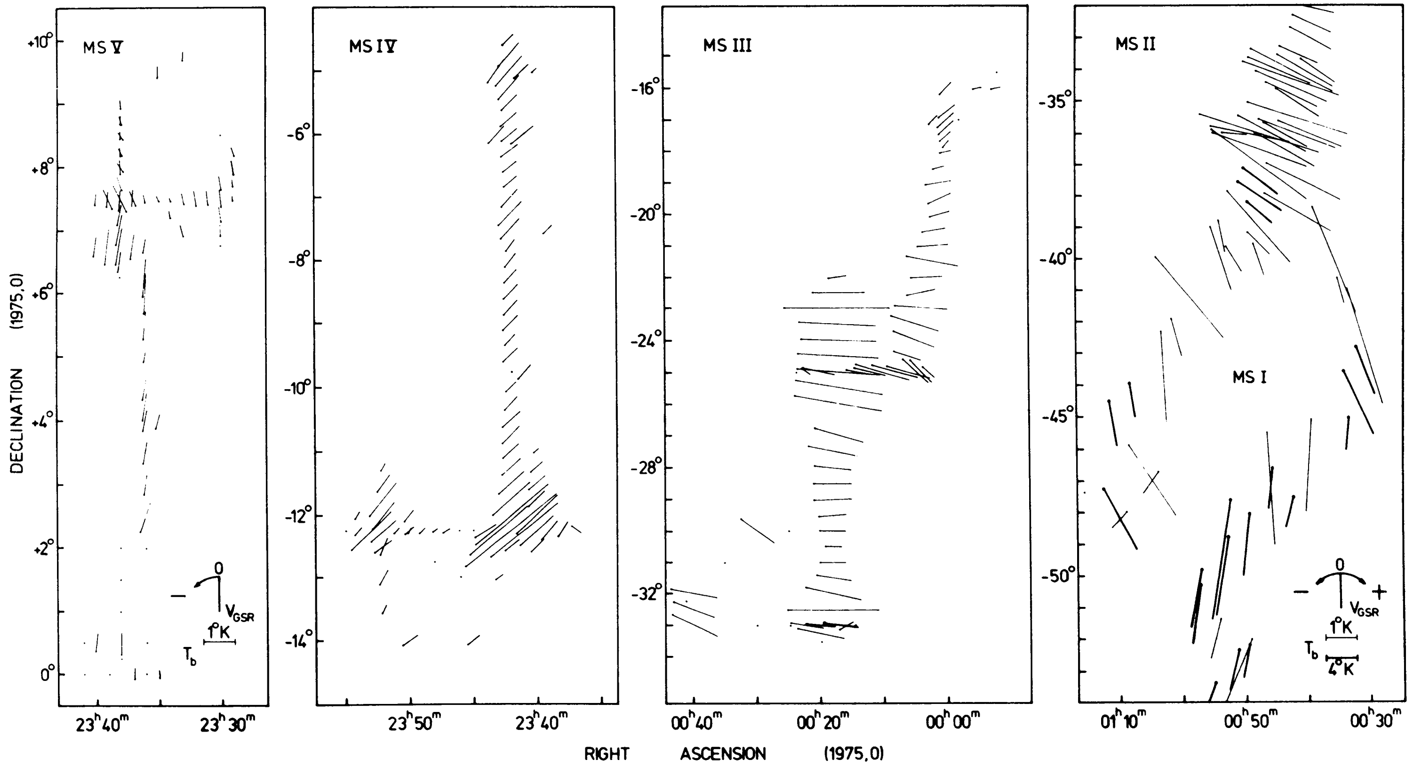

Figure 2. The velocity field along the ridge lines of the clouds of the Magellanic Stream observed with the 64-m reflector. The angle the lines make with the vertical represent V_{GSR}, the radial velocity in km s^{-1} corrected for a galactic rotation at the Sun of 225 km s^{-1}, of the peaks in the HI profiles. Dots indicate the head of each line e.g., MSIV and MSV have an average V_{GSR} of -135 km s^{-1} and -175 km s^{-1}, respectively. Anticlockwise rotation indicates a negative velocity. The length of the lines represent T_b (°K) of the peaks (see scales in bottom RH corner).

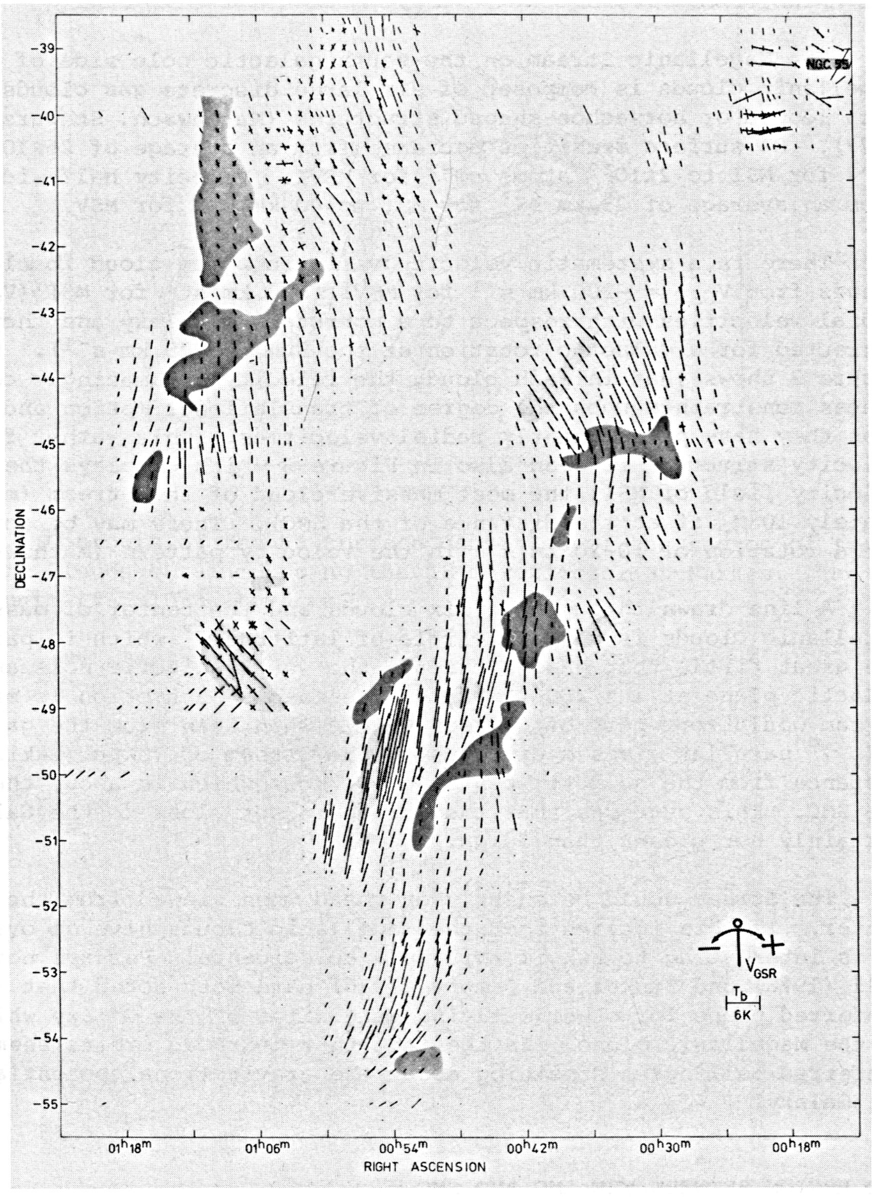

Figure 3. The velocity field of MSI obtained with the 64-m reflector. The angle the lines make with the vertical represent the radial velocity V_{GSR} (km s^{-1}) of the peaks in the HI profiles. Where velocities exceed 90 km s^{-1}, a dot marks the head of each line. Anticlockwise rotation indicates negative velocity. The length of the lines represent T_b (°K) of the peaks (see scale in bottom RH corner). The light and dark shaded regions are areas where velocity half-widths are about 20 km s^{-1} and >40 km s^{-1}, respectively. The co-ordinates are for 1975.0.

THE MAINSTREAM

The Magellanic Stream on the south galactic pole side of the Magellanic Clouds is composed of six large discrete gas clouds MSI-VI with looped or horseshoe-shaped structures (Mathewson, Schwarz and Murray 1977). HI surface densities decrease from an average of 26×10^{19} atoms cm^{-2} for MSI to 2×10^{19} atoms cm^{-2} for MSVI. Velocity half-widths increase from an average of 25 km s^{-1} for MSI to 40 km s^{-1} for MSV.

There is a systematic velocity variation from cloud to cloud which ranges from V_{GSR} = -200 km s^{-1} for MSVI to 0 km s^{-1} for MSI (V_{GSR} are radial velocities with respect to a nonrotating galaxy and they have been corrected for a galactic rotation at the Sun of 225 km s^{-1}). However Figure 2 shows that in each cloud, the velocity is amazingly constant which places constraints upon the degree of translational motion and suggests that they have predominantly radial velocities. This rather featureless velocity structure is seen also in Figure 3 which displays the entire velocity field of MSI, the most massive cloud of the Stream (mass approximately $10^8 M_\odot$ if at the distance of the SMC). There may be some evidence for a rotation of 10-20 km s^{-1} in the velocity pattern (Mathewson 1976).

A line drawn through the six clouds and the center of mass of the Magellanic Clouds is a small circle of latitude 7° which is parallel to the great circle that passes through the south galactic pole and cuts the galactic plane at l = 280°. If the reasonable assumption is made that the Stream would form part of a great circle when seen from the galactic center, this 7° parallax gives a distance to the Stream of 70kpc (taking the Sun's distance from the galactic center as 8.5kpc) which is about the distance of the SMC. This suggests that the Stream is not close to the Galaxy, certainly not closer than 30kpc.

The Stream would be exactly overhead when viewed from the galactic center. If this implies that the Magellanic Clouds have an overhead orbit, it is interesting to ask if this is a coincidence. Perhaps not, as Lynden-Bell (1976) and Kunkel and Demers (1976) have both noted that there is a preferred plane for other outlying satellites of the Galaxy which is close to the Magellanic plane. Is the fact that overhead orbits seem to be preferred telling us something about the gravitational potential field of the Galaxy?

THE REGION BETWEEN THE LMC AND SMC

Figures 4, 5, 6 and 7 show some results from an HI survey of the inter-Cloud region using the 18-m and 64-m reflectors at Parkes. Briefly the main features of these new observations germane to this discussion are:
a) HI spurs are found to run out almost at right angles to the strong bridge of gas connecting the LMC and SMC and point in the direction of the Magellanic Stream. In particular, the strongest spur at R.A.01^h50^m, Dec. -68° (Fig. 6) points almost directly at MSI. These spurs make this side

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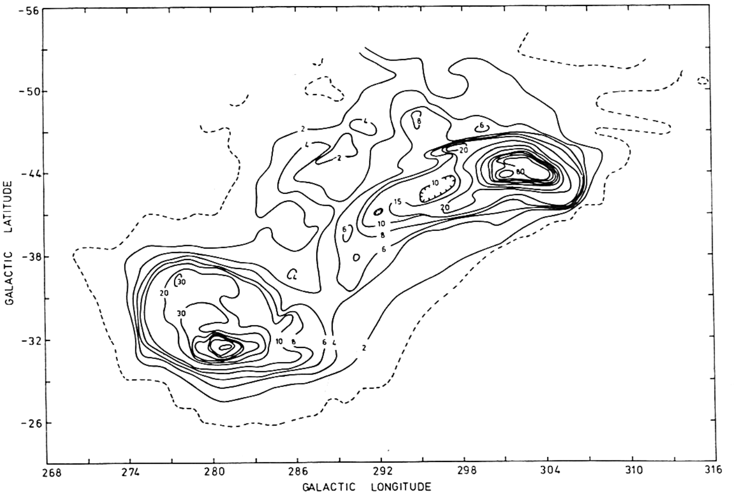

Figure 4. Contours of the HI surface densities of the region of the Magellanic Clouds obtained using the 18-m reflector at Parkes. The contour unit is 5×10^{19} atoms cm^{-2}.

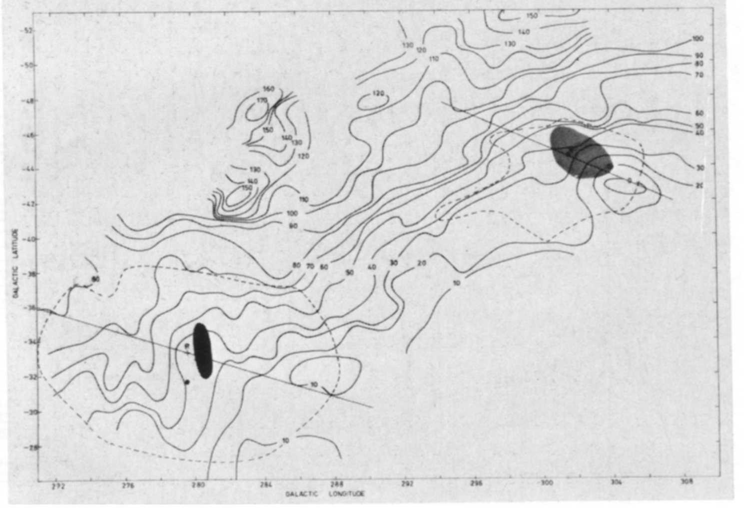

Figure 5. Contours of the center radial velocity V_{GSR} (km s^{-1}) of the HI profiles obtained using the 18-m reflector in a survey of the Magellanic Clouds. The effects of a translational motion of 250 km s^{-1} of the Magellanic Clouds along the great circle of the Stream in the direction of the galactic plane has been removed from the observed velocities. This correction does not appreciably alter the velocity field. The dashed contours give the outer limits of the clusters in the LMC and SMC, the straight lines indicate the major axes of the two galaxies and their centers of rotation are labelled R.

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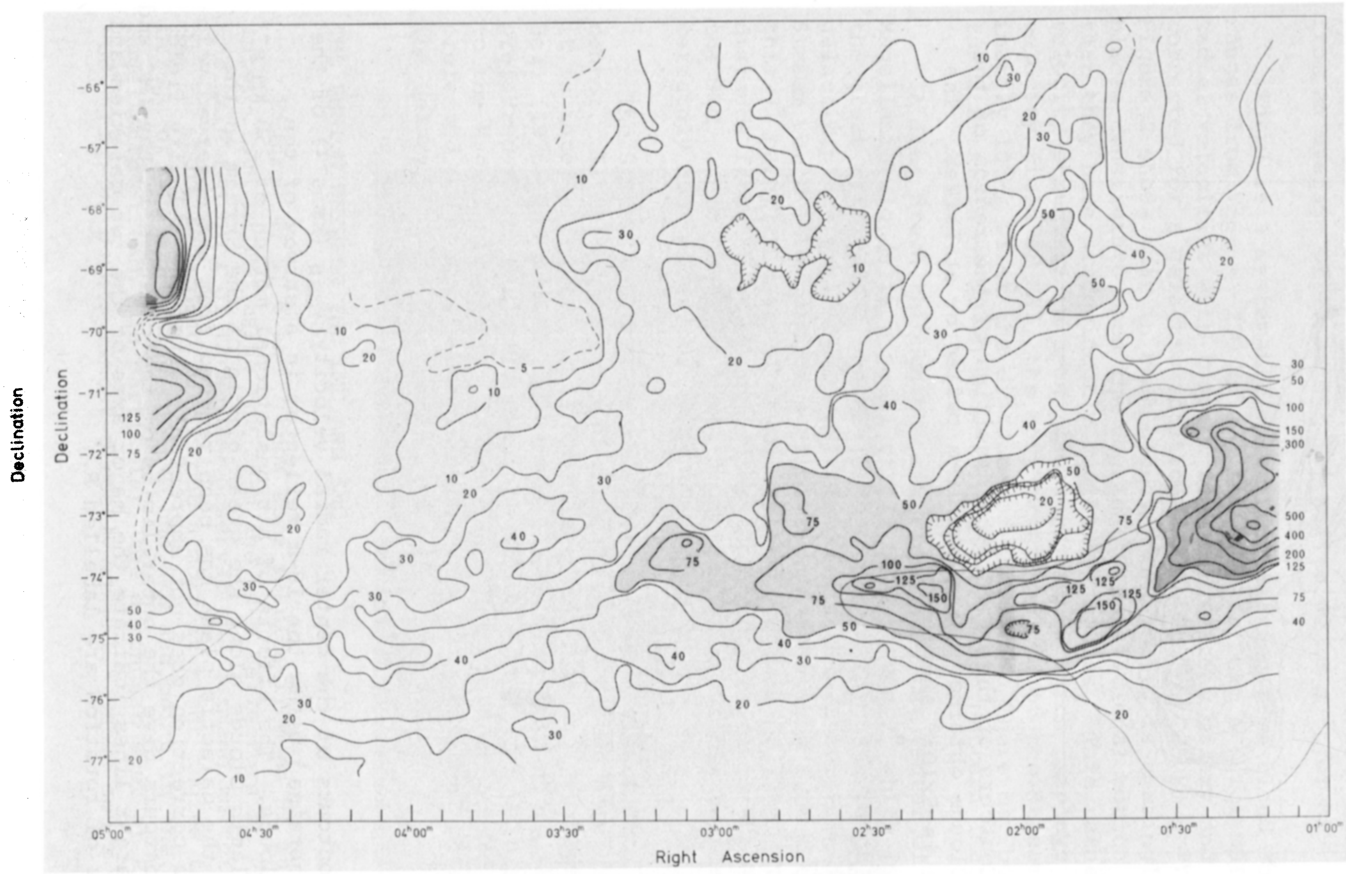

Figure 6. Contours of HI surface densities for the region between the Large and Small Magellanic Clouds obtained using the 64-m reflector at Parkes. The contour unit is 10^{19} atoms cm^{-2}. The shading indicates regions of different contour interval. Co-ordinates are for 1975.0.

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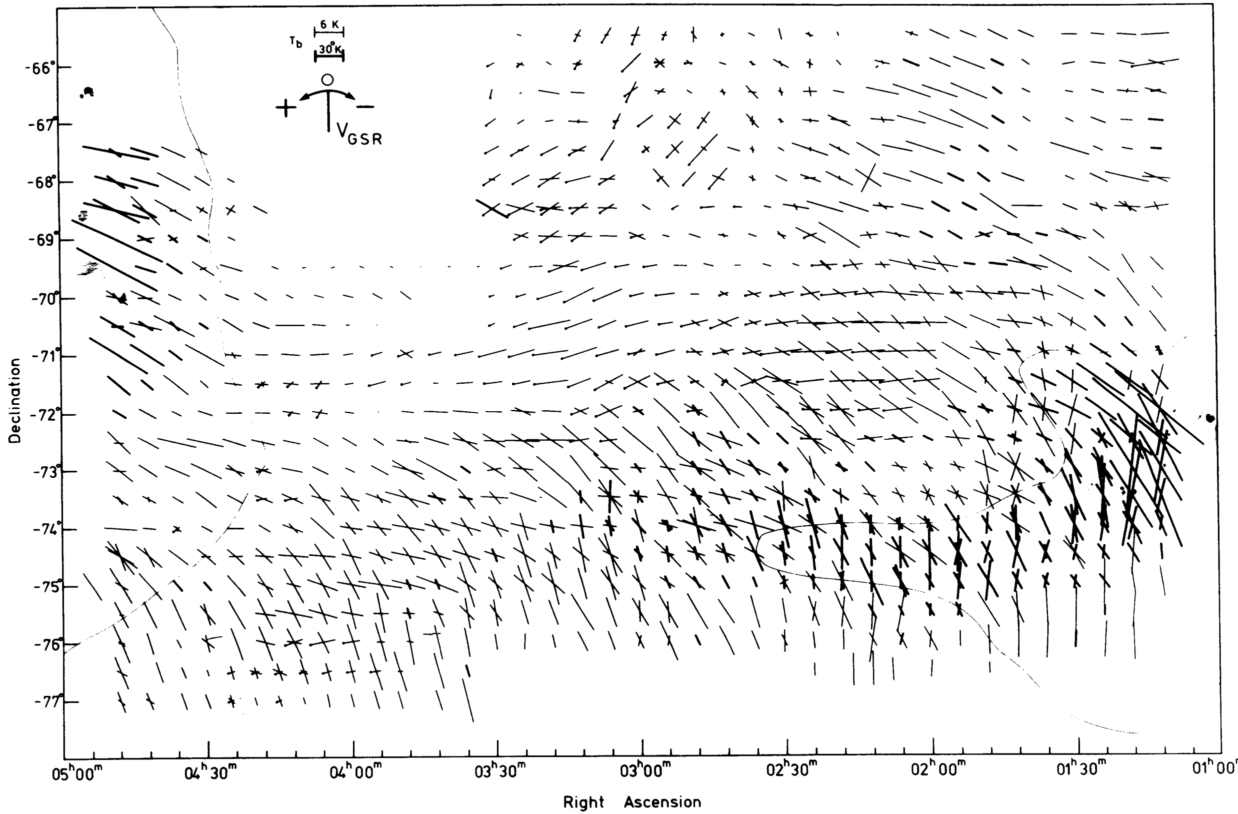

Figure 7. The velocity field of the region between the LMC and SMC obtained using the 64-m reflector. The angle the lines make with the vertical represent the radial velocity V_{GSR} (km s^{-1}) of the peaks in the HI profiles. Anticlockwise rotation indicates + ve velocity. Most velocities are + ve and always <180 km s^{-1}. Negative velocities are confined to a small area in the bottom RH corner. The length of the lines represent T_b (^oK) of the peaks (see scales in top LH corner).

of the inter-Cloud region extremely irregular which is in marked contrast to the straight, steep edge of the HI on the opposite side.

b) The radial velocity contours of the inter-Cloud region connect smoothly with the radial velocity contours of the HI in the LMC and SMC. This, plus the continuity of the general velocity gradient across the whole Magellanic System strongly suggests that the two galaxies form a bound system. This large velocity gradient of 100 km s^{-1} across the inter-Cloud region leads to a large velocity discontinuity of about 80 km s^{-1} between the end of this gas envelope around the Magellanic Clouds and the start of MSI. Indeed in the region around R.A.03^h15^m, Dec.-68°, the radial velocity of the HI is greater than the escape velocity.

REFERENCES

Chiao, R.Y., and Wickramasinghe, N.C.: 1973, Astrophys. Lett. 14, 19.
Hartwick, F.D.A., and Sargent, W.L.W.: 1978, Ap.J. 221, 512.
Hulsbosch, A.N.M.: 1975, Astron. & Astrophys. 40, 1.
Kunkel, W.E., and Demers, S.: 1976, R.Greenwich Obs. Bull. No. 182, 241.
Lynden-Bell, D.: 1976, M.N.R.A.S. 174, 695.
Mathewson, D.S., Cleary, M.N., and Murray, J.D.: 1974, Ap.J. 190, 291.
Mathewson, D.S.: 1976, R. Greenwich Obs. Bull. No. 182, 217.
Mathewson, D.S., and Schwarz, M.P.: 1976, M.N.R.A.S. 176, 47p.
Mathewson, D.S., Schwarz, M.P., and Murray, J.D.: 1977, Ap.J. 217, L5.
Philip, A.G.C.: 1976a, Bull. A.A.S. 8, 352.
Philip, A.G.C.: 1976b, Bull. A.A.S. 8, 532.
Sandage, A.R.: 1976, A.J. 81, 954.
Wannier, P., and Wrixon, G.T.: 1972, Ap.J. 173, L119.
Westerlund, B.E., and Glaspey, J. 1971, Astron. & Astrophys. 10, 1.

DISCUSSION

Basu: You showed that among the Local Group of galaxies the spirals are the most massive ones. In general, spiral galaxies have high masses. This may suggest that only those galaxies which are capable of forming a superdense body at the center, which subsequently undergoes explosions, can appear as spirals. This would not be the case if a galaxy has a mass much less than 10^{10} $M_\odot$. This also suggests that spiral phenomena are associated with explosions at the center.

Felten: In my ignorance of the subject, the following point escaped me: You deduced a distance of 50-60 kpc on the basis that if this distance is correct then the clouds lie on a great circle as viewed from the galactic center. But why should they lie on such a circle?

Matthewson: If they are in orbit about the galactic center, then they will lie on a great circle as viewed from the center.

Verschuur: The uniform velocity patterns within clouds suggest that they are falling in radially.