Spectral types in the direction of the Magellanic Stream

E. Recillas-Cruz* Instituto de Astronomía, Universidad Nacional Autónoma de México and Osservatorio Astronomico di Padova, I-35100 Padova, Italy.

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Summary. Deep hypersensitized UKSTU objective-prism plates have been used in a search for faint blue spectra belonging to early-type stars in the direction of the Magellanic Stream. The two regions studied here are coincident with the small dense neutral-hydrogen condensations near the northern tip of the Stream studied by Mirabel et al. (1979). Unwiden spectra in these regions were visually inspected and classified and the results analysed, in the hope of detecting large numbers of early-type stars at faint magnitudes which might belong to the Magellanic Stream. From apparent magnitude and spectral type estimates, we conclude that the number of early A-type stars found per square degree is almost a factor of 10 lower than what we should expect if the Stream originated out of a tidal stripping by gravitational interaction between one of the Magellanic Clouds and our own Galaxy some $2 \times 10^8$ yr ago. Furthermore, the absence of such a stellar component is discussed in terms of the assumed distance to the Magellanic Stream.

1 Introduction

The Magellanic Stream is a narrow band of neutral hydrogen that extends for more than 60° from the South Galactic Pole to the region near the galactic plane at $l = 90°$ and $b = -35°$ describing nearly a great circle which includes the Magellanic Clouds. First detected in the 21-cm surveys of Wannier & Wrixon (1972) and Mathewson, Cleary & Murray (1974), its characteristic high-negative velocity features, together with its large angular extension, the smoothness of the radial velocity profile and its narrowness, have defied every attempt to explain its origin as well as its dynamical relationship with the Magellanic Cloud and Milky Way systems. Higher sensitivity 21-cm surveys by Mirabel et al. (1979) have shown the structure of the Stream to consist of narrow filaments with small cloud-like concentrations embedded in them. These small-scale H I clouds have typical angular dimensions of $0.4 \times 0.6$ although some regions do contain higher density concentrations 5 to 15 arcmin in diameter.

* Present address: Instituto de Astronomía, UNAM, Apdo. Postal 70-264, México 04510, DF, México.

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It was decided to search for a corresponding 'high stellar density' in precisely these regions in order to detect the presence of early-type stars of apparent magnitude around $m_v = 18.5$ which would coexist with such a large mass of neutral gas (Oort 1981, private communication). The eventual detection of stars belonging to the Stream will not only give a reliable value for the distance to such a gaseous feature but also will allow the determination of a better rotation velocity $\theta_0$ at the Sun's distance from the Galactic Centre. Furthermore, a definite value for the galactocentric distance to the Magellanic Stream will put some constraints on the different models that have been proposed to explain its characteristics and origin, based on the presence of a particular stellar population. A new value for the mass of our Galaxy can also be inferred from the dynamics of and distance to the Stream (Lynden-Bell 1976; Lin & Lynden-Bell 1977) which in turn might shed some light on the existence of massive gaseous envelopes (or haloes) in galaxies.

2 Analysis of the objective-prism spectra

The observational program we devised to detect faint blue stars required the inspection of a large number of stellar spectra down to working limiting magnitudes of $m_B = 19.5$. Objective-prism plates from the UK 1.2-m Schmidt telescope were secured in regions of the sky coincident with the gaseous body of the Magellanic Stream, in the direction $l = 90^\circ$ and $b = -55^\circ$. The aim was to obtain deep, low-dispersion ($\sim 2480$ Å mm$^{-1}$ at H$\gamma$) spectra whereby spectral classification by visual inspection of as many stars as possible could be achieved. The objective prism plates used in this study were plate No. UJ 5405p

![Figure 1. Histograms are shown for regions MCD 2, I, II, III and IV, all coincident with clouds in the Magellanic Stream. Regions MCD 2 is one of Mirabel et al.'s (1979) regions while region V is the control region, outside the gas clouds. Magnitude interval is from 16.5 to 18.5 mag. As can be seen, no significant difference in the number of stars of a given spectral type is evident between regions in or out of the gas clouds.](https://academic.oup.com/mnras/article-abstract/201/2/473/1024286/1024286)
centred at \( \alpha_{1950} = 23^h 40^m \), \( \delta_{1950} = +5^\circ.00 \) and plate No. UJ 5347p centred at \( \alpha_{1950} = 23^h 40^m \), \( \delta_{1950} = +10^\circ.00 \), both plates of 60 min exposure time, on hypersensitized IIIa-J emulsion and unwidened. Regions MCD 2 (\( \alpha_{1950} = 23^h 35^m.8, \delta_{1950} = +8^\circ.2 \) to \( +8^\circ.5 \)) and MCD 3 (\( \alpha_{1950} = 23^h 34^m.3, \delta_{1950} = +2^\circ.5 \) to \( +3^\circ.5 \)) of Mirabel et al. (1979) were identified on plates UJ 5347p and UJ 5405p respectively. Only one region at a time fell on each plate as the centres of plates were chosen to coincide with POSS standard plate-centres. Therefore the areas of interest were outside three degrees from the centre and rather near the plate edges. However, the quality of the plate copies provided by the UKSTU staff was good and our estimated working magnitude limit on both plates was \( m_B = 19.5 \).

The results are presented in Figs 1 and 2 as histograms for several regions showing the proportion of stars of differing spectral types for magnitudes between \( m_B = 16.5 \) and \( m_B = 18.5 \).

These intervals were chosen assuming first that the stellar population of the Magellanic Stream consisted of A-type stars with little or no reddening; at a distance of 10 kpc an A star of mean absolute magnitude +2 will have an apparent magnitude around 17. If the distance is 15 kpc or more, the star's apparent magnitude is then 18.

For the magnitude interval \( m_B = 18.5 \) to \( m_B = 19.5 \) we do not present histograms for all of the regions as we did in Figs 1 and 2 since numbers of stars have dropped as a result of the increasingly difficult task of estimating spectral types.

Accordingly, only in two regions near MCD 3 which are shown in Fig. 3, were we able to extract some information.

There is a slight suggestion of an increase in the number of M-type stars although numbers of A and F0s remain basically unchanged. On the other hand, a similar number of

![Figure 2. Histograms are shown for regions MCD 3, I, II and III again all coincident with the hydrogen clouds in the Magellanic Stream. Region MCD 3 has also been discovered by Mirabel et al. (1979). Region V is the control region outside the clouds. Magnitude interval is from 16.5 to 18.5 mag. As in Fig. 1, no real difference can be seen in the number of stars of a given spectral type between regions in or out of the gas clouds.](https://academic.oup.com/mnras/article-abstract/201/2/473/1024286/20 January 2019)
Figure 3. Histograms for a pair of regions near the MCD 3 region and inside the gas clouds are shown. Magnitude interval here is from 18.5 to 19.5 mag. A slight increase in the number of M stars as compared with the same regions in Fig. 2 is present.

'A-type stars' has been found by other recent visual classifications of objective prism spectra of stars in the same range of magnitudes in high galactic latitudes away from the Stream (Tritton 1981, private communication).

The few faint blue objects that have been found in these surveys are being singled out in the hope of securing spectra with better resolution. Radial velocity measures and a more reliable spectral classification are needed for these stars which might be either faint white dwarfs of the halo population, QSOs (at 19.5 mag and fainter) or, less likely, subdwarfs and horizontal branch stars (Tritton 1981, private communication).

For the spectral classification of faint unwidened spectra using UKSTU objective-prism plates, we have closely followed the descriptions and standards given by Kelly, Cooke & Emerson (1980) and Krug, Morton & Tritton (1980). For the apparent stellar magnitude estimates, we took the magnitude-diameter relations for star images on the blue Palomar Sky Survey prints (King & Raff 1977). Although limiting magnitudes of UKSTU objective-prism plates have been estimated at $m_B = 20$ (Nandy et al. 1977; Krug et al. 1980) we found that assignment of spectral types for stars fainter than $m_B = 19.5$ was rather difficult and not reliable for our specific purpose. However, blue objects in large numbers should be easily detectable even at these faint magnitudes, considering that, for objects earlier than F0 in the range 18.5 to 19.5, detection is based mainly on the flatness of the continuum longward of the Balmer jump (Krug et al. 1980; Kelly et al. 1980).

After identification of the 21-cm regions on the optical fields in plates was completed, we proceeded to classify the spectral images and to estimate the apparent magnitudes of at least several hundred stars on each plate. Continuous use of Palomar Sky Survey red and blue prints was made, in order not only to estimate the magnitudes of the stellar images but also to allow us to reject those images which seemed to be produced by the superposition of two or more stars.

Areas studied were those given by Mirabel et al. (1979) and neighbouring regions of more than 2.5 square degrees on each plate. Control areas were also selected for spectral classification in the same way at regions of interest and away from these.

3 Discussion and conclusions

The results presented here for the apparent numbers of A0—F0 stars in the direction of the tip of the Magellanic Stream seem to indicate a lower than expected number of member stars (Oort 1980, private communication). Furthermore, from the statistics of more than 600 stars in selected areas within 0.5 away from the region and in the region MCD 3, no evidence of a large clustering of early-type stars is found. The numbers we find are between

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2 and 4 A-type stars per square degree and not more than 15 F0 stars per square degree in the magnitude range of $m_B = 16.5$ and $m_B = 19.5$. We have estimated that A-type members of the Magellanic Stream should be about 40 to 50 per square degree assuming the star density to be roughly equal to the solar neighbourhood values in a sphere of 100 pc in radius. The density of other blue stars would be very small at these high galactic latitudes. Moreover, the number of blue stars found does not show any dependence on position as is shown in Figs 1 and 2, for the ‘control’ region on each plate. We think that, if blue objects like A-type stars were present in large numbers, it would be rather easy to detect them as background stars. Hence we may conclude by saying that within the working plate-limit of $m_B = 20$ on our UKSTU plates, we do not find large numbers of early-type stars. With this in mind we might try to interpret the absence of stars of magnitudes $m_B = 18$, which corresponds to a distance of 15 kpc, in the following terms.

(a) Either gas and stars in the Stream do not participate in the same motion, that is, stars are displaced with respect to the gas.

(b) That part of the Stream does not contain stars ($l = 90^\circ$, $b = -60^\circ$ to $-30^\circ$).

(c) The distance to the gas and stars is very large and hence a lower limit to the distance can be given for the Stream.

The first possibility does not seem to be likely as the Stream is presumably a feature recently formed from matter being drawn out of the Clouds by the Galaxy $2 \times 10^8$ yr ago and hence is rather young so that its stars have not had time to travel away from the gas. For possibility (b), the physical absence of early-type stars in the Stream might indicate the presence of a massive gaseous halo in the Galaxy giving thus support to a recent model for the origin of the Magellanic Stream proposed by Murai & Fujimoto (1980). They attempt to explain with a tidal interaction model of the Magellanic Clouds, our Milky Way and a massive gaseous halo, most of the main characteristics of the Magellanic Stream (Mathewson et al. 1974). In their model (Murai & Fujimoto 1980), a binary nature is assumed for the Magellanic Clouds for at least the last $10^{10}$ yr which in turn might explain the common gas envelope and polarization measures observed by other authors, as well as the perturbed state of the gas around the Clouds and along the Stream (Fujimoto 1979). Gas in the Stream will further interact with the massive gaseous Milky Way halo. Orbits in Murai & Fujimoto’s model are computed and a perigalactic distance is obtained of at least 50 kpc for the LMC as well as a distance between 30 and 60 kpc from the Sun to the model Stream. This latter value for the distance to the Stream might probably explain (possibility c) why we do not find many A-type stars in our surveyed fields: stars could be much farther than previously thought. The distance to the Stream might then be at least as large as the distance to the Magellanic Clouds.

A differing value for the distance to the MS has been assumed recently by Mirabel (1981a,b) in a series of papers reporting observations of the neutral hydrogen very-high velocity clouds at various galactic latitudes and longitudes. He concludes that the VHVC are infalling features approaching the outer regions of our Galaxy. Moreover, he suggests (Mirabel 1981b) that the HVC he finds scattered in the first and second quadrant in the southern galactic hemisphere are to be associated with the Magellanic Stream. If such is the case, then the distance from the Galactic Centre to the tip of the MS is taken to be of the order of 10 to 15 kpc. Again, if the age of the Stream is assumed to be $2$ to $3 \times 10^8$ yr which should then be also the age of the youngest stars in it, we should expect to have A-type stars. Such stars should be of an apparent magnitude of the order of 17. However, no evidence of the presence of a large number of early-type stars of that particular magnitude was present in our survey.
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