Red Stars in Nearby Galaxies

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The study of the very cool stars in our Galaxy and in other galaxies is of great importance for our understanding of galaxy evolution. The first step in such an investigation is to identify these stars among the numerous warmer ones. Various search techniques are available and are here described by Professor Bengt Westerlund from the Uppsala Observatory in Sweden and formerly ESO Director in Chile. In particular, the new GRISMs at the prime focus of the 3.6 m telescope allow the detection of even very faint M, C and S stars. The extremely promising results of the initial observations are discussed by the author.

Detection of Cool Stars

Low-dispersion objective-prism spectra have been used for about 30 years for the detection of cool red stars in our Galaxy. Nassau and van Albada (1949: *Ap. J.*, **109**, 391) introduced the method of using the near infrared spectral range (6800–8800 Å) for the detection and classification of M stars by their strong TiO bands and by the VO bands appearing in the late M types. Nassau and his collaborators also showed that carbon stars may be identified by their pronounced CN bands at 7945, 8125 and 8320 Å and S stars by the appearance of LaO bands at 7403 and 7910 Å. These features may all be seen in spectra of very low dispersion; normally dispersions in the range 1400–2400 Å/mm are used, but late-type giants have been studied in dispersions as low as 6700 Å/mm. The advantage of using low dispersion is obvious: faint limiting magnitudes may be reached without having too many overlapping spectra even in rather crowded regions of the Milky Way.

Near-infrared spectral surveys of the northern part of the galactic belt were carried out at Cleveland by Nassau and his collaborators to a limiting magnitude of about I = 10.2 mag, and the distribution of M, C and S stars has been discussed in a number of papers. An extension towards southern declinations was carried out by Blanco and Münch. A complete survey of the southern Milky Way, covering a belt of ±5° along the galactic equator, was carried out by Westerlund with the Schmidt telescope of Uppsala Southern Station at Mount Stromlo Observatory to a limiting magnitude of I = 12.5. In the longitude range l = 235° to l = 7°, 1,124 carbon stars were identified (1971: *Astr. Astrophys. Suppl.*, **4,** 51) and 74 S stars (1978: *Astron. Astrophys. Suppl.*, **32,** 401).

A number of galactic regions, northern as well as southern, have been studied in detail to limiting magnitudes of about I = 13–13.5. On the basis of the surveys and the detailed studies of selected regions, a number of conclusions may be drawn regarding the distribution of the various classes of red stars. The carbon stars and S stars found in the near-infrared surveys (the coolest of these classes) belong to the disk population and are most likely spiral-arm objects. Also the early M-type stars show clusterings with preference for spiral-arm regions. The late M-type stars are more evenly distributed. Their density increases appreciably as the galactic centre is approached.

It should be noted that the near-infrared objective-prism technique does not permit a direct luminosity classification. In surveys of the type described above few red dwarfs are expected, however, and also M supergiants are rather rare. The latter may be rather easily identified in the more detailed investigations: their colours are as a rule extremely red(dened) for their apparent magnitudes.

Cool Stars in the Magellanic Clouds

It is obviously of great interest to apply the near-infrared objective prism technique to the study of our nearest neighbours among the galaxies, the Large Magellanic Cloud (LMC) and the Small Magellanic Cloud (SMC). This was first carried out by Westerlund (1960: *Uppsala Ann.*, **4,** No. 7; 1964: IAU Symp. No. 20, 239), who identified a large number of M-type supergiants and giants as well as several hundred carbon stars. The plate material had been obtained with the Uppsala Schmidt telescope of Mount Stromlo Observatory; with the dispersion used, 2100 Å/mm, the limiting magnitude was about I = 13.5 for a 90-min exposure on hypersensitized Kodak I-N plates. The carbon stars found were generally very close to the plate limit, as were many of the M giants. Attempts to find red stars of these classes in the SMC were not successful with this telescope; presumably it was not sufficiently powerful. The division of the M stars into supergiants and giants is in the case of the LMC primarily based on their spectral types and apparent magnitudes. The stars classified as supergiants are all of early M type, M0–M4, and have apparent magnitudes brighter than I = 12. The giants are of spectral types M4–M7 and have I > 12. Stars brighter than I = 9 were considered as galactic objects. It is probably unavoidable that a few foreground M stars appear among the Magellanic ones in the catalogues, but they should be few.

At the time of detection there was little or no possibility to confirm the memberships of these stars of the LMC. For this, larger telescopes and more sensitive detectors had to become available. Now, a large number of M stars have been observed with slit spectrographs by Roberta Humphreys (1979: *Ap. J. Suppl. Ser.*, **39,** 389) and by Westerlund and collaborators (unpublished) and the supergiant nature of the bright M stars in the LMC has been confirmed. Also, the identified possible carbon stars have been confirmed as of this type by extensive spectroscopy and photometry by Richer, Olander and Westerlund (1979: *Ap. J.*, **230,** 724).

An additional class of carbon stars has been shown to exist in the LMC by Sanduleak and Philip (1977: Publ. Warner & Swasey Obs. **2,** No. 5). With the thin prism on the Michigan Schmidt telescope at CTIO, Kodak IIIa-J plates were exposed and gave spectra covering the range 3300–5400 Å. Carbon stars were then identified by their Swan C_2 bands at 4737 and 5165 Å. In their catalogue there are about 400 stars not identified in the near infrared. Sanduleak and Philip suggested that they are hotter carbon stars, not showing sufficiently strong CN-bands in the near infrared to have been detected by us. The detailed study by Richer et al. referred to above has confirmed this.

The Schmidt telescopes permit large fields to be surveyed for cool stars rather rapidly with the methods just described. The limiting magnitudes of these surveys are, however, rather bright for extragalactic studies and the scale of the Schmidt telescopes may frequently be too small to avoid overlapping spectra; the central regions of both LMC and SMC are rather crowded. The limiting magnitude of the Uppsala survey is for instance about I = 13.7. This means that stars less luminous than about M_I = –5 could not be detected even if there were no overlaps to count with. In the SMC the limit must be drawn at M_I = –5.5 due to its larger distance. This may be the reason why the attempts to identify red member stars of the SMC with the Uppsala Schmidt telescope failed.

GRISMs

A very efficient method for the detection of faint red stars in the Magellanic Clouds (and in other nearby galaxies) is found in the use of transmission gratings at the prime focus of a large telescope. The method was introduced for blue objects by Hoag and Schroeder (1970: *PASP,* **82,** 1141) and later on refined by Bowen and Vaughan (1973: *PASP,* **85,** 174) who combined the grating with a prism to correct for the effects of aberrations. The GRISM, as it is now called, has been used with good results by Hoag for the detection of faint blue objects, and by Blanco, Blanco and McCarthy (1978: *Nature,* **271,** 638) for identifying carbon stars and M stars in the SMC and the LMC. The latter used the 4 m telescope at CTIO with a field of 0.12 deg^2 and a dispersion of 2300 Å/mm to sample a number of fields in the central regions of the Clouds. Their magnitude limit, on hypersensitized Kodak IV-N plates exposed for 60 min, is about m_i = 18.5. This as well as the higher plate scale compensates for the very small field covered by each plate. (At the prime focus of the ESO 3.6 m telescope the scale is 18$''\!.$9 per mm; this is to be compared with the 120'' per mm of the Uppsala Schmidt telescope at Mt. Stromlo.) Recently, two GRISMs were constructed by ESO under the direction of Dr. R. Wilson for use with the Gascoigne correctors at the prime focus of the ESO 3.6 m telescope. Their main parameters are:

		Red GRISM	Blue GRISM
Reciprocal linear dispersion		1700	1670 Å/mm
Grating	Gr/mm	150	150
	Blaze	6°17'	3°03'
	First order Littrow $\lambda\beta$	7300 Å	λ 3550 Å
	Blank	BK 7	fused silica
Prism	angle	8°135	4°667
	Blank	BK7	fused silica
Surface layer optimized for		7000 Å	3550 Å
Filter		OG590, 2 mm	BG 24, 2 mm
Field		50 mm ≈16' diameter except for vignetted part	
Focusing	by multiple exposures with settings near the ones found by knife-edge test without GRISM		

3.6 m GRISM Observations

I had the opportunity to use the red GRISM during 3 nights in the middle of October 1979. The seeing was good to reasonably good during all three nights and a number of rather useful plates were obtained. All plates used were IV-N emulsions, hypersensitized in $AgNO_3$, and efficiently so by E. Bahamondes. The setting of the telescope was done with outmost precision by J. Véliz. This was fundamental as there was no possibility to check the field except by removing the GRISM.

I observed 6 fields in the Small Magellanic Cloud, 3 in the Large Cloud, 2 in the Sculptor dwarf galaxy, 3 in the Fornax dwarf galaxy and 1 in the irregular galaxy NGC 6822. Most exposures were of 50 min duration; this was found to give the most suitable sky background for identification of faint red stars. The limiting magnitude in the I system has not yet been accurately determined. In Fornax and Sculptor we have identified some stars used for calibration in the U, B, V system: stars with V = 18.3 and colours around B–V = 1.1 are well exposed. It appears quite likely that late M stars and C stars of I = 18 may be identified.

The fields in the SMC were chosen between $01^h\,08^m$ and $01^h\,30^m$ along the Wing (~–73$^\circ\!.$4), and with one observation at $00^h 40^m$, –73$^\circ\!.$4. The distribution of the identified carbon stars, a total of 39, confirms the results by Blanco et al. that these stars are strongly concentrated towards the centre of the Cloud. We find a larger number of M stars than Blanco et al., but as time has not permitted a detailed classification we have to postpone all comments.

Of the 3 fields observed in the LMC one is at $05^h\,22^m$; –72°02' i.e. a few degrees below the Bar. The other two are in the outer eastern parts of the LMC, in the region between $6^h\,10^m$ and $6^h\,30^m$ where we had previously found a surprisingly high number of carbon stars.

In the three fields we had previously identified 2 or 3 carbon stars on our Schmidt plates. An appreciable increase on these numbers was to be expected following the results by Blanco et al. This was found true for the crowded region to the south of the Bar where we identified a total of 10 carbon stars (against 2 previously known). In the more peripheral fields we added 2 and 1, respectively, to the 3 already known. This shows the dependence of the completeness of an objective-prism survey on the general background field. It is of interest to note that one of the "new" carbon stars was previously well covered by the overlapping spectra of the stars in the cluster NGC 2249. As its distance to the centre of the cluster is only about 24" it may be considered a likely member of the cluster. Of interest in this connection is also the fact that the integrated colours of NGC 2249 (B-V = +.43; U-B = +.20) resemble those of NGC 2209 (+.52; +.36), with two carbon stars as likely members, rather much.

Carbon Stars in Dwarf Galaxies

Of the two fields photographed in the Sculptor spheroidal dwarf galaxy (m-M = 19.5) the one of the central region of the galaxy contains 2 carbon stars and 7 M stars; in the field 22' to the south there are 1 carbon star and 3 M stars.

In the Fornax dwarf galaxy (m-M = 21.4) we have so far identified 69 red stars. The distribution of the carbon stars is sufficiently uneven to indicate that regions of different degrees of metal deficiency exist.

The plate centred on the accepted centre of the dwarf galaxy contains 26 carbon stars and 11 M stars; of the two other fields, which are 16' to the north and to the south of the centre, respectively, the northern one contains 7 carbon stars and 12 M stars, and the southern one 1 carbon star and 12 M stars. Of the 7 carbon stars in the northern field, 6 fall between globular cluster No. 3 (see e.g. Hodge 1961: *A.J.,* **66,** 83) and the centre, i.e. within 825 pc from the a.

b.

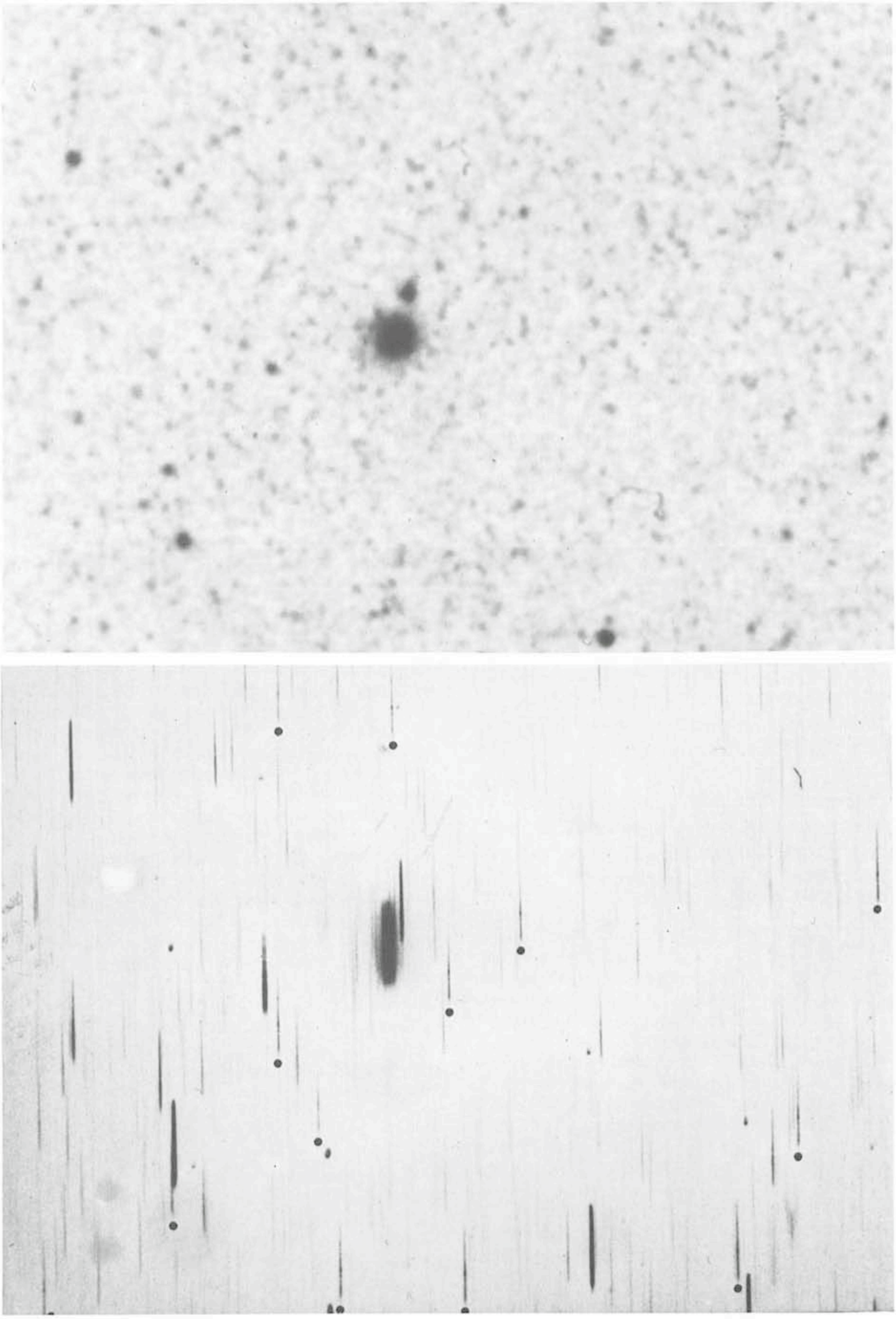

Fig. 1: *The field around the globular cluster No. 4 in the Fornax dwarf galaxy. The scale is 1 arcmin = 22.5 mm. North is up and East is to the left.*

a. *From the ESO(B) Survey. The limiting magnitude is about B = 21.5.*

b. *From a 60-min exposure with the red GRISM at the prime focus of the 3.6 m telescope. Carbon stars are identified by dots at the red ends of their spectra. A number of M stars are easily identified in the field from the pronounced TiO bands.*

centre. At a distance of 188 kpc the galaxy has a radius of 3.3 kpc. In the central field 22 carbon stars are within 330 pc from cluster No. 4, 6 are within 110 pc. All observations so far show that cluster No. 4 is the least metal poor, having [Fe/H] = −1.4. The most metal-poor clusters observed in this galaxy have [Fe/H] = −2.1. It has been suggested, on the basis of the distribution of the Magellanic Clouds, that a certain metal-poorness favours the formation of carbon stars of this type. Obviously, this poorness should not go too far, otherwise the Sculptor galaxy with [Fe/H] ≤ -1.8 should have been far richer in carbon stars than indicated by this survey.

We turn, finally, to the irregular galaxy NGC 6822. Its apparent distance modulus is m–M ~ 25. With a reddening of about E(B-V) = 0.4 its distance is about 616 kpc. From previous investigations it is known to contain many blue and red supergiants. 16 H II regions have been identified, and many similarities to the LMC have been noted. There may be a slight deficiency in N and O.

If the carbon stars have $M_I \sim -4$ we are not likely to reach them in this galaxy. Our survey has given 23 M stars. A number of them are certainly members of the galaxy; some may be foreground objects. This has to be checked, preferably with velocity determination.

For all five galaxies holds that spectroscopy of the identified faint M stars, too, should be rewarding. They have to be either members of these galaxies, or dwarf members of our galaxy. In either case, the knowledge of their characteristics would contribute essentially to the solutions of fundamental problems concerning the evolution of galaxies.

Photometric and Polarimetric Observations in NGC 6334, NGC 6357 and NGC 6302

Th. Neckel

Polarization is observed in the light of many stars and is normally attributed to interstellar dust particles aligned in an interstellar magnetic field. It is, however, quite possible that—at least in some cases—the polarization arises in dusty envelopes, surrounding stars during the earliest phases of their life. Dr. Thorsten Neckel from the Max-Planck-Institut für Astronomie in Heidelberg, FRG, has recently obtained observations of such objects from La Silla. Combining photometric and polarimetric measurements, it has become possible to provide new, important evidence for the intrinsic, bipolar model.

Several investigations carried out at the Max-Planck-Institut für Astronomie in Heidelberg within the last years are concerned with problems of star formation. Star formation is restricted to regions of high dust densities. Observations of embedded sources are often possible only at infrared wavelengths, because of the higher extinction for the visible light. One of our powerful instruments for observing recently-formed stars is an image-tube camera which is used at wavelengths up to 1 micron. Hitherto invisible young stars in the giant H II regions M 17, W 3 and others have been detected.

In these H II regions very high degrees of polarization have been found. Whereas the "normal" interstellar dust produces polarization values up to about 5 %, polarization degrees higher than 20 % were observed in M 17 and W 3 (Schulz et al., 1978). An appreciable part of the high extinction of these stars occurs in the H II regions themselves, where the densities of gas and dust are very high. Under these conditions the "Davis-Greenstein mechanism" for aligning the dust particles becomes very ineffective. So it proved to be difficult to explain these high polarization values by anisotropic extinction due to dust particles aligned in an interstellar magnetic field. Therefore, the observed high degrees of polarization are possibly due to a different mechanism (Elsässer and Staude, 1978).

Dust Envelopes

One possibility is the assumption of non-spherical dust envelopes around stars in which scattering by dust grains or electrons produces the polarization. Bipolar nebulae like "Minkowski's foot print" or S 106 are examples for such a configuration. These objects exhibit around a central star a disk of dust being nearly parallel to the line of sight and, therefore, obscuring the central star. (The central star in S 106 becomes visible in the near infrared, as shown by photographs with our image-tube camera (Eiroa et al. (1979).) Extended lobes of gas and dust, vertical to the dust disk, are visible. In these directions the disk is not optically thick. Therefore the light of the central star can illuminate the lobes. In the lobes we see predominantly scattered light which is highly polarized. The two lobes of "Minkowski's foot print", for example, are polarized to 15 % and 25 % respectively (Cohen and Kuhi, 1977).

Whereas "Minkowski's foot print" and S 106 are not obviously related to regions of star formation, the peculiar bipolar nebula NGC 6302 is only 1.°5 distant from NGC 6334, one of the largest H II regions in the Southern Milky Way. In NGC 6334 star formation is still going on, as indicated by the presence of OH masers and other very young objects (see Alloin and Tenorio-Tagle, 1979). Furthermore, the more evolved H II region NGC 6357 is located 1.°5 away. The part of the Southern Milky Way containing NGC 6302, 6357 and 6334 is shown in figure 1a. The photograph is from the red print of the Palomar Sky Survey. The H II regions NGC 6334 and 6357 are members of the Sagittarius spiral arm; for NGC 6302 no distance estimation has yet been possible.

The Observations

NGC 6334 and NGC 6357 contain many early-type stars. For the brighter ones, UBV observations were already made in 1976 at the Gamsberg in South West Africa using