Electronographic observations of a field in the Small Magellanic Cloud

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Summary. A colour–magnitude diagram to $V \approx 21.5$ mag from electronographs of a field in the western periphery of the Small Magellanic Cloud shows the presence of a distinct stellar population of age $3 \pm 1 \times 10^9$ yr. Some older stars may also be present. The population appears to be widespread throughout the SMC.

1 Introduction

The early history of the Magellanic Clouds is of importance as a clue to the evolution of irregular galaxies in general. In the case of the Small Magellanic Cloud it is of additional interest because it may provide evidence of the supposed past encounter of the Magellanic system with our Galaxy.

Ages derived from the turn-off points off the main sequence of colour–magnitude (CM) diagrams are restricted, of course, by the faint limit of the photometry. At the distance of the SMC (modulus $\sim 19$ mag) it is necessary to achieve 21 mag at least in order to recognize populations with ages in excess of $10^9$ yr. The oldest groups to be dated from their turn-off points are the globular-shaped clusters Kron 3 ($3 \times 10^9$ yr) and Lindsay 1 ($4 \times 10^9$ yr) both observed by Gascoigne (1980). In the general field, photometry by Brück & Marsoglu (1978) (Paper I) of a region to the east of the main body of the Cloud reveals a population of faint ($20–21$ mag, $B-V \approx 0–0.5$ mag) blue stars, identified as the top of a main sequence similar to that of NGC 5822. These stars are accompanied in the CM diagram by a conspicuous group at the horizontal branch position ($M_V \approx 0$, $(B-V) = 0.5$ mag) which could either be the evolved ‘clump’ of the same population or the horizontal branch of an older population or a mixture of both. Faint blue stars are very pervasive in the inner regions of the SMC, being found in several clusters and their surrounding fields (Kontizas 1980; Stewart 1980; Hardy, Melnick & Reheault 1980).

In Paper I, the horizontal branch component was interpreted as due to an older population, ascribed to the SMC halo, while the NGC 5822-type stars were explained as members of the disc. The photometry available (photographic photometry using faint standards transferred from Walker’s (1972) electronographic measurements of the cluster Kron 3) did not reach the turn-off point of even the younger component. It also suffered from an
unresolved zero-point difficulty in colour, discussed by the authors in their paper, and also by Kontizas (1980). To clarify the picture it was considered useful to choose a field well away from the main body of the SMC where the older halo component might be expected to become more clearly recognizable, and to extend photometry to a fainter limit. We have endeavoured to carry out these aims in this paper, where, by producing completely independent photometry we hope to have avoided the photometric difficulties and restrictions of the previous work.

2 Observations

The field chosen is at (0h 26m 73.0) (1950), 18 arcmin east and 4 arcmin north of the cluster Kron 3 in the west of the Cloud where the congregation of red clusters indicates an older environment. This part of the Cloud is clear of the bar and in a region where star density falls off smoothly. Photometry is based on a combination of photoelectric and electronographic observations. The former is a sequence by Cannon and Stewart (Stewart 1980) of 34 stars in B and V between 10.7 and 19.6 mag in V observed with the 1-m telescope at SAAO and the AAT. The electronographic observations were obtained (by MRSH) using the 1.5-m Danish telescope at La Silla, Chile. An 8-cm McMullan camera was used, and two 60-min exposures in both B and V were obtained. The films were of exceptionally high quality, with seeing measured from sample images of between ½ and 1 arcsec. Selection of images is best done from photographic material when available, because of the low contrast of the electronographic films. In the present instance, the COSMOS measuring machine at the Royal Observatory, Edinburgh, was used in its threshold mapping mode to scan a deep UK 1.2-m Schmidt telescope plate containing the field and to provide an objectively selected list of stars for measurement on the electronographs. This, in principle, allowed tens of thousands of stars to be measured, but as the photometric scans were to be done with a PDS machine, a practical limit of about a thousand stars was set in the first instance. The advantages of completeness and economy were offset by two disadvantages. First, the best photographic material available had a limit of about B = 22 mag for COSMOS measurable images, while the electronographs went very much deeper. This has resulted in a CM diagram terminating at B = 22 mag. The second disadvantage concerned overlapping images, which, in the COSMOS measures tended to offset the image position, resulting in an uncentred scan and consequent rejection of some of the images intended for measurement.

The COSMOS list of positions was transferred to the PDS frame of reference, and the PDS driven to each star which was raster-scanned, and a Gaussian fitted to the measured array; the procedure is described in detail by Penny (1976). The time taken to measure 1000 stars was about six hours. The rms error of one measurement was about 0.07 mag (see Hawkins 1979, 1981) and stars with a rms error of more than 3σ were omitted, as were images in which the Gaussian fitting routine failed to converge. Zero points were provided by the Cannon–Stewart data mentioned earlier. The final measurements represent a sample in an area of 30 arcmin² which is essentially complete to B = 21 mag. Of the ~ 1000 stars measured all but ~ 300 were rejected for failing to meet the criteria mentioned above. The overwhelming majority of the rejected stars were very faint and account for the steady fall off in numbers in Fig. 1 from V = 21–22 mag. The faintest images await more efficient methods, currently being developed, of exploiting the electronographic films to their limit.

3 Results

Fig. 1 shows the colour–magnitude diagram of the sample with the zero-age main sequence (Blaauw 1963) superimposed for apparent distance modulus 18.9 mag and $E_{B-V} = 0.08$ mag
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Figure 1. Colour–magnitude diagram for SMC field.

(de Vaucouleurs 1978). The lower value of $E_{B-V}$ (0.02 mag) determined more recently by McNamara & Feltz (1980) does not materially alter the position of the main sequence on the diagram. As in the field of Paper I there are two main groupings, but in this case the blue stars of the main sequence turn-off branch are fainter, at $V \approx 21$ mag, $(B-V) = 0.3$–$0.6$ mag. The other group is a well populated red horizontal branch (or clump) at $V \approx 19$ mag, $(B-V) = 0.6$–$1.0$ mag. There is also a subgiant branch and a distinct giant branch beginning at $V \approx 19.2$ mag, $(B-V) = 1.0$ mag and extending upwards 2.7 mag. Unfortunately, the photometry is still not sufficiently faint to allow us to reach the unevolved part of the main sequence. The thinning out of stars at the faint end is due to the difficulty of locating faint images for measurement as described earlier.

To interpret the CM diagram we first tried to find the best match between it and those of known clusters in the Galaxy, using Hagen's (1970) plots. The best fit as regards the upper part of the main sequence, the giant branch and the clump is NGC 2158, a distant cluster at $r = 8.7$ kpc in the anticentre direction (Arp & Cuffey 1962). The similarity between this cluster and those of the SMC, in particular Kron 3, was first recognized by Gascoigne (1963). NGC 2158 is not included among those clusters which have been re-examined using modern evolutionary models, but a comparison of its CM diagram with those which have been subject to detailed re-analysis (Demarque 1980) shows that, as regards position along the vertical (magnitude) axis, it lies almost midway between NGC 2360 and NGC 7789. The ages of these clusters are 1.3 and $1.6 \times 10^9$ yr respectively, which would place NGC 2158 at $1.5 \times 10^9$ yr. However, as has been amply demonstrated by the work of Demarque (1980) and his co-workers, a factor which in addition to age influences the morphology of cluster CM diagrams is the chemical composition. The age corresponding to any particular turn-off point from the main sequence increases with decreasing abundance Z (Ciardullo & Demarque 1977; Mengel et al. 1979). Since the metal abundance of NGC 2158 is somewhat lower ([Fe/H] = $-0.64$) than that of the other two clusters (Janes 1979) this age represents a minimum value.

We have also evaluated the age directly by consulting the Yale isochrones (Ciardullo & Demarque 1977) which are plotted for an array of combinations of age and abundance. It is generally accepted that the metal abundance in SMC is lower than in the Galaxy (Dubois, Jaschek & Jaschek 1977), and is probably not too different from the value for NGC 2158. A lower limit to the abundance of the younger component of our sample is perhaps set by the value in the nearby SMC halo clusters, known to be older than our field.

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For these clusters (Kron 3 and Lindsay 1) Gascoigne (1980) gives \([\text{Fe} \, | \, \text{H}]\) as \(-1\) or \(-1.5\) which correspond to \(Z = 0.001\) and 0.0004. The turn-off point on our sample CM diagram is at 21.2 mag \((M_V \approx 2.3 \text{ mag})\) which on the Yale isochrones represents ages respectively of 2, 3 and \(4 \times 10^9\) yr for \(Z = 0.01, 0.001\) and 0.0004 \((Y = 0.2\) in all cases). Thus we estimate the age as lying between 2 and \(4 \times 10^9\) yr. This figure is subject to error due to turn-off fitting and also additionally to possible uncertainty in the apparent distance modulus, which has been given values ranging from 18.6 mag (Clube & Dawe 1978) to 19.2 mag (Gaposchkin 1977). The value 19.0 mag (Graham 1975) favoured by Gascoigne is close to the de Vaucouleurs value \((18.9\text{ mag})\) adopted here. Taken all together the error due to these causes is probably no greater than \(0.5 \times 10^9\) yr and less than that arising from lack of precise knowledge of the abundances. It is interesting that while the age is close to that of M67 \((3.2 \times 10^9\text{ yr according to Demarque})\) the CM diagram which is otherwise similar in shape, lies 0.8 mag above that of M67.

4 Comparison with other SMC populations

The present sample obviously represents the same population as that observed by Hardy et al. (1980) who also noted a resemblance to NGC 2158. The question is now asked whether it is also the same as the younger component of the Paper I sample which showed a main sequence turn-off at 20.5 mag instead of 21.2 mag. In that sample, photometric errors were twice as large \((\sigma = 0.14\text{ mag})\) as in this instance, and a possible zero-point error was suspected, which the present observations appear to confirm. The discrepancy between the two samples is equivalent to \(10^9\text{ yr}\) when converted to age, a difference which having regard to all the uncertainties, cannot be declared significant. (The age derived in Paper I, \(0.4 \times 10^9\text{ yr}\), in any case requires revision. It was based on the age, now revised upwards to \(0.9 \times 10^9\text{ yr}\) (Demarque 1980), of the matching cluster NGC 5822, and on a distance modulus of 19.2 mag, now replaced by 18.9 mag. The reassessed age is \(2 \times 10^9\text{ yr}\), the lower limit for the present sample.)

5 Ages

The age \(3 \pm 1 \times 10^9\text{ yr}\) which we have determined, representing the youngest component of the sample, does not exclude the possibility that there are older objects present. These could be one or more separate groups, or stars with a continuum of ages from \(3 \times 10^9\text{ yr}\) upwards. A comparison of the present CM diagram with that of the \(4 \times 10^9\text{ yr}\) old Lindsay 1 (Gascoigne 1980) shows almost perfect coincidence of the giant, subgiant and horizontal branches. (This incidentally is also a reassuring mutual check on the photometries since these are entirely independent.) A short red horizontal branch is present in both cases, as well as the clump in the giant branch typical of intermediate age groups. The fundamentally identical nature of the clump and horizontal branch has been argued by Cannon (1970). In our Galaxy the emergence of a horizontal branch, in the sense of a spread in colour, is dependent on age; it is found in globular clusters \((>10^{10}\text{ yr})\) but not in open clusters \((\leq 5 \times 10^9\text{ yr})\).

The galactic globular cluster 47 Tucanae which Demarque & McClure (1977) have suggested may be relatively young \((10^{10}\text{ yr})\) has a short red horizontal branch and a giant branch morphology similar, as Gascoigne (1980) has already remarked, to the SMC examples. It is suggested, therefore, that the incipient horizontal branch in our CM diagram signifies the presence of stars of around \(10^{10}\text{ yr}\) old mingled with those of intermediate age. Such stars would contribute to the evolved part of the CM diagram but not to the upper end.
of the main sequence. By comparison with the relative numbers populating the various parts of similar galactic CM diagrams, it would appear that there is indeed a relative surplus in the giant branches of the SMC field sample. Unfortunately, this is impossible to quantify at present on account of the loss of star images at the faint end of our range of measurement (Section 2). In making a comparison of SMC intermediate age groups with 47 Tuc, it is important also to record the differences between them, to which Gascoigne (1980) drew attention in his discussion of the CM diagram of Lindsay I. The most notable of these is that the horizontal and giant branches in the SMC diagrams are significantly brighter than the corresponding regions for 47 Tuc. The displacement between our diagram and Lee’s (1977) diagram for 47 Tuc is 0.7 mag if we adopt Hartwick & Hesser’s (1974) distance modulus of 13.03 mag for the latter, or 0.3 mag adopting Harris & Racine’s (1979) figure of 13.46 mag. Our giant branch is also slightly steeper and appears to be about 0.2 mag bluer at the tip.

6 Disc or halo?

From the distribution of young (<10⁶ yr old) objects (e.g. de Vaucouleurs 1960; Brück 1975; Azzopardi & Vigneau 1977) it is inferred that the SMC has a disc in the sense of a flat structure which in projection on the plane of the sky has an elliptical outline. It is also known from faint (to B = 21.5 mag) star counts (Brück 1978) that it possesses a halo in the geometrical meaning of a quasi-spherical envelope. Profiles showing variations in star density with radial distance from the SMC centre have been obtained for various magnitude intervals up to B = 21 mag (Brück 1980); these include the clump and the horizontal branch domain, but not the main sequence turn-off region. Further observations aimed at isolating the latter group of stars is planned in order to determine whether in spatial distribution they belong to the disc or the halo.

7 Conclusions

The CM diagram of the SMC field indicates a distinct intermediate age population with a main sequence turn-off point at 21.2 mag and clump/horizontal branch at 19.2 mag or M_V = 2.3 mag and 0.3 mag respectively, for an apparent distance modulus 18.9 mag. The age is estimated at 3 ± 1 x 10⁹ yr for the youngest component of the sample but it is suggested that older stars up to 10¹⁰ yr may also be present.

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References

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