Mon. Not. R. Astron. Soc. **300,** 857–862 (1998)

The binary star population of the young cluster NGC 1818 in the Large Magellanic Cloud

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Accepted 1998 June 26. Received 1998 April 23; in original form 1998 February 12

ABSTRACT

We determine the binary star fraction as a function of radius in NGC 1818, a young rich cluster in the Large Magellanic Cloud, using *Hubble Space Telescope* images in bands F336W ($\sim U$) and F555W ($\sim V$). Our sample includes binaries with $M_{\rm primary} \sim 2$–$5.5\ {\rm M}_{\odot}$ and $M_{\rm secondary} \gtrsim 0.7 M_{\rm primary}$. The binary fraction increases towards the cluster centre, from $\sim 20 \pm 5$ per cent in the outer parts, to $\sim 35 \pm 5$ per cent inside the core. This increase is consistent with dynamical mass segregation and need not be primordial. We compare our results with expectations from *N*-body models, and discuss the implications for the formation and early evolution of such clusters.

Key words: binaries: general – globular clusters: individual: NGC 1818 – magellanic clouds – galaxies: star clusters.

1 INTRODUCTION

Binary stars play a dynamically important role in the evolution of rich star clusters, particularly in halting the runaway collapse of the core when a cluster's age exceeds its average two-body relaxation time. [For a review of the dynamical evolution of star clusters, see Elson, Hut & Inagaki (1987a), Hut et al. (1992) and Meylan & Heggie (1997).] To understand the evolution of rich clusters, it is therefore important to know the fraction of binary stars, particularly within the core, and how this population evolves with time. Such observations can also contribute to our understanding of the star formation process in the molecular clouds that are the progenitors of rich clusters.

Identification of binary stars in globular clusters, either through their position in a colour–magnitude diagram (CMD), or spectroscopically, has suggested typical fractions of 10–30 per cent for semimajor axes ranging from contact binaries to a few astronomical units (Yan & Cohen 1996; Yan & Mateo 1994; Bolte 1992; Rubenstein 1997a,b; Rubenstein & Bailyn 1997; Cote et al. 1996). However, the available range of stellar masses is necessarily limited to $\lesssim 0.8\ {\rm M}_{\odot}$, and crowding makes observations in the cores difficult. Similar binary fractions have been found in open clusters, although in this case the results are uncertain because the numbers of stars are small, and membership is difficult to determine (Mermilliod & Mayor 1990; Raboud & Mermilliod 1994; Mathieu, Latham & Griffin 1990; Mathieu & Latham 1986).

The rich star clusters in the Large Magellanic Cloud (LMC) provide an ideal laboratory for exploring binary star populations in clusters. In the young clusters the main sequence extends over a wide range of stellar masses, and the numbers of stars are typically an order of magnitude greater than in Galactic open clusters. An extensive programme of observations of eight LMC clusters with a range of ages is being carried out with the *Hubble Space Telescope* (*HST*) during Cycle 7 to explore their formation and evolution (Project 7307). As a pilot study we investigate the binary population of one of the clusters in this sample, NGC 1818, using Wide Field Planetary Camera 2 (WFPC2) data from the *HST* Archive. This cluster is ~ 2–4×10^7 yr old (Will, Bomans & de Boer 1995; Hunter et al. 1997) and has mass $\sim 3 \times 10^4\ {\rm M}_{\odot}$ (Hunter et al. 1997).

The observations and photometry are described in Section 2. The results, including the relative masses and separations of the binary components, the binary fraction as a function of radius, and the evolution of the binary population with time, are discussed and compared with models in Section 3. Our conclusions are summarized in Section 4.

2 OBSERVATIONS AND DATA REDUCTION

From the *HST* Archive we obtained images of NGC 1818 in the F336W ($\equiv U_{336}$) and F555W ($\equiv V_{555}$) bands taken with WFPC2 on 1995 December 8. Total exposure times are 960 and 880 s respectively. The images were calibrated using the standard pipeline, and co-added with a median filter to eliminate cosmic rays. Full details of the observations may be found in Hunter et al. (1997), who used these data to determine an initial mass function (IMF) for NGC 1818 in the mass range ~ 0.85–$8\ {\rm M}_{\odot}$.

The cluster has core radius $r_{\rm c} \sim 8$ arcsec (Elson, Fall & Freeman 1987b) and is centred on the Planetary Camera (PC) chip. With

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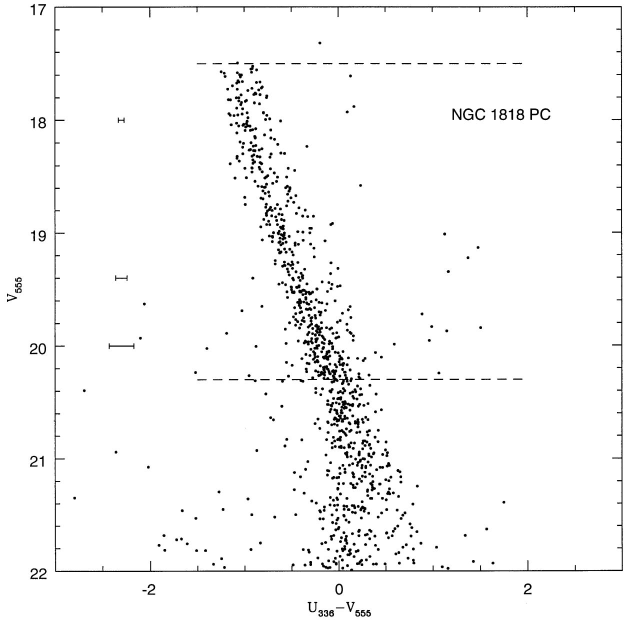

Figure 1. Colour–magnitude diagram for objects detected in the PC image (the central $\sim 2r_c$) of the young LMC cluster NGC 1818. A binary sequence stands out clearly from the main sequence. At $V_{555} \lesssim 17.5$ the stars are saturated. The dashed lines indicate the limits of the sample we use to analyse the binary population of this cluster, and correspond to single-star masses ~2–5.5 $M_\odot$. Poisson error bars are shown.

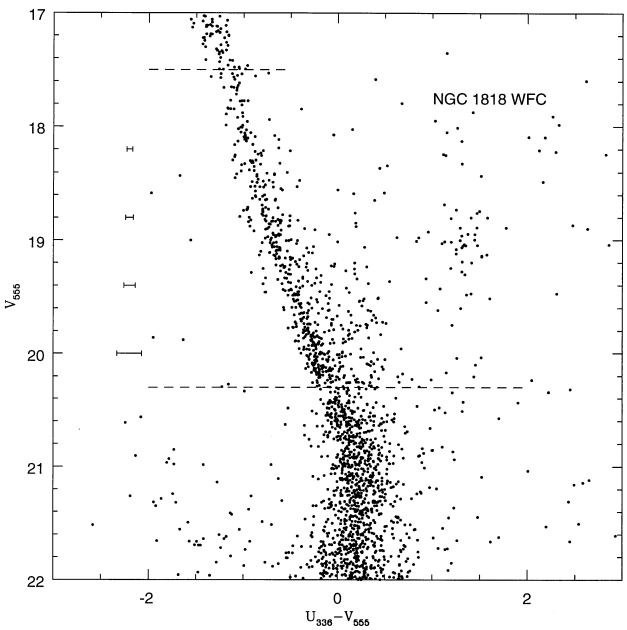

Figure 2. Colour–magnitude diagram for objects detected in the three WFC chips. Binaries are visible as a spread in colours redwards from the main sequence. At $V_{555} \lesssim 17.5$ the stars are saturated. The dashed lines indicate the limits of the sample we use to analyse the binary population of this cluster, and correspond to single-star masses ~2–5.5 $M_\odot$. Poisson error bars are shown.

scale 0.0455 arcsec pixel^{-1} the core radius corresponds to ~175 pixels. With size 800×800 pixels, the PC thus contains the inner $\sim 2r_c$ of the cluster. The Wide Field Camera (WFC) extends the field of view to $r \sim 100$ arcsec, which is about half-way to the edge of the cluster. We adopted a distance modulus for the LMC of 18.5 (cf. Panagia et al. 1991), which implies 0.243 pc arcsec^{-1}.

Detection of objects in the F555W image was carried out using DAOFIND with a threshold four times the standard deviation of the background. Detections on each chip were fitted with point spread functions (PSFs) constructed from several isolated stars using the MOFFAT15 function to model the PSF. Objects with outlying values of the fitting parameters SHARPNESS and χ^2 were eliminated from the sample. Inspection of the images revealed that most of these were spurious detections around saturated stars or along diffraction spikes. The remaining objects (~1800 stars in the PC chip and ~7500 stars in the three WFC chips) were then measured on both the F555W and F336W images using an aperture of radius 2 pixels. Aperture corrections and synthetic zero-points were applied following Holtzman et al. (1995a,b). We adopted a value for the reddening of $E(B-V) = 0.05$ (cf. Hunter et al. 1997).

A CMD for the PC sample is shown in Fig. 1. (Stars with $V_{555} < 17.5$ are saturated; the main-sequence turn-off is at $V_{555} \sim 14$.) A binary sequence is clearly visible. This binary sequence was not detected by Hunter et al., who used PSF fitting to determine magnitudes. In our experience with WFPC2 data, PSF magnitudes can result in a greater scatter than magnitudes measured with a small aperture, and the lack of a clearly separated binary sequence in their CMD may illustrate this.

For further analysis we restricted our sample to $17.5 < V_{555} < 20.3$, which is the magnitude range in which the binary sequence stands out most clearly. This range corresponds to (single) stellar masses ~2.0–5.5 $M_\odot$. Our subsample thus defined contains 521 objects in the PC chip and 558 objects in the three WFC chips (see Fig. 2). Dividing this subsample along a line given by $(U_{336} - V_{555}) = 0.427V_{555} - 8.57$, where the density of points in the CMD is at a local minimum, we find 395 single stars and 126 unresolved binary systems in the PC chip, and 436 single stars and 122 binary systems in the WFC chips. Note that a small number of detections in this magnitude range in Figs 1 and 2 with outlying colours have also been excluded. Outliers were taken to be objects redder or bluer than lines with the same slope as above and with intercepts −8.21 and −9.00.

From the CMD derived by Hunter et al. (1997) for a background field near NGC 1818 we conclude that field star contamination at these magnitudes amounts to ~1 per cent in the PC and ~9 per cent in the three WFC chips. Completeness was estimated using artificial star tests in the V_{555} band. For our relatively bright sample, completeness is not so much a function of magnitude as of crowding. Specifically, the presence of about a dozen very bright saturated giants in the PC field means that even bright stars can be missed if they are superposed on a saturated image. We estimate that our sample is ~95 per cent complete at $V_{555} \sim 18$ and ~85 per cent complete at $V_{555} \sim 20$. Finally, given the surface density of stars in our magnitude-limited sample (< 0.001 stars per pixel in the PC field), the expected number of spurious unresolved binaries created by the chance superposition of two single stars is negligible.

3 RESULTS AND DISCUSSION

3.1 Relative masses of the binary components

The observed binary sequence in Fig. 1 is clearly separated from the single-star main sequence, and has a locus 0.75 mag brighter. Naively, one might infer that our binary sample thus contains only near-equal-mass pairs, but one must be cautious about such conclusions (Hurley & Tout 1998). Fig. 3 shows theoretical

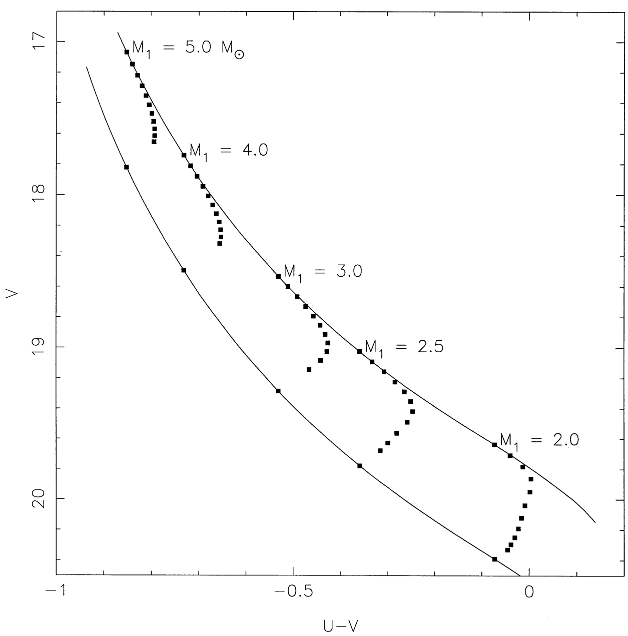

Figure 3. Theoretical single-star and equal-mass binary main sequences for metallicity $Z = 0.01$ and age 4×10^7 yr. Also plotted for five primary masses, M_1, are binary points with $M_2 = qM_1$ where q ranges from 0.5 to 1.0 in increments of 0.05. The point at $q = 0$ is also shown.

single-star and equal-mass binary main sequences derived from the models of Pols et al. (1998) for age 4×10^7 yr and metallicity $Z = 0.01$. The conversion to Johnson–Cousins magnitudes was based on the synthetic stellar spectra computed by Kurucz (1992). For five different primary masses, M_1, we show the positions of binaries with secondary mass $M_2 = qM_1$, where q ranges from 0.5 to 1.0 in increments of 0.05. As the secondary mass decreases, the binary becomes both fainter and, for q greater than some critical value, redder. For $q \gtrsim 0.7$ the locus of binaries lies very close to the equal-mass sequence. Comparing with Fig. 1, we estimate that the majority of binary systems in our sample consist of pairs of stars with $M_2 \gtrsim 0.7M_1$. We cannot of course rule out that our single-star sample actually includes a significant number of binaries with $q < 0.5$ which, given the observational errors, are indistinguishable from single stars.

Is the apparent high abundance of high-mass secondaries in our binary sample the result of dynamical selection, or does it reflect the binary star formation process? The effects of stellar encounters could in principle help to explain the predominance of binaries with near-equal-mass components. During a typical close encounter between hard binaries and either single stars or other binaries, the surviving binary will consist of the two most massive stars (Sigurdsson & Phinney 1993). The binary fraction in the cluster core would thus be biased towards equal-mass components, while binary–binary encounters would tend to destroy binaries with low-mass secondaries. However, for the stars in our sample, the time-scale for exchanges, $t_{\rm ex}$, is much greater than the age of the cluster [$t_{\rm ex} \sim 3 \times t_{\rm r}(100\,{\rm au}/a)$], where $t_{\rm r}$ is the local relaxation time and a is the semimajor axis of a binary in au. For most binaries $t_{\rm ex}$ would have been longer than the cluster age, even if the cluster core had been considerably denser in the past. The predominance of near-equal-mass binaries must therefore be primordial.

Our data suggest that it is very unlikely that the mass function of secondaries is drawn independently from the same mass function as the primaries (which is close to the Salpeter IMF; Hunter et al. 1997). The latter rises steeply towards low-mass stars, and this would produce a strong bias towards binaries with low-mass secondaries. Many of these would be indistinguishable from single stars in our data, and the binary fraction for all secondary masses would be ~100 per cent, with a large fraction of the stars being members of hierarchical multiples. A larger sample of stars, with more accurate photometry (cf. Rubenstein & Bailyn 1997), may allow us to constrain better the distribution of secondary masses; we will explore this possibility with the data from Project 7307. Instead, a more plausible way to reproduce the observed bias towards near-equal-mass binaries is to draw the binary mass ratio q at random from 0 to 1. This gives on average as many binaries with $q > 0.5$ as with $q < 0.5$ rather than a distribution biased towards small values of q. We would not expect the secondary mass function to steepen sharply just at the mass ratio where our current detection limit is, so certainly for intermediate mass ratios ($q \sim 0.5$) the secondary mass function remains flat, much flatter than Salpeter. Formally the data provide no constraints on very low mass ratio binaries for this range of primary masses.

3.2 Binary separations

The full range of initial binary separations that we would expect to be present in NGC 1818 includes values up to 20 000 au (Abt 1988). With a distance modulus of 18.5, one pixel on the PC corresponds to ~2300 au, and one WFC pixel corresponds to ~5000 au. The WFC sample thus includes slightly wider binaries than the PC sample, but the number of extra systems with separation between 2300 and 5000 au is expected to be small assuming that the population of binaries is distributed uniformly in the logarithm of separation (Popova, Tutukov & Yungelson 1982).

To determine the number of resolved binaries, with separations 2300 (5000) to 20 000 au (2–9 PC pixels or 2–4 WFC pixels), we looked for stars in our single-star sample with other stars in the same sample within nine (four) pixels. There were 47 of these in the PC and two on the three WFC chips combined. (Our initial selection of objects on the basis of χ^2 and SHARPNESS resulted in the elimination of only two star-like objects in the PC, which may be marginally resolved binaries.) Assuming the stars are uniformly distributed across the PC (which is a good approximation since the size of the PC is comparable to the size of the core), Monte Carlo simulations indicate that the expected number of chance pairs is ~35. However, we observe several triple systems and one quartet, which, if excluded from the sample, reduces the number of binary systems in excess of those due to chance alignments to ~0. This is consistent with the expectation that resolved binaries would not survive in the core of the cluster for more than $\sim 2 \times 10^7$ years, while triple or quadruple systems would be stable for much longer.

Similar simulations for the WFC chips imply ~4 chance pairs, which is consistent with our observed two resolved binaries. This suggests that there is no large population of resolved binaries in the outer parts of the cluster. If the distribution of binary semimajor axis, a, is uniform in log(a), as in the field, then we would expect ~10 resolved binaries in the three WFC chips. The observed deficit of resolved binaries in the WFC chips is marginally significant and may be the result of a depletion of binaries with $a > 10\,000$ au, for which the time-scale for breakup is comparable to the age of the cluster. We explore the disruption of binaries further in the next section.

3.3 Binary fractions and cluster evolution

Adopting the centre of the PC as the centre of NGC 1818, we

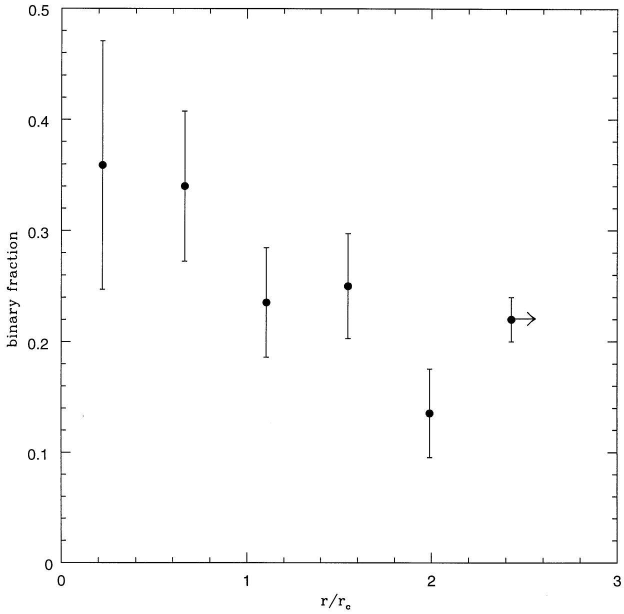

Figure 4. Binary star fraction as a function of radius. Poisson error bars are shown. The outermost point is from the three WFC chips and represents radii 4.4–24 pc. The core radius of NGC 1818 is 2.0 pc.

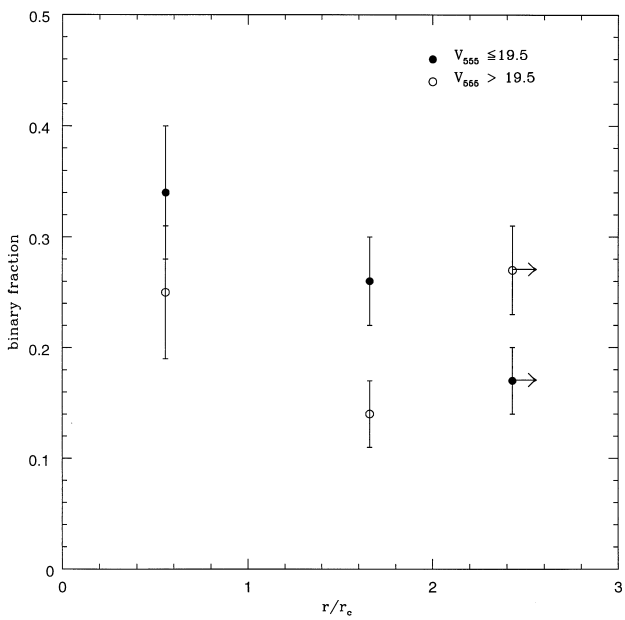

Figure 5. Binary star fraction as a function of radius for objects with $19.5 < V_{555} < 20.3$ (open circles) and $17.6 < V_{555} < 19.5$ (filled circles). Poisson error bars are shown. The outermost point is from the three WFC chips and represents radii 4.4–24 pc. The core radius of NGC 1818 is 2.0 pc.

derived the binary fraction, defined as the ratio of the number of binary systems to the total number of binary systems and single stars, as a function of radius. This is shown in Fig. 4. The point at largest radius represents the combined sample from the three WFC chips (i.e. at radii 4.4–24 pc). The binary fraction is greater by a factor of $\sim 1.8 \pm 0.5$ in the core compared to the outer parts of the cluster. (Uncertainties in the exact choice of cluster centre will not affect any of our results.)

To examine the relative distributions of the more and less massive objects we divided our sample at $V_{555} = 19.5$, the median magnitude for the PC sample. This corresponds to a single-star mass of ~ 3 M$_\odot$. The binary fraction as a function of radius in these two subsamples is shown in Fig. 5. Among the more massive objects the binary fraction increases more steeply towards the cluster centre, while among the less massive objects the binary fraction is approximately constant.

Could the excess binaries in the core have sunk to the central regions through mass segregation, or is this excess population primordial? Will stellar encounters have altered the overall binary fraction significantly? To address these questions we need to know the dynamical and structural parameters of the cluster from which we can calculate the two-body relaxation time, which is the time-scale for mass segregation and for stellar encounters. From equation (19) of Elson et al. (1987b), $t_r(r, m) = 2 \times 10^9 \sigma^3(r) m^{-1} \rho(r)^{-1}$ yr, where $\sigma(r)$ is the velocity dispersion in km s^{-1}, $\rho(r)$ is the density in M$_\odot$ pc^{-3}, and m is the mass of the stars of interest in M$_\odot$. Scaling the minimum values of $\sigma(0)$ and $\rho(0)$ from Elson et al. assuming a Salpeter IMF (which is consistent with the IMF derived by Hunter et al. 1997), we have $\sigma(0) \approx 1.5$ km s^{-1} and $\rho(0) \approx 60$ M$_\odot$ pc^{-3}. The relaxation time in the core is therefore $t_r(m) \approx m^{-1} \times 10^8$ yr. For the single stars in our sample, with mass ~ 2–5.5 M$_\odot$, the central relaxation time is ~ 2–5×10^7 yr, comparable to or somewhat greater than the age of the cluster. For the approximately equal-mass binaries in the core, with mass ~ 4–11 M$_\odot$, the relaxation time is ~ 1–2×10^7 yr, comparable to or somewhat less than the age of the cluster.

Models suggest that the core density may have been ~ 50 per cent higher in the past because the core expands as a result of mass loss as the most massive stars evolve off the main sequence (Elson, Freeman & Lauer 1989). The relaxation time in the core may therefore have been ~ 50 per cent shorter in the past. The relaxation time at the half-mass radius is more than an order of magnitude greater than the cluster age for the range of stellar masses in our sample.

Stars will undergo close encounters on a time-scale comparable to the local relaxation time-scale. An encounter between two single stars very rarely results in the formation of a new binary, so the observed overall binary fraction represents a lower limit on the primordial binary fraction. The precise effect of encounters on the binary population is best determined from simulations, but a rough scenario is as follows. In encounters between single stars and binaries, the binary can be either destroyed or hardened depending on whether it is 'soft' or 'hard'. This in turn depends on the mass of the two stars and their separation. In the cluster core, the boundary between hard and soft binaries is ~ 150 au for binaries containing 1-M$_\odot$ stars, and the separation scales as $M_1 M_2$ (Heggie 1975; Hut & Bahcall 1983; Davies 1997). The hard/soft boundary for the stars in our sample is thus ~ 500–1000 au. (Recall that our image resolution corresponds to separations $\lesssim 2300$ au.) In the following discussion we assume that the properties of binaries are smooth functions of both mass and mass ratio, so that we can extrapolate to lower values than those in our sample.

Assuming the distribution of separations is logarithmic, then ~ 20–30 per cent of our sample is vulnerable to being broken up by encounters with single stars. In close encounters between two binaries of comparable mass, one of the binaries will be broken up in about 20 per cent of the encounters (Mikkola 1983; Bacon, Sigurdsson & Davies 1996); given the observed binary fraction, these encounters will happen about as often as star–binary encounters. Outside the core, the velocity dispersion is somewhat lower, and wider binaries remain hard. Far outside the core the density is so low that no binaries will have had time to encounter other stars. Overall we estimate that the primordial binary fraction would have been ~ 30 per cent higher than the present observed fraction, or

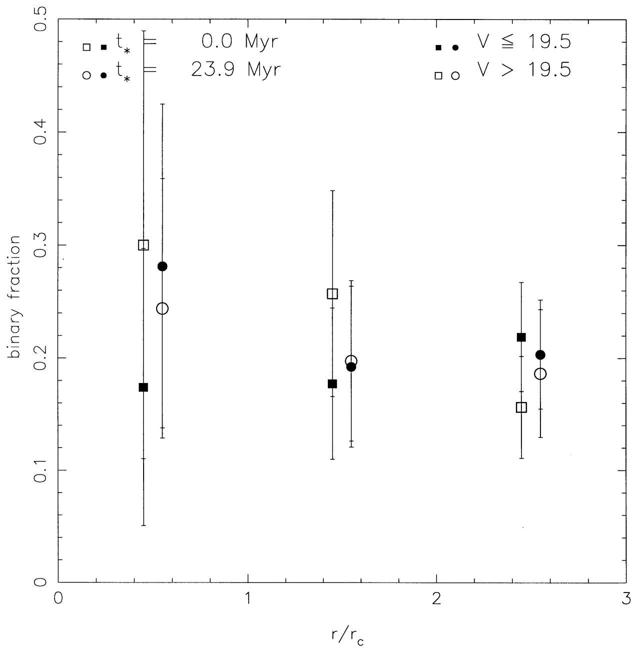

Figure 6. Binary star fraction as a function of radius for model star clusters as described in the text. Squares are the initial distribution and circles are the distribution at 4×10^7 yr. Filled and open circles indicate brighter or fainter objects, as in Fig. 4. Poisson error bars are shown.

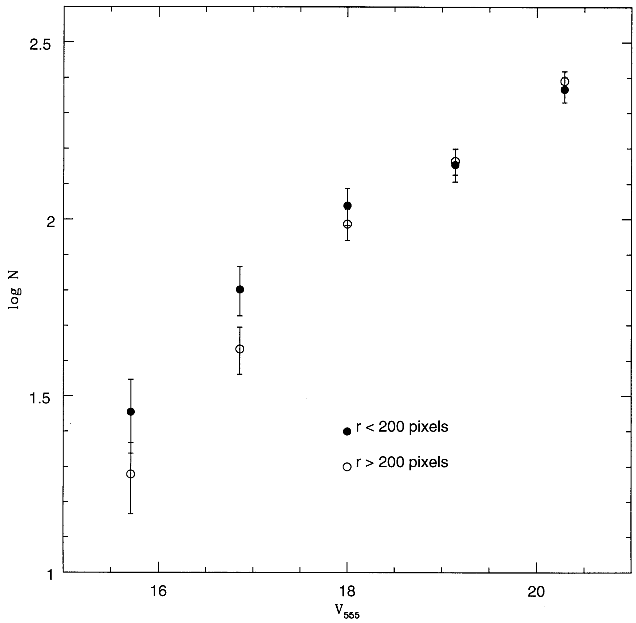

Figure 7. Luminosity functions derived from short-exposure images for stars (single and unresolved binary) less than (filled circles) and greater than (open circles) 200 pixels ($\sim 1r_c$) from the centre of NGC 1818. Poisson error bars are shown.

$\sim$40 per cent. For lower-mass stars, the hard/soft boundary separation is smaller, so a larger fraction of lower-mass binaries will have already been broken up. We would therefore expect our deeper images to reveal fewer binaries with $\sim$1-M$_\odot$ primary mass.

To investigate the evolution of a binary population within a cluster like NGC 1818 we have carried out *N*-body simulations using the Cambridge HARP special-purpose computer (Aarseth 1996; Makino et al. 1997; Tout et al. 1997). The initial setup included 12 500 single stars and 2500 binaries where the single stars and primaries were drawn from the IMF of Kroupa, Tout & Gilmore (1993) and the secondary masses were determined by choosing q randomly between 0.5 and 1.0. This gave a total mass for the cluster of $\sim 1.5 \times 10^4$ M$_\odot$, which is half the estimated mass of NGC 1818. (The smaller model mass is because of CPU constraints.) The length-scale was chosen to give $r_c = 2$ pc and the particles were initially distributed according to a Plummer model (Aarseth, Henon & Wielen 1974) to give a cluster in virial equilibrium. We considered only binaries with $q \geq 0.5$ so as to be able to compare the binaries from the simulation with those we expect to have observed in NGC 1818. Our *N*-body models are capable of providing full stellar evolution for a large range of metallicities by utilizing rapid evolution formulae derived from the models of Pols et al. (1998). For the simulations we used $Z = 0.01$, which is appropriate for young LMC clusters.

The initial distribution of binary fraction with radius, in the magnitude bins defined as in Fig. 5, is shown in Fig. 6 (squares). The distribution at a simulation time of $t_* = 2.4 \times 10^7$ yr is also shown (circles). If we scale the time by

$$t_* = t \frac{N_*}{N} \frac{\ln 0.4N}{\ln 0.4N_*}$$

according to Meylan & Heggie (1997), where N_* is the number of simulation stars and N the number of cluster stars, this corresponds to a real time of $t \sim 4 \times 10^7$ yr. We see from Fig. 6 that there is evidence for an increase in the central binary fraction of the more massive objects with time. We should note, however, that as a result of the small number of binaries within the central radial bins of the magnitude-limited sample, Poisson noise can easily overwhelm true dynamical evolution. To overcome this we need either to run simulations with larger particle numbers, which would require a large increase in computation time, or to run more simulations of the size described here and average the results. This work is under way and will be complemented by more observational data on cluster binary distributions in clusters with a large range of ages, provided by Project 7307. We also note that over the time of the simulation $\sim$50 binaries were lost through either dynamical interactions or the primary undergoing a supernova. This depletion was restricted to soft binaries and thus would not affect the ability of the binaries to halt core collapse later in the life of the cluster.

Mass segregation will be effective on time-scales slightly longer than the two-body relaxation time. Thus, we might expect the more massive binaries in our sample to have undergone mass segregation, while single stars would not have. This is consistent with our results in Fig. 5 and with the results of Hunter et al. (1997), who found no difference in the IMF slope for stars inside and outside $\sim 2r_c$, but in contrast with Fischer et al. (1998). Our data are not deep enough to compare with Fischer et al.'s intermediate population, but future data will provide a direct comparison of the cumulative luminosity function at larger magnitudes at different radii, enabling a stronger test of whether the observed mass segregation is primordial or dynamical. Stars in the inner parts of the cluster with mass $\sim$8 M$_\odot$ do, however, have ages a few times greater than their relaxation time, and should have segregated efficiently inside $\sim 2r_c$.

To test this, we derived luminosity functions from photometry obtained only from the shortest-exposure images in which the brighter stars are not saturated. As expected, we do see mass segregation for stars with mass $\gtrsim$5 M$_\odot$. This is illustrated in Fig. 7, where we plot luminosity functions for bright stars less than and greater than 200 pixels ($\sim 1r_c$) from the cluster centre. There are $\sim$50 per cent more stars with $m \gtrsim 5$ M$_\odot$ in the inner $1r_c$

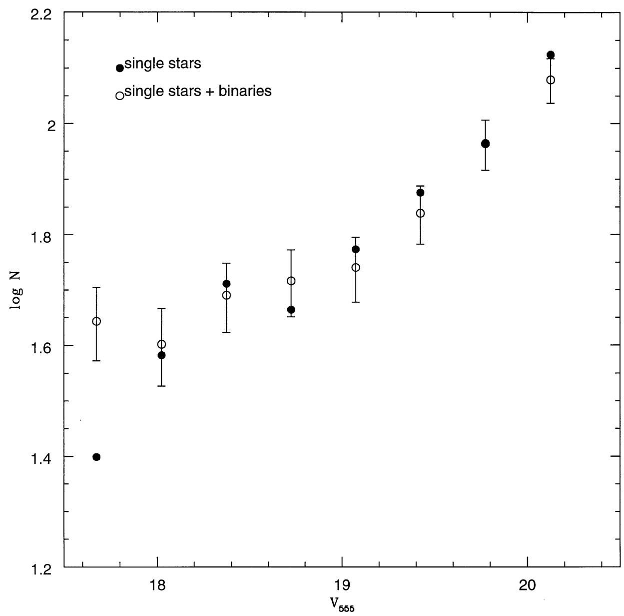

Figure 8. Luminosity functions for our single-star sample (filled circles), and for our combined single-star plus binaries sample (open circles). The single-star luminosity function has been shifted by 0.12 in $\log N$ to account for the difference in sample size. Poisson error bars are shown for the combined sample (521 objects). The error bars for the single-star sample (395 objects) are not substantially different.

than at $1-2r_c$. This is not an effect of incompleteness. (This sample includes both single and binary stars: because the main sequence becomes nearly vertical at $V_{555} \lesssim 18$, the binary sequence is no longer separated from the sequence of single stars in the CMD.)

Finally, to investigate the effect of binaries on the luminosity function, we derived luminosity functions for both our single-star sample and our single-star and binary samples combined. These are shown in Fig. 8. The two luminosity functions do not differ significantly. In contrast, a study of the Galactic globular cluster NGC 6752 found that binaries do have a significant effect on the luminosity function (Rubenstein 1997a,b). In this case there is strong mass segregation, and the observations are for the inner regions.

4 SUMMARY

We have determined the fraction of (approximately equal-mass) binaries as a function of radius in the young LMC cluster NGC 1818, for the range of (single-star) masses $\sim 2-5.5$ $M_{\odot}$. We find that the observed binary fraction is $\sim 35 \pm 5$ per cent in the core and $\sim 20 \pm 5$ per cent outside the core. The more massive binaries are more centrally concentrated than the less massive binaries. This is consistent with dynamical mass segregation, and does not require primordial mass segregation.

Our observations suggest that the secondary masses are biased towards values $\gtrsim 0.7 M_{\text{primary}}$, and that this bias is related to the formation of the binaries and not to dynamical selection.

We find no significant population of (resolved) wide binaries. While we would expect a small initial population with separations $\gtrsim 5000$ au, they would not have survived to the present in the cluster core. In the outer parts of the cluster we find fewer wide binaries than expected, but the numbers are too small to draw any firm conclusions.

In the core of the cluster we find a small number of possible triple systems. These are unlikely to be the result of chance projections, and, unlike the wide binaries, would not have been vulnerable to disruption through stellar encounters.

Our simulations suggest that the initial fraction of primordial binaries need not be substantially greater than the current distribution. However, the true dynamical evolution within the simulation may be dominated by Poisson noise so that, in order to draw accurate conclusions, we require larger-N simulations or a larger number of small simulations with averaged results (Giersz & Heggie 1994, 1996).

ACKNOWLEDGMENTS

MD acknowledges the support of the Royal Society through a URF. SS acknowledges the support of the European Union, through a Marie Curie Personal Fellowship. Funding for JH was provided by a grant from the Cambridge Commonwealth Trust, and from Trinity College. We would like to thank Sverre Aarseth and Nial Tanvir for helpful discussions.

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