Mass segregation in young compact star clusters in the
Large Magellanic Cloud: II. Mass Functions

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ABSTRACT
We review the complications involved in the conversion of stellar luminosities into
masses and apply a range of mass-to-luminosity relations to our
Hubble Space Telescope
observations of the young LMC star clusters NGC 1805 and NGC 1818.
Both the radial dependence of the mass function (MF) and the depen-
dence of the cluster core radii on mass indicate clear mass segregation in both clus-
ters at radii \( r \lesssim 20 - 30'' \), for masses in excess of \( \sim 1.6 - 2.5 M_\odot \). This result does not depend on
the mass range used to fit the slopes or the metallicity assumed. It is clear that the
cluster MFs, at any radius, are not simple power laws.
The global and the annular MFs near the core radii appear to be characterised by sim-
ilar slopes in the mass range \( -0.15 \leq \log m/M_\odot \leq 0.85 \), the MFs beyond \( r \gtrsim 30'' \)
have significantly steeper slopes.

We estimate that while the NGC 1818 cluster core is between \( \sim 5 \) and \( \sim 30 \) crossing
times old, the core of NGC 1805 is likely \( \lesssim 3 - 4 \) crossing times old. However, since
strong mass segregation is observed out to \( \sim 6R_{\text{core}} \) and \( \sim 3R_{\text{core}} \) in NGC 1805 and
NGC 1818, respectively, it is most likely that significant primordial mass segregation
was present in both clusters, particularly in NGC 1805.

Key words: stars: luminosity function, mass function – galaxies: star clusters –
Magellanic Clouds – globular clusters: individual: NGC 1805, NGC 1818

1 PRIMORDIAL VERSUS DYNAMICAL MASS
SEGREGATION
The effects of mass segregation in star clusters, with the
more massive stars being more centrally concentrated than
the lower-mass stars, clearly complicates the interpretation
of an observed luminosity function (LF) at a given position
within a star cluster in terms of its initial mass function
(IMF). Without reliable corrections for the effects of mass
segregation, hence for the structure and dynamical evolution
of the cluster, it is impossible to obtain a realistic global
cluster LF.

1.1 Dynamical Evolution in Star Cluster Cores
Dynamical evolution in dense stellar systems, such as Galac-
tic globular clusters (GCs) and rich Large Magellanic Cloud
(LMC) star clusters, drives the systems towards energy
equipartition, in which the lower-mass stars will attain
higher velocities and therefore occupy larger orbits.

Consequently, the high-mass stars will gradually sink
towards the bottom of the cluster potential, i.e., the cluster
centre (cf. Spitzer & Hart 1971), with the highest-mass stars
and those closest to the cluster centre sinking the fastest,
although this process is not negligible even at the cluster’s
edge (e.g., Chernoff & Weinberg 1990, Hunter et al. 1995).
This leads to a more centrally concentrated high-mass com-
ponent compared to the lower-mass stellar population, and
thus to dynamical mass segregation.

The time-scale for the onset of significant dynamical
mass segregation is comparable to the cluster’s dynamical
relaxation time (Spitzer & Shull 1975, Inagaki & Saslaw
1985, Bonnell & Davies 1998, Elson et al. 1998). A cluster’s
characteristic time-scale is may be taken to be its half-mass
(or median) relaxation time, i.e., the relaxation time at the
mean density for the inner half of the cluster mass for cluste-
rs stars with stellar velocity dispersions characteristic for
the cluster as a whole (Spitzer & Hart 1971, Lightman & Shapiro
1978, Meylan 1987, Mammoth & Heap 1994, Brandl et al.
1996), and can be written as (Meylan 1987):

\[
 t_{r,h} = \left(8.92 \times 10^5\right)\frac{M_{\text{tot}}^{1/2}}{(m)}\log(0.4 M_{\text{tot}}/(m))^{3/2} \text{yr}, \tag{1}
\]

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where $R_0$ is the half-mass (median) radius (in pc), $M_{\text{tot}}$ the total cluster mass, and $\langle m \rangle$ the typical mass of a cluster star (both masses in $M_\odot$).

Although the half-mass relaxation time characterises the dynamical evolution of a cluster as a whole, significant differences are expected locally within the cluster. From Eq. (1) it follows immediately that the relaxation time-scale will be shorter for higher-mass stars (greater $\langle m \rangle$) than for their lower-mass companions; numerical simulations of realistic clusters confirm this picture (e.g., Aarseth & Heggie 1998, see also Hunter et al. 1995, Kontizas et al. 1998). From this argument it follows that dynamical mass segregation will also be most rapid where the local relaxation time is shortest, i.e., near the cluster centre (cf. Fischer et al. 1998, Hillenbrand & Hartmann 1998). The relaxation time in the core can be written as (Meylan 1987):

$$t_{r,0} = (1.55 \times 10^7) \frac{v_s R_{\text{core}}^2}{\langle m \rangle \log(0.5 M_{\text{tot}} / \langle m \rangle)} \text{yr},$$

where $R_{\text{core}}$ is the cluster core radius (in pc), $v_s$ (km s$^{-1}$) the velocity scale, and $\langle m \rangle$ the mean mass (in $M_\odot$) of all particles in thermal equilibrium in the central parts.

Thus, significant mass segregation among the most massive stars in the cluster core occurs on the local, central relaxation time-scale (comparable to just a few crossing times, cf. Bonnell & Davies 1998), whereas a time-scale $\propto t_{r,0}$ is required to affect a large fraction of the cluster mass.

It should be kept in mind, however, that even the concept of a “local relaxation time” is only a general approximation, as dynamical evolution is a continuing process. The time-scale for a cluster to lose all traces of its initial conditions also depends on the smoothness of its gravitational potential, i.e., the number of stars (Bonnell & Davies 1998: larger clusters are inherently smoother, and therefore mass segregation is slower than in smaller clusters with a grainier mass distribution), the degree of equipartition reached (e.g., Hunter et al. 1995: full global, or even local, equipartition is never reached in a realistic star cluster, not even among the most massive species), and the slope of the MF (e.g., Lightman & Shapiro 1978, Inagaki & Saslaw 1985, Pryor, Smith & McClure 1986, Sozin 1997: flatter mass spectra will speed up the dynamical evolution, whereas steep mass spectra will tend to a higher degree of equipartition), among others.

In addition, as the more massive stars move inwards towards the cluster centre, their dynamical evolution will speed up, and hence the dynamical relaxation time-scale for a specific massive species is hard to define properly. This process will be accelerated if there is no (full) equipartition (cf. Inagaki & Saslaw 1985), thus producing high-density cores very rapidly, where stellar encounters occur very frequently and binary formation is thought to be very effective (cf. Inagaki & Saslaw 1985, Elson et al. 1987b). In fact, the presence of binary stars may accelerate the mass segregation significantly, since two-body encounters between binaries and between binaries and single stars are very efficient (e.g., Nemec & Harris 1987, De Marchi & Paresce 1996, Bonnell & Davies 1998, Elson et al. 1998). This process will act on similar (or slightly shorter) time-scales as the conventional dynamical mass segregation (cf. Nemec & Harris 1987, Bonnell & Davies 1998, Elson et al. 1998). In summary, the time-scale for dynamical relaxation is a strong function of position within a cluster, and varies with its age.

1.2 Primordial Mass Segregation

Although a cluster will have lost all traces of its initial conditions on time-scales longer than its characteristic relaxation time, on shorter time-scales the observed stellar density distribution is likely the result of dynamical relaxation and of the way that star formation has taken place. The process is in fact more complicated, as the high-mass stars evolve on the same time-scale as the lower mass stars (cf. Aarseth 1999). In order to understand the process of mass segregation in a cluster in detail, we have to get an idea of the amount of “primordial” mass segregation in the cluster.

The nature and degree of primordial mass segregation is presumably determined by the properties of interactions of protostellar material during the star-forming episode in a cluster. In the classic picture of star formation (Shu, Adams & Lizano 1987), interactions are unimportant, and mass segregation does not occur. However, Fischer et al. (1998) conclude that their observations of NGC 2157 seem to indicate the picture in which encounters at the early stages in a cluster’s evolution enhance mass accretion due to the merging of protostellar clumps until the mass of these clumps exceeds the initial mass of a star to be formed. More massive stars are subject to more mergers, hence accrete even more mass (cf. Larson 1991, Bonnell et al. 2001a, and references therein), and therefore dissipate more kinetic energy. In addition, they tend to form near the cluster centre, in the highest-density region, where the encounter-rate is highest (cf. Larson 1991, Bonnell et al. 1997, 1998, 2001a, Bonnell & Davies 1998). This will lead to an observed position-dependent MF containing more low-mass stars at larger radii compared to the MF in the cluster centre (although low-mass stars are still present at small radii). This scenario is fully consistent with the idea that more massive stars tend to form in clumps and lower-mass stars form throughout the cluster (Hunter et al. 1995, Brandl et al. 1996, and references therein).

Although it has been claimed that the observed mass segregation in R136, the central cluster in the large star forming complex 30 Doradus in the LMC, is likely at least partially primordial (e.g., Malumuth & Heap 1994, Brandl et al. 1996) its age of $\approx 3$–4 Myr is sufficiently long for at least some dynamical mass segregation, in particular of the high-mass stars in the core ($r \lesssim 0.5$ pc), to have taken place (cf. Malumuth & Heap 1994, Hunter et al. 1995, Brandl et al. 1996). On the other hand, the presence of the high-mass Trapezium stars in the centre of the very young Orion Nebula Cluster (ONC; $\lesssim 1$ Myr, equivalent to $\approx 3$–5 crossing times; Bonnell & Davies 1998) is likely largely due to mass segregation at birth (Bonnell & Davies 1998, based on numerical simulations; Hillenbrand & Hartmann 1998, based on the appearance of the cluster as non-dynamically relaxed, and references therein). Bonnell & Davies (1998) show convincingly that the massive stars in the core of the ONC most likely originated within the inner 10–20% of the cluster.

Hillenbrand & Hartmann (1998) argue that the young embedded clusters NGC 2024 and Monoceros R2 also show evidence for primordial mass segregation, since the outer regions of these clusters (and of the ONC as well) are not even one crossing time old.
2 THE DATA

As part of Hubble Space Telescope (HST) programme GO-7307, we obtained deep WFPC2 V and I-band imaging of 7 rich, compact star clusters in the LMC, covering a large age range. In de Grijs et al. (2001; Paper I) we presented the observational data for the two youngest clusters in our sample, NGC 1805 and NGC 1818, and discussed the dependence of the LFs on radius within each cluster. We found clear evidence for luminosity segregation within the inner \( \sim 30'' \) for both clusters, in the sense that the inner annular LFs showed a relative overabundance of bright stars with respect to the less luminous stellar population compared to the outer annular LFs.

In this paper, we will extend our analysis to the associated MFs and discuss the implications of our results in terms of the IMF and the star formation process. In Section 2 we will derive the MF slopes for both clusters, using a number of mass-to-luminosity (ML) conversions discussed in Section 3. We will take care to only include main sequence stars belonging to the clusters in our final MFs; to do so we will exclude the field LMC red giant branch stars from the colour-magnitude diagrams (CMDs), with colours \((V - I) \geq 0.67\) if they are brighter than \(V = 22\) mag (see the CMDs in Johnson et al. 2001 for comparison). In fact, as can be seen from these CMDs, the true structure of the HR diagram above the main-sequence turn-off is very complex. Stellar populations of different masses overlap in colour-magnitude space, so that unambiguous mass determination from isochrone fits, for the handful to the few dozen stars populating these areas in each cluster, is highly model-dependent (cf. Fig. 11 in Johnson et al. 2001). In a differential analysis such as presented in this paper, the uncertainties involved in their mass determinations are too large and systematic (i.e., model dependent), so that we cannot include these stars in our analysis.

Table 1 of Paper I contains the fundamental parameters for our two young sample clusters. For the analysis in this paper, however, we need to justify our choice for the adopted metallicity, age, and cluster mass in more detail.

(i) Cluster metallicities – For NGC 1805, metallicity determinations are scarce. Johnson et al. (2001) obtained an estimate of near solar metallicity, from fits to HST CMDs. The only other metallicity estimate available for NGC 1805, \([\text{Fe/H}] \sim -0.30\) (Meliani et al. 1994) is based on the average metallicity of the young LMC population and is therefore less certain.

Abundance estimates for NGC 1818, on the other hand, are readily available, but exhibit a significant range. The most recent determination by Johnson et al. (2001), based on HST CMD fits, similarly suggests near-solar abundance, \([\text{Fe/H}] \approx 0.0\). Metallicity determinations based on stellar spectroscopy range from roughly \([\text{Fe/H}] \sim -0.8\) (Meliani et al. 1994, Will et al. 1995, Oliva & Origlia 1998) to \([\text{Fe/H}] \sim -0.4\) (Jasniwicz & Thévenin 1999, Bonatto et al. 1995; see also Johnson et al. 2001).

For the purposes of the present paper, we will consider the cases of \([\text{Fe/H}] = 0.0\) and \([\text{Fe/H}] = -0.5\) for both clusters.

(ii) Age estimates – Various age estimates exist for both clusters, which are all roughly consistent with each other, although based on independent diagnostics. The age range for NGC 1805 is approximately bracketed by \(\log t(\text{yr}) = 6.95 - 7.00\) (cf. Bica et al. 1990, Barbaro & Olivi 1991, Santos Jr. et al. 1995, Cassatella et al. 1996) and \(\log t(\text{yr}) = 7.6 - 7.7\) (cf. Barbaro & Olivi 1991), the most recent determinations favouring younger ages. We will therefore adopt an age for NGC 1805 of \(\log t(\text{yr}) = 7.0^{0.3}_{-0.1}\).

Numerous age estimates are available for NGC 1818, on average indicating a slightly older age for this cluster than for NGC 1805. Most estimates bracket the age range between \(t \sim 15\) Myr (Bica et al. 1990, Bonatto et al. 1995, Santos Jr. et al. 1995, Cassatella et al. 1996) and \(t \gtrsim 65\) Myr (cf. Barbaro & Olivi 1991), with the most recent estimates, based on HST CMD fits, favouring an age \(t \approx 20 - 30\) Myr (e.g., Cassatella et al. 1996, Grebel et al. 1997, Hunter et al. 1997, van Bever & Vanbeveren 1997, Fabregat & Torrejón 2000). We will therefore adopt an age of \(t \approx 25\) Myr for NGC 1818, or \(\log t(\text{yr}) = 7.4^{0.3}_{-0.1}\).

(iii) Cluster masses – To obtain mass estimates for both clusters, we first obtained the total V-band luminosity for each cluster based on fits to the surface brightness profiles of our longest CEN exposures, in order to retain a sufficiently high signal-to-noise ratio even for the fainter underlying stellar component. We subsequently corrected these estimates of \(L_{V,\text{tot}}\) for the presence of a large number of saturated stars in the long CEN exposures (i.e., the observations where we located the cluster centre in the WFPC2/PC chip) by comparison with the short CEN exposures. Although even in the short CEN exposures there are some saturated stars (cf. Section 3.3 in Paper I), their number is small (12 in NGC 1805 and 18 in NGC 1818), so that we can get firm lower limits of \(\log L_{V,\text{tot}} / L_{V,\odot} = 4.847 \) and 5.388 for NGC 1805 and NGC 1818, respectively.

Models of single-burst simple stellar populations (e.g., Bruzual & Charlot 1996), which are fairly good approximations of coeval star clusters, predict mass-to-light (M/L) ratios as a function of age, which we can use to obtain photometric mass estimates for our clusters. This leads to mass estimates of \(M_{\text{tot}} = 3.8^{+0.5}_{-0.3} \times 10^7 M_\odot\) (log \(M_{\text{tot}} / M_\odot = 3.45^{+0.31}_{-0.31}\) for NGC 1805 and \(M_{\text{tot}} = 2.3^{+1.1}_{-0.3} \times 10^4 M_\odot\) or log \(M_{\text{tot}} / M_\odot = 4.35^{+0.18}_{-0.05}\) for NGC 1818.

Our mass estimate for NGC 1805 is low compared to the only other available mass, \(M_{\text{tot}} = 6 \times 10^3 M_\odot\) (Johnson et al. 2001), although their mass estimate, based on earlier simple stellar population models, is close to the upper mass allowed by our 1\(\sigma\) uncertainty.

For NGC 1818, our mass estimate is entirely within the probable range derived by Elson, Fall & Freeman (1987), i.e. \(4.1 \leq \log M_{\text{tot}} / M_\odot \leq 5.7\), depending on the M/L ratio, and Hunter et al.’s (1997) estimate of \(M_{\text{tot}} = 3 \times 10^4 M_\odot\) falls comfortably within our 1\(\sigma\) uncertainty. Chrysovergis et al.’s (1989) determination of \(\log M_{\text{tot}} / M_\odot = 4.69\) is outside our 1\(\sigma\) error bar; we speculate that the difference between our two estimates is due to a combination of the single-mass isotropic King cluster model used by them, versus our photometric mass determination, and a different treatment of the background stellar contribution.

3 CONVERTING LUMINOSITY TO MASS FUNCTIONS

The conversion of an observational LF (which we determined for NGC 1805 and NGC 1818 in Paper I), in a given
passband ν, φ(Mν), to its associated MF, ξ(m), is not as straightforward as often assumed. The differential present-day stellar LF, dN/dφ(Mν), i.e. the number of stars in the absolute-magnitude interval [Mν, Mν + dMν], and the differential present-day MF, dN/dξ(m), i.e. the mass in the corresponding mass interval [m, m + dm], are related through dN = −φ(Mν)dMν = ξ(m)dm (Kroupa 2000), and therefore
\[ \phi(M_i) = -\xi(m) \frac{dm}{dM_i} \] (3)

Thus, in order to convert an observational LF into a reliable MF, one needs to have an accurate knowledge of the appropriate ML – or mass–absolute-magnitude – relation, dN/dM. Empirical ML relations are hard to come by, and have so far only been obtained for solar-metallicity stars (e.g., Popper 1980; Andersen 1991; Henry & McCarthy 1993, hereafter HM93; Kroupa, Tout & Gilmore 1993, hereafter KTG93). The ML relation is, however, a strong function of the stellar metallicity, and one needs to include corrections for hidden companion stars to avoid introducing a systematic bias in the derived MF (e.g., KTG93, Kroupa 2000). For the conversion of the present-day MF to the IMF, one needs additional corrections for stellar evolution on and off the main sequence, including corrections for age, mass loss, spread in metallicity and evolution of rotational angular momentum, or spin (cf. Scalo 1986, Kroupa 2000). Although the ML relation is relatively well-established for stars more massive than ∼ 0.8 M⊙, our rather limited understanding of the lower-mass, more metal-poor stars, especially of the boundary conditions between the stellar interior and their atmospheres, have until recently severely limited the applicability of reliable ML relations to obtain robust MFs at the low-mass end.

3.1 The mass-luminosity relation down to ∼ 0.4 M⊙

As shown by Eq. (3), it is in fact the slope of the ML relation at a given absolute magnitude that determines the corresponding mass, which is therefore quite model dependent. This has been addressed in detail by, e.g., D’Antona & Mazzitelli (1983), Kroupa et al. (1990, 1993), Elson et al. (1995) and Kroupa & Tout (1997).

The slope of the ML relation varies significantly with absolute magnitude, or mass. As shown by Kroupa et al. (1990, 1993) for solar-metallicity stars with masses m ≤ 1 M⊙, it has a local maximum at M_V ≈ 7, and reaches a minimum at M_V ≈ 11.5 (see also Kroupa 2000). This pronounced minimum corresponds to a maximum in the present-day LF, while the local maximum at M_V ≈ 7 corresponds to the Wielen dip in the present-day LF of nearby stars (e.g., Kroupa et al. 1990, D’Antona & Mazzitelli 1996, and references therein).

The local maximum in the derivative of the ML relation at M_V ≈ 7 (m ≈ 0.7 M⊙) is caused by the increased importance of the H^- opacity in low-mass stars with decreasing mass (KTG93, Kroupa & Tout 1997).

The ML relation steepens near M_V = 10 (m ≈ 0.4 – 0.5 M⊙), due to the increased importance of H_2 in the outer shells of main sequence stars, which in turn leads to core contraction (e.g., Chabrier & Baraffe 1997, Baraffe et al. 1998, Kroupa 2000).

Given the non-linear shape of the ML relation and the small slope at the low-mass end, any attempt to model the ML relation by either a polynomial fit or a power-law dependence will yield intrinsically unreliable MFs (cf. Elson et al. 1995, Chabrier & Mérá 1997), in particular in the low-mass regime. This model dependence is clearly illustrated by, e.g., Ferraro et al. (1997), who compared the MFs for the GC NGC 6752 derived from a variety of different ML relations at that time available in the literature.

3.2 Age and metallicity dependence and corrections for binarity

The exact shape of the ML relation is sensitive to metallicity; metallicity changes affect the stellar spectral energy distribution and therefore the (absolute) magnitude in a given optical passband (cf. Brewer et al. 1993). In fact, it has been argued (cf. Baraffe et al. 1998) that, although the V-band ML relation is strongly metallicity-dependent, the K-band ML relation is only a very weak function of metal abundance, yielding similar K-band fluxes for [M/H] = −0.5 and [M/H] = 0.0. Although the ML relation is currently relatively well-determined for solar-metallicity stars with m > 0.8 M⊙, at low metallicities the relation remains very uncertain. This is partially due to the lack of an empirical comparison, and to our still relatively poor understanding of the physical properties of these stars, although major efforts are currently under way to alleviate this latter problem (e.g., the recent work by the Lyon group).

Fortunately, as long as we only consider unevolved main sequence stars, age effects are negligible and can therefore be ignored (cf. Brewer et al. 1993, Ferraro et al. 1997). This applies to the current study for the stellar mass range considered.

Finally, stellar populations contain in general at least 50 per cent of multiple systems. The immediate effect of neglecting a significant fraction of binary stars in our LF-to-MF conversion will be an underestimate of the resulting MF slope (cf. Fischer et al. 1998, Kroupa 2000). We will come back to this point in Section 3.3.

3.3 A comparison of mass-luminosity relations

3.3.1 Luminosity-to-mass conversion for stars with masses below 1 M⊙

Since no empirical ML relations are available for low-mass, low-metallicity main sequence stars, a test of the goodness of ML relations in this regime must therefore bear on the comparison of different models. Several recent studies have adopted this approach (e.g., Alexander et al. 1997, Ferraro et al. 1997, Kroupa & Tout 1997, Piotto, Cool & King 1997, Saviane et al. 1998).

For solar-metallicity stars in the mass range 0.1 < m ≤ 1 M⊙, Leggett et al. (1996) and Kroupa & Tout (1997) concluded that, although all models considered provided reasonable fits to the empirical ML relation, the Baraffe et al. (1995) theoretical ML relations provided the best overall agreement with all recent observational constraints. On the other hand, Bedin et al. (2001) show that these are poor at low metallicity. It should be noted that the Baraffe et al. (1995) models were based on grey model atmospheres.

Both Piotto et al. (1997) and Saviane et al. (1998), from
Figure 1. Empirical and theoretical ML relations. (a) – solid bullets: HM93; open circles: Andersen (1991). (b) – solid line: HM93 fit; dotted line: KTG93 and Kroupa & Tout (1997) semi-empirical ML relation; dashed line: Chabrier et al. (1996) theoretical ML relation for $m \leq 0.6 M_\odot$, based on a third-order polynomial fit. (c) – Theoretical ML relations for subsolar abundances: Alexander et al. (1997; solid lines, for $[M/H] = -1.3, -1.5, -2.0$ [top to bottom]), and Baraffe et al. (1997; dashed line, $[M/H] = -1.5$). For comparison, the solar-abundance ML relation of Baraffe et al. (1997) is also shown (dash-dotted line). (d) – Observational data for $m \geq 1.0 M_\odot$ stars (Andersen 1991), and – for $m \lesssim 5 M_\odot$ – theoretical models by GBBC00 for solar abundance (solid line) and $[M/H] = -1.3$ (dashed line).

a comparison of largely the same theoretical ML relations available in the literature with observational data for the low-metallicity Galactic GCs NGC 6397 ([Fe/H] $\approx -1.9$) and NGC 1851 ([Fe/H] $\approx -1.3$), respectively, concluded that the Alexander et al. (1997) theoretical ML relations for the appropriate metallicity provided the best match for masses $m \lesssim 0.6 - 0.8 M_\odot$. Similar conclusions were drawn by Piotto et al. (1997) for three other Galactic GCs, M15, M30 and M92. Alexander et al. (1997) themselves found a good to excellent overall agreement between their models and those of the Lyon group, in particular the updated Chabrier, Baraffe & Plez (1996) ones, which employ the most recent non-grey model atmospheres.

Figure 1 shows the available empirical data, on which
these comparisons are based on solar-metallicity stellar populations. The filled bullets are represented by the HM93 sample; the open circles show the higher-mass Andersen (1991) binary stars. In panel (b), we show the $m \leq 2M_\odot$ subsample. Overplotted are the best-fitting relation of HM93 (solid line), the fit to their semi-empirical ML relation (dotted line) of KTG93 and Kroupa & Tout (1997), and the theoretical ML relation of Chabrier et al. (1996; dashed line) for $0.075 \leq m \leq 0.6M_\odot$. The figure shows that the observational data allow for significant local differences in the slope of the solar-metallicity ML relation; these uncertainties propagate through the derivation of the relation when converting LFs to MFs.

The theoretical ML relation for solar abundance by Chabrier et al. (1996) closely follows the most recent semi-empirical ML relation compiled by Kroupa (KTC93, Kroupa & Tout 1997). In Fig. 4, we compare the current theoretical ML relations for subsolar metallicity: the solid lines represent the Alexander et al. (1997) ML relations for (top to bottom) $[M/\text{H}] \cong -1.3$, $-1.5$, and $-2.0$ for reasons of clarity, we only show the $[M/\text{H}] = -1.5$ ML relation of Baraffe et al. (1997), but the spread due to metallicity differences is similar to that shown by the Alexander et al. (1997) relations. The most significant differences between both sets of models are seen at masses $m \gtrsim 0.4M_\odot$. This is likely due to the slightly different treatment of the stellar atmospheres and radiative opacities. Finally, for comparison we also show the solar-metallicity theoretical ML relation of Chabrier et al. (1996) and Baraffe et al. (1997).

We plot the derivatives of the ML relations as a function of absolute visual magnitude in Fig. 2. From Fig. 2, it is immediately clear that the empirical fit to the HM93 ML relation inherently leads to unreliable luminosity-to-mass conversions because of the two sharp discontinuities in the slope.

Figure 3 shows the metallicity dependence of the slope of the ML relation; the solid lines represent the Alexander et al. (1997) ML relations with $[M/\text{H}] = -1.3$, $-1.5$, and $-2.0$, peaking from right to left. The Baraffe et al. (1997) models (cf. the dashed line, for $[M/\text{H}] = -1.5$) closely follow the Alexander et al. (1997) ones. For comparison, we have also included the solar-abundance model of Chabrier et al. (1996) and Baraffe et al. (1997), as in panel (a).

3.3.2 The more massive stellar population

The main uncertainties for the luminosity evolution of stars with $m \gtrsim 0.8M_\odot$ in the treatment of the degree of mass loss and convective core overshooting. Girardi et al. (2000, hereafter GBBC00) and Girardi (2001, priv. comm.) computed a grid of stellar evolutionary models for stars in the mass range $0.15 \leq m \leq 7M_\odot$ for metallicities between $0.5$ and $1.5$ times solar, using updated input physics, as well as moderate core overshooting.

In Fig. 5, we show the observational ML relation of Andersen (1991) for stars with masses $m \geq 1.0M_\odot$. In addition, we have plotted GBBC00’s (2000) theoretical ML relations for solar metallicity (solid line) and for $[M/\text{H}] = -1.3$ (dashed line) for stars less massive than $\sim 5M_\odot$. These models include moderate core overshooting, but the presence or absence of this process in the models does not significantly change the resulting ML relation for this mass range.

3.3.3 Comparison for our young LMC clusters

Based on the comparison and discussion in the previous sections, for the conversion of our observational (individual) stellar magnitudes (Paper I) to masses, and thence to MFs we will use

- the empirical ML relation of HM93. This ML relation is defined for stars with $M_V \geq 1.45$.
- the KTG93 and Kroupa & Tout (1997) semi-empirical ML relation for stars with $M_V \geq 2.00$, with an extension to $M_V = -3$ by adoption of Scalo’s (1986) mass-$M_V$ relation.
- the parametrisation of these by Tout et al. (1996, hereafter TPEH96), valid for masses in the range $-1 \leq \log m/M_\odot \leq 2$; we converted the corresponding bolometric luminosities to absolute $V$-band magnitudes using the bolometric corrections of Lejeune, Cuisinier & Buser (1998). The TPEH96 ML relations are given as a function of metallicity from $Z = 10^{-4}$ to $Z = 0.03$.
- the GBBC00 models. For solar metallicities, the models for their youngest isochrone of 60 Myr are defined for stars with $-3.381 \leq M_V \leq 12.911$, while for the subsolar abundance of $Z = 0.008$ this corresponds to $-4.832 \leq M_V \leq 12.562$.

Although we argued that the Baraffe et al. (1998, hereafter BCAH98) models employ the most recent input physics, their mass range, $m \leq 1.0M_\odot$, precludes us from using their models, since completeness generally drops below our 50% limit for $m \leq 0.8M_\odot$, thus leaving us with too few data points for a useful comparison.

In Fig. 3, we compare the mass estimates based on HM93, KTG93, BCAH98 and GBBC00 to TPEH96’s parametrisation, for both solar and subsolar ([Fe/H] = −0.5) metallicities and ages of ∼ 10 and 25 Myr. Significant differences are appreciated among the individual models, in particular between TPEH96 on the one hand and the high-mass end ($\log m/M_\odot \geq 0.3$) of KTG93 and between TPEH96 and the models of BCAH98, which show systematic deviations from the one-to-one relation indicated by the dashed line. It is therefore not unlikely that the differences among the models dominate the uncertainties in the derived MF and ultimately — in the IMF slope (see also Bedin et al. 2001, who reached a similar conclusion in their analysis of the Galactic GC M4). We will quantify these effects in the next section.

In Fig. 5, we show examples of the derived global cluster MFs, normalized to unit area, for three of the ML conversions adopted in this paper, KTG93, TPEH96 and GBBC00. All MFs are shown for solar metallicity and for mass bins corresponding to luminosity ranges that exceed our 50% completeness limits (see Paper I). The MFs, and all other
4 QUANTIFICATION OF MASS SEGREGATION EFFECTS

4.1 Radial dependence of luminosity and mass functions

The effects of mass segregation can be quantified using a variety of methods. The most popular and straightforward diagnostic for mass segregation effects is undoubtedly the dependence of MF slope, \( \Gamma = \frac{\Delta \log \xi(m)}{\Delta m} \) (where \( \xi(m) \propto m^\Gamma \)), on cluster radius.

In Fig. 2(a), we plot the derived MF slopes as a function of cluster radius for our four adopted ML conversions and assuming three different fitting ranges in mass:

- \( -0.15 \leq \log m/M_\odot \leq 0.30 \) for all conversions;
- \( -0.15 \leq \log m/M_\odot \leq 0.70 \) for KTG93, TPEH96 and GBBC00; and
- \( -0.15 \leq \log m/M_\odot \leq 0.85 \) for TPEH96 and GBBC00.

The adopted radial ranges for our annular MFs are indicated by the horizontal bars at the bottom of each panel. Although we see a large spread among models and mass fitting ranges, clear mass segregation is observed in both clusters at radii \( r \lesssim 20'' \), well outside the cluster core radii (indicated by the vertical dotted lines). We have also indicated the Salpeter (1955) IMF slope, \( \Gamma = -1.35 \) (dashed horizontal lines). While both the global MFs (which are dominated by the inner, mass-segregated stellar population) and the annular MFs near the core radii appear to be consistent with the Salpeter IMF slope (cf. Vesperini & Heggie 1997; for the cluster models assumed here, \( R_{\text{core}} \approx R_h \)), the MFs beyond the cluster radii where mass segregation is significant (i.e., \( r \gtrsim 30'' \)) are characterised by steeper slopes, i.e., relatively more low-mass stars compared to high mass stars than found in the inner cluster regions. This result holds for all mass fitting ranges, all ML conversions considered, solar and subsolar ([Fe/H] = -0.5) metallicity, and both clusters.

The error bars in Fig. 2 represent the formal uncertainty in the fits; the systematic uncertainties are clearly greater, and a strong function both of the adopted ML conversion and of the mass range used for the fitting of the MF slopes. In all cases, the larger mass ranges used for the fitting result in steeper MF slopes than the smaller (low-mass) range, thus presenting clear evidence for non-power law shaped MFs. In addition, the TPEH96 parametrisation results in systematically steeper slopes for all cluster-metallicity combinations.

Because of the strong model dependence, in particular because of the sensitivity to the choice of ML relation, and the accuracy of the corrections for incompleteness and background star contamination of single power law fits to MFs discussed in this paper, were corrected for incompleteness and background contamination following identical procedures as for the LFs in Paper I. Significant systematic effects result from the adoption of any given ML conversion, as can be clearly seen. For comparison, we also plot a fiducial Salpeter IMF, which appears to be a reasonable approximation for the global cluster MFs in the mass range \((-0.15 \lesssim \log m/M_\odot \lesssim 0.8)\).
Figure 3. Comparison of the mass estimates for NGC 1805 (open circles) and NGC 1818 (filled circles) resulting from various ML relations. We used TPEH96's parametrisation as comparison ML relation because of its large mass range.
Figure 4. Examples of the derived global cluster MFs, normalized to unit area, for three of the ML conversions adopted in this paper, KTG93 (solid lines), TPEH96 (dashed lines) and GBBC00 (dotted lines). All MFs are shown for solar metallicity and for mass bins corresponding to luminosity ranges that exceed our 50% completeness limits (see text). The dash-dotted lines show the Salpeter IMF corresponding to the mass range under consideration.

the annular MFs, in Fig. 6 we introduce a more robust characterisation of the presence of mass segregation in these two young star clusters. We quantified the deviations of the high-mass range of the annular MFs from the global MF following a similar procedure as defined in Paper I for the LFs. All annular MFs were normalized to the global MF in the range $0.00 \leq \log m/M_\odot \leq 0.20$, where the effects of mass segregation – if any – are negligible, as shown above; subsequently, we determined the sum of the differences between the global and the scaled annular MFs in the common mass range $0.20 < \log m/M_\odot \leq 0.60$, $\Sigma(\Delta \Gamma)$. We adopted $\log m/M_\odot = 0.60$ as upper mass limit, so that we could compare the results of all three ML conversions.

From Fig. 6 it follows that both clusters are mass segregated within $R \approx 30''$; beyond, the deviations become relatively constant with increasing radius. It is also clear (i) that there is no appreciable difference between the strength of the mass segregation in the two clusters, and (ii) that the scatter among the data points from the different models is relatively small. We therefore conclude that we have been able to quantify the effects of mass segregation in a fairly robust way by thus minimising the effects of the choice of ML conversion.

It is most likely that the effect referred to as mass segregation is indeed due to a positional dependence of the ratio of high-mass to low-mass stars within the clusters, and not to different age distributions (“age segregation”). Johnson et al. (2001) have shown that for the high-mass stars in both clusters the LF is indeed just a smoothed (almost) coeval CMD, for which age effects are only of second order importance. It is possible that for very low stellar masses, i.e. pre-main-sequence stars, age segregation may play a more important role, but this applies only to stars well below the 50% completeness limits for both clusters.

Finally, we point out that it is generally preferred to use star counts rather than surface brightness profiles to measure mass segregation effects (e.g., Elson et al. 1987b, Chernoff & Weinberg 1990). Elson et al. (1987b) argue that the use of surface brightness profiles by themselves, although initially used to study mass segregation (e.g., da Costa 1982, Richer & Fahlman 1989), is limited in the sense that one cannot distinguish between these effects and any significant degree of radial velocity anisotropy in a cluster’s outer regions (see also Chernoff & Weinberg 1990). In addition, a comparison between results obtained from star counts and from surface brightness profiles does not necessarily trace the same system, since star counts are generally dominated by main-sequence (and subgiant-branch) stars, while surface brightness profiles mostly trace the giants (and also subgiant stars) in a cluster (cf. Elson et al. 1987b).

4.2 Core radii

Conclusive results on the presence of mass segregation in clusters can also be obtained by examining the core radii of specific massive stellar species (e.g., Brandl et al. 1996), or – inversely – by measuring the mean stellar mass within a given radius (e.g., Bonnell & Davies 1998, Hillenbrand & Hartmann 1998). However, it may not always be feasible to
use this diagnostic, since the individual stellar masses of the cluster members need to be known accurately, thus providing an additional observational challenge. In addition, the results depend critically on which stars are used to obtain the mean mass, and can be severely affected by small number statistics (cf. Bonnell & Davies 1998).

Figure 7 and Table 1 show the dependence of the derived cluster core radius on the adopted magnitude (or mass) range. Core radii were derived based on fits to stellar number counts – corrected for the effects of incompleteness‡ and

‡ We only used magnitude (mass) ranges for which the completeness fractions, as determined in Paper I, were at least 50%.
Figure 6. Deviations of the annular MFs from the global MF as a function of radius, as discussed in the text. Filled symbols were obtained using the ML relation of KTG93, open symbols are based on TPEH96's ML conversion, and crossed open symbols result from the GBBC00 models. The horizontal bars at the bottom of the figure indicate the radial range used to obtain the data points, the cluster core radii are indicated by the vertical dotted lines.

Figure 7. Core radii as a function of magnitude (mass). The filled circles are the core radii after correction for the effects of (in)completeness, area covered by the observations, and background stars; the open circles are not background subtracted and serve to indicate the uncertainties due to background correction. We have also indicated the mean cluster core radii, obtained from surface brightness profile fits (dotted lines). The horizontal bars at the bottom of the panels indicate the magnitude ranges used to obtain the core radii; the numbers indicate the approximate mass (in $M_\odot$) corresponding to the centre of each magnitude range.
Equation (4) reduces to a modified Hubble law for GCs (King 1966), which is a good approximation to the canonical King model in the outer regions of the cluster, and

\[
\mu(r) = \mu_0 + \left(1 + \left(\frac{r}{a}\right)^2\right)^{-\gamma/2},
\]

(4)

where \(\mu(r)\) and \(\mu_0\) are the radial and central surface brightnesses, respectively, \(\gamma\) corresponds to the profile slope in the outer regions of the cluster, and \(R_{\text{core}} \approx a(2^{\gamma/2} - 1)^{1/\gamma} \approx R_h\). Equation (4) reduces to a modified Hubble law for \(\gamma = 2\), which is a good approximation to the canonical King model for GCs (King 1966).

For both NGC 1805 and NGC 1818 we clearly see the effects of mass segregation for stars with masses \(m/M_\odot \gtrsim 0.2\) (\(M_V \gtrsim 24; m \gtrsim 1.6 M_\odot\)). It is also clear that the brightest four magnitude ranges, i.e. masses \(\log m/M_\odot \gtrsim 0.4 (m \gtrsim 2.5 M_\odot)\), show a similar concentration, while a trend of increasing core radius with decreasing mass (increasing magnitude) is apparent for lower masses. The larger scatter for NGC 1818 is due to the smaller number of stars in each magnitude bin compared to NGC 1805; for NGC 1818 the associated uncertainties are determined by a combination of the scatter in the derived core radii and background effects, while the uncertainties for NGC 1805 are dominated by the effects of background subtraction.

We have also indicated the core radii obtained from profile fits to the overall surface brightness profiles of the clusters. It is clear that these are dominated by the mass-segregated high-mass (bright) stars.

### 5 A COMPARISON OF MASS FUNCTION SLOPES – TRACING THE IMF?

#### 5.1 Comparison with previously published results

Few studies have published MFs of sufficient detail and quality for the two young LMC clusters analysed in this paper to allow useful comparisons. Santiago et al. (2001) published global MFs and MFs determined in the annulus \(4.9 < R < 7.3\) pc (\(19.4 < R < 28.8\)) for both NGC 1805 and NGC 1818, based on the same observations used for the present study, while Hunter et al. (1997) published the global MF as well as the core MF derived from the HST WFPC2/PC chip of NGC 1818. In Fig. 8 we compare our results with those of Hunter et al. (1997) and Santiago et al. (2001).

Although Santiago et al. (2001) used a different ML conversion than done in the present paper, the slopes and the dependence on the adopted mass fitting range they derived for their annular MFs are fully consistent with the range seen at this radius, using any of the ML relations employed by us. However, their and Hunter et al.'s (1997) global MF slopes are somewhat shallower than ours. The difference is sufficiently small, however, that it can be explained as due to the combination of different ML relations and a different treatment of the background stellar population (see Paper I for a discussion of the latter). Hunter et al. (1997) found no significant difference in MF slope between the core MF (\(\Gamma = -1.21 \pm 0.10\)) and the global MF (\(\Gamma = -1.25 \pm 0.08\)), in the mass range between 0.85 and \(9 M_\odot\) \((0.07 < \log m/M_\odot < 0.95)\). The PC field of view samples the inner \(r \sim 18\)″; we have also included their core data point in Fig. 8. Although Hunter et al.'s (1997) PC MF slope appears to be slightly steeper than most of our MF slope determinations at these radii, this can easily be explained as due to a combination of the uncertainties in the ML conversion used (as evidenced by the range in MF slopes seen in Fig. 8) and the intrinsic curvature of the MF. From Fig. 8 it follows that the MF slopes get steeper if increasingly higher mass stars are included in the fitting range (compare the location of the open, filled and open-crossed symbols, which indicate increasing mass fitting ranges). Hunter et al.'s (1997) PC MF slope determination is based on a mass range extending up to \(9 M_\odot\), while our largest fitting range only includes stars \(\lesssim 7 M_\odot\). The observed curvature in the MF will therefore result in a slightly steeper slope for the Hunter et al. (1997) MF slope, although still fairly similar to the slopes determined using our greatest mass fitting ranges at these radii (cf. Fig. 8).

With regard to the use of different ML relations, it is worth noting here that the difference between the MF slopes derived by us and those of both Hunter et al. (1997) and Santiago et al. (2001) may be largely due to the adopted isochrones: while for older clusters the MF slopes for main-sequence stars are almost independent of age, small differences between MF slopes as a function of age are appreciated for younger stellar populations. This difference is in the sense that using isochrones for older stellar populations will result in slightly shallower MF slopes. This is the most likely explanation for the slight shift between our MF slopes (based on solar neighbourhood-type stellar populations) and those of Hunter et al. (1997) and Santiago et al. (2001), who both used younger isochrones to obtain their mass estimates. However, the expected steepening in MF slope from evolved to young stellar populations is almost entirely contained within the observed spread in MF slope in both clusters (cf. Hunter et al. 1997). In fact, for the ML conversion based on the GBBC00 models, we used their youngest isochrone (at \(t = 6 \times 10^7\) yr); the resulting MFs are shown as circles in Fig. 8. Hunter et al. (1997) showed that if they had used a 30–40 Myr isochrone instead of the one at 20 Myr used by these authors, would make the IMF slope appear shallower by \(\Delta \Gamma \sim 0.15\), Thus, it appears that the GBBC00 slopes are entirely consistent with the slopes obtained from the other ML relations, however, which emphasizes our statement that any slope difference due to the
**5.2 Primordial or dynamical mass segregation?**

The key question is whether the observed mass segregation in both young LMC star clusters is the result of the process of star formation itself or due to dynamical relaxation. In Fig. 9 we have plotted the half-mass relaxation time as a function of mass, using Eq. (1) and the mass-dependent core radii of Fig. 7. For comparison, we have also indicated the ages of both clusters. For NGC 1805 significant dynamical mass segregation is expected to have occurred out to its half-mass radius for stars more massive than about 3 $M_\odot$ ($\log m/M_\odot \simeq 0.48$), while for NGC 1818 this corresponds to stars exceeding $\sim 8M_\odot$ ($\log m/M_\odot \gtrsim 0.90$). However, from Fig. 7 it follows that mass segregation becomes significant for masses $m \gtrsim 2.5M_\odot$, out to at least 20–30″, or 3–6$R_{\text{core}}$.

Dynamical mass segregation in the cluster cores will have occurred on 10–20× shorter time-scales, in particular for the more massive stars (cf. Eq. 1). In fact, if the cluster...
contains a significant amount of gas, e.g., \( M_{\text{gas}} \gtrsim M_{\text{stars}} \) (cf. Lada 1991, Bonnell & Davies 1998), this will increase the cluster’s gravitational potential, and thus the virialised stellar velocity dispersion (Bonnell & Davies 1998). Therefore, in this case a larger number of two-body encounters, and hence time, is required to reach a dynamically relaxed state. Thus, the relaxation time estimates obtained by considering only the contributions of the cluster’s stellar component should be considered lower limits, especially for young star clusters, which are generally rich in gas.

Elson et al. (1987b) estimated the central velocity dispersion in NGC 1818 to be in the range \( 1.1 \lesssim \sigma_0 \lesssim 6.8 \) km s\(^{-1}\). Combining this central velocity dispersion, the core radius of \( \sim 2.6 \) pc, and the cluster age of \( \sim 25 \) Myr, we estimate that the cluster core is between \(~5\) and \(~30\) crossing times old, so that dynamical mass segregation in the core should be well under way. Although we do not have velocity dispersion information for NGC 1805, it is particularly interesting to extend this analysis to this younger (~10 Myr) cluster. We know that its core radius is roughly half that of NGC 1818, and its mass is a factor of \(~10\) smaller. Simple scaling of Eq. (4) shows then that the half-mass relaxation time of NGC 1805 is \(~4\)—\(~5\)\times\) as short as that of NGC 1818; if we substitute the scaling laws into Eq. (5), we estimate that the central velocity dispersion in NGC 1805 is \( \gtrsim 10\times\) smaller than that in NGC 1818. From this argument it follows that the cluster core of NGC 1805 is \( \lesssim 3\) —\( 4\) crossing times old.

However, since strong mass segregation is observed out to \( \sim 6 R_{\text{core}}\) and \( \sim 3 R_{\text{core}}\) in NGC 1805 and NGC 1818, respectively, for stellar masses in excess of \( \sim 2.5 M_\odot\), it is most likely that significant primordial mass segregation was present in both clusters, particularly in NGC 1805. Although this was initially suggested by Santiago et al. (2001), we have now substantiated this claim quantitatively. Relevant to this discussion is the study by Bonnell & Davies (1998), who found that whenever a system of massive stars is found at the centre of a young star cluster, like the Trapezium stars in the ONC, a major fraction of it most likely originated in the inner parts of the cluster. N-body simulations are currently being carried out to investigate the fraction of massive stars, and their mass range, that will have to have originated in the cluster centres to result in the observed distribution. We will include these in a subsequent paper (de Grijs et al., in prep.; Paper III).

5.3 The slope of the cluster mass function

We will now return to the discussion of Figs. 3 and 4. In section 4.2, we showed (i) that the slope of the global cluster MF is relatively well approximated by that at the cluster core radius; (ii) that at the cluster core radius the effects of strong mass segregation are still clearly visible; and (iii) that in the outer cluster regions, the slope of the (annular) cluster MFs approaches a constant value.

Within the uncertainties, we cannot claim that the slopes of the outer MFs in NGC 1805 and NGC 1818 are significantly different. Starting with the work by Pryor et al. (1986) and McClure et al. (1986), it is expected that clusters with similar metallicities exhibit similar MF slopes. However, Santiago et al. (2001) claimed to have detected a significantly different MF slope for both the global and their annular MF between both clusters. As is clear from Fig. 4, their annular MFs were not taken at sufficiently large radii to avoid the effects of mass segregation. Since both clusters are affected by mass segregation in a slightly different way (which may just be a reflection of the difference in their dynamical ages), it is not surprising that Santiago et al.’s (2001) annular MFs exhibit different slopes.

Recent studies show that the actual value of the MF slope may vary substantially from one region to another, depending on parameters such as the recent star formation rate, metallicity, and mass range (cf. Brandl et al. 1996). The outer cluster regions of R136/30Dor (Malumuth & Heap 1994, Brandl et al. 1996), M5 (Richer & Fahlman 1987), M15 (Sosin & King 1997) and M30 (Sosin 1997) are all characterised by MF slopes \( \Gamma \lesssim 2.0\). Bonnell et al. (2001b) explain this rather steep MF slope naturally due to the process of star formation and accretion itself, resulting from the combination of a gas dominated and a stellar dominated regime within the forming cluster. This results in a double power law MF, where the lower mass stars have a shallower slope and the high-mass IMF slope is steeper \( (\Gamma \approx -1.5\) and \(-2 \leq \Gamma \lesssim -2.5\), respectively), due to the different accretion physics operating in each regime (i.e., tidal-lob accretion versus Bondi-Hoyle accretion for low-mass and high-mass stars, resp.).

As mentioned in section 5.2, if there is a significant percentage of binary or multiple stars in a star cluster, this will lead us to underestimate the MF slope. In other words, the MF slopes determined in this paper are lower limits, because we have assumed that all stars detected in both clusters are single stars. Elson et al. (1998) found a fraction of \( \sim 35 \pm 5\) per cent of roughly similar mass binaries (with mass of the primary \(~2\) — \(~5.5 M_\odot\)) in the centre of NGC 1818, decreasing to \(~20\) \pm \(5\) per cent in the outer regions of the cluster, which they showed to be consistent with dynamical mass segregation. It is not straightforward to correct the observed LFs for the presence of binaries, in particular since the binary fraction as a function of brightness is difficult to determine. If we consider the information at hand, (i) the small \((\sim 15\%)\) gradient in the total binary fraction derived by Elson et al. (1998) for the inner \(~3\) core radii of NGC 1818; (ii) the result of Rubenstein & Bailyn (1999) that the binary fraction increases at fainter magnitudes in the Galactic GC NGC 6572; and (iii) the similarity of our annular LFs for faint magnitudes for all annuli and both clusters, we conclude that the effects of a binary population in either or both of NGC 1805 and NGC 1818 are likely smaller than the observed differences in LF shapes as a function of radial distance from the cluster centres. This is corroborated by Elson et al.’s (1998) result for NGC 1818.

6 SUMMARY AND CONCLUSIONS

We have reviewed the complications involved in the conversion of observational LFs into robust MFs, which we have illustrated using a a number of recently published ML relations. These ML relations were subsequently applied to convert the observed LFs of NGC 1805 and NGC 1818, the two youngest star clusters in our HST programme of rich compact LMC star clusters, into MFs. The radial dependence of the MF slopes indicate clear
mass segregation in both clusters at radii \( r \lesssim 20 - 30'' \), well outside the cluster core radii. This result does not depend on the mass range used to fit the slopes or the metallicity assumed. In all cases, the larger mass ranges used for the fitting result in steeper MF slopes than the smallest mass range dominated by the lowest-mass stars, thus presenting clear evidence for non-power law shaped MFs. Within the uncertainties, we cannot claim that the slopes of the outer MFs in NGC 1805 and NGC 1818 are significantly different. We also argue that our results are consistent with previously published results for these clusters if we properly take the large uncertainties in the conversion of LFs to MFs into account. The MF slopes obtained in this paper are in fact lower limits if there is a significant fraction of binary stars present in the clusters.

The global cluster MFs (which are dominated by the inner, mass-segregated stellar population) and the annular MFs near the core radii appear to be characterised by similar slopes, the MFs beyond the cluster radii where mass segregation is significant (i.e., \( r \gtrsim 30'' \)) are characterised by steeper slopes. It is, however, not unusual for star clusters to be characterised by rather steep MF slopes; Bonnell et al. (2001b) explain this naturally as due to the different accretion physics operating in the low and high-mass star forming regime.

We analysed the dependence of the cluster core radius on the adopted magnitude (mass) range. For both clusters we clearly detect the effects of mass segregation for stars on the adopted magnitude (mass) range. For both clusters regime.

We estimate that the NGC 1818 cluster core is between \( 30'' \) and \( 30'' \) crossing times old, so that dynamical mass segregation in its core should be well under way. Although we do not have velocity dispersion information for NGC 1805, we clearly detect the effects of mass segregation for stars with masses \( \log m / M_\odot \gtrsim 0.2 \). It is also clear that stars with masses \( \log m / M_\odot \gtrsim 0.4 \) show a similar concentration, while a trend of increasing core radius with decreasing mass (increasing magnitude) is apparent for lower masses. The characteristic cluster core radii, obtained from profile fits to the overall surface brightness profiles, are dominated by the mass-segregated high-mass stars.

We estimate that the NGC 1818 cluster core is between \( 3 - 4 \) crossing times old. However, since strong mass segregation is observed out to \( \sim 6 R_{\text{core}} \) and \( 3 R_{\text{core}} \) in NGC 1805 and NGC 1818, respectively, for stellar masses in excess of \( \sim 2.5 M_\odot \), it is most likely that significant primordial mass segregation was present in both clusters, particularly in NGC 1805. We are currently investigating this further using N-body simulations.

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