The Large Magellanic Cloud cluster NGC 2214

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ABSTRACT
Johnson BV CCD observations have been made of the young Large Magellanic Cloud cluster NGC 2214 and a nearby field using the Anglo-Australian Telescope. It has been suggested in the literature that this elliptical cluster is actually two clusters in the process of merging. No evidence is found from profile fitting or the colour–magnitude diagrams to support this contention. Completeness factors are estimated for the CCD frames. These values are used in conjunction with luminosity functions to estimate the initial mass function (IMF) for NGC 2214. A power law is assumed for the IMF, with a good fit being found for the exponent \((1 + x) = 2.01 \pm 0.09\). There is some indication that the low-mass end \((\lesssim 3 \, M_\odot)\) has a lower gradient than the high-mass end of the derived IMF. This value is in reasonable agreement with literature values for other Magellanic IMFs, and not substantially different from those of the poorly determined Galactic IMFs, suggesting the possibility of a ‘universal’ IMF over the Magellanic Clouds and our Galaxy in the mass range \(~ 1\) to \(~ 10 \, M_\odot\).

Key words: Star Clusters – Large Magellanic Cloud

1 INTRODUCTION

NGC 2214 \((\alpha_{2000} = 6^h 12^m 57^s, \delta_{2000} = 68^\circ 15' 33''\, \text{South})\) is a young \((32 \times 10^6 \, \text{yr}; \text{Elson} \, 1991)\) populous star cluster situated in a relatively uncrowded field to the far north-east of the bar in the Large Magellanic Cloud (LMC). Meylan & Djorgovski (1987) analysed an intensity profile of the cluster and found that the core was abnormal. They conjectured that perhaps it had collapsed, although Elson, Fall & Freeman (1987) have shown that the two-body relaxation time of the cluster is \(~ 2 - 6 \times 10^7 \, \text{yr}, \text{and so greater than age}\). Bhatia & MacGillivray (1988) found the cluster to have a very elliptical \((c = 0.5)\) core with an almost spherical halo, and suggested that this unusual shape could be due to NGC 2214 being a binary star cluster in an advanced age of merging. Comparison with N-body simulations lent support to this idea. Sagar, Richtler & de Boer (1991a) used a 1.54-m ESO Danish telescope in \(~ 1\)-arcsec seeing, and presented a \(BV\) colour–magnitude diagram (CMD) with two well-defined supergiant branches, separated by \(~ 2\) mag in \(V\). The older population was more centrally condensed than the younger one, and Sagar et al. (1991a) suggested that the first published CMD (Robertson 1974) had failed to detect the older branch due to the problems of photometry in such a crowded region.

A major objective of the present study was to derive an estimate of the initial mass function (IMF) of the cluster. The IMF is defined as the frequency distribution of stellar masses on the main sequence at the formation time of a group of stars (Scalo 1986). Mass is one of the primary factors influencing stellar evolution, and a detailed knowledge of the IMF would be important in a wide range of studies ranging from galactic evolution to the spectral properties of binary stars (see Tinsley 1980). A fundamental question about the IMF is whether it is universal in time and location, or whether the distribution of stars formed is a function of parameters such as metallicity.

Derivation of the IMF is not straightforward. An initial approach might be to use the nearby solar neighbourhood to do this, but this technique is complicated by the fact that these stars have a range of distances, ages, and metallicities. For instance, the random velocities of the stars, combined with their lifetimes, means that, while massive stars will still be near the site of their formation, low-mass stars will have travelled significant distances. Variations in composition may result just from such spatial considerations, if not from galactic evolution as well. Scalo (1986) comments that the many assumptions, such as any variation in the star formation rate with time, complicate estimates of the field IMF to the point of impracticality. In addition, a universal nature is assumed for the IMF in such studies.

A better approach is to use clusters, where the component stars will be effectively coeval and of the same composition. Such work is complicated by effects such as dynamical evolution leading to mass segregation in the cluster, tidal stripping (which in the presence of mass segregation will lead to the proportional decrease of low-mass stars; see Spitzer...
1987), and stellar evolution as stars evolve off the main
sequence, which leads to no easily derivable mass function in-
formation for stars of a main sequence lifetime less than the
age of the cluster. The mass function of the cluster may alter
substantially with time, and it is best to select young clusters
where these effects have not had time to become significant.
Many studies have centred on young Galactic open clusters
with their large observable mass range (e.g. Phelps & Janes
1993; Reid 1992; Stauffer et al. 1991). However, such work
is complicated by field star contamination, counting incom-
pleteness, and low number statistics (see Scala 1986 for more
details), as well as the problem that most open clusters suffer
substantial and variable reddenings due to their positions in
the Galactic disc (Mateo 1988). There is no strong evidence
for variations in the shapes of their mass functions (Sagar &
Richler 1991). Globular clusters offer better statistics due
the increased number of stars they contain, but the ob-
server mass range is limited due to their distances and
age. Evolutionary effects, such as mentioned above, are
additional complications. The resulting mass functions appear
to vary considerably between clusters, and may be corre-
lated with metallicity (Sagar & Richler 1991), although this
is clouded by the above problems.

The LMC clusters are effectively a mixture of the best
features of these two types of star clusters. They are popu-
ulous, with resulting good statistics, and span a wide range
of ages and metallicities (Da Costa 1991). The clusters are
distant enough to subdue only a small angle on the sky,
and yet not too distant to suffer from resolution problems.
Questions, such as the universal nature of the IMF, might
be able to be addressed using these clusters, although the very
populous nature of both the clusters and their fields leads
counting incompleteness problems. A major portion of
this study involved the derivation of counting estimates, in
order to correct observed luminosity functions to the ‘real’
distribution.

IMFs have been derived for some LMC clusters by
Mateo (1988), Sagar & Richler (1991), Cayrel, Tarrab &
Richler (1988), and Elson, Fall & Freeman (1989). The re-
results have not been in good agreement. The first three stud-
ies were based on CCD frames, and attempted to estimate
the counting incompleteness using artificial star trials (see
below). A power law \( \frac{dN}{dM} = M^{-(1 + \alpha)} \) was assumed for the
IMF, where \( dN \) is the number of stars in a given mass in-
terval \( dM \) at mass \( M \). Mateo (1988) found that the IMFs of
six Magellanic clusters (the Small Magellanic Cloud cluster
NGC 330 was included) could all be fitted with the same
power law with \( \alpha = 2.52 \pm 0.16 \) over the mass interval 0.9 to
10.5 \( M_\odot \). Sagar & Richler (1991) used a different method
of estimating the incompleteness (see below), and arrived at
an \( \alpha \) value of \( -1.1 \), not too different from the Salpeter (1955)
value of 1.35 and in reasonable agreement with the value of
1.2 for NGC 330 and NGC 1818 derived by Cayrel et al.
(1988). They commented that if they used the same incom-
pleteness technique as Mateo (1988) on NGC 1711, which
was the only cluster studied by both, then the mass function
estimate of Mateo (1988) was confirmed. All these values
contrast sharply with the photographic star count analysis
of Elson et al. (1989), which gave \( x \) values between -0.2
and 0.8 (over 1.5–6.0 \( M_\odot \)). In light of these differences and
the comment of Sagar & Richler (1991) about NGC 1711, a
review of the incompleteness techniques is obviously of ma-
jor importance given the effect a chosen method has on the
derivation of the mass function slope, and any subsequent
conclusions about the universality of the IMF.

2 OBSERVATIONS

Johnson \( B\) \( V \) observations of NGC 2214 were collected on the
night of 1993 March 1/2 using a 1024 by 1050 pixel TEK
CCD at the prime focus of the Anglo-Australian Telescope.
The pixel scale was 0.39 arcsec per pixel, resulting a field of
view approximately 6.7 \( \times \) 6.7 arcmin square. The FWHM
seeing was \( \sim 2.2\) arcsec. Observations were also made of a
field 5-arcmin north of the cluster. Exposure times for both
these regions were 30 and 300 s in \( V \), and 60 and 600 s in \( B \).

The initial reductions of the CCD frames were carried
out at the Anglo-Australian Observatory, and included trim-
ing the frames of the overscan rows, subtraction of the
mean of the overscan (the CCD has negligible bias struc-
ture), and flat-field division using sky flats. Given already
derived extinction coefficients (Da Costa, private commu-
ication), the observed Graham (1982) E2 and E3 standards
were used in the IRAF PHOTCAL package to derive the zero-
point shift in the following transformation equations:

\[
\begin{align*}
b &= (1.067 \pm 0.007) + 0.12 (B - V) - (0.4 - 0.02(B - V)) X + B \\
v &= (1.03 \pm 0.006) - 0.27 X + V
\end{align*}
\]

where \( X \) is the airmass and the lower case letters refer to the
observed instrumental magnitudes. The root mean squares
of the fits were 0.018 and 0.016 mag for \( B \) and \( V \) respectively.

3 RESULTS

3.1 Colour–magnitude diagrams

The DITHER package of IRAF, which includes DAOPHOT
(Skleton 1987), was used to reduce the crowded frames, per-
form aperture corrections, and transform the data across to
the standard system. The final colour–magnitude diagrams
are given as Figs 1 and 2. 2919 and 1832 stars are plotted in
the cluster and field diagrams respectively. The matching
point between the long and short exposures was chosen to
be the region where the data sets had similar errors, and
was magnitudes 16 and 17 for \( V \) and \( B \) respectively.

\( \chi \) is the ratio of the actual scatter, about a point spread
function (PSF) fit, divided by the expected scatter given
the star and background sky brightnesses combined with the
CCD readout noise. A value of \( \chi \) near unity indicates a good
fit. Only stars with a \( \chi \) value of 3.0 or less were accepted (as
in Mateo & Hodge 1986). Examination of \( \chi \) plotted against
observational magnitude showed this to be an acceptable
limit, with the vast majority of detected `stars' being within
it. A further constraint was the use of the ‘sharpness’ mea-
sure of the difference between the square of the width of
the object and the square of the width of the PSF. Values
should be close to zero for single stars, large and positive
for blended doubles and partially resolved galaxies, and
large and negative for cosmic rays and blemishes. Examination
of this parameter for all detected `stars' showed that the ma-
jority had values inside [0.2]. The final selection criterion was