The ‘remarkable’ M31 globular cluster 037–B327 revisited

Pauline Barmby,1 Kathryn M. Perrett,2 Terry J. Bridges3
1Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138
2Department of Physics, Queen’s University, Kingston, Ontario K7L 3N6, Canada
3Anglo–Australian Observatory, Epping, NSW, 1710 Australia

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ABSTRACT

The M31 globular cluster candidate 037–B327 has long been known to be an extremely red, non-stellar object. The first published spectrum of this object is used to confirm that it is a globular cluster belonging to M31, with rather typical values of $v_r = -338 \pm 12$ km s$^{-1}$ and $[\text{Fe}/\text{H}] = -1.07 \pm 0.20$ dex. Using the spectroscopic metallicity to predict the intrinsic colours, we derive a reddening value of $E(B-V) = 1.30 \pm 0.04$, in good agreement with the value obtained using reddening-free parameters. The extinction-corrected magnitude of 037–B327 is $V_0 = 12.73$ (absolute magnitude $M_V = -11.74$), which makes it the most luminous globular cluster in M31. We examine van den Bergh’s (1968) argument regarding the brightest and most-reddened globular cluster in M31; we find that the brightest clusters are more heavily-reddened than average, but this can be explained by selection effects rather than a different $R_V$ in M31.

Key words: galaxies: individual (M31) – galaxies: star clusters – globular clusters: general

1 INTRODUCTION

The study of globular clusters in M31 dates back to Hubble (1932). Since that pioneering work, over a thousand objects have been proposed as possible M31 globular clusters (GCs), and over 200 have been confirmed as belonging to M31. The M31 GCs has long been one of the standard extragalactic globular cluster systems used for comparison to the Milky Way GCs, and comparisons of the two systems have been both fruitful and puzzling.

Few individual M31 GC candidates have attracted as much interest as the object known as B327 (B for ‘Baade’), Bo037 (Bo for ‘Bologna’), or 037–B327 [in the nomenclature introduced by Huchra, Brodie & Kent (1991)]. This object (Figure 1) was first identified as a globular cluster candidate by Baade, using plates taken in c. 1945. A portion of Baade’s M31 GC candidate list appears in Seyfert & Nasan (1945), but the coordinates of 037–B327 were first published by Vetesnik (1962a). Kron & Mayall (1960) first measured an extremely red colour for this object and suggested that it must be highly reddened and extremely luminous. Vetesnik (1962b) found that 037–B327 was the most highly-reddened in his sample of 209 objects with $E(B-V) = 1.28$. van den Bergh (1968; 1969) used these results to argue that the value of $R_V = A_V/E(B-V)$ in M31 was 2.5, instead of the Milky Way value of 3.0. Sargent et al. (1977) rejected 037–B327 from their M31 GC candidate list because of its stellar appearance, but Buonanno et al. (1982) confirmed its non-stellar nature using measurements of its image size on photographic plates. Using low-resolution spectroscopy, Crampton et al. (1985) again found 037–B327 to be the most highly-reddened GC candidate in M31, with $E(B-V) = 1.48$. Sharov & Lyutyi (1989) concluded that it was the most luminous GC in M31, while cautioning that its true nature was still unknown. Barmby et al. (2000) echoed both of these results: they measured $E(B-V) = 1.38$ and $V_0 = 12.54$, corresponding to a luminosity four times that of the brightest Milky Way GC.

In this paper, we confirm that 037–B327 is an M31 globular cluster. We discuss its photometric and spectroscopic properties and provide a new estimate of its reddening. Since van den Bergh’s arguments about the value of $R_V$ in M31 were motivated in part by the properties of 037–B327, we revisit that argument using the properties of this cluster and others reported in Barmby et al. (2000).

2 PROPERTIES OF 037–B327

As part of a larger project, Perrett et al. (2001, in preparation) obtained spectra of about 200 M31 globular clus-
eters using the WYFFOS Wide-Field Fibre Optic Spectrograph at the William Herschel 4.2 m telescope* in November 1996. The R1200R grating was used to provide a dispersion of 1.5 Å/pixel and a spectral resolution of 5.1 Å. The integration time was one hour (3 × 1200 s). Using the data reduction and analysis procedure outlined in Perrett et al. (2001), 037–B327 was found to have a heliocentric radial velocity of \( v = -338 \pm 12 \text{ km s}^{-1} \) and a metallicity of \([\text{Fe/H}] = -1.07 \pm 0.20\). The spectrum of 037–B327 is shown in Figure 2, with the spectrum of another M31 cluster of comparable metallicity for comparison. The two objects’ spectra are very similar, except for the suppressed blue continuum of 037–B327, and the radial velocity leaves little doubt that 037–B327 is indeed an M31 globular cluster.

The photometric measurements summarised in Table 1 demonstrate the very red colour of 037–B327. Barmby et al. (2000) used their CCD photometry to construct reddening-free parameters and estimate the reddening of 037–B327 at \( E(B-V) = 1.38 \pm 0.02 \). This was the largest reliable reddening value in their sample of 221 objects. Predicting the intrinsic colours from the spectroscopic metallicity using the method described in Barmby et al. (2000), we determine a value for the reddening of 1.30±0.04, in good agreement with the previous work. The weighted combination of values from the two methods gives a final reddening value of 1.32±0.05. Assuming \( R_V = 3.1 \) and a distance to M31 of \( \mu = 24.47 \) [Stanek & Garnavich (1998); Holland (1998)] the absolute magnitude of 037–B327 is \( M_V = -11.74 \). The next-brightest M31 GC, 023–078, has \( M_V = -11.36 \), while the brightest Milky Way GC is 0.05 Cen with \( M_V = -10.29 \) (Harris 1996).

The spectrum used here to measure 037–B327’s radial velocity does not have sufficient resolution to measure a velocity dispersion, but if 037–B327 has a mass-to-light ratio typical of M31 GCs \([M/L_V \approx 2; \text{Dubath & Grillmair (1997)}]\), its luminosity implies a mass of \( 8.5 \times 10^6 \text{M}_\odot \). This places it among the most massive GCs in M31; for example, Meylan et al. (2001) find masses in the range \( 7–17 \times 10^6 \text{M}_\odot \) for the M31 cluster 000–001.

### Table 1. Photometric data for 037–B327

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V = 16.92, B-V = 2.15 )</td>
<td>Kron &amp; Mayall (1960)</td>
</tr>
<tr>
<td>( V = 16.70, B-V = 2.11 )</td>
<td>Vetešnik (1962b)</td>
</tr>
<tr>
<td>( V = 16.80, B-V = 2.17 )</td>
<td>van den Bergh (1969)</td>
</tr>
<tr>
<td>( V = 16.71, B-V = 2.13 )</td>
<td>Buonanno et al. (1982)</td>
</tr>
<tr>
<td>( V = 16.82, B-V = 2.05 )</td>
<td>Barmby et al. (2000)</td>
</tr>
<tr>
<td>( K = 10.95, J-K = 1.25, H-K = 0.28 )</td>
<td>Bönoli et al. (1987)</td>
</tr>
<tr>
<td>( V-R = 1.28, V-I = 2.63 )</td>
<td>Barmby et al. (2000)</td>
</tr>
</tbody>
</table>

### Table 2. The Brightest M31 Globular Clusters

<table>
<thead>
<tr>
<th>Name</th>
<th>V</th>
<th>( E(B-V) )</th>
<th>( R_V )</th>
<th>( R_V )</th>
<th>[Fe/H]</th>
</tr>
</thead>
<tbody>
<tr>
<td>000–001</td>
<td>13.75</td>
<td>0.08</td>
<td>4</td>
<td>3</td>
<td>-1.08</td>
</tr>
<tr>
<td>023–078</td>
<td>14.22</td>
<td>0.36</td>
<td>2</td>
<td>1</td>
<td>-0.92</td>
</tr>
<tr>
<td>037–B327</td>
<td>16.82</td>
<td>1.32</td>
<td>1</td>
<td>2</td>
<td>-1.07</td>
</tr>
<tr>
<td>082–144</td>
<td>15.54</td>
<td>0.72</td>
<td>3</td>
<td>4</td>
<td>-0.86</td>
</tr>
<tr>
<td>151–205</td>
<td>14.83</td>
<td>0.38</td>
<td>5</td>
<td>6</td>
<td>-0.75</td>
</tr>
<tr>
<td>225–280</td>
<td>14.15</td>
<td>0.15</td>
<td>6</td>
<td>5</td>
<td>-0.70</td>
</tr>
</tbody>
</table>

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* The William Herschel Telescope is operated on the island of La Palma by the Isaac Newton Group in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias.

van den Bergh (1968) calculated the absolute magnitudes of the intrinsically-brightest GCs in M31 by assuming a single intrinsic colour and using this to determine the colour excess. He found that if \( R_V = 3.0 \) was adopted, 037–B327 was the brightest M31 GC. van den Bergh argued that, since ‘there is no a priori reason why the intrinsically brightest globular clusters in the Andromeda nebula should also be the most highly-reddened’, the value of \( R_V \) in M31 was more likely to be 2.5 instead of the Milky Way’s 3.0, as first suggested by Kron & Mayall (1960). With this value of \( R_V \), he found that 037–B327 became the fifth-brightest GC in M31. Table 2 summarises the photometric data from Barmby et al. (2000) and metallicties from Huchra, Brodie & Kent (1991) (for all objects except 037–B327) for the six intrinsically-brightest M31 GCs. For the four objects in common with Table II of van den Bergh (1968, our values of \( E(B-V) \) from Barmby et al. (2000) are significantly lower. This is because van den Bergh’s assumed value of \( (B-V)_0 \) = 0.6, corresponding to \([\text{Fe/H}] \approx -1.9\), is too low: all of these clusters have \([\text{Fe/H}] \geq -1.1\). These six clusters remain the brightest M31 GCs whether \( R_V = 2.5 \) or 3.1 is used, although their magnitude ranks change: for \( R_V = 2.5 \), 037–B327 becomes the second-brightest, not the fifth as van den Bergh found. This renders his argument somewhat less compelling.

Four of the six globular clusters in Table 2 have values for \( E(B-V) \) well above the M31 average of 0.22; the high reddening of the brightest M31 GCs was part of van den Bergh’s argument. But is this effect a persua-
Figure 3. $V_0$ vs. $E(B-V)$ for M31 GCs for the $V<18$ sample used by Barmby et al. (2001).

sive argument for a different $R_V$ in M31? We believe it is more likely a selection effect. Assuming that intrinsic luminosity is uncorrelated with observed extinction, only the intrinsically-brightest clusters in a magnitude-limited sample will show the full range of the extinction distribution. This is shown graphically in Figure 3 for the sample of clusters with $V<18$ used by Barmby, Huchra & Brodie (2001). For either $R_V = 2.5$ or $R_V = 3.1$, the brighter clusters have a larger range of reddening values.

Examining the entire reddening/magnitude distribution, we find that the intrinsically brightest 10 per cent of the clusters have an average $E(B-V)$ of 0.42, 0.21 mag larger than the average value for the other 90 per cent of clusters. We modeled this effect by simulating 200 M31 globular cluster luminosity functions (GCLFs). We drew clusters' extinction-free magnitudes from a realistic GCLF with peak $V_0 = 16.8$ and dispersion $\sigma_1 = 1.0$, applying to each an extinction drawn at random from the observed distribution for M31 GCs, and computed the observed magnitude. Removing clusters whose observed magnitudes were fainter than the magnitude limit $V = 18$, we then computed the mean $E(B-V)$ for the brightest 10 per cent and fainter 90 per cent of the remaining clusters. In more than 90 per cent of the trials, the brighter clusters were more reddened, with an average difference between brighter and fainter clusters of $E(B-V) = 0.21$. This is very similar to what we see in the actual distributions for M31. The situation where the brightest cluster is also the most reddened (the case for 037–B327 and $R_V = 3.1$) occurs in only 3 of the simulated GCLFs. However, the situation where the second brightest cluster is the most reddened (as would be the case for $R_V = 2.5$) is no more common, so we conclude that the case of 037–B327 does not provide sufficient reason to adopt $R_V = 2.5$.

The assumption made above that reddening and intrinsic luminosity are uncorrelated is probably an oversimplification. Figure 8 of Barmby et al. (2000) shows that the more heavily-reddened clusters are preferentially located toward the centre of M31, and Barmby et al. (2001) found that clusters closer to the centre of M31 are, on average, brighter (although this result disagrees with some previous work on radial variation in the GCLF). The combination of radial variations in reddening and luminosity with the magnitude-limit selection effect makes it more likely for the brightest cluster to be the most heavily-reddened.

Another possible explanation of both the apparent radial GCLF variation and 037–B327’s unusual properties (both brightest and most reddened) is the postulate that $R_V$ in M31 increases with distance from the centre of the galaxy $R_{gc}$. Much of the previous work on this topic is based on the colour distribution of M31 globular clusters. Changes in the reddening law are often taken as indicative of changes in $R_V$; however, the analytic models in Table 3 of Cardelli, Clayton & Mathis (1989) indicate that changing $R_V$ from 3.1 to 2.5 changes $X(UBV) = E(U-B)/E(B-V)$ from 0.72 to 0.75, less than 5 per cent. Freedman & Madore (1990) cite unpublished results by L. Searle showing a decrease in $X(UBV)$ with distance from the galaxy centre, but find that either decreasing or constant $R_V$ are consistent with their M31 Cepheid distance-modulus results. Iye & Richter (1985) examined the mean colours and magnitudes of M31 GCs in spatial bins, and measured marginally significant differences in $X(UBV)$ between inner and outer clusters. They also derived a best-fit value of $R_V = 2.6 \pm 0.7$ for clusters projected near the major axis, and an average value of $X(UBV) = 1.01 \pm 0.11$.

Using more complete photometric and spectroscopic data, Barmby et al. (2000) found that the M31 and Milky Way reddening laws were the same to within observational error. Examining those results in more detail, we found no evidence for variation in the extinction law with $R_{gc}$. We attempted to replicate Iye & Richter’s (1985) study with our more modern data. We found $X(UBV) = 0.72 \pm 0.13$, identical to the canonical Milky Way value for $R_V = 3.1$, and no reason to prefer $R_V = 2.5$ over $R_V = 3.1$ to describe the distribution of $(B-V)$ against $(V)$. While we thus find no evidence for radial variation in the M31 extinction law from GC colours, studies using other methods and classes of objects would be helpful to confirm our conclusions.

Aside from being more heavily-reddened, which we have argued to be a selection effect, the brightest globular clusters in M31 are not particularly unusual. As noted above, they tend to be metal-rich; all have $\text{[Fe/H]} \geq -1.1$, while the M31 median is $\text{[Fe/H]} = 1.15$ (Barmby et al. 2000). Djorgovski et al. (1997) measured velocity dispersions for 21 clusters including 000–001, 023–078, and 225–280; these three objects had the three highest velocity dispersions. All three have values of $\sigma_v \sim 25 \text{ km s}^{-1}$, indicating that they have the large masses which would be expected for such bright objects. The cluster 000–001, also known as G1 or Mayall II, has been the subject of several high-resolution imaging studies (Pritchet & van den Bergh 1984; Rich et al. 1996; Meylan et al. 2001), all of which noted that it was quite flattened, with $e = 1 - b/a \sim 0.2$. Meylan et al. (2001) find that, like the bright Milky Way cluster $\omega$ Cen, 000–001 shows evidence for a metallicity spread, and suggest that it may in fact be the core of a dwarf elliptical galaxy. Hubble Space Telescope observations of 225–280 (Fusi Pecci et al. 1996; Stephens et al. 2001) show it to be a very metal-
rich ([Fe/H] ≈ −0.3, somewhat higher than the spectroscopic metallicity) but otherwise unremarkable cluster. The ellipticities of the other brightest clusters, as measured by Staneva, Spassova & Golev (1996), range from 0.02 to 0.08, well within the range of values for the fainter clusters.

4 CONCLUSIONS

The ‘remarkable object 037–B327’ is an M31 globular cluster. It is extremely reddened, with $E(B-V) = 1.32 ± 0.05$, and extremely luminous (almost four times as luminous as the brightest Milky Way globular). However, its radial velocity and metallicity are entirely unremarkable. We use the M31 globular clusters’ reddening values to examine van den Bergh’s (1968) argument than the value of $R_V$ in M31 differs significantly from that in the Milky Way. We find that the brighter clusters are more heavily-reddened, but suggest that this is a combination of two other effects: selection bias in a magnitude-limited sample, and variation in the M31 GCLF with distance from the galaxy centre. A radial variation in $R_V$ in M31 could possibly account for the GCLF variation and the reddening/magnitude distribution, but there is at present no evidence for such a variation.

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