037-B327 IN M31: LUMINOUS GLOBULAR CLUSTER OR CORE OF A FORMER DWARF SPHEROIDAL COMPANION TO M31?[1]

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ABSTRACT

The cluster 037-B327 is of interest because it is both the most luminous and the most highly reddened cluster known in M31. Deep observations with the Advanced Camera for Surveys on the *Hubble Space Telescope* provide photometric data in the F606W band and also show that this cluster is crossed by a dust lane. We have determined the structural parameters of 037-B327 by fitting the observed surface brightness distribution to a King model with $r_c = 0\farcs72$ ($= 2.69$ pc), $r_t = 5\farcs87$ ($= 21.93$ pc), and a concentration index $c = \log (r_t/r_c) = 0.91$. The surface brightness profile appears to be essentially flat within $0\farcs25$ of the center and shows no signs of core collapse. Although the dust lane affects the photometry, the King model fits the surface brightness profile well except for the regions badly affected by the dust lane. We also calculate the half-light radius, $r_h = 1\farcs11$ ($= 4.15$ pc). Combined with previous photometry, we find that this object falls in the same region of the M_V versus $\log R_h$ diagram as do ω Centauri, M54, and NGC 2419 in the Milky Way and the massive cluster G1 in M31. All four of these objects have been claimed to be the stripped cores of former dwarf galaxies. This suggests that 037-B327 may also be the stripped core of a former dwarf companion to M31.

Subject headings: galaxies: evolution — galaxies: individual (M31) — globular clusters: individual (037-B327)

1. INTRODUCTION

It has been speculated that some of the most luminous known globular clusters (GCs) might be the remnants of tidally stripped dwarf galaxy nuclei (Zinnecker et al. 1988; Freeman 1993; Bassino et al. 1994). The study of globular clusters in M31 was initiated by Hubble (1932), who discovered 140 GCs with $m_{pg} \leq 18$ mag. The continued importance of the study of GCs in this galaxy has been reviewed by Barmby et al. (2000). Here we examine the M31 globular cluster B327 (B for "Baade"), or Bo 037 (for "Bologna"; see Battistini et al. 1987), which, following the nomenclature introduced by Huchra et al. (1991), will subsequently be referred to as 037-B327. The extremely red color of this object was first noted by Kron & Mayall (1960).

The brightest globular clusters in M31 are more luminous than the giant Galactic cluster ω Centauri. Among these are 037-B327 (van den Bergh 1968) and G1 (see details in Barmby et al. 2002b). The latter has been considered as the possible remnant core of a former dwarf galaxy that lost most of its envelope through tidal interactions with M31 (Meylan & Heggie 1997; Meylan et al. 2001). Subsequently, Mackey & van den Bergh (2005) strengthened these conclusions.

In this Letter, we determine the structural parameters of 037-B327 using a deep image obtained with the Advanced Camera for Surveys (ACS) on the *Hubble Space Telescope* (*HST*). Combining this with the previous photometry, we find that the cluster lies in the same region of the $\log R_h$ versus M_V diagram as do ω Cen, M54, and NGC 2419 in the Milky Way and G1 in M31. This suggests that 037-B327 may also be the remnant

core of a now defunct dwarf companion to the Andromeda galaxy.

2. OBSERVATIONS AND DATA REDUCTION

We searched the *HST* archive and found that 037-B327 had been observed with the ACS Wide Field Channel (WFC) in the F606W and F814W bands. We mainly used the image in F606W, which was obtained on 2004 August 2 with 2370.0 s of exposure time. We deconvolved the image using the IRAF task LUCY (Lucy 1974). The image of 037-B327 observed in F606W and its deconvolved counterpart are shown in Figure 1. The central structure is clearly more complex in the deconvolved image. The WFC resolution is $0\farcs05$ pixel^{-1}. We used the IRAF task ELLIPSE to fit the image with a series of elliptical annuli from the center to the outskirts, with the length of the semimajor axis increasing by 10% in each step. Figure 2 shows the ellipticity and position angle plotted as a function of the semimajor axis. The ellipticity varies significantly with position along the semimajor axis a. The mean ellipticity is $\epsilon \simeq 0.23$. The position angle is not significantly variable for semimajor-axis values a larger than $0\farcs5$. It is of interest to note that the high ellipticity of 037-B327, which is the most luminous cluster in M31, confirms the empirical rule (van den Bergh 1996) that the brightest globular cluster in a galaxy is also usually one of the most flattened. The ellipticities and position angles shown in Figure 2 (particularly near $r = 0\farcs5$) are quite strongly affected by the dust lane.

We fitted King (1962) models to the surface brightness profiles. As is usual, we parameterized the model with the core radius r_c, the concentration index $c = \log (r_t/r_c)$ (r_t being the tidal radius), and $\mu(0)$, the central surface brightness. The derived parameters are $r_c = 0\farcs72$ and $r_t = 5\farcs87$, implying a concentration index $c = \log (r_t/r_c) = 0.91$. The surface brightness profile appears to be essentially flat within $0\farcs25$ of the center and shows no signs of core collapse. The central surface brightness is 17.21 mag arcsec^{-2}. Figure 3 plots the surface brightness profile and a fitted King model. As already noted, this cluster contains a clear dust lane (see Fig. 1, especially the deconvolved

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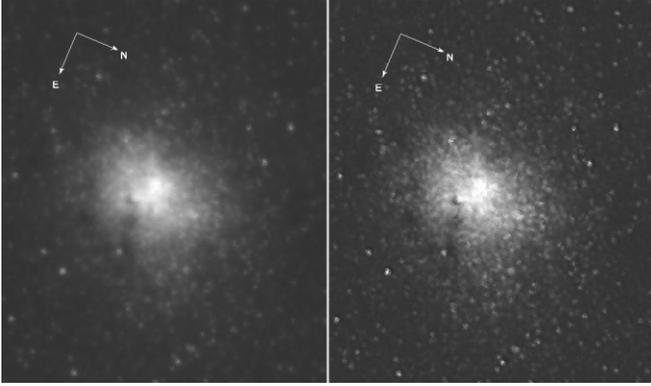
Fig. 1.—Image of GC 037-B327 observed in F606W (*left*) and its deconvolved counterpart (*right*). The central structure is clearly more complex in the deconvolved image. The image size is $7\rlap{.}{''}8 \times 8\rlap{.}{''}8$.

image). So, some data points are affected by this dust lane, as evident in Figure 3. Except for some photometric data affected badly by the dust lane, the King model fits the surface brightness profile well. We also calculate the half-light radius (the radius containing half of the light, in projection) to be $r_h = 1\rlap{.}{''}11$. With an adopted distance to M31 of 770 kpc (Meylan et al. 2001), the core radius, the half-light radius, and the tidal radius are 2.69, 4.15, and 21.93 pc, respectively.

3. ABSOLUTE MAGNITUDE FOR 037-B327

Cluster 037-B327 is remarkable for being the most luminous and most highly reddened (van den Bergh 1968) cluster in M31. Vetešník (1962a) determined the magnitudes of 257 M31 GC candidates in the *UBV* photometric system, including 037-B327. Using this photometric catalog, Vetešník (1962b) studied the intrinsic colors of M31 GCs and found that 037-B327 was the most highly reddened, with $E(B-V) = 1.28$, in his sample of M31 GC candidates. Using low-resolution spectroscopy, Crampton et al. (1985) also found this cluster to be the most highly reddened GC candidate in M31, with $E(B-V) = 1.48$. With a large database of multicolor photometry, Barmby et al. (2000) determined the reddening value for each individual M31 GC, including 037-B327, using the correlations between optical and infrared colors and metallicity by defining various "reddening-free" parameters. Again, Barmby et al. (2002b) derived the reddening for this cluster, using the spectroscopic metallicity to predict the intrinsic colors. The dust lane shown in Figure 3 might be responsible for the bulk of the reddening. In this Letter, we adopt $E(B-V) = 1.32 \pm 0.05$ for 037-B327, as derived by Barmby et al. (2002b) from a weighted combination of values from their two methods (see Barmby et al. 2002b for details), and $m_V = 16.82$ from by Barmby et al. (2000). Assuming $R_V = 3.1$ and a distance to M31 of 770 kpc (Meylan et al. 2001), the absolute magnitude of 037-B327 is $M_V = -11.71$, which makes it the most luminous globular cluster in M31.

4. LUMINOUS GLOBULAR CLUSTER OR CORE OF A FORMER DWARF SPHEROIDAL COMPANION TO M31?

As a globular cluster evolves, its core contracts and its envelope expands. However, it has been shown by Spitzer & Thuan (1972), Hénon (1973), Lightman & Shapiro (1978), and Murphy et al. (1990) that the half-light radius of an evolving cluster changes little over periods as long as 10 relaxation times. The half-light radius of a cluster therefore can be used to trace
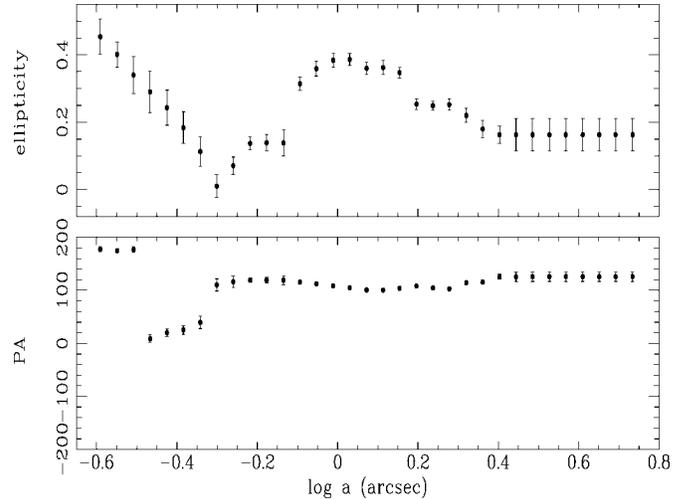

Fig. 2.—Ellipticity and position angle as a function of the semimajor axis, which are quite strongly affected by the dust lane, particularly near $r = 0\rlap{.}{''}5$ ($\log a = -0.3$).

the initial size of a cluster and, hence, the physical conditions in its host galaxy at early epochs. In previous papers (van den Bergh & Mackey 2004; Mackey & van den Bergh 2005), it has been shown that three Galactic globular clusters and one M31 globular cluster lie above and to the brightward of the line
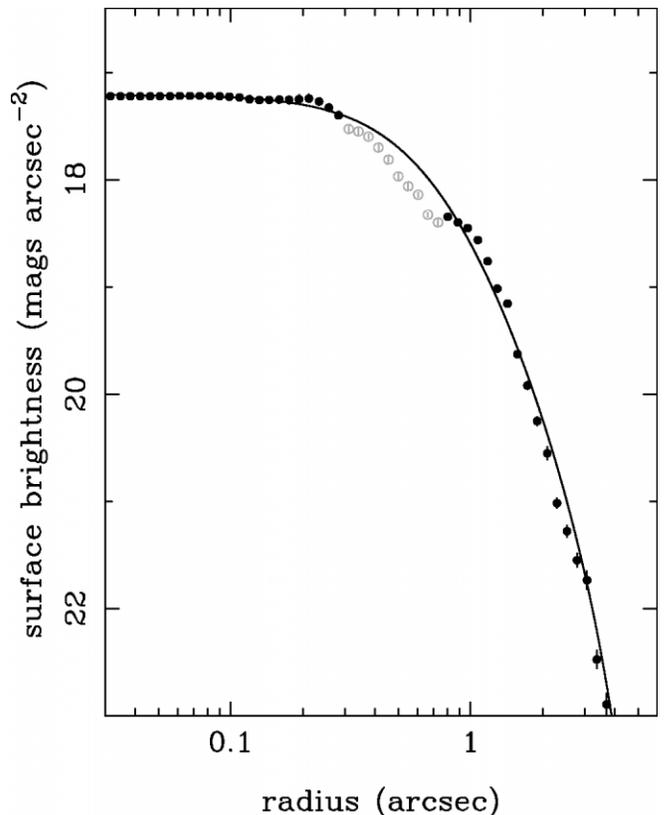
$$\log R_h = 0.25 M_V + 2.95, \tag{1}$$

Fig. 3.—Surface brightness profile of 037-B327. The solid line represents the King model fitted to the observed profile. When fitting this profile, we did not use the data plotted as open circles, since they were badly affected by the dust patches.

where R_h and M_V are the cluster half-light radius and absolute magnitude. Figure 11 of Mackey & van den Bergh (2005) shows that the overwhelming majority of normal globular clusters lie below and faintward of the line defined by equation (1). The clusters that do fall above this relation are mostly objects suspected of being the cores of now defunct dwarf galaxies.

Figure 4 shows a plot of $\log R_h$ versus M_V. On this plot 037-B327 can be seen to lie above and brightward of the line defined by equation (1), as do ω Cen, M54, and NGC 2419 in the Milky Way and the massive cluster G1 in M31. All four of these objects have been suggested to be the stripped cores of former dwarf galaxies (for details, see Mackey & van den Bergh 2005). This result suggests that the most luminous cluster, 037-B327, in M31 may also be the stripped core of a now defunct dwarf companion to M31.

5. SUMMARY

In this Letter, we determined the structural parameters of 037-B327 from an F606W image obtained with the Advanced Camera for Surveys on the *Hubble Space Telescope*, by fitting between the surface brightness distribution and the King model. Combined with the previous photometry, we find that this object falls in the same region of the M_V versus R_h diagram as do ω Cen, M54, and NGC 2419 in the Milky Way and the massive cluster G1 in M31 on the size ($\log R_h$) versus luminosity (M_V) diagram. All four of these objects have been suggested to be the stripped cores of former dwarf galaxies. We thus argue that 037-B327 may also be the core of a former dwarf spheroidal companion to M31. We also compared the the F606W and F814W images and did not find any difference in the colors of the brightest "incipiently" resolved stars, where this term is used in the sense that the image is not clearly resolved into individual stars but has a mottled or granular appearance, such as employed by Baade (1963, p. 43).
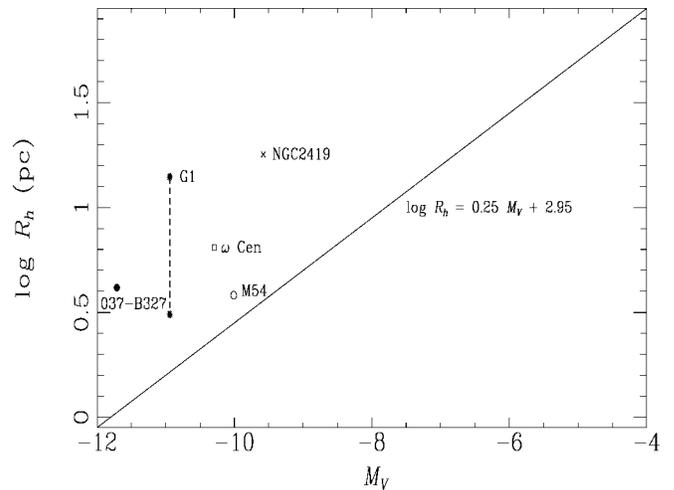

FIG. 4.—Relation between M_V and R_h for 037-B327. The figure shows that 037-B327 lies above and brightward of eq. (1) in the M_V vs. $\log R_h$ plot. The data for ω Cen, M54, NGC 2419, and G1 were taken from Mackey & van den Bergh (2005). G1 is marked by two linked points, representing the two discrepant measurements of R_h for this cluster. The upper point is the measurement of Meylan et al. (2001), while the lower point is that of Barmby et al. (2002a).

REFERENCES

Baade, W. 1963, Evolution of Stars and Galaxies (Cambridge: Harvard Univ. Press)
Barmby, P., Holland, S., & Huchra, J. P. 2002a, AJ, 123, 1937
Barmby, P., Huchra, J. P., Brodie, J. P., Forbes, D. A., Schroder, L. L., & Grillmair, C. J. 2000, AJ, 119, 727
Barmby, P., Perrett, K. M., & Bridges, T. J. 2002b, MNRAS, 329, 461
Bassino, L. P., Muzzio, J. C., & Rabolli, M. 1994, ApJ, 431, 634
Battistini, P., Bònoli, F., Braccesi, A., Federici, L., Fusi Pecci, F., Marano, B., & Börngen, F. 1987, A&AS, 67, 447
Crampton, D., Cowley, A. P., Schade, D., & Chayer, P. 1985, ApJ, 288, 494 (erratum 322, 1074 [1987])
Freeman, K. C. 1993, in ASP Conf. Ser. 48, The Globular Cluster–Galaxy Connection, ed. G. H. Smith & J. P. Brodie (San Francisco: ASP), 608
Hénon, M. 1973, A&A, 24, 229
Hubble, E. 1932, ApJ, 76, 44
Huchra, J. P., Brodie, J. P., & Kent, S. M. 1991, ApJ, 370, 495
King, I. 1962, AJ, 67, 471
Kron, G. E., & Mayall, N. U. 1960, AJ, 65, 581

Lightman, A. P., & Shapiro, S. L. 1978, Rev. Mod. Phys., 50, 437
Lucy, L. B. 1974, AJ, 79, 745
Mackey, A., & van den Bergh, S. 2005, MNRAS, 360, 631
Meylan, G., & Heggie, D. C. 1997, A&A Rev., 8, 1
Meylan, G., Sarajedini, A., Jablonka, P., Djorgovski, S. G., Bridges, T., & Rich, R. M. 2001, AJ, 122, 830
Murphy, B. W., Cohn, H. N., & Hut, P. 1990, MNRAS, 245, 335
Spitzer, L., Jr., & Thuan, T. X. 1972, ApJ, 175, 31
van den Bergh, S. 1968, Observatory, 88, 168
———. 1996, Observatory, 116, 103
van den Bergh, S., & Mackey, A. D. 2004, MNRAS, 354, 713
Vetešník, M. 1962a, Bull. Astron. Inst. Czechoslovakia, 13, 180
———. 1962b, Bull. Astron. Inst. Czechoslovakia, 13, 218
Zinnecker, H., Keable, C. J., Dunlop, J. S., Cannon, R. D., & Griffiths, W. K. 1988, in IAU Symp. 126, The Harlow-Shapley Symposium on Globular Cluster Systems in Galaxies, ed. J. E. Grindlay & A. G. D. Philip (Dordrecht: Kluwer), 603