THE PEAK BRIGHTNESS AND SPATIAL DISTRIBUTION OF ASYMPTOTIC GIANT BRANCH STARS NEAR THE NUCLEUS OF M32

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ABSTRACT

The bright stellar content near the center of the Local Group elliptical galaxy M32 is investigated with 0.12 FWHM H and K images obtained with the Gemini Mauna Kea telescope. Stars with K = 15.5, which are likely evolving near the tip of the asymptotic giant branch (AGB), are resolved to within 2" of the nucleus, and it is concluded that the peak stellar brightness near the center of M32 is similar to that in the outer regions of the galaxy. Moreover, the projected density of bright AGB stars follows the visible light profile to within 2" of the nucleus, indicating that the brightest stars are well mixed throughout the galaxy. Thus, there is no evidence for an age gradient, and the radial variations in spectroscopic indices and ultraviolet colors that have been detected previously must be due to metallicity and/or some other parameter. We suggest that either the bright AGB stars formed as part of a highly uniform and coherent galaxy-wide episode of star formation or they originated in a separate system that merged with M32.

Subject headings: galaxies: evolution — galaxies: individual (M32) — galaxies: stellar content — stars: AGB and post-AGB

1. INTRODUCTION

As the closest galaxy with characteristics reminiscent of massive classical elliptical galaxies (e.g., Wirth & Gallagher 1984; Kormendy 1985), M32 provides an unprecedented laboratory for probing the stellar contents of early-type galaxies and testing predictions drawn from integrated spectra. The star-forming history of M32 is a matter of ongoing debate, although the bulk of evidence seems to indicate that an intermediate-age population is present. The spectrum of the central few arcseconds of M32 cannot be represented by that of an old star cluster population (O’Connell 1980; Rose 1985; Davidge 1990; Bica, Alloin, & Schmidt 1990) and, while Cole et al. (1998) argue that the integrated ultraviolet-visible color of M32 is consistent with an old population, they also stress the considerable uncertainties present in the models. The spectrum of M32 shows deep Hβ absorption (Burstein et al. 1984), and the origin of this feature is of critical importance for establishing if an intermediate-age component is present. Brown et al. (2000) resolved hot horizontal branch stars near the center of M32 and, after finding that these objects cannot on their own explain the strength of Hβ absorption, conclude that it will be difficult to explain this feature without resorting to a young population or a large number of blue stragglers. Finally, Guarnieri, Renzini, & Ortolani (1997) investigated the stellar content of M32 using the metal-rich globular cluster NGC 6553 as a benchmark and found that the brightest infrared source in this cluster is a long-period variable that, if viewed at the distance of M32, is more than 0.5 mag fainter in K than the brightest stars in M32 (Davidge 2000).

With a few exceptions (Brown et al. 2000; Davidge 2000), crowding has restricted studies of resolved stars to the outer regions of M32 (Freedman 1989, 1992; Elston & Silva 1992; Davidge & Jones 1992; Grillmair et al. 1996), and population gradients (Cohen 1979; Davidge 1991; O’Connell et al. 1992; Hardy et al. 1994; Brown et al. 1998; Ohl et al. 1998) complicate efforts to tie together predictions made from resolved stars and integrated spectra. In fact, the ultraviolet-visible color of M32 changes by 1.5 mag in the central 10" (Ohl et al. 1998), thus demonstrating the importance of pushing studies of the resolved stellar content to smaller and smaller radii. In the current Letter, images with 0.12 FWHM are used to resolve bright asymptotic giant branch (AGB) stars to within 2" of the galaxy center; for comparison, the majority of AGB tip stars resolved by Davidge (2000) are at distances in excess of 10" from the nucleus.

2. OBSERVATIONS AND REDUCTIONS

M32 was observed during the night of 2000 July 5 UT with the University of Hawaii adaptive optics (AO) system Hokupa’a, which was mounted at the f/16 focus of the 8 m Gemini Mauna Kea telescope. The data were obtained during engineering time as part of a program to assess the feasibility of using galaxy nuclei as reference beacons for AO compensation. Hokupa’a contains a 36-element curvature wave front sensor and bimorph mirror, and additional details of this instrument can be found in Graves et al. (1998). The images were recorded with the University of Hawaii QUIRC camera, which contains a 1024 ×
1024 Hg:Cd:Te array with an angular scale of 0\'02 pixel\(^{-1}\) when mounted on Hokupa’a. The nucleus of M32 was positioned near the center of the science field and was used as the reference source for AO compensation. Four 30 s integrations were recorded in H and K at each of four dither positions. The seeing conditions were average for Mauna Kea, and the delivered image quality was 0\'12 FWHM in each filter.

The data were reduced using the procedures described by Davidge & Courteau (1999), and the final K image is shown in Figure 1. The processed images were smoothed with a 2\' × 2\' median filter to produce a template of the unresolved body of the galaxy, and this was subtracted from the data prior to making photometric measurements. Stellar brightnesses were then measured with the point-spread function (PSF)–fitting program ALLSTAR (Stetson & Harris 1988), using PSFs and star lists constructed with tasks in DAOPHOT (Stetson 1987). The photometric calibration was defined using standard stars from Hunt et al. (1998). The outer wings of the PSF extend over a few arcseconds and contain a significant fraction (∼10% when \(r > 0\'5\)) of the total PSF energy. The faint outer portions of the PSFs cannot be traced in crowded fields, and so the photometric measurements were adjusted for this component using corrections obtained from AO-compensated images of moderately bright stars with FWHMs comparable to the M32 data.

3. RESULTS

The \((K, H−K)\) color-magnitude diagrams of sources in four radial intervals, centered on the nucleus of M32, are shown in Figure 2. The error bars show the uncertainties predicted by artificial star experiments, and these indicate that the dispersion in \(H−K\) is dominated by photometric errors. These experiments also indicate that the trend of bluer \(H−K\) colors toward fainter brightnesses is a systematic effect resulting from crowding.

If two or more stars fall in the same resolution element then they will appear as a single bright object, and this is a major concern for photometric studies in dense environments. One signature of blending is a trend of increasing peak stellar brightness toward progressively smaller radii. The region within 2\' of the nucleus contains sources that are significantly brighter than those at larger radii, suggesting that these objects are artifacts of crowding, likely involving more than two stars. However, when \(r > 2\'\) the peak stellar brightness remains fixed near \(K = 15.5\) mag, which is in excellent agreement with what is seen in the outer regions of the galaxy (Davidge 2000; Freedman 1992; Elston & Silva 1992). Hence, (1) when \(r > 2\'\) the brightest sources are individual stars, and (2) if M32 contains a population that is younger than the brightest stars in the main body of the galaxy then it is restricted to the central 2\'.

The photometric measurements in Figure 2 are consistent with those made by Davidge (2000). Not only is there good agreement between the peak stellar brightnesses, but the brightest stars in Figure 2 have \(H−K\) colors that are similar to the brightest stars in the outer field studied by Davidge (2000). Photometric errors and sample incompleteness in the current data become very large near the red giant branch (RGB) tip, which occurs at \(K ∼ 17.8\) mag (Davidge 2000), and blur this feature. The majority of sources with \(K ≥ 18\) in Figure 2 are undoubtedly blended objects.

The spatial distribution of bright AGB stars follows the integrated light profile of M32 into the central regions of the galaxy. This is demonstrated in Figure 3, where the \(K\) luminosity functions (LFs) of sources in the current data set are compared with the outer field \(K\) LF from Davidge (2000) and AGB tip star counts from the wide-field infrared survey of Elston & Silva (1992). The outer field LF and AGB tip counts have been scaled to match the mean surface brightness in each radial interval based on the Kent (1987) light profile, which
AGB stars can be demonstrated using star counts from the outer region of the galaxy. Davidge (2000) found five stars within 1 mag of the AGB tip in a 0.25 arcmin² field 2.3' from the nucleus and, after scaling according to the Kent (1987) r-band surface brightness profile, the predicted densities of bright AGB stars near the nucleus are 0.008 (7.3'-13.4'), 0.016 (4.4'-7.3'), and 0.038 (2.5'-4.9') stars per 0.06 radius resolution element. The number of blends expected in each radial interval is then 0.01, 0.05, and 0.2. The incidence of blending climbs very quickly for fainter objects.

At a fixed age, the brightness of the AGB tip is expected to vary with metallicity. However, metallicity is likely not a major consideration when comparing AGB tip brightnesses throughout M32. Long-slit spectroscopic observations indicate that \( \Delta M_{\text{r,AGB}} = -0.06 \) between the Davidge (2000) outer field and 2' if \( \Delta M_{\text{r,AGB}}/\Delta r = -0.03 \) (Hardy et al. 1994), and this corresponds to \( \Delta [Fe/H] = 0.3-0.4 \) dex using Worthey’s (1994) solar metallicity models. Bertelli et al. (1994) modeled the evolution of stars up to and including the AGB. These models predict that \( M_{\text{r,AGB}} \) changes by only 0.1-0.2 mag between \( z = 0.008 \) and \( z = 0.020 \), in the sense of becoming brighter toward higher metallicities.

The spatial distribution of bright AGB stars follows the r-band surface brightness profile measured by Kent (1987) to within 2'' of the nucleus, indicating that these stars are uniformly mixed throughout the galaxy. If the brightest stars are younger than the underlying body of the galaxy, then this result could indicate that these objects formed throughout the galaxy during a remarkably coherent episode of star formation, which would require that the star-forming material cooled in such a way as to follow the mass profile of the underlying galaxy. This is evidently not the case in most early-type galaxies, which typically harbor an age gradient of size \( \Delta \log t_{\text{sys}}/\Delta \log R = 0.1 \) (Henry & Worthey 1999). Alternatively, a uniformly mixed population of bright stars is consistent with a coeval system, which is a model for M32 suggested by del Burgo et al. (2000).

Many nearby elliptical galaxies have experienced mergers, and so it is worth investigating if the bright stars, which presumably formed during intermediate epochs, were part of another system that was subsequently accreted by M32. If the intermediate-age component accounts for 10% of M32 by mass (Davidge 2000), then the accreted galaxy would have had an integrated brightness \( M_r \) \( \leq -13.5 \) mag, which overlaps with those of Local Group dwarf galaxies. If merger-induced mixing did occur in M32 then (1) the age of the brightest AGB stars predicted by models indicates that any redistribution of stellar content must have occurred on a timescale of only a few gigayears (Davidge 2000) and (2) any mixing would have to act preferentially on the intermediate-age population and not annihilate the metallicity gradient. Could an interaction between two galaxies of different masses redistribute the stellar content of the smaller object, while not completely removing population gradients in the larger system? Models of non-dissipative mergers between equal-mass systems indicate that the progenitor populations are not fully mixed by such interactions (White 1980). However, the extent of mixing may be very different if the mass ratio differs significantly from unity. Indeed, models in which a low-mass galaxy interacts with a disk indicate that the stars in the smaller system can be redistributed in much less than a Hubble time (Helmi & White 1999) while not destroying the metallicity gradient in the progenitor disk (Quinn, Hernquist, & Fullagar 1993). Hernquist & Quinn (1988) modeled the interaction between a low-mass system and larger spherical galaxy and found that shells may be produced as the
smaller object is consumed by the larger system. M32 does not contain shells, and structures of this nature may have been removed by interactions with M31.

A problem with the merging model is that the timescale for dynamical friction depends on the inverse of system mass (e.g., Binney & Tremaine 1987), and it is not clear that low-mass systems can merge in only a few gigayears. A further complication is that if the AGB stars formed in a low-mass system, then they would likely be more metal-poor than the majority of stars in M32. If this is the case then the intermediate-age component would be even younger than estimated by Davidge (2000), who assumed a solar metallicity, thereby producing even tighter requirements on the mixing timescale.

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