THE DWARF ELLIPTICAL GALAXIES OF THE LOCAL GROUP & THE STELLAR POPULATIONS AND AGE OF M32

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I. Introduction

An active debate continues over whether elliptical galaxies are primarily old stellar systems or whether they have had major star formation events in the recent past. Not only is this question of interest with regard to understanding the stellar populations and star formation history of nearby systems, but the resolution of this issue influences the interpretation of the spectra of high-redshift galaxies and has profound consequences for our understanding of galaxy, and therefore ultimately, of cosmological evolution.

Our lack of understanding of the stellar make-up in elliptical galaxies has persisted for some time because there are no giant elliptical galaxies near enough to allow the study of their stellar populations directly. Most information on the stellar populations of elliptical galaxies rely on the interpretation of integrated light. However, direct information on the bright stellar content of low-luminosity elliptical galaxies *can* be obtained from a study of the Local Group dwarf ellipticals. The nearby Andromeda galaxy, M31 has four low-luminosity elliptical companions: M32, NGC 205, NGC 185 and NGC 147, the subjects of this review.

This review will begin with a broad summary of population characteristics of dwarf elliptical galaxies (dE's), it will briefly summarize what is known about the stellar populations of the four Andromeda companions, and then discuss the specific case of M32 in detail. M32, the highest surface brightness Andromeda companion, has characteristics very simliar to the giant ellipticals, and has therefore been the focus of much of the controversy surrounding the issue of the ages of elliptical galaxies. Studies of its integrated light, in combination with new studies of its brightest resolved giants, particularly in the near-infrared, may help to resolve many of the outstanding questions regarding the stellar populations in elliptical galaxies.

II. General Properties

All four dwarf elliptical companions to Andromeda were first resolved by Baade (1944). M32, a compact dwarf, is the closest companion, lying 24 arcmin away from the M31 nucleus. The next nearest companion is NGC 205, well-known to have undergone very recent star formation as evidenced by a small population of young OB stars. Seven degrees away lie the low-luminosity pair of dwarf ellipticals, NGC 147 and NGC 185, themselves separated by 58 arcmin. A few bright blue stars in NGC 185 have also been noted (Baade 1951). Properties of the Andromeda companions have previously been reviewed by van den Bergh (1975) and Hodge (1989).

Relation to Giant Ellipticals

The relation of the low-luminosity dwarf ellipticals to giant ellipticals has been dis-

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cussed extensively in the literature. For example, Wirth and Gallagher (1984) and Kormendy (1985) conclude that the more luminous ellipticals and compact ellipticals (for example, M32) are physically distinct from the diffuse (low-surface-brightness) dwarfs. Alternatively, Sandage *et al.* (1985) have argued that many observed global properties (for example, the luminosity and effective surface brightness) show a continuity between the massive ellipticals and the low-surface-brightness ellipticals. Very recent results on the kinematics of dwarf ellipticals (*e.g.* Bender and Nieto 1990; Bender, Paquet and Nieto 1991; Carter and Sadler 1990; Held, Mould, and de Zeeuw 1990) have found that contrary to earlier expectations (Davies *et al.* 1983), these galaxies are ***not*** rotationally flattened, and are thus they are similar in this respect to the the giant ellipticals.

Color-Magnitude Diagrams

With the availability of CCD detectors, the stellar content of all four Andromeda dE's has been subject to recent investigations. *I* versus *(V-I)* color magnitude diagrams for the four companions are presented in Figure 1.

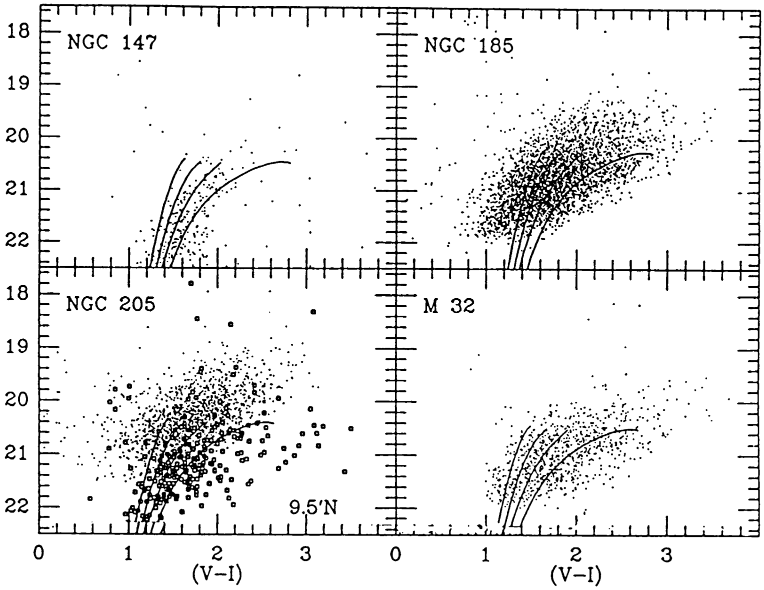

Fig. 1 – *I* versus $(V\text{-}I)_0$ color-magnitude diagrams.

The data for NGC 147 are from Mould, Kristian and da Costa (1983); those for NGC 185 are from Lee, Freedman and Madore (1992a); open circles for NGC 205 are from Mould, Kristian and da Costa (1984) and small dots are from Lee, Freedman and Madore (1992b); finally the data for M32 are from Freedman (1989). Globular cluster sequences for M15, NGC 6752, NGC 1851 and 47 Tuc from Da Costa and Armandroff (1990) have been shifted to the appropriate distance modulus for each galaxy. These sequences correspond to [Fe/H] values of −2.2, −1.6, −1.3, and −0.71, respectively. The distance moduli and the mean metallicity of the giant branch stars and its dispersion are summarized for all four galaxies in Table 1. Lower limits are given in the cases where there is incompleteness in the *V* data. Note that in the case of NGC 205, the data of Lee, Freedman and Madore were obtained in the central regions of NGC 205, and crowding effects result in a much brighter limiting magnitude than for the case of the outer Mould, Kristian and Da Costa field.

TABLE 1

Galaxy	μ_0	$<Z> \pm 1\sigma_z$
M32	24.2 ± 0.3	$>-0.7 \pm 0.3$
N205	24.3 ± 0.2	$>-0.9 \pm 0.4$
N147	24.0 ± 0.15	-0.9 ± 0.3
N185	23.9 ± 0.2	$>-1.3 \pm 0.3$

Ultraviolet observations

Large elliptical galaxies form a fairly narrow sequence in a plane defined by Mg_2 versus the ultraviolet (1550 – V) color (Burstein *et al.* 1988). M32 lies on the low-luminosity end of that sequence, but NGC 205 has an extremely blue UV color and is displaced from the sequence by about 4 magnitudes. These ultraviolet studies indicate that if elliptical galaxies are undergoing very recent star formation (as is the case for NGC 205), such galaxies may be identified on the basis of their ultraviolet properties. For example, both NGC 205 and NGC 185 have very flat UV spectra shortward of 3000 Angstroms (Buson, Bertola and Burstein 1990). In contrast the UV spectrum of M32 falls rather sharply in the wavelength range from 3000 to 2000 Angstroms.

III. Individual Galaxies

NGC 205

The stellar content of NGC 205 was first discussed by Baade (1951) who noted that the dominant population of this galaxy was made up of red giant stars, while the presence of OB supergiants indicated a very recent epoch of star formation. In addition to very young supergiants, NGC 205 also contains a population of luminous red stars (Gallagher and Mould 1981) and luminous carbon stars (Richer *et al.* 1984), which are likely stars of intermediate age (*i.e.,* several Gyr). From Figure 1 it can be seen that the brightest red giants in NGC 205 are about 0.8 mag brighter than those in M32, for example. The mean metallicity of this system falls between that of M32 and NGC 185, and there is a significant dispersion about this mean (see Table 1). Several prominent dust patches are visible in NGC 205, the neutral hydrogen has been mapped and appears to be distributed in a rotating disk, very near to the dust and blue stars (Johnson and Gottesman 1983). CO has been searched for in NGC 205, but more sensitive measurements are needed for a positive detection (Sage and Wrobel 1989). The origin of the gas in this galaxy is still unclear; the proximity of NGC 205 to M31 leaves open the option that the gas has been stripped from M31. Hodge (1973) noted an isophote twist of about 30 degrees toward M31, most likely due to a tidal interaction with M31 (*e.g.,* see discussion and Fig. 7 of Kormendy 1982). The galaxy has a color gradient in the sense that the inner regions are significantly bluer than the outer regions (*e.g.,* Hodge 1973). As noted in the previous section, the ultraviolet colors of NGC 205 are very blue relative to elliptical galaxies in general. All of these data suggest a complex history of star formation in NGC 205, with star formation continuing to the present day.

NGC 185

The dominant population of resolved stars in this galaxy is again composed of red giant stars, although Baade (1951) noted the presence of a small number of blue supergiants. The luminous red stars in NGC 185 resemble those in NGC 205, the brightest giants in this case being approximately 0.6 mag brighter at I than those in M32. Recently Saha and Hoessel (1990) have detected about 150 RR Lyraes in this galaxy, signalling the presence of a *bona fide* old ($>10^{10}$ year old) population. NGC 185 contains 6 known globular clusters (*e.g.,* Harris 1990). The mean metallicity of the globular clusters has been measured by Da Costa and Mould (1988) who find [Fe/H] = –1.65 ± 0.25, somewhat lower than (but consistent to within the errors) the mean metallicity of –1.3 ± 0.3 for individual giant stars measured by Lee, Freedman and Madore (1992a). The central regions of NGC 185 are also bluer than its outer regions (Hodge 1963; Price 1985). NGC 185 also has two rather conspicuous dust patches, it contains approximately 10^5 $M_\odot$ of both neutral hydrogen (Johnson and Gottesman 1983) and molecular gas (Wiklind and Rydbeck 1986), and it has blue ultraviolet colors. Much like NGC 205, NGC 185 appears to have continued forming stars for an extended period of time. However, NGC 185 is much further away from M31 than NGC 205, and the origin of its interstellar medium remains to be explained.

NGC 147

In contrast, NGC 147 displays no evidence for recent star formation. The galaxy has not been detected in neutral hydrogen, no prominent dust patches are obvious, no blue supergiants are present, and as can be seen from Figure 1, unlike NGC 185, NGC 205 and M32, very few stars are seen above the luminosity defined by those in Galactic globular clusters. From these data Mould, Kristian and Da Costa (1983) place a limit of 10% on the possible contribution from a population of intermediate age. Despite the lack of recent activity, the mean metallicity of giants in NGC 147 is similar to those in NGC 205: –0.9 ± 0.3 according to the calibration of Da Costa and Armandroff (1990). Saha, Hoessel and Mossman (1990) have recently detected an old population of RR Lyraes in this galaxy.

M32

No young blue stars are observed in M32 (although it should be noted that the center of this galaxy cannot be resolved as in the case of NGC 205 or NGC 185). No dust patches are evident. The most prominent characteristic of the color-magnitude diagram is the presence of a population of red giant branch stars, the brightest of which resolve at an I magnitude of about 19.5 mag. Although it is very close to M31, Kent (1987) finds no truncation in its surface brightness profile which might indicate a significant tidal interaction. M32 has the highest surface brightness of the four Andromeda companions, and it is the most metal rich. Freedman (1989) places a lower limit of [M/H] = –0.5 dex (based on the revised Yale isochrones) on the metallicity of the giant stars in a field 2 arcmin south of the M32 nucleus, and studies of nuclear integrated spectra suggest a metallicity of about solar (*e.g.,* O'Connell 1985). M32 is the only Andromeda companion with no globular clusters of its own.

Because of its high surface brightness in comparison to the other Andromeda dE's, the similarity of many of its structural properties relative to giant ellipticals (gE's), and because of its proximity (in contrast to the gE's), M32 has acted as a focal point for stellar population studies. It is everyone's "stellar population standard galaxy" for population synthesis studies. It must be borne in mind that it is not yet established whether M32 is typical of elliptical galaxies in general, or merely the "M32 prototype" (that is, a low luminosity elliptical galaxy which is a companion to a luminous spiral galaxy). However, it is clear that if we do not understand M32, it is doubtful that we can understand the stellar populations in more distant galaxies. For example, current population synthesis techniques applied to M32 *and* giant elliptical galaxies lead to a similar end result (see discussion below).

Integrated Studies

As distinct from spiral galaxies, elliptical galaxies have only trace amounts of gas and dust, and the colors of nearby ellipticals are red and exhibit very little scatter. Moreover, the Hubble diagram (magnitude versus redshift) also has very little scatter. These observations have given rise to the classical picture in which elliptical galaxies are viewed as old systems evolving passively with little or no recent star formation.

Opponents to this classical picture (*e.g.,* O'Connell 1980; Pickles 1985) argue that the integrated spectra of the nuclei of M32 and giant elliptical galaxies show evidence for substantial recent star formation activity, while at the same time showing very little dispersion in abundance. Alternatively, it has been argued (*e.g.,* Renzini 1986; Renzini and Buzzoni 1986; Frogel 1988) that if stellar population models adequately allow for a dispersion in metallicity within ellipticals, an older age follows.

In actual fact, both groups are highlighting the same underlying problem discussed extensively many times before (Renzini and Buzzoni 1986; O'Connell 1986); namely, that from integrated spectra alone, it is not possible to measure *directly* the underlying age *and* abundance distributions of a composite stellar population. Rather, in practice, a temperature is measured, and disentangling the effects of age and metallicity is non-trivial. Extracting the age and metallicity then requires either (1) *a priori* knowledge of the star formation history or abundance distribution, or (2) an assumption about the dispersion in one of the parameters. The absence of knowledge of (1) has resulted in the dichotomy discussed above: two different groups arguing either for a low metallicity dispersion, or alternatively for a small age dispersion. The one robust conclusion to emerge from all these studies is that early-type galaxies are not simple stellar populations with only a single-age, single-metallicity population.

As discussed elsewhere in this volume by E. Bica (and references therein), and of interest in the context of M32, are recent population synthesis studies which make use of star clusters as templates. The abundance distribution inferred from these models for M32 agrees with the inferred abundance spread (based on the observed color spread) of giant stars by Freedman (1989). At the same time, in agreement with previous studies of the integrated nuclear spectrum of M32, they argue for a presence of an intermediate age component, although somewhat less substantial than concluded in earlier studies. However, as noted by Schmidt *et al.* (1991), detailed simulations and tests of their method indicate that one of the most difficult cases to model are those where a model galaxy evolves to solar metallicity "*in the presence of old and intermediate-age populations*" [*i.e.,* precisely the type of model believed to apply to M32]. Even when constraints (evolutionary scenarios) are imposed on the models (Bica, Alloin and Schmidt 1990), their two best solutions yield very different relative contributions of the intermediate-age component of 30% and 70% respectively. The final adopted solutions are still constrained more by assumptions than by the input data.

Given the notorious difficulty in putting together a complete library (containing stars and/or clusters representative in age and metallicity of stars in elliptical galaxies), and given the non-uniqueness of population synthesis, it is perhaps not surprising that the results of such studies are still very controversial, and that the issue of the age spread within M32 and other elliptical galaxies is not yet resolved.

Color Gradients

In the case of M32, spectral synthesis studies to date have been confined to the nucleus of the galaxy, whereas crowding and confusion effects have limited color-magnitude diagrams to fields off the nucleus. The lack of positional overlap in the two types of studies leads to the question of whether the stellar populations being sampled in the inner and outer areas might be systematically different. One possible manifestation of differences in stellar population might be a color gradient as a function of radius.

An early UBV photoelectric study of an on- and off-nuclear region in M32 by Sandage, Becklin and Neugebauer ([SBN], 1969) suggested that a color gradient might be present across M32. However, a later compilation of a more extensive set of data (including those of SBN) covering 100 arcsec in extent, failed to reveal a significant gradient in *(U-B)* or (B−V) (Sharov and Lyuti (SL) 1983, 1988 and references therein). Readers can judge for themselves whether Freedman (1989) has misquoted these results as claimed by O'Connell (1990). New results obtained at high resolution (Michard and Nieto [MN] 1991; Lauer, private communication) find no significant gradient even in the innermost regions. In Figure 2, *UBVI* data obtained at the Palomar 1.5m in August 1990 also show no evidence for a significant color gradient. In addition Peletier (1991, private communication) has completed both an optical and near-infrared study of M32 and again finds no significant gradients.

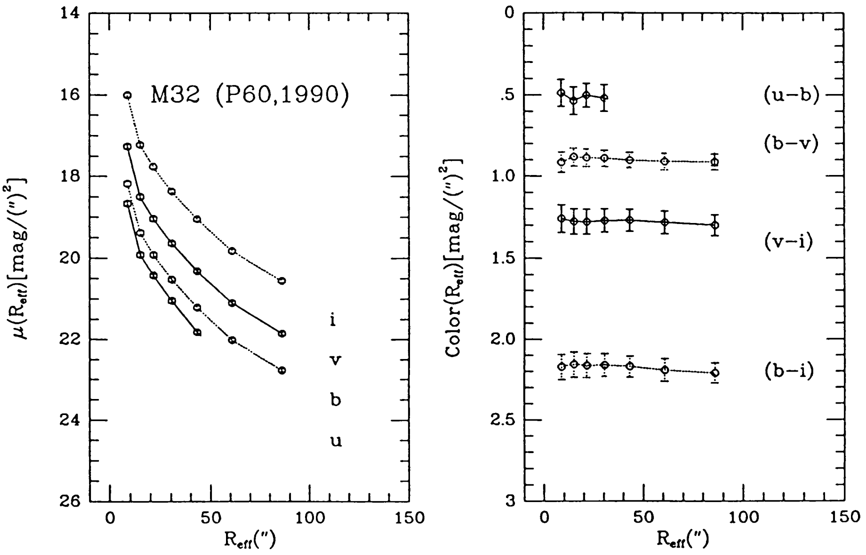

Fig. 2 – Surface photometry and color gradients in M32 based on Palomar 1.5m data. The calibration of the UBV photometry is from SL and MN. The *I* data are uncalibrated.

An interesting (and as yet unexplained) new observation reported by O'Connell (this conference) is a large ultraviolet color gradient in M32. The ultraviolet color gets bluer with increasing radius (which is contrary to the sense of a decreasing metallicity gradient) and is in the opposite sense to that observed in M31, M81 and NGC 1399.

Spectral Gradients

In his extensive population study, Rose (1985) found no evidence for spectral line gradients in M32. Both Cohen (1979) and Davidge (1991) found absorption features which weaken with radius; however, in detail the agreement of individual features is very poor. Faber (this conference) reports that no significant spectral gradients are present in M32.

Direct Studies of Individual Stars in M32

Freedman (1989) resolved individual giant stars in M32 and found (1) evidence for a spread in metallicity of the giants, and (2) a population of stars more luminous than the tip of the first red giant branch. A lower limit to the mean metallicity from the mean (V–I) color is -0.5 dex with a 2σ spread of 0.6 dex. As discussed by Freedman (1989) this dispersion is larger than can be accounted for by photometric error alone. Furthermore, the observed spread is a lower limit only, since the *V*-band frame does not extend faint enough to measure extremely red and metal-rich stars, if they are indeed present in M32. These results appear to rule out population synthesis models which assume a single metallicity population. Spectroscopic followup for stars in M32 is planned.

As can be seen in Table 1, this inferred abundance spread is found in all four of the Andromeda dE's. It is interesting to note that abundance spreads of similar magnitude were predicted by Searle (1979) for the halos of giant galaxies in addition to dwarf galaxies. His prediction ($\sigma = 0.45$ dex [FWHM=1.05]) was based on simple considerations of mass loss in a stellar system undergoing chemical enrichment.

In order to study this population of red giant stars in more detail, new near-infrared data were obtained at the Palomar 5m. A region in M32 covering 90" x 60" was mosaiced in *JHK*. An interesting new result to emerge from this study is that stars up to 2 bolometric magnitudes above the tip of the first red giant branch are present in M32. Many of these stars are not present in Figure 1 because they are so red that they were simply undetected on the *V* CCD frame. These stars are illustrated in a K_0 versus $(J-K)_0$ color magnitude diagram (Figure 3). Positions of the giant branch loci for several Galactic globular clusters are drawn to illustrate the extent to which the luminosities of the giant stars in M32 exceed those of first red giant branch stars. A comparison field taken at the same isophotal level in M31, but removed from the body of M32 indicates that the bulk of this population does indeed belong to M32 itself, and is not simply contamination from the disk of M31.

The presence of such bright red stars in consistent with the recent 2μm spectroscopy of Davidge (1990). Davidge concludes that a component more luminous and cooler than the first red giant branch is needed to fit the near-infrared spectrum of the M32 nucleus.

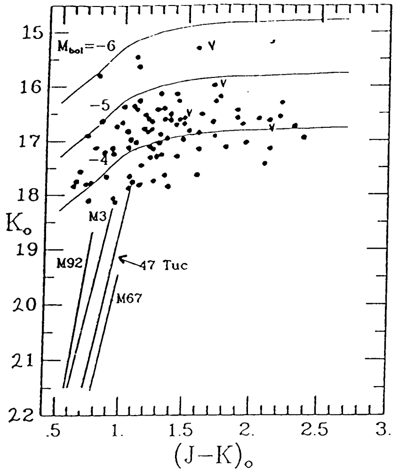

Fig. 3 – K_0 versus $(J\text{-}K)_0$ color-magnitude diagram for M32. The giant branch loci are from Cohen, Frogel, and Persson (1978). For the purposes of this plot, distance moduli of 14.2 and 24.2 mag have been assumed for the Galactic Bulge and M32, respectively.

The brightest stars in M32 have $M_{bol} = -5.5$ mag. In contrast, the brightest stars in the Galactic Bulge have a sharp cutoff at $M_{bol} = -4.2$ mag (Frogel and Whitford 1987). The sample of stars observed in the near-infrared by Frogel and Whitford were selected on the basis of the objective-prism survey carried out in the Bulge by Blanco, McCarthy and Blanco ([BMB], 1984). It is entirely possible that the bolometrically most luminous stars found at K in M32 would have been missed in the optical BMB survey.

The existence of a population of bright stars in the bulge of M31 similar to those in M32 has been reported by Rich (this conference) and Rich and Mould (1991), but Davies, Frogel and Terndrup (1991) suggest that these stars result from contamination by the disk of M31. However, the latter study assumes the maximum disk contribution consistent with the photometry of Kent (1987). Further studies already in progress by these groups should soon resolve this issue.

There are several possible explanations for this newly-discovered bright population in M32: If the stars belong to an *old* population then:

a) the stars may be similar to the most luminous long-period variable stars (LPVs) observed in Galactic globular clusters. Frogel and Elias (1988) have shown that a population of long-period variable stars having bolometric magnitudes in excess of the core-helium-flash luminosity exists in the most metal-rich clusters. A population of this type could be present in M32 since its mean metallicity is comparable to, or slightly greater than, the most metal-rich Galactic globular clusters. Such stars are also observed in the Galactic Bulge. Frogel *et al.* (1990) find that the mean bolometric luminosity of LPVs in the Bulge and Galactic globular clusters is −4.2 mag in both cases.
b) as suggested by Renzini and Greggio (1990) the stars may be a result of a population of binary stars which have merged to produce stars with sufficient mass and fuel in their envelopes to achieve higher luminosities as they evolve up the asymptotic giant branch.
c) the stars belong to a super-metal-rich tail of the metallicity distribution of M32. For example, Frogel and Whitford (1987) have argued that the most luminous stars in the Galactic Bulge may be explained as a result of the fact that the main-sequence lifetimes of metal-rich stars are longer (*e.g.*, VandenBerg and Laskerides 1987). Thus stars with a higher metallicity enter the giant phase at a later age. Old, super-metal-rich stars may therefore have slightly higher-mass progenitors than those of metal-poor giants, and again have additional fuel which allows them to evolve up the asymptotic giant branch at a higher luminosity.

Alternatively, d) the stars may be evidence for a *younger* population: that is an extended asymptotic giant branch population as observed in Searle-Wilkinson-Bagnuolo (1980) clusters of intermediate age in the Magellanic Clouds (Frogel, Mould and Blanco 1990).

Can the observed population of bolometrically luminous stars in M32 then be simply explained by a population of old stars similar to those observed in the Galactic globulars? This question can be addressed by the near-infrared and optical data already obtained, and the answer is a very clear no. For 3 years I have been monitoring the M32 giants for variability. A search for variable star candidates has been successful (there are about 350 candidates based on 4 epochs of data). Several of the brightest variable candidates are indicated in Figure 3. Given the areal coverage of the search, the numbers of variable candidates in M32 are consistent with that predicted by scaling the numbers of long-period variables observed in Galactic globular clusters to the luminosity of M32. However, the fraction of variable star candidates that have been detected at K is *less than 10% of the total.* That is, most of the stars which have been observed in the near-IR are, in fact, non-variable. These numbers are consistent with the conclusion of Impey *et al.* (1986) that $<15\%$ of the 1-2μm radiation comes from asymptotic giant branch stars. More stars with such cool photospheres would result in a larger observed dispersion in the near-infrared colors.

The numbers of stars also appear to be larger than can be accounted for by a population of binaries (Renzini, private communication). Possibility c) (very high metallicity) is unlikely since the luminosity of stars in M32 exceed those observed in the Galactic Bulge by 1 magnitude. In this case, a population of stars must exist in M32 with a metallicity greater than that observed in the Galactic Bulge. The mean metallicity of giants in the Galactic Bulge is about twice solar (Rich 1988), significantly larger than the mean metallicity of M32 stars.

Spectra of the bolometrically most luminous stars in M32 are being obtained in an effort to distinguish between alternatives c) and d). In addition, it will be interesting to determine the period distribution of the long-period variable stars (LPVs) for a comparison with the Galactic Bulge. The period distribution of the Galactic Bulge stars peaks at about 400 days (Whitelock, Feast and Catchpole 1991), and contrary to earlier reports (lacking direct period determinations), there are no LPV's in the Bulge with periods of 1500 days. It had been argued (*e.g.,* Harmon and Gilmore 1988) that the presence of >1000 day long-period variables was a signature of a population of a few billion years in the Bulge. The period distribution of LPVs in M32 will provide a further constraint on the age distribution of stars in this galaxy.

Undoubtedly some of the brightest stars in M32 belong to an old population resembling the long-period variables in Galactic globular clusters. However, most of these luminous red stars are perhaps simplest understood if they belong to a population of intermediate age (5-10) Gyr stars. The existence of an age spread for stars in M32 of course cannot be used to infer the existence of an age spread for more distant ellipticals. But given that population synthesis techniques applied to elliptical galaxies yield results similar to those for M32, these results underscore the difficulty and complexity inherent in the interpretation of the integrated spectra of both nearby and high-redshift ellipticals.

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P. te Lintel Hekkart: Did IRAS detect M32, and was the FIR flux consistent with the number of LPVs found?

W. Freedman: Yes, M32 was detected by IRAS, as were NGC 147 and NGC 185 (*e.g.,* Jura *et al.* 1987, *Ap. J.*,**213**,L11). The latter two galaxies were found to have anomalously low 12μm emission relative to other ellipticals. M32 was also measured at 2 and 10 μm by Impey *et al.* (1986) who found that the 10 μm emission cannot be accounted for by photospheric emission from giant stars alone. Both the 2 and 10 μm emission in M32 have the same spatial distribution as the stars. As mentioned in the talk, this flux is consistent with the emission from LPVs as found for example in the Galactic Bulge. And the upper limit from the Impey *et al.* study of a 15% contribution from luminous LPVs is consistent with the fraction of LPVs found in M32.

G. Da Costa: Can you tell whether or not the very young stars in the center of NGC 205 come from a single burst of short duration or from a more extended or continuous star formation?

W. Freedman: I have not undertaken any modelling of the type discussed by Monica Tosi (this volume). But my suspicion is that ultimately there will still be a problem of non-uniqueness; that is several models would be consistent with the available data.

A. Renzini: I've two questions: 1) on the basis of the metallicity distributions inferred from the RGB color distribution, did you try to infer an average turnoff color for M32, assuming it is as old as globulars? And 2) did you try to estimate the frequency *per unit sampled luminosity* of the stars brighter than, say, M_{bol} = -4.5 respectively in the Bulge and in M32?

W. Freedman: In answer to your first question, no I myself have not inferred an average turnoff color, but as you yourself have stressed many times, an older turnoff age will result when a metallicity spread is taken into account. But the difficulty of course is measuring the true underlying distributions in *both* age and metallicity. The existence of a metallicity spread indicates that models with a small adopted abundance dispersion are in error, but it cannot be used to *rule out* the possibility that the population may also have a spread in age. The answer to your second question is yes, I calculated the fraction of the total light contributed by these bright giants, and it amounts to approximately 10%.