Publication Year	1992
Acceptance in OA@INAF	2023-02-03T16:22:53Z
Title	IUE observations of UB-bright stars in M 3
Authors	BUZZONI, Alberto; Cacciari, C.; Fusi Pecci, F.; Buonanno, R.; Corsi, C. E.
Handle	http://hdl.handle.net/20.500.12386/33153
Journal	ASTRONOMY & ASTROPHYSICS
Number	254

1992A&A...254..110B

Astron. Astrophys. 254, 110–115 (1992)

ASTRONOMY
AND
ASTROPHYSICS

IUE Observations of UV-bright stars in M3*

A. Buzzoni[1], **C. Cacciari**[2], **F. Fusi Pecci**[2], **R. Buonanno**[3], **and C.E. Corsi**[3]

[1] Osservatorio Astronomico di Brera, Via Brera 28, I-20121 Milano, Italy
[2] Osservatorio Astronomico di Bologna, Via Zamboni 33, I-40126 Bologna, Italy
[3] Osservatorio Astronomico di Roma, V.le Parco Mellini 84, I-00136 Roma, Italy

Received June 17, accepted August 27, 1991

Abstract. IUE UV observations of three "UV-bright" stars in M3 are presented. The brightest object – vZ1128 – is confirmed to be a bright Post-AGB star with $\log L/L_{\odot}=3.09$ and $T_e=30{,}000$ K, which contributes about 25% of the integrated UV light from the cluster at $\lambda=1500$Å. The nature of the two other stars, i.e. 524 ($\log L/L_{\odot}=2.06$, $T_e=33{,}000$ K) and 7561 ($\log L/L_{\odot}=2.04$, $T_e=35{,}000$ K), is still controversial. They might be respectively AGB-manqué stars of the sort suggested by Greggio & Renzini (1990), or the result of mergers of binary systems according to Iben (1990), but other possibilities are considered and discussed.

Key words: Clusters: globular – Stars: evolution of – Stars: luminosities of – Stars: temperatures of – UV radiation

1. Introduction

The so-called "UV-bright" stars, which have been found in several Galactic globular clusters in the area of the HR diagram 2-4 mag brighter than the horizontal branch (HB) (Zinn *et al.* 1972, Harris *et al.* 1983), actually include different kinds of stars, such as late and "peculiar" HB members, early asymptotic giant branch (E-AGB) stars, and thermally pulsing (T-AGB) and post-AGB objects (P-AGB) (Renzini and Fusi Pecci, 1988). Most of these objects are single stars evolving towards their final white dwarf (WD) stage, after having ejected most of their H-rich envelope; some of them might be interpreted as the result of stellar mergers or binary mass transfer (Baylin and Iben, 1989; Iben, 1990 and references therein). The variety of definitions and acronyms used so far to describe their properties is nicely reviewed by Sandage (1987), and further information and discussion can be found in the Proceedings of the "Second Conference on Faint Blue Stars" (Philip *et al.*, 1987). A better understanding of their characteristics and intrinsic properties provides information on:

i) The final evolutionary stages of low mass (single and binary) stars.
ii) The final mass of currently dying globular cluster stars.
iii) The specific contribution of this class of objects to the integrated UV flux of old stellar systems (e.g. globular clusters, elliptical galaxies, high redshift galaxies; see Burstein *et al.*, 1988, Greggio and Renzini, 1990, and references therein for discussion).

The total sample of known UV-bright stars is still quite poor and subject to strong selection effects. Their detection is made difficult by two main aspects: first, their lifetimes, if treated as "normal" single stars, are very short (a few 10^5 yr, Renzini and Fusi Pecci, 1988) and consequently their predicted frequency is negligibly low unless very wide populations are observed. Second, the *optical* surveys are inadequate to pick them up as they are bolometrically bright but optically faint stars. The most recent compilation of UV-bright stars in globular clusters (Harris *et al.*, 1983) lists 129 such stars in 29 clusters, 49 of which are bluer than the instability strip, the sample being still incomplete for the selection effects mentioned above. Renzini (1985) estimated that an appropriate search (i.e. extended to the far-UV region of the spectrum) in the 20 brightest Galactic globular clusters (with global integrated luminosity $\sim 10^7 L_{\odot}$) should yield about 100 P-AGB stars brighter than $\sim 100 L_{\odot}$. The few P-AGB candidates in Galactic globular clusters which have been well studied in the UV (Cacciari *et al.*, 1984; de Boer, 1985; Caloi *et al.*, 1986; Adelman *et al.*, 1990) represent thus only the cool tail of the population.

Besides extending the search to cover the very hot temperature range, it is crucial to study in detail and in the UV-wavelength range as many as possible UV-bright stars detected in globular clusters. This approach represents the only tool able to yield direct information on this class of objects which may contribute a very significant fraction of the total UV flux for a given stellar population (see Greggio and Renzini, 1990).

We report here on the study of the three most luminous UV-bright stars in the globular cluster M3. They were detected in the early M3 star photometric study by Sandage (1953) and were subsequently studied by Minkowski and Osterbrock (1959), Strom and Strom (1970), Hills (1971), and de Boer (1985). Their B,V magnitudes have been re-measured in the photometric study of M3 carried out by Buonanno *et al.* (1986, 1988, 1991). It is here worth mentioning that the aim of that study was to obtain very populous and complete stellar samples for each evolutionary stage of the HR diagram, and this goal was achieved by measuring over 10,000 stars in a small area around the cluster (see the CM diagram in Fig. 1, where the UV-stars here studied are specifically marked).

These samples were then used both to get empirical luminosity functions and to test theoretical evolutionary sequences. The overall agreement between observations and theoretical predic-

---

Send offprint requests to: A. Buzzoni

* Based on observations obtained with the International Ultraviolet Explorer, ESA-Villafranca, Spain

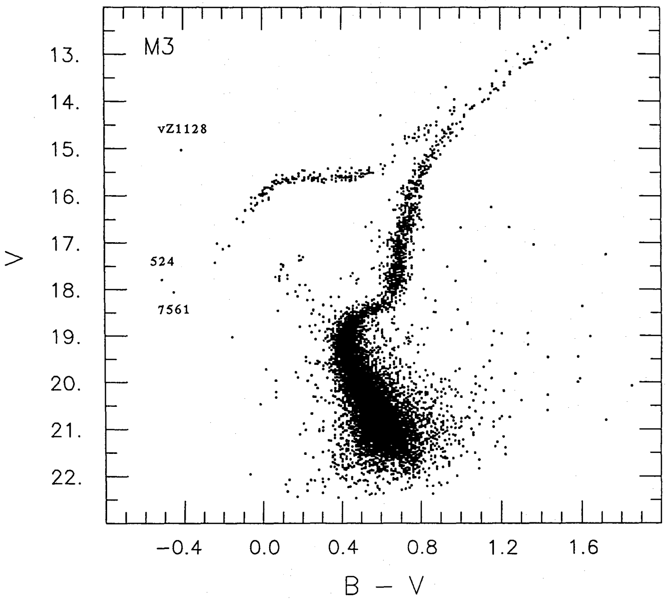

Fig. 1. Colour-Magnitude diagram of M3. The three program stars are identified as vZ1128, 524, and 7561 (see text).

tions was found to be excellent for the well populated branches, while the comparison was less significant for evolutionary phases such as the P-AGB, where the sample of objects is poor and the B,V magnitudes are unsuitable to yield reliable information on them. In fact, in the 10,000 star sample there are only three possible such stars, i.e. the well known vZ1128, which is certainly a P-AGB star already observed with IUE (de Boer, 1985), and the two candidates marked in Fig. 1. The study of their intrinsic nature and characteristics are the subject of this paper.

The specific aim of these observations has been to determine the effective temperature and bolometric correction (i.e. luminosity) of these three UV-bright stars and locate them exactly in the HR diagram. This has been achieved by taking low resolution SWP and LWP spectra (see Sect. 2) in order to have the UV part of the spectral energy distribution over a sufficiently long baseline, along with B and V data. In Sect. 3 we present the adopted procedures and the results. The discussion of the results and the conclusions are finally reported in Sect. 4. In the Appendix a few comments are presented on the possible scientific use of the IUE FES photometric data of the guide stars, that are normally taken for tracking purposes.

2. Observations

Sandage (1953) found 6 UV-stars in M3, that were later studied by Minkowski and Osterbrock (1959), Strom and Strom (1970) and Hills (1971) (note that I-III-87 was erroneously identified as I-IV-87 by Hills 1971). This sample was increased to 9 stars by Buonanno *et al.* (1986, 1988, 1991), adopting the selection criterion that the stars be at least as luminous as the Horizontal Branch, and bluer than B–V≤–0.10 (see Table 1). Of these 9 stars, the three bluest ones are possible candidates for being P-AGB stars and have been selected for the present IUE observations, while the other stars, most likely hot HB members, will be the subject of a future observing run.

Table 1. V magnitudes and B–V colours for the entire sample of UV-bright stars with (B–V)≤–0.10 in M3, from Buonanno *et al.* (1991)

Star[a]	Star[b]	V[b]	B–V[b]	Note
I-III-87	524	17.79	–0.51	
I-V-37	7561	18.06	–0.45	
I-II-57	156	15.03	–0.41	vZ1128
I-VI-54	843	17.42	–0.24	
I-I-58	352	17.01	–0.23	
...	264A	17.13	–0.20	(1)
...	964	17.06	–0.17	
...	358	16.48	–0.13	
I-III-57	621	16.55	–0.10	

[a]: Sandage (1953)
[b]: Buonanno *et al.* (1991)
(1): blended with 264 (V=16.65, B–V=0.73)

Table 2. IUE spectra for the program UV-bright stars in M3

Star	Image	Exp.Time (min)	DN above BKG
I-III-87	SWP38290	240	86
	LWP17460	134	41
I-V-37	SWP38296	140	54
	LWP17465	140	48
vZ1128	SWP38297	35	146
	LWP17466	33	79

The program stars are therefore I-III-87 and I-V-37 in the Sandage (1953) list, which correspond to 524 and 7561 respectively in the Buonanno *et al.* (1991) identification; vZ1128 (I-II-57 and 156 in the above photometric studies) was also included in the program for direct comparison. The stars were observed with the IUE in the low resolution mode, and the parameters of the observations are listed in Table 2. The images were processed at the VILSPA-IUE Observatory using the standard extraction routines, their exposure levels being sufficiently good so as to need no special treatment. A careful search of the field around each star in a deep plate revealed the presence of a brighter companion (V=14.5, B–V=0.83) located at ~7 arcsec NE of 524. The relative position-angle (North to East) is 74 deg, while the position-angle of the IUE large aperture (10×20 arcsec) during the observations was 143 deg. This placed the bright companion 1.5 arcsec outside the aperture along the short axis, and off-set from the target by 2.5 arcsec along the long axis (i.e. perpendicular to the direction of the dispersion). Therefore little or no contribution from the companion star is likely to be present, especially in the short-wavelength range, as confirmed by a careful inspection of the spectra spatial distribution.

Table 3 lists the V and B fluxes outside Earth atmosphere (Allen, 1976) from the photometric data in Table 1, and the UV fluxes derived from the present observations in the same narrow wavelength bands as used by de Boer (1985) for convenience of comparison.

Table 3. Logarithm of V, B, and UV fluxes ($erg/cm^2/sec/Å$) for the program UV-bright stars in M3.

λ / $\Delta\lambda$ (Å)	vZ1128 (156)	I-III-87 (524)	I-V-37 (7561)
V	-14.42	-15.53	-15.63
B	-13.99	-15.06	-15.19
1300 / 100	-12.49	-13.56	-13.58
1400 / 100	-12.61	-13.66	-13.72
1550 / 150	-12.70	-13.76	-13.87
1800 / 150	-12.90	-13.96	-14.01
2200 / 150	-13.17	-14.29	-14.36
2500 / 100	-13.35	-14.44	-14.46
2980 / 60	-13.58	-14.53	-14.66

No reddening correction was applied, since M3 is believed to be reddening-free. The fluxes we have derived for vZ1128 compare very well with the values listed by de Boer.

3. Results

The effective temperatures and gravities for the program stars have been derived by comparing the observed spectral slopes (13–18) and (18–V) with Kurucz (1979) model atmospheres, where the above notations are convenient forms for (m_{1300}–m_{1800}) and (m_{1800}–m_V) respectively (see Fig. 2). The typical errors in both colours are ± 0.1 mag due to the S/N of the UV spectra and to the absolute calibrations on different spectral ranges. As a result, temperatures and gravities are estimated with uncertainties approximately $\pm$ 5,000 K and 0.5 respectively.

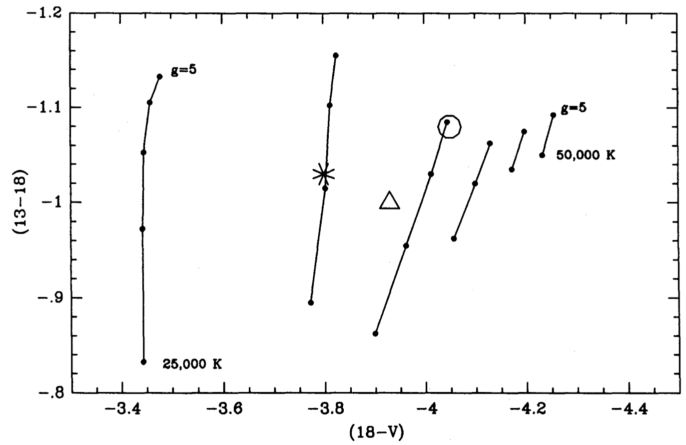

Fig. 2. UV colours (13–18) vs. (18–V) from Kurucz (1979) model atmospheres. The solid lines indicate the models at different temperatures, increasing from 25,000K to 50,000K in steps of 5,000K (left to right). For each model the gravity decreases from 5.0 (top dot) in steps of 0.5. The position of the program stars in this diagram is indicated by an asterisk (156), a triangle (524), and a circle (7561).

The colour combination (13–18) vs. (18–V) has been chosen in analogy with de Boer (1985), and also because these colours revealed to be fairly sensitive indicators of gravity and temperature respectively. Other UV colour combinations have been tried, using the fluxes at 1400Å, 1550Å, and 2980Å, with less satisfactory results. The only interesting indication one might get from using (15–V) instead of (18–V) is a faint tendency to slightly higher temperatures for the star 524, but much stronger evidence is needed before one might conclude that the CIV line at 1550Å is indeed weakened, as suggested by Greggio and Renzini (1990) for hot HB and AGB-manqué candidates.

Since metal-poor theoretical models of T≥ 10,000 K are not available (M3 has [Fe/H]=–1.7), the comparison was made with solar-abundance models. However this is not a problem, as from the Kurucz grid it appears that for $T_e \geq$ 10,000 K the spectral energy distributions in the ultraviolet are practically unaffected by blanketing effects (de Boer, 1985; Crocker *et al.*, 1988). A comparison with the independent analysis by de Boer (1985) on vZ1128 shows perfect agreement.

In Figure 3 we compare the energy distribution of 7561 with the energy distributions of the two other program stars. Taking into account the effect of gravity, which acts in the opposite sense as the temperature (i.e. a lower gravity mimicks the effect of a higher temperature), one can see that in all cases the differences are significant, and confirm the ranking in temperature inferred from Figure 2.

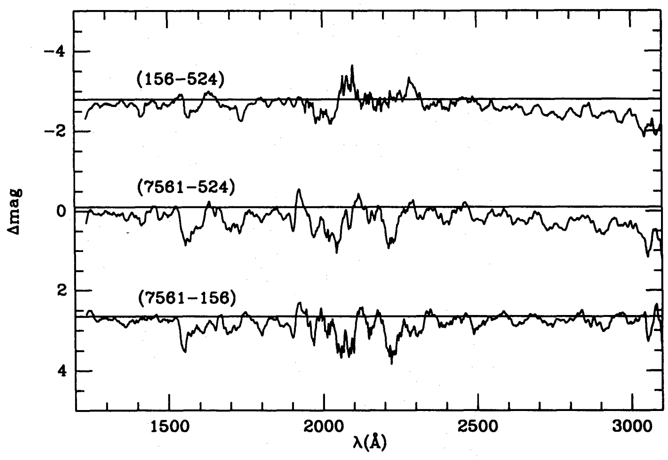

Fig. 3. Comparison of the UV energy distributions of each star relative to the other two

In order to test that the temperatures we have derived are not just "lower limits" due to colour-temperature saturation effects, we have performed some checks by comparing the energy distribution of the hottest star (i.e. 7561) with Black Body energy distributions at temperatures T_e=50,000 K, 70,000 K and 100,000 K, and indeed we may conclude that our temperature estimates are "realistic" values within the quoted incertainty. The UV to V energy distributions of the program stars are shown in Figure 4, where the corresponding Kurucz model atmospheres have been superposed. Table 4 lists the physical parameters that have been derived assuming $(m-M)_o(M3)=15.0$ and $M_{bol}(\odot)=4.72$.

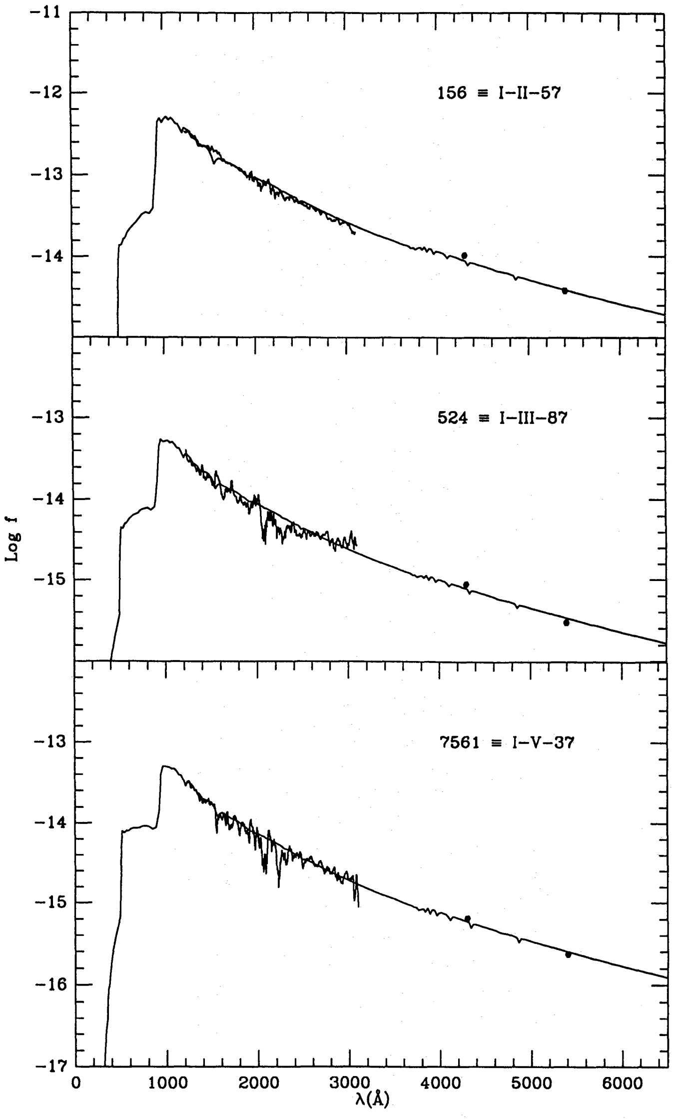

Fig. 4. Energy distributions of the three program stars, including the points corresponding to B and V fluxes. The best-fit Kurucz models are shown superposed (the corresponding values of temperature and gravity are listed in Table 4.).

Table 4. Effective temperature, gravity, bolometric correction and luminosity for the program UV-bright stars in M3, estimated from the colours (13–18) and (18–V) and comparison with Kurucz models.

Star	T_{eff}	log g	B.C.	$\log L/L_\odot$
vZ1128 (156)	30,000 K	4.0	–3.01	3.09
I-III-87 (524)	33,000 K	4.3	–3.20	2.06
I-V-37 (7561)	35,000 K	5.0	–3.40	2.04

4. Discussion and Conclusions

In the theoretical logL-logT_e plane, vZ1128 appears to lie on that part of the P-AGB evolutionary track which is still flat and at its highest luminosity (see Fig.6 in Renzini and Fusi Pecci, 1988), and may therefore be considered a *bona fide* P-AGB star (the one and only presently found in M3).

The expected number of P-AGB stars in a cluster is given by Renzini's (1985) formula:

$$N_{PAGB}=1.7\times 10^{-11}\times 3\times 10^5\times L_{M3}$$

and since the total luminosity of M3 is $\log L_{M3}/L_\odot=5.3$ (Webbink, 1985) one would expect about 1.5 stars in the P-AGB phase, which is compatible with the present results, given the uncertainties of small number statistics.

The two other program stars, 524 and 7561, fall in a region of the HR diagram which is not crossed by any P-AGB track of low mass (i.e. 0.5 - 0.8 $M_\odot$) stars. According to the values of luminosity, temperature and gravity in Table 4 and assuming "normal" single-star evolution, then 524 can only be a hot post-HB star evolving through the "AGB-manqué" phase towards the usual P-AGB tracks, as defined by Greggio and Renzini (1990) on the basis of the theoretical models by Sweigart *et al.* (1974), Gingold (1974, 1976), Sweigart (1978), and Caloi (1987,1989). This phase, however, lasts less than ~15-20% of the time spent on the Zero Age HB (ZAHB) or nearby (Caloi, 1989), so one would expect ~5-6 progenitor HB stars at $\log T_e \geq 4.4$, while none is present. On the other hand, if this star were indeed a P-AGB star with true luminosity $\log L/L_\odot \sim 3.10$ (to place it on a P-AGB evolutionary track in Renzini and Fusi Pecci's Fig. 6), its temperature should be $T_e \sim 87{,}000$ K exceeding the value estimated from the UV data by more than 3σ. As far as 7561 is concerned, the estimated large value for the gravity seems rather to argue in favour of the binary hypothesis suggested by Iben and Tutukov (1986), Baylin and Iben (1989), and Iben (1990).

A better insight on the nature of these two stars could probably be achieved by studying properly the whole group of stars located on the extension of the HB with $(B–V)\leq–0.05$. As a matter of fact, one can see in the CMD (Fig. 1) that the morphology of the blue HB extension in M3 is quite peculiar, showing a gap and a group of stars well separated from the bulk of the blue HB population. A detailed discussion of the possible interpretations and consequences on the global treatment of the M3 stellar population can be found in Buonanno *et al.* (1991). Here we simply recall some indications suggesting that they are somehow peculiar objects:

i) Crocker *et al.* (1988) have taken spectra for some of these stars deriving lower surface gravities than for "normal" HB stars by $\Delta\log g \sim 0.3$.

ii) In the computation of evolutionary lifetimes based on the ratio of the number of stars in each branch with respect to the total population (see Buonanno *et al.* 1991 for details), the HB lifetime turns out to be about 20% longer than expected from standard and canonical models (Sweigart, 1987). This could be due to some underestimate in the models due to the existence of "breathing pulses" or to the effect of overshooting (see Renzini and Fusi Pecci 1988 for references and discussion), but the discrepancy could be easily removed if the 7 red HB stars one can see in the CMD of Fig.1 are interpreted as BS-progeny, and the 6 objects at the blue end of the HB are the product of a different evolutionary path from that of normal HB stars.

Crocker *et al.* (1988) examined several alternative scenarios for the interpretation of their observational results (see their

Table 4), and we do not see any other possible explanation in addition to those they proposed. Therefore, while 524 seems to be a good AGB-manqué candidate (but the lack of candidate HB progenitors is a problem...), 7561 is better consistent with the interpretation related to mergers of binary systems. As pointed out by Iben (1990), the location in the HR diagram of the models resulting from merging of binary systems is extremely sensitive to the prior thermal history of the stars (in addition to the parameters assumed for the binary system). Hence the resulting different objects can occupy during their lifetimes a wide area in the HR diagram, spanning from $\log T_e = 4.0$ up to 5.0 and $\log L/L_\odot = 0$ up to 5. Although many alternatives are therefore presumably possible, and specific models could be tailored to optimize the interpretation, the models presented so far do not offer easy solutions that match the observed properties of 7561. The temperature and luminosity could correspond to a model of the 0.3 $M_\odot$ cooling helium dwarf in Iben and Tutukov (1986) Table 1, although the correspondence is not very strict. This interpretation is supported by the large value of gravity we have estimated for this star.

The other alternatives are related to helium enrichment and/or rapid rotation. In fact, helium mixed into the envelope at the core flash would move the star location on the ZAHB bluewards (but at a slightly lower surface gravity, see Crocker *et al.*, 1988), and a similar effect would be produced by an increase of core rotation via the chain: higher rotation → higher core mass → higher flash luminosity → higher mass loss → smaller envelope on the ZAHB → bluer and slightly brighter ZAHB location (Renzini, 1977; Buonanno *et al.*, 1985). Unfortunately, both phenomena yield small effects if limited within the ranges compatible with other observational constraints.

In conclusion, it appears that the three program stars belong to three different evolutionary phases. While vZ1128 is certainly a P-AGB star, 524 shows characteristics of an AGB-manqué candidate, and 7561 is better consistent with the results of binary-system mergers. An accurate and independent determination of surface gravity is crucial in order to test and confirm these hypotheses.

Finally, a few considerations are in order concerning the contribution of the program stars to the integrated cluster UV light. While the program stars (see Table 3) contribute a negligible fraction of the integrated V flux of the cluster ($\log f_V(\mathrm{M3}) \sim -4.95$), they do contribute about 2% each at $\lambda = 1550$ Å, and up to 25% for vZ1128, using the integrated far-UV flux from OAO-2 $\log f_{1550}(\mathrm{M3}) = -12.07$ (de Boer, 1985). The ANS integrated flux is 0.45 mag fainter, which may indicate that some fraction of the cluster population has been missed by the smaller ANS aperture.

Acknowledgements. We are indebted to L. Greggio, A. Renzini and R.T. Rood for helpful comments and discussions. We wish to thank T. Martin, D. Pike and M. Lolli for their help and advice with the FES photometry of the stars discussed in the Appendix, W. Wamsteker and the VILSPA staff for making this facility available to us while still in its testing phase, and C.Bartolini, A.Guarnieri, A.Piccioni, M.Teodorani and G.Cosentino for their assistance with the observations and reduction of the corresponding ground-based visual data.

Appendix

The guide stars that were used for tracking during the IUE observations were selected among the brightest stars in the field, and happened to be cluster members near the tip of the Red Giant Branch (RGB), namely 268 (V=12.74, B–V=1.41) and 1299 (V=12.80, B–V=1.45) according to Buonanno *et al.* (1991), and V225, which is reported as a variable star in Sawyer-Hogg (1973) (also n.837 in Sandage, 1953, corresponding to vZ837). The period of V225 is P = 89.59 days, and the "instantaneous" photometric parameters V=12.68 and B–V=1.50 by Buonanno *et al.*, (1991) are consistent with the data listed by Sawyer-Hogg $B_{max} = 13.86$ and $B_{min} = 14.26$.

At the time of the observations VILSPA was testing the use for scientific purposes of the telemetry data (i.e. guide star counts) from the Fine Error Sensor (FES), which is normally used only for monitoring and locking the telescope pointing on the guide star. Although in a preliminary and uncalibrated form, this facility was very kindly made available to us and we took this opportunity to search for microvariability or flickering in these RGB stars.

The sampling time of the FES data is alternately 358 and 410 msec for the slow/overlap tracking mode that was used. The FES counts were then analysed for periodic and non-periodic variations starting from the raw data and progressively increasing the smoothing factor. A rebin over at least 60 sec worth of data was necessary in order to improve the signal-to-noise and try to approach the photon noise, so any information on shorter term variabily (if any) was lost. Longer term periodic variability with period up to 30 min was tested for the stars 268 and 1299, but none was detected. The variable star V225 could only be monitored for a total of ≤ 10 min, since it was used as guide star for vZ1128 which needed short integration times, and the longest period checked was 5 min.

As far as non-periodic variability was concerned, we have plotted in Figure A1 the FES counts for the guide stars.

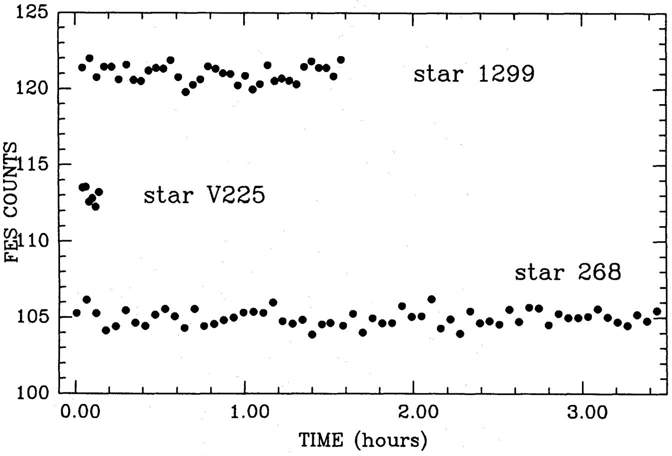

Fig. A1. Monitoring the FES counts for the guide RGB stars. Each dot represents the average of 540 measures, i.e. ∼ 3 min worth of data, for stars 268 and 1299, while the data for star V225 were rebinned over 180 measures, i.e. ∼ 1 min, and off-set by +3 counts for the sake of clarity. Typical errors of the measurements are ±0.20 counts for the stars 268 and 1299, and ±0.60 counts for stars V225.

The data for stars 268 and 1299 were rebinned over 540 measures, i.e. ∼ 3 min worth of data, which gave the best compromise between signal-to-noise and time resolution, while the data for star V225 were rebinned over ~ 1 min worth of data only. The r.m.s. errors of the data points are 0.2 counts, i.e. approximately ten times smaller than the variation amplitude of the respective sets of data for stars 268 and 1299, apparently suggesting that some irregular variability is present with amplitude ≤ 2 counts (i.e. 0.02 mag). In order to draw firm conclusions, however, better S/N high-speed photometric data were necessary, which were taken at the 1.5m telescope in Loiano using the available two-head photometer. The integration times were typically 1-10 sec, and the data were then progressively rebinned to match the FES time resolution, reaching an accuracy of a few 0.001 mag on the individual data points. No absolute photometric calibration was attempted, since our aim was only to check for variability against the unidentified comparison stars. These data confirmed that no light variation was present with amplitude larger than 0.01 mag and time-scale shorter than a few hours.

The average values of the FES counts are 105, 121 and 110 for 268, 1299 and V225 respectively, which can be transformed to FES magnitudes yielding FES = 12.64, 12.48, and 12.59 respectively. The FES magnitudes are only roughly comparable to V, since the FES has a different response from the Johnson V filter. The ranking, however, should be the same having the stars very similar B–V colours, while 1299 results brighter than 268 in FES and fainter in V. The available data do not allow to decide whether this is due to some instrumental effect or to a real variation in luminosity, which only a monitoring over a sufficiently long period of time could reveal.

References

Adelman, S.J., Cacciari, C., Leckrone, D.S., 1990, *Astron. Astrophys. Suppl.* **88**, 393.

Allen, C.W., 1976, *Astrophysical Quantities*, The Athlone Press, London.

Bailyn, C.D., Iben, I.Jr., 1989, *Astrophys. J. Lett.* **347**, L21.

Buonanno, R., Buzzoni, A., Corsi, C.E., Fusi Pecci, F., Sandage, A., 1986, Mem. S.A.It. **57**, 391.

Buonanno, R., Buzzoni, A., Corsi, C.E., Fusi Pecci, F., Sandage, A., 1988, in *Globular Cluster System in Galaxies*, IAU Symp. n.126, Ed. J.E. Gringlay and A.G. Davis Philip, Kluwer, Dordrecht, p. 621.

Buonanno, R., Corsi, C.E., Fusi Pecci, F., Hardy, E., Zinn, R.J., 1989, *Astron. Astrophys.* **152**, 65.

Buonanno, R., Buzzoni, A., Corsi, C.E., Fusi Pecci, F., Renzini, A., Sandage, A.R., 1991, *Astron. J.*, to be submitted.

Burstein, D., Bertola, F., Buson, L., Faber, S.M., Lauer, T.R., 1988, *Astrophys. J.* **328**, 440.

Cacciari, C., Caloi, V., Castellani, V., Fusi Pecci, F., 1984, *Astron. Astrophys.*, **139**, 285.

Caloi, V., 1987, in *The Second Conference on Faint Blue Stars*, IAU Coll. n.95, L.Davis Press, Schenectady, N.Y., p.539.

Caloi, V., 1989, *Astron. Astrophys.* **221**, 27.

Caloi, V., Castellani, V., Danziger, J., Gilmozzi, R., Cannon, R.D., Hill, P.W., and Boksenberg, A., 1986, *M.N.R.A.S* **222**, 55.

Crocker, D.A., Rood, R.T., O'Connell, R.W., 1988, *Astrophys. J.* **332**, 236.

de Boer, K.S., 1985, *Astron. Astrophys.*, **142**, 321.

Gingold, R.A., 1974, *Astrophys. J.* **193**, 177.

Gingold, R.A., 1976, *Astrophys. J.* **204**, 116.

Greggio, L., Renzini A., 1990, *Astrophys. J.* **364**, 35.

Harris,H.C., Nemec,J.M., and Hesser,J.E. 1983, *Publ. Astron. Soc. Pacific*, **95**, 256.

Hills, J.G., 1971, *Astron. Astrophys.* **12**, 1.

Iben, I.Jr, 1990, *Astrophys. J.* **353**, 215.

Iben, I.Jr., Tutukov, A.V., 1986, *Astrophys. J.* **311**, 742.

Kurucz, R.L., 1979, *Astrophys. J. Suppl.* **40**, 1.

Minkowski, R., Osterbrock, D., 1959, *Astrophys. J.* **129**, 583.

Philip, A.G.D., Hayes, D.S., Liebert, J.W., 1987, Ed.s of *The Second Conference on Faint Blue Stars*, IAU Coll. n.95, L.Davis Press, Schenectady, N.Y.

Renzini, A., 1977, in *Advanced Stages in Stellar Evolution*, Ed.s P. Bouvier and A. Maeder, Geneva Obs., p.149.

Renzini, A., 1985, in *Horizontal Branch and UV-Bright Stars*, Ed. A.G.D. Philip, L.Davis Press, Schenectady, N.Y., p.19.

Renzini, A., Fusi Pecci, F., 1988, *Ann. Rev. Astron. Astrophys.*, **26**, 199.

Sandage, A., 1953, *Astron. J.* **58**, 61.

Sandage, A., 1987, in *The Second Conference on Faint Blue Stars*, IAU Coll. n.95, L.Davis Press, Schenectady, N.Y., p.469.

Sawyer-Hogg, H.B., 1973, Publ. David Dunlop Obs. Vol.3, No.6.

Sweigart, A.V., 1978, in *The HR Diagram*, Ed.s A.G.D. Philip and D.S. Hayes, Reidel, Dordrecht, p.333.

Sweigart, A.V., 1987, *Astrophys. J. Suppl.* **65**, 95.

Sweigart, A.V., Mengel, J.G., Demarque, P., 1974, *Astron. Astrophys.* **30**, 13.

Strom, S.E., Strom, K.M., 1970, *Astrophys. J.* **159**, 195.

Webbink, R.F., 1985, in *Dynamics of Star Clusters*, IAU Symp. n.113, Ed.s J.Goodman and P. Hut, Dordrecht: Reidel,p.541.

Zinn, R.J., Newell, E.B., and Gibson, J.B., 1972, *Astron. Astrophys.* **18**, 390.

This article was processed by the author using Springer-Verlag TEX A&A macro package 1991.