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TWO HIGH-VELOCITY STARS SHOT OUT FROM THE CORE OF THE GLOBULAR CLUSTER 47 TUCANAE[1]

G. MEYLAN[2]
Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218

AND

P. DUBATH AND M. MAYOR
Geneva Observatory, 51, Ch. des Maillettes, CH-1290 Sauverny, Switzerland
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ABSTRACT

We report the discovery of two high-velocity stars in the core of the globular cluster 47 Tucanae. Located respectively at about 3″ and 38″ from the center, they have radial velocities relative to the cluster equal to −36.7 and +32.4 km s^{-1}, corresponding to 4.0 and 3.6 times the velocity dispersion in the core, which is equal to σ_p(core) = 9.1 km s^{-1}. These velocities are of the order of, or larger than, the central escape velocity estimates.

The long time baseline between repeated observations and the constancy of the radial velocity values indicate that neither of these two stars is a binary or a pulsating star. They have positions on the red giant branch and asymptotic giant branch in the color-magnitude diagram which favor their membership. Because of its rather high Galactic latitude ($b = -44°$), 47 Tuc does not suffer too strong a Galactic pollution by field stars. Therefore, the probability of finding two such stars inside the central 40″ of 47 Tuc is extremely low. There is no indication that these stars are not members of the cluster.

The main mechanism which may be called upon for explaining these two interlopers is the ejection out of the core by stellar encounters between a single star and a binary, or between two binary stars. From different astrophysical considerations, two important facts can be inferred: (1) the mechanism of ejection operated quite recently; and (2) the two stars, having had only little time to evolve in the color-magnitude diagram, were ejected when they were already giants. The large stellar radii involved (about 40 and 100 $R_\odot$) imply large impact parameters. Therefore, it is not known if, during stellar encounters, the most energetic interactions can involve giant stars; neither is it known if such interactions can accelerate giant stars sufficiently enough to produce the high-velocity stars observed.

Subject headings: clusters: globular — stars: high-velocity — stars: stellar dynamics

1. INTRODUCTION

Attractive from more than one point of view, globular clusters challenge our present knowledge in at least three different fundamental topics. In astrophysics, they provide a unique opportunity to observe and study dense stellar systems that are much closer to us than Galactic nuclei. In statistical mechanics, concepts of negative heat capacity and resulting gravothermal instability point out the limitations of the present framework of statistical descriptions of dynamical systems (with gaseous sphere and Fokker-Planck models). Having reached the limits of applicability of statistical approximations, we face the prospect of full star-by-star simulations of globular cluster evolution, still out of reach for present-day hardware and software capabilities (Hut, Makino, & McMillan 1988; Makino & Hut 1991).

During the last decade, our understanding of the dynamics of globular clusters has evolved and changed dramatically. Supported by new improved theoretical simulations and high-resolution CCD observations, earlier theoretical predictions as well as some spare observational indices have now turned into evidences: globular clusters are not as simple as they were thought.

From a theoretical point of view, the worst problem is their dynamical evolution which turns out to be unstable. From whatever point of view—e.g., (1) two-body relaxation ejects stars from the core which contracts as the envelope expands (Hénon 1961); (2) with realistic stellar mass spectrum, two-body relaxation causes the more massive stars to sink toward the cluster center, inducing mass-segregation instability (Spitzer 1969); (3) beyond a certain central concentration the core of the cluster can no longer stay in equilibrium with the envelope but suffers a thermodynamics turnabout (Antonov 1962; Lynden-Bell & Wood 1968)—we should expect the core of a globular cluster eventually to collapse. From an observational point of view, there are clear evidences that King models, quite successful in fitting some clusters like ω Centauri and 47 Tucanae, encounter some difficulties in matching surface brightness profiles of some clusters with higher concentrations. Part of these problems could be the result of the discrete nature of the core of such clusters, whose light is dominated by the contribution of a few (less than 10) bright stars (Meylan & Mayor 1991), but these problems could be also the signature of a dynamically evolved core having suffered a gravitational collapse (see the recent conference proceedings edited by Janes 1991).

Binary stars are potentially very important in cluster evolution because they can give up energy to passing stars and become more and more tightly bound as a result of stellar

[1] Based on observations collected at the European Southern Observatory, La Silla, Chile.

[2] Affiliated with the Astrophysics Division, Space Science Department, European Space Agency.

encounters. While the energy absorbed by soft (loose) binaries is negligibly small, that given up by hard (tight) binaries may strongly influence the cluster evolution, so much so to delay, to halt, and even to reverse the collapse of the core (Spitzer 1987).

As a contribution to the understanding of the dynamics of such clusters, we are undertaking a survey dedicated to the measurement of the central velocity dispersion in the core of Galactic and Magellanic globular clusters (Dubath, Meylan, & Mayor 1992). We present here the data—part of the above survey—concerning 47 Tuc, a high-concentration Galactic globular. These data consists of the velocity dispersion from integrated light spectra in the core of this cluster (§ 2). They are completed by a second determination of the velocity dispersion, from mean stellar radial velocities of about 50 stars located within 1′ of the cluster center (§ 3). The memberships of the two high-velocity stars discovered in the core are discussed (§ 4), and the possible ejection mechanisms as well as their astrophysical consequences are outlined (§ 5).

2. INTEGRATED LIGHT SPECTRA WITH CASPEC

2.1. *Observations and Reduction*

The integrated light spectra consist of observations obtained in the core of 47 Tuc with CASPEC, the Cassegrain Echelle Spectrograph of the European Southern Observatory (ESO), mounted on the ESO 3.6 m telescope at La Silla, Chile. The charge coupled device (CCD) used is the ESO CCD No. 8. It is an RCA SID 503 high-resolution, thinned, backside-illuminated device, with 1024 × 640 pixels of 15 μm square each, and with a readout noise of about 24 electrons. The instrument setup is standard, with the 31.6 line mm^{-1} grating and with a wavelength domain between 4250 and 5250 Å. We have two spectra obtained at an interval of two nights, during the nights 1989 July 6–7 and 8–9. Both nights are characterized by strong winds and seeing values of the order of 2″ FWHM. The integration time is 15 minutes for both spectra, with a spectrum of a thorium-argon lamp taken before and after each exposure. The dimensions of the entrance slit is 1″.4 × 6″.0 for the first series of observation, and 1″.2 × 6″.0 for the second one. During the two exposures on the cluster core, a scanning of the nucleus was done with the entrance slit, in order to cover a zone of 6″ × 6″ so to avoid any problem of sampling which could occur if integrating only over a few bright stars. This sampling area is represented in Figure 1*b* by the dashed-line square of 6″ × 6″, superposed on a portion of a CCD image of the core of 47 Tuc, obtained at the ESO/MPI 2.2 m telescope at La Silla, Chile, during the night 1988 December 12–13, with a standard *B* filter and 2 s of integration with a seeing of 0″.8 FWHM. The same sampling area is represented in Figure 1*c* by a similar dashed-line square superposed on a portion of an image obtained by the *Hubble Space Telescope* Faint Object Camera at 2200 Å (Paresce et al. 1991). Taken in F/96 mode, it has a point-spread function of about 0″.07 FWHM.

The spectra are reduced following standard procedures. The CCD frames are first cleaned to remove bad areas and median-filtered to suppress cosmic events. Then, the background is subtracted, the different orders extracted and wavelength-calibrated by using the corresponding thorium-argon spectra. No flat-field operation is applied, since flux calibration is useless when cross-correlating spectra for obtaining radial velocity or velocity dispersion. The reduced spectrum is then cross-correlated with a numerical mask. The properties of this mask, as well as the details of our cross-correlation technique, are described in a previous study concerning the Magellanic globular cluster NGC 1835 (Dubath, Meylan, & Mayor 1990). The mask used so far for optical cross-correlation with the spectrophotometer CORAVEL (COrrelation-RAdial-VELocities; see Baranne, Mayor, & Poncet 1979) has been simply extended in order to cover the complete spectral domain of our CASPEC spectra, i.e., the interval from 4245 to 5275 Å. Our cross-correlation technique produces a cross-correlation function (CCF) which is nearly a perfect Gaussian. Comparison with CCFs of standard stars displays the broadening of the cluster CCF, produced by the Doppler line broadening present in the integrated light spectra because of the random spatial motions of the stars. The quadratic difference between the standard deviations of the Gaussians fitted to the CCFs gives a precise estimate of the stellar velocity dispersion in the sampled area of the globular cluster (Dubath et al. 1990).

2.2. *Results from CASPEC Spectra*

Figure 2 shows the CCFs—relative intensity as a function of the radial velocity—for the two spectra obtained in the core of 47 Tuc. The squares represent the CCFs themselves; the continuous lines, the fitted functions which are combinations of two Gaussians. The latter are represented separately only in the case of the upper CCF. In a totally unexpected manner, both CCFs coming from two similar but independent spectra, exhibit an identical double dip. The deepest Gaussian represents the light coming from the cluster as a whole, since it reproduces ($V_r = -18.4$ and -19.1 km s^{-1}, respectively; see Table 1) the systemic radial velocity of 47 Tuc, known to be $V_r = -18.8 \pm 0.6$ km s^{-1} from the radial velocities of 272 member stars (Meylan & Mayor 1986). This Gaussian is also much broader than the mean CCF (stellar Gaussian) defined as the mean of a set of CCFs from standard stars with late spectral types (Dubath et al. 1992). Consequently, the projected velocity dispersion σ_p in the core of 47 Tuc is derived, the two independent CCFs giving $\sigma_p = 9.0$ and 9.2 km s^{-1}, respectively (Table 1).

The second, less deep, Gaussian corresponds to a radial velocity totally different from the systemic radial velocity of the cluster. Its width is much smaller and typical of CCFs obtained from single star. Therefore, we conclude that this second dip reveals the presence of a relatively bright star, inside the 6″ × 6″ sampling area, with a radial velocity value $V_r = -55.5$ km s^{-1} ($V_r = -55.4 \pm 0.2$ and -55.5 ± 0.2 km s^{-1}, from the upper and lower CCFs, respectively). Its radial velocity relative to the cluster is 4.0 times larger than the velocity dispersion in the core of the cluster, i.e., V_r(star 74) − V_r(47 Tuc) = −36.7 km s^{-1} with σ_p(core) = 9.1 km s^{-1}.

Challenged by this double dip, we were wondering which star in the sampling area (Figs. 1*b* and 1*c*) was the interloper.

TABLE 1

STAR 74 IN THE CORE OF 47 TUCANAE

Instrument	$\bar{V}_r$(cluster) (km s^{-1})	σ_p(core) (km s^{-1})	V_r(star 74) (km s^{-1})
CASPEC integrated light spectra within $r = 3''$:			
1989 Jul 6–7	−18.4	8.8–9.2	−55.4 ± 0.2
1989 Jul 8–9	−19.1	9.1–9.3	−55.5 ± 0.2
CORAVEL measurements:			
1990 Dec 26–27	...	...	−54.3 ± 1.6
1990 Dec 28–29	...	...	−55.5 ± 2.2

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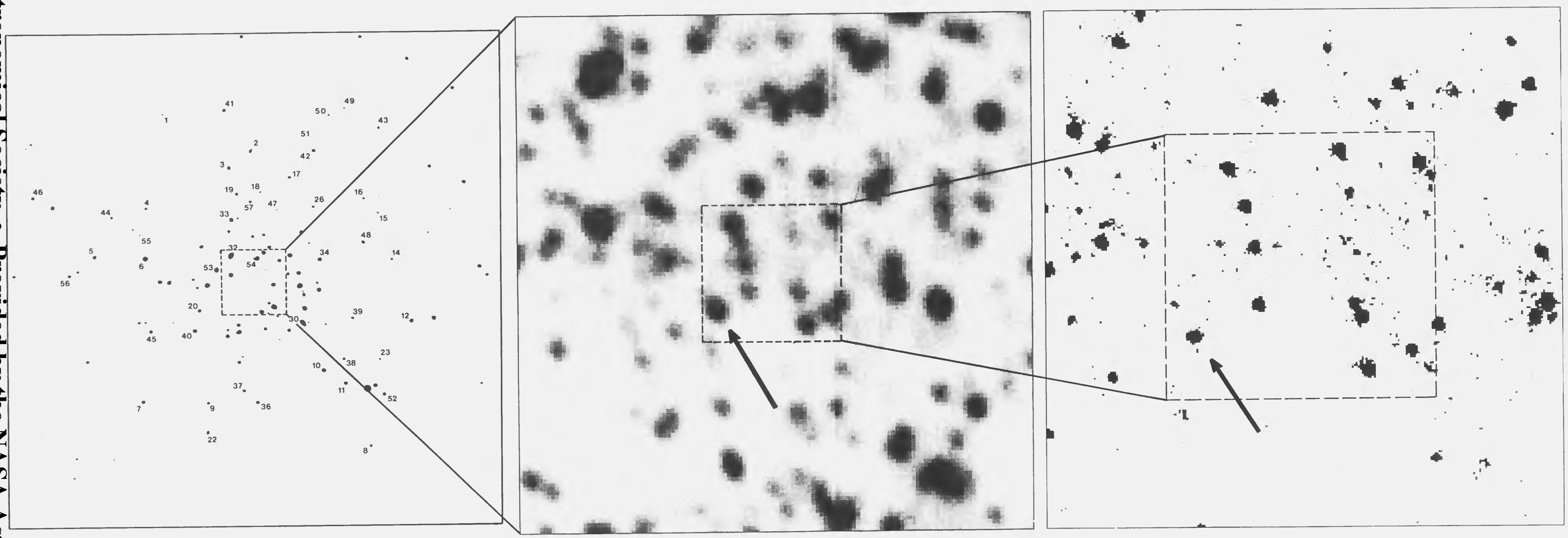

FIG. 1.—(*a*) Chart of 2′ × 2′ in size of the central area of 47 Tuc, from a CCD frame obtained at the ESO NTT telescope at La Silla, Chile, during the night 1990 December 26–27, with 2 s of integration. All the stars with radial velocities measured with CORAVEL are indicated by the numbers corresponding to those in Table 2. (*b*) Enlarged chart of the innermost area of 47 Tuc obtained at the ESO/MPI 2.2 m telescope at La Silla, Chile, during the night 1988 December 12–13, with a standard *B* filter and 2 s of integration with a seeing of 0″.8 FWHM. The dashed square represents the 6″ × 6″ sampling area. The high-velocity star 74 is indicated by the arrow. (*c*) The dashed square represents the same 6″ × 6″ sampling area in an enlarged chart of the innermost area of 47 Tuc obtained by the Hubble Space Telescope Faint Object Camera at 2200 Å (Paresce et al. 1991). Taken in F/96 mode, it has a point-spread function of about 0″.07 FWHM. The high-velocity star 74 is indicated by the arrow.

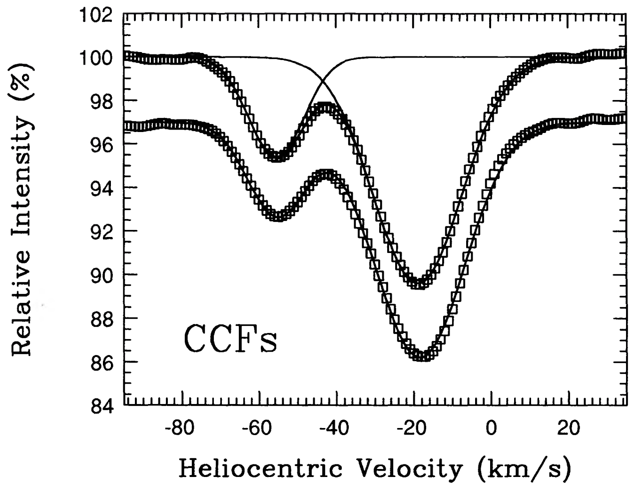

FIG. 2.—Cross-correlation functions (CCFs)—relative intensity as a function of the radial velocity—from the two integrated light spectra obtained in the core of 47 Tuc. The squares represent the CCFs themselves; the continuous lines, the fitted functions which are combinations of two Gaussians.

We have solved the puzzle, by obtaining individual radial velocities for some of the brightest stars in the sampling area. These results, acquired in 1990 December by direct radial velocity measurements with CORAVEL mounted on the ESO 1.54 m Danish telescope at La Silla, Chile, allow us to locate the high-velocity star (74), identified by an arrow in Figures 1*b* and 1*c*. The CASPEC radial velocities are confirmed by two CORAVEL measurements which give $V_r = -54.3 \pm 1.6$ km s^{-1} on 1990 December 26–27 and $V_r = -55.5 \pm 2.2$ km s^{-1} on 1990 December 28–29 (Table 1 and last line in Table 2). These observations show also that the radial velocity of this star is not variable. The long time baseline between the CASPEC and the CORAVEL observations and the constancy of the velocity values are an indication that the star is not a pulsating star neither part of a binary system.

Table 1 summarizes the above results. The errors on the radial velocities from integrated light, mentioned in this table, are formal errors. A more realistic uncertainty on these values is of the order of ≤ 1 km s^{-1}. For a more detailed discussion about the accuracy of such results, reference is made to Dubath et al. (1990, 1992).

3. STELLAR RADIAL VELOCITIES WITH CORAVEL

3.1. *Observations and Reduction*

The above measurements of radial velocities of individual stars in 47 Tuc are not the first ones done with CORAVEL. During the past decade, a few hundred stars, members of 47 Tuc, have been measured (Mayor et al. 1983 and 1992). For a few years, individual radial velocity measurements for a sample of about 50 stars located within the central arcminute ($\simeq 2r_c$) from the center of 47 Tuc, have been carried out using CORAVEL mounted on the ESO 1.54 m Danish telescope. All these stars are identified by their numbers in Figure 1*a*, a $2' \times 2'$ chart from a CCD frame obtained at the NTT telescope at La Silla, Chile, during the night 1990 December 26–27, with 2 s of integration. Table 2 gives for each star its identification number (in Fig. 1), its mean radial velocity V_r and the corresponding uncertainty ϵ_{V_r}, the number of measurements N, and the mean accuracy $\bar{\epsilon}_1$ of a single measurement. The minimum interval of time between two measurements of the same star is about one year. For radial velocity measurements, the stars with a standard deviation significantly larger than the mean uncertainty are marked "variable" in the last column. Such small variations (less than a couple of km s^{-1}) are negligible for the present dynamical analysis. The short-exposure CCD frame used as a chart in Figure 1*a* reveals that some stars have very close faint companions which may have contaminated slightly the measurements. These stars are denoted by "crowded." These contaminations are again negligible in the present context.

TABLE 2

CORAVEL DATA FOR INDIVIDUAL STARS

Star Number	V_r (km s^{-1})	ϵ_{V_r} (km s^{-1})	N	$\bar{\epsilon}_1$ (km s^{-1})	Remark
1	−19.17	0.38	2	0.5	
2	−28.15	0.40	3	0.7	
3	−14.16	0.33	3	0.6	
4	−16.60	0.33	3	0.6	
5	−17.14	0.55	3	0.7	
6	−22.54	1.32	7	0.7	Variable
7	−16.13	0.32	3	0.6	
8	+1.14	0.91	5	0.8	Variable + crowded
9	+2.69	0.40	3	0.7	
10	+13.20	0.69	3	0.6	
11	−43.81	0.51	3	0.5	
12	−12.52	0.84	3	0.7	Crowded
13	−16.56	0.26	3	0.5	
14	−24.69	0.40	3	0.7	Crowded
15	−4.47	0.60	1	0.6	
16	−36.78	0.49	3	0.9	
17	−22.51	0.45	2	0.6	
18	−16.17	0.71	6	1.3	Crowded
19	−35.98	1.40	1	1.4	Crowded
20	−24.60	1.20	2	1.7	
22	−21.23	1.50	7	1.2	Variable + crowded
23	−3.56	0.62	2	0.7	
26	−24.25	1.04	3	1.8	Crowded
30	−14.83	1.57	3	0.8	Variable + crowded
32	−26.29	0.49	2	0.7	Crowded
33	−10.10	0.64	2	0.9	
34	−36.88	0.38	4	0.7	
36	−21.79	0.44	2	0.6	
37	−21.21	0.47	2	0.7	
38	−29.62	0.54	2	0.7	
39	−23.51	0.45	2	0.6	
40	−16.97	0.85	4	0.6	Variable + crowded
41	−24.01	0.73	3	1.3	
42	−26.93	0.47	2	0.6	
43	−24.67	0.42	2	0.6	
44	−18.14	0.40	2	0.6	
45	−15.87	0.41	3	0.7	
46	−9.93	0.79	1	0.8	
47	−12.78	1.48	2	0.9	Variable + crowded
48	−8.40	0.54	2	0.8	Crowded
49	−16.31	0.45	2	0.6	
50	−26.81	0.45	2	0.6	
51	−15.39	0.55	2	0.8	
52	−10.86	0.77	2	0.7	
53	−29.22	0.99	1	1.0	
54	−16.13	0.89	1	0.9	
55	−10.43	0.47	2	0.7	
56	−24.24	1.56	3	0.7	Variable
57	−11.40	1.80	1	1.8	
74	−54.90	1.40	2	1.9	

3.2. *Results from CORAVEL Measurements*

A histogram of all the radial velocities contained in Table 2, including the high-velocity star found in § 2, is presented in

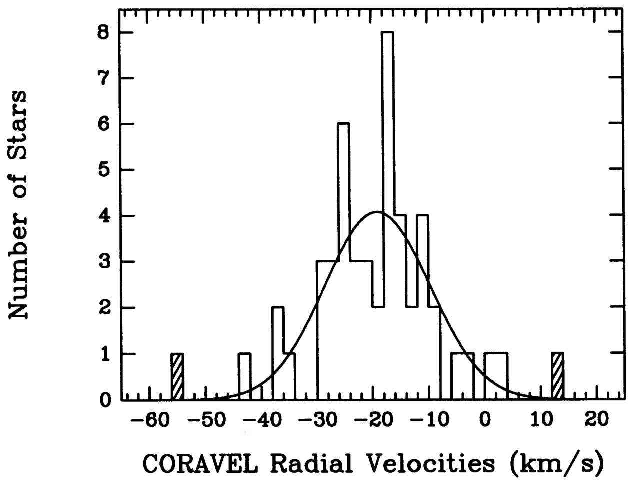

FIG. 3.—Histogram of the 50 radial velocities contained in Table 2, including the high-velocity star 74 found in CASPEC spectra and later observed with CORAVEL, and the high-velocity star 10 observed with CORAVEL.

Figure 3. It reveals, in addition to the central star ($V_r = -55.5$ km s^{-1}, with star 74 in Table 2), a second high-velocity star ($V_r = +13.20$ km s^{-1}, with star 10 in Table 2 and Fig. 1*a*) with a radial velocity relative to the cluster 3.6 times larger than the velocity dispersion, i.e., V_r(star 10) − V_r(47 Tuc) = +32.4 km s^{-1} with σ_p(core) = 9.1 km s^{-1}. Again, the long time baseline between the three CORAVEL observations and the constancy of the velocity values are an indication that the star is not a pulsating star nor part of a binary system.

Omitting these two high-velocity stars, this sample of 48 stars gives a systemic radial velocity of -19.2 ± 1.3 km s^{-1} and a dispersion of 9.4 ± 1.0 km s^{-1}. Values of both systemic radial velocity and velocity dispersion, obtained here from individual radial velocities, are in perfect agreement with those obtained in § 2 from integrated light spectra, i.e., a systemic radial velocity of -18.8 ± 0.6 km s^{-1} and a dispersion of 9.1 ± 1.0 km s^{-1}. They also agree perfectly with the previous determinations from Illingworth (1976), Mayor et al. (1984), and Meylan & Mayor (1986).

4. MEMBERSHIP OF THE TWO INTERLOPERS

By considering the histogram in Figure 3, the probability of getting two such high-velocity stars is extremely low, independently of their nature and formation mode. By considering the Gaussian fitting the bulk of data, the probability to get a star at 4.0 σ from the mean is 1.3×10^{-4} and the probability to get a star at 3.6 σ from the mean is 6.1×10^{-4}. These probabilities are somewhat uncertain because the distribution function of the velocities is not necessarily Gaussian in the wings, especially if the two stars are actually escaping.

Before discussing the membership of these stars, it is worth mentioning that Gunn & Griffin (1979) find two similar high-velocity stars in their seminal study of the globular cluster M3 ≡ NGC 5272. Their interlopers have velocities at 4.5 and 3.5 σ from the mean velocity dispersion in the core of M3, which is σ_p(core) ≃ 5 km s^{-1}.

1. *Radial velocities.*—Unfortunately, the relatively low systemic radial velocity of 47 Tuc ($V_r \simeq -19$ km s^{-1}) does not allow an immediate discrimination between field stars and members of the clusters. Relative to the cluster, the two stars travel in opposite directions: star 74 with $V_r = -36.7$ km s^{-1} and star 10 with $V_r = +32.4$ km s^{-1}.

2. *Positions on the color-magnitude diagram.*—A required check consists of looking at their positions in the color-magnitude diagram (CMD). Two CCD images of the core of 47 Tuc, obtained at the ESO/MPI 2.2 m telescope at La Silla, Chile, during the night 1988 December 12–13, with standard *B* and *V* filters and 2 s of integration each, give a CMD (Fig.4) which is calibrated by using photometry of the same area from Aurière & Ortolani (1988). This gives rough photometry for the two stars: $V \simeq 12.96$ and $B-V \simeq 1.25$ for star 74, and $V \simeq 11.89$ and $B-V \simeq 1.35$ for star 10. The solid lines superposed on the CMD are the fiducial sequences for the RGB, HB, and AGB of 47 Tuc published by Hesser et al. (1987). The two stars have positions on the red giant branch and asymptotic giant branch which tends to confirm their membership (Dubath, Meylan, & Mayor 1991). However, foreground dwarf stars cannot be ruled out since dwarfs at a distance of about 100 pc may appear superposed on the giant branch of 47 Tuc. From the CMD of 47 Tuc of Hesser et al. (1987), at $B-V = 1.2$, the difference in magnitude between a dwarf and a giant is about 8 mag, indicating that a dwarf superposed on the giant branch should be about 40 times closer than a giant of similar apparent magnitude.

Galactic pollution.—Because of its rather high Galactic latitude ($b = -44°$), 47 Tuc does not suffer too strong a Galactic pollution by field stars. Bahcall & Soneira (1981) predict 47 stars per square degree brighter than $I^{mag} = 12$, and 97 stars per square degree with $12.5 \leq I^{mag} \leq 13.5$. Similarly, taking into account the color range, estimates of number of field stars per square arcmin toward 47 Tuc (Ratnatunga & Bahcall 1985) give 1.4×10^{-2} stars per square arcmin with $B-V = 1.10$, and 3.8×10^{-3} stars per square arcmin with $B-V \geq 1.30$. Therefore, the probability of finding two such stars inside the central 40″ of 47 Tuc is very low.

From all the above considerations, there is no reason to disregard these two high-velocity stars: there is no indication that they are not members of the cluster. The still tiny but

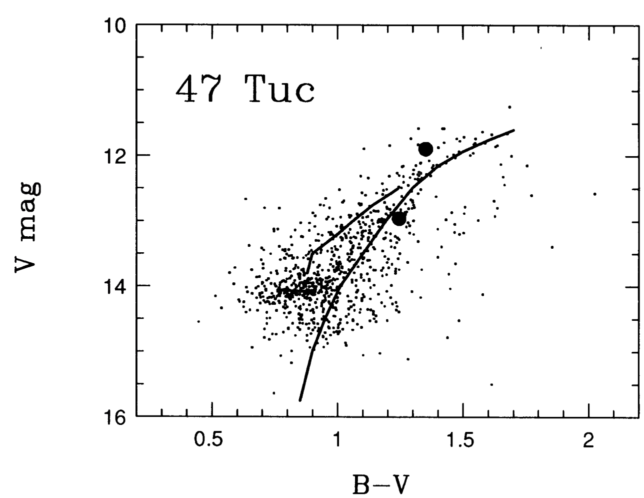

FIG. 4.—Color-magnitude diagram of the center of 47 Tucanae, from two CCD images obtained at the ESO/MPI 2.2 m telescope at La Silla. The superposed solid lines are the fiducial sequences corresponding to the RGB, HB, and AGB. The two stars (*large dots*) have positions on the red giant branch and asymptotic giant branch which tend to confirm their membership.

remaining doubt concerning the membership of these high-velocity stars has to be definitely eliminated. The simplest way consists of obtaining spectroscopic observations, and deducing the luminosity classes of the two stars. If they are giants, their apparent magnitudes put them at about the distance of 47 Tuc, where field pollution is absolutely negligible, given the rather high Galactic latitude ($b = -44°$): their membership will be certain.

5. MECHANISM OF EJECTION OUT OF THE CORE

With an age of about 15×10^9 yr, 47 Tuc has a turnoff mass of about 0.8 $M_\odot$. The tracks of evolutionary models of a star with such a mass (Chiosi et al., private communication, in Charlot & Bruzual 1991) indicate that the evolution time along the red giant branch, upward from the level of the horizontal branch to the helium flash, is about 100×10^6 yr, with a stellar radius increasing from about 10 to 140 $R_\odot$; the time spent as a horizontal branch star is about 100×10^6 yr, with a stellar radius increasing from about 10 to 25 $R_\odot$; the time spent as an asymptotic giant branch star is about 25×10^6 yr, with a stellar radius increasing from about 25 to 125 $R_\odot$. The total evolutionary time in the CMD of an 0.8 $M_\odot$ star, from the main sequence to any position above the level of the horizontal branch star, is extremely long, i.e., of the order of 10^9 yr.

The two stars have observed velocities of the order or larger than the central escape velocity estimates (Peterson & King 1975). Had they been ejected with a spatial velocity of 35 km s^{-1} when they were still on the main sequence, the two high-velocity stars would have travelled a distance of about 36 kpc(!) during the above quoted evolutionary time of 10^9 yr. At the adopted distance of 47 Tuc, viz., 4.7 kpc, the core radius of $25'' = 0.57$ pc (Meylan 1989) is traversed in about 15×10^3 yr; with a concentration $c = \log r_t/r_c \simeq 2.0$, the time required to reach the tidal radius is about 1.5×10^6 yr. The two stars observed are in projection right over the core. These facts point out two important clues: (1) the mechanism of ejection operated quite recently; and (2) the two stars, having had only a little time to evolve in the CMD, were ejected when they were already giants, i.e., with rather large stellar radii. Given their respective positions on the CMD, star 74 has a radius of about 40 $R_\odot$, and star 10, a radius of about 100 $R_\odot$.

The main mechanism which may be called upon for explaining these two interlopers is the ejection out of the core by stellar encounters between a single star and a binary, or between two binary stars. The presence of binaries is now confirmed in globular clusters through different kinds of observations. The core of 47 Tuc contains one low-mass X-ray binary (Hertz & Grindlay 1983a, b). In addition, indications of the influence or presence of binaries in 47 Tuc can be seen in the existence of 11 millisecond pulsars (Manchester et al. 1990, 1991; the review by van den Heuvel 1991) and the very high density of centrally clustered blue stragglers recently observed by *HST* (Paresce et al. 1991). Apart from being primordial, binaries can be formed in the core of globular clusters through two different channels: "three-body binaries" created during the encounter of three single stars (Heggie 1975), and "tidal-capture binaries" created when two strongly interacting stars dissipate enough of the relative kinetic energy through tidal oscillations (Fabian, Pringle, & Rees 1975; Lee & Ostriker 1986). For every marginal escape, there must be many collisions and coalescences (Verbunt & Meylan 1988), of which the observed blue stragglers could be an end product.

A large number of binary-binary scattering experiments (Leonard 1991) show that gravitational interactions can eject stars at very high velocity. The maximum velocity that a low-mass companion ejected from a binary-binary interaction can attain is roughly the escape velocity V_{esc} from the surface of the most massive star involved in the interaction. The maximum velocity that the most massive star involved in the interaction can attain is roughly half the escape velocity from the star's surface. In the case of our two giants of about 0.8 $M_\odot$, with $V_{esc} = (2GM_*/R_*)^{1/2}$, the escape velocity are V_{esc}(star 74) = 87 km s^{-1} and V_{esc}(star 10) = 55 km s^{-1}. If the giants involved are the most massive stars in the interaction, $V_{max} = V_{esc}/2 = 43$ km s^{-1} and 27 km s^{-1}, respectively, similar to the observed velocities -36.7 and $+32.4$ km s^{-1}. Nevertheless, in explaining the cases of 47 Tuc stars, there is a serious shortcoming with the above scattering experiments, which are valid only for main-sequence stars.

The orbital velocities of the binaries involved in a binary-binary collision are comparable with the velocity of the fastest star ejected by the collision. With $V_{circ} = (GM_*/2A)^{1/2}$, the circular velocity of two stars of 0.8 $M_\odot$ orbiting each other at a distance $A = 1$ AU is about 19 km s^{-1}. A smaller value of A would increase this velocity to the range of the observed radial velocities, but in the present case, given the large radii of the two stars, $A = 1$ AU $= 215$ $R_\odot$ implies already tidal effects during the encounter (Fabian et al. 1975; Lee & Ostriker 1986). Because of their large size, giants cannot be members of close binaries. McMillan, Taam, & McDermott (1990) have demonstrated that tidal capture is possible between a 1.4 $M_\odot$ neutron star and an 0.8 $M_\odot$ giant, so long as the giant is not too far above the subgiant branch. In the present case, stars 74 and 10 are situated well above the subgiant branch, with radii of about 40 and 100 $R_\odot$, respectively. These large radii imply large impact parameters; therefore, it is not known if the most energetic interactions can involve giant stars; neither is it known if such interactions can accelerate giant stars sufficiently enough to produce the high-velocity stars observed in 47 Tuc and M3. We are not aware of any study investigating the ejection of stars with larger radii.

A way to alleviate the problem of the observed large stellar radii may consist of considering acceleration of main-sequence stars out of the core into elongated orbits toward the outskirts of the cluster, with period $P \sim 10^6$ yr. Such a scenario explains the presence of a pulsar out of the core of M15 (Phinney & Sigurdsson 1991; Phinney 1991). In the present case, the two stars would evolve toward a giant stage quickened out of the core, but would also survive the effect of dynamical friction over about 1000 orbits.

From the fact that two high-velocity giants are observed in 47 Tuc, and in M3 as well (Gunn & Griffin 1979), one can deduce that we are not only missing all the other giants, ejected more or less perpendicularly to the line of sight, but also all the main-sequence dwarfs, much more numerous and dynamically more easily ejectable than the giants, but too faint to be measured in radial velocity. This raises interesting questions about the stellar dynamics processes happening in the dense core of the globular clusters. Is 47 Tuc burning its primordial binaries in order to delay its core collapse? This emphasizes also our present lack of knowledge concerning the importance of the phenomenon of evaporation of globular clusters. Has the Galactic halo been significantly populated by stars previously members of globular clusters, stellar systems which could have been severely pruned, and for some of them even totally dissolved?

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