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THE CLUSTERS AGES EXPERIMENT (CASE). II. THE ECLIPSING BLUE STRAGGLER OGLEGC 228 IN THE GLOBULAR CLUSTER 47 TUC[1]

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ABSTRACT

We use photometric and spectroscopic observations of the eclipsing binary OGLEGC 228 (V228) to derive the masses, radii, and luminosities of the component stars. Based on measured systemic velocity, proper motion, and distance, the system is a blue straggler member of the globular cluster 47 Tuc. Our analysis shows that V228 is a semidetached Algol. We obtain $M = 1.512 \pm 0.022\ M_\odot$, $R = 1.357 \pm 0.019\ R_\odot$, and $L = 7.02 \pm 0.050\ L_\odot$ for the hotter and more luminous primary component and $M = 0.200 \pm 0.007\ M_\odot$, $R = 1.238 \pm 0.013\ R_\odot$, and $L = 1.57 \pm 0.09\ L_\odot$ for the Roche lobe–filling secondary.

Key words: binaries: close — binaries: spectroscopic — globular clusters: individual (47 Tucanae) — stars: individual (OGLEGC 228)

1. INTRODUCTION

Blue straggler (BS) stars are defined by their location above and to the blue of the main-sequence turnoff on the color-magnitude diagram of their parent population. Since their discovery in the globular cluster M3 (Sandage 1953), BSs have been identified in many globular and open clusters (Piotto et al. 2004; De Marchi et al. 2006), as well as in the field (Carney et al. 2005). The currently most popular BS formation mechanisms are mass transfer in a close binary (McCrea 1964) and merger of two stars induced by a close encounter (Benz & Hills 1987). There are numerous examples of confirmed binary BSs in open clusters, and for a few, masses of both components have been accurately established from analyses of radial and light curves (see, for example, Sandquist et al. 2003). In the case of globular clusters, the sample of candidate BSs includes several contact binaries (Rucinski 2000), as well as a sizable population of SX Phe pulsating variables, which have been detected in over a dozen clusters (Rodríguez & López-Gonzáles 2000). However, until now not a single direct mass determination is available for a binary BS belonging to a globular cluster. De Marco et al. (2005) used *HST* spectra to estimate masses for 24 apparent single BSs from three clusters (see also Shara et al. 1997). They derived an average mass of 1.07 $M_\odot$ with a wide range of uncertainty for the masses of individual objects. There thus seems to be evidence for both BS formation mechanisms in open and globular clusters.

The eclipsing binary OGLEGC 228 (hereafter V228) was discovered by Kaluzny et al. (1998) during a survey for variable stars in the field of the globular cluster 47 Tuc. They presented a *V*-band light curve for the variable and found an orbital period of $P = 1.1504$ days. Further *VI* photometry of V228 along with a finding chart was published by Weldrake et al. (2004; star WSB V7 in their catalog). On the color-magnitude diagram of the cluster, the variable occupies a position near the top of the BS sequence.

In this paper we report results of photometric and spectroscopic observations aimed at a determination of absolute parameters of V228. The data were obtained as a part of a long-term Clusters Ages Experiment (CASE) project conducted at Las Campanas Observatory (Kaluzny et al. 2005). Sections 2 and 3 describe the photometry of the variable and an analysis of its orbital period. Section 4 presents the radial velocity observations. The combined photometric and spectroscopic element solutions are given in § 5, while the membership in 47 Tuc is discussed in § 6. The last, § 7, discusses the properties of V228 in the 47 Tuc context.

2. PHOTOMETRIC OBSERVATIONS AND REDUCTIONS

The photometric data were obtained with the 1.0 m Swope telescope at the Las Campanas Observatory using the SITE3 CCD camera at a scale of 0.435″ pixel^{-1}. Most of the images were taken with the detector subrastered to 2048 × 3150 pixels, but occasionally we also used subrasters of 2048 × 2150 or 2048 × 700 pixels. Most observations were collected during the 1997, 1998, and 2001 observing seasons. The same set of *BV* filters was used for all observations. Some additional data were obtained with the *V* filter in 2003 and 2004, with the goal of refining the period of the system. Exposure times ranged from 120 to 200 s for the *V* filter and from 180 to 240 s for the *B* filter. The raw data were preprocessed with the IRAF CCDPROC package.[6] The time series photometry was extracted using the ISIS, version 2.1, image subtraction package (Alard & Lupton 1998; Alard 2000).

To minimize the effects of a variable point-spread function we used 600 × 600 pixel subimages in the analysis with the variable located in the center of the field. Transformation of instrumental photometry to the standard *BV* system was accomplished using measurements of 198 standard stars from Stetson's catalog (Stetson 2000) which are present in the observed field.

In Figure 1 we show the *BV* light curves of V228 phased with the ephemeris given in the next subsection. These curves contain

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[1] This paper utilizes data obtained with the 6.5 m Magellan Telescopes located at Las Campanas Observatory, Chile.

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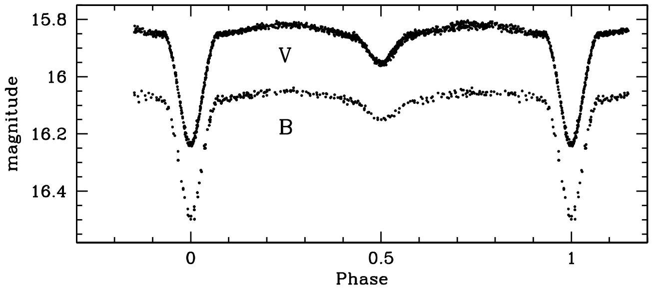

FIG. 1.—Phased BV light curves of V228.

a total of 1199 and 274 data points for V and B, respectively. The colors and magnitudes of V228 at minima and at quadrature are listed in Table 1. The quoted errors do not include possible systematic errors of the zero points of the photometry, which we estimate at about 0.01 mag.

3. THE ORBITAL PERIOD

From the available data we measured nine times of eclipses for V228; their values, along with errors determined using the method of Kwee & van Woerden (1956), are given in Table 2. The first listed minimum is based on the OGLE-I data from Kaluzny et al. (1998). The $O - C$ values listed in the table correspond to the linear ephemeris

$$\text{Min. I} = \text{HJD } 2{,}451{,}064.82019(16) + 1.15068618(14)E, \quad (1)$$

determined from a least-squares fit to the data. A linear ephemeris provides a good fit, and there is no evidence for any detectable period change during the interval 1993–2004 covered by the observations.

4. SPECTROSCOPIC OBSERVATIONS

Spectroscopic observations of V228 were obtained with the MIKE echelle spectrograph (Bernstein et al. 2003) on the Magellan II (Clay) telescope of the Las Campanas Observatory. The data were collected during five observing runs between 2003 August 16 and 2004 October 4. For the current analysis we used the data obtained with the blue channel of MIKE covering the range from 380 to 500 nm with a resolving power of $\lambda/\Delta\lambda \approx 38{,}000$. All of the observations were obtained with a $0.7'' \times 5.0''$ slit and with 2×2 pixel binning. At 4380 Å the resolution was ~2.7 pixels at a scale of 0.043 Å pixel^{-1}. The seeing ranged from $0.7''$ to $1.0''$.

The spectra were first processed using a pipeline developed by D. Kelson following the formalism of Kelson (2003, 2006) and then analyzed further using standard tasks of the IRAF Echelle package. Each of the final individual spectra consisted of two 600–900 s exposures interlaced with an exposure of a thorium-argon lamp. We obtained 40 spectra of V228. For the wavelength interval 400–500 nm, the average signal-to-noise ratios (S/Ns) ranged between 14 and 39, depending on the observing conditions. In addition to observations of the variable, we also obtained high-S/N spectra of radial velocity template stars.

TABLE 1
BV PHOTOMETRY OF V228 AT MINIMA AND QUADRATURE

Phase	V	B	$B - V$
Max.	15.854(1)	16.081(2)	0.227(2)
Min. I	16.239(1)	16.484(3)	0.245(3)
Min. II	15.954(1)	16.146(2)	0.192(2)

TABLE 2
TIMES OF MINIMA AND $O - C$ VALUES FOR V228

Cycle	T_0 (HJD − 2,400,000)	Error	$O - C$
−1589.0	49,236.3820	0.0016	−0.0022
0.0	51,064.8204	0.0006	−0.0002
279.0	51,385.8615	0.0002	0.0001
344.0	51,460.6564	0.0002	−0.0002
380.5	51,502.6554	0.0005	0.0009
968.0	52,178.6845	0.0005	−0.0001
1632.0	52,942.7401	0.0002	−0.0001
1631.0	52,941.5893	0.0002	0.0001
1939.5	53,296.5766	0.0010	−0.0006

We have analyzed the spectra of V228 for radial velocity variations using a code based on the broadening function (BF) formalism of Rucinski (2002). A spectrum of HD 138549 was used as a template. According to Nordström et al. (2004) the relevant properties of HD 138549 are $V_{\rm rad} = 11.6$ km s^{-1}, $V \sin i = 1$ km s^{-1}, [Fe/H] $= +0.01$, and $T_{\rm eff} = 5457$ K. We used the spectra in the wavelength range from 400 to 495 nm excluding the Balmer series lines. Figure 2 presents examples of fitting a model to the BFs calculated for two spectra taken near opposite quadratures. Our radial velocity measurements of V228 are listed in Table 3, with last two columns giving residuals from the spectroscopic orbit solution, as presented in the next section. The current implementation of the BF method does not give reliable estimates of internal errors of the measured radial velocities; in the following analysis the velocities for a given

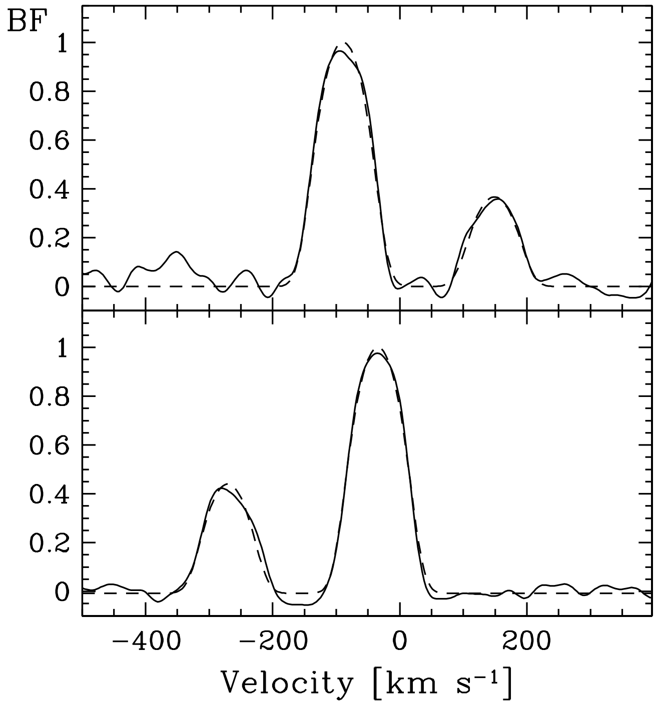

FIG. 2.—BFs extracted from the spectra of V228 obtained near the first (*top*) and second (*bottom*) quadratures. The dashed lines show fits of a model BF to the observed ones. Note that the two components appear to be well detached from each other. However, our solution presented in §§ 5–7 shows that the secondary fills it Roche lobe, which is relatively small because of the small mass ratio, $q = 0.13$.

TABLE 3

Radial Velocities of V228 and Residuals from the Adopted Spectroscopic Orbit

HJD − 2,450,000	Phase	RV_1	$(O-C)_1$	RV_2	$(O-C)_2$
3179.9358	0.134	−44.16	−1.03	125.07	−7.53
2872.8162	0.233	−49.98	−0.07	184.85	2.25
2872.8401	0.254	−49.69	0.38	188.25	4.45
2872.8702	0.280	−47.73	1.87	179.64	−0.96
2946.5904	0.346	−41.87	3.38	144.00	−5.70
2923.5936	0.361	−43.81	−0.13	138.65	0.15
3282.6263	0.377	−43.24	−1.45	124.33	−0.47
2923.6196	0.383	−42.14	−1.23	120.58	2.18
3282.6451	0.393	−40.39	−0.81	113.47	4.87
2923.6448	0.405	−38.60	−0.70	97.03	0.92
3282.6624	0.408	−38.54	−1.08	92.80	−0.07
2923.6656	0.423	−34.76	0.45	74.25	−1.69
2944.5689	0.589	−9.02	−1.17	−130.08	5.62
3183.9315	0.607	−4.75	0.69	−157.91	−4.31
2944.6061	0.622	−5.46	−1.98	−166.76	1.24
3281.7577	0.622	−3.65	−0.30	−175.19	−6.29
3280.6190	0.633	−3.39	−1.25	−184.66	−6.96
2944.6464	0.657	−2.18	−2.60	−200.99	−4.89
3280.6808	0.686	2.52	−0.37	−214.24	−0.64
3182.8927	0.704	4.10	0.17	−220.12	0.88
3280.7041	0.706	5.11	1.08	−224.38	−2.68
3182.9159	0.724	3.70	−1.00	−222.97	3.43
3280.7281	0.727	4.60	−0.18	−228.28	−1.28
2868.7919	0.736	4.97	0.03	−233.58	−5.48
3182.9385	0.744	4.61	−0.42	−224.97	3.73
3280.7535	0.749	6.07	1.01	−228.59	0.31
2868.8263	0.766	5.86	0.93	−230.37	−2.47
3280.7787	0.771	4.08	−0.73	−227.37	−0.37
2868.8604	0.795	4.12	0.18	−224.09	−3.39
2867.7283	0.811	3.65	0.62	−209.28	4.72
2927.5675	0.814	5.88	3.05	−208.65	3.85
2868.8945	0.825	3.60	1.50	−205.68	1.42
2927.5915	0.835	−0.28	−1.46	−199.58	0.82
2868.9231	0.850	−0.52	−0.36	−191.24	−0.74
2867.7738	0.851	2.43	2.69	−190.73	−0.93
2927.6145	0.855	−0.04	0.74	−188.95	−3.05
2927.6376	0.875	−2.74	0.34	−164.35	4.35
2867.8024	0.876	−2.45	0.63	−165.83	2.87
2927.6607	0.895	−5.10	0.59	−145.26	3.84
2867.8313	0.901	−6.67	−0.28	−137.99	5.81

component were weighted according to the rms of its $O-C$ residuals from the fitted spectroscopic orbit.

5. COMBINED ANALYSIS OF THE LIGHT AND RADIAL VELOCITY CURVES

We analyzed the light and radial velocity curves of V228 using the Wilson-Devinney model (Wilson & Devinney 1971) as implemented in the PHOEBE package (Prša & Zwitter 2005). We adopted an iterative scheme in which the light and radial velocity curves were fitted independently and alternately.

The following parameters were adjusted in the light curve solution: the orbital inclination i, the gravitational potentials Ω_1 and Ω_2, the effective temperature of the secondary T_2, and the relative luminosities L_1/L_2 in B and V. The mass ratio was fixed at the value resulting from the spectroscopic solution. The temperature of the primary, T_1, was determined from the dereddened color index $(B-V)_1$ using the calibration of Worthey & Lee (2006). We adopted an interstellar reddening of $E(B-V)=0.04$ following Harris (1996) and a metallicity $[\mathrm{Fe/H}]=-0.67$ from Alves-Brito et al. (2005). In the first iteration, the color index of the primary was assumed to be the same as the observed color index of the binary at quadrature, leading to an initial $T_1=7630$ K. In the following iterations we used the previous step solution to disentangle the magnitudes and colors of both components at the maximum light. For the primary component, the bolometric albedo and the gravitational-brightening coefficients were set at values appropriate for stars with radiative envelopes, $A_1=1.0$ and $g_1=1.0$, while for the cooler secondary we used values appropriate for stars with convective envelopes, $A_2=0.5$ and $g_2=0.32$. An attempt was also made to solve the light curves with $A_2=1.0$ and $g_2=1.0$, but the obtained fit was substantially poorer than the one derived with $A_2=0.5$ and $g_2=0.32$. Specifically, the χ^2 quantity increased by a factor of 2.6, and a systematic dependence of residuals on phase became apparent in both minima. In the photometric solution the mass ratio was set to the value measured from the spectroscopic solution. The free parameters in the spectroscopic solution were the semimajor axis a, the systemic velocity V_0, and the mass ratio $q=M_2/M_1$. The solutions were started with a detached configuration but converged quickly to a semidetached configuration with the secondary component filling its Roche lobe. The starting value of the mass ratio was established from the ratio of the spectroscopic radial velocity semiamplitudes K_2 and K_1, as derived from the preliminary sine curve fits.

TABLE 4

Orbital Parameters for V228

Parameter	Value
P (days)	1.15068618 (fixed)
T_0 (HJD − 2,450,000)	1064.82019 (fixed)
e	0.0 (fixed)
Derived quantities:	
a ($R_\odot$)	5.529 ± 0.024
q	0.1321 ± 0.0042
M_1+M_2 ($M_\odot$)	1.711 ± 0.022
V_0 (km s^{-1})	−22.51 ± 0.40
Other quantities:	
σ_1 (km s^{-1})	1.27
σ_2 (km s^{-1})	3.61

The derived parameters of the spectroscopic orbit are listed in Table 4. Figure 3 shows the computed radial velocity curves together with radial velocity measurements. The light-curve solution is listed in Table 5, and the residuals between the observed and synthetic light curves are shown in Figure 4. The quantities listed in the last column of Table 5 are the weighted averages of the values obtained from the solutions for the V and B filters. One may notice that the parameters derived from solutions based on V and B photometry are consistent with each other.

Using the luminosity ratios from the light-curve solution, one may obtain the observed visual magnitudes of the components

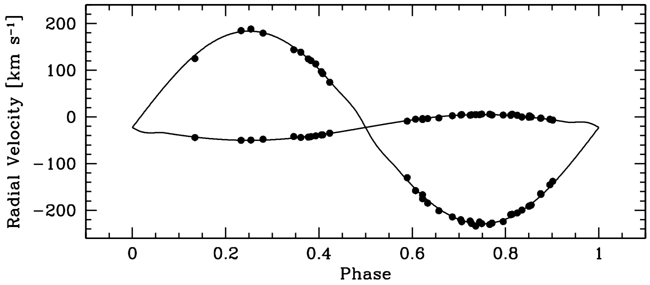

Fig. 3.—Spectroscopic observations and adopted radial velocity orbit for V228.

TABLE 5

Light-Curve Solution for V228

Parameter	V	B	Adopted
i (deg)	77.03 ± 0.11	77.01 ± 0.07	77.02 ± 0.06
Ω_1	4.232 ± 0.130	4.215 ± 0.058	4.2178 ± 0.053
T_1 (K)	8075 (fixed)	8075 (fixed)	8075 (fixed)
T_2 (K)	5855 ± 50	5782 ± 45	5814 ± 33
(L_1/L_2)	4.664 ± 0.034	7.361 ± 0.047	...
$r_{1,\mathrm{pole}}$	0.2436 ± 0.0077	0.2447 ± 0.0035	0.2445 ± 0.0032
$r_{1,\mathrm{point}}$	0.2466 ± 0.0076	0.2477 ± 0.0036	0.2475 ± 0.0032
$r_{1,\mathrm{side}}$	0.2457 ± 0.0075	0.2468 ± 0.0036	0.2466 ± 0.0032
$r_{1,\mathrm{back}}$	0.2463 ± 0.0075	0.2475 ± 0.0036	0.2473 ± 0.0032
$r_{2,\mathrm{pole}}$	0.2063	0.2063	0.2063
$r_{2,\mathrm{point}}$	0.3053	0.3053	0.3053
$r_{2,\mathrm{side}}$	0.2145	0.2145	0.2145
$r_{2,\mathrm{back}}$	0.2461	0.2461	0.2461
rms (mag)	0.0070	0.083	...

TABLE 6

Absolute Parameters for V228

Parameter	Value
M_1 ($M_\odot$)	1.512 ± 0.022
M_2 ($M_\odot$)	0.200 ± 0.007
R_1 ($R_\odot$)	1.357 ± 0.019
R_2 ($R_\odot$)	1.238 ± 0.013
T_1 (K)	8075 ± 131
T_2 (K)	5814 ± 73
$L_{\mathrm{bol},1}$ ($L_\odot$)	7.02 ± 0.50
$L_{\mathrm{bol},2}$ ($L_\odot$)	1.57 ± 0.09
$M_{\mathrm{bol},1}$ (mag)	2.62 ± 0.07
$M_{\mathrm{bol},2}$ (mag)	4.25 ± 0.06
M_{V_1} (mag)	2.66 ± 0.07

of V228 at the maximum light. We obtained $V_1 = 16.064 \pm 0.002$, $B_1 = 16.219 \pm 0.002$, $V_2 = 17.741 \pm 0.010$, and $B_2 = 18.391 \pm 0.006$, where the errors represent the respective uncertainties in the solution and do not include the contribution from zero-point uncertainties of our photometry of about 0.01 mag. For a reddening of $E(B-V) = 0.04$, the dereddened color index of the secondary component is $(B-V)_{20} = 0.610 \pm 0.018$, which implies an effective temperature of $T_2 = 5685 \pm 85$ K according to the calibration of Worthey & Lee (2006). It is encouraging to see that T_2 derived in this way is consistent with the value resulting from the light curve solution listed in Table 5.

The absolute parameters of V228 obtained from our spectroscopic and photometric analysis are given in Table 6, and the position of the binary on the color-magnitude diagram of 47 Tuc is shown in Figure 5. The uncertainty of temperature T_1 includes estimated uncertainties of both the photometric zero point of $\delta(B-V) \simeq 0.01$ and the reddening of $\delta E(B-V) \simeq 0.01$. The uncertainty in the reddening arises from a comparison of that commonly used for 47 Tuc, $E(B-V) = 0.04$ (Harris 1996), with the value of $E(B-V) = 0.030$ resulting from the reddening map of Schlegel et al. (1998).

6. MEMBERSHIP STATUS

Before discussing the evolutionary status of V228 it is worth considering its membership in 47 Tuc. The variable was included in the proper-motion study of 47 Tuc conducted by Tucholke (1992). According to that study, V228 (designation 2604) is a genuine proper-motion member of the cluster with a probability of 98.2%. The systemic velocity of the binary, $V_0 = -22.51$ km s^{-1}, agrees with the radial velocity of 47 Tuc, $v_{\mathrm{rad}} = -18.7 \pm 0.5$ km s^{-1} (Gebhardt et al. 1995). At the location of the variable—about 10′ from the cluster center—the velocity dispersion of cluster stars is about 7 km s^{-1} (Gebhardt et al. 1995). We conclude that V228 is a radial velocity member of 47 Tuc. From the light-curve solutions one may estimate the observed visual magnitudes of the components of the binary at maximum light. For the primary component we obtained $V_1 = 16.06 \pm 0.01$. Using $M_{V_1} = 2.66 \pm 0.07$ (see Table 6) one obtains an apparent distance modulus $(m-M)_{V_1} = 13.40 \pm 0.07$ for the primary component of V228. This value is compatible with several of the recent estimates of the distance of 47 Tuc, which span a range $13.12 < (m-M)_V < 13.55$ (McLaughlin et al. 2006). An attempt to obtain a distance modulus for the binary based on the luminosity of the secondary component is hampered by the difficulty of precisely accounting for ellipsoidal light variations.

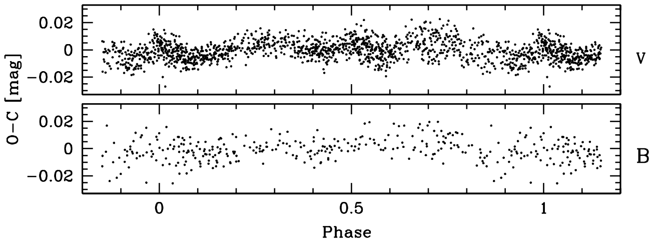

Fig. 4.—Residuals from the light-curve solution in the BV bands.

In summary, V228 has the same proper motion and radial velocity as 47 Tuc and is located at the cluster distance. We conclude that the binary is a certain member of 47 Tuc.

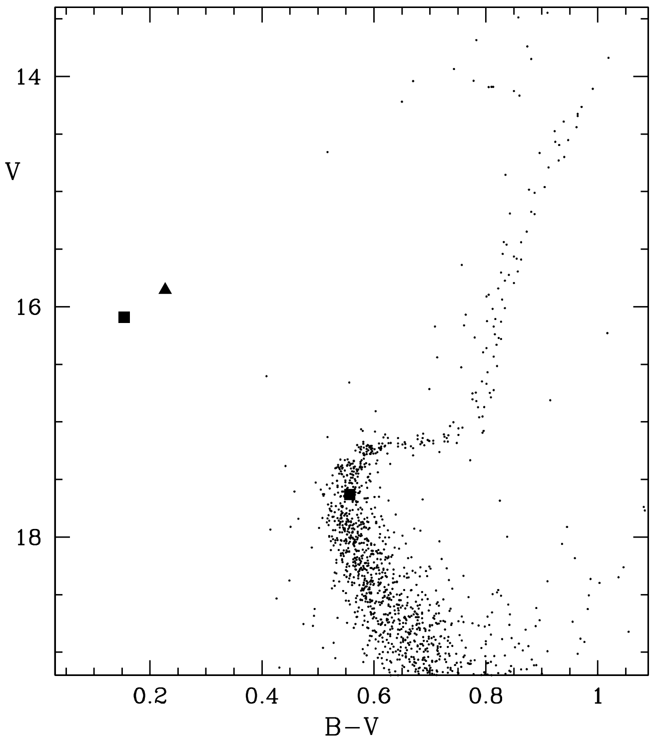

Fig. 5.—Position of V228 in the color-magnitude BV diagram for 47 Tuc. The triangle gives the position for the combined light, whereas the squares show the positions of each of the components separately.

7. EVOLUTIONARY STATUS

Our study of the light and radial velocity curves of V228 shows that the binary belongs to the class of semidetached, low-mass, "cool" or "conventional" Algol variables. Several well-studied systems of this kind are discussed in the literature. In particular, AS Eri (Popper 1980) and R CMa (Sarma et al. 1996) are examples of Algols with parameters closely resembling those of V228. A comprehensive discussion of evolutionary models leading to the formation of such systems along with a summary of the observational data is given by Eggleton & Kiseleva-Eggleton (2002) and Nelson & Eggleton (2001). An earlier but still useful review of the subject was given by Paczyński (1971). According to widely accepted scenarios, the Algol systems form by mass transfer leading to the reversal of the original mass ratio of the binary so that the present primaries were originally the less massive components.

The current secondary component of V228 is noticeably oversized and overluminous for its mass. The low value of the observed mass ratio, $q \approx 0.13$, and the overluminosity of the secondary (exceeding 5 mag) indicate that the mass transfer occurred in the so-called case B evolution (Paczyński 1971). In such a case, the original primary filled its Roche lobe while starting its ascent onto the giant branch. Its luminosity is currently generated in a hydrogen-burning shell surrounding a degenerate helium core. The present mass transfer in the binary is expected to occur on a nuclear timescale. As we have shown above, observations with a time base of 11 yr failed to reveal any change of the orbital period of V228.

At first sight the primary component of V228, with $R = 1.36\ R_\odot$, seems to be undersized for its mass of $M = 1.51\ M_\odot$. However, one has to keep in mind that the existing empirical mass-radius calibrations are based on stars with approximately solar composition and that stellar models of unevolved stars predict a decrease in the radius (for a given mass) for a lower metallicity. For example, the models of VandenBerg et al. (2006) predict a zero-age main-sequence (ZAMS) radius of $R = 1.26\ R_\odot$ at $M = 1.515\ M_\odot$ and $Z = 0.008$ ($[\mathrm{Fe/H}] = -0.705$]), while the models of Girardi et al. (2000) for the same metallicity predict a ZAMS radius of $R = 1.33\ R_\odot$ for $M = 1.5\ M_\odot$. These models also show that the bolometric luminosity of the primary is appropriate for an unevolved star with $M = 1.51\ M_\odot$ and the metallicity of 47 Tuc. In particular, for $Z = 0.008$ and mass $M = 1.5\ M_\odot$, Girardi et al. (2000) give $L_{\mathrm{ZAMS}} = 6.6\ L_\odot$.

The absolute parameters of V228 have implications for the current turnoff mass of 47 Tuc. According to the evolutionary model developed by M. J. Sarna (2007, in preparation), the binary entered the phase of mass transfer about 0.2 Gyr ago. Based on the current total mass of the system of $1.71\ M_\odot$, we may infer that the original primary had a mass exceeding $0.85\ M_\odot$. This is a conservative lower limit assuming a scenario with perfectly conservative mass transfer. Isochrones from VandenBerg et al. (2006) for $[\alpha/\mathrm{Fe}] = +0.3$ and the age of 14 Gyr have turnoff masses of 0.868 and 0.852 $M_\odot$ for $[\mathrm{Fe/H}] = -0.606$ and -0.707, respectively. The observed parameters of V228 together with an evolutionary interpretation of its current status suggest an upper limit to the age of 47 Tuc of 14 Gyr. This can be compared with a recent age estimate of the cluster by Gratton et al. (2003). They obtained an age of 10.8 Gyr using models with diffusion and an age of 11.2 Gyr for models with no diffusion. If the cluster age is indeed close to 11 Gyr, then one has to conclude that the mass transfer in V228 resulted in a mass loss from the system.

For old stellar systems like 47 Tuc, it is expected that relatively more massive stars such as binaries should sink into the core region due to mass segregation. Apparently this is not the case for V228. Located at a projected distance of $r = 588''$, or 28 core radii from the cluster center, V228 belongs to the "external" subpopulation of the cluster BSs as defined by Ferraro et al. (2004). The observed spatial distribution of the BS population in 47 Tuc was studied in detail by Mapelli et al. (2004). On the basis of extensive simulations they concluded that a sizeable fraction of these objects is formed in the outer regions of the cluster from primordial binaries experiencing mass transfer, induced purely by stellar evolution. This conclusion is further supported by the recent detection of a subpopulation of carbon/oxygen-depleted BSs in 47 Tuc (Ferraro et al. 2006). In that context it would be worth determining the orbital parameters of V228 in the cluster. As shown by McLaughlin et al. (2006), the determination of accurate proper motions for stars in 47 Tuc is possible from *HST* images with a time base of a few years. Unfortunately, the *HST* archive does not contain any images of the V228 field.

In § 6 we estimated the distance of V228 to check its membership in the cluster. One may use the reverse approach and use the binary to obtain a distance estimate for the cluster. The largest source of uncertainty arises from estimates of the effective temperature and bolometric correction from the color index $B - V$. The surface brightness method may provide a more robust and secure determination of distance to V228 than available from our data (Clausen 2004; Ribas 2006). In particular, recent progress in interferometric techniques has resulted in substantial improvement of precise calibrations of surface brightness in the near-IR bands (Kervella et al. 2004; Di Benedetto 2005). It would be useful to obtain IR photometry for V228 for an accurate and independent 47 Tuc distance determination.

To summarize, we have used photometric and spectroscopic observations of the blue straggler V228, a member of the globular cluster 47 Tuc, to derive the masses, radii, and luminosities of the component stars. The resulting masses indicate that V228 is a BS which formed through a mass transfer in a close binary system. We derive an upper limit of 14 Gyr for the turnoff age of 47 Tuc.

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