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# THE RED HORIZONTAL-BRANCH STAR HD 17072

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## ABSTRACT

We summarize the results of a spectroscopic analysis of HD 17072, finding it to be a metal-poor ([Fe/H] = −1.17) red horizontal-branch star with $T_{\rm eff} = 5375$ K and log $g = 2.4$. We also derive a radial velocity of 62.8 km s$^{-1}$. It has the best determined *Hipparcos* trigonometric parallax among the metal-poor field horizontal-branch stars and supports the fainter luminosities for such stars found from statistical parallax and Baade-Wesselink analyses, in contradiction to the results of main-sequence fitting of metal-poor field dwarfs to globular cluster main sequences.

*Key words:* stars: horizontal-branch — stars: individual (HD 17072)

## 1. INTRODUCTION

The relative and absolute luminosities of RR Lyrae variables are of fundamental importance in the determination of distances to Local Group galaxies and the subsequent calibration of other "standard candles." The RR Lyrae distance scale is also of fundamental importance in the estimation of the relative and absolute ages of globular clusters (cf. Chaboyer, Demarque, & Sarajedini 1996; Chaboyer et al. 1998). The *Hipparcos* catalog of trigonometric parallaxes (Perryman et al. 1997) has been exploited to try to resolve the debate, but unfortunately, the results have not yet proved conclusive. To demonstrate, we adopt a reference metallicity, which we choose to be [Fe/H] = −1.9, and a slope of the $M_V$ versus [Fe/H] relation. We adopt 0.20 mag dex$^{-1}$ for the slope, following Carney, Storm, & Jones (1992), Cacciari, Clementini, & Fernley (1992), Fernley (1994), Fusi Pecci et al. (1996), and Fernley et al. (1998b). Main-sequence fitting analyses applied to selected globular clusters by Reid (1997), Chaboyer et al. (1998), and Gratton et al. (1997) have yielded $M_V$ values for RR Lyrae variables of $0.25 \pm 0.1$, $0.36 \pm 0.14$, and $0.33 \pm 0.17$ mag, respectively. These values are considerably brighter, leading to a longer extragalactic distance scale and younger globular cluster ages, than those obtained from Baade-Wesselink analyses (cf. Carney et al. 1992 and Fernley et al. 1998, which predict $M_V$ values of 0.72 and 0.60 mag, respectively, at [Fe/H] = −1.9).

Baade-Wesselink analyses are subject to potential systematic errors, both in the conversion of radial velocities into pulsational velocities and in the conversion of color indices into temperatures. However, two other *Hipparcos*-based analyses support the fainter $M_V$ values and, hence, shorter extragalactic distances and older cluster ages. A statistical parallax analysis based on *Hipparcos* proper motions (Fernley et al. 1998a) leads to $M_V = 0.70 \pm 0.15$ mag, under the above assumptions. This agrees with the previous ground-based statistical parallax analysis of Layden et al. (1996), whose results indicate $M_V = 0.65 \pm 0.12$, again under the same assumptions. Further, the trigonometric parallaxes of blue horizontal-branch, RR Lyrae, and red horizontal-branch stars in the *Hipparcos* Catalogue analyzed by Gratton (1998) lead to $M_V = 0.69 \pm 0.10$ mag.

As we seek to resolve this dichotomy in the $M_V$ values, we must identify and explore the weaknesses of the several methods. One possible solution, that the field and cluster horizontal branches have different luminosities at similar metallicities, appears to be ruled out by a period-shift analysis (Catelan 1998). We focus here on the parallaxes of field horizontal-branch stars utilized by Gratton (1998). Specifically, the single most important star in his analysis is HD 17072, which has by far the smallest ratio $\sigma_\pi/\pi$ and, consequently, by far the best determined $M_V$ value, $0.97 \pm 0.15$ mag, before any systematic corrections are applied. HD 17072 is thought to be a red horizontal-branch star, but a test of that assumption using high-resolution spectroscopy appears to be required, and we report the results here.

## 2. HD 17072

Despite being a rather bright star, with $V = 6.61$ mag, HD 17072 has not been extensively studied. The primary study, which led to its identification as a red horizontal-branch star, is that of Anthony-Twarog & Twarog (1994, hereafter ATT), who employed $uvby\beta$ photometry to estimate the star's reddening, luminosity, and metallicity. As expected for its high latitude ($b = -45°$), the reddening is small, $E(b-y) = 0.008$ mag. ATT estimate [Fe/H] = −1.0 based on the $m_0$ index, and in the $c_0$ versus $(b-y)_0$ plane (ATT, Fig. 11) the star lies in a region identified with red horizontal-branch stars. A recent study by Eggen (1997) confirmed these results. Gratton's (1998) [Fe/H] value of −0.77 follows from a comparison of the metallicities derived by ATT for stars analyzed spectroscopically by Gratton, Carretta, & Castelli (1996). The three key questions are as follows: (1) Is HD 17072 a red horizontal-branch star or a red giant? (2) What is its metallicity? (3) Are its chemical abundances and kinematics consistent with the field and cluster halo population?

## 3. OBSERVATIONS

The basic data for HD 17072 are given in Table 1. We obtained two high signal-to-noise ratio (total ≈250) echelle spectra of HD 17072 using the Cerro-Tololo Inter-American Observatory 4 m telescope and its Cassegrain echelle spectrograph. The Tektronix 2048 × 2048 CCD, 31.6 line mm$^{-1}$ echelle grating, long red camera, and G181 cross-disperser were employed. The slit width was 150 μm, or about 1".0, which projected to 2.0 pixels and yielded an effective resolving power $R = 28{,}000$. The spectrum had complete spectral coverage from 5560 to 8050 Å.

TABLE 1

STELLAR DATA

| Parameter | Value |
| --- | --- |
| $\alpha$ (J2000.0) ........ | 2 40 39.4 |
| $\delta$ (J2000.0) ........ | −69 14 00 |
| $l$ (deg) ............ | 289.7 |
| $b$ (deg) ............ | −45.0 |
| $V$ .................. | 6.61 |
| $b-y$ ............. | 0.441 |
| $m_1$ ................ | 0.132 |
| $c_1$ ................. | 0.452 |
| $v_{\rm rad}$ (km s$^{-1}$)...... | 62.8 |

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

The raw data frames were trimmed, bias-corrected, and flat-fielded using the IRAF ARED and CCDRED packages. The echelle apertures were then extracted to form one-dimensional spectra, which were continuum-fitted and normalized. Equivalent widths were measured using the IRAF package NMISC. We excluded lines that were velocity-shifted onto telluric features.

## 4. ANALYSIS

The equivalent width measurements are listed in Table 2. Solar *gf*-values were adopted for iron lines (Fry & Carney 1997), and these are listed also. The analysis began by using a first guess for the star's temperature, gravity, and metallicity. The temperature was estimated using the relation between $\Theta_{\rm eff}$ and $b-y$, $c_1$, and [Fe/H] derived via the infrared flux method by Alonso, Arribas, & Martínez-Roger (1996). For the adopted reddening and metallicity from ATT, this results in $T_{\rm eff} \approx 5470$ K. If we assume the star has a mass of 0.7 $M_\odot$ and a bolometric correction of −0.22 mag (Carney 1983), the *Hipparcos* parallax yields $M_V = 0.97$ mag, $M_{\rm bol} = 0.75$ mag, and, thus, log $g = 2.6$. Fry & Carney (1997) used these same *gf*-values to derive temperatures, gravities, and microturbulent velocities for Cepheids and a few dwarfs in open clusters. There is a fairly well defined relation between log $g$ and $v_{\rm turb}$:

$$v_{\rm turb} = -0.5 \log g + 3.9 \ . \tag{1}$$

This predicts a microturbulent velocity of 2.5 km s$^{-1}$ for HD 17072.

A 72-depth model atmosphere with $T_{\rm eff} = 5500$ K, log $g = 2.5$, and [Fe/H] = −1.0 was computed using the program ATLAS9, written and supplied by R. L. Kurucz. Assuming that the star would prove to be metal-poor, the models were computed using opacity distribution functions with enhanced abundances of all the "$\alpha$" elements (O, Ne, Mg, Si, S, Ar, Ca, and Ti). The enhancements, of 0.4 dex, are important since several of these elements are quite abundant and are major electron donors to the $H^-$ opacity. This provided our initial model.

The abundance analysis was performed using Kurucz's program WIDTH9, which integrates the line to continuum opacity through the model atmosphere. Following Fry & Carney (1997), we used the Ünsold approximation to estimate the damping due to the van der Waals force. We began by restricting the analysis to those Fe I lines with log $(W_\lambda/\lambda) \leq -5.2$ (i.e., the linear part of the curve of growth) and comparing the abundances as a function of excitation

TABLE 2

LINE DATA

| Line (Å) | $\chi$ (eV) | log *gf* | $W_\lambda$ (mÅ) | log $\epsilon$ |
| --- | --- | --- | --- | --- |
| [O I]: | | | | |
| 6300.23...... | 0.00 | −9.75 | 13.7 | 8.18 |
| O I: | | | | |
| 7771.95...... | 9.14 | 0.360 | 77.9 | 8.66 |
| 7774.18...... | 9.14 | 0.210 | 62.6 | 8.57 |
| 7775.40...... | 9.14 | −0.010 | 44.2 | 8.47 |
| Na I: | | | | |
| 5682.65...... | 2.10 | −0.700 | 31.6 | 5.20 |
| 5688.22...... | 2.10 | −0.450 | 50.3 | 5.26 |
| 6154.23...... | 2.10 | −1.530 | 4.7 | 5.07 |
| 6160.75...... | 2.10 | −1.230 | 10.8 | 5.15 |
| Mg I: | | | | |
| 5711.10...... | 4.34 | −1.750 | 60.7 | 6.74 |
| Al I: | | | | |
| 6696.03...... | 3.14 | −1.340 | 8.8 | 5.35 |
| 7835.32...... | 4.02 | −0.500 | 6.3 | 5.21 |
| 7836.13...... | 4.02 | −0.340 | 9.1 | 5.22 |
| Si I: | | | | |
| 5701.12...... | 4.93 | −2.050 | 20.6 | 6.93 |
| 5793.08...... | 4.93 | −2.060 | 18.9 | 6.89 |
| 5948.55...... | 5.08 | −1.220 | 58.3 | 6.92 |
| 6155.14...... | 5.62 | −0.840 | 44.5 | 6.87 |
| Ca I: | | | | |
| 5857.46...... | 2.93 | 0.240 | 99.5 | 5.58 |
| 6166.44...... | 2.52 | −1.140 | 32.1 | 5.42 |
| 6169.04...... | 2.52 | −0.800 | 60.4 | 5.55 |
| 6169.56...... | 2.52 | −0.480 | 72.9 | 5.42 |
| 6439.08...... | 2.52 | 0.390 | 129.7 | 5.48 |
| 6449.82...... | 2.52 | −0.500 | 80.7 | 5.54 |
| 6455.61...... | 2.52 | −1.290 | 22.0 | 5.34 |
| 6471.67...... | 2.52 | −0.690 | 64.4 | 5.48 |
| 6493.79...... | 2.52 | −0.110 | 94.7 | 5.39 |
| 6499.65...... | 2.52 | −0.820 | 54.0 | 5.45 |
| Ti I: | | | | |
| 6258.11...... | 1.44 | −0.360 | 26.0 | 4.01 |
| 6258.71...... | 1.46 | −0.270 | 33.2 | 4.08 |
| 6261.11...... | 1.43 | −0.480 | 22.0 | 4.03 |
| Cr I: | | | | |
| 5787.93...... | 3.32 | −0.240 | 5.8 | 4.37 |
| 6330.09...... | 0.94 | −2.920 | 4.2 | 4.36 |
| Fe I: | | | | |
| 5618.64...... | 4.20 | −1.328 | 11.7 | 6.31 |
| 5619.61...... | 4.38 | −1.515 | 4.8 | 6.27 |
| 5633.95...... | 4.98 | −0.340 | 19.5 | 6.38 |
| 5638.27...... | 4.21 | −0.763 | 32.7 | 6.31 |
| 5679.03...... | 4.64 | −0.734 | 17.9 | 6.38 |
| 5701.56...... | 2.55 | −2.116 | 52.4 | 6.24 |
| 5731.77...... | 4.25 | −1.133 | 11.5 | 6.15 |
| 5806.73...... | 4.60 | −0.843 | 10.4 | 6.18 |
| 5809.22...... | 3.88 | −1.583 | 12.0 | 6.24 |
| 5852.23...... | 4.54 | −1.202 | 7.4 | 6.31 |
| 5862.37...... | 4.54 | −0.351 | 49.8 | 6.53 |
| 5905.68...... | 4.64 | −0.766 | 17.5 | 6.39 |
| 5916.26...... | 2.44 | −2.954 | 23.5 | 6.44 |
| 5956.71...... | 0.86 | −4.558 | 36.2 | 6.59 |
| 5983.69...... | 4.54 | −0.720 | 30.8 | 6.56 |
| 5984.83...... | 4.72 | −0.266 | 34.0 | 6.35 |
| 5987.07...... | 4.78 | −0.399 | 22.4 | 6.30 |
| 6024.07...... | 4.54 | 0.033 | 62.9 | 6.35 |
| 6027.06...... | 4.07 | −1.174 | 28.5 | 6.47 |
| 6056.01...... | 4.72 | −0.448 | 26.6 | 6.38 |
| 6065.49...... | 2.60 | −1.580 | 88.3 | 6.31 |
| 6127.91...... | 4.13 | −1.410 | 12.9 | 6.34 |
| 6151.62...... | 2.17 | −3.311 | 21.5 | 6.44 |
| 6157.73...... | 4.07 | −1.238 | 21.7 | 6.37 |
| 6165.36...... | 4.13 | −1.529 | 13.5 | 6.48 |
| 6173.34...... | 2.21 | −2.904 | 38.1 | 6.41 |
| 6200.32...... | 2.60 | −2.407 | 38.6 | 6.34 |
| 6213.44...... | 2.21 | −2.576 | 60.8 | 6.44 |
| 6219.29...... | 2.19 | −2.480 | 63.6 | 6.35 |
| 6226.74...... | 3.88 | −2.128 | 4.2 | 6.27 |
| 6229.23...... | 2.83 | −2.915 | 12.8 | 6.48 |
| 6232.65...... | 3.65 | −1.178 | 41.8 | 6.27 |

TABLE 2—*Continued*

| Line (Å) | $\chi$ (eV) | log *gf* | $W_\lambda$ (mÅ) | log $\epsilon$ |
|---|---|---|---|---|
| 6252.57...... | 2.39 | −1.747 | 93.2 | 6.31 |
| 6256.37...... | 2.44 | −2.167 | 64.5 | 6.33 |
| 6265.14...... | 2.17 | −2.562 | 59.5 | 6.36 |
| 6290.97...... | 4.72 | −0.557 | 22.5 | 6.38 |
| 6297.80...... | 2.21 | −2.797 | 29.7 | 6.15 |
| 6322.69...... | 2.58 | −2.356 | 46.8 | 6.39 |
| 6330.85...... | 4.72 | −1.191 | 4.4 | 6.22 |
| 6335.34...... | 2.19 | −2.328 | 72.2 | 6.33 |
| 6336.83...... | 3.65 | −0.815 | 57.0 | 6.15 |
| 6344.16...... | 2.42 | −2.923 | 29.1 | 6.48 |
| 6380.75...... | 4.18 | −1.325 | 20.6 | 6.54 |
| 6392.54...... | 2.27 | −3.982 | 3.7 | 6.37 |
| 6393.61...... | 2.42 | −1.632 | 107.1 | 6.48 |
| 6411.66...... | 3.64 | −0.543 | 75.5 | 6.15 |
| 6419.96...... | 4.71 | −0.269 | 37.6 | 6.39 |
| 6430.86...... | 2.17 | −2.106 | 88.4 | 6.33 |
| 6469.19...... | 4.81 | −0.622 | 13.2 | 6.26 |
| 6498.95...... | 0.95 | −4.657 | 20.6 | 6.43 |
| 6533.94...... | 4.54 | −1.156 | 6.9 | 6.20 |
| 6546.25...... | 2.75 | −1.725 | 80.2 | 6.44 |
| 6574.25...... | 0.99 | −4.924 | 8.5 | 6.31 |
| 6593.88...... | 2.42 | −2.382 | 57.6 | 6.39 |
| 6627.56...... | 4.91 | −1.171 | 4.2 | 6.37 |
| 6677.99...... | 2.68 | −1.466 | 100.1 | 6.42 |
| 6703.58...... | 2.75 | −3.045 | 9.7 | 6.36 |
| 6705.11...... | 4.59 | −1.065 | 8.0 | 6.22 |
| 6710.32...... | 1.48 | −4.873 | 3.6 | 6.38 |
| 6726.67...... | 4.59 | −1.059 | 10.8 | 6.35 |
| 6733.15...... | 4.62 | −1.462 | 4.1 | 6.34 |
| 6750.16...... | 2.41 | −2.611 | 45.1 | 6.41 |
| 6752.72...... | 4.62 | −1.265 | 9.2 | 6.52 |
| 6806.86...... | 2.72 | −3.158 | 10.8 | 6.49 |
| 6810.27...... | 4.59 | −0.986 | 14.0 | 6.41 |
| 6828.60...... | 4.62 | −0.918 | 15.5 | 6.42 |
| 6839.84...... | 2.55 | −3.442 | 8.2 | 6.46 |
| 6843.66...... | 4.53 | −0.870 | 17.2 | 6.33 |
| 6857.25...... | 4.06 | −2.130 | 3.0 | 6.28 |
| 6858.16...... | 4.59 | −0.996 | 13.6 | 6.40 |
| 6978.86...... | 2.47 | −2.470 | 50.0 | 6.39 |
| 7090.39...... | 4.21 | −1.059 | 22.5 | 6.32 |
| 7130.93...... | 4.20 | −0.639 | 38.0 | 6.20 |
| 7132.99...... | 4.06 | −1.650 | 10.7 | 6.37 |
| 7418.67...... | 4.12 | −1.526 | 11.0 | 6.31 |
| 7440.92...... | 4.89 | −0.682 | 17.3 | 6.49 |
| 7445.76...... | 4.24 | −0.045 | 66.9 | 6.09 |
| 7491.65...... | 4.28 | −1.011 | 22.5 | 6.32 |
| Fe II: | | | | |
| 5991.38...... | 3.15 | −3.569 | 25.9 | 6.39 |
| 6084.26...... | 3.19 | −3.828 | 14.9 | 6.38 |
| 6113.33...... | 3.21 | −4.158 | 6.4 | 6.33 |
| 6149.25...... | 3.87 | −2.772 | 28.8 | 6.39 |
| 6238.39...... | 3.87 | −2.576 | 36.3 | 6.34 |
| 6247.55...... | 3.89 | −2.378 | 51.9 | 6.44 |
| 6369.46...... | 2.88 | −4.202 | 15.2 | 6.43 |
| 6383.72...... | 5.55 | −2.115 | 3.2 | 6.32 |
| 6416.93...... | 3.87 | −2.683 | 29.6 | 6.31 |
| 6432.68...... | 2.88 | −3.607 | 40.2 | 6.40 |
| 6456.39...... | 3.90 | −2.120 | 66.2 | 6.42 |
| 7515.84...... | 3.89 | −3.508 | 7.6 | 6.40 |
| 7711.73...... | 3.89 | −2.596 | 41.0 | 6.40 |
| Ni I: | | | | |
| 5754.67...... | 1.93 | −2.330 | 26.6 | 5.01 |
| 5847.01...... | 1.68 | −3.210 | 9.2 | 5.08 |
| 6108.12...... | 1.68 | −2.450 | 31.8 | 4.94 |
| 6191.19...... | 1.68 | −2.510 | 44.3 | 5.22 |
| 6327.60...... | 1.68 | −3.150 | 16.2 | 5.26 |
| 6482.81...... | 1.93 | −2.630 | 15.5 | 4.98 |
| 6643.65...... | 1.68 | −2.300 | 61.1 | 5.23 |
| 6767.78...... | 1.83 | −2.170 | 52.8 | 5.13 |
| Ba II: | | | | |
| 5853.69...... | 0.60 | −1.010 | 91.1 | 0.76 |
| 6141.73...... | 0.70 | −0.080 | 147.6 | 0.25 |
| 6496.91...... | 0.60 | −0.370 | 148.8 | 0.41 |

TABLE 3

ELEMENTAL ABUNDANCES

| Element | [X/H] | [X/Fe] | $\sigma$ (per Line) | Number of Lines |
|---|---|---|---|---|
| [O I]...... | −0.75 | +0.42 | ... | 1 |
| O I........ | −0.36 | +0.81 | 0.10 | 2 |
| Na I....... | −1.16 | +0.01 | 0.08 | 4 |
| Mg I ...... | −0.84 | +0.33 | ... | 1 |
| Al I ....... | −1.21 | −0.04 | 0.08 | 3 |
| Si I........ | −0.65 | +0.52 | 0.03 | 4 |
| Ca I....... | −0.89 | +0.28 | 0.08 | 10 |
| Ti I........ | −0.95 | +0.22 | 0.04 | 3 |
| Cr I ....... | −1.30 | −0.13 | 0.01 | 2 |
| Fe I ....... | −1.17 | ... | 0.10 | 70 |
| Fe II ...... | −1.15 | ... | 0.01 | 13 |
| Ni I ....... | −1.14 | +0.03 | 0.12 | 8 |
| Ba II ...... | −1.66 | −0.39 | 0.26 | 3 |

potential. New models were computed with a slightly lower effective temperature until the slope of the log $A$ versus $\chi$ relation was zero. The stronger Fe I lines were then added and the microturbulent velocity altered until the log $\epsilon$ versus log $(W_\lambda/\lambda)$ relation had zero slope. Finally, we analyzed the gravity-sensitive Fe II lines, recomputing new models until the iron abundances derived from the Fe I lines agreed with those derived from the Fe II lines. Our final values were $T_{\rm eff} = 5375$ K, log $g = 2.4$, $v_{\rm turb} = 2.1$ km s$^{-1}$, and [Fe/H] $= -1.17$, not too dissimilar from our initial estimates.

For other elements, *gf*-values given by Beveridge & Sneden (1997 and references therein) were used, using the data from their Table 2. Element-to-iron ratios were determined and are summarized in Table 3. We searched for the 6707 Å line of lithium but could not detect it, as expected for a highly evolved star.

## 5. RESULTS

HD 17072 has a fairly low metallicity, consistent with belonging to the Galactic halo. A secondary test is to see whether it shows enhanced abundances of the "$\alpha$" elements, as we assumed in our computation of the stellar model atmospheres. We also wish to estimate the star's kinematics to see if it belongs to the dynamically "hot" halo or thick disk populations.

### 5.1. *Kinematics*

The proper motion of HD 17072 has been measured many times. The SAO Catalog summarizes it as $\mu_\alpha = +0\overset{s}{.}0122 \pm 0\overset{s}{.}0019$ yr$^{-1}$ and $\mu_\delta = -0\overset{''}{.}035 \pm 0\overset{''}{.}009$ yr$^{-1}$. The *Hipparcos* parallax yields a distance of 132 ± 8 pc. The star has no published radial velocity, so far as we are aware, although Eggen (1997) quotes a value of +62.6 km s$^{-1}$. We have employed our spectra to make a new measurement. We cross-correlated about 20 orders in the spectrum with the same orders observed for the sky, and for the star BD −6°855, which was observed immediately after HD 17072. Spectrograph flexure was measured using the ThAr comparison lines for each star. We obtained $v_{\rm rad} = 295.5 \pm 0.2$ km s$^{-1}$ for BD −6°855, which compares well with the known value of $+296.2 \pm 0.2$ km s$^{-1}$ (Carney et al. 1994). We derive $v_{\rm rad} = 62.8 \pm 0.2$ km s$^{-1}$ for HD 17072. With these parameters, we derive the following kinematics: $U = +6 \pm 6$ km s$^{-1}$, $V = -62 \pm 5$ km s$^{-1}$, and $W = -8 \pm 4$ km s$^{-1}$. Our results are, not surprisingly, similar to those derived by Eggen (1997) and indicate that

HD 17072 has kinematics rather like a thick disk star rather than a halo star. Nonetheless, if its chemical composition matches that of globular clusters, it should be an acceptable "standard candle" to derive cluster distances.

### 5.2. *Oxygen*

We derived [O/Fe] using two different sets of lines: the forbidden line, $\lambda$6300, and the oxygen triplet near 7774 Å. These high-excitation lines often show higher oxygen abundances for metal-poor stars than do the [O I] $\lambda\lambda$6300, 6363 lines or the OH lines in the ultraviolet and infrared portions of the spectrum (cf. Tomkin et al. 1992; Balachandran & Carney 1996). But our primary concern is simply whether or not HD 17072 shows an enhanced [O/Fe] value, and so we compare the results obtained from the triplet with other analyses relying on the triplet, specifically, the results of Tomkin et al. (1992) and Carney et al. (1997). Figure 1 compares HD 17072 with the stars from the other studies. Excluding the highly unusual star BD +80°245, the average [O/Fe] value is roughly +0.85, in very good agreement with what we have found for HD 17072, +0.81 dex.

We also determined [O/Fe] using the [O I] $\lambda$6300 line, finding +0.42 dex. This agrees very well with the enhanced oxygen abundances seen in the globular cluster red giants that have not (yet) been subjected to CNO cycling and mixing (cf. Carney 1996).

As a number of studies have shown (see the review by Kraft 1994), many red giant branch stars in globular clusters show depletions of oxygen, especially in stars near the red giant branch tip. This is probably due to CNO cycling and mixing of those products to the stellar photosphere, so it is somewhat surprising to see no sign of such oxygen depletion in HD 17072, which is apparently in a post–red giant evolutionary state. There are two possible, related explanations. The first invokes a possible difference between the field red giants analyzed by Sneden et al. (1991) and Kraft et al. (1992), who found somewhat different mixing histories between the field and cluster stars. The field stars appear to show weaker signs of mixing and oxygen depletion in their photospheres, and HD 17072's high oxygen abundance would be consistent with this view. If this is true, the application of field star luminosities to cluster stars will require some care. On the other hand, the field versus cluster difference has not yet been proved, in part because the field and cluster stars studied to date do not sample the same range in luminosity (and, therefore, degree of mixing). Instead, we prefer a second explanation, which also has to do with mixing and its consequences. Sweigart (1997) has noted that prolonged mixing may extend the lifetime of a red giant and its mass loss. This would result in a blue horizontal-branch star, so the fact that we are dealing with a red horizontal-branch star suggests that its mixing may not have been as extreme. Thus, in the globular cluster M5, with a metallicity nearly identical to that of HD 17072 (Sneden et al. 1992), the horizontal-branch stars are spread fairly uniformly from the blue to the red. If this distribution reflects differences in degrees of mixing and mass loss, then perhaps the red horizontal-branch stars in the cluster would also show high oxygen abundances. Detailed abundance analyses of such cluster horizontal-branch stars are recommended. But the fact that the red horizontal-branch star HD 17072 has not, apparently, depleted the oxygen abundance in its photosphere may not be so surprising.

### 5.3. *Other "α" Elements*

In Figure 2, we show the average enhancements of means of magnesium, silicon, calcium, and titanium for HD 17072 and stars analyzed by Gratton & Sneden (1988), Edvardsson et al. (1993), McWilliam et al. (1995), and Carney et al. (1997). Table 3 shows that the mean enhancement of Mg, Si, Ca, and Ti is $+0.33 \pm 0.06$ dex (unweighted error of the mean). As in the case of oxygen, HD 17072

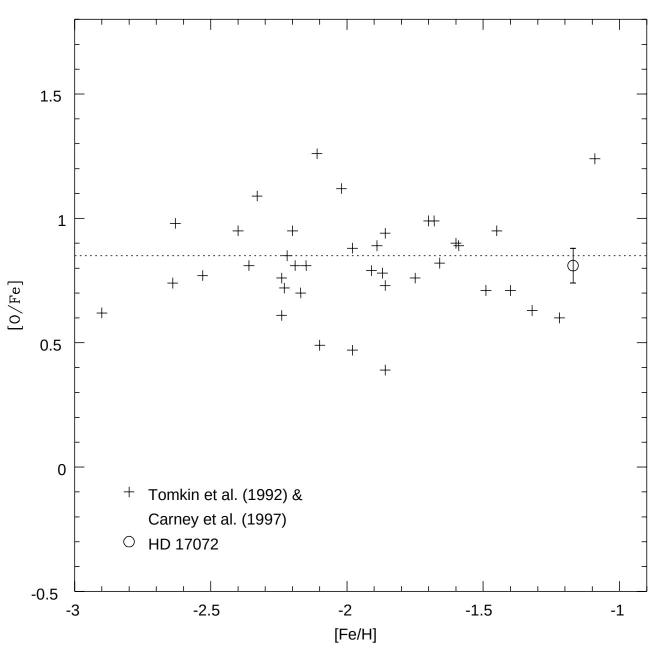


FIG. 1.—[O/Fe] vs. [Fe/H] for HD 17072 compared with results from Tomkin et al. (1992) and from and from Carney et al. (1997). All the results were obtained from analyses of the high-excitation O I triplet near 7774 Å.

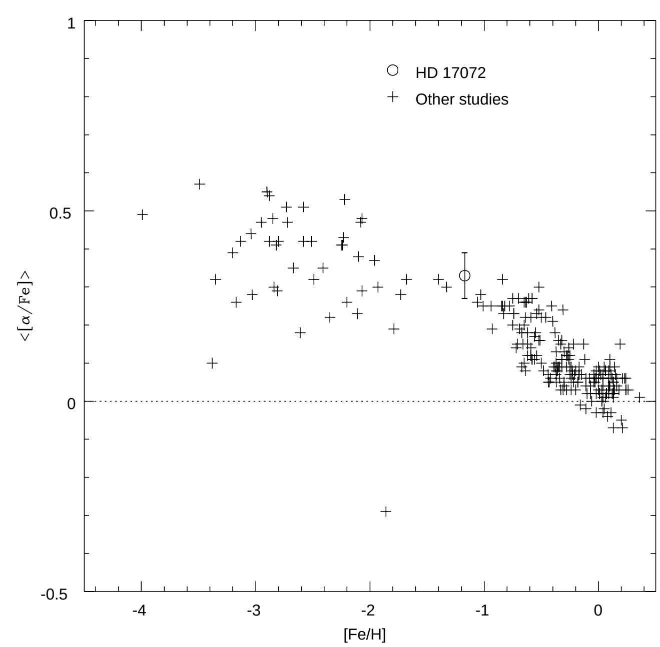


FIG. 2.—Enhancement [α/Fe] vs. [Fe/H] for HD 17072 compared with results from Gratton & Sneden (1988), Edvardsson et al. (1993), McWilliam et al. (1995), and Carney et al. (1997).

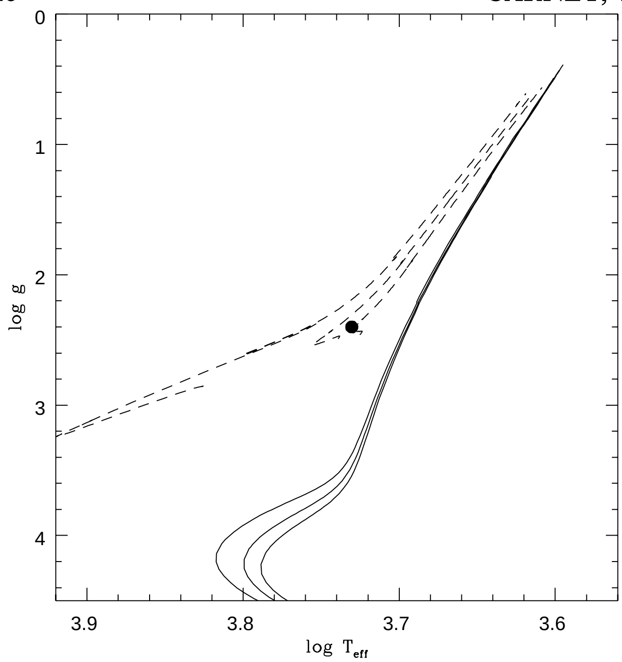


FIG. 3.—Plot of log $T_{eff}$ vs. log $g$. The solid lines are the model isochrones of Demarque et al. (1996) for $Z = 0.001$, while the dashed lines are horizontal-branch evolutionary tracks of Yi, Demarque, & Kim (1997), also for $Z = 0.001$.

shows the normal enhanced levels of these elements compared with iron, and in agreement with the abundances seen in globular clusters (see the review by Carney 1996).

### 5.4. *Comparison with Stellar Models*

In Figure 3, we compare the location of HD 17072 in the log $g$ versus log $T_{eff}$ plane with those of model stellar evolution calculations. The solid lines represent model isochrones with $Y = 0.23$, $Z = 0.001$ ([Fe/H] $= -1.26$ for scaled solar abundances), and ages of 10, 15, and 20 Gyr, taken from the latest Yale isochrones (Demarque et al. 1996). The dashed lines represent stellar evolution tracks for stars with $M = 0.64$, 0.72, and 0.90 $M_{\odot}$, $Y = 0.24$, and $Z = 0.001$, taken from Yi, Demarque, & Kim (1997). The input physics and opacities from these two sets of stellar evolution calculations are essentially identical. HD 17072 falls, as expected, on the more massive horizontal-branch model track, but considerably hotter than the red giant model isochrone tracks. The temperature difference is large, over 400 K, suggesting that HD 17072 is *not* a red giant. The difference becomes even larger when we utilize models with enhanced abundances of the "$\alpha$" elements, since (1) the overall metallicity rises and (2) the abundances of some of the key electron donors increases. Both of these results would shift the red giant tracks to lower temperatures, increasing the difference between the tracks and HD 17072.

## 6. SUMMARY

HD 17072 appears to be a bona fide metal-poor ([Fe/H] $= -1.17$; ["$\alpha$"/Fe] $= +0.33$) thick disk population red horizontal-branch star, presumably suitable for estimating the luminosity of the horizontal branch and the distances to similar stars in the field and in clusters, both in the Milky Way and in nearby galaxies. The faint luminosity obtained from the *Hipparcos* satellite's parallax measurement, and for the other horizontal-branch stars analyzed by Gratton (1998), agrees well with the results of statistical parallax and Baade-Wesselink analyses of other field RR Lyrae variables and is in serious contradiction to the results obtained from main-sequence fitting. The resolution of the dichotomy in luminosity estimates for horizontal-branch stars requires considerably more work and insight.

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