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THE METAL ABUNDANCE OF PAL 13

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ABSTRACT

Low-resolution spectrograms have been obtained of the three RR Lyrae variables in the distant and very sparse globular cluster Pal 13. A comparison of these spectrograms with similar ones of several RR Lyrae variables in the globular clusters M4, M5, and M22 reveals that Pal 13 is intermediate to M5 and M22 in metal abundance. A value of [Fe/H] = − 1.67 ± 0.15 is obtained for Pal 13 by adopting Zinn's (1980a) values of [Fe/H] for these other clusters. Pal 13 is another example of a distant halo object that is not extremely metal poor.

I. INTRODUCTION

Pal 13 is a very sparse globular cluster lying 26 kpc from the galactic center. Because only nine globulars, including Pal 13, are known to be more distant than 25 kpc (Harris and Racine 1979), the metal abundance of Pal 13 is an important datum for measuring the size of the metal abundance gradient in the outer halo of the Galaxy (cf. Searle and Zinn 1978; Harris and Canterna 1979; Zinn 1980b). Pal 13 has the lowest luminosity ($M_v = -2.6$; Ciatti, Rosino, and Sussi 1965) of the 103 globulars for which luminosity estimates exist. Its extreme sparseness is manifest in the color-magnitude diagram of its central area (Ciatti *et al.* 1965), which shows that the subgiant horizontal branches are thinly populated and that the red giant branch consists of only one star which is ~0.5 mag brighter than the horizontal branch. An abundance determination must rely, therefore, on observations of stars near the magnitude of the horizontal branch. Our determination is based on observations of the three RR Lyrae variables that have been discovered within 90″ of the cluster center.

There have been three previous investigations of the metal abundance of Pal 13. The first (Cowley, Hartwick, and Sargent 1978) consisted of low-dispersion spectroscopy of two stars. A comparison of these spectrograms with similar ones of the brightest and coolest red giants in the very metal-poor globular clusters M15 and M92 revealed that the Pal 13 stars have weaker metal lines and stronger hydrogen lines. Cowley *et al.* concluded that the Pal 13 stars are either more metal poor than the M15 and M92 stars or simply stars of higher effective temperature, in which case their method for estimating metal abundance would not yield meaningful results. The second investigation of Pal 13 (Canterna and Schommer 1978) consisted of photometry on the Washington system of three suspected red giants, which yielded a value of [Fe/H] = − 1.9 ± 0.4 for the cluster. Canterna and Schommer noted that the two stars observed by Cowley *et al.* are not red giants, but are rather an RR Lyrae variable and a nonvariable horizontal branch star. This confirmed the suspicion of Cowley *et al.* that these stars may be significantly hotter than red giants. The third investigation (McClure and Hesser 1981) was another low-dispersion spectroscopic survey of suspected red giants. They observed five stars, only two of which have the weak MgH bands that are characteristic of red giants in globular clusters, and only for one of these two stars was the spectrogram of adequate quality to estimate metal abundance. This star appears to be more metal weak than the red giants in M92. Although McClure and Hesser did not mention the work of Canterna and Schommer in their paper, their observations have some impact on Canterna and Schommer's results. One of the stars that McClure and Hesser identified as a field star was considered to be a cluster member by Canterna and Schommer (CS No. 9). The removal of this star from Canterna and Schommer's sample reduces it to two stars that have rather discordant values of [Fe/H] (− 1.3 and − 2.2), which yield − 1.75 ± 0.6 for the mean metal abundance of the cluster.

Some of the motivation for the present investigation came from an examination of Fig. 4 in the paper by Cowley *et al.* (1978), which shows the spectrogram of star CHS No. 1 (= RR Lyrae var. V2). In this spectrogram, the K line of Ca II is considerably stronger than either Hγ or Hδ and is approximately as strong as the Ca II H + Hϵ blend. This observation appears to rule out the possibility that this star is as metal poor as M15 or M92, for even at minimum light, when the K line is strongest and the H lines are weakest, the K lines of very metal-poor RR Lyrae variables are much weaker than Hγ, Hδ, and the H + Hϵ blend. V2 also has significant absorption in the *G* band (Cowley *et al.* 1978), which is another sign that it is not extremely metal poor (see Butler 1975). According to Butler (1975), the RR Lyrae variables in M15 and M92 have mean values of ΔS of 11.3 and 12.2, respectively. If V2 were as metal poor as these clusters, then its spectrum should resemble that of X Ari ($\Delta S = 11.7$, Bulter 1975), which it clearly does not (cf.

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Fig. 4 of Cowley *et al.* and Fig. 1 of Preston 1959). We have obtained additional observations of the RR Lyrae variables in Pal 13 to test whether this interpretation is correct and to measure accurately its metal abundance.

II. OBSERVATIONS

The three RR Lyrae variables near the center of Pal 13 and, for comparison, several RR Lyrae variables in the globular clusters M4, M5, and M22 and one in the field (UY Boo) were observed in 1979 June with the 2.5-m DuPont telescope of Las Campanas Observatory in Chile. In addition, Gary Da Costa has kindly made available his observations of two of the RR Lyrae variables in M22, which were obtained with the same telescope and spectrograph in 1979 August. These observations were made with the reticon system attached to the Cassegrain spectrograph. With this photon-counting device, one can accurately measure the light from the night sky and remove it from the spectrum of an object. The spectrograms, which are digital in form, cover the wavelength range 3500–6400 Å and have resolution of ~4 Å.

Table I lists the variables, their periods, the Julian dates of the observations, the phases at the times of observation, and the quantities *W*(H), *W*(K), *W*′(K), and [A/H], which are described later. The phases were calculated from the ephemerides given by Ciatti *et al.* (1965), Sawyer Hogg (1973), Sturck (1977), and Zessewitsch, Firmaniuk, and Kreiner (1979). The light curves and the periods of these stars indicate that they are either Bailey type *a* or *b*.

The variables in Pal 13 have faint apparent magnitudes ($V \sim 17.7$); consequently, relatively long integration times were required to obtain good-quality spectrograms. This conflicted with the requirement that the integration times should be very short in comparison with the periods of the stars so that they do not encompass significant variations in effective temperature (T_{eff}). Our observations were made with integrations time $\leqslant 70$ min, which corresponds to Δ (phase)$\leqslant 0.08$. The T_{eff} variations during the integrations were consequently very small, but some of the spectrograms have less than ideal signal-to-noise ratios. Nonetheless, the strengths of the Ca II K lines and the H lines could be accurately measured in all of the spectrograms. The spectrograms of the Pal 13 variables and of the variables in the other globular clusters are shown in Fig. 1.

III. METAL ABUNDANCE

The most commonly used method for estimating the metal abundance of RR Lyrae variables from low-resolution spectrograms is, of course, Preston's (1959) ΔS technique. While this method has the advantage of being thoroughly tested and calibrated, it has the drawback that the phases of the variables at the times of the observations must be accurately known (see Butler 1975). The existing ephemerides for the Pal 13 variables, which were determined from plates taken over the interval 1951–1962 (Ciatti *et al.* 1965), may not provide this information for our observations. This is particularly true for V1 because Ciatti *et al.* found evidence that its period is slightly variable. The appearances of the spectrograms suggest that the phases calculated from the ephemerides of V2 and V3 are not grossly incorrect, but the phase obtained for V1 (0.32) is clearly spurious. The spectrogram of V1 has very strong H lines, which suggests that it was taken near maximum light. Since the phases of the observations are poorly known, we have not attempted to use the ΔS method. Fortunately there exists an alternative method that does not rely so heavily on phase information (see Freeman and Rodgers 1975).

Since the surface gravity of a type *ab* variable remains essentially constant over most of its light cycle (see, e.g., Oke, Giver, and Searle 1962), the variations in K-line strength are primarily due to changes in effective temperature, which can be accurately monitored by measuring the strengths of the H lines. A curve is produced when, for a series of observations of a variable, the equivalent width of the K line is plotted against the equivalent width of an H line or, preferably, the mean of the equivalent widths of several H lines. Type *ab* variables

TABLE I. Journal of observations.

Cluster	Var.	Period (days)	J.D.[a]	Phase[b]	*W*(H) (Å)	*W*(K) (Å)	*W*′(K) (Å)	[A/H]
Pal 13	V1	0.54	4047.850	0.32	11.2	1.8	1.7	− 1.58
	V2	0.60	4044.856	0.42	3.8	5.1	5.0	− 1.33
	V3	0.58	4044.898	0.16	10.0	2.0	1.9	− 1.59
	V3	0.58	4047.886	0.33	6.7	3.2	3.1	− 1.46
M4	V15	0.44	4045.539	0.56	6.6	4.4	3.8	− 1.23
	V35	0.63	4045.563	0.67	4.0	5.9	5.3	− 1.21
M5	V18	0.46	4045.623	0.28	6.1	3.6	3.5	− 1.39
	V19	0.47	4045.608	0.63	4.7	4.8	4.7	− 1.23
	V32	0.46	4045.592	0.58	4.4	5.7	5.6	− 1.03
M22	V7	0.65	4045.574	0.73	3.9	3.6	3.2	− 1.80
	V10	0.65	4112.642	0.12	7.9	2.6	2.2	− 1.66
	V13	0.67	4112.616	0.24	6.5	2.7	2.3	− 1.77
Field	UY Boo	0.65	4047.473	0.54	4.1	2.9	2.8	− 1.88

[a] J.D. − 2440000.0.

[b] The phases of the Pal 13 observations may be substantially in error.

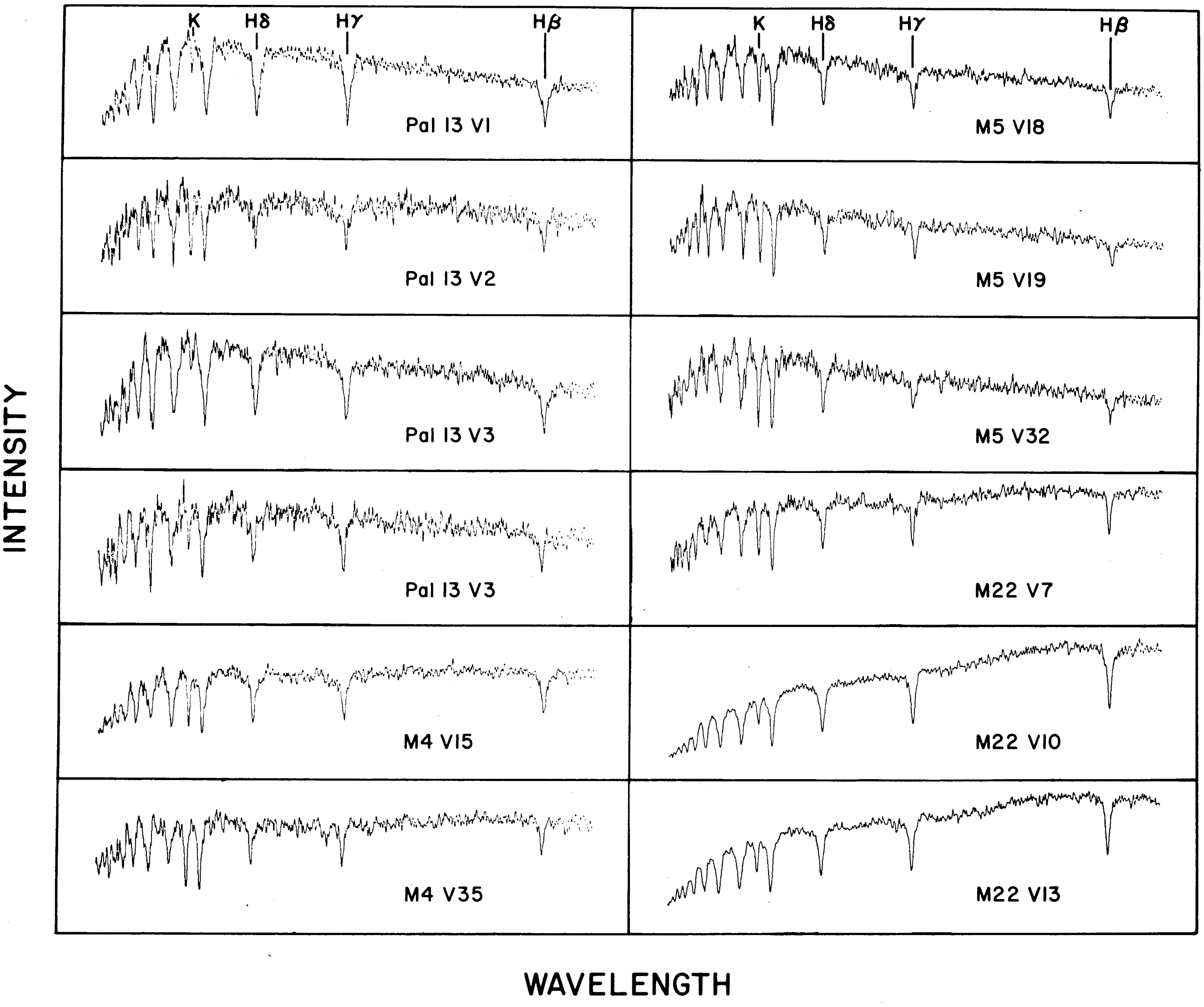

FIG. 1. The low-resolution (~ 4 Å) spectrograms of the globular cluster variables. The ordinate, "intensity," is the number of counts received in each channel on an arbitrary scale. The horizontal lines dividing the figure into 12 panels coincide with the zero intensity levels. The spectrograms are arranged in the same order as the data in Table I.

that have the same calcium abundance lie along the same curve in the K-H plane since variables of this kind have very nearly the same surface gravities and ranges in effective temperature. Differences in abundance among these variables show up as differences in K-line strength at constant H-line strength. These differences may be calibrated in terms of [Ca/H] by calculating the K- and H-line strengths for different temperatures and abundances. These calculations also provide the shapes of the curves in the K-H plane; hence, it is not necessary to observe a variable more than once during its light cycle. It is important, however, to avoid making observations during the rising branch phase of the light cycle, when the effective gravity of a variable is larger than at other times. Because of the sensitivity of the K line to surface gravity, spuriously low abundances may be deduced from observations made during this time. The first calculations of curves in the K-H plane (Freeman and Rodgers 1975) were based on some rough approximations. More recently, these curves have been determined from spectrum synthesis calculations (Manduca and Bell 1978; Manduca 1981).

It is difficult, if not impossible, to measure true equivalent widths in low-resolution spectrograms such as ours because the true continuum is never seen. We have therefore measured equivalent widths from pseudo-continua that can be consistently placed. Similar pseudo-equivalent widths must be provided by the calculations. The great advantage of the spectrum synthesis method is that this can be done using exactly the same techniques that were used to reduce the observations. For example, to calibrate the ΔS method, Manduca (1981) calculated synthetic spectra that have the same resolution as Butler's (1975) observations. He then followed Butler's procedures for measuring the pseudo-equivalent widths.

The Butler-Manduca prescriptions for the pseudo-equivalent widths [see Butler's (1975) Fig. 8 and Manduca's (1981) Fig. 1] have been followed here so that our observations may be compared with Manduca's calculations. The measurements are given in Table I, where *W*(K) and *W*(H) are, respectively, the pseudo-equivalent width of the K line and the mean of the pseudo-equivalent widths of the Hβ, Hγ, and Hδ lines. The uncertainties in the placements of the pseudo-continua and the noise in the line profiles produce uncertainties in *W*(K) and *W*(H) of about 0.4 and 0.25 Å, respectively.

Before the data in Table I may be compared, it is necessary to correct the observed values of *W*(K) for the contamination by interstellar K lines. To do this, we have adopted Butler's (1975) estimates of the interstellar contributions, which are 0.6, 0.4, and 0.1 Å, respectively, for M4, M22, and the high-latitude objects (Pal 13, M5, and UY Boo). The subtraction of these quantities from the values of *W*(K) yields the pseudo-equivalent widths of the stellar lines, *W'*(K), which are listed in Table I and are plotted in Fig. 3. Butler's corrections for the interstellar lines were not measured from spectrograms of stars in the clusters, but are simply averages of the interstellar K lines in stars that lie at roughly the same galactic coordinates as the clusters. The accuracy of these corrections may be quite low because the interstellar medium is nonuniform on small scales and the relative radial velocities of the clusters and the intervening interstellar clouds are unknown (see Butler, Carbon, and Kraft 1976). Fortunately, our final results are not affected much even if these values are in error by 50%.

Since our spectrograms have somewhat higher resolution than Manduca's synthetic ones, it is questionable whether our measurements are precisely on his system. Consequently, we have not relied on only these calculations to estimate the metal abundance of Pal 13. They are used as a guide when comparing the observations of the Pal 13 variables with those of the variables in M4, M5, and M22. Pal 13 is ranked with respect to these other clusters whose metallicities have been measured previously. This procedure should also lessen the impact of any systematic errors in the calculations. Since values of [Fe/H] are inferred from the ranking provided by the strength of the K line, it is implicitly assumed that the abundances of calcium and iron are correlated. Analyses of high-dispersion spectrograms of field RR Lyrae variables have shown that a tight correlation exists (Butler 1975; Butler and Deming 1979).

The success of our procedure depends to some extent on how well the calculations by Manduca reproduce the variations in K- and H-line strengths that occur over a star's light cycle. In Fig. 2, Manduca's (1981; 1981, private communication) calculations are compared with observations that cover most of the light cycles of two variables. These observations, which were obtained for another purpose, were made with the same instruments as the Pal 13 observations but with a different grating in the spectrograph, which yielded a resolution of ~1.2 Å instead of ~4 Å. Figure 2 shows that there is a close match between the shapes of the curves produced by Manduca's calculations and the observational points.

In Fig. 3, the observations of the variables listed in Table I are compared with Manduca's (1981) calculations. The variables in each cluster define a sequence in Fig. 3 that is not significantly different in shape, considering the size of the observational errors, from the curves generated by Manduca's calculations. There is therefore no evidence of any internal dispersion in the calcium abundances of the clusters, nor does it appear that any of the observations were obtained during the

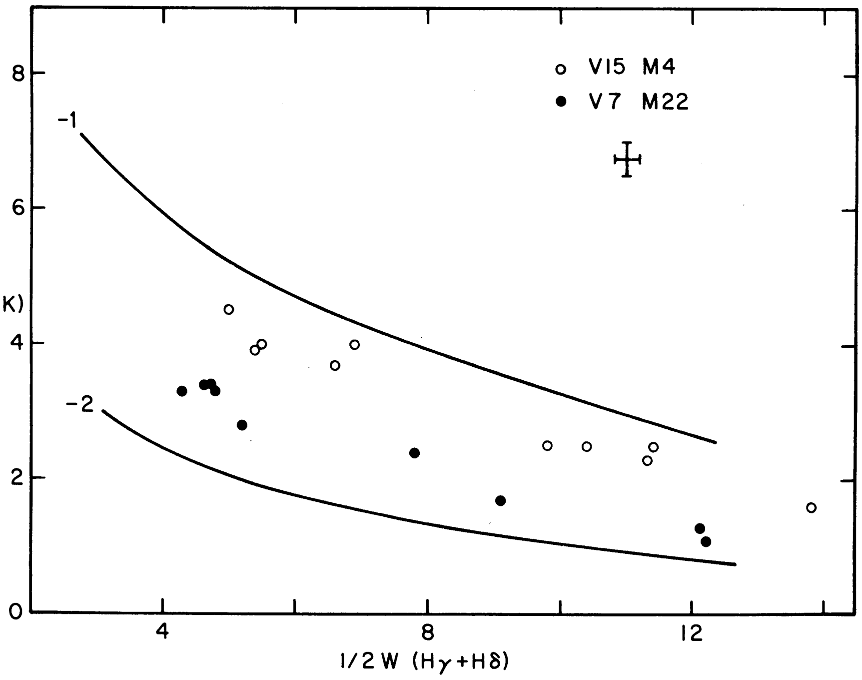

FIG. 2. For the high-resolution (~1.2 Å) observations that cover most of the light cycles of V15 in M4 and V7 in M22, the mean of the pseudo-equivalent widths of the Hγ and Hδ lines is plotted against the pseudo-equivalent width of the K line [*W'*(K)]. The curves are the results of Manduca's (1981; 1981, private communication) calculations for [A/H] = −1 and −2. Note that the observational points define curves that have approximately the same shapes as those given by the calculations.

rising branch phase of the light cycle. A value of [A/H] was determined for each observation (see Table I) by linearly interpolating between the curves in Fig. 3, and the following mean values were obtained for Pal 13, M4, M5, and M22, respectively: − 1.49, − 1.22, − 1.22, and − 1.74. The fact that the calcium abundance of Pal 13 is intermediate to those of M5 and M22 is also evident from a visual inspection of the spectrograms (see Fig. 1).

For the reasons given above, the values of [A/H] that were derived from Fig. 3 have been used only to rank the clusters. The results for M4, M5, and M22 and Zinn's (1980a) values of [Fe/H] for the same clusters (− 1.46, − 1.58, and − 1.86, respectively) have been used to define a transformation between [A/H] and [Fe/H]. Zinn's values were used instead of some others that are available because we wish to compare Pal 13 with other distant globular clusters that Zinn has measured. Zinn's measurements consisted of photometry of the integrated light of the clusters, which was calibrated via Cohen's (1978, 1979) spectroscopic measurements of [Fe/H] for M3, M13, M15, and M92, and Frogel, Persson, and Cohen's (1979) estimate, from infrared photometry, for M71. Cohen's (1980) subsequent spectroscopic study of several red giants in M71 has suggested that this earlier estimate for the metal abundance of M71 is much too large. There is not, however, universal agreement that the old value is far wrong, and the metal abundance of M71 is presently a controversial subject (see Bell and Gustafsson 1982). Fortunately for us, the values of [Fe/H] that are derived from Zinn's (1980a) photometry of M4, M5, and M22 do not depend very much on whether one adopts the old value for M71 or Cohen's (1980) new one (see Zinn 1980b). Cohen (1981) has also recently measured the metal abundance of M22 from high-dispersion spectrograms of red giants. There is good agreement between her value ([Fe/H] = − 1.78) and Zinn's, as there should be if the integrated-light photometry provides an accurate ranking by metal abundance.

The transformation between [A/H] and [Fe/H] yields a value of − 1.67 for the [Fe/H] of Pal 13. It is difficult to estimate the standard error of this value, but ± 0.15 seems reasonable considering the size of the observational errors and the uncertainties associated with the corrections for the interstellar K lines and the transformation between [A/H] and [Fe/H]. This estimate does not include an allowance for the uncertainty in the [Fe/H] scale; hence it is the standard error of Pal 13's rank with respect to other globular clusters.

We have assumed that the observations of a few RR Lyrae variables in a globular cluster can yield an accurate measurement of the cluster's mean metallicity. This may not be true, of course, if there is a range in metallicity within the cluster. The numerous investigations of M4 and M5 (see, e.g., Smith and Butler 1978; Searle and Zinn 1978; Cacciari and Freeman 1980) have not detected any variation in metallicity, and they place small upper limits on the ones that may be present. There is no firm evidence for or against a dispersion in Pal 13; consequently we assume that it, like the majority of globular clusters, possesses very little, if any.

The case of M22 is more problematical, however, and it deserves some discussion. Hesser, Hartwick, and

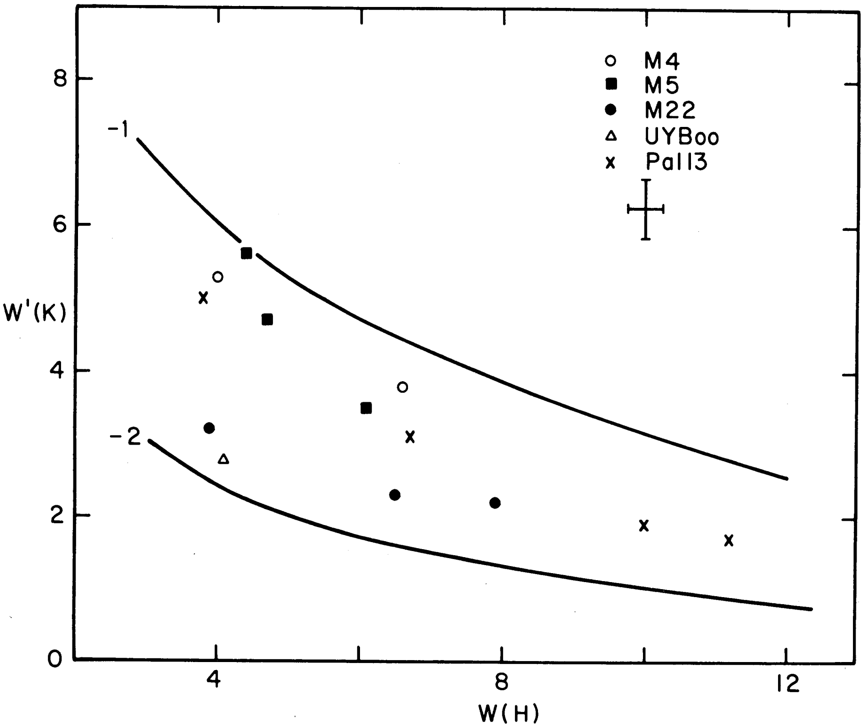

FIG. 3. The measurements of the low-resolution spectrograms (Table I) are compared with Manduca's (1981) calculations for [A/H] = − 1 and [A/H] = − 2. W(H) is the mean of the pseudo-equivalent widths of the Hβ, Hγ, and Hδ lines. W'(K) is the pseudo-equivalent width of the K line corrected for interstellar absorption. This diagram is used to rank the Pal 13 variables with respect to the variables in the other clusters.

McClure (1977) and Peterson (1980) have reported the detection of a significant dispersion within M22. These results have been questioned, however, by Lloyd Evans (1978) and Cohen (1981), respectively, and the present evidence appears to be against the existence of a large dispersion within M22. Even so, it is important to consider the effect that a dispersion in M22 might have on our results for Pal 13. There is no significant variation in metallicity among the six stars in Butler's (1975) sample of RR Lyrae variables in M22, which includes two of the three stars that we have observed. Butler's observations of RR Lyrae variables in M22 and other metal-poor globular clusters provide a ranking by metallicity that is in good agreement with Zinn's (1980a) integrated-light measurements. Consequently, should there exist a significant dispersion within M22, our procedure of equating Zinn's value of [Fe/H] for M22 with the mean value of [A/H] obtained from Fig. 3 would probably introduce very little error in the value of [Fe/H] inferred for Pal 13.

It is important to note that our measurements for M4 and M5, which suggest that these clusters have the same metal abundance, are slightly at odds with Butler's (1975) results based on the ΔS method (i.e., $[\mathrm{Fe/H}]_{\Delta S} = -1.24$ and -1.01, respectively). This disagreement worsens if Smith and Butler's (1978) data for M4 are combined with Butler's; then for M4, $[\mathrm{Fe/H}]_{\Delta S} = -1.4$. However, several other measures of metallicity, e.g. Q_{39}, $(B-V)_{0,g}$, and $\Delta V_{1.4}$ (Zinn 1980a; Sandage 1982) indicate that M4 is more metal rich than M5 rather than the reverse. We have no explanation for this lack of agreement, and it might be worthwhile to obtain additional observations of the RR Lyrae variables in both clusters and some observations of red giants as well. The position of UY Boo in Fig. 3 is consistent with the previous measurements by Preston (1959) and Butler (1975).

IV. DISCUSSION

Our observations indicate that Pal 13 is a cluster of "intermediate" metallicity much like M3 ([Fe/H] = − 1.69, Zinn 1980a). It is not nearly as metal poor as M92 ([Fe/H] = − 2.19), for example. This result is consistent with the spectrogram of V2 that was obtained by Cowley *et al.* (1978) (see Sec. I). It is also in good agreement with the mean value of [Fe/H] given by Canterna and Schommer's (1978) observations, but as explained in Sec. I, their results do not carry much weight. There is some disagreement between our result and McClure and Hesser's (1981) measurements for one star, which suggest that Pal 13 is more metal poor than M92. Unfortunately, McClure and Hesser do not provide an estimate of the accuracy of their measurements. Since their spectrograms of stars in Pal 13 and NGC 7006 appear to have similar signal-to-noise ratios (see Fig. 1 in McClure and Hesser 1981), it seems reasonable to assign the same standard deviation (σ) to both sets of observations. Since the interpretation of the DDO colors of the stars as measures of metallicity is compromised by the variations in CH and CN strength from star to star, we consider only the results obtained from the measurements of the H and K lines of Ca II. The H and K strengths (i.e., m_{HK}) of the ten stars in NGC 7006 vary considerably. Since McClure and Hesser do not attribute this scatter to a metallicity dispersion, and since other observers have found no evidence of a dispersion (Searle and Zinn 1978; Cohen and Frogel 1982), we assume that it is caused by the random errors of the measurements. The scatter has a range of ~1.5 dex, and the σ of one observation is ~0.46 dex. If the most deviant star is thrown out of the sample on the grounds that it may not be a cluster member, the range and σ drop to ~0.7 and ~0.27 dex, respectively. Thus it seems reasonable to assign a σ of 0.3 to the value of [Fe/H] = − 2.3 given by McClure and Hesser's observation of the Pal 13 star. On the same [Fe/H] scale, our Pal 13 result is $[\mathrm{Fe/H}] = -1.54 \pm 0.15$. The difference between this value and McClure and Hesser's is 0.76 dex or $\sim 2.3\sigma$, which is on the borderline of being insignificant.

From a spectroscopic and photometric study of red giants in NGC 7006, Cohen and Frogel (1982) claim that McClure and Hesser's value of [Fe/H] for NGC 7006 is too low by about 0.4 dex. If McClure and Hesser's observation of the Pal 13 star suffers from a systematic error of similar magnitude, then the disagreement with our result essentially disappears.

It is important to note, too, that while the star observed by McClure and Hesser (1981) has the DDO colors and the weak MgH absorption of a red giant, it lies relatively far from the cluster center (~1ʹ.7), which casts some doubt on its membership. From star counts, Kinman and Rosino (1962) obtained a value of 1ʹ.05 for the tidal radius (r_t) of Pal 13 as defined by King (1962). Ciatti *et al.* (1965) state that their star counts indicate an apparent radius (r_t?) of 1ʹ.5, but they also note that an RR Lyrae variable lying at a radius of ~ 5ʹ has many of the same properties as the variables within 1ʹ.5. Peterson and King (1975) refitted a King (1962) model to Kinman and Rosino's (1962) star counts and obtained $r_t \geqslant 1'.25$. While no firm conclusion can be drawn from these estimates of r_t about McClure and Hesser's star, it is clearly important to test the star's membership in Pal 13 by means of radial velocity measurements.

In the following discussion we give weight only to our value of [Fe/H] for Pal 13 because it was determined from observations greater in number and higher in precision than the ones used to determine previous values. Moreover, the stars that we observed are undoubtedly cluster members.

There has been considerable discussion over the past few years on the questions of whether a metal abundance gradient exists in the galactic halo at galactocentric distances $(R) > 9$ kpc (see, e.g., Cowley *et al.* 1978; Canterna and Schommer 1978; Searle and Zinn 1978; Harris and Canterna 1979; Butler, Kinman, and Kraft 1979; Zinn 1980b; Butler, Kemper, Kraft, and Suntzeff

1981; Da Costa, Ortolani, and Mould 1982). While there remains some disagreement on this issue, it is clear that many of the halo stars and globular clusters that lie at large values of R are not extremely metal poor. The values of [Fe/H] and R (25.7 kpc, Harris and Racine 1979) for Pal 13 indicate that it is another example of a distant object that has only a moderate metal deficiency. On the same [Fe/H] scale as we have used here, Zinn's (1980a,b) sample of 31 clusters that lie in the zone $9 \leqslant R < 40$ kpc has a mean [Fe/H] of -1.73. Pal 13 is therefore slightly more metal rich than the average cluster in this zone. It is one of the more distant of these clusters; consequently, the observations reported here provide additional evidence that there is at most a small gradient in metal abundance (see Zinn 1980b).

Recently, Freeman and Seitzer (see Freeman and Norris 1981) have pointed out that a gradient does exist among the clusters in the 9–40-kpc zone if [Fe/H] is plotted againt perigalacticon distance ($R_{\min}$) instead of R. They suggest that this may be evidence that the clusters formed near the perigalacticon points in their orbits. $R_{\min}$ is estimated from r_t, and Freeman and Seitzer found in the literature estimates of r_t for 25 of the 31 clusters in Zinn's sample. Da Costa, Ortolani, and Mould (1982) have recently measured the metal abundance ([Fe/H] $= -1.55$), distance, and r_t of Pal 14. They obtained $R_{\min} > 30$ kpc and pointed out that their measurements provide substantial evidence against the existence of a gradient in the [Fe/H] $- R_{\min}$ plane, as do, to a lesser extent, the data for Pal 12 ([Fe/H] $= -0.6$, $R_{\min} \sim 16$ kpc; see Fig. 5 in Freeman and Norris 1981) and Pal 5 ($R_{\min} > 15$ kpc, Sandage and Hartwick 1977; [Fe/H] $= -1.48$, Zinn 1980a).

The investigations of globular clusters (e.g., Zinn 1980b) and halo RR Lyrae variables (Butler, Kemper, Kraft, and Suntzeff 1981) have shown that a range in metallicity of ~ 1 dex exits out to $R \sim 40$ kpc and probably beyond (Da Costa, Ortolani, and Mould 1982). While only globular clusters can be plotted in the [Fe/H] $- R_{\min}$ diagram, and accurate estimates of $R_{\min}$ exist for only a fraction of the distant clusters, it appears that a range of ~ 1 dex also exists at large values of $R_{\min}$. Since the addition of new objects to the samples can only increase the ranges in [Fe/H] seen at various values of R and $R_{\min}$, the conclusion that large ranges exist is a firm result, and it is the one that should be given the most weight when modeling the evolution of the Galaxy (see Zinn 1980b; Butler *et al.* 1981).

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