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METAL ABUNDANCE IN THE PRAESEPE AND HYADES CLUSTERS

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ABSTRACT

Calcium K-line photometry is used together with the *uvbyβ* photometry of Crawford and Barnes to study metal abundance in 27 A-type stars in Praesepe. Praesepe is found to have general metal and calcium abundances about a factor of 2 higher than solar-neighborhood field stars or young stars in Orion and other clusters. Praesepe's close resemblance to the Hyades supports Eggen's association of these two clusters as a single moving group.

Subject headings: clusters: open — stars: abundances — stars: early-type

I. INTRODUCTION

Crawford and Barnes (1969, hereafter CB) obtained four-color and Hβ photometry for 97 stars in the Praesepe (NGC 2632, M44) open star cluster and also briefly reviewed the literature on this cluster. They pointed out that "the space motions of this cluster are essentially the same as for the Hyades stars, and the two clusters have been considered the nucleus of an extended moving group of stars scattered over the sky" (see Eggen 1960, 1963; Breger 1968). CB confirmed that the metal abundances in Praesepe are similar to those in the Hyades; that is, they are substantially higher than among field stars.

We report here calcium K-line photometry for 27 A-type stars in Praesepe. The motivation was to obtain a rigorous separation of Am stars and to confirm and extend the previous work. We also compare our data with the Hyades K-line observations of Hesser and Henry (1971).

II. OBSERVATIONS

Our previous K-line photometry used the K-line spectrometer of Henry (1969) or the CTIO two-channel scanner (Hesser, McClintock, and Henry 1977). We made the present observations using two interference filters centered on the wavelengths (3933 Å, 3915 Å) of the two bands of the K-line spectrometer. The filters, which will be described in more detail elsewhere, had a full width at half-transmission of about 15 Å; they were used in an ordinary photometer on the No. 4, 40 cm telescope at Kitt Peak National Observatory. Observations were obtained on the nights of 1973 March 25 and 26 (UT). Standard stars from Henry (1969) were observed frequently on both nights, and the relation

$$k = 2.122\,(k_{\rm obs}) + 0.405$$

was found to reproduce the literature values for the K-line-strength parameter k. The observations on the two nights agreed well with each other. In order to obtain an estimate of the error in the mean value of k for each star, each observation, which consisted of two 15 s integrations with the K-line filter and two with the continuum filter, was treated as two separate observations. The difference between the two observations separated by only a few seconds was found to be fully comparable to the difference between the two observations made about 24 hours apart. Four independent observations exist for each star, and thus a reasonably meaningful error can be assigned to the mean value of k for each star.

In Table 1 are listed, for each star, the KW number (Klein Wassink 1927); the mean k value; the $1\,\sigma$ uncertainty in the mean value of k; the $b - y$ color from CB; Δk, the deviation of k from the normal (Henry 1969) value for a star of that color (positive Δk indicates a relatively high calcium abundance); Strömgren (1966, 1967) $[m_1] = m_1 + 0.18\,(b - y)$, $[c_1] = c_1 - 0.20\,(b - y)$, and $[u - b] = [c_1] + 2[m_1]$ indices (from the photometry of CB) and group designation (L = late group, E = early group); $\Delta[m_1]$, the deviation of the reddening-independent general metallicity parameter $[m_1]$ (Strömgren 1966) from the normal (Strömgren 1967) value (negative $\Delta[m_1]$ indicates a relatively high abundance of metals); and remarks, where Am means that the star was so designated by Bidelman (1956).

III. THE RESULTS

The cluster is reported by CB to be essentially free from interstellar reddening. Thus, in Figure 1, k is

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TABLE 1

OBSERVATIONS OF PRAESEPE STARS

KW	$k \pm \sigma_k$	$b - y$	Δk	$[m_1]$	$[c_1]$	$[u - b]$	Group	$\Delta[m_1]$	Remarks
45......	0.936 ± 0.035	0.131	+0.205	0.237	0.832	1.306	L	−0.023	
50......	0.653 ± 0.006	0.120	−0.080	0.191	0.998	1.379	L	+0.019	
114......	0.779 ± 0.032	0.122	+0.088	0.233	0.857	1.323	L	−0.020	
150......	0.895 ± 0.032	0.157	+0.079	0.209	0.911	1.329	L	−0.009	
154......	0.847 ± 0.015	0.149	+0.057	0.224	0.763	1.211	L	−0.010	
203......	0.641 ± 0.058	0.126	−0.067	0.227	0.854	1.307	L	−0.013	
204......	1.067 ± 0.057	0.153	+0.267	0.208	0.964	1.379	L	+0.006	
207......	0.764 ± 0.018	0.104	+0.152	0.218	0.948	1.384	L	−0.008	
224......	0.392 ± 0.024	0.104	−0.220	0.249	0.943	1.441	L	−0.044	Am
229......	0.249 ± 0.043	0.143	−0.539	0.263	0.799	1.325	L	−0.050	Am
265......	0.182 ± 0.020	0.005	+0.037	0.160	1.094	1.414	E	−0.016	
271......	1.083 ± 0.025	0.192	+0.177	0.229	0.681	1.138	L	−0.023	
276......	0.337 ± 0.019	0.075	−0.146	0.248	0.989	1.484	L	−0.049	Am
279......	0.278 ± 0.017	0.099	−0.313	0.278	0.917	1.473	L	−0.076	Am
284......	0.946 ± 0.018	0.161	+0.122	0.209	0.905	1.323	L	−0.007	
286......	0.174 ± 0.066	0.113	−0.480	0.236	0.931	1.404	L	−0.027	Am
292......	0.924 ± 0.030	0.198	−0.051	0.208	0.769	1.185	L	0.000	
300......	0.475 ± 0.017	0.091	−0.081	0.235	1.019	1.490	L	−0.034	Am
318......	0.736 ± 0.030	0.181	−0.142	0.230	0.713	1.172	L	−0.021	
323......	0.762 ± 0.058	0.130	+0.036	0.212	0.874	1.299	L	+0.002	
328......	0.917 ± 0.018	0.109	+0.280	0.229	0.998	1.455	L	−0.021	
348......	0.752 ± 0.022	0.091	+0.196	0.211	0.734	1.480	L	−0.012	
350......	0.640 ± 0.089	0.190	−0.262	0.256	0.714	1.226	L	−0.044	Am
375......	0.523 ± 0.062	0.129	−0.197	0.199	0.859	1.258	L	+0.019	
385......	0.894 ± 0.047	0.144	+0.121	0.222	0.826	1.270	L	−0.007	
429......	0.928 ± 0.050	0.194	+0.015	0.208	0.741	1.157	L	−0.002	
445......	0.790 ± 0.060	0.120	+0.107	0.223	0.887	1.332	L	−0.011	

plotted against CB's observed $b - y$ color. The mean relation for field stars of Henry (1969) is also shown, as well as his theoretical relations for 1 and 2 times solar calcium abundance. Stars designated as Am by Bidelman are shown as filled symbols; all of these fall well below the field-star relation, in accord with the classification as Am. In addition, five other stars fall below the line. These could be unrecognized Am stars or relatively metal-deficient stars. The remainder of the stars fall very significantly *above* the mean relation for field stars, which suggests—from comparison with the theoretical relations shown—that they contain more calcium by a factor of 2 than do general field stars. The blue straggler KW 265 has a normal calcium abundance.

In Figure 2, Δk is plotted against $\Delta[m_1]$. In a plot of this type, metal-rich stars occupy the second quadrant, metal-poor stars the fourth quadrant, and classical Am stars the third quadrant. The curved line in the figure bounds the region occupied by spectroscopically normal field stars (Henry 1969). All of the stars designated Am by Bidelman (1956) fall in the third quadrant. Two stars (KW 203 and KW 318) are probably previously unrecognized weak Am stars. The other three stars that fall "below the line" in Figure 1 lie in the fourth quadrant, usually associated with relatively metal-poor stars. The remaining 15 stars in the cluster appear to be relatively metal-rich. One star (KW 204) has an abnormally strong K line and slightly weak metal lines.

IV. DISCUSSION

Inspection of Figure 2 shows that the metals including calcium are generally overabundant (relative to field stars) in Praesepe and that a considerable scatter in metal-abundance indices (Δk, $\Delta[m_1]$) occurs. Among the clusters so far investigated by K-line photometric techniques (Hesser and Henry 1971; Hesser, McClintock, and Henry 1977), Praesepe and the Hyades are the only two that show these characteristics.[1] Figure 10 of Hesser and Henry (1971) contains the same information for the Hyades star cluster. If stars considered to be Am stars on the basis of K-line photometry are excluded, the Praesepe stars show entirely comparable dispersion in Δk and nearly comparable dispersion in $\Delta[m_1]$ to those of the Hyades, an observation that differs from CB's evaluation of the *uvbyβ* data. However, it is clear from

[1] Two stars, KW 50 and KW 375, although lying within the boundaries of the "normal" field stars, appear to be relatively metal-poor. Comparison with Fig. 10 of Henry (1969) or with Fig. 4 of Henry and Hesser (1971) shows that KW 375, in particular, is located in a sparsely populated region, which is remarkable considering the relative sizes of the cluster and field-star samples being compared and the otherwise high average metal abundance of the Praesepe cluster sample. CB identify KW 375 as a single-line spectroscopic binary, but examination of the relevant references (Bidelman 1956; Treanor 1960; Dickens, Kraft, and Krzeminski 1968) leaves the origin of that remark unclear; Crawford (private communication) recommends that the star not be considered a spectroscopic binary.

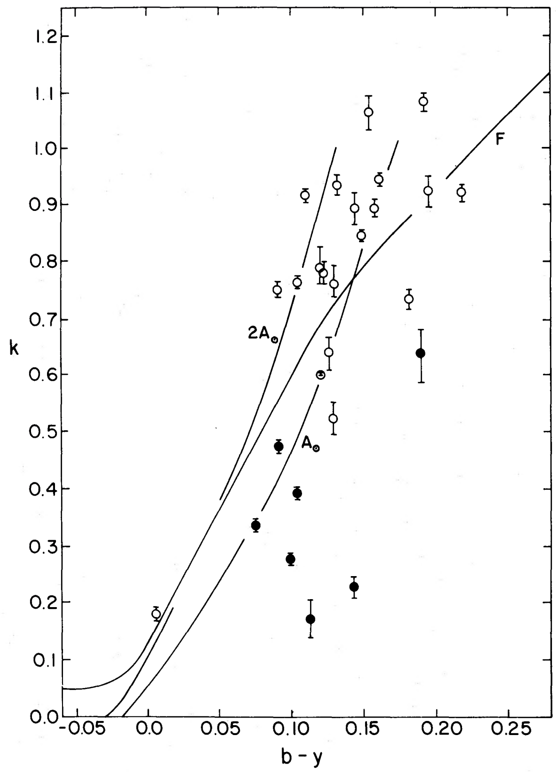

FIG. 1.—The calcium K-line-strength parameter k is plotted against $b - y$ for A stars in the unreddened Praesepe cluster. Error bars are $\pm 1\ \sigma$ statistical errors. Spectroscopically recognized Am stars are shown as filled symbols. The mean field-star relation (marked F) of Henry (1969), as well as his theoretical relations for 1 and 2 times solar abundance, is also plotted. Most stars appear to be about a factor 2 high in abundance of calcium compared to field stars.

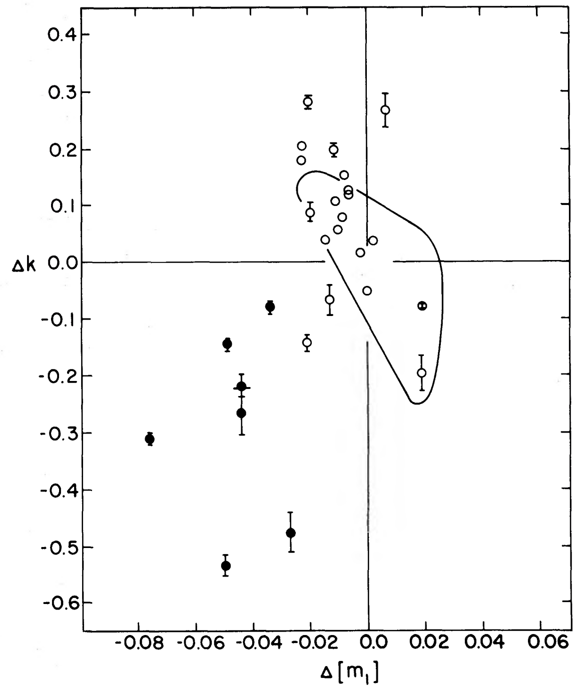

FIG. 2.—The deviation Δk from normal of the calcium K-line-strength parameter is plotted against the deviation $\Delta[m_1]$ from normal of the metal-abundance parameter. The curved line gives the region occupied by spectroscopically normal field stars. Two weak Am stars (KW 203 and 318) have been discovered photometrically from this diagram. The Praesepe cluster stars show both a large dispersion in metal abundance, and a large systematic overabundance in metals and in calcium compared with the average for field stars.

Figure 1 that only much larger amounts of differential reddening than are suggested by Dickens, Kraft, and Krzeminski (1968) could account for the wide range of Δk values derived here. We believe, therefore, that our data support CB's conclusion that differential reddening is not the source of all of the poor correlations found with rotational velocity and, therefore, that significant "cosmic scatter" exists in general metal-abundance and K-line-strength indices among the Praesepe stars. Furthermore, the $\langle \Delta k \rangle$ for the Praesepe stars observed here lends additional support to CB's observation that Praesepe stars are as metal-enriched as Hyades stars.

Eggen (1960, 1963) has emphasized that Praesepe and Hyades should be considered *together*, along with certain field stars that share their motion (see also Breger 1968). In Figure 3 we have combined the present Praesepe data with the Hyades data of Hesser and Henry (1971) and of Hesser, McClintock, and Henry (1977). In this figure we have deliberately refrained from differentiating "Am" stars from "normal" stars. Eggen (1976) has pointed out that "astronomical jargon can be as confusing in meaning as it is helpful in brevity," and he has constructively and extensively criticized the concept of "Am-ness." Henry (1969) and Henry and Hesser (1971) have shown that "Am" stars exist which have a normal K-line strength and that "Am" stars exist which have a normal $[m_1]$ index. We consider all of the stars in the third quadrant of Figure 3 to be "Am" stars in the sense that some physical process has been at work in these stars that has not (detectably) been at work in the other stars. This "process" tends to move stars in the 225° direction in this diagram. It is conceivable that a few stars in the second quadrant have been affected by this process too.

Figure 3 also shows that KW 204, the Praesepe star having an abnormally strong K line and slightly weak metal lines, is not an isolated exceptional star but is rather just on the edge of a general spread in $\Delta[m_1]$ values among the most calcium-rich stars in the population.

Abt (1966) found a weak anticorrelation between the luminosity increase from zero-age main sequence and the difference in spectral types derived from hydrogen and calcium lines, which seemed to indicate that Am characteristics are moderated with increasing age. This has been confirmed and extended by Smith (1971) and by Henry and Hesser (1971) for both field and cluster Am stars, and more recently it has been investigated and confirmed by Eggen (1976) for

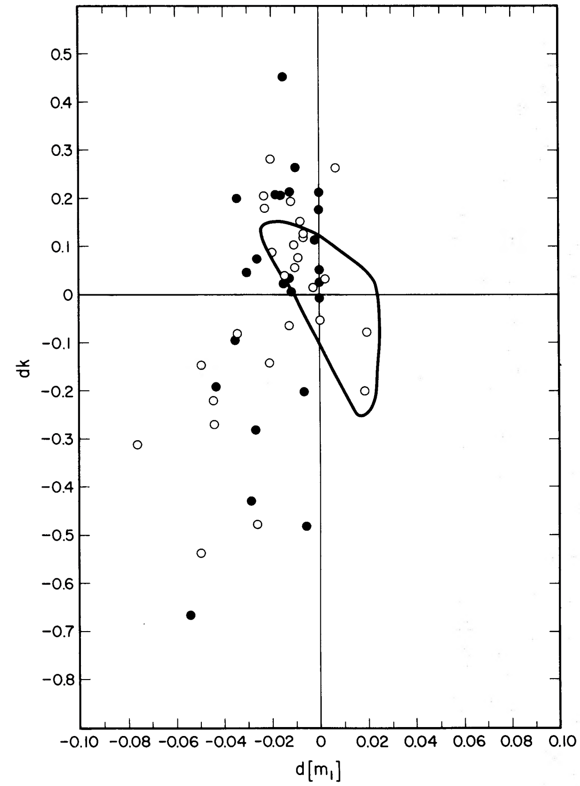

FIG. 3.—This figure is identical to Fig. 2, except that the Hyades stars (*filled symbols*) have been added. Stars recognized spectroscopically as Am have not been distinguished, in order to permit an unbiased assessment of the information content of the photometry. All of the stars in the third quadrant of the figure are regarded as Am stars on the basis of the photometry, and some stars in the second quadrant may have been affected by whatever physical process leads to the Am phenomenon.

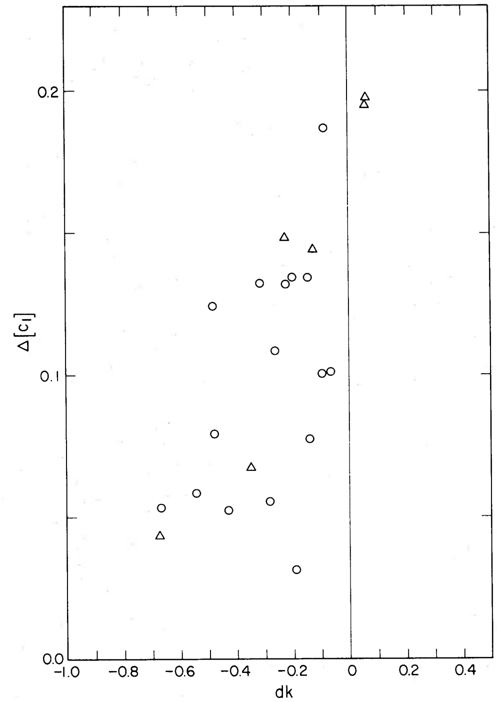

FIG. 4.—The parameter $\Delta[c_1]$ gives an indication of how far a star has evolved off the zero-age main sequence, while a large negative *dk* indicates a star with an extreme Am character. Evolved (large $\Delta[c_1]$) stars in Praesepe-Hyades do not exhibit strong Am characteristics. Triangles indicate Hyades-group field stars (Eggen 1976).

14 stars in the Hyades group. In Figure 4 we add data for seven Praesepe Am stars to Eggen's plot (Fig. 3 of his 1976 paper). The added data only strengthen the conclusion stated above.

V. CONCLUDING REMARKS

Narrow-band photoelectric observations provide evidence favoring Eggen's association of the nearby Hyades and Praesepe star clusters into a single moving group having, on the average, about a factor of 2 higher metal abundance than solar-neighborhood field stars, as well as high internal dispersion in metal-line strengths. Also, very young stars in Orion (Hesser, McClintock, and Henry 1977) and in other clusters do not show any substantial abundance excess, although the field stars show an internal "cosmic scatter" that corresponds to about a factor of 2 dispersion in derived calcium abundance (Henry 1969). Where and how did the Praesepe-Hyades stars acquire their high average metal abundances, K-line strengths, and associated dispersions? Could the abundance of metals in these stars in any way, however remotely, be connected with any one or more of the physical mechanisms responsible for the surprising behavior of K-line strengths in the anomalous globular cluster ω Cen (Freeman and Rodgers 1975; Butler 1975)? Or, given recent evidence of CN strength indices (see, e.g., Hesser, Hartwick, and McClure 1976, 1977), could the high metal abundances of these stars be connected with major gaps in our understanding of the chemical transition from halo to disk populations in the Galaxy? Answers to these and related questions of importance to our understanding of chemical evolution in galaxies deserve vigorous pursuit by various techniques. Studies of many additional Population I clusters with both *uvbyβ* and K-line photometry would seem to be of potentially fruitful, independent, and quantitative value in approaching the problem.

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