Membership of Low-Mass Stars in the
Open Cluster α Persei[1]

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Abstract

The results of a combined astrometric, photometric, and spectroscopic search for low-mass members in the intermediate-age open cluster α Persei are presented. Over 130 low-mass new members have been identified to $M_V \simeq 12.5$, almost doubling the previous number of known members. The new membership information suggests a slight upward revision of α Per's age to $\sim 8 \times 10^7$ yrs. α Per is noticeably spatially elongated in a direction parallel to the Galactic plane, most likely due to tidal deformation. Analysis of the distribution of relative Hα emission strengths among α Per members confirms the view that the mean Hα strength decreases in increasingly older systems. Allowing for survey incompleteness, one cannot reject the idea that the luminosity function is consistent with the field luminosity function to $M_V \simeq 9$ or 10.

1. Introduction

van den Bergh & Sher (1960) found from studying several open clusters that in general the faint end of the cluster luminosity function decreased or remained constant down to the level of observation. If true, the observed cluster luminosity functions are unable to account for the luminosity function of nearby field stars which increases to faint magnitudes. One possible solution is that additional unidentified low-mass stars exist in most (or all) open clusters.

Recent studies in the Hyades (Weis & Hanson 1988, Griffin *et al.* 1988, Stauffer 1982), Pleiades (Stauffer *et al.* 1991, Prosser *et al.* 1991), and Praesepe (Mermilliod *et al.* 1990, Jones & Stauffer 1991) have identified faint candidate members. It is the aim of this study to determine the existence, and some of the properties, of the low-mass membership in the open cluster α Persei. α Per was chosen for study because of the limited information on low-mass membership, because it is nearby (which enables both proper motion analysis and observation of low-mass candidates), because no other clusters of the same relatively youthful age have been studied completely, and because of the existence of the photographic plate material needed for the proper motion analysis.

After a brief review of the history and previous work in this cluster, the proper motion survey of this study is described. This is accompanied by a description of the CCD photometry and spectrocopy programs employed to aid in identifying cluster members. A review of current information on previous members and possible members is also given, followed by a section presenting the new members and candidate members found in this study. An analysis of some cluster properties including luminosity function, age, spatial distribution of members, reddening, Hα emission strengths, and rotational velocity distribution is presented. Finally, the last section provides a general review of the results found in α Per.

2. History and Previous Work.

The α Persei cluster is not a strikingly apparent cluster visually, because its low galactic latitude ($b = -7^{\circ}$) projects it onto a high stellar density field. Boss (1910), Eddington (1910), and Kapteyn (1910) showed that a number of early-type stars in the direction of α Per shared a common motion. They correctly interpreted this common motion in space as evidence for the existence of a cluster.

A landmark investigation of the bright membership down to V $\simeq$ 12 was made by Heckmann *et al.* (1956) and Heckmann & Lübeck (1958). These studies provide the most complete *bright* membership list to date. UBV photometry (Mitchell 1960) of Heckmann's candidates provided not only reddening and distance estimates but also a means for further analysis and rejection of non-members. These studies produced a list of $\sim$ 150 members and likely members down to V $\simeq$ 12 ($M_V \sim 6$). Further analysis of the cluster's membership required radial velocity determinations, and this was provided for most stars by Petrie & Heard (1970) and Kraft (1967a). With a high background field star density and low (but measurable) relative proper motion, the identification of fainter members of α Per was a daunting task until the appearance and application of automatic scanning measuring machines which enable one to rapidly scan for magnitudes and positions, as in Stauffer *et al.* (1989). Altogether, Stauffer *et al.* (1985,1989) identified $\sim$ 80 members over a limited region down to V= 16.5 ($\sim$ 30 Heckmann *et al.* (HE) stars and $\sim$ 50 confirmed new members).

Due to α Per's low galactic latitude and small relative proper motion, members must be identified not only on the basis of proper motion and photometry, but also on radial velocity, spectral type, chromospheric Hα emission (faint end), and, if possible, the presence of lithium. This program therefore has required a variety of methods of analysis and measurement: astrometric measurements, CCD photometry, low-resolution CCD spectroscopy, and high-resolution (echelle) CCD spectroscopy.

3. Proper Motion Survey.

Because the purpose of this research is a search for faint members, the brighter stars have been neglected. The Palomar Schmidt $6^{\circ} \times 6^{\circ}$ field [E/O 1249, plate center: 3h 30m 44s, $+48^{\circ}19'13''$ (1950)] covers most of the α Per cluster. The entire blue and red Schmidt plates for this field were scanned for magnitudes and positions with the Minnesota scanning machine, producing a sample of over 330,000 stars. It was from a color-selected sample of a portion of this scanning output that Stauffer *et al.* (1989) obtained their list of candidates to be measured for proper motion. The same procedure was adopted here, but now including stars over the entire Schmidt field. We chose the same color selection as Stauffer *et al.* (1989). Figure 1 shows a fraction of the stars scanned, with the color-selection based on previous members indicated. The new color-selected sample went to the plate limit and included approximately 30,000 stars. Stars of bad image quality were deleted. The Minnesota scan output provided the following characteristics of the image quality and shape: (1) goodness of fit of a circle to the image, (2) the difference in the diameter between ellipse fitting and circular fitting of the image, and (3) the distance between the image centers as found on the red and blue plates. By comparing objects of different image quality on the plate, we placed a subjective limit on these characteristics – leaving a sample of about 24,500 stars.

The sample was measured in groups of 1000 stars at a time, the maximum number of measurements that can be accommodated at one time on the Lick Automatic Measuring Engine (AME). Each star was measured on four Schmidt plates (two blue, two red) in both direct and reverse orientations. The Schmidt plates used are identified in Table 1. The direct and reverse measures were combined and averaged, discarding discrepant measures. In the end, a little over 23,000 stars, or 94% of the input sample, were successfully measured for proper motions. Those which could not be accurately measured typically had poor image quality or image blending with other stars. Proper motions were determined using a modified central-plate-overlap iterative technique as described in Jones & Walker (1988). The typical one-sigma error in the proper motions was $0\farcs6$ to $0\farcs7$ cent^{-1}. Figure 2 shows the cluster proper motion vector point diagram for regions measured near the central part of the cluster. The center of the cluster's distribution in the proper motion diagram is seen to be $(+1.9, -2.4)$.

A box region was defined about the cluster center in the proper motion diagram, extending $\pm 2.5\sigma$ (where $\sigma = 0\farcs6$ cent $^{-1}$), containing 1784 stars selected for further study. The size of this region could not be enlarged much without significantly encroaching upon the field star distribution about (0,0). When all Schmidt proper motions are plotted, the cluster condensation does not stand out as clearly as it does in Figure 2 where only regions spatially near the cluster center were considered.

Many of the brighter stars ($V \leq 16.0$) were also measured on astrograph plates taken at Lick Observatory for its Northern Proper Motion (NPM) program. Table 2 catalogues the astrograph plates available for the fields which cover a significant part of the area of the sky encompassed by the Palomar Schmidt field. Some stars were measured on more than one astrograph field due to their location. Once the astrograph fields were all measured, those stars with small errors in their proper motions ($< 1\farcs0$ cent^{-1}) determined from astrograph plates alone were used to transform the astrograph system of proper motions onto the Schmidt system. The multiple proper motions were then averaged, with any largely discrepant determinations being rejected. As a result of averaging the Schmidt and astrograph proper motions, many of the stars moved out of the original box region, generally towards the field distribution at (0,0). The astrograph plates, taken in blue and yellow simultaneously, also provide the additional benefit of fairly accurate magnitudes and colors ($\pm 0\overset{m}{.}2$) for the stars - providing a further discriminant in the selection of cluster candidates. The B and V magnitudes from the 9062 and 9168 astrograph fields were used for a further color selection. Almost half of the 779 stars measured (339 stars) were rejected as having photographic photometry incompatible with membership.

The averaged proper motions were used to select likely new candidate members to the cluster. The 'AP' stars, members identified by Stauffer *et al.* (1985,1989), recovered in this survey were used to guide the proper motion selection criteria. Figure 3 shows the proper motion diagram for the group with the recovered AP members indicated. Stars at a radial distance greater than $1''\!\!.25$ cent^{-1} from the cluster motion were rejected as proper motion nonmembers. The spread of the known AP members indicated that the 237 stars within the $1''\!\!.25$ cent^{-1} radius needed further observation to determine their membership status. An additional 79 stars within the same proper motion limit, but without accurate astrograph magnitudes, were also included as candidates. Thus, a total of 316 candidates down to the limiting magnitude of the astrograph plates (V$\simeq$ 16) was obtained from the sequence of color and proper motion selections. These candidates were later augmented by another group of almost 400 stars included in the original 1784, but which were too faint to be measured on astrograph plates. Their proper motions were derived from Schmidt plate measures alone. They satisfy the same criteria as the brighter candidates, falling within a radius of $1''\!\!.25$ cent^{-1} from the cluster motion in the proper motion diagram. The bright and faint proper motion candidates combined bring the total number of candidates to approximately 715.

Since not all 715 candidates are actual members, additional membership criteria must be used. The photometry used in the color-selection is not of the highest accuracy and, due to the cluster's low galactic latitude, one can expect a significant number of field stars along the line of sight to show proper motions similar to that of the cluster. Accurate photometry is needed to further accurately locate members. In addition, in a cluster as young as α Per ($\sim 5\times10^7$ yrs) the low-mass stars will exhibit Hα in emission (Stauffer *et al.* 1984, Herbig 1985). For the brighter candidates, which are generally too early in spectral type to show Hα emission, radial velocities measured from high resolution echelle spectra can be used to confirm membership. The echelle spectra can also be used for the detection of the presence of the λ6707Å Li line, another piece of evidence supporting cluster membership.

A second proper motion survey of the Lick astrograph plate field 9062 was later performed in an attempt to identify low-mass cluster members beyond the boundaries of the Schmidt plate field. This preliminary survey yielded one additional member (AP 119 in Table 10).

4. BVI CCD Photometry.

Photometry of the candidate members in α Per was obtained at the 1-m Nickel Telescope of Lick Observatory using a TI 500×500 pixel CCD with 15 μ pixels at a scale of $0''\!\!.54$/pixel. Observations in B, V, and I were obtained, although B-band observations exist only for the brighter candidates and the Heckmann *et al.* (1956) (HE) stars (see section 6). V and I magnitudes were determined for the large portion of the faint candidates.

DAOPHOT (Stetson 1987) was employed to determine instrumental magnitudes using aperture photometry with annular sky value subtraction. Occasionally, point spread function fitting was used to extract magnitudes in cases of image blending in crowded fields. Standard stars in BVI (Kron) from Stauffer *et al.* (1985) were used to correct for first order extinction and to transform instrumental bvi magnitudes onto the BVI (Kron) system. The resulting standard deviations in the fits were: $\sigma_{\Delta \mathrm{V}} = 0.058, \sigma_{\Delta(\mathrm{V-I})} = 0.047$, and $\sigma_{\Delta(\mathrm{B-V})} = 0.026$.

While multiple observations were averaged, for stars in common with Stauffer *et al.* (1985,1989) the new photometry was also averaged with theirs to produce more accurate mean magnitudes. An exception to this was in cases where we only had V and I magnitudes for a star in common — in that case we kept their B−V value for the star. Another exception was for the photometry of known variables, in which case we kept the mean magnitudes of Stauffer *et al.*.

5. Spectroscopy.

5.1 Low-Dispersion.

Low-dispersion CCD spectra centered on Hα (λ6563Å) were obtained for the faint proper motion candidate members whose V,I photometry indicated that they were likely members. The CCD spectra were taken at the 1-m Nickel and 3-m Shane telescopes of Lick Observatory at a resolution of $\sim$ 2.6 Å/pix, using a 600 ln/mm grism with blaze at 6500Å. The spectra were used for: (1) determination of spectral type, (2) detection of Hα emission, and (3) measurement of the equivalent width of Hα emission.

Spectral types were estimated from the spectra using the index calibration from the Pleiades (Prosser *et al.* 1991), based on the relative strengths of TiO bands. MK standards from spectral types K3 to M5.5 (Keenan & McNeil 1976) were observed and used to transform the index values measured to a spectral type. The spectral types, referred to as pseudo-MK (or 'pMK') spectral types, are good to ± 0.5 in spectral type subclass and can also be used to confirm membership. Analysis of the spectroscopic information will be presented in section 8.

5.2 High-Dispersion (Echelle).

A large fraction of the bright candidates were observed using the Hamilton echelle spectrograph (Vogt 1987) with both the 3-m Shane and Coudé Auxilary telescopes. The benefit of having several wavelength orders per observation enabled all of the following analyses: detection of weak Hα emission, detection of Li absorption (λ6707Å), determination of radial velocity and rotational velocity, and, in some cases, classification of SB1 or SB2 status.

Observations were made using a TI 800 $\times$ 800 pixel CCD which provided an intermittent wavelength coverage from $\sim$ 4600Å to $\sim$ 7300Å over $\sim$ 50 orders with each order comprising $\sim$ 40Å on the chip. A slit width of 640 microns was used, corresponding to $\sim 1.5''$ on the sky and a projected resolution of $\sim$ 3 pixels. The echelle spectra were reduced in a normal manner that included flatfielding, dark count subtraction, and inter-order count subtraction. The presence of Hα emission and/or Li absorption was easily determined in the spectra, which have a dispersion of $\sim$ 0.056Å/pixel at these line locations.

The signal-to-noise of the spectra typically ranged from 30 to 60 (at λ5180). Two select orders were used for measurement of radial and rotational velocities. One order (110) had a wavelength range from $\sim$ 5163Å to 5197Å, and included the strong Mgb I lines at 5168, 5173, and 5184Å. The other order (102) covered the range from 5568Å to 5604Å and contained numerous lines of FeI, CaI, and NiI. The strong Mgb lines are useful in radial velocity determinations from weak S/N spectra because they provide a strong cross-correlation spectrum allowing confident centroid identification.

A radial velocity standard was observed on each night, with a spectral type (F-G V) similar to the α Per candidates being observed. The candidates' spectra were cross-correlated (in pixel space) with the radial velocity standard. A polynomial fit applied to the cross-correlation curve provided the centroid value and the velocity relative to the standard. The candidates' observed radial velocities were corrected to heliocentric radial velocities. The Mgb line order was primarily used for the radial velocity determination. As a check, those radial velocities derived from the Mgb order were compared for some stars with those derived using order 102 and the values were found to agree to within the error of measurement. Errors in the determined radial velocity ranged from 0.4 pixels (= $\pm$1.0km/s) for slow rotators ($v \sin i \leq$ 10km/s) to $\sim$ 2 pixels ($\pm$5.km/s) for higher rotators ($v \sin i \sim$ 100km/s).

Rotational velocities were measured as follows. A low rotation ($v \sin i <$ 10 km/s) field star was observed and reduced in the same manner as the α Per stars. This low rotator's spectrum was then artifically broadened in increasing amounts by convolving its spectrum with the broadening function due to rotation (Gray 1976). The artifically-broadened spectrum was cross-correlated with the original nonrotating spectrum and the FWHM value of the cross-correlation peak measured. A calibration curve between FWHM and $v \sin i$ was obtained after repeating this process for a range in $v \sin i$. The α Per star could then be cross-correlated with the nonrotator standard, a FWHM value measured, and a corresponding $v \sin i$ value determined from the calibration curve.

The orders 110 (with the Mgb lines) and 102 were also used for the rotational velocity measurements. Because the stars range from late-F to K dwarfs, a set of low rotating standards were used: HR 6831 (F8V, $v \sin i < 6$ km/s), HR 996 (G5V, $v \sin i \leq 5.6$ km/s), and HD 75935 (G8V, $v \sin i \leq 6$ km/s). Each program star was cross-correlated with the standard nearest in spectral type. The Mgb lines are unsuitable for measuring rotation for low $v \sin i$ values because their line widths are very sensitive to temperature changes (Gray 1976).

As a check on the rotational velocities, we compared (Table 3) our rotational velocities with those determined by Soderblom *et al.* (1989) and Kraft (1967b). Reasonable agreement is found for the order 102 values for $v \sin i < 50$ km/s. For $v \sin i > 50$ km/s, the order 102 values fall systematically too high, reflecting the difficulty of using weak lines which become easily 'washed-out' at these higher rotational velocities and do not provide a well defined cross-correlation curve. The agreement at large $v \sin i$ using order 110 values, though not perfect, is an improvement. As a result of the above analysis order 102 was used for rotational measures for the slow rotators ($v \sin i \leq 50$ km/s) and order 110 for the rapid rotators ($v \sin i > 50$ km/s). Based on the comparison to the 'standard' $v \sin i$ values, the error in the present $v \sin i$ values for the slow rotators appears less than ± 5 km/s (with a few exceptions) while the uncertainty at large $v \sin i$ is on the order of ± 5 to ± 8 km/s. During the course of the field star observations, HR 7034 was found to be a double-lined binary.

Echelle spectra were also obtained for the 'HE' (Heckmann *et al.* 1956) stars not having previous radial or rotational velocity determinations. Two observations each (one with the 3-m Shane and one with the Coudé Auxiliary (CAT) telescope) of HE 334, HE 660, and HE 841 were also obtained to compare the present $v \sin i$ measures with those of Stauffer *et al.*. Reasonable agreement with their earlier $v \sin i$ values is obtained (Table 3), with the possible exception of HE 841 for which the present values deviate by ~ 10 km/s.

6. Previous Candidate Member Information.

As mentioned in section 2, the researches by Heckmann *et al.* (1956,1958) and Stauffer *et al.* (1985,1989) form the basis of all previously known members of the α Per cluster. In this section we provide data on all known members; the HE and AP stars.

Table 4 lists the HE stars, mainly derived from the membership list of Heckmann *et al.* (1956). In Table 4, the first column lists the HE star number (followed by 'N' if it is a nonmember), followed by the V,B−V photometry from Mitchell (1960), BD identification, and coordinates determined from the x,y coordinates in arcsec given by Heckmann *et al.* (1956). The remaining columns give radial and rotational velocities from a variety of sources, along with membership determinations based on photometry (PH), echelle spectra (ECH), presence of Li, a final membership determination, and some additional notes. The 'Ref' column contains the reference numbers for the sources (given at the end of the table) of the radial and/or rotational velocity data.

Identification of nonmembers in Table 4 was usually based on the star's photometry and radial velocity. The mean heliocentric radial velocity of α Per members is ~ -2 km/s. Slow rotators ($v \sin i \leq 20$ km/s) with radial velocities within ~ 2 km/s of the cluster mean were considered members; with the allowed deviation increasing to several km/s for the most rapidly rotating stars. The expected one co-ordinate velocity dispersion is ~ 0.5 km/s. The observed deviations that were deemed within acceptable membership limits are therefore more than twice the theoretical estimate, and are several times the theoretical estimate for the rapid rotators because of measurement uncertainties [see additional note regarding influence of the spatial distribution of cluster members on radial velocity in section 8.3].

During this study, HE 416, HE 1144, and HE 1162 were found to be additional candidates for membership and they have been included in Table 4. Stauffer *et al.* (1985,1989) obtained BVRI photometry of many HE proper motion candidates and their photometry was also used to aid in membership determinations. Table 5 lists a few bright stars that in the past have been considered as cluster members that were not in the survey of Heckmann *et al.*.

Fresneau (1980) reanalyzed the HE stars for membership by recalculating proper motions using astrograph positions of Heckmann *et al.* (1956) and his own Schmidt plate measures, providing a list of 'suggested' members of the cluster. Trullols *et al.* (1989) obtained $uvby-\beta$ photometry for a number of these and assigned a membership status to them. In this study, photometry and echelle spectra for Fresneau's suggested members were obtained. Table 6 presents the observations of these suggested members (not including seven stars previously considered by Heckmann *et al.* 1958). Table 6 gives the star's name, VBI photometry, number of observations in each magnitude, BD designation, coordinates from Heckmann *et al.*, and the membership probability from Fresneau (1980). The individual star's membership status on the basis of the VBI photometry is given, together with the Trullols *et al.* determination. Radial and rotational velocity information (mostly from echelle spectra obtained in this study) follow, along with some notes and a final membership determination. The membership determinations of Trullols *et al.* are generally confirmed by the new observations. Some stars with questionable membership will require further analysis, including improved proper motions. Of the 58 suggested members by Fresneau, only 13 appear to be members (Y), with an additional five being possible members (Y?).

The AP stars are generally fainter than the HE stars. Those AP stars confirmed as cluster members are presented in Table 7 with photometry and positional information, and radial and rotational velocity measures if available. Included in the table are the stars AP 8, 16, and 34 which were recovered in this study as proper motion candidates and which were subsequently identified as cluster members. Table 8 lists the 14 AP members that were not recovered in this survey and the reason why each star was not recovered. Some AP and HE stars originally identified as members by Stauffer *et al.* have radial velocities discrepant with cluster membership. For some of these, the discrepant radial velocities were confirmed with additional (unpublished) observations mentioned in Balachandran *et al.* (1988), and they are therefore considered radial velocity nonmembers. The stars are: AP61, AP68, AP81, AP105, AP111, HE444, HE457, HE462, HE493, and HE771. Additional corrections/additions to the information published in the Stauffer *et al.* are given in Appendix A.

Table 9 lists the remaining AP stars which are mainly proper motion candidates. Some are recovered HE stars, but the majority require accurate photometric and spectroscopic observations in order to determine their membership status. None of these remaining AP stars were recovered as proper motion candidates in the present study.

7. New Members and Candidate Members.

In this section data for the new confirmed members and candidate members are presented. These are the proper motion candidates with membership determinations based on the additional photometric and spectroscopic observations.

The proper motion candidates are those stars having motions within $1\overset{''}{.}25$ cent^{-1} of the cluster motion (Figure 3), approximately 715 candidates to the scanning limit of the Schmidt plates. Among these were approximately 40 AP stars and 9 HE stars (not all of which are true cluster members). As is discussed below, approximately 135 new cluster members (and some likely members) have been identified, together with $\sim$ 370 nonmembers and 35 to 40 undecided, possible candidate members.

Photometry (mostly in V and I) was obtained for about 590 candidates. Figure 4 shows the V vs. V$-$I diagram for all the proper motion candidates observed, with the final membership determinations indicated. Especially for the fainter magnitudes, one sees how useful the V$-$I color is in separating the cluster stars from the background field star population. The AP, HE, and new members form a well-defined cluster sequence in the diagram (see also Figure 10). The photometric errors increase beyond V$\simeq$ 17, resulting in an artifical widening of the cluster sequence. The cluster sequence is also broadened by the presence of binaries, variables, and extremely rapid rotators. Errors in the photometry are generally on the order of $0\overset{m}{.}06$ to $0\overset{m}{.}08$, increasing to $\sim 0\overset{m}{.}1$ among the faintest stars observed (particularly in the V and B magnitudes). Due to the large number of candidates to be observed, some accuracy in the photometry was sacrificed. However, since many of these low-mass stars are probably variable due to starspots and/or flare activity, several observations per star are required for magnitudes and colors having errors on the order of $0\overset{m}{.}01$. One example of variability of a cluster member is given in Prosser (1991a) where relative photometry of the newly identified member AP149 is given.

We allowed for the presence of binaries and flare stars and for errors in the photometry in our photometric membership criteria. The vast majority of stars lying below the apparent cluster sequence in Figure 4 were considered nonmembers based on their photometry. Additional photometric and spectroscopic data were obtained for stars falling slightly below the general cluster sequence in an effort to determine their status. Criteria for acceptance for membership on the basis of spectral type are given below. For those stars with echelle data, the same membership criteria were applied as were used for the brighter HE stars (section 6). A conclusive membership determination was not always possible, particularly for those stars which fall below but near the general cluster sequence.

Low-dispersion spectra (section 5.1) centered at Hα were obtained for 177 stars, including many AP stars. Figure 5 shows a color-magnitude diagram for all stars having spectra, indicating those which did and did not show noticeable Hα emission. A V vs. spectral type diagram is shown in Figure 6 for the same set of stars using the derived spectral type information from the TiO bands. Those stars showing definite emission at low-dispersion form a fairly well-defined sequence in Figure 6. Those stars falling below this sequence have spectral types too early for their apparent magnitudes and would be considered nonmembers on the basis of their spectral type (allowing for a ±0.5 measurement uncertainty in spectral type subclass). Many of the stars falling below the cluster sequence are late-type (K, early M) stars, with consequently weak Hα absorption. Some stars along the cluster sequence labeled 'Hα filled' may be stars having weaker Hα emission that is not strong enough to result in a noticeable emission feature at this resolution. Hα filled stars falling below the cluster sequence likely have Hα in absorption but the contributing factors of low-resolution and low signal-to-noise spectra did not make identification of an absorption feature possible.

The presence or absence of emission itself should *not* be used as a sole membership criteria. That has not been done here. The spectral type information is an effective aid in assessing membership and the Hα observations are used essentially as a confirmation or additional secondary aid. It is interesting to note however that in this sample of candidates observed there were no stars falling on the cluster sequence beyond V$\simeq$ 15 which did not show Hα in emission or filled. Further analysis of the Hα emission strength as a function of spectral type will be given in section 8.5.

For most faint (V$\geq$ 17.5) proper motion/photometric candidates, low-dispersion Hα spectra were obtained at the Multiple Mirror Telescope for the author by Lee Hartmann and his associates and John Stauffer. Only the presence/absence of Hα emission could be determined from these spectra. Most of these show noticeable Hα emission (only a couple having Hα filled). Thus, all the new low-mass members having low-dispersion spectra show definite Hα emission (the majority of stars) or show Hα filled. Those candidates which do not have low-dispersion spectra but are considered members or possible members are AP 148, 159, 160, 177, and 262. No selection effect on the basis of the presence/strength of Hα emission has been introduced in deriving the membership status of the candidates.

Table 10 presents the results of the above photometry and spectroscopy observations for those candidates whose final membership determination indicated that they were members (Y), likely members (Y?), or undecided (?) candidates. There are 132 new members and likely members and 16 undecided candidates. To prevent undue difficulty in regards to identification, the new members and candidate members are given the designation of 'AP' stars and are numbered consecutively to follow the lists of Stauffer *et al.* (1985,1989). The columns give the AP number, VBI photometry, number of observations in V, B, and I, 1950 coordinates, relative proper motions and errors in $''\text{cent}^{-1}$, Hα equivalent width, and spectral type from low-dispersion spectra. These data are followed by the individual membership determinations for the star on the basis of photometry, Hα emission/filled, spectral type, and Hamilton echelle spectra data. (The Hα column lists Y = emission, F = filled, WA = weak absorption, or N = no emission.) A final membership determination is indicated, together with any additional notes. The note 'MMT' in Table 10 means that a low-dispersion MMT spectrum at Hα was obtained. Table 11 lists the radial and rotational velocity data and Li 6707 line presence for the new AP stars. Finding charts for the new AP stars are available upon request from the author and are given in Prosser (1991a).

All those proper motion candidates that were classified as nonmembers (N) or likely nonmembers (N?) on the basis of their photometry and/or additional observations are given in Prosser (1991a). The information there on the rejected candidates will hopefully be of use to other observers in rejecting the same candidates that may be recovered in the future.

It is instructive at this point to look at the distribution of members, nonmembers, and undecided stars in the original proper motion diagram. Figure 7 shows the proper motion candidates with their final membership status indicated. Notice that the new members extend all the way to the limiting radius of the sample – indicating the likely existence of cluster members beyond those limits. This was not unexpected given the typical errors in the proper motions ($1\sigma \sim 0\farcs6$ cent^{-1}) and that the candidate selection area was only slightly over 2σ in radius. (As discussed in section 3, the area size was limited due to encroachment upon the adjacent field distribution about $(\mu_x, \mu_y) = (0, 0)$.) One sees also that the nonmembers are well distributed throughout the selection area, with a slight indication that the fraction of nonmembers begins to increase in the direction towards the field distribution. The distribution of members as a function of magnitude in the proper motion diagram is discussed in Prosser (1991a).

Figure 8 is the same as Figure 7 but with the nonmembers removed. Figure 8 indeed shows that, while the cluster members extend to the limiting radius, they are concentrated at the cluster mean motion. The proper motion candidates were observed for CCD photometry primarily in order of their radial distance from the cluster mean motion. Of the $\sim$ 715 candidates, photometry was not obtained for approximately

123 stars. These unobserved stars fall in the region of the proper motion diagram that is most severely contaminated by the tail of the field star distribution (i.e. the extreme upper right of Figures 7 and 8). It is expected that there are only a few cluster members within the group of faint stars without photometry. The loss of these few potential members will not affect the general analysis in the next section.

8. Analysis of α Persei Cluster Members.

Combining all HE, AP, and new AP members and likely members, one finds that the α Per cluster has a total of about 300 currently known members. The new observations in this study result in a 'cleaner' HR diagram than previously, as is shown for the upper main sequence in Figure 9. A similar color-magnitude diagram is presented in Figure 10 for the lower main sequence. While there remain membership uncertainties among some of the brightest stars (which were not the object of this study), the refined and additional membership information enables several characteristics of the α Per cluster to be investigated.

8.1 Luminosity Function.

Current membership for α Per extends to V$\simeq$ 18.8. Using a mean reddening of E(V$-$I) = 0.16 and distance modulus of $(\mathrm{m-M})_o$ = 6.1 (Stauffer *et al.* 1989), this limiting magnitude corresponds to $\mathrm{M_V} \simeq 12.5$ [note: $\mathrm{A_V} = 1.9\times$ E(V$-$I) $\simeq .30$], reaching a very low-mass domain ($\leq .25\mathrm{M}_\odot$). Table 12 gives the observed luminosity function for α Per and also for the Pleiades, corrected for incompleteness (Stauffer *et al.* 1991). The observed luminosity function for α Per is shown in Figure 11, together with the Pleiades distribution scaled to that of α Per and the scaled field luminosity function (Weilen 1974). The Pleiades distribution has been normalized to have the same number of stars as α Per for $1 < \mathrm{M_V} < 3$, while the interval $4 < \mathrm{M_V} < 6$ was used in normalizing the field distribution to that of the clusters.

There is no known bias effect in the present survey which could cause the 'dip' seen in α Per's luminosity function at $\mathrm{M_V} = 8$. Instead, this feature appears to be a recovery of the 'Wielen dip' feature (Bahcall 1986) seen in Wielen's field luminosity function in the range $6 \leq \mathrm{M_V} \leq 10$. The reality of the existence of this dip in the field luminosity function (compared to Luyten's (1968) smoothed field luminosity function) has been supported by the investigations of Upgren & Armandroff (1981) and Pritchet (1983). [This feature is also seen in the analysis of the low-mass membership of IC 4665 (Prosser 1991b).] One can see that α Per's observed luminosity function does not match either that of the Pleiades or field – however there is likely to be considerable incompleteness for $\mathrm{M_V} \geq 5$. The fact that there is some incompleteness in the present survey has been demonstrated in regards to the distribution of members in the proper motion diagram (i.e. Figure 7).

Two methods were used to estimate the amount of incompleteness. First, the number of HE members recovered in the present survey was compared to the total number of HE members in the magnitude range common to both samples: $11 \leq V < 12$. Allowing for differences in area coverage between the surveys considered, an incompleteness factor of ~ 1.7 was found. Second, the number of AP stars recovered, which extend to fainter magnitudes than the HE sample, was compared to the number of previous AP members. The present survey recovered about 36 out of around 50 original AP stars now considered members (Table 7). This yields a incompleteness factor of $\sim$ 1.4 for the present survey. On the basis of the incompleteness factor estimates and obvious incompleteness exhibited in the proper motion diagram of new members, one cannot reject the idea that α Per's luminosity function is consistent with the distributions of the Pleiades and field down to $M_V \simeq 9$ or 10 (disregarding the evolutionary effects in the high-mass star domain of the field distribution). Only further membership studies will determine if increases in the number of members by the factors of about two and four for the Pleiades and α Per respectively are possible at the faintest magnitudes in order to bring the cluster distributions into agreement with the general field.

No allowance for the presence of binary systems has been made in the observed luminosity function for α Per. Attempting to correct the luminosity function for binary systems at this time would be premature, due to the incompleteness of the survey and to the errors in the photometry which do not allow a completely accurate identification for example between likely binary systems and flare stars on the pre-main sequence. The Pleiades luminosity function also did not allow for binary systems. Preliminary study of the HR diagram for α Per indicates that the number of binary systems is not as large as in many other clusters, and correcting for binary systems would not significantly affect the above conclusions.

8.2 Age.

What is the age of the α Per cluster? Stauffer *et al.* (1985,1989) found that an age of $\sim 5 \times 10^7$yrs was consistent with the then available membership data of the lower main sequence. The large number of new members identified in this study enables a reanalysis to be made. VandenBerg's (1987, unpublished) theoretical evolutionary tracks for low-mass stars (from 1.0 to 0.3 $M_\odot$) were provided to the author by John Stauffer and used to construct isochrones for various ages. VandenBerg's models are for Y= 0.27, Z= 0.169, and $M_{bol\odot} = 4.72$. The following procedure was used to convert the isochrones from the theoretical (M_{bol}, log T_{eff}) to observational (V,V−I) plane: (1) for each isochrone, the vertical displacements between the theoretical zero-age main sequence (ZAMS) and the isochrone were determined over a range of effective temperatures, (2) the relation between temperature and V−I was determined (discussed below) and corresponding V−I values calculated, and (3) the vertical displacements for each isochrone determined at various V−I values were added to an observational ZAMS (assuming $\Delta M_V = \Delta M_{bol}$).

Two sets of calibrations were employed for the temperature to V−I conversion. For log $T_{eff} > 3.62$, temperature was converted to B−V using the empirical relation given by Arribas & Roger (1988,1989), which are in agreement with the computed B−V values given by VandenBerg for the 0.7-1.0 $M_{\odot}$ evolutionary tracks. The B−V value was then converted to V−I using a color-color relation derived from the field star photometry of Kron *et al.* (1957). At the lower mass end, log $T_{eff} < 3.62$, a R−I value was determined for a given temperature using the relation tabulated in Mould & Hyland (1976). The R−I value was then transformed to B−V and V−I values, again using the Kron standards. To make the transition between log $T_{eff} > 3.62$ and log $T_{eff} < 3.62$ more continuous, a small offset was added to the B−V and V−I values for log $T_{eff} < 3.62$: $\Delta(B-V) = -0.035$ and $\Delta(V-I) = -0.050$. The observational zero-age main sequence (ZAMS) was obtained from a lower envelope fit to the observed V vs. V−I diagram of the Pleiades (Stauffer 1990), shifted to the distance and reddening for α Per. The individual isochrone displacements were added to the corresponding ZAMS position at that V−I. The observational ZAMS is not truly a ZAMS at the faint end, since the Pleiades stars are still contracting. However, this observational ZAMS and the solar-metallicity ZAMS for M dwarfs by Stauffer & Hartmann (1986) are in agreement to V−I $\simeq$ 1.9 (mass $\sim$ 0.5 $M_{\odot}$). Redward of this value they gradually diverge, the M dwarf ZAMS lying only about $0\overset{m}{.}15$ below the Pleiades lower envelope curve at V−I = 2.2. Hence, the observational ZAMS derived from the lower envelope Pleiades fit is accurate for most of the domain in α Per covered by the isochrones. Figure 12 shows the V vs. V−I diagram for α Per with the transformed isochrones and lower envelope Pleiades fit. The isochrones are tabulated in Prosser (1991a).

From Figure 12, the isochrone that provides the best fit to the single star pre-main sequence is 8×10^7yrs. An age of $\sim 7 \times 10^7$yrs cannot be ruled out however, given the errors in the current photometry, uncertainties in the theoretical models, and errors introduced in the transformation of the isochrones from the theoretical to observational plane. The 5×10^7yr isochrone in Figure 12 is not significantly different from that plotted by Stauffer *et al.* (1985,1989), lending credence to the positions of the other isochrones. The main sequence turn-on point associated with the 8×10^7yr isochrone occurs at V$\simeq$ 13.6. Better photometry, low-mass evolutionary models, and temperature calibrations will all be needed to enable one to obtain a more accurate age determination.

Earlier age estimates for α Per, based on upper main sequence fitting, yielded an age of $\sim 5 \times 10^7$yrs (Mermilliod 1981). The older age of $\sim 8 \times 10^7$yrs found here from fitting the lower pre-main sequence is in accord with other recent increased age estimates for the Pleiades and Hyades clusters. Mazzei & Pigatto (1988,1989) have determined an age of 1.5×10^8yrs for the Pleiades and $\sim 10^9$yrs for the Hyades age, where earlier determinations had estimated 7.7×10^7yrs and 6.6×10^8yrs respectively (Mermilliod 1981). The apparent age differences between the upper and lower cluster main sequences have been used to argue in favor of a sequential star formation process (i.e. Eggen & Iben 1988). However, Mazzei & Pigatto (1989) (see also Stahler 1985) recount the uncertainties inherent in the age determination process and make a plausible argument against the idea that the difference in age determinations from the upper and lower main sequences is particularly meaningful and implies sequential star formation. The lower main sequence of α Per does not appear to show the presence of a significant age spread ($>> 10^7$yrs).

8.3 Spatial Distribution.

The earliest studies on the bright members of α Per comment on the cluster's elongated shape as seen on the sky. Eddington (1910) remarks that "The stars are arranged in a kind of chain and not in the form of a globular cluster." Eighty years later, from the results of past and present membership studies, we can see if the spatial distribution of bright members reflects the general distribution of the cluster as a whole.

The spatial distribution of members and likely members is shown in Figure 13. One immediately sees that the cluster's distribution on the sky is decidedly non-circular. Using known members to define the cluster's extent, the flattened distribution has a major axis of at least 7° and a minor axis of $\sim 5°$ projected on the sky ($\sim$ 20pc and 14pc respectively at the distance of α Per). This elongation is parallel to the galactic plane – as predicted from theories of tidal deformation. The tidal radius of α Per is on the order of 10pc, in agreement with the semi-major axis of 3.5° found above; however cluster members can be found beyond the tidal radius of a cluster (see discussion in Terlevich 1983). Terlevich also mentions the recent observational indications of flattening for the Hyades (Oort 1979) and Pleiades (van Leeuwen 1983). The elongation or flattening shown in this present study on α Per however is currently believed to be the best observational confirmation of cluster flattening. The flattening may be due to tidal deformation. However other possibilities exist, such as a residual angular momentum component in the cluster system. It will require accurate proper motions and radial velocity studies in order to distinguish the exact cause.

The spatial distribution of α Per influences the dispersion in distance moduli and radial velocities of cluster members. If one assumes a 'depth' of the cluster of 20pc and a distance of 165pc ($(m-M)_o = 6.1$), then the distance moduli of members will vary from $(m-M)_o = 5.95$ to $(m-M)_o = 6.22$. If not accurately accounted for, variable reddening will increase the observed spread in $(m-M)_o$. Geometrical considerations of the cluster's extent, together with its mean radial velocity, absolute proper motion, and distance, lead to an expected variation in observed radial velocity of ± 1.5 km/s about the mean radial velocity of ~ -2 km/s. This variation should appear as a smooth gradient in the mean radial velocity that represents a total change of about 3 km/s across the cluster. For Praesepe, a calculated variation of ± 2.3 km/s, or total change of 4.6 km/s, has been estimated (Mermilliod *et al.* 1990). Of course, any membership determinations based on distance modulus and/or radial velocity should allow for the expected variations in these quantities. Allowances for such variations in radial velocity have been made in the membership determinations in this study. The current membership and radial velocity information is not complete enough however to allow confident detection of the spatial variation in cluster radial velocity.

8.4 Interstellar Reddening.

Color excesses, E(V−I), were determined for late-type members with low-dispersion spectra. The analysis follows the method outlined in Prosser *et al.* (1991). The spectral type derived from a low-dispersion spectrum is used to estimate the star's reddening-free V−I color. A comparison of this with the observed V−I color gives the color excess, E(V−I).

The relationship between the derived spectral types and V−I color was determined from the large sample of Gliese stars observed in the course of the Pleiades research. Observed V−I colors were obtained for those stars from Stauffer & Hartmann (1986) where possible. Otherwise, since the Gliese catalog (1969) does not provide V−I colors, the GL stars' R−I colors were transformed to V−I using the color-color relation of the Kron field standards used in the theoretical isochrone analysis. A mean relation between pMK spectral type and $(V-I)_{\rm Kron}$ color for the field stars was then fit by eye (additional details are in Prosser 1991a). Only the stars with pMK spectral type $\geq$ M 0.0 are considered due to the increasing difficulty of accurately measuring spectral types from the TiO bands for earlier classes and due to the difficulty of establishing an accurate pMK spectral type vs. V−I relation earlier than M0.0 with the present data.

Individual E(V−I) reddenings were determined following the procedure outlined above for those α Per M dwarfs with low-dispersion spectra available (Table 15 in Prosser 1991a). The derived E(V−I) values do fluctuate somewhat, occasionally being negative, as would be expected as a result of the uncertainties in the pMK spectral types and approximate transformation of these into reddening-free V−I values. ¿From the 75 M dwarfs with E(V−I) values, the mean reddening is determined to be $<E(V-I)>= 0.184 \pm 0.001$ (s.d. mean). This mean value, although slightly larger than the value of 0.16 usually adopted for the cluster, is not significantly different if one takes into account the variations in reddening observed across the cluster. This mean value corresponds to E(B−V) = 0.11 and E(b−y) = 0.08, in good agreement with the mean reddenings determined by Crawford & Barnes (1974) for the A stars (E(b−y) = 0.076) and the B stars (E(b−y) = 0.078), though their value for the F stars gave only E(b−y) = 0.060.

The variation in reddening across the cluster is shown in Figures 14 and 15. Figure 14 shows the locations of bright members, with reddenings from Crawford & Barnes (1974) indicated. Figure 15 shows the cluster distribution with the M dwarf reddenings indicated. The reddening determinations presented here for the M dwarfs are only preliminary values because the V−I photometry for a fair fraction of these is not of the highest precision. Comparison of the figures suggests that a few areas have enhanced reddening: the region to the east (and slightly north) of α Per itself, and an area around $(\alpha,\ \delta) = (49°, 47.6°)$ in the south-central region possibly extending east-west. The present data provide a rough indication of the scale and distribution of the reddening across the cluster; for instance, no general smooth trend in E(V−I) is seen in any particular direction across the cluster. The individual reddenings are near the mean over most of the cluster area, with a few localized high-reddening areas described above. Due to the preliminary nature of the E(V−I) values, no attempt has been made here to produce a reddening corrected HR diagram for α Per. Such a diagram however is very important to reduce observational spread of the main sequence, to provide better identification of possible binary stars and rapid rotators, and to determine whether an age spread significantly contributes to any observed spread of the main sequence.

8.5 Hα Emission.

In the study of the low-mass membership of the Pleiades (Prosser *et al.* 1991), the Hα emission strength as a function of spectral type was studied using field stars, Hyades members, and Pleiades members. That study is extended here with the younger α Persei members.

The Hα equivalent widths (hereafter 'EW') for the new AP stars are given in Table 10. Additional spectroscopic obervations for other AP stars are given in Table 13. As in the Pleiades study, the EW values are not considered accurate in the cases of weak emission (≤ 1Å) due to the difficulty in continuum placement. For comparison with the earlier study, the α Per equivalent widths have been transformed onto the Stauffer/Hartmann ('SH') system using the transformation given in Figure 7 in Prosser *et al.* (1991). The SH values are considered to be more accurate, since SH used higher resolution spectra.

Figure 16 shows the Hα EW vs. pMK spectral type for α Per. The dashed line is a rough fit to the mean upper envelope for the Pleiades cluster (Prosser *et al.* 1991). From comparison with the earlier study of the Pleiades, Hyades and field, one finds that the α Per stars show a significant overlap with the other distributions.

A clearer representation of the data can be made by removal of the spectral type dependence seen in Figure 16. The relative Hα strength, $f_{H\alpha}$, is defined as the ratio of the star's observed Hα EW to the EW of the Pleiades upper envelope curve at the star's observed spectral type. Prosser *et al.* (1991) show that use of $f_{H\alpha}$ instead of $EW_{H\alpha}$ should eliminate the spectral type dependence and enable a more physically meaningful comparison of emission-line strength between the clusters.

Due to the inaccuracies present for spectral types earlier than M0.0 as a result of the low-dispersion and weak emission, analysis of the relative Hα strengths are restricted to those cluster stars of pMK types of M0.0 and later. Table 14 tabulates the $f_{H\alpha}$ distributions found previously in the Pleiades and Hyades clusters (Prosser *et al.* 1991) along with that for α Per from the M dwarfs in Tables 10 and 13. The sample sizes are comparable, and observations in each cluster extend from M0.0 to about M4.5. The α Per observations confirm the conclusion that the mean Hα emission strength decreases as one moves to systems of increasing age. As discussed in Prosser *et al.* (1991), the decline in mean strength is qualitatively compatible with evolutionary schemes in which both stellar surface activity and rotation decline with advancing age. Like the Pleiades and Hyades, the relative emission strengths in α Per show a marked spread. The distribution for α Per does show a noticeable tail extending to stronger emission strengths than the Pleiades. The mean relative emission strength for α Per appears only slightly larger than that for the Pleiades. This is not too surprising considering the relative cluster ages. The larger displacement in mean strength between the Hyades and Pleiades distribution is accompanied by a change in age that is a factor of 3 to 4 bigger than the age differential from Pleiades to α Per.

During this study one apparent flare star member was detected: AP203. A MMT spectrum of the star in 1989 showed tremendous Hα emission ($EW_{H\alpha} \sim 45$Å). A second spectrum obtained in 1990 showed a more typical emission strength ($EW_{H\alpha} \sim$ 10Å). This is at present the only known flare star member of α Per. Tsvetkov and collaborators (Tsvetkov 1991) are currently planning an α Per flare star survey. Such a survey will be very important not only for studying flare activity in the cluster but also for the identification of new candidate cluster members. An efficient flare star survey should improve the completeness of the low-mass membership in this cluster.

8.6 Rotational Velocity Distribution.

In recent years there has been increased interest in the study of the rotational velocity distribution in young to intermediate age open clusters (e.g. Stauffer & Hartmann 1987). The $v \sin i$ determinations from this study do not alter the previous conclusions of Stauffer *et al.* (1985,1989). Figure 17 shows the $v \sin i$ distribution as a function of reddening-corrected B−V, using a mean value of E(B−V) = 0.10. Ideally, one would want to correct each star individually due to the variable reddening, however that is not possible to do with sufficient accuracy at the present time. Small individual changes however will not affect the general overall $v \sin i$ distribution and do not change the conclusions drawn. [Note that those stars with $v \sin i \leq$ 10km/s have been plotted at the upper bound of 10km/s in Figure 17.]

As Figure 17 shows, there is a broad range of observed $v \sin i$ values at a given color among the low-mass stars. Stauffer *et al.* (1985) mention three possible contributing influences to such a spread in $v \sin i$: (1) spread in initial angular momentum, (2) variation in inclination angles, and (3) an age spread among the low-mass stars. As they point out, it is not possible at present to distinguish between these; however the increased number of new members found in the present study will aid future detailed studies on this issue. The $\sin i$ distributions can in fact be determined through the use of $v \sin i$ and photometric period determinations. Only a few stars in α Per have reliable photometric periods however (see Prosser 1991a).

8.7 Binaries.

From past membership studies, several members and candidate members have been identified as binaries (SB1 or SB2) or possible binaries, although no periods were determined. When many other clusters have been studied to some extent in regards to their binaries, such as IC 4665, it is remarkable that a similar study in α Per has not been previously undertaken. However, a study of the binary frequency of α Per's upper main sequence has just recently been completed (Morrell & Abt 1991). Mermilliod (1991) has also provided some additional SB identifications (Table 4).

The identification of binaries will be of increasing importance in the future as the structure of the lower main sequence is investigated. Figure 18 shows the transition region between main sequence and pre-main sequence, where a large percentage of the stars have radial and rotational velocity determinations. There are a significant number of stars lying above the main sequence here. During this study, four SB2's and at least two SB1?'s were identified – each from only one observation. These are indicated in the figure. One sees from the figure that stars having rapid rotation are not necessarily displaced from the general main sequence position. After accounting for known binaries, possible SB1's, and rapid rotators, there remains a number of stars lying above the main sequence in the diagram. The observational data for these stars give every indication that they are members. Reasons for their displacement from the main sequence could be (1) some (or all) really are binaries which were not detected from the single observation, or are wide binaries undetectable at the current resolution limit, (2) the possibility of inaccurate photometry, (3) stellar variability, or (4) the influence of enhanced reddening for these stars. The photometry however is believed to be accurate at this magnitude level, and several stars have more than one observation for photometry. While it is quite likely that at least some are undiscovered binaries, it is also possible that enhanced reddening comes into play in some cases. Those stars which may possibly lie in high-to-moderate reddening areas are listed in the caption to Figure 18. Further observations of photometry, radial velocities, and reddening are all desirable for these stars.

During the course of the CCD photometry of proper motion candidates, some visual binary systems were discovered in which the photometry suggests both stars are members or possible members. This allowed the survey to be extended to even lower mass stars. Table 15 lists the visual binaries with their associated photometry and positional information. Low-dispersion spectra were obtained for AP6C and AP107 and these do show Hα emission (AP107) and Hα filled (AP6C). Since it appears that the original identification of AP107 by Stauffer *et al.* was a duplicate identification of AP106, the faint companion to AP106 has been termed AP107. AP143C has every indication of being a member, although it lacks a confirming low-dispersion spectrum. It appears to be the lowest mass member of the cluster discovered to date.

9. Summary and Discussion

An extensive membership survey concentrating on low-mass stars has been conducted in the relatively young open cluster α Persei. A comprehensive data set of proper motions, photometry, and spectroscopy has been obtained to identify members. Over 130 low-mass cluster members have been identified to $M_V \simeq 12.5$, almost doubling the number of known members in this cluster.

Analysis of the α Per members has indicated that, allowing for effects of incompleteness in the present survey, one cannot reject the idea that the luminosity function for α Per is consistent with the Pleiades and field luminosity functions to $M_V \simeq 9$ or 10. Inspection of the location of the new members in the HR diagram suggests a slight upward revision of the cluster's age to $\sim 8 \times 10^7$ yrs. Improved low-mass evolutionary calculations are desirable in order to better compare to the observations. Perhaps in a few years such calculations will become available as new opacity information becomes available. The lower main sequence observations also suggest that α Per does not show the presence of a significant age spread ($>> 10^7$ yrs).

The present survey has shown that the α Per cluster is spatially elongated in a direction parallel to the Galactic plane. The most straightforward explanation for such flattening is tidal deformation. Detailed study of such cluster flattening in the future should reveal much information about the interactions between clusters and their environment and provide an observational comparison to present theoretical modeling. The distribution of α Per members over an extended area on the sky has consequences in regards to the observed range in the values of radial velocities and distance moduli for cluster members.

Comparison of photometry and spectral types for 75 M dwarfs has resulted in a mean reddening of $E(V-I) \simeq 0.18$, in good agreement with earlier estimates. Some spatial variation in reddening across the cluster is seen, although the data is not accurate enough to allow precise reddening corrections to be applied. Study of the distribution of relative Hα emission line strength in cluster members confirmed the idea that the mean Hα strength increases in progressively younger systems. The α Per observations show a range in relative emission strengths, but with a noticeable tail in its distribution that extends to stronger relative strengths than observed in the Pleiades.

The observed rotational velocity distribution in α Per was updated with the new observations. The previous findings by Stauffer *et al.* (1985,1989) have not been altered. Continued high-dispersion observations are needed in order to investigate the morphology of the lower main sequence and pre-main sequence with respect to binaries and rapid rotators. Finally, some visual binary systems were found to be likely cluster members, including one system containing the lowest mass cluster candidate member at $M_V \simeq 13.5$.

Does the luminosity function of most open clusters resemble the field luminosity function for low-mass stars? Results here have shown that this possibility cannot be rejected for α Per. If one takes this result along with the results of other recent studies (e.g., Jones & Stauffer 1991, Stauffer *et al.* 1991, Adams *et al.* 1983), it is clearly shown that intensive surveys do identify low-mass members and help remove the earlier belief that there is a real discrepancy in the luminosity function of low-mass stars between clusters and the general field. Some clusters may exist which do have a steeply declining luminosity function at low-masses. However, results of several current surveys have begun to suggest that this is not the norm. Given the currently available technology in the areas of astrometry, photometry, and spectroscopy, there remains much work to be done in the area of open cluster membership studies.

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Appendix A

Listed below are some corrections/additions to the information on previous AP stars published in the Stauffer *et al.* papers.

AP 19: = HE 622

AP 28: RA = $3^h 22^m 21.6^s$

AP 50: = HE 716

AP 89: wrong star marked on Stauffer *et al.* chart, AP 89 is bright star north of one marked.

AP 90: = HE 389, Fresneau suggested member.

AP107: this star identified by Stauffer *et al.* is believe to be a duplicate identification of their AP106. However, in this study a faint companion lying $\sim 4.5''$ NNE of AP106 was found and has been termed AP107.

AP110: DEC = $49°51'18''$

AP115: nonmember, spectral type (this study) appears too early for membership in cluster.

It should be noted that Balachandran *et al.* (1988) have given a listing for AP107 which is apparently a duplicate measure of AP106. In this study, HE1225 is considered to be a nonmember on the basis of its distance modulus (Crawford and Barnes 1974), duplicity, and radial velocity.

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Figure Captions

Fig 1. Color-magnitude diagram of a representative fraction of the stars from the Schmidt plate scan. Some previous cluster members are identified. The color-selection is indicated by the line, below which stars were rejected from further consideration. The one member falling below the line is AP 20. Its color is off because it lies within a ghost image defect on the Schmidt plates.

Fig. 2. Proper motion vector point diagram from Schmidt plate measures for regions which are spatially near the cluster center. The cross at $(+1.9, -2.4)$ marks the center of the cluster's distribution and the dashed box indicates the region within which stars were considered for further measurement and observation.

Fig. 3. Proper motion vector point diagram showing only the 440 stars kept after the astrograph color selection. The recovered members ('AP' stars) are indicated. The cross at $(2.05, -2.35)$ marks the center as defined by the recovered members. All stars falling within $1\farcs25$ cent^{-1} from this center were considered to be proper motion candidates needing further observations.

Fig. 4. V vs. V-I diagram for all proper motion candidates observed, with their final membership status indicated.

Fig. 5. V vs. V-I diagram of those candidates for which low-dispersion spectra were obtained. The status of the Hα feature is indicated.

Fig. 6. V vs. pMK spectral type for the group of stars in Figure 5. The spectral types are on plotted on the system K3 = -4, K5 = -2, K7 = -1, M0 = 0.0, M1 = 1.0, ..., through M5 = 5.0. Some stars are seen to be too early in spectral type for cluster membership for their apparent magnitude.

Fig. 7. Vector point diagram for the proper motion candidates with their membership status indicated.

Fig. 8. Same as Figure 7, but with the nonmembers removed. The new members tend to be concentrated near the cluster motion, however they do extend to the limits of the area under consideration.

Fig. 9. Color-magnitude diagram of the upper main sequence region for α Per. Approximate spectral type locations are indicated.

Fig. 10. Color-magnitude diagram of the lower main sequence for α Per, with approximate spectral type locations indicated.

Fig. 11. Observed luminosity function for α Per (Table 12), along with that for the Pleiades and solar neighborhood. The Pleiades distribution has been scaled to the distribution for α Per. The scaled field luminosity function was adopted as an relation intermediate between the field function scaled to the Pleiades luminosity

function, which has been corrected for survey incompleteness by Stauffer *et al.* (1991), and the field function scaled to α Per, which suffers from incompleteness effects for $M_V \geq 5$.

Fig. 12. V vs. V-I diagram for α Per with transformed isochrones and Pleiades lower envelope plotted.

Fig. 13. Spatial distribution of cluster members. Brighter stars are denoted by larger symbols. The dashed region indicates the approximate limits of the present survey for low-mass cluster members. An obvious elongation of the cluster members is seen. The elongation is in a direction that is parallel to the galactic plane.

Fig. 14. E(V-I) reddening distribution for the brighter members (HE stars) with available E(b-y) values from Crawford and Barnes (1974). The small dots represent stars which do not have reddening determinations.

Fig. 15. E(V-I) reddening distribution for M dwarfs using reddening values given in Prosser (1991a). The symbols are the same as those given in Figure 14.

Fig. 16. Hα equivalent width vs. pMK spectral type distribution for α Per. Those stars with Hα in absorption or filled are plotted with equivalent width = 0. The mean upper envelope to the Pleiades Hα distribution is indicated.

Fig. 17. Rotational velocity distribution as a function of reddening corrected B-V color for members and likely members. Approximate corresponding spectral types are indicated.

Fig. 18. V vs. V-I diagram of transition region between upper and lower main sequence. Known spectroscopic binaries and extremely rapid rotators are identified, along with some other stars falling above the main sequence that may be binaries. The stars AP 93, 158, 197, 199, and 264 lie in areas of possible high or moderate reddening.