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Laurence A. Marschall
Gettysburg College

Neil F. Comins
University of Maine - Main

Gary B. Karshner
Gettysburg College

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Keywords
UBV observations, photometry, Trumpler 37, open cluster stars

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PHOTOMETRY OF THE YOUNG OPEN CLUSTER TRUMPLER 37

LAURENCE A. MARSCHALL[a)]
Gettysburg College, Gettysburg, Pennsylvania 17325

NEIL F. COMINS[a)]
University of Maine, Orono, Maine 04469

GARY B. KARSHNER[a)]
Gettysburg College, Gettysburg, Pennsylvania 17325
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ABSTRACT

Photoelectric *UBV* observations of 120 stars in the young open cluster Trumpler 37 are presented, primarily in the magnitude range $10.0 < V < 13.5$. An analysis of the color–magnitude diagram of the cluster yields an age of 6.7×10^6 yr and reveals the presence of a number of possible pre-main-sequence stars in the cluster.

INTRODUCTION

Trumpler 37 (Co 2137 + 572, $l = 99.3°$, $b = 3.73°$), an open cluster associated with the H II region IC 1396, has been identified with the nucleus of the Cep OB2 Association (Simonson 1968). It is one of the very youngest of the open clusters in the Milky Way ($\log t < 7.0$), comparable in age NGC 2264, NGC 2244, IC 1805, and NGC 6530. Its hottest star, HD 206267, which excites the surrounding nebula, is classified as O6.5 V ((f)) by Walborn (Walborn and Panek 1984). This star, along with its nearby companions, has often been noted as a multiple system bearing a striking resemblance to the O stars in the Orion Trapezium (Abt 1986). Also like the Trapezium region, Tr 37 is embedded in a region of active star formation. It has long been identified as a T association, and Kun (1986), has identified a large number of faint emission stars in the vicinity, many of which may be low-mass, pre-main-sequence cluster members.

With a distance modulus of approximately 10.0 (Garrison and Kormendy 1976), Tr 37 would seem an inviting target for studies of early stellar evolution; but it has not yet drawn as much attention as NGC 2264 and the Orion Trapezium. Because Tr 37 is more diffuse than these clusters, as well as more distant, there is more confusion with other stars along the line of sight, and identification of bona fide members of Tr 37 has been difficult. Moreover, unlike the Trapezium, it has no dark absorbing cloud behind it to reduce confusion with background stars. In a recent proper-motion study of the cluster, Marschall and Van Altena (1987) identified 486 stars with kinematic membership probabilities greater than 80% within a 30 arcmin radius of HD 206267. These stars form a preliminary sample for studies of the physical characteristics of the cluster population.

Previous photometric and spectroscopic studies of the cluster are limited in number and depth. Garrison and Kormendy (1976) presented photoelectric UBV photometry for 37 stars and MK spectral classifications for 51 stars, all brighter than $V = 10.1$, in a region about 3° in diameter surrounding the cluster. Eleven of these stars were identified as members by Marschall and Van Altena. Cardon de Lichtbuer (1982) supplemented this photometry with photoelectric *UBVRI* magnitudes of 26 fainter cluster stars in the magnitude range $10.5 < V < 15.75$. More recently, Kun (1986) has conducted an objective prism search for emission stars in the region covered by Garrison and Kormendy, along with photographic photometry of 155 stars fainter than approximately $V = 13.5$. Only 15 of these were common to Marschall and Van Altena's study, seven of which appear to be cluster members. Most recently Clayton and Fitzpatrick (1987) obtained *IUE* spectra of 17 stars from the list of Garrison and Kormendy and derived ultraviolet extinction curves from their data.

In Kun's color–magnitude diagram of the Tr 37 stars (which includes the data of Garrison and Kormendy), there is a conspicuous gap in the sampling between $V = 10.0$ and $V = 13.5$. The present paper reports on UBV photometry of 120 stars, selected from Marschall and Van Altena's probable members, and lying primarily in this magnitude range. These data, combined with the previous photometric data, enable us to construct a more complete color–magnitude diagram for Tr 37, permitting an estimate of the cluster age and revealing the presence of a population of stars above the lower end of the main sequence which may be possible pre-main-sequence cluster members.

OBSERVATIONS

Photoelectric photometry was carried out on the Kitt Peak 1.3 m telescope equipped with the Mark III automated photometer on 29, 30, and 31 October 1986, and on the Kitt Peak No. 2 0.9 m telescope equipped with the Automated Filter Photometer on 11 October 1985. Additional observations of about 20 stars were obtained using the 1.3 m on 22 December 1987 and the No. 2 0.9 m on 4 and 6 November 1988. Standard *UBVRI* filters were used. Between one and two dozen stars from Landolt's lists of equatorial standards (Landolt 1973, 1983) were observed every night, covering a range of colors and at a range of airmasses sufficient to derive both extinction and transformation equations simultaneously for each night's observations using standard least-squares techniques. Only during the 1987 and 1988 observing runs were standard stars chosen specifically from Landolt's second list, which includes *R* and *I* measurements as well as

[a)] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, which is operated by AURA, Inc., under contract with the National Science Foundation.

values of *UBV*. Thus we present primarily *UBV* measurements for all stars, with *R* and *I* only for the stars observed in 1987 and 1988.

The reduced magnitudes for 120 observed stars in Tr 37 are presented in Table I. Column 1 lists the number of the star (MVA) and columns 2 and 3 list the epoch 1950 coordinates of the star from Marschall and Van Altena's 1987 astrometry. Columns 4–8 list the photometric magnitudes and color indexes of the stars, and column 9 contains information on the kinematic membership probability and possible binarity of the stars. In column 9, stars with a membership probability less than 80% in Marschall and Van Altena's study are denoted probable nonmembers of the cluster. The binary nature of two stars, MVA 234 and MVA 550, is taken from a radial-velocity survey of the cluster presently being carried out by one of us (L.A.M.) using telescopes at Fred L. Whipple Observatory and Oak Ridge Observatory.

The internal precision of our measurements may be gauged by the rms deviation of the reduced magnitudes of the standard stars from the standard values used for fitting. These were typically 0.015 mag in V, 0.02 mag in $B-V$, 0.03 mag in $U-B$, and 0.007 mag in $V-R$ and $R-I$. About half of the stars in our sample were observed on more than one night, and the night-to-night deviation in the reduced magnitudes and color indexes for a single star is essentially the same as the internal errors for individual nights. No systematic trends were seen in the reduced values.

A comparison with the published photometry of Garrison and Kormendy and Cardon de Lichtbuer also yields good agreement, indicating that systematic errors cannot be large. We have observed eight stars in common with Garrison and Kormendy, and 15 stars in common with de Lichtbuer.

Garrison and Kormendy claim random errors of 0.025 mag in V, 0.016 mag in $B-V$, and 0.019 mag in $U-B$. For the eight common stars, we find only slight systematic differences between our measurements and theirs (in the sense of our measurements minus that of Garrison and Kormendy): an average of 0.01 mag in V, and 0.03 mag in $B-V$ and $U-B$. Cardon de Lichtbuer claims internal errors of 0.05 in V, $B-V$, and $U-B$. Again we find only slight systematic differences (in the sense of our measurements minus those of Carbon de Lichtbuer) of -0.02 mag in V, -0.02 mag in $B-V$, and 0.06 mag in $U-B$. Both sets of previous measurements could be transformed to the system defined by our measurements with a scatter that is within the claimed precision. This agreement may in some degree by fortuitous, since neither Garrison and Kormendy nor Cardon de Lichtbuer used Landolt's stars as standards, and since the latter paper quotes internal errors somewhat in excess of those we claim for this study.

We have only six photometrically measured stars in common with Kun's photographic study (1986), but we also carried out a comparison of these data. Kun quotes errors of 0.1 mag in V and B and 0.2 mag in U and R. For five of the common stars (MVA 328, 432, 433, 516, and 634) we find agreement to better than these limits in V and B. Our measurements of MVA 70, however, differ by more than a magnitude in V. Kun notes such scatter for some of the stars in the photographic study, and attributes it to stellar variability rather than measurement error. Indeed, the emission-line criterion for inclusion in Kun's study would tend to select for such stars. Nevertheless, Kun's measurements of $U-B$ seem systematically smaller than ours by about 0.2 mag, which may be due to a systematic difference in Kun's reduction to standard magnitudes. We will comment on this discrepancy in the next section.

DATA ANALYSIS

By combining our data with that of Garrison and Kormendy, Cardon de Lichtbuer, and Kun, we are able to present more extensive color–magnitude and color–color diagrams of this cluster than have previously been available. We shall use these data to determine the age of the cluster and to investigate its pre-main-sequence population.

Of the 120 stars we have observed (Table I), 110 have kinematic membership probabilities, based on proper motions, of greater than 80%. We eliminate two of these (MVA 550 and MVA 234) because they are known spectroscopic binaries. (Undoubtedly, the remaining stars contain a substantial percentage of binaries, and we are continuing to obtain spectroscopic data on them.) Table II lists photometry from other sources. Three of these stars have kinematic membership probabilities of greater than 80% (these are bright stars observed by Garrison and Kormendy), while 36 fainter stars from Kun's study, too faint to be included in kinematic membership study of Marschall and Van Altena, are considered as possible members simply because they lie within 30 arcmin of HD 206267.

The undereddened color–magnitude diagram of the combined sample of 147 stars is presented in Fig. 1. The ZAMS line (Cohen and Kuhi 1979) plotted there has been reddened by $E_{B-V}=0.54$ and $R=A_v/E_{B-V}=3.0$. This value of E_{B-V} is the result of averaging the value of the individual values of E_{B-V} determined by Garrison and Kormendy from spectroscopy and photometry of the brighter cluster members, while the value of R is a standard value for normal interstellar reddening (Scheffler and Elsasser 1987). Whether this standard value is appropriate to the interstellar medium between us and Trumpler 37 is uncertain. Anomalous values of R have been reported around other extremely young clusters, such as Orion (Breger, Gehrz, and Hackwell 1981), and in what follows we will examine the effects of using different values of R to deredden the color–magnitude diagram.

The simplest method of accounting for reddening of a cluster is to assume that the reddening is constant across the cluster, and using a single value of E_{B-V} for each star. We have done this in Fig. 2(a), using a uniform value of $E_{B-V}=0.54$ and the photometric data in Table I and II. (The ZAMS line is also shown here, along with lines indicating deviations from the ZAMS by ± 0.1 in $B-V$.)

In young clusters like Trumpler 37, however, which are still associated with patchy gas and dust, differences in reddening from one star to another can be substantial (Sager 1987). For eight of the stars plotted in Fig. 2(a), Garrison and Kormendy obtained spectra and determined E_{B-V} for each individual star using a calibration of the spectral types. In Fig. 2(b) we have dereddened these eight stars using the individual color excesses of Garrison and Kormendy. The reduced scatter around the ZAMS line in Fig. 2(b) compared with Fig. 2(a) shows that the assumption of uniform color excess is questionable, and that adopting a model of nonuniform reddening as we have done should yield some improvement.

As a second-order approach to dereddening the photometry, we have used 12 spectroscopically determined values of the color excess (Garrison and Kormendy 1976; Clayton

TABLE I. Photometry of Tr 37 stars.

MVA	RA (1950)	DEC	V	B-V	U-B	V-R	R-I	Comment
22	21 35 8.75	57 5 13.5	14.53	1.60		0.90	0.88	
23	21 35 13.69	57 5 17.2	14.42	0.88	0.36	0.52	0.50	nonmem
25	21 35 17.87	57 4 44.4	12.42	2.13				nonmem
60	21 35 18.54	57 17 40.1	13.41	1.71	1.08	1.06	1.07	nonmem?
63	21 35 4.92	57 20 35.9	11.03	0.48	-0.25	0.30	0.35	nonmem?
70	21 35 16.67	57 22 0.7	13.44	0.59	0.17			nonmem
81	21 34 52.05	57 24 35.8	11.51	0.49	0.16			
86	21 34 55.64	57 26 4.9	12.26	0.63	0.43			nonmem?
95	21 34 55.55	57 30 12.3	13.50	0.72	-0.11			nonmem
108	21 35 38.73	56 59 24.7	13.34	0.62	0.46			
144	21 35 51.63	57 9 35.9	12.19	0.62	0.26			
147	21 36 10.15	57 7 31.0	11.38	0.41	0.03			
148	21 36 21.90	57 7 32.6	11.42	1.26	1.06			
149	21 36 14.97	57 8 14.1	13.90	1.53				
150	21 36 19.04	57 8 50.3	13.65	0.70	0.03			
153	21 36 8.52	57 9 36.3	12.34	0.37	0.20			
164	21 35 47.54	57 11 42.2	12.44	0.53	0.29			
169	21 35 51.45	57 14 44.9	14.02	0.72	0.62			
181	21 35 46.03	57 17 48.8	11.84	0.58	0.25			
182	21 35 47.21	57 17 17.1	11.93	0.47	0.03			
194	21 36 8.54	57 20 4.6	8.39	0.38	-0.49			nonmem
203	21 36 14.88	57 21 21.3	13.55	1.11	0.61			
217	21 36 29.18	57 23 18.9	11.09	0.75	0.01			
221	21 36 46.01	57 22 5.9	12.94	1.29				
224	21 36 28.59	57 24 33.3	13.05	0.53	0.34			
229	21 35 38.13	57 26 58.6	13.09	0.62	0.40			
232	21 35 38.71	57 28 43.9	14.25	1.15	0.63			
234	21 36 2.22	57 27 8.4	14.18	1.10	0.55			Bin:SB2
252	21 35 50.70	57 31 35.1	11.96	0.52	0.03			
257	21 36 24.39	57 29 19.0	14.28	0.71	-0.20	0.43	0.52	
258	21 36 23.92	57 28 47.4	13.66	0.61	0.42	0.31	0.35	
266	21 36 32.67	57 1 8.0	13.65	0.51	0.36	0.29	0.34	
268	21 36 49.37	57 0 55.7	9.08	1.20	1.07			nonmem
275	21 36 53.71	57 1 20.4	14.68	0.89	0.70	0.61	0.56	
276	21 36 56.35	57 1 31.8	13.82	0.98	0.50	0.62	0.59	
293	21 37 40.27	56 59 17.9	11.69	0.28	-0.05			
294	21 37 37.11	56 58 24.3	11.72	2.01				
299	21 36 44.16	57 6 16.3	12.93	1.45	1.15			
302	21 37 35.87	57 1 58.4	14.84	1.61		0.87	0.81	
312	21 38 21.85	57 1 10.9	14.47	0.96		0.59	0.58	
320	21 38 12.61	57 3 21.3	13.51	0.91		0.56	-0.51	nonmem
321	21 38 17.69	57 3 18.1	14.27	0.72		0.41	0.46	
326	21 38 21.45	57 4 3.9	14.38	2.37		1.44	1.41	
328	21 38 34.41	57 4 36.7	14.67	1.76		0.96	0.90	
335	21 39 26.23	56 57 58.6	12.53	1.44	1.16			

TABLE I. (continued)

MVA	RA (1950)	DEC	V	B-V	U-B	V-R	R-I	Comment
337	21 39 24.62	57 2 32.5	12.85	2.11				
367	21 39 57.61	57 4 46.7	12.70	0.73	0.43			
369	21 38 11.84	57 9 51.5	11.80	0.54	0.38			
371	21 38 12.84	57 10 22.8	13.32	0.68	0.50			
374	21 38 32.27	57 9 44.8	12.17	1.48	1.28			
412	21 37 6.41	57 8 26.5	9.11	0.38	-0.46			
420	21 37 33.99	57 6 17.1	11.36	0.41	0.25			
423	21 37 53.12	57 5 6.6	9.24	0.88	0.33			
426	21 36 35.67	57 13 13.8	11.59	0.34	0.18			
430	21 37 36.49	57 11 19.2	12.12	0.48	-0.30			
431	21 37 41.35	57 9 38.3	13.21	1.20	0.75			
432	21 37 47.75	57 10 24.4	13.81	0.82	0.74			
433	21 37 51.27	57 10 15.5	14.47	1.12	0.76			nonmem
436	21 38 3.03	57 9 42.5	14.08	0.71	0.46			
437	21 37 45.53	57 12 11.9	11.59	0.49	-0.01			
447	21 36 53.56	57 15 5.9	11.75	0.69	0.50			
454	21 37 39.89	57 14 56.9	12.34	0.51	0.37			
455	21 37 49.02	57 14 8.0	10.58	0.40	0.10			nonmem
459	21 36 46.74	57 16 36.1	14.50	2.29				nonmem
462	21 37 23.74	57 16 3.1	8.01	0.18	-0.68			
463	21 37 38.90	57 16 20.7	11.92	0.50	0.34			nonmem
464	21 37 54.22	57 15 23.5	8.31	0.37	-0.52			
467	21 37 30.42	57 16 52.7	14.26	1.20	0.23			nonmem
468	21 36 35.53	57 17 52.8	10.64	0.34	-0.10			
469	21 36 44.63	57 17 47.8	14.87	1.53				
472	21 36 46.56	57 18 22.5	13.69	0.67	0.28			
480	21 37 36.83	57 17 49.5	13.45	0.68	0.38			
486	21 37 1.43	57 21 25.4	13.83	1.63				
497	21 37 49.27	57 18 11.7	12.76	0.50	0.29			
498	21 37 53.03	57 18 10.3	13.58	1.20	0.81			
514	21 37 51.40	57 21 32.6	12.46	2.19				
516	21 37 56.50	57 20 43.1	14.00	0.69	0.42			
523	21 37 26.73	57 23 14.5	12.73	0.90	0.46			
535	21 37 28.17	57 24 24.7	11.29	0.37	0.05			
545	21 36 44.82	57 26 27.9	11.52	0.65	0.47			
550	21 37 18.72	57 26 15.5	11.72	1.02	0.63	0.62	0.60	Bin:SB1
555	21 37 49.09	57 25 34.8	9.09	1.04	0.79			
558	21 36 56.77	57 27 48.0	10.71	0.58	0.38			
564	21 37 35.27	57 28 32.3	11.58	0.52	0.33			
565	21 37 43.61	57 28 36.6	12.51	1.37	1.14			
566	21 37 46.21	57 28 52.3	10.85	0.48	0.32			
575	21 37 53.54	57 31 35.4	12.60	1.38	1.08			
576	21 37 57 71	57 31 21.0	12.40	0.37	0.18			nonmem
583	21 38 37.59	57 12 12.5	10.81	0.23	-0.27			
598	21 38 14.79	57 15 5.9	12.40	0.66	0.14			nonmem
615	21 39 50.09	57 11 48.4	12.69	0.81	0.34			
633	21 38 44.93	57 17 0.0	10.12	0.25	-0.43			
634	21 38 47.06	57 17 43.8	13.54	0.73	0.36			
640	21 38 13.58	57 19 14.5	10.97	0.47	0.36			
641	21 38 20.66	57 19 30.3	14.20	0.66	-0.19			
647	21 38 56.35	57 19 58.5	12.83	0.51	0.23			
657	21 38 4.25	57 21 29.9	13.07	0.60	0.32			
658	21 38 7.95	57 21 17.9	10.95	0.18	-0.23			

TABLE I. (continued)

MVA	RA (1950)	DEC	V	B-V	U-B	V-R	R-I	Comment
660	21 38 7.82	57 21 31.2	13.32	0.45	0.31			
662	21 38 14.68	57 22 35.1	10.62	0.29	-0.13			
712	21 38 42.07	57 28 50.6	13.02	2.33				
713	21 38 39.25	57 28 7.5	11.15	0.34	-0.34			
741	21 39 49.54	57 31 34.1	10.52	0.17	-0.23			
746	21 39 39.46	57 32 48.7	9.85	0.12	-0.46			
747	21 38 24.47	57 22 38.0	9.71	0.12	-0.47			
800	21 38 57.63	57 3 1.3	10.03	1.13	0.89			
805	21 40 2.05	57 8 43.2	11.04	0.26	-0.31			
822	21 40 49.32	57 7 2.0	11.48	0.39	0.03			
842	21 40 27.94	57 20 10.2	10.44	0.30	-0.26			nonmem
850	21 40 30.21	57 25 32.7	11.90	0.33	0.20			
864	21 40 50.42	57 30 25.3	6.91	0.21	-0.76			nonmem
898	21 41 33.32	57 21 2.7	10.82	1.16	0.77			nonmem
910	21 41 9.30	57 31 37.3	11.67	1.07	0.73			
936	21 42 27.65	57 12 33.5	10.47	0.46	0.16			
967	21 42 47.02	57 30 24.6	9.00	0.32	0.01			nonmem
1098	21 40 55.55	57 37 5.4	10.00	0.15	-0.18			
1290	21 32 24.68	57 27 21.6	11.27	1.74				
1312	21 34 24.36	57 7 24.6	10.34	0.33	-0.30			
1313	21 34 33.44	57 6 37.0	12.80	2.25				
1318	21 33 48.43	57 8 19.8	11.66	0.38	0.16			
1328	21 34 11.95	57 14 35.8	8.39	0.39	-0.54			nonmem
1444	21 37 30.59	56 43 23.6	9.12	0.26	-0.42			
1510	21 38 3.83	56 50 25.5	12.56	0.86	0.49			

and Fitzpatrick 1987) to interpolate for reddening of stars which lie between them on the sky. The list of stars and their corresponding E_{B-V}'s are presented in Table III. We have not, however, included stars with values of E_{B-V} greater than 0.60 to avoid cases where reddening may be due to localized circumstellar clouds. This procedure should smooth out some of the variation in extinction along differing lines of sight to the cluster, even though the distribution of known color excesses is coarse. As we note later, this procedure seems effective in decreasing the scatter on the HR diagram and in the age calculation. For the time being, a "third order" approach, using individual E_{B-V}'s for each star determined spectroscopically or by infrared photometry (see, e.g., Guetter and Vrba 1989) must await further observations.

Using a surface-fitting routine on the 12 known values of the color excess we have determined values of E_{B-V} for all the program stars. The resulting isoreddening contour surface is shown in Fig. 3. The dereddened color–magnitude diagram is shown in Fig. 4(a) using $R = 3.0$ and in Fig. 4(b) with $R = 5.0$.

For 119 stars (from all the sources listed above) we also have $U-B$ data, and the combined raw color–color diagram for these stars is presented in Fig. 5. The main-sequence line (FitzGerald 1970), reddened using $E_{B-V} = 0.54$ is shown for comparison. We note that the redder stars in our sample of kinematic members seem to have colors more typical of giants than dwarfs, consistent with their position above the ZAMS on Fig. 4. However, some of the "possible" members from Kun's study (shown as asterisks), chosen simply on the basis of position in the sky, fall considerably above the main-sequence line. It is likely that they are not members of the cluster at all, but we have noted earlier that Kun's values of $U-B$ seem systematically smaller than ours by about 0.2 mag. Thus a nonstandard calibration of $U-B$ by Kun could well account for their anomalous position. Whatever the reason for their anomalous colors, we exclude those stars from the age determination that follows.

THE AGE OF THE CLUSTER

The temporal sequence of star formation in clusters is rather uncertain, and it has long been noted that the determination of the ages of the youngest clusters is complicated by this uncertainty. One school of thought argues that star formation in clusters begins with low-mass stars, moving towards higher-mass stars until star formation is stopped by stellar winds from one or more O stars that disperse the remaining interstellar gas (see, e.g., Herbig 1962). More recently, Stahler (1985) argues that this sequential star-formation scheme should be replaced with a contemporaneous scheme of star formation in which stars with a large range of mass form at the same time until the gas is depleted or disrupted. Given any initial mass function (Kennicutt 1983), more low-mass stars form at any time than higher-mass stars, but as Stahler puts it, there is no "secular" shift to a greater proportion of higher mass stars as the cluster ages.

The age of Trumpler 37 is customarily taken to be 3×10^6

TABLE II. Photometry of Tr 37 stars from other sources.

	Alk #	MVA #	Kun #	V	B-V	U-B	E(B-V)[1]
G&K	171	1440		7.42	0.11	-0.79	0.42
"	174	1444		9.11	0.23	-0.49	0.46
"	442	71		8.62	0.29	-0.58	0.51
"	455	217		11.14	0.71	-0.01	0.85
"	475	423		9.30	0.85	0.31	0.81
"	477	464		8.37	0.37	-0.54	0.67
"	486	633		10.10	0.21	-0.45	0.44
"	721	1037		10.13	0.33	-0.33	0.53
Kun			53	14.08	1.29	0.69	
"			56	15.16	1.16	-0.19	
"		1180	58	14.61	1.16	-0.01	
"			59	14.25	1.15	0.91	
"			60	14.48	0.93	0.45	
"		1209	66	14.40	2.17	-1.00	
"		70	68	13.33	0.44	0.14	
"			71	15.05	1.65		
"		225	73	14.56	1.79		
"		512	83	14.12	1.22	-0.19	
"		433	85	14.55	1.15	0.53	
"		508	86	15.34	0.94	-0.20	
"		516	87	13.89	0.91	-0.11	
"		726	92	14.77	1.20	-0.11	
"			94	14.98	1.62		
"			96	15.04	1.42	0.24	
"		637	97	14.06	0.75	-0.11	
"			98	15.34	1.21		
"		625	100	14.57	0.99	0.00	
"			102	15.54	1.06		
"			103	14.67	2.19		
"			104	13.81	1.18	-0.28	
"			105	16.00	1.00		
"			106	14.77	2.09		
"		852	107	14.99	0.15		
"			109	14.95	1.05	0.13	
"			110	15.36	1.77		
"			112	13.93	1.01	1.45	
"			116	15.55	0.92	0.04	
"			118	14.79	1.82		
"			119	14.95	1.14	-0.05	
"			120	14.54	0.97	0.21	
"			122	15.05	0.89	0.23	
"		943	123	15.03	0.51	0.29	
"			126	15.80	1.60		
"			127	15.08	0.49	0.34	

[1] obtained spectroscopically by Garrison and Kormendy

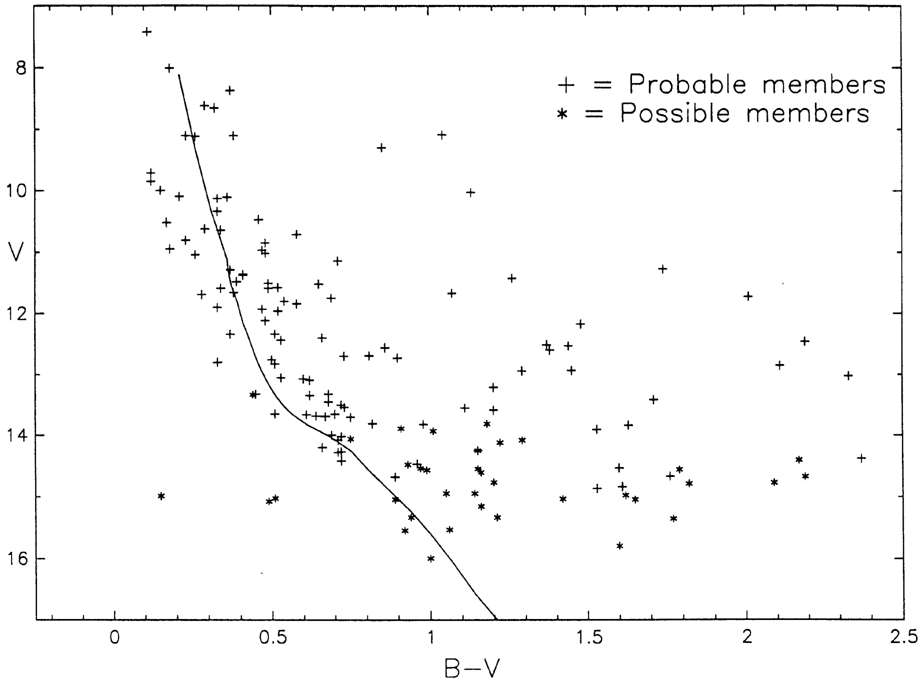


FIG. 1. The undereddened color–magnitude diagram of Trumpler 37.

yr (Clayton and Fitzpatrick 1987). Recently, however, Schroeder and Comins (1988) presented a new, statistical method for determining the age of very young clusters, assuming contemporaneous star formation along the lines of Stahler, which lends itself to the cumulative data presented in this paper. In this method, the cluster age is determined from the fraction of the stars in a given mass range that have arrived at the ZAMS (± 0.1 in $B-V$). Stars are binned in different mass ranges by plotting the ZAMS and the theoretical pre-main-sequence contraction tracks (Cohen and Kuhi 1979) on the color–magnitude diagram. The tracks for stars of masses 1.5, 3.0, 5.0, and 9.0 $\mathscr{M}_\odot$ serve as the arbitrary boundaries for the different mass ranges used in calculating the cluster age.

To compare the data with the tracks, we have transformed the tracks from $\log T_{\rm eff}$–$\log(L_*/L_0)$ space to the observed V–$(B-V)$ space. We have used main-sequence bolometric corrections from Schmidt–Kaler (1982) and temperature–color relations from Bohm-Vitense (1981).

The transformed ZAMS, the contraction tracks, and the $\pm(B-V)$ lines around the ZAMS are shown in Fig. 4(a). These lines were used to calculate the cluster ages for all the other figures, but were removed to reduce clutter. Using the method described in Schroeder and Comins (1988) on the data yields the age determinations of Table IV. In Table IV: Column 1 indicates the assumptions used to deredden the raw data; column 2 the range of masses used to calculate cluster age; columns 3 and 4 the number of stars in the mass range on and off the main sequence (± 0.1 in $B-V$); column 5 the fraction of stars on the main sequence; column 6 the calculated value of omega (described on Schroeder and Comins); columns 7, 8, and 9 the calculated age and age limits in units of 10^6 yr; and column 10 the formal standard deviation for the age.

There is a spread in the range of ages determined by our method because of the different number of stars in each mass range, the relatively small number of stars, and the inclusion of unrecognized nonmember stars in our sample. In particular, observe that the higher ages for the cluster occur when the lower mass stars are included. These are the stars that take the longest to reach the main sequence and, assuming contemporaneous star formation, the result indicates that a higher proportion, but not all, of the low-mass stars in this cluster have not yet reached the main sequence. (Note that in the contemporaneous scenario we have adopted, there can be low-mass stars, with the same mass, both on and off the main sequence until star-formation ceases.)

We define a most plausible age by averaging the results for individual mass ranges 1.5–3.0, 3.0–5.0, and 5.0–9.0 $\mathscr{M}_\odot$, weighted by the number of stars in each mass range. The $R=3.0$, uniform reddening case yields an age of 7.4×10^6 yr, the R 3.0, nonuniform reddening case yields an age of 6.8×10^6 yr and the $R=5.0$, nonuniform reddening case yields an age of 4.1×10^6 yr. The values of the standard deviation are purely formal; they are the variances obtained by assuming binomial statistics in the derivation of the age equation.

DISCUSSION

Although the $R=5.0$ results give the best apparent agreement with previous age determinations, these earlier age determinations assumed normal, not anomalous, reddening. There seems no reason to assume a higher value than $R=3.0$, and in fact, preliminary investigations of the reddening in the direction of Tr 37 indicate a value that does not differ substantially from 3.0 (Roth 1987). Based on the method we have used we believe that an age of 7×10^6 yr rather than 3×10^6 is to be preferred. We should note that the assumption of contemporaneous star formation that we

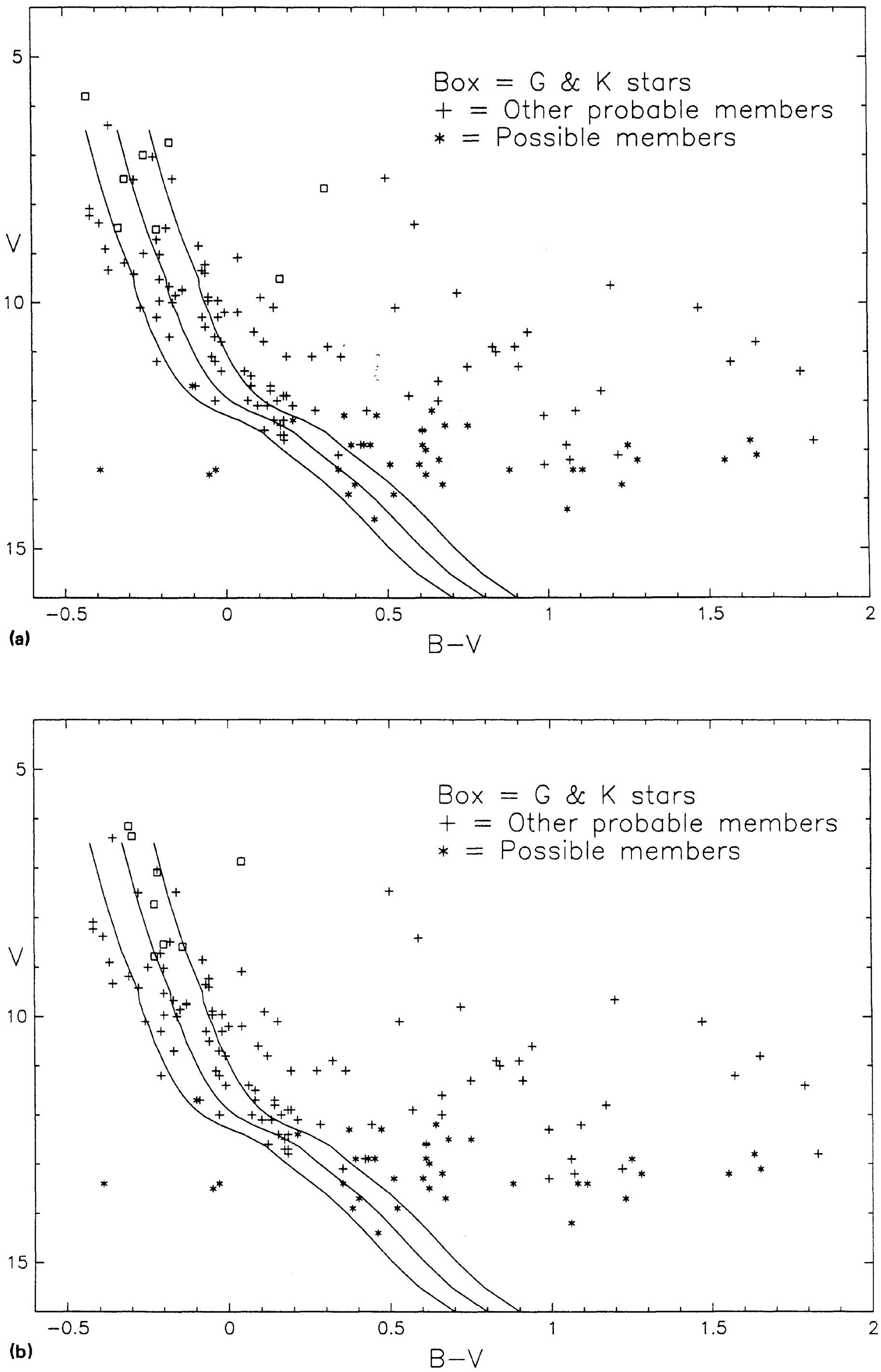


FIG. 2. (a) Color–magnitude diagram of Trumpler 37 dereddened with a uniform color excess $E_{B-V} = 0.54$. The ZAMS is shown, flanked by lines showing offsets from the ZAMS of ± 0.1 in $B-V$. (b) The same as Fig. (a), except that stars observed by Garrison and Kormendy (1976) have been dereddened using individual color excesses determined from a comparison of their observed spectral type and color.

TABLE III. Spectroscopically determined reddening for stars in the vicinity of HD 206267.

Alksinis	MVA	$E(B-V)$
136		0.42[a]
174	1444	0.46[a,b]
207		0.50[a]
426	19	0.52[a]
441	59	0.54[a,b]
442	71	0.55[a,b]
466 AB	460	0.52[a,b]
486	633	0.44[a]
677		0.48[a]
686		0.42[a]
721	1037	0.53[a]
750	864	0.52[a]

[a] Garrison and Kormendy (1976).
[b] Clayton and Fitzpatrick (1987).

have adopted does not rule out the presence of an O6 star (HD 206267) in a cluster of this age any more than the sequential scenario does. Since stars of any mass can form until formation ceases, the cluster age is not limited by the main-sequence lifetime of the most massive star.

We need note further that the notion of "age" for very young clusters is a term fraught with ambiguity. Whatever the scenario of star formation one adopts, not all stars reach the main sequence at the same time. Moreover, in the "contemporaneous" scenario we have adopted, even stars of the same mass do not reach the main sequence at the same time. Therefore in the youngest clusters the time elapsed since the stars first reached the main sequence is comparable to the timescale for the entire star-formation process to run its course. By "age" we could mean the average nuclear-burning age of all stars in the cluster, or the time since the last massive star formed, or the time since the first stars in a given mass range reached the main sequence. Our value is an age in this third sense. The method of age analysis we have adopted, in fact, yields a number which is essentially the time elapsed since the first low-mass stars (in the mass ranges included in our analysis) reached the main sequence (Schroeder and Comins 1988).

The HR diagram of the cluster reveals a substantial number of probable members above the main sequence. These are likely pre-main-sequence stars. A number of these have already been recognized as emission-line stars in the objective-prism study of Kun (1986). If these stars in indeed pre-main-sequence members of the Trumpler 37, then our value for the age of the cluster indicates that star formation in this very young cluster has been going on for at least 7×10^{6} yr.

The pre-main-sequence candidates in Tr 37 are of magnitude 13.5–15.5. While slightly fainter than the young stars in Taurus-Auriga and Orion (regions which have been the main focus for studies of pre-main-sequence stars to date), such stars can now be studied spectroscopically with modern spectrographs and moderate-sized (2 m) telescopes at higher resolution than they have been so far. They deserve closer investigation to determine whether they are radial-velocity members of the cluster and whether they show additional evidence of pre-main-sequence status: e.g., Ca II H and K emission and especially strong Li I 6707 Å absorption. Spectroscopic study of these stars, may, in addition, reveal additional information on binary statistics among pre-main-se-

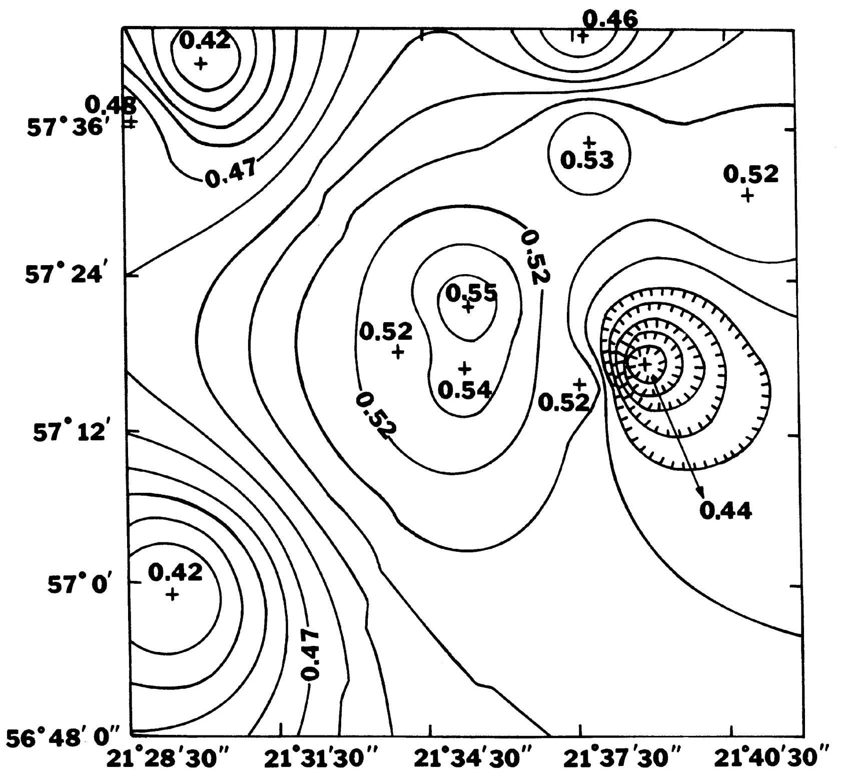
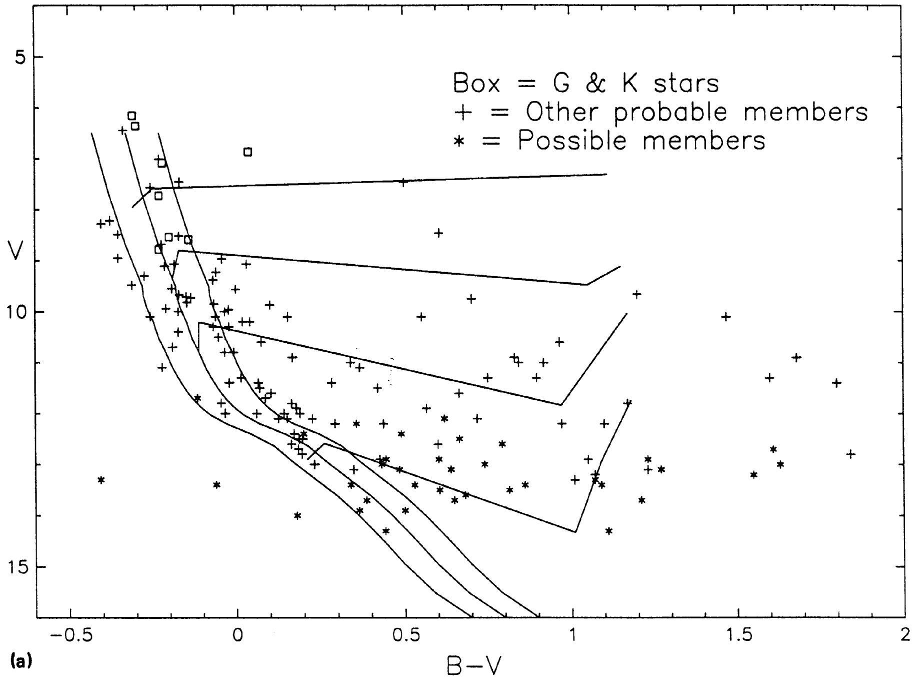


FIG. 3. Isoreddening contours adopted for the region around Trumpler 37 based on the color excesses of stars from Garrison and Kormendy (1976).



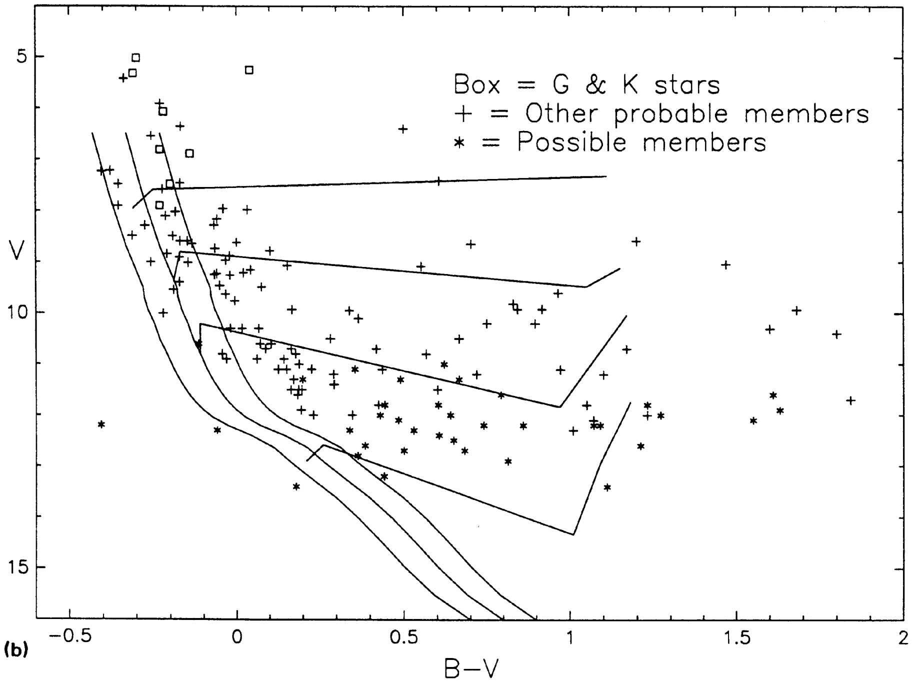


FIG. 4. (a) Color–magnitude diagram for Trumpler 37 dereddened using color excesses interpolated from the isoreddening contours of Fig. 3 with a ratio of total to selective absorption $R = 3.0$. The ZAMS (flanked by lines showing offsets from the ZAMS of ± 0.1 in $B-V$) and pre-main-sequence contraction tracks used to calculate the age of the cluster are shown. (b) Color–magnitude diagram for Trumpler 37 dereddened using color excesses interpolated from the isoreddening contours of Fig. 3 with a ratio of total to selective absorption $R = 5.0$. As in (a), the ZAMS and pre-main-sequence contraction tracks used to calculate the age of the cluster are shown.

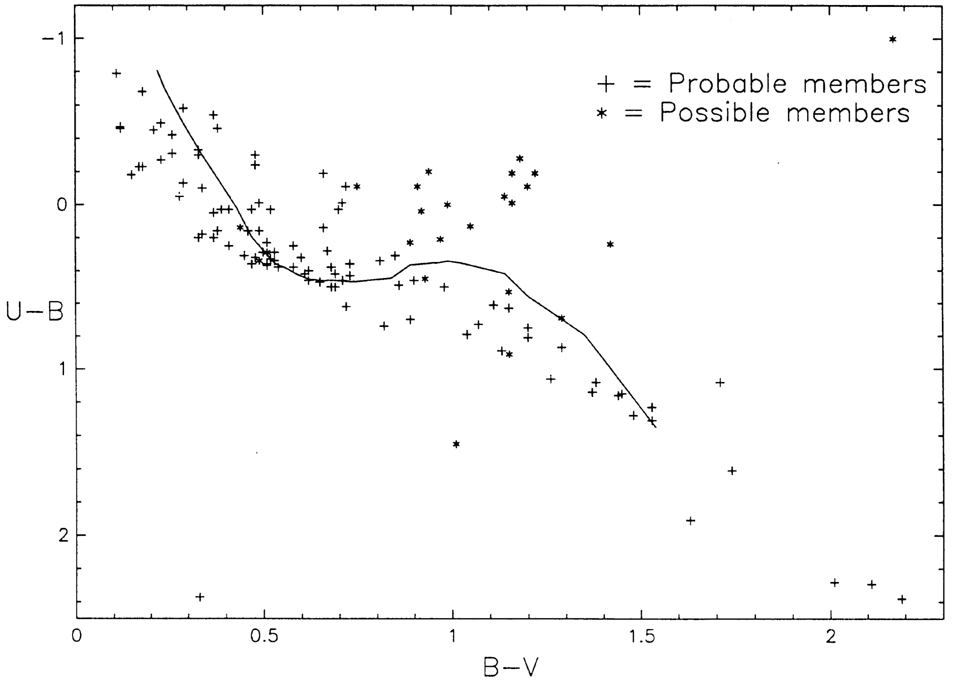


FIG. 5. $U-B$ vs $B-V$ color–color plot for Trumpler 37. The undereddened magnitudes are plotted along with a ZAMS shifted along a normal reddening line appropriate to $E_{B-V}=0.54$

TABLE IV. Age calculations for Tr 37 using Schroeder and Comins (1988).

REDDENING	MASS RANGE	ON M.S.	OFF M.S.	n_{ms}	Ω(m1,m2)	T	T_+	T_-	SIGMA
	1.5-3.0	21	35	.375	.546	11.54	12.88	10.45	.065
R=3.0	3.0-5.0	10	22	.313	.105	2.02	2.29	1.80	.082
UNIFORM	5.0-9.0	8	2	.800	.027	1.78	4.82	1.09	.126
REDDENING	1.5-5.0	31	57	.352	.439	8.95	9.71	8.30	.051
	3.0-9.0	18	24	.429	.0775	1.79	2.07	1.58	.076
	1.5-9.0	39	59	.398	.390	8.56	9.32	7.91	.049
	1.5-3.0	17	37	.315	.546	10.53	11.60	9.64	.063
R=3.0	3.0-5.0	11	21	.344	.105	2.11	2.42	1.87	.084
VARIABLE	5.0-9.0	9	2	.818	.027	1.96	5.40	1.20	.116
REDDENING	1.5-5.0	28	58	.326	.439	8.60	9.31	8.00	.051
	3.0-9.0	20	23	.465	.0775	1.91	2.23	1.68	.076
	1.5-9.0	37	60	.381	.390	8.32	9.04	7.71	.049
	1.5-3.0	2	45	.043	.546	7.54	7.79	7.30	.031
R=5.0	3.0-5.0	6	29	.171	.105	1.67	1.81	1.55	.064
VARIABLE	5.0-9.0	12	12	.500	.027	0.71	0.90	0.59	.102
REDDENING	1.5-5.0	8	74	.098	.439	6.43	6.67	6.13	.033
	3.0-9.0	18	41	.305	.0775	1.47	1.61	1.36	.060
	1.5-9.0	20	86	.189	.390	6.35	6.66	6.07	.038

quence stars, data that is presently based on fewer than a dozen known candidates (Mathieu, Walter, and Myers 1989).

Further photometry, especially IR studies of probable cluster members, can be used to determine individual color excesses for a more refined determination of the age of this cluster. Further spectroscopy can refine the membership roster of the cluster and should also be directed to investigating the pre-main-sequence status of the redder stars.

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