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Photometry of the Open Cluster NGC 6913

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Abstract

Photoelectric *UBV* magnitudes and colours have been determined for 103 stars in the field of NGC 6913. The reddening across the cluster is variable. The distance modulus to the cluster is estimated at $10^{m}.85 \pm 0^{m}.15$. It is found that cluster stars have ages between 0.3 to 1.75 Myr.

Key words: H-R diagram; Open clusters; Reddening; *UBV* photometry.

1. Introduction

The open cluster NGC 6913 (M2) in Cygnus [$\alpha = 20^{h}22^{m}.1$, $\delta = +38°22'(1950)$; $l = 76°.92$, $b = +0°.60$] is located near the bright star γ Cyg. Sanders (1973) has determined the relative proper motions for 228 stars in the cluster field with a mean error of $\pm 0''.25$ per century and has computed the probabilities of cluster membership, p, for all the stars. Out of the 105 stars having $p \geqq 50\%$, only 17 stars have the *UBV* photoelectric values (cf. Mermilliod 1976), some stars have *UBV* photographic values (cf. Hoag et al. 1961), while the remaining stars have only approximate values of V (mean error $= \pm 0.1$ mag) (cf. Sanders 1973). Crawford et al. (1977) have presented *ubvy* and Hβ photometry for the 26 stars in the cluster region, out of which only 20 stars have $p \geqq 50\%$.

As the *UBV* photoelectric magnitudes and colours are not available for most of the cluster members, a fresh *UBV* photoelectric photometric study of the cluster was considered necessary.

2. Observations and Reductions

The observations were carried out between October 1978 and December 1981 on the 104-cm Sampurnanand reflector of the Uttar Pradesh State Observatory. The methods of observations and instrumentation are the same as described by Sagar and Joshi (1979). For standardising the instrumental magnitudes and colours, we have used photoelectric sequence given by Hoag et al. (1961). The stars used for this purpose are marked in table 1. Stars 135 and 149 (the variation of which are within the errors of observations) were used for the determination of atmospheric extinction coefficients on observing nights. The standard deviations of our observations are better than ± 0.025 mag in $(U-B)$, $(B-V)$ and V magnitudes. A minimum of two sets of observations, on different nights were made for each star and the average values have been adopted. The large error may be because of the faint photoelectric standards and observations taken lergely at low altitudes.

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Table 1. Photoelectric *UBV* magnitudes and colours of stars in NGC 6913. Stars with asterisked number belong to the photoelectric sequence by Hoag et al. (1961). Star numbers and the corresponding membership probability, *p*, are taken from Sanders (1973). The adopted values of $E(B-V)$ are also given.

Star No.	V (mag)	$B-V$ (mag)	$U-B$ (mag)	$E(B-V)$ (mag)	p (%)	Remarks
1	13.31	0.63	0.10	—	0	—
2	12.04	0.53	0.07	0.63	72	2, 4
7	13.01	0.84	−0.08	1.07	86	2
9	13.39	0.71	1.01	0.73	81	3
10	13.46	0.58	—	—	0	—
11	12.86	0.64	0.24	0.71	79	2
15	9.03	0.61	−0.34	0.87	81	2
17	13.38	0.57	0.21	0.63	86	2
18	13.14	0.76	0.23	0.86	85	2
19	13.53	0.63	0.34	0.66	67	2
24	13.07	1.39	0.55	0.80	83	3
26	10.33	0.60	−0.17	0.80	82	2
28	12.97	1.85	0.33	0.75	67	3, 6
32	12.20	0.41	0.47	0.35	84	2
33	13.28	0.69	0.31	0.75	82	2
36	13.41	0.74	0.35	0.79	62	2
37	10.62	1.57	1.74	0.86	66	3, 6
38	13.53	0.66	0.55	—	4	—
40	13.60	0.80	0.47	0.83	71	2
42	13.23	1.01	—	0.80	68	3
47	10.91	0.42	0.25	0.43	58	2
49	13.28	0.83	0.69	0.75	73	3
51	13.59	0.56	0.03	0.68	77	2
52	13.40	0.63	0.21	0.70	87	2
54	13.25	0.78	0.32	0.85	88	2
55	10.16	0.55	−0.14	0.73	86	2
58	13.14	0.51	0.04	0.61	85	2
61	11.96	0.52	0.11	0.60	61	2
64	13.03	0.83	0.04	0.99	83	2
66	12.61	0.88	0.68	0.75	78	3
69	9.33	0.54	−0.29	0.75	84	2
71	12.77	0.74	0.06	0.89	78	2
72	14.95	0.61	0.02	0.74	87	2, 4
73	12.09	0.51	−0.04	0.64	89	2, 6
74	12.73	0.91	0.59	0.83	71	3
76	13.67	0.80	0.25	0.90	89	2
87	10.78	0.38	0.09	0.44	87	2
89	11.21	1.87	1.56	—	0	—
96	12.98	0.61	0.56	0.63	81	3
98	11.40	0.55	0.21	0.61	66	2
101	12.81	1.71	—	0.76	83	3, 6
102	13.57	0.76	0.23	0.86	73	2
104	13.11	1.77	1.51	0.83	85	3, 6
105	13.70	0.77	1.15	0.79	70	3
106	11.62	0.35	0.23	—	2	—

Table 1. (Continued)

Star No.	V (mag)	B−V (mag)	U−B (mag)	E(B−V) (mag)	p (%)	Remarks
107	12.64	0.44	0.20	0.47	87	2
110	11.98	0.67	0.16	0.77	82	2
111	13.84	0.76	0.19	0.87	86	2
115	13.19	0.75	0.04	0.91	88	2
116	13.75	0.70	0.20	0.79	68	2
119	13.50	1.02	0.46	0.80	84	3
120	12.74	1.02	0.50	0.80	87	3
121	13.32	1.36	0.51	0.79	88	3
123	12.18	0.44	0.33	0.67	87	3
*124	12.20	0.72	−0.03	0.90	77	2
125	9.47	0.87	−0.34	1.15	83	1, 4, 5
126	12.22	0.79	0.12	0.94	82	2
130	12.07	0.89	0.11	0.92	87	2, 5
131	13.17	0.58	0.05	0.70	78	2
133	12.90	0.79	0.27	0.88	86	2, 4
*135	8.57	0.43	0.08	0.16	76	1, 5, 6
136	13.53	1.08	0.54	0.80	88	3
*139	9.35	0.80	−0.14	1.08	79	1
140	11.37	0.87	0.15	—	42	—
141	13.15	1.06	0.32	0.80	88	3
142	12.90	0.84	0.19	0.97	89	2
143	11.88	1.09	0.41	0.88	87	3, 6
144	13.50	0.68	0.62	0.68	59	3, 4
147	10.24	0.70	−0.13	0.98	83	1
148	11.80	0.46	0.10	0.53	83	2
*149	8.93	0.78	−0.18	1.08	78	1
151	12.49	1.31	0.36	0.80	74	3
152	12.54	0.76	0.08	0.91	88	2
153	12.96	1.32	0.41	0.88	86	3
155	8.91	0.78	−0.20	0.80	79	2, 6
*157	8.84	0.92	−0.05	1.13	57	1
159	8.89	0.83	−0.10	1.11	72	1
166	13.67	0.81	0.50	0.52	87	3
*167	11.84	1.06	0.85	0.52	71	3
168	13.20	1.67	1.35	0.52	79	3, 6
169	10.79	0.49	0.05	0.58	88	2
171	12.35	0.52	0.13	0.59	70	2
*174	10.11	0.18	−0.28	0.31	63	2
176	12.80	0.53	0.07	0.63	58	2
179	13.84	1.01	1.04	0.52	88	3
181	13.68	0.61	0.09	0.72	81	2
182	10.47	0.18	−0.58	0.42	72	2, 4
184	12.63	1.08	0.24	0.65	86	3
185	12.70	0.55	0.03	0.67	75	2
187	11.38	0.63	−0.09	0.81	65	2
191	13.32	0.56	0.16	0.63	86	2
192	11.53	1.43	0.20	0.65	88	3, 6
199	12.77	0.76	0.03	0.93	72	2
204	12.37	0.45	0.10	0.52	75	2

Table 1. (Continued)

Star No.	V (mag)	B−V (mag)	U−B (mag)	E(B−V) (mag)	p (%)	Remarks
208	12.22	0.49	−0.06	0.62	77	2
209	12.08	0.43	0.12	0.54	89	3
214	11.14	0.32	0.04	0.38	59	2
215	13.34	1.03	—	0.38	68	3
216	12.33	0.66	0.14	0.77	86	2
217	12.93	0.71	0.06	0.86	84	2
219	11.90	1.63	0.46	0.38	86	3, 6
221	12.42	0.64	0.19	0.46	58	2
222	12.84	0.45	0.07	0.38	58	3

Notes: Explanation for numbers under remarks column:

(1) $E(B-V)$ values are estimated on the basis of spectral classes known from Mermilliod's (1976) catalogue.

(2) $E(B-V)$ values are estimated using the photometric method.

(3) $E(B-V)$ values are estimated from the average $E(B-V)$ of the nearest stars.

(4) The difference between the *UBV* photoelectric values listed here and the value of Mermilliod's (1976) catalogue, is large in comparison to the observational errors. Therefore, these stars are suspected variables.

(5) Double stars. They could just be separated by the 104-cm reflector. Their combined *UBV* values are reported here.

(6) Peculiar stars from the standpoint of stellar evolution (cf. discussion in section 5).

3. Reddening

The $(U-B)$, $(B-V)$ colour-colour diagram (CCD) of NGC 6913 is plotted in figure 1, in which we have fitted the intrinsic zero-age main sequence (ZAMS), after adopting the slope of reddening line to be 0.72, by Allen (1976) to the early-type main-sequence stars of the cluster. We find that the colour excess $E(B-V)$ varies from $E(B-V)_{\min} = 0^{m}.41$ to $E(B-V)_{\max} = 1^{m}.05$ [i.e. $\Delta E(B-V) = E(B-V)_{\max} - E(B-V)_{\min} = 0^{m}.64$] with a mean value of $E(B-V) = 0^{m}.78$. According to Burki (1975), $\Delta E(B-V)$ greater than $0^{m}.11$ is an indication of the presence of nonuniform extinction across the cluster. Therefore, we can infer that the reddening across the cluster is extremely variable. Presence of nonuniform reddening across the cluster has also been noticed earlier by Morgan and Harris (1956). In order to determine the spatial distribution of the reddening across the cluster, we have divided the cluster field into areas of 5×5 square minutes of arc as indicated in table 2 and have determined the average reddening across each box in the same way as was done by us previously for other clusters (cf. Sagar and Joshi 1978, 1979). Table 2 shows the variation of reddening across the cluster field.

In view of the above, individual stars have been suitably dereddened in the discussions to follow. The $E(B-V)$ values for stars have been estimated in the following manner:

(1) Using the MKK classifications (cf. Mermilliod 1976).

(2) With the help of photometric method as described earlier by us (cf. Sagar and Joshi 1979), if the spectral classification for the star is not known.

(3) The average $E(B-V)$ of the nearest stars, if none of the above methods could be applied.

The reddening value $E(B-V)$ for each individual star, thus estimated, is listed in table 1.

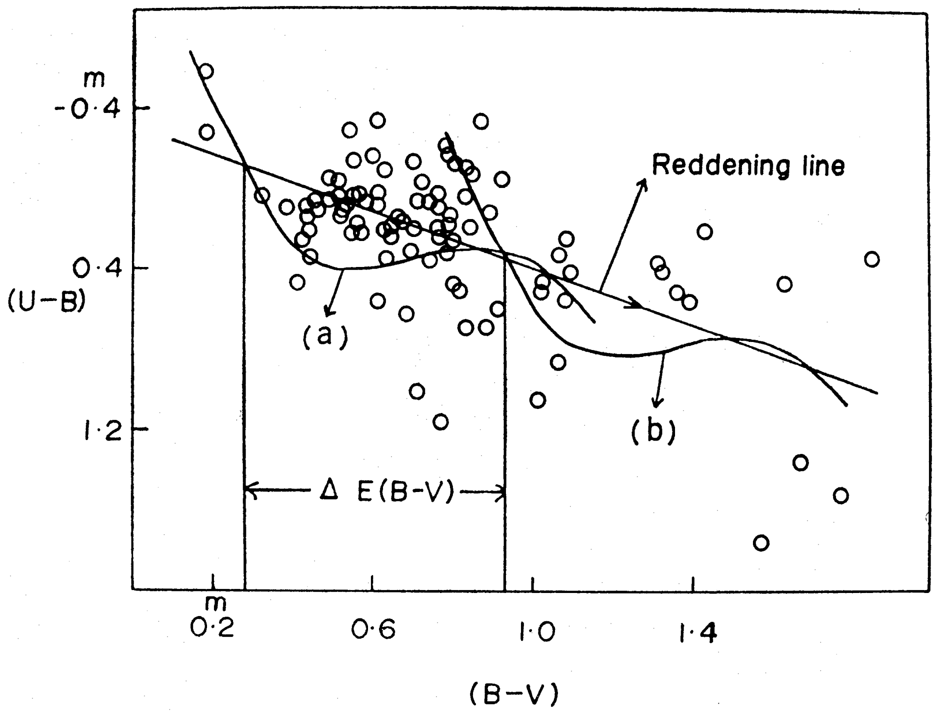

Fig. 1. The $(U-B)$, $(B-V)$ diagram of NGC 6913. Continuous curves correspond to fitted intrinsic ZAMS for (a) the minimum and (b) the maximum values of reddening, in early-type main-sequence cluster stars. $\Delta E(B-V)=E(B-V)_{\max}-E(B-V)_{\min}$.

Table 2. Variation of reddening across the cluster NGC 6913. The average value of the reddening, $E(B-V)$, in areas 5×5 square minutes of arc is indicated in the appropriate boxes along with the number of stars used for the determination of reddening, given in parentheses. Coordinates are relative to $\alpha=20^{h}22^{m}9^{s}$, $\delta=38°21'.6$ (1950) in arc minutes.

$\Delta\delta$	$\Delta\alpha$							
	15′ to 20′	10′ to 15′	5′ to 10′	0′ to 5′	−5′ to 0′	−10′ to −5′	−15′ to −10′	−20′ to −15′
15′ to 20′	—	—	—	—	—	—	—	0.80 (1)
10′ to 15′	0.38 (1)	—	—	—	—	—	0.84 (3)	0.76 (3)
5′ to 10′	0.82 (2)	—	—	—	—	0.67 (2)	0.52 (2)	0.86 (1)
0′ to 5′	—	—	0.59 (1)	0.80 (1)	—	0.63 (2)	—	0.65 (2)
−5′ to 0′	0.54 (2)	—	0.52 (4)	0.88 (8)	0.79 (7)	—	0.72 (2)	—
−10′ to −5′	—	0.93 (1)	—	—	0.84 (2)	0.83 (3)	0.75 (1)	0.75 (3)
−15′ to −10′	0.52 (1)	0.65 (2)	—	—	0.79 (3)	—	0.68 (1)	—
−20′ to −15′	—	0.81 (1)	0.58 (1)	—	—	—	—	0.83 (1)

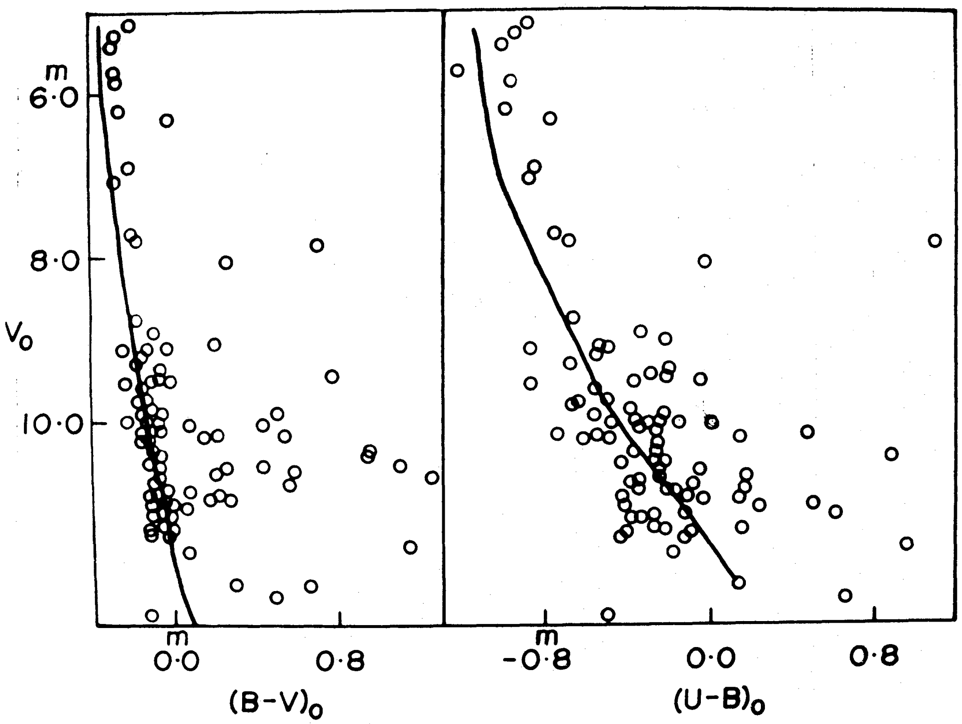

Fig. 2. The V_0, $(B-V)_0$ and V_0, $(U-B)_0$ diagrams of NGC 6913. The solid curves represent the ZAMS given by Allen (1976) fitted on to the cluster main sequence.

4. Distance

We have determined the intrinsic $(B-V)_0$ and $(U-B)_0$ colours and V_0 magnitudes of the cluster stars using their individual values of $E(B-V)$ listed in table 1, in the same way as described earlier by us (Sagar and Joshi 1979). The distance modulus to the cluster is obtained by fitting the ZAMS given by Allen (1976) onto the unevolved part of the cluster main sequence present in the V_0, $(B-V)_0$ and V_0, $(U-B)_0$ diagrams (figure 2) yielding the values $10^{\mathrm{m}}.9 \pm 0^{\mathrm{m}}.1$ and $10^{\mathrm{m}}.8 \pm 0^{\mathrm{m}}.1$ respectively. We have adopted a mean value of the distance modulus to be $10^{\mathrm{m}}.85 \pm 0^{\mathrm{m}}.15$, which corresponds to a cluster distance, $d=(1.5 \pm 0.12)$ kpc. For the same cluster, the estimate of distance by various authors (cf. Alter et al. 1970; Crawford et al. 1977) range from 0.8 kpc to 2.8 kpc.

5. H-R Diagram

After correcting for variable reddening as described in section 3, the H-R diagram of NGC 6913 is plotted in figure 3 for a true distance modulus of $10^{\mathrm{m}}.85$. From the H-R diagram, the following inferences can be drawn:

(1) A well defined cluster main sequence, extending from $M_v = -5^{\mathrm{m}}.5$ to $0^{\mathrm{m}}.5$ is clearly visible.

(2) Star numbers 28, 37, 101, 104, 135, 143, 155, 168, 192 and 219 are occupying their positions well above the main sequence, while star number 72 is occupying its position well below the main sequence in the H-R diagram. These positions are peculiar from the standpoint of stellar evolution. Such type of stars are also found in other open clusters (cf. McNamara and Sanders 1976; Sagar and Joshi 1978, 1979, 1981, 1983; Joshi and Sagar 1983a, b). The above-mentioned stars have their cluster membership prob-

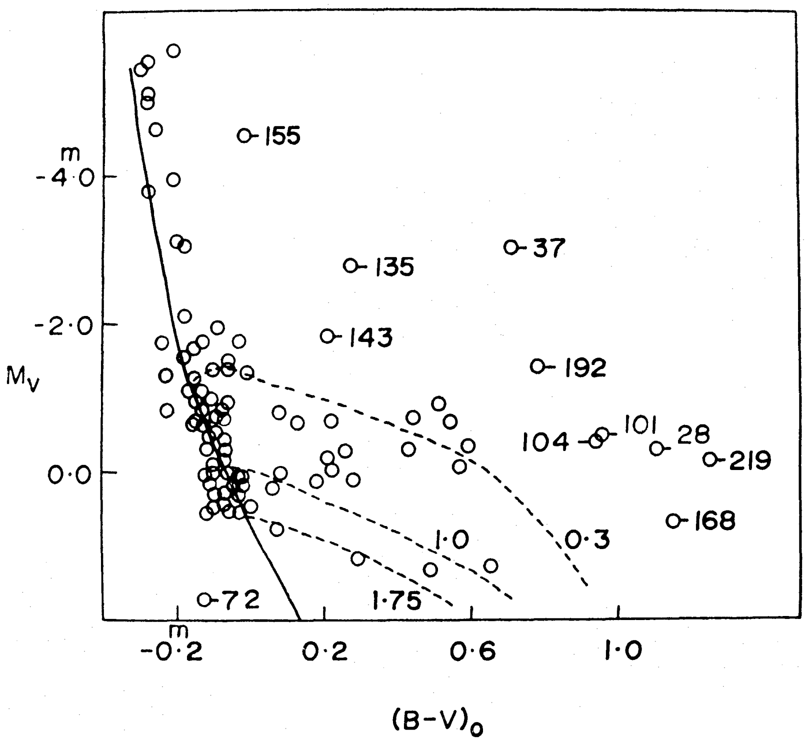

Fig. 3. H-R diagram of NGC 6913. The solid curve is the ZAMS taken from Allen (1976). Peculiar stars from the standpoint of stellar evolution are marked. Dotted curves are the theoretical gravitational isochrones for the ages (in million years) indicated alongside.

abilities more than 50%. It is highly probable that these are field stars. The stars situated towards right of ZAMS at a distance $\geqq 0^{m}.1$ in $(B-V)_0$ and having $M_v > -2^{m}.0$ and $(B-V)_0 \leqq 0^{m}.65$ are possibly field stars, because it is hard to believe that these are pre-main-sequence stars on the basis of their masses and coeval theroy of evolution.

6. Age of the Cluster Stars

We have estimated the age of cluster stars using the theoretical evolutionary tracks given by Iben (1965) for the pre-main-sequence stars. From the fit of the theoretical gravitational isochrones (cf. Sagar 1979) in figure 3, it is found that rather than assigning a unique age to the cluster stars, it would be preferable to say that the cluster stars have ages between 0.3 to 1.75 Myr with a few even younger than 0.3 Myr. On these grounds we can say that stars of the cluster are not all of the same age. This is in keeping with the presence of large quantities of gas and dust in the cluster region, as evidenced by variable extinction across the cluster.

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References

Allen, C. W. 1976, *Astrophysical Quantities*, 3rd ed. (Athlone Press, London), p. 206.
Alter, G., Ruprecht, J., and Vanýsek, J. 1970, *Catalogue of Star Clusters and Associations*, 2nd ed. (Akadémia Kiadó, Budapest).
Burki, G. 1975, *Astron. Astrophys.*, **43**, 37.
Crawford, D. L., Barnes, J. V., and Grahm, H. 1977, *Astron. J.*, **82**, 606.
Hawarden, T. G. 1971, *Observatory*, **91**, 78.
Hoag, A. A., Johnson, H. L., Iriarte, B., Mitchell, R. I., Hallam, K. L., and Sharpless, S. 1961, *Publ. U.S. Naval Obs. 2nd Ser.*, **17**, 349.
Iben, I., Jr. 1965, *Astrophys. J.*, **141**, 993.
Joshi, U. C., and Sagar, R. 1983a, *Monthly Notices Roy. Astron. Soc.*, **202**, 961.
Joshi, U. C., and Sagar, R. 1983b, *J. Roy. Astron. Soc. Canada*, **77**, 40.
McNamara, B. J., and Sanders, W. L. 1976, *Astron. Astrophys.*, **52**, 53.
Mermilliod, J.-C. 1976, *Astron. Astrophys. Suppl.*, **24**, 159.
Morgan, W. W., and Harris, D. L. 1956, *Vistas Astron.*, **2**, 1124.
Sagar, R. 1979, *Studies in Star Clusters*, Ph. D. thesis (University of Gorakhpur), p. 118.
Sagar, R., and Joshi, U. C. 1978, *Monthly Notices Roy. Astron. Soc.*, **184**, 467.
Sagar, R., and Joshi, U. C. 1979, *Astrophys. Space Sci.*, **66**, 3.
Sagar, R., and Joshi, U. C. 1981, *Astrophys. Space Sci.*, **75**, 465.
Sagar, R., and Joshi, U. C. 1983, *Monthly Notices Roy. Astron. Soc.*, in press.
Sanders, W. L. 1973, *Astron. Astrophys. Suppl.*, **9**, 221.