

## Photometric study of the core of the globular cluster M 15

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Photometry of the central parts of globular clusters has always been a difficult problem. Some attempts made in the past more recently have brought questionable results.

Investigation of the core of globular clusters on short-exposure plates taken with large focal length telescopes are necessary to determine the structural parameters, colour profile and the behaviour of the central stars on the colour-magnitude diagram (Alcaino et al., 1982; Martins et al., 1980). Such investigations are of importance for the identification of the X-ray sources found in some globular clusters (Martins et al., 1980).

M 15 is a X-ray galactic globular cluster. Until very recently it was relatively unstudied from a photometric point of view. Brown (1951) carried out  $m_{pv}$ ,  $m_{pg}$  photometry and proper motion observations. Sandage (1970) set up photoelectric UBV sequence near the cluster and photometry in BV system for 210 stars has been published by Cudworth (1976). Two years ago Auriere et al. (1981a) has derived the first C-M diagram of the nucleus of M 15 and has published BV magnitudes for 734 stars in  $1' \times 1'$  square field centered on the cluster.

In this paper BV photometry for 206 stars in the central part of the cluster M 15 is presented. Four V plates (103 aD+GG11) and three B (ORWOZU 21+GG13, 103 aO+GG13) short exposure plates taken at Kassegren focus of the Schemaha 2 m ( $7''/m$ ) and 2 m Bulgarian ( $12''.8/m$ ) telescopes were measured by an iris photometer at Pulkovo Observatory (USSR). For the reduction from iris readings to magnitudes photoelectric (22) and photographic (44) standard stars were used (Brown, 1951; Sandage, 1970). Photographic magnitudes for the standard stars derived in this paper are given in Table 1 (columns 6,7 and 8). The comparison of our magnitudes with standards is shown in Fig. 1. Our standard observations show the rms errors:  $\pm 0.062$  (V),  $\pm 0.055$  (B),  $\pm 0.061$  (B-V).

Within a radius of  $2'.5$  from the cluster center all stars brighter 14.90 (V) and well resolved on the short exposed V-plates were measured. For  $r < 12''$  the clustering of the stars makes iris measurements impossible. In this area ( $12'' < r < 2'.5$ ) we have measured 223 stars. From an intercomparison of the magnitudes, obtained from different plates the rms errors are:  $\pm 0.044$  (V) and  $\pm 0.026$  (B).

Table 1

№ K	S	Standard mag.			Photographic mag.		
		V	B	(B-V)	V	B	(B-V)
1	2	3	4	5	6	7	8
*	X-9	11,15			11,15		
386		12,62	14,04	1,42	12,63	14,08	1,45
490		12,64	13,79	1,15	12,62	13,77	1,15
583		12,67	14,11	1,14	12,60	13,99	1,39
757		12,69	14,16	1,47	12,70	14,30	1,56
462		12,70	14,07	1,37	12,64	14,04	1,40
853		12,73	14,07	1,34	12,76	14,16	1,40
341		12,76	14,13	1,37	12,79	14,10	1,31
160*	—5	12,87	13,65	0,78	12,89	13,66	0,77
144*	II-75	13,00	14,24	1,24	13,10	14,35	1,25
431	—1	13,02	14,22	1,20	13,00	14,23	1,23
817*	X-20	13,30	13,90	0,60	13,26	13,92	0,66
1040*	—6	13,35	14,56	1,21	13,40	14,58	1,18
1115*	—30	13,40	14,04	0,64	13,49	14,13	0,64
387	—3	13,45	14,54	1,09	13,48	14,49	1,01
749		13,46	14,52	1,06	13,59	14,60	1,01
169	II-64	13,48	14,60	1,12	13,49	14,62	1,17
23*	X-7	13,50	14,26	0,76	13,60	14,22	0,62
146	—7	13,54	14,62	1,08	13,51	14,65	1,14
*	X-4	13,65	14,22	0,57	13,74	14,18	0,44
*	X-15	13,69	14,95	1,26	13,82	14,98	1,36
28*	X-5	13,72	14,74	1,02	13,70	14,71	1,01
*	X-19	13,73	14,63	0,90	13,60	14,56	0,96
928	I-43	13,83	14,86	1,03	13,86	14,92	1,06
260	III-14	13,90	14,63	0,73	14,00	14,61	0,61
736		13,91	14,84	0,93	14,00	14,97	0,97
*	X-12	13,92	14,82	0,90	13,82	14,82	1,00
918	S-23	14,01	15,05	1,04	13,99	15,10	1,09
936		14,21	15,15	0,94	14,21	15,24	1,03
943	I-38	14,24	15,18	0,94	14,31	15,27	0,96
731	II-63	14,24	15,22	0,98	14,30	15,30	1,00
366		14,31	15,28	0,97	14,28	15,26	0,98
934	I-62	14,45	15,35	0,90	14,36	15,24	0,88
956		14,52	15,46	0,94	14,53	15,47	0,94
1056	S-19	14,76	15,72	0,96	14,68	15,66	0,98
902	IV-31	14,84	15,77	0,93	14,84	15,72	0,88
922		14,75			14,77		
1096	X-1		14,64			14,62	
1106*	X-2		14,59			14,58	
172*	P-5		14,75			14,75	
29*	X-6		15,12			15,19	
*	P-13		15,29			15,34	
*	P-8		15,47			15,44	
609*	P-14		15,64			15,64	
1133*	X-10		15,74			15,74	
989	I-72		15,94			16,01	
	S-2		16,04			16,05	
	IV-2		16,05			16,03	
	I-11		16,08			16,06	
	I-54		16,08			16,13	
	I-9		16,09			16,14	
	S-10		16,09			16,10	
	I-51		16,07			16,04	
	IV-66		16,10			16,03	
	IV-44		16,04			15,99	
	I-7		16,20			16,30	

Table 1 (continuation)

1	2	3	4	5	6	7	8
	S-27		16,25			16,25	
	III-28		16,26			16,24	
	S-20		16,36			16,34	
	IV-46		16,36			16,32	
	S-9		16,47			16,46	
	I-42		16,48			16,48	

\* — photoelectric magnitudes

There are 62 stars in common with the photoelectric and photographic magnitudes of C u d w o r t h (1976) and B r o w n (1951). A comparison with these photometries shows an excellent agreement and implies an external ms error of  $\pm 0.031$  mag. for the presented V and B magnitudes. The magnitudes determined by B r o w n (1951) were transformed into a BV system by means of photoelectric standards given by S a n d a g e (1970).

There are 45 stars in common with the photographic BV observations of A u r i e r e et al. (1981a). The result of the comparison is shown in Fig. 2 and indicates that there is a systematic difference of about 0.40 mag. in V and B between the two scales. This difference is significant in B colour where there is a obvious dependence of  $\Delta B = B_S - B_A$  on the distance from the center of the cluster  $r$  (Fig. 3).

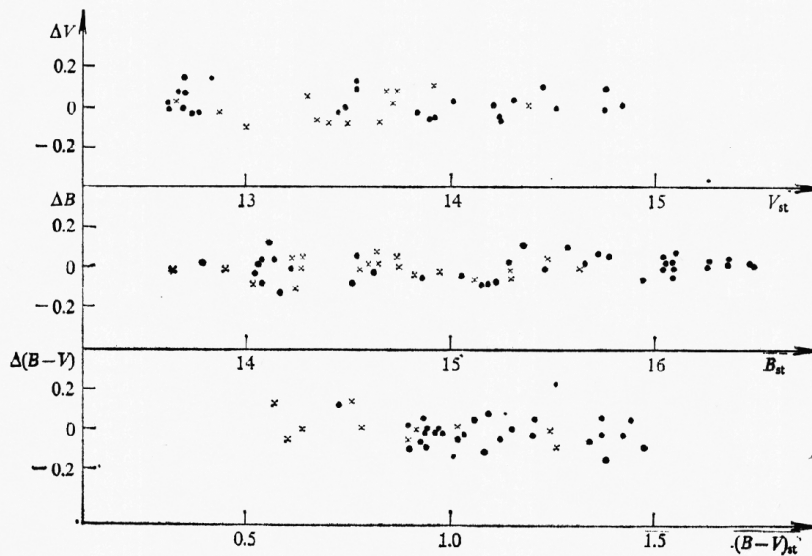


Fig. 1

The final V and B magnitudes of the central stars of globular cluster M 15 measured in this paper are presented in Table 2A and Table 2B. The first column of Table 2 A indicated the star identification in the numbering system of Kustner and the first column of Table 2 B indicates our number. The

second column lists the numbers assigned by Sandage (1970) and by Auriere et al. (1981a). The next two columns give the  $V$  magnitudes and  $(B-V)$  colours. The last column lists the membership of the stars to the cluster as derived by Spasova (1981).

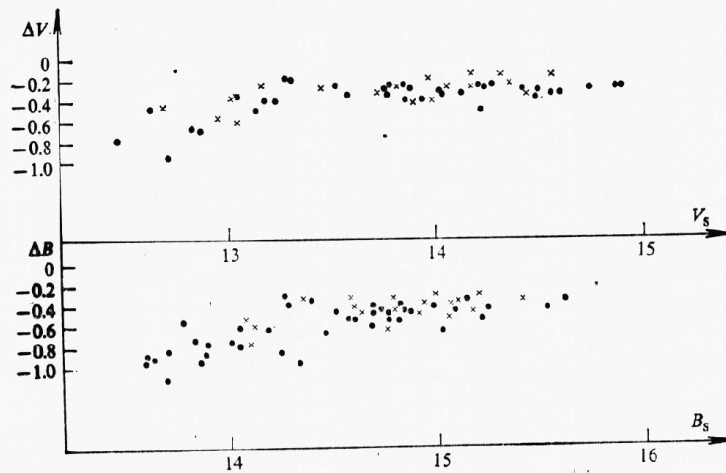


Fig. 2

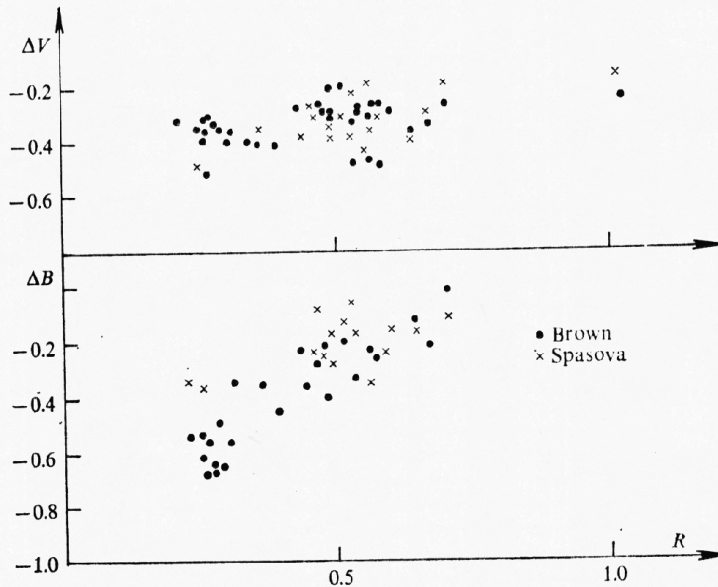


Fig. 3

There are still 17 stars in the investigation region which are in close contact with fainter stars: Kustner number 277, 237, 343, 373, 461, 479, 496, 534, 575, 635, 639, 644, 673, 701, 792, 863 and 930.

The chart in Fig. 4 identifies the stars in Table 2B.

Table 2A

K	ID	V	(B-V)	K	ID	V	(B-V)
1	2	3	4	5	6	7	8
134	SIII-8	13,66	1,49 F	391		14,26	0,69 m
136		14,90	0,80 m	393	SII-42	13,25	1,11 m
141	SIII-19	14,88	0,94 m	401	A 535	14,13	0,84 m
144	SII-75	13,00	1,25 m	403	A 539	14,21	0,93 m
154	SIII-9	14,77	0,83 m	406		13,81	0,94 m
158	SIII-33	13,98	1,00 m	421		12,51	1,31 m
147	SIII-34	12,57	0,83 F	422		14,29	1,00 m
169	SII-64	13,49	1,17 m	427		13,91	1,02 m
179		15,04	0,70 m	428		14,74	0,84 m
185		14,48	0,88 m	431	SI-1	13,00	1,23 m
193	SIII-44	14,93	0,90 m	434	A 523	13,88	0,90
205		14,90	0,94 m	435	A 529	13,48	1,04 m
224	SII-30	13,38	1,14 m	436	A 530	14,23	0,89 m
235		14,43	0,88 m	447		13,20	0,83 m
238	SII-29	13,26	1,18 m	449		14,29	0,81 m
240		12,71	1,45 m	450	A 14	13,76	0,96 m
254	SII-31	13,26	1,19 m	458		14,57	0,56 m
260	SIII-14	14,00	0,61 m	459		14,08	0,79 m
272	SIII-27	13,51	1,08 m	462	A 13	12,64	1,40 m
280	SIII-12	14,54	0,89 m	470	A 503	14,27	0,79 m
284	SII-15	14,69	0,98 m	474		13,80	0,89 m
288	SII-16	13,75	1,08 m	475		14,56	1,27 m
290		13,31	1,14 m	481		13,86	1,03 m
293		14,71	0,96 m	482	SIII-59	14,33	0,82 m
296	SIII-26	14,53	0,95 m	487	A 349	13,94	0,88 m
305	SIII-46	14,76	0,90 m	490	A 463	12,62	1,15 m
306	SII-9	14,57	0,87 m	497		13,04	1,23 m
319		13,55	1,12 m	506	SIII-77	14,70	0,90 m
323		14,52	0,91 m	508		13,69	1,02 m
328	SIII-48	13,72	1,04 m	511	A 800	13,05	1,21 m
346		13,92	1,01 m	514	A 825	14,47	0,13 m
347		14,66	0,81 m	519	A 15	13,78	0,91 m
332		14,70	0,93	531		12,89	1,24 m
354	SII-40	14,43	0,89 m	532		14,66	0,75 m
357	SII-44	14,59	0,97 m	537	A 423	14,18	0,48 F
361		13,95	1,01 m	539	A 6	12,87	1,33 m
366		14,28	0,98 m	559		14,95	—0,24 m
381		15,06	0,88	560	SIII-70	14,40	0,92 m
383	A 12	13,99	1,00 m	561	A 417	13,23	0,85 m
386	A 21	12,64	1,45 m	562		14,84	0,81
565	A 803	14,05	0,79 m	721		14,62	0,75 F
566	A 407	13,82	0,90 m	731	SI-63	14,30	1,00 m
567		13,26	1,08 m	733	A 11	13,31	1,08 m
535		14,57	0,89 m	734	A 650	13,28	1,10 m
569	SIII-83	13,88	1,04 m	735	A 651	13,98	0,89 m
488		13,46	1,12 m	736		14,00	0,97 m
570		12,50	1,50 m	749		13,59	1,01 m
578		13,96	0,96 m	753		14,58	0,97 m
581	A 127	13,26	1,14	757	SIV-38	12,70	1,56 m
572		13,72	1,05 m	764		13,81	1,09 m
582	SIV-62	14,38	0,85 m	775		14,82	0,79 m
583		12,60	1,39 m	796		14,78	0,88 F
584		14,24	0,84 m	803		14,44	0,83 m
591		14,51	0,97 m	806		14,54	0,92 m
592	SIV-65	14,00	1,06 m	809		14,74	0,74 m
596	A 754	14,14	0,76 m	810		14,48	0,87 m
601	A 12	13,04	1,12 m	848	SI-23	13,99	0,89 m

Table 2A (continuation)

1	2	3	4	5	6	7	8
607		14,20	0,98 m	851		14,90	0,75 m
613		14,84	0,90 m	853		12,76	1,40 m
618	A 716	13,70	0,50 m	866	SI-28	14,51	0,84 m
619		14,47	0,80 m	884	SI-34	14,20	0,92 m
625	A 731	14,48	0,54 m	902	SIV-31	14,84	0,88 m
634		12,60	1,41 m	912	SIV-48	14,41	0,93 m
642	A 710	13,92	0,83 pm	919	SI-50	13,66	1,02 m
648	A 10	13,77	-0,13 pm	925	SIV-30	14,68	0,84 m
656		14,90	0,09	928	SI-43	13,86	1,06 m
657		14,70	0,57	932	SI-56	14,41	0,93 m
661	A 207	14,10	0,79 m	934	SI-62	14,36	0,83 m
670		13,60	1,21 m	936		14,21	1,03 m
672	SI-6	13,82	0,97 m	943	SI-38	14,31	0,94 m
684		14,25	0,81 m	956		14,53	0,94 m
693	A 681	14,62	0,72 pm	961	SI-41	14,18	1,00 m
702		12,84	1,32 m	990	SIV-10	13,82	1,10 m
706		12,92	1,27 m	993	SI-74	14,00	1,03 m
709	SIV-58	13,61	1,11 m	996		14,47	-0,11 m
718		14,72	0,38 pm	652	RRLyr	14,83	0,43

Table 2B

	ID	V	(B-V)		ID	V	(B-V)
1	A 1	12,90	1,30	29		14,85	0,27
2	A 271	13,80	0,47	30		14,68	0,71
3	A 787	13,90	0,92	31		14,82	0,78
4	A 780	13,40	0,75	32		14,81	0,87
5	A 761	13,05	1,20	33		14,77	0,95
6	A 2	13,18	1,09	34		14,90	0,73
7	A 623	12,83	0,99	35		14,84	0,69
8	A 7	13,98	0,84	36	A 604	14,74	0,36
9		14,90	0,00	37 <sub>c</sub>	A 416	14,60	0,29
10		14,82	0,47	38 <sub>c</sub>	A 415	14,54	0,52
11		14,73	0,76	39		14,90	0,70
12		13,77	1,00	40	A 466	14,76	0,74
13	A 576	13,74	1,02	41		14,88	0,55
14	A 414	12,97	1,23	42		14,41	0,75
15	A 442	14,22	0,92	43	A 493	14,87	0,70
16	A 8	13,76	0,96	44		14,78	0,80
17	A 451	13,86	1,04	45	A 546	14,87	0,74
18		14,65	0,79	46	A 468	14,42	0,82
19 <sub>c</sub>		15,09	0,80	47		14,52	0,75
20	A 488	13,58	1,06	48		14,70	0,79
21	A 247	12,71	1,29	49		14,67	0,81
22		13,74	1,00	50		14,90	0,75
23	A 727	14,88	0,40	51		14,69	0,87
24	A 801	14,88	0,65	52		13,77	1,24
25		14,52	0,88	53		13,33	1,13
26		14,83	0,47	54	A 281	13,60	1,12
27	A 573	14,56	0,62	55	A 832	14,76	0,34
28		14,82	0,58				

Note: c — the star is in contact.

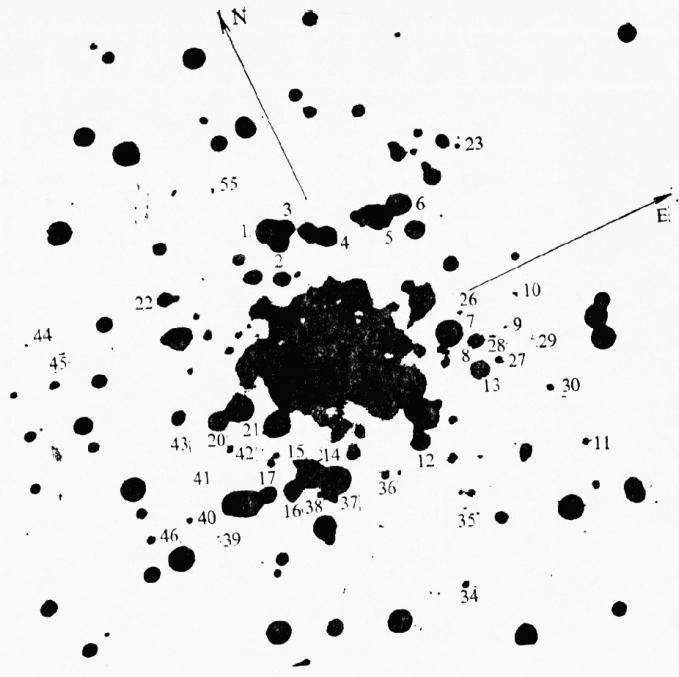


Fig. 4

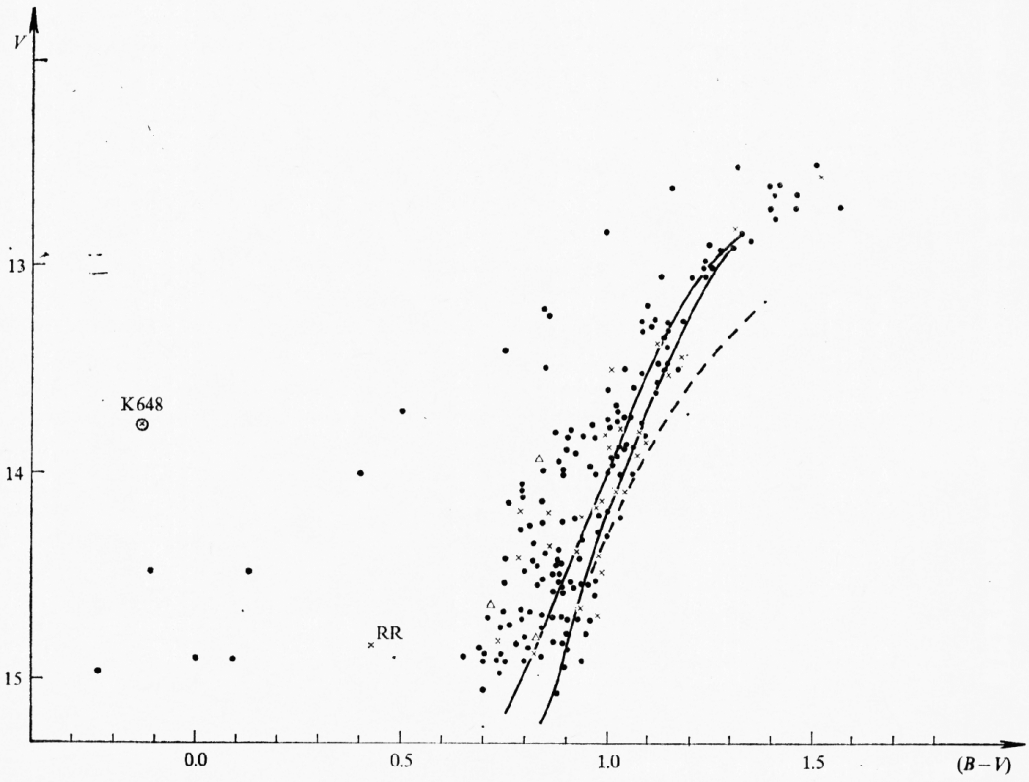


Fig. 5

Colour-magnitude diagram for the bright stars in the nucleus of M 15 is shown in Fig. 5. Dots indicate stars which are members of the cluster as derived by Spasova (1981), Brown (1951) and Cudworth (1976) on the basis of proper motion criteria, and stars without proper motions but because of their closeness to the cluster center ( $r < 45''$ ) make a strong case for membership. Triangles represent probable member stars. With the straight line are plotted representative points from the C-M diagram obtained for the external part of the cluster by Sandage (1970). The crosses indicate stars-cluster members measured by Spasova (unpublished) in the outer regions of the cluster. There is no systematic difference in the photometry of both regions due to the fact that we avoided measuring stars in the central part where the background increases.

The comparison of our diagram with that of Sandage (1970) and Auriere et al. (1981b) shows:

1. There is a significant difference between the slope of the red giant branch in Auriere's diagram (1981b) and ours. The diagram in this paper do not confirm the smaller slope of the red giant branch derived by Auriere et al. (1981b). The mean RGB from Auriere's paper is presented by dash line on the diagram.

2. 99 bright stars measured for the first time populate well the red giant branch which reaches to  $V=12.60$  and  $(B-V)=1.56$ . There are still 49 resolved stars within  $R < 12''$  with photometry of low weight which can't exchange essentially the slope and the extension of the red giant branch. Here it must be mentioned that there are none brighter than  $V=13.90$  stars-members of the cluster in the outer region ( $45' \times 45'$ ) of the cluster (Kadla, Spasova, 1974).

3. There are twelve stars outlying toward the blue side of the diagram. Seven of them, Rustner numbers 260, 421, 447, 490, 514, 559 and 996, are pointed out by Brown (1951) as stars lying on the left of the red giant branch. The stars K559 and K996 are AHB stars (Zinn et al., 1972) and K 421 are practically two stars. The rest stars are found in our study. A similar sequence named by Kadla et al. (1976) "special" is detected in the globular cluster M 13. There are still some stars falling in this sequence but belonging to the outer part of the cluster. One of them K 73, a very probable cluster member, is plotted on the diagram. What is the nature of these stars which have not been discussed previously as AHB stars? According to the author they could be double stars or variable stars. It is not impossible to observe highly evolved stars which form actual sequence on the C-M diagram. It is clear that our observational material do not allow us to make some definitive conclusion about the nature of these stars and sequence and more photometric and spectral investigations are needed.

On the diagram are plotted also the planetary nebulae, K 648, and one RR Lyrae star, K 652, measured in this paper.

Over the part of the area of the cluster covered in this paper there are some stars (No 10, 23, 26, 27, 28, 29, 36, 37) and K 625, K 657, K 718 with high possibility of variability, and their positions are not marked on the C-M diagram.

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## Фотометрическое исследование ядра шарового скопления М 15

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(Резюме)

Получены В- и V-величины 206 звезд в центральной части шарового скопления М 15 со средней ошибкой 0,031. Построена диаграмма „цвет—величина“ исследуемых звезд. Двенадцать звезд, пять из которых найдены в этом исследовании, лежат левее клона красных гигантов в области „особых звезд“.

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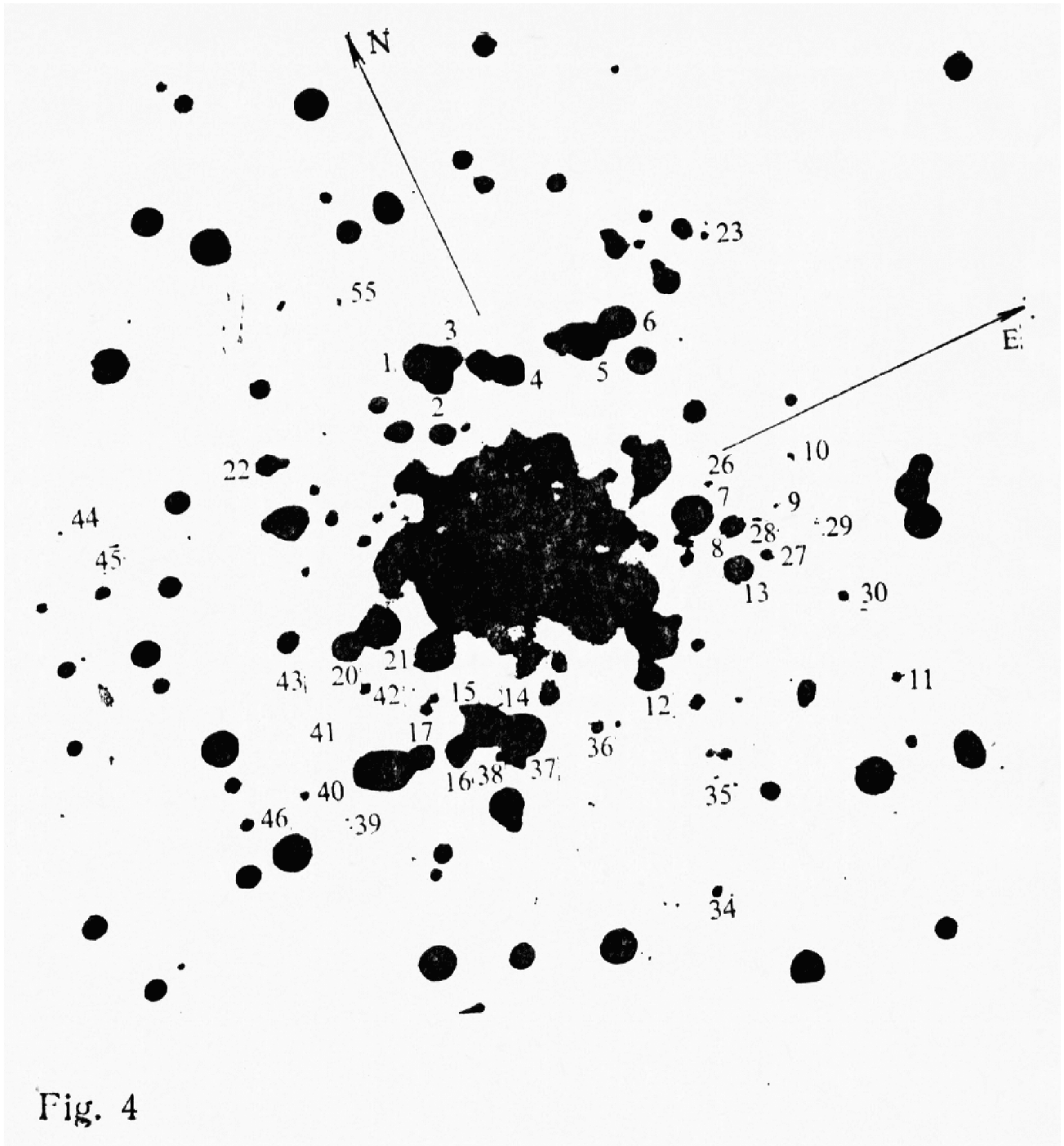


Fig. 4