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Detection of red supergiant stars on the colour–colour diagrams in the system UBVRI

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Abstract. Normal colours of red stars of luminosity classes I, III and V, as well as reddening lines, are presented on the colour–colour diagrams in the system UBV (Johnson) and RI (Kron–Cousins). The dispositions of the red supergiants on the colour–colour diagrams in UBV, BVR, VRI, UVI, BRI and BVI are pointed out with the help of 14 well known K–M Milky Way supergiants and a few samples of photometric data of red stars. The selection criteria of red supergiants are derived. A list of 52 red supergiant candidates, suspected among the used samples of red stars, is given.

Key words: supergiant — photometry — classification method

1. Introduction

Multicolour photometry is basic method in investigations of the structure and evolution of stellar systems. Moreover, the use of the brightest stars in the galaxies as distance indicators is the most important method for investigation of the structure of the nearby universe. The brightest red supergiants are very interesting in this aspect since the recent investigations of Karachentsev and Tikhonov (1994), Rozanski and Rowan–Robinson (1994) show a distance error of about 0.3^m for the red supergiants and up to 0.5^m for the blue supergiants. Unfortunately, the revealing of the brightest red supergiants in the resolved galaxies meets serious difficulties because of the contamination by foreground dwarf stars.

Many works deal with the classification of red stars with the help of narrow band photometrical systems (see Golay, 1974; Straizys, 1977; 1987), but these systems have low transparency and they are not suitable for extragalactic observations. Though, the system UBVRI gives some possibilities. One method of classification of red stars as dwarfs and giants, based on BVI photometry is shown by Robertson and Hamilton (1987). Another example, in the system UVRI, is given by Weis (1991).

In the present paper we show the possibilities for detection of red supergiant stars using colour–colour diagrams in the contemporary UBVRI system, defined by Bessel (1990) and Landolt (1983, 1992). We present the colour–colour diagrams, the reddening lines and the criteria for classification of red stars in the systems UBV (Fig.1), BVR (Fig.2), VRI (Fig.3), UVI (Fig.4), BVI (Fig.5), and BRI (Fig.6). The colour ranges of the diagrams, corresponding to the spectral classes K and M, are (U–B) > 1, (B–V) > 1, (V–R)> 0.5 and (V–I) > 0.3. In the end we present a list of red supergiant candidates found by us in the analyzed samples of data.

Though the criteria derived here aim to detect red supergiant candidates. The nature of such kind of stars may be proved by spectral observations.

2. Photometric data

The curves in each of Figures 1–6 represent the normal colours of the stars of luminosity classes V (dwarfs, upper curve), III (giants, middle curve) and I (supergiants, lower curve), derived from Vilnius spectra (Straizys, 1977; 1987). Here the colours (V–R), (R–I) and (V–I) are transformed from the system of Johnson to the system of Kron-Cousins with the help of the relations of Fernie (1983b). We checked independently these relations using the photometric data of common stars measured in the systems of Johnson (Moffet and Barnes, 1979; Kunkel and Rydgren, 1979) and Kron-Cousins (Landolt, 1983; 1992) and confirmed them. Another (not so rich) system of computed normal colours of stars, derived again from Vilnius spectra, is published by Bessel (1990). Both data systems, of Straizys and Bessel, are in good agreement, though, in this paper we prefer the data of Straizys because they are more rich and smooth. The colour curves are given in Table 1. The diagonal lines, drawn as tails of each curve of the supergiants, correspond to the reddening lines obtained here.

We found the most considerable distinctions between the data of Straizys and Bessel in the colours of the red supergiants. Only the class M2Iab is present in the data of Bessel and it is essentially more red than that of Straizys. This class corresponds to the brightest red supergiants (Humphreys, 1978), that is why it is especially added in Table 2 and presented in the diagrams as a single red supergiant star.

The source of UBVRI data for 7 K3I–K5I supergiants and for 7 MI supergiants is the paper of Fernie (1983a). The colours (B–R) and (R–I) from this paper are transformed to the system of Kron–Cousins by the relations of Fernie (1993b). The data are presented in Table 2. In all diagrams the K and M supergiants are designated by big open and filled boxes, respectively.

We compare the computed curves and the position of the certain red supergiants on all colour–colour diagrams with two samples of the red stars having UBVRI data and (B–V)>1.1. One of them consists of 170 red standards (Landolt, 1983; 1992). Another has 350 red stars (125 of them without (U–B) colour), detected in the objective prism survey (Weis, 1991). We transformed the red colours of the stars of Weis to the system of Kron-Cousins in the same manner as in the previous cases. On all diagrams the stars of Landolt are designated by middle sized boxes and those of Weis – by small boxes. The data in BVRI for 23 red dwarf and giant stars having large proper motion, taken from the paper of Dawson and Forbes (1989), are designated on the relevant diagrams by triangles.

Additionally we analyzed the distribution of other samples of red stars with (B–V)>1.1. In the case of the system BVR we used the sample of 15 red giants in nearby open galactic clusters (Coleman, 1982). In the case of the system BVI we used the distribution of 128 M stars, situated in the direction of the north galactic pole (Pesch and Dahn, 1982), the majority of which are considered as probable M dwarfs. Another sample of BVI data comprehends 54 K-M stars, detected in the objective prism survey (Robertson and Hamilton, 1987). The measurements in the system of Johnson for 33 red stars of Moffet and Barnes (1979) and for 20 red stars of Kunkel and Rydgren (1979) have been also analyzed.

3. Colour–colour diagrams and reddening lines

Six colour–colour diagrams are presented in Figs. 1–6. We consider that the correspondence between the computed and observed colours is good enough. The exception is the blueward shift of (V–R) and (R–I) transformed colours of Weis (1991) by about 0.05^m and 0.15^m, respectivelly. Probably the relations of Fernie (1983b) are not suitable for these cases.

Numerous reddened stars of Landolt (1983, 1992) and Weis (1991), probably K and M giants and supergiants can be seen in the low parts of all diagrams. We used these stars to derive raw estimations of the slopes of the reddening lines for the yellow and red stars. The results are given in Table 3.

The coefficient of the reddening line for the red supergiants in the system UBV (Fig.1) is essentially greater than the value of 0.72, which is usually accepted for the OB stars. Though our estimation is in good agreement with the similar results of Straizys (1977), Talbot et al. (1979) and Iye and Richter (1985). The estimations of the coefficients of the reddening lines in the diagrams BVR (Fig.2) and BVI (Fig.5) are higher than the estimations of Rieke and Lebofsky (1985) – 1.28 and 0.62, respectively, as well as of Coleman (1982) for BVR – 1.19, because the data of these authors correspond to the system of Johnson.

4. Detection of the red supergiants on the colour–colour diagrams

In all diagrams presented in Figures 1–6 the red dwarfs are situated in the upper parts of the diagrams and the red supergiants – in the lower parts. The most significant distinction between the dwarfs and supergiants can be seen in the systems UBV (Fig.1) and UVI (Fig.4). In the systems BVR (Fig.2) and BVI (Fig.5) the distinction between the red dwarfs and red supergiants is well pronounced and the distinction between the G–K dwarfs and G–K supergiants is also considerable. Note that the diagrams in the systems BVR (Fig.2) and BVI (Fig.5) look almost uniform, but in the second case the abscissa axis is really twice as long. In the systems VRI (Fig.3) and BRI (Fig.6) the red stars of luminosity classes I, III and V practically coincide and they are not suitable for classification of red stars.

Generally, nevertheless, the normal colours of the brightest K and M red supergiants are not known for sure, such kind of stars may be suspected on the colour–colour diagrams in the system UBV, UVI, BVR and BVI. But since the contemporary CCD detectors have low sensitivity in the U band, BVR and BVI systems give practically the most significant possibilities. The areas of the red supergiants are the lower parts of the colour–colour diagrams. They are situated below the computed curves of the red supergiants and left–down from the reddening lines.

Astronomers have applied simple colour criteria to detection of red supergiants candidates for many years, but the presented diagrams lead to the conclusion that one–dimensional colour criteria for revealing of red supergiants, such as (B–V)>1.6, are not very confident. Though we collected in Table 4 such "one-colour" criteria for the practical cases when only one colour is available. Using the above mentioned relations we give also the criteria for the system VRI of Johnson.

A list of 52 red supergiant candidates suspected by us in the used samples of red stars, obtained with the help of the colour–colour diagrams, are listed in Table 5. Six stars are found in more than one publication.

We note that 10 red supergiants with the obtained absolute magnitudes and normal colours are listed by Mermilliod and Maeder (1986). The most investigated red supergiants of the Milky Way are listed by Humphreys (1978).

5. Conclusions

The presented investigation gives evidence that the colour–colour diagrams in the widespread observing systems BVR and BVI show well pronounced division between red dwarf and red supergiant stars. If the photometric accuracy is about 0.1^m, these diagrams permit selection of red supergiant candidates of classes K5–M2. This conclusion is important for detection of red supergiants in distant resolved galaxies, when the foreground red giants can be rejected as very bright stars and only the contamination of the foreground dwarfs must be avoided. However, the colour–colour diagrams in the systems BVR and BVI are not sufficient for confident detection of red supergiants in the crowded fields of the Milky Way because of the contamination of the reddened G–K giants. The adjustment of the normal colours of the red supergiants rests an important problem.

We note that yellow supergiants of classes G-K also may be detected (although less sure) in the colour–colour diagrams of the systems BVR and BVI. This may be important for the distance estimations of the galaxies belonging to the Virgo cluster since the first results in this field has been already obtained (Pierce et al., 1992, Shanks et al., 1992). Unfortunately, now no calibration exists for the brightest yellow supergiants in the galaxies as distance indicators, it only seems that they are by about 1 magnitude brighter than the brightest red supergiants (Humphreys, 1978).

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References

Bessell M.S.: 1990, Publ. Astr. Soc. Pacific, **102**, 1181.
Coleman L.A.: 1982, Astron. J., **87**, 369.
Dawson P.C., Forbes D.: 1989, Publ. Astr. Soc. Pacific, **101**, 614.
Fernie J.D.: 1983a, Astrophys. J. Suppl. Ser., **52**, 7.
Fernie J.D.: 1983b, Publ. Astr. Soc. Pacific, **95**, 782.
Golay M.: 1974, Introduction to Astronomical photometry, Reidel
Humphreys R.M.: 1978, Astrophys. J. Suppl. Ser., **38**, 309.
Iye M., Richter O.G.: 1985, Astron. Astrophys., **114**, 471.
Karachentsev I.D., Tikhonov N.A.: 1994, Astron. Astrophys., **286**, 718.
Kunkel W.E., Rydgren A.E.: 1979, Astron. J., **84**, 633.
Landolt A.U.: 1983, Astron. J., **88**, 439.
Landolt A.U.: 1992, Astron. J., **104**, 340.
Mermilliod J.-C., Maeder A.: 1986, Astron. Astrophys., **158**, 45.
Moffett T.J., Barnes T.G.: 1979, Astron. J., **84**, 627.
Pesch P., Dahn C.: 1982, Astron. J., **87**, 122.
Pierce M.J., McClur R.D., Racine R.: 1992, Astrophys. J., **393**, 523.
Rieke G.H., Lebofsky M.J.: 1985, Astrophys. J., **288**, 618.
Robertson T.H., Hamilton J.E.: 1987, Astron. J., **93**, 959.
Rozanski R. and Rowan-Robinson M.: 1994, Mon. Not. R. Astron. Soc., **271**, 530.
Shanks T., Tanvir N.R., Major J.V., Doel A.P., Dunlop C.N., Mayers R.M.: 1992, Mon. Not. R. Astron. Soc., **256**, 29p
Straizys V.: 1977, Multi colour photometry of stars, Mocslas, Vilnius
Straizys V.: 1987, Bulletin of the Vilnius Observatory, **78**, 43
Talbot R., Jensen E., Dufor R.: 1979, Astrophys. J., **229**, 91
Weis E.W.: 1991, Astron. J., **102**, 1795.

Table 1: *Normal colours of the red stars derived from the data of Straizys (1977; 1987)*

Class	U–B	B–V	V–R	R–I	V–I	U–V	B–R
G8I	1.25	1.22	0.58	0.52	1.10	2.47	1.80
K0I	1.49	1.35	0.64	0.58	1.23	2.84	1.99
K1I	1.60	1.45	0.69	0.61	1.30	3.05	2.14
K2I	1.68	1.50	0.72	0.66	1.38	3.18	2.22
K3I	1.75	1.55	0.77	0.69	1.46	3.30	2.32
K5I	1.86	1.62	0.81	0.79	1.61	3.48	2.43
K7I	1.88	1.64	0.83	0.84	1.66	3.52	2.47
M0I	1.91	1.66	0.85	0.88	1.72	3.57	2.51
M1I	1.92	1.69	0.89	0.94	1.82	3.61	2.58
M2I	1.91	1.71	0.95	1.04	2.00	3.62	2.66
M3I	1.89	1.73	1.06	1.23	2.30	3.62	2.79
M4I	1.83	1.77	1.18	1.41	2.59	3.60	2.95
M5I	1.60	1.80	1.37	1.56	2.88	3.40	3.17
K1III	1.03	1.08	0.57	0.51	1.08	2.11	1.65
K2III	1.17	1.16	0.59	0.52	1.12	2.33	1.75
K3III	1.44	1.29	0.68	0.62	1.26	2.73	1.97
K4III	1.62	1.40	0.76	0.67	1.42	3.02	2.16
K5III	1.80	1.51	0.84	0.80	1.64	3.31	2.35
M0III	1.88	1.56	0.87	0.80	1.68	3.44	2.43
M1III	1.89	1.58	0.89	0.85	1.76	3.47	2.47
M2III	1.89	1.59	0.93	0.98	1.92	3.48	2.52
M3III	1.85	1.60	1.01	1.17	2.19	3.45	2.61
M4III	1.72	1.59	1.15	1.42	2.40	3.31	2.74
M5III	1.45	1.56	1.33	1.65	2.92	3.01	2.89
M6III	1.00	1.55	1.63	1.81	3.25	2.55	3.18
K5V	1.12	1.15	0.70	0.57	1.27	2.27	1.85
K7V	1.23	1.35	0.82	0.69	1.52	2.57	2.17
M0V	1.23	1.44	0.90	0.81	1.72	2.67	2.34
M1V	1.23	1.47	0.95	0.95	1.92	2.70	2.42
M2V	1.15	1.49	1.00	1.08	2.10	2.64	2.49
M3V	1.13	1.51	1.05	1.20	2.28	1.64	2.56
M4V	1.17	1.54	1.11	1.33	2.44	2.71	2.65
M5V	1.24	1.58	1.16	1.47	2.61	2.82	2.74
M6V	1.31	1.65	1.23	1.58	2.77	2.96	2.88
M7V	1.40	1.75	1.39	1.69	2.98	3.15	3.14
M8V	1.50	1.85	1.52	1.82	3.18	3.35	3.37

Table 2: *Magnitudes and colours of the certain K and M supergiants from the paper of Fernie (1983a)*

HD/BD/CD	V	U–B	B–V	V–R	R–I	V–I	U–V	B–R	Class
50877	3.86	1.87	1.74	0.84	0.74	1.58	3.61	2.58	K3Iab
187238	7.10	2.06	2.04	1.05	0.96	2.01	4.10	3.09	K3Iab-Ib
22764	5.81	1.70	1.81	0.93	0.92	1.85	2.51	2.74	K4Ib
4817	6.12	1.82	1.90	0.97	0.95	1.96	3.72	2.87	K5Ib
43152	6.97	1.82	1.49	0.82	0.70	1.52	3.31	1.69	K5Ib
200905	3.77	1.82	1.66	0.82	0.82	1.52	3.48	2.48	K5Ib
201065	7.64	2.07	1.82	0.90	0.80	1.73	3.89	2.72	K5Ib
52877	3.41	1.75	1.69	0.89	0.87	1.77	3.44	2.58	MOIab
185622	6.38	2.11	1.99	1.07	1.11	2.23	4.10	3.06	MOIab-Ib+B3V
31220	7.40	2.22	1.80	0.99	1.28	2.38	4.02	2.79	MOIb
30178	7.86	2.08	1.86	1.10	1.34	2.44	3.94	2.96	M2Ib
77522	9.27	1.8*	1.78	1.00	1.11	2.11	3.6*	2.78	M3Ia
44213	7.99	1.89	1.83	1.15	1.36	2.52	3.72	2.98	M3Ib-II
-21.4897	9.96	1.98	2.39	1.70	1.86	3.32	4.37	4.09	M4I
–	–	2.16	1.84	1.11	1.28	2.39	4.00	2.95	M2Iab**

*) The colours (U–B) and (U–V) are estimated by us because there are no U data in the original paper.

**) These computed colours are given in the paper of Bessell (1990)

Table 3: *Estimations of the coefficients of the reddening lines*

E(U–B)/E(B–V) = 1.1 E(U–V)/E(V–I) = 1.7
E(B–V)/E(V–R) = 1.6 E(B–V)/E(V–I) = 0.8
E(V–R)/E(V–I) = 1.1 E(B–R)/E(R–I) = 1.5

Table 4: *Blue limits of the normal colours of the red supergiants*

Class	Contemporary system UBVRI							System VRI of Johnson		
	U–B	B–V	V–R	R–I	V–I	U–V	B–R	V–R	R–I	V–I
K2 and later	>1.7	>1.6	>0.8	>0.8	>1.6	>3.3	>2.4	>1.1	>0.9	>2.0
M1 and later	>1.8	>1.7	>1.0	>1.0	>2.0	>3.5	>2.7	>1.3	>1.0	>2.3

Table 5: *Red supergiant candidates found in the present work*

Ident.No.	V	U–B	B–V	V–R	R–I	V–I	Reference
57884	9.135	3.864	2.299	1.264	1.019	2.287	Landolt,1983
60826	8.983	5.118	2.741	1.495	1.178	2.677	
79097	7.601	1.933	1.628	0.990	1.100	2.087	
140850	8.816	2.078	1.670	0.948	0.947	1.895	
+4 3508	9.326	2.077	1.753	0.974	0.900	1.874	
110-353	8.477	2.292	2.002	1.186	1.120	2.306	
111-775	10.747	2.042	1.738	0.965	0.897	1.864	
111-1969	10.384	2.304	1.961	1.181	1.223	2.405	
111-2864	8.292	2.017	1.716	0.933	0.853	1.786	
188934	9.351	2.102	2.040	0.942	0.787	1.731	
92-235	10.595	1.984	1.638	0.894	0.911	1.806	Landolt,1992
95-330	12.174	2.233	1.999	1.166	1.100	2.268	
95-275	13.479	1.740	1.763	1.011	0.931	1.944	
97-75	11.483	2.100	1.872	1.047	0.952	1.999	
98-L3	14.614	1.837	1.936	1.091	1.047	2.142	
98-618	12.723	2.144	2.192	1.254	1.151	2.407	
98-675	13.398	1.936	1.909	1.082	1.002	2.085	
109-199	10.990	1.967	1.739	1.006	0.900	1.904	
110 L1	16.252	2.953	1.752	1.066	0.992	2.058	
110-280	12.996	2.133	2.151	1.235	1.148	2.384	
110-315	13.637	2.256	2.069	1.206	1.133	2.338	
110-365	14.686	1.895	2.261	1.360	1.270	2.631	
110-502	12.330	2.326	2.326	1.373	1.250	2.625	
111-775	10.744	2.029	1.738	0.965	0.896	1.862	
111-1965	11.419	1.865	1.710	0.951	0.877	1.830	
111-1969	10.382	2.306	1.959	1.177	1.222	2.400	
137	10.95	2.14	1.75	0.99	0.71	1.70	Weis,1991
219	11.90	2.24	1.77	0.99	0.69	1.68	
303	9.91	2.07	1.73	1.06	0.77	1.83	
474	10.38	2.36	2.04	1.29	0.89	2.18	
555AB	11.03	1.95	1.78	1.16	0.87	2.03	
574	11.27	2.21	1.91	1.15	0.81	1.96	
796	12.33	2.08	1.68	1.03	0.77	1.80	
860	10.96	1.99	1.74	1.10	0.83	1.93	
1235	11.64	2.33	1.75	1.12	0.87	1.99	
1317	8.53	2.02	1.70	0.95	0.69	1.64	
1499	10.64	2.52	2.29	1.61	1.09	2.70	
1504	10.92	2.15	1.86	1.10	0.75	1.85	
1505	12.05	2.28	2.07	1.53	1.14	1.67	
R 154	10.43	-	1.75	1.34	1.22	2.56	
97-75	11.48	-	1.87	1.00	1.04	2.04	Kunkel,Rydgren,1979
109-199	10.97	-	1.75	0.94	0.95	1.89	
111-1342	9.22	-	1.69	0.93	0.95	1.88	
110-353	8.44	2.28	1.98	1.11	1.10	2.21	Moffet, Barnes,1979
111-2864	8.30	2.07	1.70	0.92	0.83	1.75	
N7789-72	10.08	-	1.69	0.87	-	-	Coleman,1982
266	10.90	-	1.70	-	-	1.89	Robertson,Hamilton,1987
274	11.36	-	1.77	-	-	1.82	
279	11.35	-	1.71	-	-	1.78	
420	11.53	-	1.80	-	-	1.90	
LHS 185	15.30	-	1.79	0.98	0.85	1.83	Dawson,Forbes,1989
LHS 197	16.45	-	1.72	0.90	0.93	1.83	

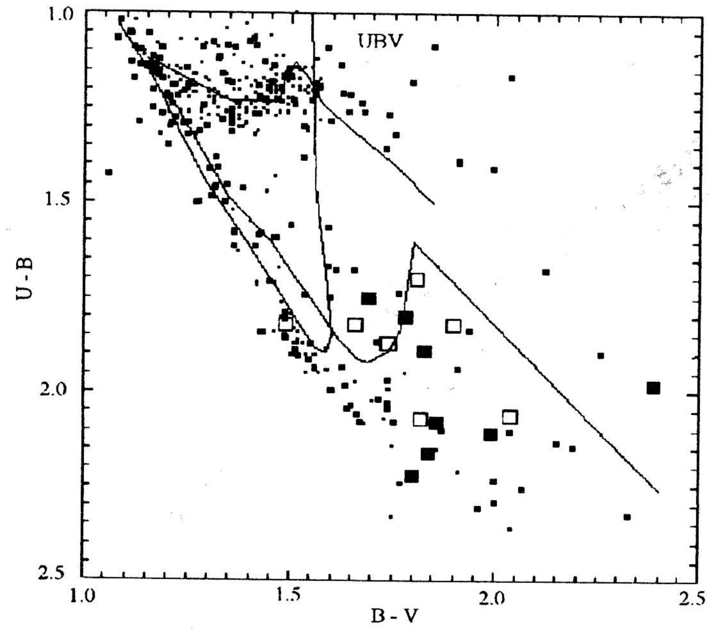

Figure 1: *The diagram (U–B) — (B–V). The curves present the computed normal colours of the stars of the luminosity classes V (dwarfs, upper curve), III (giants) and I (supergiants) of Straizys (1977; 1987). The diagonal tail of the curve of the supergiants in the right-down part of the diagram corresponds to the reddening line for the red supergiant stars. The data for K and M supergiants from Table 1 are designated by big open and filled boxes, respectively. The data for the red standard stars of Landolt (1983; 1992) are presented by middle-sized filled boxes. The data for the red stars of Weis (1991) are designated by small filled boxes.*

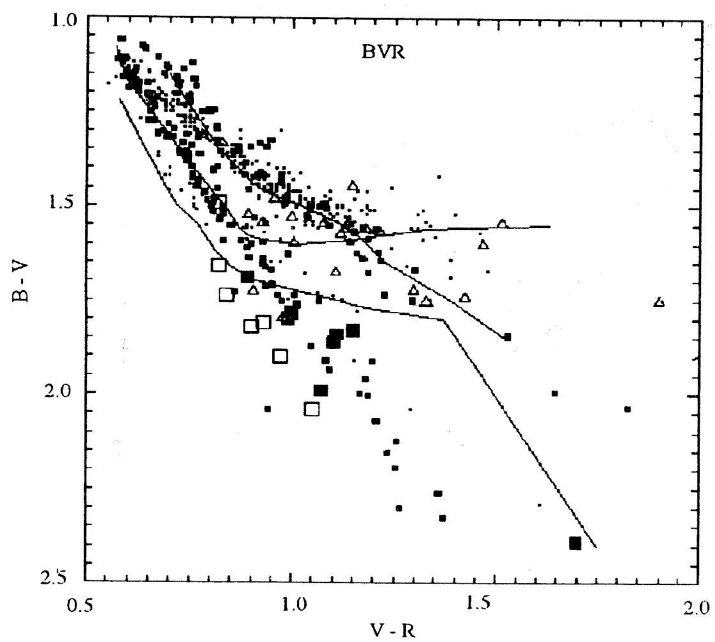

Figure 2: *The diagram (B–V) — (V–R). The presentation is the same as in Fig.1 and the data of Dawson and Forbes (1989) are added by triangles.*

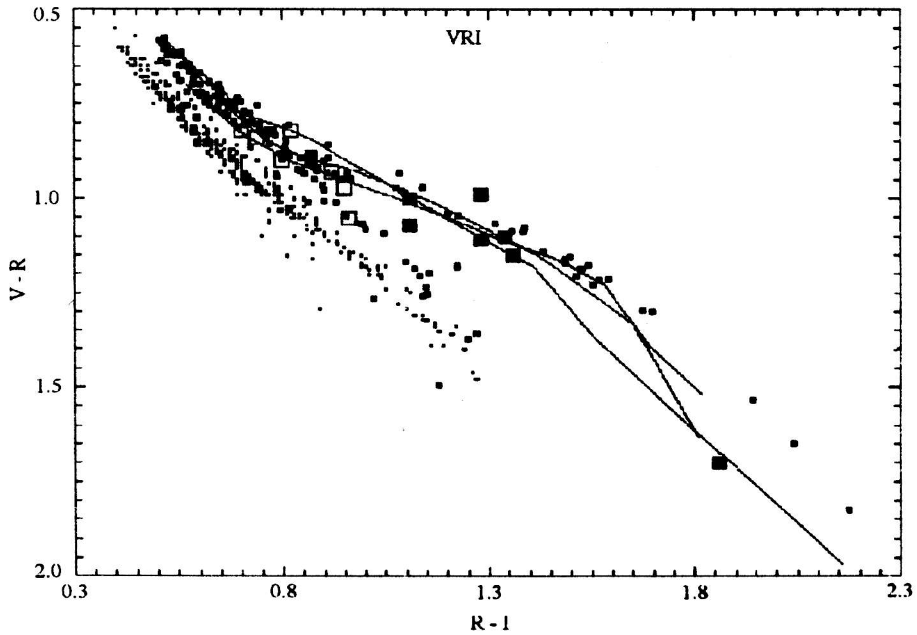

Figure 3: *The diagram (V–R) — (R–I). (See Figs.1 and 2.)*

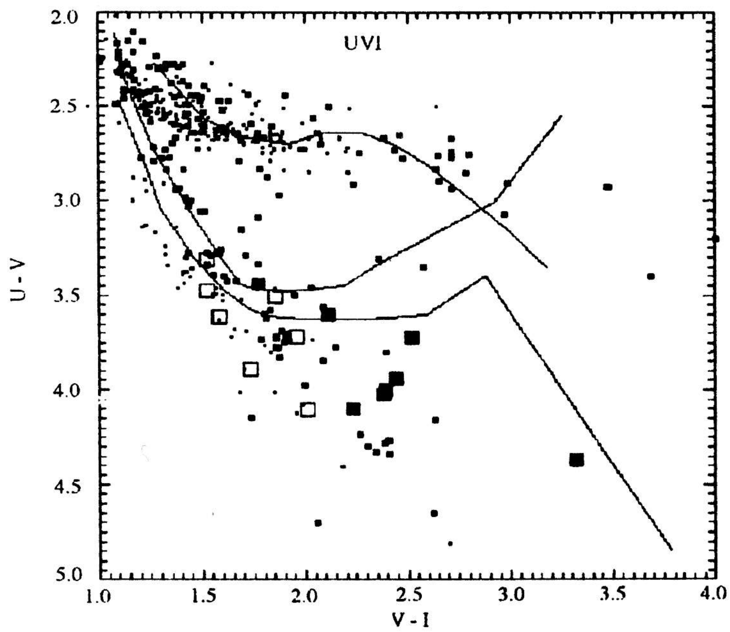

Figure 4: *The diagram (U–V) — (V–I). (See Figs.1 and 2.)*

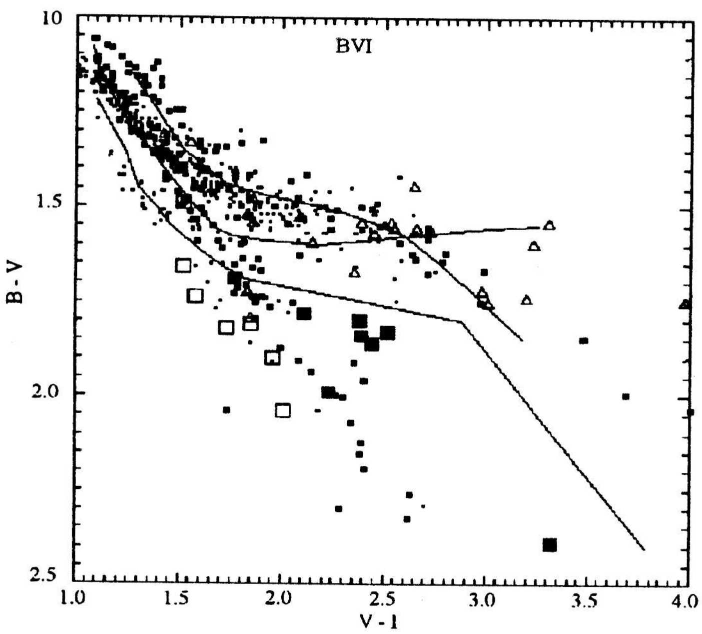

Figure 5: *The diagram (B–V) — (V–I). (See Figs.1 and 2.)*

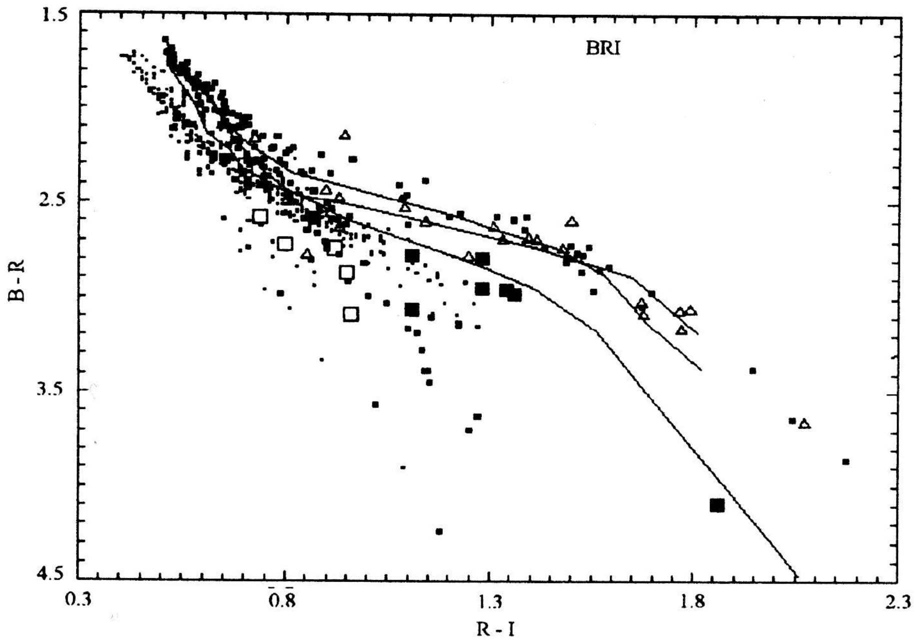

Figure 6: *The diagram (B -R) — (R–I). (See Figs.1 and 2.)*