COMMISSION 27 OF THE I. A. U.
INFORMATION BULLETIN ON VARIABLE STARS

NUMBER 355

Konkoly Observatory
Budapest
1969 June 7

LIGHT VARIATIONS OF SMALL AMPLITUDE IN THE RED GIANTS OF THE DISC POPULATION

Abstract

Light variations with amplitude greater than $0^m.05$ have been found in 78 bright, M-type stars. The variation for about one-half these objects has also been found by others. The boundary of the red instability region in the (M_B, T_E) plane is near the temperature represented by (102,65) = $-0^m.6$ (blackbody color temperature near 3400°) for these disk population stars. Comparison with the narrow band, continuum colors, (102,65), shows the lack of resolution, for these red giants, of the MK spectral types and the (B-V) colors.

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Many red giants of spectral type M have been found to be slightly variable in light (e.g. Stebbins and Huffer 1930). Whether the variation is classified as semiregular (SR) or irregular (I) often depends on the amplitude of variation and the extent of the observations. Most are quasi-periodic and the known periods extend from 20 to more than a hundred days.

All of the M-type stars in the Bright Star Catalogue (BSC = HR) (Hoffleit 1964) that are south of 0° declination, and most of those in the north, have been observed in the narrow band (102,65,62) system (Eggen 1967 and Eggen and Stokes 1970). Extensive observations in the (UBV) system over several seasons have also been obtained for most of the stars. The 78 objects in Table 1, which omits known supergiants, have been found to have light variations (V_E) of at least $0^m.05$ and are not listed in the second edition of the VARIABLE STAR CATALOGUE (Kukarkin et al 1957). About one-half of these stars have also been found to be variable by others, mostly at the Cape Observatory (Cousins and Stoy 1963, Cousins, Lake and Stoy 1966, and subsequent issues of Monthly Notes of the Astronomical Society of Southern Africa). These objects are indicated by (1) in the last column of Table 1. Two northern stars found to be variable by Uppsala observers (Haggkvist and Oja 1966, Ljunggren and Oja 1964) are noted by (2) in Table 1. A light curve for HR 5134, with an approximate period of 80 days, has been

Table 1

Red Giant Variables of Small Amplitude

HR	V_E	(B-V)	(U-B)	(102)	(65,62)	(102,65)	ΔV	N	t (yrs)	ΔV (other)
46	5.10	+1.62	+1.82	2.37	+0.55	−0.23	0.10	16	4	0.07(1)
48	4.38	+1.63	+1.97	2.04	+0.485	−0.54	0.08	8	2	0.07(1)
105	4.85	+1.65	+1.80	2.09	+0.58	−0.15	0.11	6	3	0.1 (1)
257	5.70	+1.56	+1.75	2.27	+0.675	+0.47	0.20	8	3	0.13(1)
304	6.20	+1.64	+1.90	3,61	+0.56	−0.20	0.10	5	2	0.08(1)
435	6.30	+1.66	+1.86	3.45	+0.59	−0.03	0.15	6	2	0.15(1)
555	4.40	+1.60	+1.70	1.35	+0.65	+0.165	0.15	6	2	0.15(1)
587	5.50	+1.49	+1.38	1.69	+0.71	+0.745	0.20	5	2	0.11(1)
904	6.20	+1.74	+2.04	3.75	+0.48	−0.465	0.18	8	4	0.06(1)
911	2.45	+1.62	+1.94	0.09	+0.46	−0.555	0.05	8	3	0.06(1)
977	5.85	+2.15	–	2.59	+0.425	+0.005	0.3	3	2	0.4 (1)
1003	3.60	+1.60	+1.78	0.74	+0.60	−0.05	0.10	8	3	0.11(1)
1264	4.50	+1.64	+1.80	1.53	+0.60	−0.02	0.18	8	3	0.23(1)
1345	6.10	+1.63	+1.82	2.84	+0.66	+0.335	0.20	6	2	0.08(1)
1496	4.30	+1.59	+1.80	1.59	+0.575	−0.195	0.06	6	3	0.07(1)
1556	4.77	+1.79	+2.01	1.75	+0.61	+0.14	0.12	8	3	–
1695	5.20	+1.62	+1.84	2.41	+0.60	−0.03	0.10	4	2	–
1722	5.64	+1.58	+1.62	1.90	+0.71	+0.53	0.10	8	2	–
1939	6.30	+2.05	+2.09	3.00	+0.535	+0.08	0.19	6	2	–
1964	5.80	+1.72	+1.82	2.78	+0.60	+0.13	0.15	7	3	0.13(1)
2091	4.29	+1.70	+1.77	1.06	+0.61	+0.12	0.10	8	3	0.18(2)
2151	6.45	+1.58	+1.77	3.25	+0.725	+0.315	0.12	3	1	–
2203	5.60	+1.68	+2.00	2.76	+0.575	−0.10	0.11	4	1	–
2215	4.98	+1.83	+1.96	1.66	+0.615	+0.14	0.11	8	3	–
2393	6.30	+1.64	+1.91	3.53	+0.565	−0.105	0.13	4	1	0.13(1)
2631	5.99	+1.59	+1.67	2.79	+0.64	+0.14	0.13	6	2	–
3061	6.40	+1.56	+1.58	2.98	+0.72	+0.365	0.06	6	2	0.19(1)
3155	6.33	+1.57	+1.87	3.51	+0.60	+0.005	0.09	5	2	0.06(1)
3169	6.02	+1.64	+1.91	3.30	+0.55	−0.27	0.11	5	2	–
3521	6.30	+1.59	+1.55	3.40	+0.575	−0.09	0.14	7	2	–
3698	5.89	+1.60	+1.62	2.30	+0.705	+0.40	0.18	5	2	–
3793	5.90	+1.68	+1.68	3.07	+0.495	−0.135	0.07	5	2	–
3803	3.15	+1.55	+1.88	1.21	+0.375	−0.92	0.05	6	3	0.08
4007	6.20	+1.67	+1.75	3.11	+0.62	+0.055	0.25	8	2	0.23(1)
4045	6.30	+1.55	+1.43	2.84	–	+0.40	0.20	5	2	0.14(1)
4184	6.08	+1.60	+1.78	3.07	+0.61	−0.02	0.18	5	2	–
4463	5.71	+1.68	+1.93	2.88	+0.57	−0.30	0.19	6	2	0.23(1)
4483	5.26	+1.56	+1.57	1.90	+0.70	+0.37	0.12	8	2	–
4491	6.15	+1.62	+1.75	3.35	+0.61	−0.05	0.11	5	4	0.08(1)
4497	5.98	+1.66	+2.03	3.70	+0.47	−0.605	0.05	4	2	0.13(1)
4547	6.35	+1.66	+1.46	2.04	+0.77	+1.28	0.50	8	2	0.28(1)
4671	4.15	+1.58	+1.57	0.60	+0.69	+0.475	0.12	4	1	0.15(1)
4739	5.45	+1.58	+1.58	1.89	+0.715	+0.545	0.16	6	3	–

Table 1 - continued

HR	V_E	(B-V)	(U-B)	(102)	(65,62)	(102,65)	ΔV	N	t (yrs)	ΔV (other)
4755	6.06	+1.55	+1.54	3.26	+0.565	-0.085	0.07	4	1	-
4765	4.99	+1.61	+1.81	2.14	+0.57	-0.19	0.08	6	3	-
4858	6.40	+1.59	+1.81	3.85	+0.555	-0.36	0.06	5	2	0.05(1)
4902	4.78	+1.60	+1.54	2.15	+0.54	-0.30	0.06	6	4	0.10(1)
4938	6.22	+1.68	+1.83	3.48	+0.58	-0.125	0.09	4	1	0.11(1)
4949	5.50	+1.58	+1.50	1.91	+0.725	+0.50	0.13	6	2	0.33(2)
5052	6.15	+1.66	+1.81	3.32	+0.575	-0.175	0.17	5	2	-
5134	5.15	+1.62	+1.55	-	-	-	1.10	15	2	0.90(3)
Min	6.22	+1.58	+1.20	1.50	+0.92	+1.53				
5135	6.28	+1.67	+1.78	3.26	+0.64	+0.125	0.08	4	1	-
5192	4.23	+1.50	+1.44	0.31	+0.735	+0.78	0.09	10	3	0.1 (1)
5299	5.22	+1.56	+1.58	1.65	+0.70	+0.47	0.19	8	2	-
5331	6.48	+1.60	+1.77	3.65	+0.63	-0.125	0.25	4	4	-
5603	3.28	+1.68	+1.91	0.52	+0.555	-0.265	0.07	8	1	0.10(1)
5654	5.90	+1.51	+1.41	2.71	+0.635	+0.19	0.23	3	1	-
6020	4.71	+1.68	+1.67	1.38	+0.64	+0.34	0.15	8	1	0.16(1)
6128	5.22	+1.75	+2.05	2.64	+0.535	-0.275	0.14	8	7	0.06(1)
6242	5.93	+1.59	+1.65	2.57	+0.675	+0.29	0.20	5	1	-
6346	6.29	+1.56	+1.64	2.80	+0.695	+0.335	0.20	4	1	-
6429	5.92	+1.67	+1.80	2.87	+0.60	+0.065	0.10	6	2	0.14(1)
6495	6.21	+1.61	+1.67	2.78	+0.70	+0.36	0.16	5	1	-
6543	6.50	+1.56	+1.60	3.03	+0.72	+0.40	0.08	6	3	-
6832	3.08	+1.56	+1.70	0.31	+0.575	-0.24	0.07	12	1	0.06(1)
6834	6.05	+1.60	+1.56	2.89	+0.68	+0.25	0.14	5	1	0.10(1)
6861	6.18	+1.96	+1.86	2.24	+0.705	+0.82	0.22	6	2	-
7201	6.61	+1.56	+1.54	3.32	+0.65	+0.27	0.11	6	1	-
7509	6.44	+1.60	+1.53	2.52	+0.77	+0.75	0.22	4	1	-
7523	6.36	+1.61	+1.86	3.55	+0.64	+0.13	0.52	6	2	-
7650	4.55	+1.64	+1.81	1.30	+0.64	+0.185	0.15	8	3	0.11(1)
7951	4.41	+1.65	+1.90	1.76	+0.58	-0.21	0.06	12	1	0.08(1)
8416	5.13	+1.55	+1.65	1.97	+0.685	+0.235	0.09	5	2	-
8421	6.13	+1.60	+1.73	2.70	+0.655	+0.24	0.14	11	2	-
8481	5.30	+1.52	+1.10	0.91	+0.775	+1.18	0.36	8	2	0.06(1)
8560	4.15	+1.58	+1.70	1.09	+0.615	+0.055	0.11	5	1	0.09(1)
8582	4.75	+1.60	+1.70	1.87	+0.625	+0.005	0.09	6	2	0.2 (1)
9089	4.35	+1.60	+1.80	1.44	+0.575	-0.07	0.07	5	3	0.09(1)

obtained by Knipe (1963, (3) in Table 1). Table 1 includes the mean magnitudes, (V_E) and (102), and colors, (B-V), (U-B), (65,62), (102,65) and the observed range in V_E from the number of observations, N, in the number of observing seasons, t. The amplitude in (102) is only a small fraction of that in V_E (Eggen 1967).

Omitting named variables, and known supergiants, 12 stars found to be variable by Stebbins and Huffer are

included in Table 1 and 19 are not. The stars in the later group (HR 211,750,1451,2609,2703,2967,3319,3870,5219,5300, 5452,6010,6452,6815,7566,8698, 8815, 8940 and 9047) were not, with the exception of HR 5300, observed adequately enough in the present program to deny the variation. With possible exception of HR 5452,6452 and 8047, these objects are all in the same range of color (102,65) as the stars in Table 1. It seems likely that all red giants with (102,65) redder than about $-0^{m}.6$ (blackbody temperature near 3400°) are variable; all stars redder than this, that have been adequately observed in the present program or by Stebbins and Huffer, have been found to vary in light. The correlation of the observed light amplitudes with (102,65) is shown in Figure 1 where the open circles represent stars from Table 1. The temperature scale in Figure 1 is that for blackbodies (Eggen 1967). A few named, small

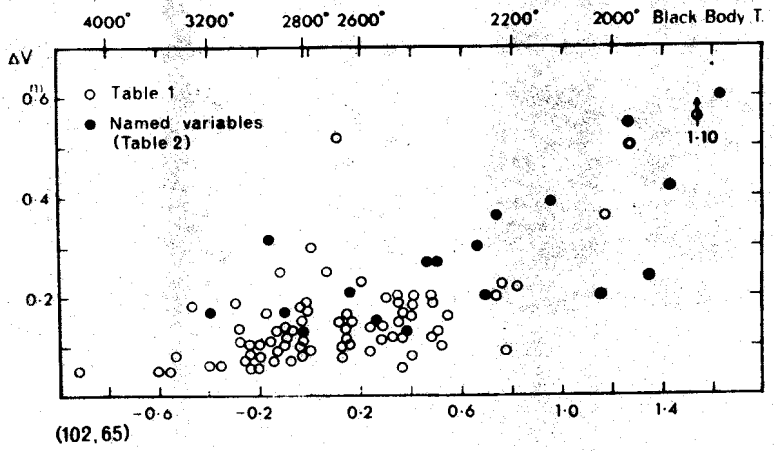

Fig.1
Observed amplitude in V_E correlated with the mean value of the continuum color (102,65)

amplitude variables are listed in Table 2 where the presently observed light range and number of observations is also given. These stars are shown in Figure 1 by filled circles. The approximate periods, in days, are listed in the last column of Table 2 when known.Most of these stars, and those in Table 1, are probably quasi-periodic in relatively short cycles. A selected group of southern objects from Table 1, now being monitored, have shown periods as short as 10 days.

Table 2

Named quasi-periodic red variables of small amplitude

Name	HR	V_E	(B-V)	(U-B)	(102)	(65,62)	(102,65)	ΔV	N	P (days)
Z Eri	832	6m46	+1m58	+1m36	2m60	+0m775	+0m09	0m39	7	80
RZ Ari	867	5.86	+1.44	+1.05	1.19	+0.91	+1.31	0.28	8	?
ρ Per	921	3.42	+1.61	+1.70	-0.12	+0.68	+0.35	0.13	5	40
RX Lep	1693	5.85	+1.51	+1.10	1.00	+0.89	+1.65	0.60	8	?
η Gem	2216	3.30	+1.60	+1.62	0.52	+0.54	-0.18	0.32	25	230
BQ Gem	2717	5.07	+1.64	+1.74	1.93	+0.665	+0.155	0.21	10	?
VZ Cam	2742	4.86	+1.63	+1.80	1.83	+0.645	-0.035	0.13	10	24
VY UMa	4195	5.95	+2.46	+4.45	2.86	+0.43	-0.10	0.17	10	?
VY Leo	4267	5.87	+1.43	+1.20	1.44	+0.88	+1.15	0.20	10	?
TU CVn	4909	5.90	+1.56	+1.44	1.96	+0.75	+0.70	0.20	4	?
W Boo	5490	4.77	+1.65	+1.89	2.36	+0.53	-0.39	0.17	6	?
RR UMi	5589	4.67	+1.57	+1.54	0.93	+0.72	+0.49	0.27	10	40
LQ Her	6039	5.76	+1.57	+1.59	2.25	+0.71	+0.455	0.27	9	?
AT Dra	6086	5.42	+1.62	+1.67	2.00	+0.67	+0.26	0.15	5	?
g Her	6146	5.08	+1.52	+1.12	0.10	+0.90	+1.28	0.55	14	70
OP Her	6702	6.06	+1.61	+1.56	2.14	+0.74	+0.66	0.30	8	?
R Lyr	7157	4.00	+1.58	+1.46	0.03	+0.76	+0.735	0.36	16	46
EU Del	7886	6.15	+1.38	+0.97	1.10	+0.915	+1.44	0.42	10	60

Table 3

Extreme Values of (102,65) for various spectral types

HR	Sp	(102,65)	b	HR	Sp	(102,65)	b
	K4III				M1III		
5241		-1.45	- 2°	1393		-1.03	-44
4143		-1.335	+10	4920		-0.765	+80
5598		-0.855	-12	7414		-0.44	-10
4145		-0.84	+29	5181		-0.49	+43
	K5III				M2III		
6076		-1.365	+21	1663		-0.96	-37
186		-1.285	-57	4449		-0.725	+28
5219		-0.26	+75	4586		-0.225	+36
1699		-0.58	-35	6128		-0.275	+27
	M0III				M3III		
5797		-1.135	+10	7686		-0.41	+22
8685		-1.13	-62	519		-0.39	-64
759		-0.53	-59	9089		-0.07	-66
4906		-0.585	+20	4763		-0.12	+ 6
4008		-0.605	+48		M4III		
				5603		-0.265	+29
				105		-0.15	-82
				4483		+0.37	+64
				4532		+0.38	+34

As accurate location of the border to the red instability region in the (M_B, T_e) plane, and its possible dependence on mass and chemical composition, may be of some importance when presently available stellar models are extended to cover this evolutionary state. Neither spectral types or B-V colors have enough resolution to locate this border accurately. The HR stars for which spectral types between K4 III and M4 III, on the MK system, are available are shown in Figure 2. The spread in (102,65)

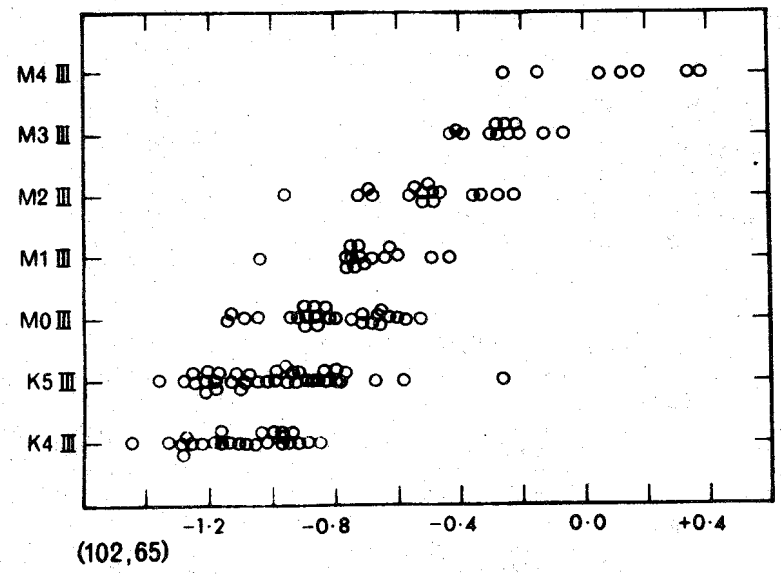

Fig.2

The spread of values of (102,65) for MK spectral types

for each type is near $0^m.6$. The 2 or 3 bluest and reddest stars of each type are listed in Table 3. The relation between (B-V) and (102,65) for the non-variable stars is fairly well defined and is shown as the broad curve in Figure 3. However the stars in Tables 1 (open circles) and 2 (filled circles), with (102,65) redder than $-0^m.6$, show very little correlation with B-V. The (B-V) scale collapses near $+1^m.65$. A similar effect is seen in the (B-V) scale for dwarfs redder than $+1^m.4$ (e.g. Eggen 1965).

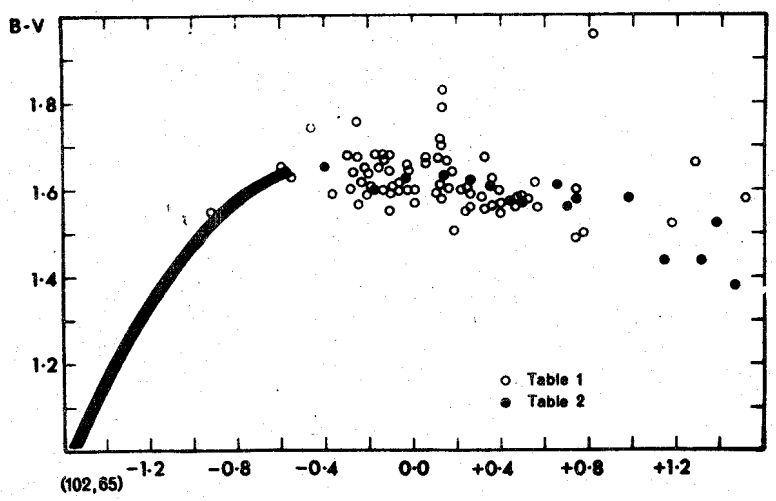

Fig.3
The correlation between the colors (102,65) and (B-V). The broad curve represents the nonvariable stars bluer than (102,65) = $-0^{m}.6$.

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