1978, *Astron. Astrophys. Suppl.* **33**, 213-217.

THE VARIABLE SHELL STAR HR 5999: III. A NEW LIGHTCURVE BASED ON WALRAVEN AND STRÖMGREN PHOTOMETRIES

P.S. THÉ, R. BAKKER, T.J.H. WESSELINK and TH. J. VAN DER LINDEN
Astronomical Institute, University of Amsterdam, The Netherlands
A.M. VAN GENDEREN
Leiden Southern Observatory, Hartbeespoortdam, South Africa

Received January 1, 1978

The irregular variable shell star HR 5999 has been observed on the Walraven and Strömgren photometric systems from July 9 until October 22, 1977. The lightcurve derived from these observations shows two maxima, at $V_J = 6^m.80$ and one fainter at $V_J = 7^m.05$. The brightness variation of the star is in general smooth, except at the maxima where it shows irregularities. At these maximum brightnesses we are looking through the circumstellar shell at places where the column density of the dust grains is small. The colourcurve does not exhibit large variations. It is clear, however, that the star becomes somewhat redder when it is fainter.

Key words: variable star – shell star – Ae type star in nebulosity

1. INTRODUCTION

The number of relatively bright variable shell stars associated with nebulosity is not large. By studying the light variation of such stars in different wavelength regions it is possible to obtain a better knowledge of several physical characteristics of the dust grains, which play an important role in the light variation of the star (see Thé and Tjin A Djie 1978 a, b, hereafter called papers I and II). In those cases where we can estimate the distance of the star indirectly, it is possible, by comparison with theoretical calculations, to have an idea of the evolutionary stage of the star. Such a case is the star HR 5999.

HR 5999 (R.A. = 16^h07^m; Dec. = $-39°.0$, 1975) has been discovered as a variable shell star of spectral type A5III-II for the first time by Bessell and Eggen (1972). With the star HR 6000 it is forming a double star system Δ199 (separation 45″), which is surrounded by a T association consisting of more than 10 faint Hα–emission stars discovered by Thé (1962), (see also Eggen 1975). All these objects are seen projected against the centre of a butterfly shaped dark nebulosity. HR 5999 is creating a faint reflection nebula at this dark cloud. It is therefore generally believed that the objects mentioned above are physically related to each other, and that they are forming a group of very young objects.

Published photometric observations up till 1976 show that the star HR 5999 is varying irregularly, but in such a way that its maximum brightness never exceeds $V_J = 6^m.8$ and that its lowest minimum is at $V_J = 8^m.0$ (the index J stands for Johnson). From July 9 until October 22, 1977, we have observed this star photometrically, for the following purposes. Firstly, we want to know whether there are short-time variations in the brightness of the star. Secondly, we want to check whether above mentioned absolute maximum and minimum brightnesses are still valid. Furthermore, we want to know whether the same physical characteristics as observed in 1976 (see paper I) can be derived from our new observations.

The photometric observations were carried out by R.B., T.J.H.W. and A.M.v.G. with the Walraven photometer attached to the 90 cm lightcollector of the Leiden Southern Observatory Hartbeespoortdam (South Africa), and by Th.J.v.d.L. with a Strömgren-type photometer mounted at the Danish 50 cm telescope located at the European Southern Observatory, La Silla, Chile.

Descriptions of the Walraven photometer can be found in publications by Walraven and Walraven (1960), Rijf *et al.* (1969) and Lub and Pel (1977). The Danish Strömgren-type photometer is described by Grønbech *et al.* (1976).

In the present paper the lightcurve and colourcurve of HR 5999 are shown and discussed.

2. THE PHOTOMETRY

The measurements on the Walraven system were made from July 9 to August 16, and from September 24 to October 22, 1977. At most photometric nights, in the first period, the star was observed twice with a time interval of about 2 hours. In the second period the star is not observed as frequent. A diaphragm of 15″ is used in the first, and 23″ in the second period. The measurements of HR 5999 are reduced to those of HR 6000; the colour indices and V_w magnitude of the comparison star on the Walraven system are published in paper I. The results of the reductions are given in table 1. Each data is the average of a series consisting of symmetrically planned measurements of comparison and variable stars. The number of measurements of the variable is indicated in the column headed by n. The standard deviations of the data given in table 1 are estimated to be: ± 0.003 for V_w, and ± 0.002 for $(V-B)_w$, $(B-L)_w$, $(B-U)_w$ and $(B-W)_w$. It should be mentioned here that in the Walraven photometry the measurements are given in logarithms to the base 10 of the visual intensity and relevant intensity ratios.

The Strömgren photometry has been performed from August 1 to 30. The diaphragm used is of 30″ diameter. The method of measurement is essentially the same as that used in the Walraven photometry, only that here per series the number of measurements is larger than that with the Walraven photometer. Values of colour-indices and the y magnitude of the comparison star HR 6000 are published by Grønbech and Olsen (1976). The results of our reductions are given in table 2. The standard deviations are estimated to be: $\pm 0^m.004$ for y, $\pm 0^m.005$ for $(b-y)$ and $(v-b)$, and $\pm 0^m.006$ for $(u-v)$.

It is of interest to mention here that both the Walraven photometer and the Danish Strömgren-type photometer used, measure the light of the stars at the different passbands, simultaneously.

If transformation of the Walraven and Strömgren photometric results to the Johnson system is desired, formulas published, respectively by Pel (1976) and by Grønbech *et al.* (1976) can be used.

3. THE LIGHTCURVE AND THE COLOURCURVE

In order to draw the lightcurve and the colourcurve of the variable star HR 5999 the Strömgren visual magnitudes and the $b-y$ colour-indices were transformed to the Walraven system using, respectively, the following formulae:

$$\begin{array}{c} V_w = 2.756 - 0.400\,\{y_s + 0.16\,(b-y)_s\} \\ \pm\,0.001 \qquad\qquad \pm\,0.01 \end{array}$$

and

$$\begin{array}{c} (V-B)_w = -0.009 + 0.66\,(b-y)_s \\ \pm\quad 0.001 \pm 0.01 \end{array}$$

The indices w and s stand for Walraven and Strömgren, respectively. These formulae are derived using 61 commonly observed stars by Lub and Pel (1977) on the Walraven system, and by Grønbech and Olsen (1976) on the Strömgren system. The transformed visual magnitudes and the $(V-B)_w$ colour indices are listed in the last two columns of table 2.

Figures 1 A, B and C depict the lightcurve and the colourcurve based on both Walraven and Strömgren photometries. In this lightcurve we see two maxima and two minima; at $V_J = 6^m.80$ and $7^m.05$, and at $V_J = 7^m.26$ and $7^m.29$, respectively. They are derived not from the lightcurve, but from observations giving the largest and lowest visual intensities. The values of V_J at the first maximum correspond closely to the largest brightness ($V_J = 6^m.8$) sofar observed for HR 5999. After the second minimum the brightness of the star grows assymptotically towards $V_J = 6^m.8$. In October 1977 the star exhibits a shallow minimum, after which it stays a long time at $V_J = 6^m.8$ again. The two minima are not as deep as the absolute minimum brightness observed in 1976 (see paper I); they are about $0^m.7$ brighter.

It has been shown previously (paper I) that dust grains in the circumstellar shell play a dominant role in the light variation of HR 5999. At the maxima near $V_J = 6^m.8$ we are perhaps looking through places of the dusty shell, where the column density is at its minimum value, which can be designated as the normal state of the shell. At these instances with minimum extinction the lightcurve is not smooth; it shows that the brightness of the star is varying rapidly. This is also the case at the maximum near $V_J = 7^m.05$.

The behaviour of the colourcurve is almost the same as in 1976 (see paper I). In general the colourindex $(V-B)_w$ does not change very much; it is clear, however, that at light minima the star becomes slightly redder than usual.

A further study of the physical characteristics of the circumstellar shell of HR 5999, based on the new observations, is under way, and will be published in a subsequent paper.

REFERENCES

Bessell, M.S., Eggen, O.J.: 1972, *Astrophys. J.* **177**, 209.
Eggen, O.J.: 1975, *Publ. Astron. Soc. Pacific* **87**, 37.
Grønbech, B., Olsen, E.H. and Strömgren, B.: 1976, *Astron. Astrophys. Suppl.* **26**, 155.
Grønbech, B. and Olsen, E.H.: 1976, *Astron. Astrophys. Suppl.* **25**, 213.
Lub, J. and Pel, J.W.: 1977, *Astron. Astrophys.* **54**, 137.
Pel, J.W.: 1976, *Astron. Astrophys. Suppl.* **24**, 413.
Rijf, R., Tinbergen, J. and Walraven, Th.: 1969, *Bull. Astron. Inst. Neth.* **20**, 279.
Thé, P.S.: 1962, *Contr. Bosscha Obs.* no. 15.
Thé, P.S. and Tjin A Djie, H.R.E.: 1978a, *Astron. Astrophys.* **62**, 439.
Thé, P.S. and Tjin A Djie, H.R.E.: 1978b, *Proc. I.A.U. Coll. No. 42,* 137.
Walraven, Th. and Walraven, J.H.: 1960, *Bull. Astron. Inst. Neth.* **15**, 67.

P.S. Thé
R. Bakker
T.J.H. Wesselink
Th.J. Van der Linden

Astronomical Institute
University of Amsterdam
Roetersstraat 15
NL–1018 WB Amsterdam, The Netherlands

A.M. Van Genderen

Leiden Southern Observatory
P.O. Box 13
Broederstroom 0240, South Africa

Table 1 Results of Photoelectric Photometry of the star HR 5999 on the Walraven system. Entries are in logarithms to the base 10.

JD −2443000	V_w	$(V-B)_w$	$(B-L)_w$	$(B-U)_w$	$(B-W)_w$	n
334.30	−0.076	+0.126	+0.204	+0.474	+0.672	2
334.37	−0.074	0.128	0.206	0.477	0.668	2
337.29	−0.040	0.123	0.204	0.468	0.659	2
337.35	−0.035	0.122	0.202	0.464	0.659	2
342.47	−0.026	0.124	0.201	0.469	0.639	2
343.33	−0.013	0.125	0.206	0.472	0.678	2
343.39	−0.007	0.122	0.203	0.473	0.678	2
344.25	+0.009	0.119	0.205	0.467	0.660	2
344.41	+0.024	0.119	0.192	0.476	0.670	2
345.30	−0.001	0.123	0.210	0.483	0.678	2
345.38	−0.029	0.124	0.215	0.479	0.692	2
346.31	+0.013	0.116	0.204	0.474	0.659	2
346.38	0.000	0.119	0.203	0.490	0.685	2
347.41	−0.031	0.123	0.208	0.485	0.653	2
348.21	−0.026	0.125	0.208	0.479	0.713	2
348.30	−0.016	0.125	0.207	0.479	0.719	2
349.25	−0.022	0.127	0.206	0.481	0.673	2
351.35	−0.082	0.124	0.208	0.486	0.732	2
351.42	−0.086	0.124	0.210	0.486	0.684	2
353.29	−0.163	0.140	0.214	0.488	0.735	2
353.34	−0.163	0.141	0.215	0.484	0.665	2
355.29	−0.145	0.147	0.219	0.494	0.752	2
355.36	−0.125	0.144	0.214	0.489	0.702	2
358.32	−0.078	0.130	0.207	0.485	0.716	2
358.39	−0.074	0.127	0.212	0.488	0.682	2
360.31	−0.093	0.134	0.208	0.482	0.716	2
360.38	−0.097	0.130	0.207	0.482	0.671	2
361.29	−0.109	0.131	0.210	0.484	0.720	2
363.25	−0.147	0.136	0.210	0.479	0.712	2
365.23	−0.174	0.149	0.212	0.478	0.716	2
366.24	−0.176	0.153	0.219	0.487	0.732	2
371.28	−0.043	0.128	0.210	0.492	0.735	2
372.33	−0.022	0.124	0.210	0.490	0.740	2
411.22	−0.024	0.127	0.206	0.467	0.636	2
416.24	−0.041	0.135	0.217	0.501	0.720	2
418.31	−0.046	0.133	0.215	0.483	0.657	2
422.22	+0.007	0.123	0.203	0.466	0.645	2
423.23	+0.014	0.122	0.207	0.467	0.663	2
428.22	+0.020	0.121	0.205	0.471	0.645	2
435.22	+0.014	0.118	0.204	0.469	0.622	1
439.23	−0.017	0.121	0.206	0.470	0.637	1

Table 2 Results of photoelectric Observations of the star HR 5999 on the Strömgren system, and derived values of V_w and $(V-B)_w$ on the Walraven system. Entries are in magnitudes, except the last two columns in logarithms to the base 10.

JD −2443000	y	b−y	v−b	u−v	n	V_w	$(V-B)_w$
357.34	7.044	0.203	0.371	1.395	10	−0.063	0.125
357.42	7.054	0.198	0.374	1.384	9	−0.067	0.122
358.29	7.132	0.196	0.376	1.383	1	−0.098	0.121
358.36	7.043	0.197	0.364	1.402	1	−0.062	0.121
358.38	7.108	0.190	0.373	1.395	1	−0.088	0.117
358.41	7.015	0.211	0.374	1.410	2	−0.051	0.131
358.44	7.099	0.195	0.369	1.375	4	−0.085	0.120
359.32	7.065	0.200	0.366	1.409	8	−0.071	0.123
362.40	7.200	0.204	0.374	1.385	8	−0.125	0.126
363.32	7.244	0.215	0.384	1.375	8	−0.143	0.134
363.45	7.256	0.216	0.387	1.375	7	−0.148	0.134
367.28	7.283	0.231	0.382	1.422	3	−0.159	0.144
367.40	7.271	0.226	0.401	1.407	4	−0.154	0.141
368.45	7.152	0.214	0.397	1.397	4	−0.106	0.133
370.32	7.022	0.197	0.370	1.407	8	−0.054	0.121
372.33	6.933	0.192	0.367	1.407	11	−0.018	0.118
372.42	6.915	0.192	0.364	1.413	4	.0.011	0.118
373.34	6.905	0.185	0.363	1.419	6	−0.007	0.113
373.42	6.898	0.188	0.360	1.415	5	−0.004	0.115
374.31	6.873	0.182	0.353	1.398	10	+0.006	0.111
374.42	6.874	0.185	0.355	1.387	5	+0.005	0.113
375.30	6.864	0.180	0.353	1.400	7	+0.009	0.110
375.38	6.873	0.182	0.358	1.399	8	+0.006	0.111
376.38	6.877	0.187	0.357	1.335	7	+0.004	0.115
377.31	6.868	0.190	0.360	1.369	10	+0.008	0.117
377.43	6.868	0.187	0.359	1.366	7	+0.008	0.115
379.33	6.847	0.180	0.355	1.354	8	+0.016	0.110
379.40	6.842	0.184	0.354	1.354	7	+0.018	0.113
381.28	6.837	0.181	0.355	1.364	8	+0.020	0.111
381.33	6.837	0.182	0.355	1.359	6	+0.020	0.111
381.38	6.829	0.185	0.356	1.368	6	+0.023	0.113
382.28	6.837	0.185	0.357	1.364	8	+0.020	0.113
382.35	6.834	0.182	0.357	1.368	10	+0.021	0.111
383.29	6.839	0.181	0.354	1.356	6	+0.017	0.111
383.36	6.846	0.180	0.357	1.347	12	+0.021	0.110
386.29	6.838	0.190	0.356	1.345	4	+0.020	0.117
386.35	6.848	0.188	0.353	1.343	8	+0.016	0.115

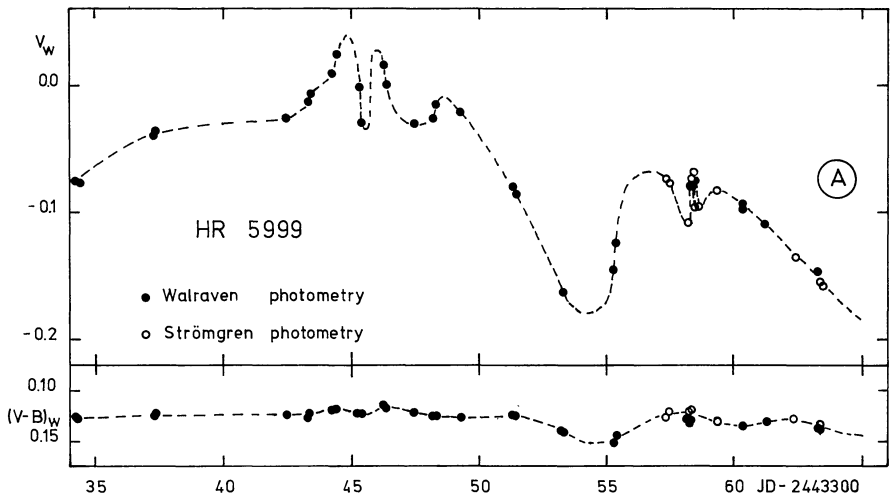

Figure 1 a

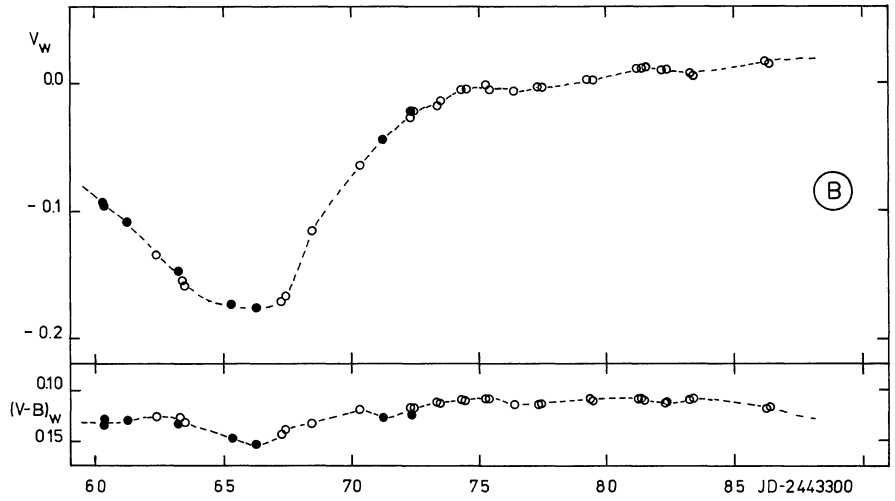

Figure 1 b

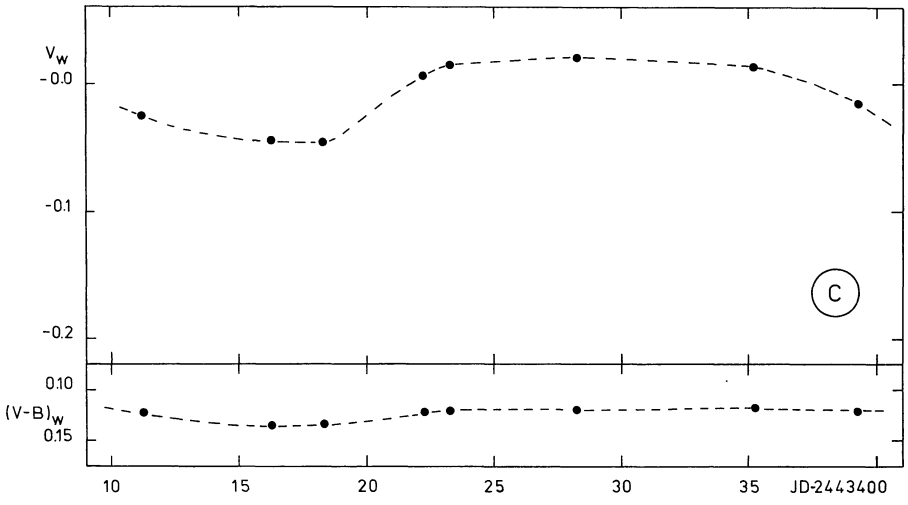

Figure 1 c

In these figures the lightcurve and the colourcurve of the variable shell star HR 5999 are given. The data on the Strömgren system have been transformed to the Walraven system.