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Once again, about the changes in the period of S Vul

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We used Hertzsprung (1919) method to calculate 288 moments of maximum light of the classical Cepheid S Vul and this allowed us to construct an $O-C$ diagram covering a time interval of 160 years. This also allows us to calculate the evolutionary period change at a rate of $dp/dt = 533.0 \pm 11.4$ s/year that corresponds to the theoretical calculations for the third crossing of the instability strip.

Keywords: Stars: variables: Cepheids; stars: oscillations

1 Introduction

The classical Cepheid S Vul was noticed because of the large difference in its brightness after two visual estimations in 1836 and 1837, but its observations as a variable star began only in 1861 (Mueller and Hartwig 1920).

In the third edition of the General Catalogue of Variable Stars (Kukarkin et al. 1970), S Vul was listed as a semiregular variable. However, fairly stable light and color curves and amplitude, as well as a relatively stable period gave Fernie (1970), Machmoud and Szabados (1980) and other researchers the reason to attribute S Vul to Cepheids. And now, in the fifth edition of the General Catalogue of Variable Stars (Samus et al. 2017) S Vul is classified as a classical Cepheid with a period 68.464 days.

The S Vul period is subject to changes. The view of the $O-C$ diagram allowed us to suggest that together with the jumps in the change of the S Vul period, there is a tendency for its gradual increase (Wachmann 1966, Makarenko 1968, Machmoud and Szabados 1980, Berdnikov 1994, Csoernyei et al. 2022 and other authors).

The study of variable star period variability is based on analysis of $O-C$ diagram. The most accurate method of determining the $O-C$ residuals (for stars with stable light curves) is the Hertzsprung (1919) method but no one applied this method to explore period changes in S Vul.

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The purpose of this research is to study the stability of the S Vul pulsation period using the Hertzsprung method.

2 Observational data

S Vul is quite a bright star (8.7–9.4 mag in V) and had been observed frequently over a long period of time. The earliest visual observations were published in an inconvenient format, so we took them from the American Association of Variable Star Observers (AAVSO) International Database where they are given in the usual form of (JD, mag). We also used AAVSO unpublished data for S Vul, and photographic photometry from the Digital Access to a Sky Century at Harvard (DASCH) database of digitized astronomical plate data from Harvard University (Grindlay et al. 2009). Additionally we used Charge-Coupled Device (CCD) observations from INTEGRAL-OMC catalog (Alfonso-Garzon et al. 2012), and Kamogata/Kiso/Kyoto Wide-Field Survey (KWS) (Maehara 2014) and Mini-MegaTORTORA (MMT) (Karpov et al. 2018) projects.

Table 1 summarizes the information about the number of observations used. The total time span of the data set (16274 observations) used is 160 years.

Table 1 Observational data for S Vul.

Data source	No. of observations	Type of observations	JD interval
AAVSO	2197	Visual (Vis)	2401827–2459107
DASCH	3726	Photographic (Pg)	2412444–2447238
Literature	2209	Vis,Pg	2401107–2438591
Literature	1555	Photoelectric (U, B, V, R, R_c, I_c)	2439746–2451041
INTEGRAL-OMC	136	CCD (V)	2453348–2454066
MMT	3832	CCD (V)	2456870–2459899
KWS	2619	CCD (V, I_c)	2455700–2460096

3 Pulsation period changes

We investigated the pulsation period changes in S Vul using the Hertzsprung (1919) method, the computer implementation of which was described by Berdnikov (1992a).

Table 2 lists the computed $O - C$ residuals of seasonal light curves of S Vul. The first and second columns give the inferred time of maximum brightness and its standard error, respectively; the third column gives the type of observations used (see Table 1); the fourth and fifth columns give the number of epoch, E, and the $O - C$ residual (in days), and the sixth and seventh columns give the number of observations, N, and the data source, respectively. The data listed in Table 2 are shown in the $O-C$ diagram (Fig. 1) by the empty squares for DASCH data and by filled circles for others; the vertical $O-C$ error bars are smaller than the symbols almost everywhere.

The $O - C$ diagram can be approximated by a parabola:

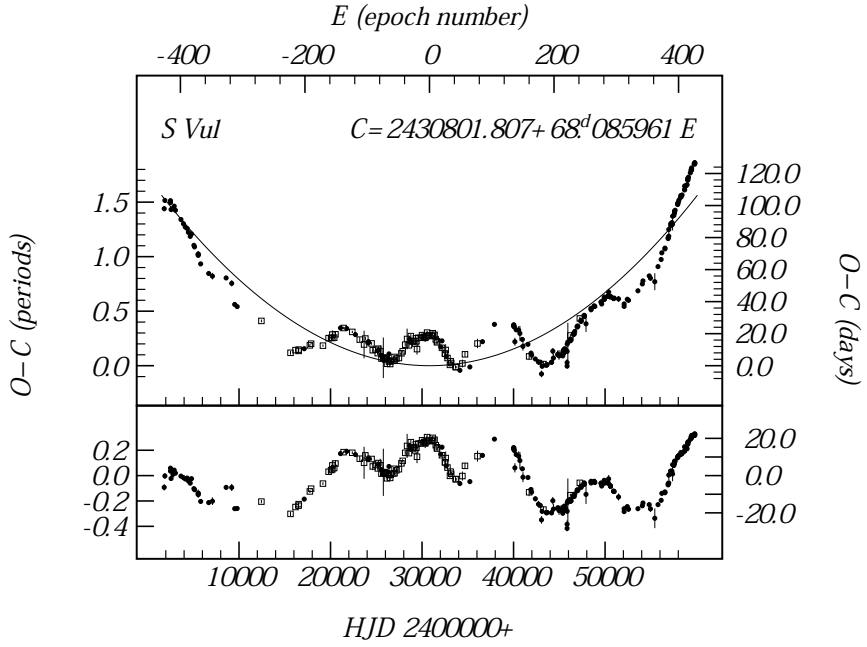


Figure 1 $(O-C)$ diagram for S Vul relative to the linear (top) and quadratic (bottom) elements (1). The line is a parabola corresponding to the elements (1). Empty squares are for the DASCH data and filled circles are for other data

$$\mathrm{Max\,HJD} = 2430801.8069 + 68.085961343\ \mathrm{E} + 0.57498\ 10^{-3}\ \mathrm{E}^2, \qquad (1)$$

$$\pm 1.0727 \quad \pm 0.3204710^{-2} \quad \pm 0.1227610^{-4}$$

which means that period is increasing at the rate of $dp/dt = 533.0 \pm 11.4$ s/year. This rate corresponds to the theoretical calculations for the third crossing of the instability strip (Turner et al. 2006, Fadeyev 2014).

The linear part of equation (1) was used to calculate the $O-C$ residuals in Table 2. These ephemerides were used to draw the parabola in the upper part of Fig. 1 and deviations from this parabola are shown in its lower part.

We use the method proposed by Lombard and Koen (1993) to confirm that the changes in the pulsation period are real. To this end, we calculated the differences $\triangle(O-C)_i$ of the successive $O-C$ residuals from Table 2, $\triangle(O-C)_i = (O-C)_{i+1} - (O-C)_i$, and plotted $P'_i = \triangle(O-C)_i/(E_{i+1}-E_i)$ against $E'_i = (E_i+E_{i+1})/2$ (Fig. 2). P'_i, which have the meaning of the mean period in an epoch interval $E_{i+1} - E_i$, corresponding to the behavior of the $O-C$ residuals in Fig. 1.

Data from Table 2 allows us to estimate the magnitude of random fluctuations in the pulsation period. To do this, we calculated delays $u(x) = \mid z(r+x) - z(r) \mid$ for maxima separated by x cycles. The average value of $\langle u(x) \rangle$, according to Eddington and Plakidis (1929), should be related to the random fluctuation of the period ε by the ratio:

$$\langle u(x) \rangle^2 = 2\alpha^2 + x\varepsilon^2, \qquad (2)$$

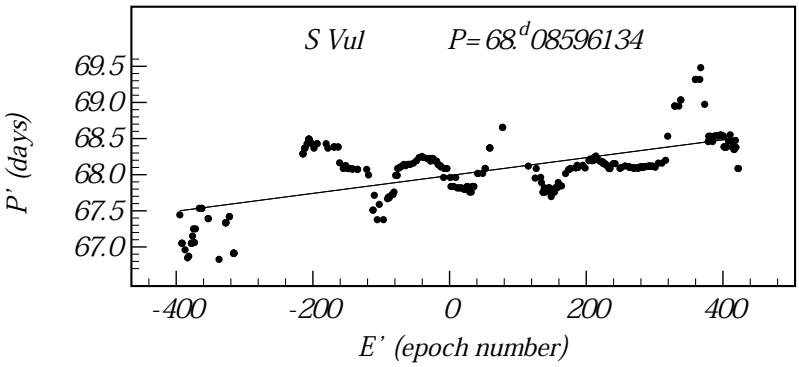


Figure 2 $P'_i = ((O-C)_{i+1} - (O-C)_i)/(E_{i+1} - E_i)$ versus $E'_i = (E_i + E_{i+1})/2$. P'_i, which have the meaning of the mean period in an epoch interval $E_i - E_{i+1}$, correspond to the behavior of the $O-C$ residuals in Fig. 1.

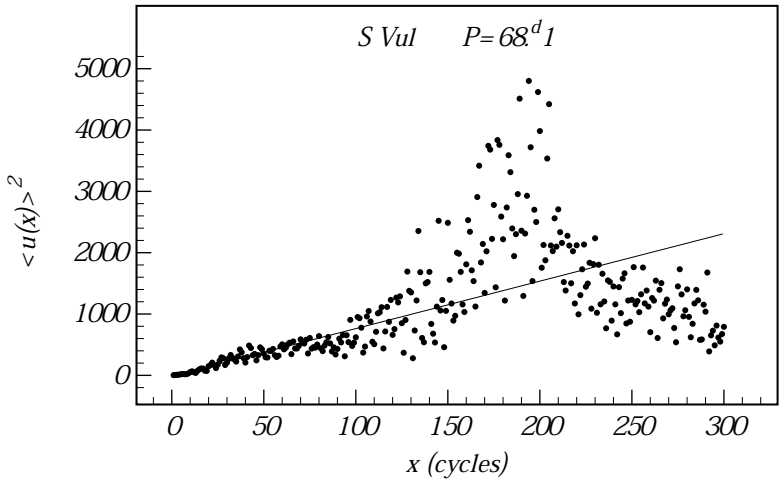


Figure 3 Square of the mean accumulated delay $u(x)$ versus cycle difference x for the Cepheid S Vul. The line is the fit of Eq. (2) for $x < 60$ that gives the random period fluctuation $\varepsilon = 2.78 \pm 0.68$ days ($\varepsilon/P \approx 0.041$).

where α characterizes the magnitude of the random errors of the measured moments of maximum brightness.

The line in Fig. 3 is the fit of equation (2) for $x < 60$ that gives the random period fluctuation $\varepsilon = 2.78 \pm 0.68$ days ($\varepsilon/P \approx 0.041$).

The large random period fluctuations are responsible for frequent period jumps. Thanks to the high precision of the $O-C$ residuals obtained with the Hertzsprung method, one can see that these jumps form $O-C$ diagram as a series of of successive straight-line segments. Similar $O-C$ diagrams have V1496 Aql (Berdnikov 2004), GY Sge (Berdnikov 2007), ET Vul (Berdnikov 2020), whose periods are over 50 days, as well as some other Cepheids (Csoernyei et al. 2022).

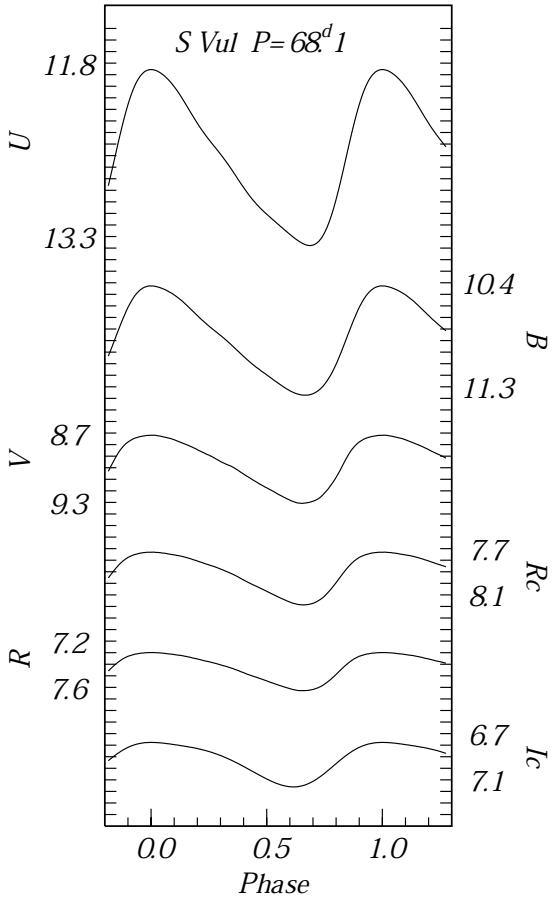


Figure 4 Light-curve templates for the Cepheid S Vul in filters U, B, V, R_c, R, and I_c.

These types of $O - C$ diagrams confirm our assumption (Berdnikov 1994) that evolutionary period changes of Cepheids show up as cyclical variations tracing progressive changes; in turn, these cyclical variations result from frequent abrupt period changes.

The maximum brightness of Cepheids is delayed with an increase in the wavelength of the filters used in observations. Together with the inaccuracy of determining the maximum brightness of light-curve templates, this leads to systematic errors in determining the moments of maximum brightness. To avoid these errors, we calculated the differences of the times of maximum light (from Table 2) in different filters relative to V. These corrections (in days) for maximums in filters U, B, R, R_c, and I_c are $3.1212\pm0.4065, 1.9624\pm0.3827, -4.6097\pm0.6809, -0.9839\pm1.0411$ and 3.3160 ± 0.9151 respectively.

We applied these corrections when Figs. 1-4 were created and ephemerides (1) were determined, which therefore refers to the V band light curve.

Table 2 Times of maximum brightness of S Vul.

Max HJD	Error, days	Band	E	$O-C$, days	N	Data source
2401827.1491	1.6667	*Vis*	−427	98.0477	17	AAVSO
2401900.3695	1.5734	*Vis*	−426	103.1821	33	AAVSO
2402511.8588	0.8992	*Vis*	−417	101.8978	28	AAVSO
2402512.9952	0.6329	*Vis*	−417	103.0342	57	AAVSO
2402575.5213	1.1522	*Vis*	−416	97.4743	91	Turner and Blagg (1917)
2402780.5413	1.7112	*Vis*	−413	98.2364	34	AAVSO
2402918.0592	1.1070	*Vis*	−411	99.5824	46	AAVSO
2403051.6974	0.8577	*Vis*	−409	97.0487	60	AAVSO
2403658.6826	0.6158	*Vis*	−400	91.2603	42	AAVSO
2403928.3920	0.7265	*Vis*	−396	88.6258	60	AAVSO
2404130.5798	0.7842	*Vis*	−393	86.5557	44	AAVSO
2404333.9629	0.6516	*Vis*	−390	85.6810	60	AAVSO
2404467.7037	0.6007	*Vis*	−388	83.2498	40	AAVSO
2404669.4444	0.7052	*Vis*	−385	80.7327	60	AAVSO
2404807.1344	1.1309	*Vis*	−383	82.2507	36	AAVSO
2405072.3755	0.8201	*Vis*	−379	75.1479	60	AAVSO
2405139.4926	0.5862	*Vis*	−378	74.1791	40	AAVSO
2405542.7491	0.9453	*Vis*	−372	68.9198	40	AAVSO
2405543.2764	2.1762	*Vis*	−372	69.4472	27	AAVSO
2405543.5838	0.8110	*Vis*	−372	69.7545	60	AAVSO
2405809.7451	0.7719	*Vis*	−368	63.5720	60	AAVSO
2406688.8621	0.7950	*Vis*	−355	57.5714	50	AAVSO
2407095.7067	2.0509	*Vis*	−349	55.9003	44	Zinner (1932)
2408592.4939	1.1254	*Vis*	−327	54.7964	25	Wilsing (1897)
2409201.9073	1.9283	*Vis*	−318	51.4361	35	Wilsing (1897)
2409529.1312	0.8861	*Vis*	−313	38.2302	52	Turner and Blagg (1917)
2409800.1429	0.8113	*Vis*	−309	36.8981	35	AAVSO
2412444.6075	0.8755	*Pg*	−270	27.9745	26	DASCH
2415624.7338	1.1628	*Pg*	−223	8.0606	50	DASCH
2416171.0820	0.6704	*Pg*	−215	9.7211	42	DASCH
2416511.0301	1.7991	*Pg*	−210	9.2393	13	DASCH
2416511.8397	0.8472	*Pg*	−210	10.0490	49	DASCH
2417125.1751	1.0112	*Pg*	−201	10.6107	29	Lazareva (1996)
2417740.0481	0.7863	*Pg*	−192	12.7101	50	DASCH
2417877.2552	0.4141	*Pg*	−190	13.7452	43	DASCH
2419169.6738	0.7522	*Pg*	−171	12.5306	50	DASCH
2419787.1058	1.2832	*Pg*	−162	17.1890	39	DASCH
2420059.6060	0.7752	*Pg*	−158	17.3453	38	DASCH
2420195.7754	1.6299	*Pg*	−156	17.3427	7	DASCH
2420197.9008	2.5924	*Pg*	−156	19.4681	7	DASCH
2420400.2220	0.7366	*Pg*	−153	17.5315	76	DASCH
2420538.4834	1.8417	*Pg*	−151	19.6209	13	DASCH

Table 2 continued.

Max HJD	Error, days	Band	E	$O-C$, days	N	Data source
2421089.0851	1.2717	*Vis*	−143	23.5707	52	Doberck (1919)
2421427.5300	0.7347	*Pg*	−138	23.5500	48	DASCH
2421769.5863	0.4023	*Vis*	−133	23.2123	205	Leiner (1922)
2422378.2941	0.7710	*Pg*	−124	21.1107	51	DASCH
2422719.0005	0.5647	*Vis*	−119	19.4230	173	Leiner (1923)
2423190.5113	1.5018	*Pg*	−112	16.2963	40	DASCH
2423664.0499	8.5913	*Pg*	−105	13.2333	11	DASCH
2423803.9669	1.1259	*Pg*	−103	16.9783	49	DASCH
2424075.5790	0.5731	*Vis*	−99	14.2823	151	Ahnert (1931)
2424143.7086	0.5295	*Vis*	−98	14.3259	172	Ahnert (1931)
2424144.4340	0.3717	*Vis*	−98	15.0513	254	Beyer (1930)
2424481.7507	0.8352	*Pg*	−93	13.9025	42	DASCH
2424613.7036	1.9693	*Pg*	−91	9.6834	18	DASCH
2424954.4105	0.8135	*Pg*	−86	9.9605	36	DASCH
2425156.5419	1.1276	*Pg*	−83	7.8341	44	DASCH
2425227.4090	1.4860	*Pg*	−82	10.6153	21	DASCH
2425228.5335	0.2525	*Pg*	−82	9.7754	174	Beyer (1930)
2425430.1772	3.5077	*Pg*	−79	9.1255	25	DASCH
2425497.8434	0.6118	*Vis*	−78	6.7415	136	Ahnert (1931)
2425561.7021	1.0462	*Pg*	−77	4.4785	74	DASCH
2425632.8581	0.6131	*Vis*	−76	5.5843	115	Ahnert (1931)
2425766.0295	1.2756	*Pg*	−74	4.5480	25	DASCH
2425766.4073	12.6757	*Pg*	−74	4.9259	4	DASCH
2425766.5555	1.3491	*Pg*	−74	5.0741	8	DASCH
2425902.3424	1.0804	*Pg*	−72	4.6890	13	DASCH
2425969.6408	0.5830	*Pg*	−71	3.9015	99	DASCH
2426171.2001	1.0449	*Pg*	−68	1.2029	48	DASCH
2426312.6783	0.5888	*Vis*	−66	4.5449	104	Nielsen (1932)
2426376.9475	1.3145	*Pg*	−65	2.6924	50	DASCH
2426383.5689	1.0197	*Vis*	−65	7.3495	83	Terkan (1935)
2426511.4696	1.0762	*Pg*	−63	1.0425	46	DASCH
2426581.2296	0.7564	*Pg*	−62	2.7166	46	DASCH
2426853.9016	1.2759	*Pg*	−58	3.0447	6	DASCH
2426990.1497	1.0668	*Pg*	−56	3.1210	50	DASCH
2426992.5072	0.7771	*Pg*	−56	5.4784	80	DASCH
2427195.7607	0.9339	*Pg*	−53	4.4741	49	DASCH
2427468.4454	1.2288	*Pg*	−49	4.8149	49	DASCH
2427743.7166	1.3866	*Pg*	−45	7.7423	48	DASCH
2427881.1344	0.8675	*Pg*	−43	8.9881	48	DASCH
2428157.6007	1.0281	*Pg*	−39	13.1106	49	DASCH
2428365.4243	6.4616	*Pg*	−36	16.6763	35	DASCH
2428565.7084	1.2635	*Pg*	−33	12.7026	49	DASCH

Table 2 continued.

Max HJD	Error, days	Band	E	$O-C$, days	N	Data source
2428637.6332	0.7406	Pg	−32	16.5413	19	Lazareva (1996)
2428703.9403	0.5603	Pg	−31	14.7625	79	Azhusenis (1956)
2428775.7358	1.2434	Pg	−30	18.4720	49	DASCH
2428976.6376	1.3752	Pg	−27	15.1160	55	DASCH
2429113.0883	2.1927	Pg	−25	15.3947	23	DASCH
2429247.6997	1.0459	Pg	−23	13.8342	45	DASCH
2429319.0505	0.8333	Pg	−22	17.0990	49	DASCH
2429385.2612	0.7950	Pg	−21	15.2238	43	DASCH
2429448.4847	3.4409	Pg	−20	10.3613	60	DASCH
2429591.6945	1.1511	Pg	−18	17.3992	48	DASCH
2429864.1237	0.9888	Pg	−14	17.4846	51	DASCH
2430001.8902	1.0113	Pg	−12	19.0791	50	DASCH
2430205.0864	0.6447	Pg	−9	18.0175	44	DASCH
2430340.6165	2.5670	Pg	−7	17.3756	34	DASCH
2430340.7456	1.1394	Pg	−7	17.5047	49	DASCH
2430477.8058	2.6416	Pg	−5	18.3930	21	DASCH
2430548.1662	1.1685	Pg	−4	20.6674	49	DASCH
2430750.8330	0.8187	Pg	−1	19.0764	44	DASCH
2431090.6865	1.3957	Pg	4	18.5001	49	DASCH
2431160.5545	1.1499	Pg	5	20.2821	48	DASCH
2431227.0888	0.5203	Pg	6	18.7305	74	DASCH
2431363.8226	0.9576	Pg	8	19.2923	68	DASCH
2431497.0934	0.8462	Pg	10	16.3912	45	DASCH
2431631.4651	0.5618	Pg	12	14.5910	78	DASCH
2431632.1600	1.5255	Pg	12	15.2859	52	DASCH
2432039.0241	0.5668	Vis	18	11.6699	26	AAVSO
2432172.7327	1.0362	Pg	20	11.1708	49	DASCH
2432179.0175	0.6543	Vis	20	15.4914	30	AAVSO
2432509.4759	1.6669	Pg	25	7.4843	66	DASCH
2432509.5107	1.0970	Pg	25	7.5191	57	DASCH
2432579.8715	3.5578	Pg	26	9.7939	39	DASCH
2432645.7357	0.4255	Vis	27	5.6079	30	AAVSO
2432779.1347	1.0956	Pg	29	4.7992	49	DASCH
2433047.1853	1.0111	Pg	33	0.5060	20	DASCH
2433117.5807	1.1628	Pg	34	2.8154	34	DASCH
2433184.5573	1.1232	Pg	35	1.7061	61	DASCH
2433658.6540	1.0690	Pg	42	−0.7990	36	DASCH
2433726.6026	0.6908	Pg	43	−0.9364	56	DASCH
2434133.1682	0.4411	Pg	49	−2.8865	23	Wachmann (1966)

Table 2 continued.

Max HJD	Error, days	Band	E	$O-C$, days	N	Data source
2434409.7772	2.4173	Pg	53	1.3787	14	DASCH
2434687.8431	1.6102	Pg	57	7.1007	17	DASCH
2435224.6336	1.2026	Pg	65	−0.7965	22	Lazareva (1996)
2436056.3211	2.9396	Pg	77	13.8595	10	DASCH
2436602.1467	0.5558	Pg	85	14.9974	89	Chuprina (1968)
2437906.5909	0.6581	Pg	104	25.8083	82	Chuprina (1968)
2440015.1568	0.4756	U	135	24.8662	17	Stebbins et al. (1952)
2440016.8282	0.6843	B	135	25.3808	18	Stebbins et al. (1952)
2440016.8944	0.3602	B	135	25.4471	16	Fernie (1970)
2440018.0857	0.4585	V	135	24.6741	17	Fernie (1970)
2440085.6392	0.3821	V	136	24.1416	15	Stebbins et al. (1952)
2440144.5558	2.4655	Vis	137	14.9722	24	AAVSO
2440288.1551	0.7437	Vis	139	22.3996	60	AAVSO
2440560.2544	2.6221	Vis	143	22.1550	8	AAVSO
2440694.4337	4.5858	Vis	145	20.1625	16	AAVSO
2440963.0189	1.1449	Vis	149	16.4037	60	AAVSO
2441026.7964	2.6658	Vis	150	12.0954	29	AAVSO
2441572.7350	0.9079	Vis	158	13.3463	60	AAVSO
2441699.3917	2.1054	Pg	160	5.7953	53	DASCH
2441908.9676	0.6610	R	163	7.8554	12	Schmidt (1976)
2441974.5236	1.4807	Vis	164	6.6191	14	AAVSO
2442380.5879	1.3240	Vis	170	4.1676	24	AAVSO
2442719.1152	1.7859	Vis	175	2.2650	106	AAVSO
2442923.3371	1.1347	Vis	178	2.2291	63	AAVSO
2443052.1360	2.0391	Vis	180	−5.1439	11	AAVSO
2443125.0015	1.2113	Vis	181	−0.3644	26	AAVSO
2443260.5990	1.7774	Pg	183	1.0254	50	DASCH
2443603.2664	0.5919	R_c	188	0.3149	17	Harris (1980)
2443605.7550	0.8949	I_c	188	0.4716	17	Harris (1980)
2443670.8215	0.3498	V	189	0.7679	16	Harris (1980)
2444146.8153	0.5728	B	196	2.1243	21	Mahmoud & Szabados (1980)
2444148.8132	0.6807	V	196	2.1579	21	Mahmoud & Szabados (1980)
2444355.7042	2.6818	Vis	199	4.7910	25	AAVSO
2444832.4206	0.3806	B	206	6.8700	4	Szabados (1991)
2444834.6089	0.2921	V	206	7.0940	4	Szabados (1991)
2444969.8354	2.3668	Vis	208	6.1486	5	AAVSO
2445038.3600	1.2588	Vis	209	6.5872	33	AAVSO
2445105.3163	1.1088	Pg	210	7.4218	76	DASCH
2445378.3201	1.1134	Vis	214	6.1175	59	AAVSO
2445445.7325	0.1753	U	215	8.5650	11	Berdnikov (1986)
2445448.8539	0.2167	R_c	215	7.5815	12	Berdnikov (1986)

Table 2 continued.

Max HJD	Error, days	Band	E	$O-C$, days	N	Data source
2445450.1185	1.6546	Vis	215	9.8299	14	AAVSO
2445514.5905	0.2654	B	216	8.1802	12	Berdnikov (1986)
2445516.5468	0.1716	V	216	8.1723	12	Berdnikov (1986)
2445583.9320	0.5060	U	217	10.5926	13	Berdnikov (1986)
2445652.0890	0.2055	B	218	9.5068	16	Berdnikov (1986)
2445654.6453	0.1689	V	218	10.0988	17	Berdnikov (1986)
2445655.4388	0.6136	R_c	218	9.9085	17	Berdnikov (1986)
2445848.5553	1.5853	V	221	−0.2490	21	Berdnikov (1986)
2445851.7501	2.1346	R_c	221	1.9619	21	Berdnikov (1986)
2445854.6712	1.4356	U	221	8.9879	21	Berdnikov (1986)
2445860.3258	0.1345	B	221	13.4857	21	Berdnikov (1986)
2445931.6732	11.9960	Vis	222	14.7829	12	AAVSO
2446202.7364	0.0559	U	226	16.6233	44	Berdnikov (1987)
2446205.7518	0.1435	R_c	226	15.5338	44	Berdnikov (1987)
2446206.1198	0.8384	Pg	226	18.8500	75	DASCH
2446271.5610	0.0839	B	227	16.2052	44	Berdnikov (1987)
2446273.3615	0.1074	V	227	16.0414	45	Berdnikov (1987)
2446546.6989	0.0842	U	231	20.1560	28	Berdnikov (1992b)
2446550.1632	0.1637	R_c	231	19.5154	32	Berdnikov (1992b)
2446615.6841	0.0711	B	232	19.8985	32	Berdnikov (1992b)
2446617.4953	0.1098	V	232	19.7454	32	Berdnikov (1992b)
2446687.2040	0.7590	Vis	233	21.3682	35	AAVSO
2446959.2067	0.1875	U	237	24.1480	16	Berdnikov (1992c)
2446960.5507	0.0997	B	237	24.3353	18	Berdnikov (1992c)
2446962.8679	0.1375	V	237	24.6882	18	Berdnikov (1992c)
2447031.9372	0.1480	R_c	238	24.6877	18	Berdnikov (1992c)
2447238.0562	1.0565	Pg	241	29.4969	72	DASCH
2447371.7598	0.2019	U	243	28.1854	20	Berdnikov (1992d)
2447373.0089	0.1066	B	243	28.2777	30	Berdnikov (1992d)
2447374.4922	0.1250	V	243	27.7967	30	Berdnikov (1992d)
2447375.3363	0.1729	R_c	243	27.6570	32	Berdnikov (1992d)
2447715.0931	0.1116	U	248	31.0889	34	Berdnikov (1992e)
2447716.6026	0.0873	B	248	31.4416	40	Berdnikov (1992e)
2447718.3466	0.1157	V	248	31.2213	41	Berdnikov (1992e)
2447718.7504	0.1595	R_c	248	30.6413	41	Berdnikov (1992e)
2447917.5469	5.1500	Vis	251	26.1637	23	AAVSO
2448469.9102	0.1616	B	259	35.8036	21	Berdnikov (1992f)
2448471.6488	0.1971	V	259	35.5779	21	Berdnikov (1992f)
2448471.9579	0.1853	R_c	259	34.9032	21	Berdnikov (1992f)
2448811.8504	0.1116	B	264	37.3140	27	Berdnikov (1993)
2448813.6630	0.1029	V	264	37.1623	27	Berdnikov (1993)

Table 2 continued.

Max HJD	Error, days	Band	E	$O-C$, days	N	Data source
2448882.5428	0.2027	R_c	265	36.9723	27	Berdnikov (1993)
2449563.0544	0.2541	B	275	39.5724	13	Berdnikov & Vozyakova (1995)
2449565.3012	0.2574	V	275	39.8549	13	Berdnikov & Vozyakova (1995)
2449633.0514	0.4481	R_c	276	38.5353	13	Berdnikov & Vozyakova (1995)
2449905.3269	0.8919	B	280	41.4151	5	Berdnikov et al. (1997)
2449907.3539	0.1728	V	280	41.4778	38	Berdnikov et al. (1997)
2449909.7523	0.7698	R_c	280	42.8924	7	Berdnikov et al. (1997)
2449910.7227	0.3118	I_c	280	41.5309	38	Berdnikov et al. (1997)
2450315.6729	0.1040	B	286	43.2453	37	Berdnikov et al. (1998)
2450317.9862	0.1183	V	286	43.5944	36	Berdnikov et al. (1998)
2450318.7708	0.2308	R_c	286	43.3951	36	Berdnikov et al. (1998)
2450388.4378	2.0313	Vis	287	45.9600	6	AAVSO
2450587.6480	0.1249	B	290	42.8766	23	Ignatova & Vozyakova (2000)
2450590.0619	0.2068	V	290	43.3262	23	Ignatova & Vozyakova (2000)
2450590.7407	0.2019	R_c	290	43.0212	23	Ignatova & Vozyakova (2000)
2450927.0710	0.1229	B	295	41.8698	26	Ignatova &Vozyakova (2000)
2450929.2720	0.1669	V	295	42.1065	26	Ignatova & Vozyakova (2000)
2450998.4163	0.2990	R_c	296	42.1810	26	Ignatova & Vozyakova (2000)
2451473.5531	1.8664	Vis	303	41.6999	10	AAVSO
2452081.6428	0.9203	Vis	312	37.0160	70	AAVSO
2452083.2022	1.2744	Vis	312	38.5754	11	AAVSO
2452426.5432	1.0277	Vis	317	41.4866	12	AAVSO
2452562.0606	1.4418	Vis	319	40.8320	31	AAVSO
2453589.2904	1.0926	Vis	334	46.7724	47	AAVSO
2454070.1690	0.1890	V	341	51.0493	136	INTEGRAL-OMC
2454140.1523	0.9991	Vis	342	52.9466	30	AAVSO
2454824.1291	1.1123	Vis	352	56.0638	32	AAVSO
2454958.8688	1.6308	Vis	354	54.6316	41	AAVSO
2455433.2796	5.2852	Vis	361	52.4406	8	AAVSO
2455783.1288	0.3083	V	366	61.8601	51	KWS
2456128.0019	0.2600	V	371	66.3034	36	KWS
2456200.2737	1.2072	Vis	372	70.4892	27	AAVSO
2456543.1681	0.3347	V	377	72.9538	65	KWS
2456546.9585	0.7117	I_c	377	73.4284	58	KWS
2456890.0101	0.2266	V	382	79.3660	63	KWS
2456893.9412	0.3602	I_c	382	79.9813	62	KWS
2456959.5834	0.8667	V	383	80.8533	11	MMT
2456963.8128	2.9010	Vis	383	85.0827	7	AAVSO
2457169.6155	0.6561	B	386	88.5918	54	KWS
2457238.9259	0.1984	V	387	87.8519	182	KWS

Table 2 continued.

Max HJD	Error, days	Band	E	$O-C$, days	N	Data source
2457239.0806	0.3064	V	387	88.0067	26	MMT
2457242.1294	0.2693	I_c	387	87.7397	193	KWS
2457308.5322	0.2710	V	388	89.3723	25	MMT
2457375.5690	3.8683	Vis	389	88.3231	38	AAVSO
2457378.6112	0.4995	B	389	93.3296	114	KWS
2457515.2182	1.1682	B	391	93.7647	62	KWS
2457587.3476	0.3046	V	392	95.8439	184	KWS
2457587.4704	0.4647	V	392	95.9666	95	MMT
2457588.0683	0.1436	V	392	96.5646	164	MMT
2457590.1093	0.5511	I_c	392	95.2898	94	KWS
2457656.6311	0.1359	V	393	97.0414	193	MMT
2457932.8625	0.0878	V	397	100.9289	228	KWS
2457933.1758	0.2062	V	397	101.2423	156	MMT
2457935.9266	0.2876	I_c	397	100.6773	101	KWS
2458002.1026	0.0775	V	398	102.0831	276	MMT
2458071.5248	0.2540	V	399	103.4193	163	MMT
2458277.6773	0.1738	V	402	105.3139	81	KWS
2458278.6079	0.2238	V	402	106.2446	278	MMT
2458280.9465	0.2505	I_c	402	105.2673	144	KWS
2458346.6312	0.2668	V	403	106.1819	71	MMT
2458415.1268	0.0995	V	404	106.5915	212	MMT
2458690.6295	0.3406	V	408	109.7504	195	MMT
2458690.8397	0.1851	V	408	109.9606	98	KWS
2458696.3882	0.3465	I_c	408	112.1933	133	KWS
2458760.8953	0.1108	V	409	111.9302	200	MMT
2458829.4460	0.2616	V	410	112.3950	199	MMT
2458966.2084	0.9628	Vis	412	112.9855	17	AAVSO
2459037.1522	0.1080	V	413	115.8432	239	MMT
2459037.3626	0.1043	V	413	116.0537	155	KWS
2459038.3225	0.1246	V	413	117.0135	463	MMT
2459041.0697	0.1589	I_c	413	116.4450	122	KWS
2459107.0656	1.4655	Vis	414	117.6708	28	AAVSO
2459314.0654	0.1806	V	417	120.4126	138	MMT
2459383.9007	0.1876	V	418	122.1620	129	MMT
2459451.8972	0.2479	V	419	122.0725	72	KWS
2459453.3090	0.1727	V	419	123.4844	135	MMT
2459455.9152	0.6031	I_c	419	122.7747	94	KWS
2459728.1570	0.3104	V	423	125.9884	161	MMT
2459796.1310	0.4345	V	424	125.8765	92	KWS
2459796.6599	0.1483	V	424	126.4054	163	MMT
2459797.0677	0.1866	V	424	126.8132	140	MMT
2459799.9598	0.7972	I_c	424	126.3895	81	KWS

Table 3 U, B, V and R band template curves of S Vul.

Phase	U	B	V	R	Phase	U	B	V	R
0.000	11.856	10.428	8.719	7.299	0.500	13.107	11.197	9.174	7.544
0.005	11.856	10.428	8.719	7.299	0.505	13.116	11.204	9.179	7.548
0.010	11.858	10.428	8.719	7.299	0.510	13.125	11.211	9.185	7.552
0.015	11.860	10.430	8.719	7.299	0.515	13.134	11.219	9.190	7.555
0.020	11.863	10.432	8.720	7.300	0.520	13.143	11.226	9.195	7.559
0.025	11.867	10.434	8.722	7.301	0.525	13.152	11.233	9.201	7.562
0.030	11.872	10.437	8.724	7.301	0.530	13.160	11.241	9.206	7.566
0.035	11.878	10.440	8.725	7.301	0.535	13.169	11.248	9.212	7.569
0.040	11.884	10.443	8.727	7.302	0.540	13.178	11.255	9.218	7.573
0.045	11.891	10.447	8.729	7.303	0.545	13.187	11.262	9.224	7.576
0.050	11.898	10.451	8.732	7.304	0.550	13.195	11.269	9.230	7.580
0.055	11.906	10.455	8.734	7.305	0.555	13.204	11.276	9.235	7.583
0.060	11.915	10.459	8.736	7.306	0.560	13.213	11.283	9.240	7.586
0.065	11.924	10.464	8.738	7.308	0.565	13.221	11.290	9.245	7.589
0.070	11.934	10.469	8.741	7.309	0.570	13.230	11.297	9.251	7.593
0.075	11.944	10.475	8.743	7.310	0.575	13.239	11.304	9.256	7.596
0.080	11.955	10.481	8.745	7.311	0.580	13.247	11.310	9.261	7.599
0.085	11.966	10.486	8.748	7.312	0.585	13.256	11.317	9.266	7.602
0.090	11.978	10.492	8.751	7.313	0.590	13.264	11.322	9.271	7.605
0.095	11.991	10.498	8.755	7.315	0.595	13.273	11.328	9.275	7.608
0.100	12.004	10.505	8.758	7.316	0.600	13.281	11.334	9.280	7.611
0.105	12.017	10.512	8.762	7.318	0.605	13.289	11.339	9.285	7.614
0.110	12.031	10.520	8.766	7.319	0.610	13.298	11.344	9.289	7.617
0.115	12.045	10.527	8.770	7.321	0.615	13.306	11.348	9.293	7.619
0.120	12.060	10.535	8.774	7.322	0.620	13.313	11.353	9.296	7.621
0.125	12.075	10.543	8.778	7.323	0.625	13.321	11.357	9.300	7.623
0.130	12.091	10.551	8.782	7.324	0.630	13.328	11.360	9.303	7.625
0.135	12.107	10.559	8.786	7.326	0.635	13.335	11.363	9.305	7.627
0.140	12.123	10.568	8.790	7.328	0.640	13.342	11.366	9.306	7.628
0.145	12.139	10.578	8.794	7.330	0.645	13.348	11.368	9.307	7.628
0.150	12.156	10.587	8.798	7.332	0.650	13.354	11.370	9.308	7.628
0.155	12.172	10.596	8.802	7.334	0.655	13.360	11.372	9.308	7.628
0.160	12.189	10.606	8.806	7.336	0.660	13.364	11.372	9.307	7.628
0.165	12.206	10.616	8.810	7.338	0.665	13.369	11.372	9.306	7.628
0.170	12.223	10.626	8.815	7.340	0.670	13.372	11.372	9.304	7.627
0.175	12.239	10.635	8.819	7.343	0.675	13.375	11.372	9.303	7.627
0.180	12.256	10.645	8.824	7.346	0.680	13.377	11.371	9.301	7.626
0.185	12.272	10.654	8.829	7.348	0.685	13.378	11.369	9.299	7.624
0.190	12.288	10.664	8.833	7.350	0.690	13.378	11.366	9.296	7.622
0.195	12.304	10.674	8.838	7.352	0.695	13.376	11.363	9.293	7.620
0.200	12.320	10.683	8.844	7.354	0.700	13.374	11.360	9.290	7.618

Table 3 continued.

Phase	U	B	V	R	Phase	U	B	V	R
0.205	12.336	10.693	8.849	7.357	0.705	13.370	11.355	9.286	7.616
0.210	12.351	10.703	8.854	7.359	0.710	13.365	11.350	9.282	7.612
0.215	12.366	10.713	8.859	7.362	0.715	13.359	11.344	9.277	7.608
0.220	12.380	10.722	8.864	7.364	0.720	13.351	11.337	9.272	7.605
0.225	12.394	10.730	8.868	7.367	0.725	13.342	11.329	9.266	7.600
0.230	12.408	10.739	8.873	7.370	0.730	13.330	11.321	9.258	7.596
0.235	12.422	10.748	8.878	7.372	0.735	13.317	11.312	9.250	7.591
0.240	12.435	10.757	8.883	7.374	0.740	13.303	11.302	9.240	7.586
0.245	12.449	10.766	8.887	7.376	0.745	13.286	11.291	9.230	7.579
0.250	12.461	10.774	8.891	7.378	0.750	13.267	11.279	9.219	7.572
0.255	12.474	10.783	8.896	7.381	0.755	13.247	11.265	9.208	7.565
0.260	12.487	10.791	8.901	7.383	0.760	13.225	11.251	9.197	7.558
0.265	12.499	10.799	8.906	7.386	0.765	13.200	11.236	9.185	7.550
0.270	12.512	10.807	8.912	7.388	0.770	13.174	11.220	9.172	7.542
0.275	12.524	10.815	8.917	7.391	0.775	13.146	11.204	9.158	7.534
0.280	12.536	10.823	8.923	7.393	0.780	13.116	11.186	9.144	7.525
0.285	12.549	10.831	8.929	7.396	0.785	13.084	11.167	9.130	7.515
0.290	12.561	10.839	8.934	7.399	0.790	13.051	11.147	9.115	7.507
0.295	12.574	10.848	8.940	7.402	0.795	13.015	11.126	9.100	7.497
0.300	12.587	10.855	8.946	7.405	0.800	12.979	11.105	9.083	7.488
0.305	12.600	10.863	8.951	7.408	0.805	12.940	11.082	9.066	7.478
0.310	12.613	10.872	8.956	7.411	0.810	12.901	11.058	9.049	7.468
0.315	12.627	10.880	8.960	7.414	0.815	12.860	11.034	9.031	7.458
0.320	12.640	10.889	8.965	7.416	0.820	12.819	11.010	9.012	7.449
0.325	12.654	10.897	8.970	7.419	0.825	12.776	10.985	8.992	7.439
0.330	12.668	10.906	8.974	7.422	0.830	12.733	10.959	8.973	7.430
0.335	12.682	10.915	8.978	7.425	0.835	12.689	10.933	8.954	7.420
0.340	12.697	10.924	8.982	7.429	0.840	12.645	10.907	8.935	7.411
0.345	12.711	10.933	8.986	7.432	0.845	12.601	10.881	8.917	7.403
0.350	12.726	10.943	8.991	7.435	0.850	12.557	10.854	8.899	7.394
0.355	12.741	10.952	8.997	7.438	0.855	12.513	10.828	8.882	7.386
0.360	12.756	10.962	9.002	7.443	0.860	12.470	10.803	8.866	7.378
0.365	12.771	10.971	9.009	7.446	0.865	12.427	10.777	8.851	7.371
0.370	12.786	10.981	9.015	7.450	0.870	12.385	10.752	8.838	7.364
0.375	12.802	10.990	9.021	7.453	0.875	12.344	10.727	8.826	7.357
0.380	12.817	10.999	9.028	7.457	0.880	12.304	10.703	8.814	7.351
0.385	12.832	11.009	9.035	7.462	0.885	12.266	10.680	8.804	7.346
0.390	12.847	11.018	9.042	7.466	0.890	12.229	10.657	8.794	7.341
0.395	12.861	11.028	9.048	7.469	0.895	12.193	10.634	8.785	7.336
0.400	12.876	11.037	9.055	7.473	0.900	12.159	10.613	8.778	7.331
0.405	12.890	11.046	9.061	7.477	0.905	12.127	10.594	8.771	7.328

Table 3 continued.

Phase	U	B	V	R	Phase	U	B	V	R
0.410	12.904	11.055	9.068	7.481	0.910	12.096	10.576	8.765	7.325
0.415	12.918	11.064	9.074	7.486	0.915	12.068	10.558	8.759	7.322
0.420	12.932	11.073	9.080	7.489	0.920	12.041	10.541	8.753	7.319
0.425	12.945	11.082	9.086	7.492	0.925	12.016	10.526	8.748	7.316
0.430	12.958	11.090	9.092	7.496	0.930	11.993	10.511	8.744	7.313
0.435	12.971	11.099	9.099	7.499	0.935	11.972	10.499	8.741	7.311
0.440	12.983	11.107	9.105	7.503	0.940	11.953	10.487	8.738	7.310
0.445	12.995	11.115	9.111	7.506	0.945	11.936	10.477	8.735	7.308
0.450	13.006	11.123	9.117	7.509	0.950	11.921	10.467	8.732	7.306
0.455	13.018	11.131	9.123	7.512	0.955	11.907	10.459	8.730	7.304
0.460	13.029	11.138	9.129	7.516	0.960	11.896	10.452	8.728	7.304
0.465	13.039	11.145	9.135	7.519	0.965	11.886	10.445	8.726	7.303
0.470	13.050	11.153	9.142	7.523	0.970	11.877	10.440	8.725	7.302
0.475	13.060	11.161	9.147	7.526	0.975	11.870	10.436	8.723	7.301
0.480	13.070	11.169	9.152	7.530	0.980	11.865	10.433	8.721	7.300
0.485	13.079	11.175	9.158	7.533	0.985	11.861	10.430	8.720	7.300
0.490	13.089	11.182	9.164	7.537	0.990	11.858	10.428	8.720	7.299
0.495	13.098	11.189	9.169	7.540	0.995	11.856	10.427	8.720	7.299

Table 4 R_c and I_c band template curves of S Vul.

Phase	R_c	I_c	Phase	R_c	I_c	Phase	R_c	I_c
0.000	7.731	6.776	0.335	7.905	6.919	0.670	8.185	7.141
0.005	7.731	6.776	0.340	7.909	6.924	0.675	8.184	7.137
0.010	7.730	6.777	0.345	7.914	6.928	0.680	8.183	7.133
0.015	7.731	6.777	0.350	7.918	6.933	0.685	8.181	7.128
0.020	7.732	6.777	0.355	7.923	6.938	0.690	8.178	7.124
0.025	7.733	6.778	0.360	7.928	6.943	0.695	8.176	7.118
0.030	7.733	6.779	0.365	7.933	6.948	0.700	8.173	7.113
0.035	7.734	6.779	0.370	7.938	6.953	0.705	8.169	7.107
0.040	7.735	6.780	0.375	7.943	6.958	0.710	8.165	7.101
0.045	7.737	6.781	0.380	7.949	6.963	0.715	8.160	7.095
0.050	7.738	6.782	0.385	7.955	6.968	0.720	8.154	7.088
0.055	7.739	6.783	0.390	7.960	6.974	0.725	8.148	7.081
0.060	7.740	6.784	0.395	7.966	6.979	.730	8.142	7.074
0.065	7.742	6.786	0.400	7.971	6.984	0.735	8.135	7.067
0.070	7.744	6.787	0.405	7.976	6.990	0.740	8.128	7.059
0.075	7.746	6.788	0.410	7.982	6.995	0.745	8.120	7.052
0.080	7.748	6.789	0.415	7.987	7.001	0.750	8.111	7.044
0.085	7.749	6.791	0.420	7.992	7.006	0.755	8.101	7.036
0.090	7.751	6.792	0.425	7.997	7.012	0.760	8.090	7.027
0.095	7.752	6.794	0.430	8.002	7.017	0.765	8.079	7.019
0.100	7.754	6.795	0.435	8.007	7.023	0.770	8.068	7.011
0.105	7.756	6.797	0.440	8.012	7.028	0.775	8.057	7.002
0.110	7.758	6.798	0.445	8.016	7.034	0.780	8.045	6.994
0.115	7.759	6.799	0.450	8.021	7.039	0.785	8.032	6.985
0.120	7.761	6.801	0.455	8.025	7.045	0.790	8.020	6.977
0.125	7.763	6.803	0.460	8.030	7.050	0.795	8.007	6.968
0.130	7.765	6.804	0.465	8.035	7.056	0.800	7.994	6.960
0.135	7.768	6.806	0.470	8.040	7.061	0.805	7.981	6.951
0.140	7.770	6.807	0.475	8.045	7.066	0.810	7.967	6.943
0.145	7.773	6.809	0.480	8.049	7.072	0.815	7.953	6.934
0.150	7.775	6.811	0.485	8.054	7.077	0.820	7.940	6.926
0.155	7.778	6.812	0.490	8.059	7.082	0.825	7.927	6.918
0.160	7.781	6.814	0.495	8.064	7.087	0.830	7.914	6.910
0.165	7.784	6.816	0.500	8.069	7.093	0.835	7.901	6.902
0.170	7.787	6.818	0.505	8.074	7.097	.840	7.888	6.894
0.175	7.790	6.819	0.510	8.079	7.102	0.845	7.876	6.887
0.180	7.794	6.821	0.515	8.084	7.107	0.850	7.864	6.880
0.185	7.797	6.823	0.520	8.089	7.112	0.855	7.853	6.872
0.190	7.800	6.825	0.525	8.094	7.116	0.860	7.842	6.866
0.195	7.803	6.827	0.530	8.099	7.120	0.865	7.831	6.859
0.200	7.807	6.829	0.535	8.103	7.125	0.870	7.822	6.852

Table 4 continued.

Phase	R_c	I_c	Phase	R_c	I_c	Phase	R_c	I_c
0.205	7.810	6.832	0.540	8.108	7.129	0.875	7.813	6.846
0.210	7.814	6.834	0.545	8.114	7.132	0.880	7.804	6.840
0.215	7.817	6.836	0.550	8.118	7.136	0.885	7.797	6.835
0.220	7.820	6.839	0.555	8.123	7.139	0.890	7.789	6.829
0.225	7.824	6.841	0.560	8.127	7.143	0.895	7.783	6.824
0.230	7.827	6.844	0.565	8.132	7.146	0.900	7.776	6.819
0.235	7.831	6.846	0.570	8.136	7.148	0.905	7.771	6.815
0.240	7.834	6.849	0.575	8.141	7.151	0.910	7.766	6.810
0.245	7.837	6.852	0.580	8.145	7.153	0.915	7.762	6.806
0.250	7.840	6.855	0.585	8.150	7.155	0.920	7.758	6.803
0.255	7.844	6.858	0.590	8.154	7.157	0.925	7.754	6.799
0.260	7.847	6.861	0.595	8.158	7.158	0.930	7.751	6.796
0.265	7.850	6.864	0.600	8.162	7.160	0.935	7.748	6.793
0.270	7.853	6.868	0.605	8.166	7.160	0.940	7.746	6.790
0.275	7.857	6.871	0.610	8.170	7.161	0.945	7.743	6.788
0.280	7.860	6.875	0.615	8.173	7.161	0.950	7.740	6.786
0.285	7.864	6.878	0.620	8.175	7.161	0.955	7.738	6.784
0.290	7.868	6.882	0.625	8.178	7.161	0.960	7.737	6.782
0.295	7.872	6.886	0.630	8.180	7.160	0.965	7.735	6.781
0.300	7.876	6.889	0.635	8.183	7.159	0.970	7.734	6.779
0.305	7.880	6.893	0.640	8.184	7.157	0.975	7.733	6.778
0.310	7.884	6.897	0.645	8.185	7.155	0.980	7.732	6.778
0.315	7.888	6.902	0.650	8.186	7.153	0.985	7.731	6.777
0.320	7.893	6.906	0.655	8.186	7.151	0.990	7.731	6.777
0.325	7.897	6.910	0.660	8.187	7.148	0.995	7.731	6.776
0.330	7.901	6.915	0.665	8.186	7.145			

Note that the results concerning period changes that we report in this paper are based on concrete light-curve templates given in Tables 3 and 4 and shown graphically in Fig. 4.

4 Conclusions

1. Using the Hertzsprung method we calculated 288 moments of maximum light for S Vul and constructed the $O-C$ diagram, which spans a 160-year long time interval, allowing us to calculate the evolutionary period change at a rate of $dp/dt = 533.0 \pm 11.4$ s/year.

2. The $O-C$ diagram shown in Fig. 1 leads to the conclusion that evolutionary period changes of S Vul are not monotonous. They show up as cyclical variations tracing progressive changes; in turn, these cyclical variations result from frequent abrupt period changes.

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