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IMAGE-TUBE SPECTROSCOPIC STUDIES OF RAPID VARIABLES

I. SPECTROSCOPIC AND PHOTOMETRIC OBSERVATIONS OF SS CYGNI*

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ABSTRACT

Single-trail spectroscopic observations of SS Cygni demonstrate that the rapid, irregular light variations at minimum result entirely from changes in the intensity of the continuum; the emission-line intensities are unchanged. Observations during the rise to maximum of the 4-mag nova-like outbursts show the absorption spectrum characteristic of this phase and demonstrate (1) that the outburst is associated with the hot star and (2) that at least up to the observed phase of the outburst no appreciable expansion of the photosphere has occurred. The observations reveal a hitherto undetected doubling of the K-line of Ca II. At minimum the K-line is (occasionally) double in emission, probably because of a rotating ring or shell of material surrounding the hot star. During the rise to maximum of the 4-mag outbursts, the K-line is double in absorption. Apparently the rise to maximum is accompanied by a large increase in Ca II emission, the hydrogen emission remaining constant. The orbital period of the system is found to be increasing linearly with time, the rate of increase corresponding to a mass loss of 1 8 $\times 10^{-7}\,\mathfrak{M}_\odot$ year^{-1}. This is much larger than the value of $7 \times 10^{-9}\,\mathfrak{M}_\odot$ year^{-1} derived by Gaposchkin for the mass ejected during the 4-mag outbursts, so that continual mass loss through the second Lagrangian point of the binary system appears to dominate.

I. INTRODUCTION

Following the successful application of the Lallemand electronic camera to the study of the spectroscopic changes associated with the rapid light variations of AE Aqr (Walker 1965, 1966), similar observations were undertaken for a number of rapid variables of different type. Among the stars investigated was SS Cyg, chosen because it is the brightest member of the U Gem class of variable stars. SS Cyg is a double-line spectroscopic binary with a period of 6^h38^m (Joy 1956). At intervals of about 50 days, the brightness of the system increases by about 4 mag in the course of a few days and then returns to its normal (minimum) state in about 10–20 days. At minimum, rapid, irregular variations in light of a few tenths of a magnitude in a few minutes occur (Walker 1954, 1957; Grant 1955); the primary purpose of the present investigation was to determine, by means of the high speed and linear response of the electronic camera, what spectroscopic changes are associated with these variations.

II. OBSERVATIONAL MATERIAL

The spectroscopic observations were made with the Lallemand electronic camera mounted at the focus of the 20-inch Schmidt camera of the coudé spectrograph of the 120-inch reflector, in the manner described previously (Lallemand, Duchesne, and Walker 1960; Walker 1962, 1966). A grating was used that gave a dispersion of 48 Å mm^{-1} on the photocathode of the electronic camera and 65 Å mm^{-1} on the Ilford G5 nuclear research plates used to record the electronic image. As discussed elsewhere (Walker 1966), the resolution of the system is comparable to that of a Kodak IIaO plate

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exposed directly to the optical image, while the information gain at 4000 Å is of the order of 15 over a baked IIaO plate.

In order to obtain a continuous, high-time-resolution record of the spectroscopic changes in the system, the observations were made by allowing the star to travel once along the slit of the spectrograph at a constant rate, the value of which was determined by the brightness of the system and the quality of the seeing. The rate was controlled by keeping the star on the moving wire of a micrometer eyepiece that viewed the light reflected from the slit of the spectrograph. The wire position was advanced by equal increments at intervals of 18 sec on July 21, 1965 (U.T.), 40 sec on August 6, 1965 (U.T.), and 38 sec on October 16, 1965 (U.T.). Data concerning the plates obtained are listed in Table 1.

TABLE 1

SINGLE-TRAIL SPECTROSCOPIC OBSERVATIONS OF SS CYGNI

Plate No. (ECL)	Date (U.T.)	Exposure (U.T.)		Hour Angle Mid-Exp.	J.D.⊙ Mid-Exp. 2430000+
		Start	Stop		
	1965				
364....	July 21	$8^h03^m15^s$	$8^h41^m15^s$	1^h30^m E.	8962 851
365....	July 21	8 48 36	9 25 50	0 44 E.	8962 882
371....	August 7	5 32 25	6 54 30	2 32 E.	8979.763
372.... .	August 7	6 58 50	8 22 50	1 06 E.	8979 823
373....	August 7	8 25 50	9 45 50	0 21 W.	8979 882
374..... .	August 7	10 04 00	11 26 00	2 00 W.	8979 951
375A.	August 7	11 29 30	11 52 30	2 56 W.	8979 990
375B* ..	August 7	11 59 00	11 59 35	3 14 W.	8980 003
381.....	October 16	3 48 51	5 09 51	0 20 W.	9049 689
382.... .	October 16	5 20 21	6 42 41	1 52 W.	9049 754
	1966				
419†......	April 26	11 08 00	11 44 30	4 05 E.	9241.974

* Multiple-trail "slitless" spectrogram; for energy curve only.
† Multiple-trail slit spectrogram; for radial velocity only.

On two nights, July 21 and August 7, simultaneous photoelectric observations were obtained using the 24-inch photometric reflector. The photometer employed a 1P21 photomultiplier tube refrigerated with dry ice, and the following filters: *V:* Corning 3384, standard optical thickness; *B:* 1-mm Schott BG 12 + 2-mm Schott GG 13; *U:* Corning 9863, standard optical thickness. Standard stars of the *UBV* system (Johnson and Morgan 1953) were observed before and after the observations of SS Cyg. In order to provide detailed coverage of the light curve for comparison with the spectroscopic observations, the star was monitored mostly in ultraviolet light, interrupting these observations only occasionally for measurements of the sky background, of the other colors, and of the radium source. The photoelectric observations are listed in Tables 2–4. In the reductions and tables, the magnitudes have been given to 0.001 mag in order to delineate more accurately the intrinsic variations of the star. However, the tie-in of these magnitudes to the *UBV* system is good only to about 0.01 or 0.02 mag.

III. OBSERVATIONS AT MINIMUM LIGHT

a) Appearance of the Spectrum

The appearance of the spectrum of SS Cyg at minimum light has been described by several observers. (A complete list and discussion of all of the older observations is given by Gaposchkin 1957 and in the very extensive study of SS Cyg by Zuckermann 1962; it will not be repeated here.) In general, the spectrum at minimum has been found to consist of a dG-type absorption spectrum, partially to completely veiled by an overlying blue continuum. Superimposed on the continuum and absorption spectrum are strong, broad emission lines of hydrogen and weaker bright lines of He I and Ca II. These features are shown in the single-trail spectrograms of SS Cyg obtained in the present investigation. Figure 1 (Plate 3) reproduces the observations obtained on July 21 (*top*) and October 16 (*bottom*). In both instances, time increases linearly from top to bottom, the space between the two successive exposures on each night being adjusted to equal the time interval between exposures. The observations on July 21

TABLE 2

PHOTOELECTRIC OBSERVATIONS OF SS CYGNI IN YELLOW LIGHT

J.D.⊙ 2438000+	V (mag)	J.D.⊙ 2438000+	V (mag)
962 7155	11 644	979 8195	9 346
962 7162	11 556	979 8258	9.342
962 7287	11 301	979 8319	9 302
962 7489	11 199	979 8371	9 273
962 7697	11 404	979.8444	9 225
962 7878	11 657	979 8530	9 160
962 8135	11 472	979 8593	9 255
978 8...	11 23	979 8610	9 230
979 7301	9 591	979 8676	9 223
979 7451	9 484	979 8855	9 200
979 7555	9 533	979 8892	9 185
979 7617	9 544	979 8940	9 180
979 7666	9 538	979 8999	9 173
979 7885	9 428	979 9077	9 247
979 7977	9 379	979 9121	9 161
979 8017	9 420	979 9385	9 066
979 8065	9 377	979 9440	9 118
979 8093	9 373	979 9510	9 096
979 8121	9 333	979 9552	9 084
979.8145	9 359	979 9635	9 039
979 8156	9 350	979 9794	8 977

cover an interval of 83 min, while those on October 16 cover 176 min. The spectrograms taken on the latter night also show emission lines of mercury at 3650 and 4046 Å due to the lights of San Jose.

The observations on July 21 show a feature not previously detected in this system: a doubling of the Ca II K-emission. Joy (1956) reported that on some plates, a sharp component of K-emission was visible that had the same radial velocity as the absorption lines of the G-type star. The phenomenon observed here appears to be different. As discussed in the next section, the velocity of the center of the double-emission feature agrees with that of the other emission lines.

b) Radial-Velocity Measurements

As pointed out by Joy (1956), measurement of radial velocities in SS Cyg is extremely difficult because of the faintness of the absorption-line spectrum and the width of the emission lines. Because of these difficulties, measurements of each spectrogram were made only for the middle of each exposure. These measurements, together with the velocities measured by Joy, are listed in Tables 5 and 6. In Table 5 the emission-line

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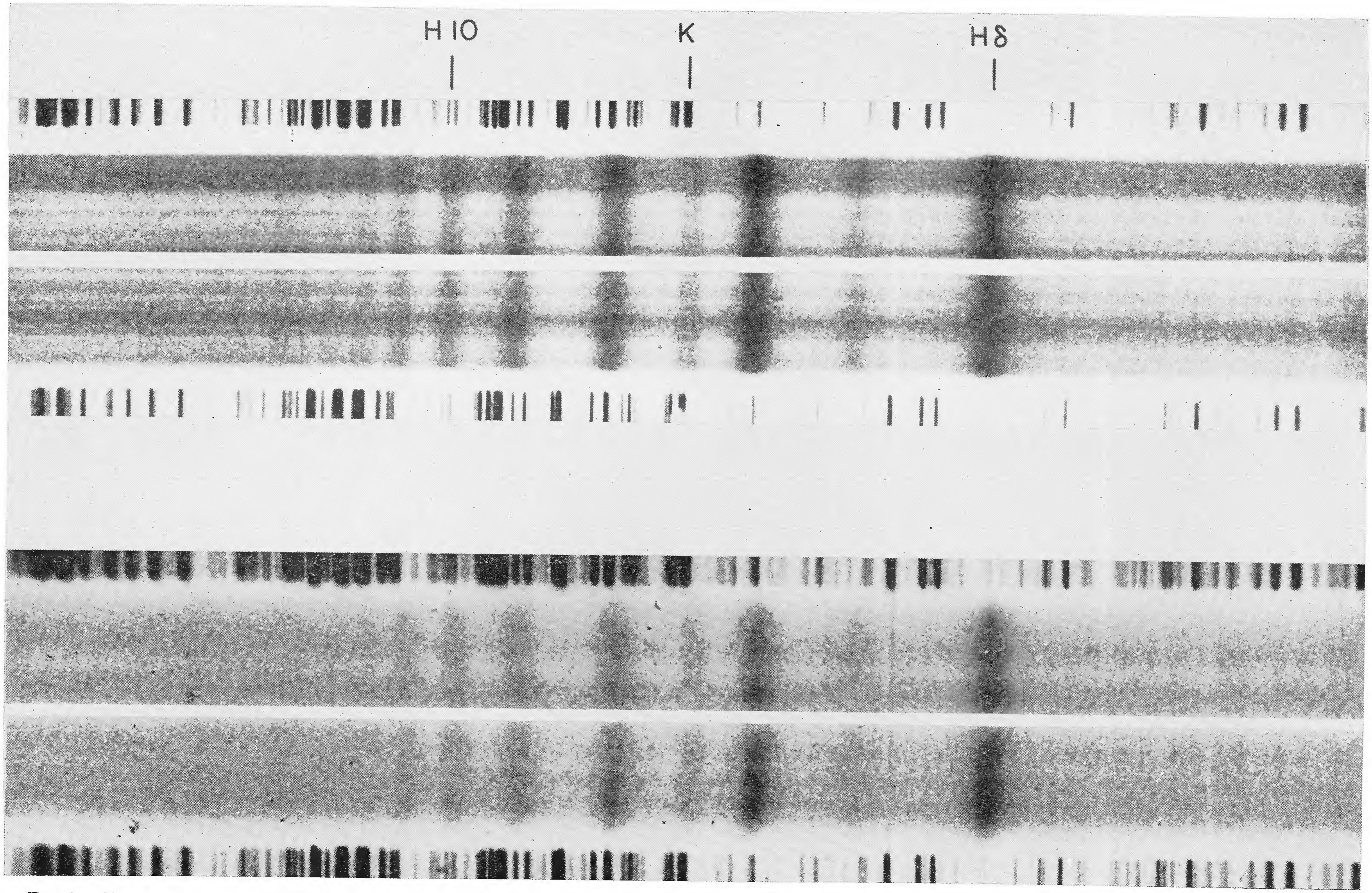

FIG. 1.—Single-trail spectra of SS Cyg observed on July 21, 1965 (*top*), and October 16, 1965 (*bottom*). Time increases uniformly from top to bottom of the spectra. The separation of the two spectra on each night equals the time interval between them. The observations on July 21 cover an interval of 83 min, while those on October 16 cover 176 min.

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TABLE 3

PHOTOELECTRIC OBSERVATIONS OF SS CYG IN BLUE LIGHT

JD⊙ 2438000+	B mag.	JD⊙ 2438000+	B mag.
962.7176	11.927	962.8152	11.671
.7183	11.851	.8197	11.547
.7232	11.841	.8204	11.577
.7253	11.828	.8211	11.552
.7260	11.643	.8218	11.472
.7267	11.612	.8253	11.385
.7301	11.634	.8260	11.480
.7329	11.507	.8267	11.325
.7336	11.631	.8274	11.355
.7371	11.611	.8294	11.430
.7398	11.704	.8301	11.365
.7405	11.554	.8308	11.250
.7412	11.624	978.8	11.75
.7427	11.549	979.7305	9.859
.7503	11.617	.7461	9.784
.7532	11.732	.7558	9.820
.7537	11.782	.7621	9.811
.7544	11.805	.7669	9.808
.7586	11.832	.7829	9.709
.7593	11.812	.7834	9.706
.7600	11.738	.7892	9.656
.7603	11.693	.7968	9.658
.7621	11.534	.8011	9.685
.7629	11.574	.8022	9.686
.7648	11.839	.8058	9.628
.7655	11.789	.8086	9.629
.7676	11.852	.8100	9.628
.7683	11.792	.8116	9.591
.7704	11.740	.8123	9.589
.7711	11.805	.8140	9.600
.7739	11.866	.8161	9.592
.7746	11.817	.8185	9.594
.7753	11.864	.8197	9.604
.7774	11.851	.8263	9.566
.7780	11.733	.8310	9.577
.7787	11.779	.8367	9.519
.7850	11.996	.8440	9.455
.7857	12.057	.8525	9.495
.7860	12.129	.8600	9.475
.7886	11.971	.8614	9.440
.7892	11.841	.8671	9.450
.7898	11.778	.8860	9.420
.7919	11.931	.8886	9.425
.7926	11.876	.8937	9.425
.7933	11.784	.9004	9.394
.7954	12.044	.9072	9.367
.7961	12.004	.9114	9.367
.7968	11.874	.9392	9.286
.7975	11.834	.9430	9.351
.7996	11.823	.9503	9.322
.8003	11.674	.9548	9.308
962.8010	11.761	.9628	9.251
		979.9781	9.135

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TABLE 4

PHOTOELECTRIC OBSERVATIONS OF SS CYG NI IN ULTRAVIOLET LIGHT

JD$_\odot$ 2438000+	U mag.	JD$_\odot$ 2438000+	U mag.	JD$_\odot$ 2438000+	U mag.
962.7204	10.725	962.8235	10.453	962.8574	10.700
.7246	10.997	.8239	10.423	.8579	10.880
.7308	10.652	.8246	10.613	.8586	10.854
.7364	10.610	.8277	10.637	.8589	10.789
.7378	10.544	.8284	10.487	.8593	10.859
.7383	10.731	.8287	10.587	.8600	10.914
.7386	10.673	.8324	10.462	.8607	10.964
.7421	10.607	.8329	10.572	.8614	10.841
.7510	10.692	.8336	10.627	.8617	10.646
.7517	10.595	.8343	10.597	.8621	10.716
.7524	10.668	.8350	10.627	.8628	10.681
.7551	11.051	.8357	10.680	.8635	10.716
.7558	11.031	.8364	10.880	.8642	10.680
.7565	10.951	.8371	10.710	.8648	10.755
.7572	10.908	.8378	10.590	.8746	10.830
.7609	10.796	.8385	10.533	.8760	10.785
.7610	10.720	.8392	10.433	.8767	10.745
.7614	10.640	.8398	10.533	.8774	10.760
.7635	10.636	.8405	10.625	.8780	10.775
.7638	10.686	.8412	10.405	.8787	10.893
.7662	10.959	.8426	10.485	.8794	10.789
.7669	11.079	.8433	10.498	.8798	10.693
.7718	10.926	.8440	10.498	.8805	10.573
.7725	10.925	.8447	10.488	.8808	10.563
.7760	10.994	.8454	10.508	.8822	10.425
.7767	11.089	.8461	10.438	.8829	10.475
.7839	10.983	.8468	10.623	.8836	10.495
.7843	11.063	.8475	10.823	.8843	10.535
.7902	10.915	.8489	10.993	.8850	10.660
.7940	11.020	.8496	11.034	.8864	10.835
.7947	11.090	.8503	10.985	.8885	11.069
.7989	10.928	.8510	11.025	.8912	11.019
.8017	11.037	.8517	11.005	.8919	11.089
.8024	10.857	.8524	10.987	.8926	10.957
.8030	10.952	.8530	10.977	.8940	10.877
.8169	10.830	.8537	10.947	.8947	10.912
.8173	10.770	.8544	10.827	.8961	11.057
.8176	10.844	.8551	10.810	.8975	11.103
.8183	10.916	.8565	10.820	.8989	11.012
962.8190	10.866	962.8572	10.775	962.8996	10.923

TABLE 4 (continued)

JD⊙ 2438000+	U mag.	JD⊙ 2438000+	U mag.	JD⊙ 2438000+	U mag.
962.9003	10.822	979.7697	9.746	979.8114	9.545
.9010	10.834	.7711	9.740	.8128	9.501
.9017	10.862	.7718	9.714	.8138	9.644
978.8	11.08	.7725	9.709	.8169	9.497
979.7315	9.804	.7732	9.689	.8176	9.504
.7322	9.807	.7739	9.703	.8190	9.546
.7329	9.782	.7746	9.653	.8275	9.466
.7336	9.756	.7753	9.656	.8280	9.493
.7350	9.804	.7760	9.631	.8287	9.493
.7357	9.833	.7766	9.716	.8294	9.493
.7364	9.890	.7774	9.689	.8301	9.503
.7371	9.865	.7781	9.649	.8329	9.414
.7378	9.859	.7787	9.624	.8336	9.362
.7385	9.844	.7794	9.676	.8343	9.414
.7392	9.826	.7801	9.676	.8346	9.387
.7399	9.811	.7843	9.604	.8353	9.426
.7406	9.784	.7850	9.534	.8357	9.444
.7412	9.759	.7857	9.559	.8360	9.409
.7419	9.719	.7864	9.599	.8378	9.379
.7426	9.716	.7871	9.601	.8385	9.384
.7433	9.716	.7874	9.606	.8392	9.434
.7437	9.692	.7906	9.561	.8399	9.429
.7440	9.664	.7919	9.581	.8406	9.399
.7447	9.622	.7926	9.561	.8412	9.414
.7468	9.765	.7940	9.621	.8419	9.389
.7565	9.824	.7947	9.636	.8426	9.349
.7572	9.836	.7954	9.638	.8433	9.264
.7579	9.811	.7961	9.623	.8447	9.342
.7586	9.808	.7973	9.588	.8454	9.387
.7593	9.819	.7982	9.573	.8461	9.387
.7600	9.821	.7989	9.588	.8468	9.362
.7607	9.817	.7996	9.603	.8475	9.392
.7626	9.796	.8003	9.617	.8482	9.378
.7635	9.791	.8006	9.617	.8485	9.397
.7642	9.770	.8027	9.625	.8489	9.377
.7649	9.801	.8044	9.613	.8496	9.292
.7652	9.791	.8051	9.613	.8503	9.317
.7676	9.793	.8072	9.611	.8510	9.397
.7683	9.776	.8079	9.580	.8517	9.397
979.7690	9.701	979.8107	9.570	979.8534	9.402

TABLE 4 (continued)

JD$_{\odot}$ 2438000+	$\underline{U}$ mag.	JD$_{\odot}$ 2438000+	$\underline{U}$ mag.	JD$_{\odot}$ 2438000+	$\underline{U}$ mag.
979.8539	9.472	979.8787	9.367	979.9156	9.274
.8544	9.447	.8794	9.347	.9162	9.269
.8551	9.402	.8801	9.357	.9169	9.259
.8558	9.347	.8808	9.367	.9176	9.292
.8565	9.367	.8815	9.337	.9399	9.121
.8569	9.332	.8822	9.337	.9406	9.131
.8572	9.357	.8829	9.307	.9423	9.203
.8579	9.382	.8836	9.327	.9461	9.199
.8586	9.397	.8843	9.317	.9468	9.184
.8605	9.352	.8871	9.333	.9475	9.179
.8621	9.307	.8878	9.317	.9482	9.164
.8628	9.352	.8881	9.297	.9489	9.184
.8635	9.327	.8899	9.300	.9496	9.194
.8649	9.267	.8906	9.270	.9524	9.134
.8656	9.327	.8912	9.282	.9530	9.119
.8662	9.337	.8919	9.282	.9537	9.139
.8666	9.307	.8929	9.307	.9541	9.144
.8683	9.357	.8930	9.307	.9565	9.126
.8687	9.392	.9017	9.274	.9572	9.144
.8690	9.367	.9024	9.274	.9579	9.134
.8697	9.347	.9030	9.259	.9586	9.119
.8704	9.357	.9037	9.274	.9593	9.089
.8711	9.330	.9044	9.274	.9600	9.112
.8718	9.312	.9051	9.244	.9607	9.122
.8725	9.342	.9058	9.231	.9614	9.092
.8732	9.352	.9065	9.211	.9621	9.090
.8739	9.360	.9086	9.211	.9767	8.974
.8746	9.352	.9093	9.249	.9774	8.954
.8753	9.352	.9100	9.207	.9815	8.936
.8760	9.334	.9107	9.194	.9822	8.921
.8767	9.392	.9129	9.229	.9836	8.972
.8774	9.382	.9135	9.244	.9846	8.999
979.8780	9.362	.9142	9.229	.9857	8.994
		979.9149	9.259	979.9871	8.999

velocities are based on the measures of the hydrogen lines only, while the absorption-line velocities are based on measures of Fe I λλ4132 and 4143. The measurements of the two components of the Ca II K-emission are listed separately in Table 6.

It was found that the new observations cannot be represented using the value of the period given by Joy (1956). Nor can a satisfactory fit of all of the available observations be obtained using any constant value of the period. Reasonable agreement is possible, however, on the assumption that the period is increasing with time at a constant rate. Under this assumption, the best fit of all the observations is obtained using the elements

$$\text{Zero phase} = \text{J.D.}_{\odot}\ 2430267.770 + 0^{d}.2762440E + 9^{d}.54 \times 10^{-11}E^{2}\,.$$

TABLE 5

RADIAL VELOCITIES OF SS CYGNI AT MINIMUM LIGHT

J.D ⊙ 2430000+	Phase* ($P=1$)	Radial Velocity (km sec⁻¹) Em	Abs	J D ⊙ 2430000+	Phase* ($P=1$)	Radial Velocity (km sec⁻¹) Em	Abs
0267 770	0 000	−106	+ 52	5029 833	0 509	+ 20	− 18
1309 944	653	− 76	+ 52	5029 844	549	− 74	+ 67
1310 774	658	− 52	+ 40	5030 639	426	+ 68	− 63
2098 661	787	−104	+110	5030 705	665	−127	+ 91
2098 724	015	− 75	+ 72	5030 755	846	−152	+130
2098 778	211	+ 73	− 93	5030 840	154	+104	− 84
2098 839	432	+ 95	−132	5316 769	201	+118	−110
2110 719	437	+ 69	−106	5316 810	349	+ 70	− 70
2110 795	712	− 89	+ 77	5316 848	487	− 23	+ 10
2111 837	484	+ 5	− 16	5316 881	606	−125	+ 88
5028 644	205	+108	−111	5316 915	.730	−114	+ 83
5028 770	661	− 81	+ 45	5316 958	885	− 54	+102
5028 837	903	−100	+ 82	5316 996	023	+ 32	− 12
5029 626	759	−168	+113	8962 851	748	−103	+102
5029 668	911	−148	+ 89	8962 882	860	−129	+147
5029 708	056	+ 36	− 44	9049 689	097	+ 35	− 49
5029 774	295	+ 87	−114	9049 754	332	+ 53	− 83
5029 804	0 404	+ 79	− 92	9241 974	0 159	+ 36	†

* Zero phase = J D ⊙ 2430267 770 + $0^{d}.2762440E + 9^{d}.54 \times 10^{-11} E^{2}$

† Absorption spectrum obliterated by continuous emission

TABLE 6

RADIAL VELOCITIES OF DOUBLE Ca II EMISSION IN SS CYGNI AT MINIMUM LIGHT

J D ⊙ 2430000+	Phase* ($P=1$)	Radial Velocity (km sec⁻¹) 1	2	Av
8962 851	0 748	−243	+ 63	− 90
8962 882	860	−368	+ 62	−153
9049 689	097	−136†	+347†	+105†
9049 754	0 332	−160†	+294†	+ 67†

* See Table 5 † Low weight

Phases, calculated from these elements, are given in Tables 5 and 6, and the velocity curve, based on the data in Table 5, is shown in Figure 2. In this figure the emission-line velocities are represented by open symbols, absorption-line velocities by filled symbols. The observations by Joy near J.D. 2432000 are indicated by triangles, while his observations near J.D. 2435000 are indicated by circles. The present observations, near J.D. 2439000, are indicated by squares. The same epoch as given by Joy has been retained, since, using the revised elements, this choice of epoch causes gamma velocity to occur at zero phase within the observational error. The curves in Figure 2 are sine curves

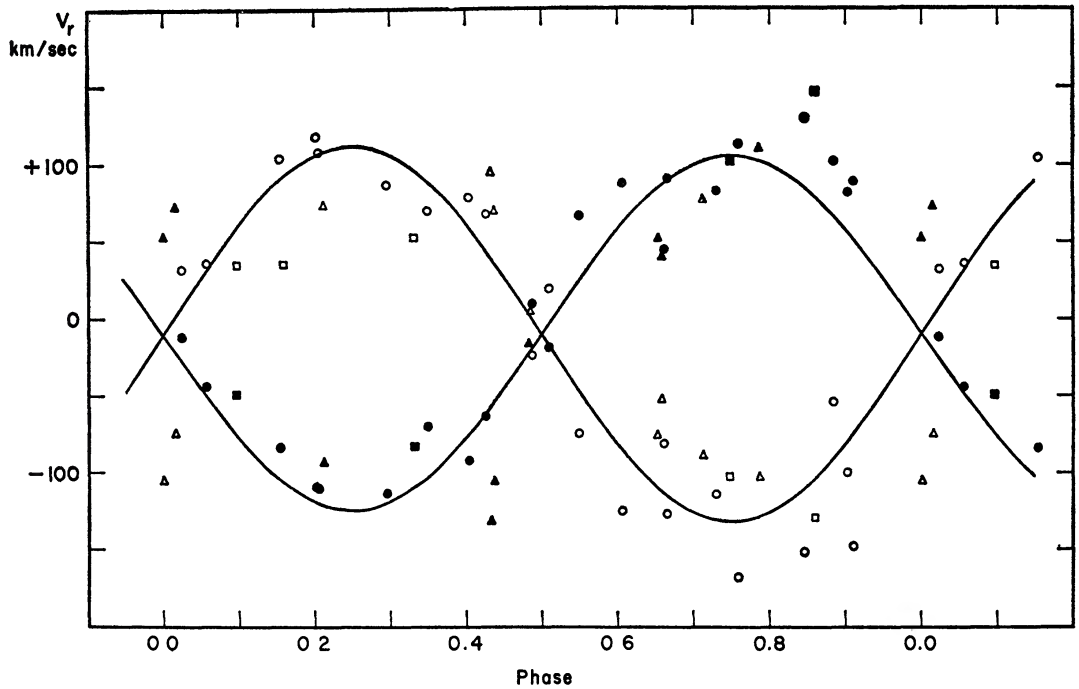

FIG. 2.—Velocity curve of SS Cyg *Ordinate:* radial velocity; *abscissa:* phase calculated from the formula zero phase = J.D.$_\odot$ 2430267 770 + $0^d.2762440E + 9^d.54 \times 10^{-11} E^2$ Emission-line velocities are represented by open symbols, absorption-line velocities by filled symbols Observations near J.D. 2432000 are indicated by triangles, near J D. 2435000 by circles, and near J.D 2439000 by squares. The curves correspond to the orbital elements derived by Joy.

corresponding to the elements derived by Joy: $K_1 = 115$ km sec^{-1} (absorption lines), $K_2 = 122$ km sec^{-1} (emission lines), $e = 0$, $\gamma = -9$ km sec^{-1}, $a_1 \sin i = 4.37 \times 10^5$ km, $a_2 \sin i = 4.63 \times 10^5$ km, $\mathfrak{M}_1 \sin^3 i = 0.20\, \mathfrak{M}_\odot$, $\mathfrak{M}_2 \sin^3 i = 0.18\, \mathfrak{M}_\odot$; the observational error is too large to permit any meaningful improvement in Joy's values. It will be noted that there is a slight tendency for the observations near J.D. 2432000 to lie to the right of the mean velocity curve. Thus the assumption of a uniform increase in the length of the period with time may not be exactly correct. However, the number and accuracy of the observations are not sufficient to permit a reliable determination of the variation of the rate of change of the period with time.

Using the formula given by Kraft (1963), the period change indicated by the above elements corresponds to a mass loss of $1.8 \times 10^{-7}\, \mathfrak{M}_\odot$ year^{-1}. According to Gaposchkin (1957), a U Gem star ejects about $10^{-9}\, \mathfrak{M}_\odot$ during each outburst. For SS Cyg, which experiences an outburst every 50 days on the average, this would amount to 7×10^{-9}

$\mathfrak{M}_\odot$ year^{-1}. Thus it would appear that the mass loss during the outbursts cannot explain the observed change in period, and, in view of the model of the system discussed below, we conclude that the observed change is due almost entirely to ejection of material from the system through the second Lagrangian point. The continual ejection of material from the system could eventually produce a circumstellar absorption cloud; the existence of such a cloud is suggested by the observed colors of SS Cyg (Grant and Abt 1959; Zuckermann 1962).

As mentioned earlier, Table 6 shows that the averages of the measured velocities of the two components of Ca II K-emission agree with the velocity curve for the other emission lines, so that this feature is associated with the hot star. Kraft (1962, 1963) has found double-emission lines in several U Gem variables and old novae and has postulated a model in which the late-type star fills its lobe of the inner Lagrangian surface and ejects material into a disk rotating about the other component. The emission-line spectrum originates in the disk rather than in the hot component of the system, and when this disk is viewed edge-on, these lines appear doubled. In the case of SS Cyg, this model encounters two difficulties: (1) only the K-line shows the doubling; (2) despite a careful search, no eclipse has been detected (Grant 1955; Walker 1968), so that the line of sight must be considerably inclined to the plane of the orbit. The former effect could be due to the greater intrinsic widths of the hydrogen and neutral helium lines. The fact that doubling is observed when the inclination is considerably less than 90° would seem to indicate that in SS Cyg, in contrast to the other U Gem stars, the rotating material around the hot star is not confined to a thin disk but must rather occupy a ring or shell having an appreciable thickness perpendicular to the plane of the orbit.

If the double emission is due to a rotating ring or shell around the hot star, we would expect the radius of that shell to be approximately equal to the radius of the orbit of the hot star. Adopting the orbital elements derived by Joy, we may calculate the circulation radius of the shell from the formula

$$r \sin i = \frac{G \mathfrak{M}_2 \sin^3 i}{(v \sin i)^2}$$

(see Kraft 1963), where $v \sin i$ is given by half the separation of the emission peaks of the K-line. Giving double weight to the observations on July 21, the mean of the separations in Table 6 is 402 km sec^{-1}, so that $v \sin i = 201$ km sec^{-1}, from which $r \sin i = 5.9 \times 10^5$ km. This value is somewhat larger than the orbital radius of the hot star, $a_2 \sin i = 4.6 \times 10^5$ km. However, in view of the uncertainty in the observational data, this agreement is probably sufficiently good, and we may conclude that the observations are consistent with the model discussed above.

Whatever the exact nature of the source of the double Ca II emission, the observations indicate that it is not a stable configuration. The doubling is well shown only in the spectra of July 21. It is present, though much less easily visible, on the spectrograms taken on October 16 and is absent on the plate taken on April 22. Furthermore, a special search of that plate material indicates that it is not clearly shown on any of the spectrograms taken by Joy. Another indication of instability of this feature is the change in its appearance during the observations on October 16. On the first of the two spectrograms obtained that night, the violet component of the double was stronger than the red, while on the second plate they are more nearly equal. This change, as well as the general weakening of the effect on October 16, could be due in part to a change in the structure and visibility of the double emission with orbital phase similar to that found by Kraft (1962, 1963) in U Gem. Additional observations covering complete orbital periods of SS Cyg are clearly needed in order to investigate this phenomenon.

c) *Spectroscopic Changes Associated with the Rapid Light Variations*

As discussed earlier, simultaneous photometric and spectroscopic observations were obtained on two nights, July 21 and August 7, 1965 (U.T.). On August 7 the system was undergoing one of the 50-day outbursts, and these observations are discussed separately in the following section. The analysis of the simultaneous spectroscopic and photometric behavior at minimum light therefore rests only on the observations of July 21.

Inspection of the spectrograms obtained on July 21, reproduced at the top of Figure 1 (Plate 3), show that large changes in the intensity of the continuum occurred during

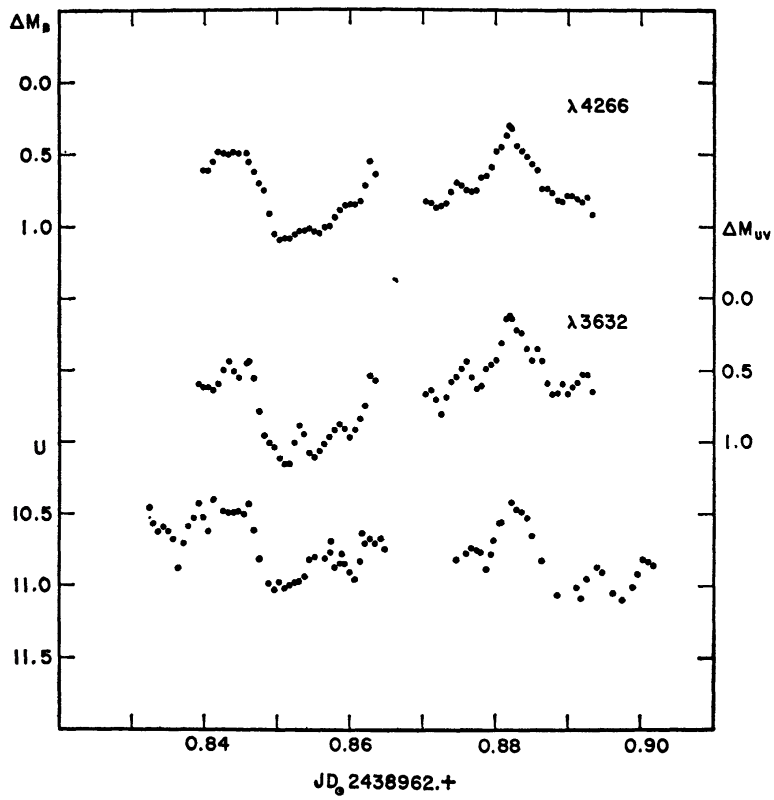

FIG. 3.—Observations of the rapid light variations of SS Cyg on July 21, 1965. The top and middle curves were derived from microphotometer scans of the spectra at the indicated wavelength. The bottom curve is the simultaneous photoelectric light curve Ordinate of the top and middle curves is arbitrary magnitude corrected for extinction; of the bottom curve, *U* magnitude. Abscissa is heliocentric Julian date.

the observations. In order to compare these with the photoelectric observations, microphotometer scans were made perpendicular to the direction of dispersion at several wavelengths. The microphotometer was operated as a densitometer, so that the resulting tracings were in arbitrary intensity units, owing to the linear relationship on plates taken with the electronic camera between number of incident photoelectrons and specular plate density (Frieser and Klein 1958; Frieser, Klein, and Zeitler 1959; Vernier 1959; Méallet 1961; Duchesne and Méallet 1962; Valentine 1966; Kron and Papiashvili 1967; Kron 1968; Walker 1968). Measurements of two of these tracings, at 4266 and 3632 Å, corrected for extinction and converted to arbitrary magnitudes, are listed in Table 7 and are shown, together with the photoelectric observations in ultraviolet light, in

TABLE 7

SPECTROPHOTOMETRIC LIGHT VARIATIONS OF SS CYGNI

$JD_{\odot}$ 2438000+	Arbitrary mag. at: λ4266	λ3632	$JD_{\odot}$ 2438000+	Arbitrary mag. at: λ4266	λ3632
962.8392	---	+0.60	962.8635	+0.64	+0.57
.8398	+0.58	0.62	.8704	0.83	0.67
.8405	0.54	0.62	.8711	0.84	0.64
.8412	0.56	0.64	.8718	0.87	0.71
.8419	0.49	0.60	.8725	0.86	0.81
.8426	0.50	0.50	.8732	0.84	0.69
.8433	0.51	0.44	.8739	0.76	0.58
.8440	0.49	0.51	.8746	0.70	0.55
.8447	0.50	0.55	.8753	0.72	0.49
.8458	0.50	0.45	.8760	0.75	0.44
.8461	0.56	0.44	.8767	0.76	0.55
.8468	0.63	0.56	.8774	0.75	0.63
.8475	0.71	0.79	.8780	0.66	0.61
.8482	0.76	0.96	.8787	0.65	0.49
.8489	0.92	1.01	.8794	0.59	0.46
.8496	1.06	1.04	.8801	0.48	0.43
.8503	1.10	1.12	.8808	0.45	0.31
.8510	1.09	1.16	.8815	0.37	0.14
.8517	1.09	1.16	.8819	0.30	0.12
.8524	1.06	1.01	.8822	0.32	0.14
.8530	1.04	0.89	.8829	0.44	0.22
.8537	1.03	0.95	.8836	0.48	0.24
.8544	1.02	1.08	.8843	0.52	0.35
.8551	1.04	1.11	.8850	0.57	0.43
.8558	1.05	1.07	.8857	0.61	0.35
.8565	1.01	1.02	.8864	0.74	0.43
.8572	1.00	0.97	.8871	0.74	0.59
.8579	0.94	0.92	.8878	0.77	0.67
.8586	0.89	0.88	.8885	0.82	0.66
.8593	0.86	0.91	.8892	0.83	0.60
.8600	0.85	0.97	.8899	0.79	0.67
.8607	0.85	0.92	.8905	0.79	0.62
.8614	0.83	0.84	.8912	0.81	0.59
.8621	0.72	0.75	.8919	0.83	0.53
962.8628	+0.55	+0.54	.8926	0.80	0.53
			962.8933	+0.92	+0.65

Figure 3. The agreement between the spectrophotometric and photoelectric observations is quite good, especially in view of the fact that the spectroscopic observations were made with a slit width of 0".8, while the size of the seeing disk during the observations was about 3". Fortunately, the size of the seeing disk changed very little during the observations, slowly becoming slightly better toward the end; this improvement in seeing is probably responsible for the fact that the later maxima and minima appear brighter relative to the earlier ones in the spectrophotometric light curves than they do in the photoelectric one. Another difficulty in reducing the spectrophotometric light curves was the determination of the correct time scale. Since no time marks are available on the plates, it was only possible to assume that the midpoint of the single trail represented the time of mid-exposure. The points representing the beginning and end of the exposures are not well determined and were assumed to be given by the point at which the intensity had dropped to half its value near the end of the trail. As a result, small shifts can be expected between the locations of features on the spectrophotometric curves and the photoelectric light curve.

The light curves in Figure 3, together with additional spectrophotometric light curves in the emission lines not reproduced here, demonstrate clearly that in SS Cyg, unlike AE Aqr (Walker 1965, 1966), the rapid variations in light result exclusively from changes in the brightness of the continuum; except in the case of the "ultraviolet flares" discussed below, no detectable change in the strengths of the emission lines occurs. These observations thus confirm the result of Zuckermann (1962), who arrived at the same conclusion on the basis of three-color photoelectric observations.

The observations on July 21 are especially well suited for the determination of the difference in the energy distribution of the star at maximum and minimum of the rapid light variations, since at the beginning of these observations a relatively flat maximum occurs, followed by a relatively constant interval at minimum. Microphotometer tracings were therefore made at points on the spectrogram corresponding to J.D.$_\odot$ 2438962.8426 (maximum) and 2438962.8503 (minimum). The resulting intensity traces were reduced to no atmosphere and then corrected for the sensitivity functions of telescope, spectrograph, and photocathode by means of observations of the extremely hot star BD+28°4211, whose energy curve has been observed by Oke (1968) with a photoelectric scanner. The resulting values of the intensity (in wavelength units) are listed in the columns marked "1" and "2" of Table 8. The wavelengths given in this table are accurate only to ± 1 or ± 2 Å, and are adjusted to give the laboratory rather than the apparent wavelengths of the observed lines. In making these two tracings, the same microphotometer settings were used and the traces were made in rapid succession. Thus the tabulated intensities should be on the same (arbitrary) intensity scale and therefore directly comparable. Smooth curves drawn through these data are shown in Figure 4. Again, these curves show that the change from minimum to maximum is the result of a change in the intensity of the continuous emission; the strengths of the emission lines remain the same within the observational error. That the brightening is not due to a change in the G-type star is shown by the fact that the weak absorption lines tend to become still weaker during the maxima. Similar results were obtained from the observations on October 16, but the details of these measures have not been published here, since the changes in brightness are less pronounced and since there are no simultaneous photoelectric observations.

The brightening of the continuum radiation could result either from a change in the effective temperature of the hot component or from the turning on and off of another source of continuous emission. It is not possible to choose between these two alternatives on the basis of our present observations. If we suppose that another source of radiant energy is turned on, then we may derive its energy distribution by taking the differences

TABLE 8

SPECTROPHOTOMETRIC OBSERVATIONS OF SS CYGNI

Wavelength (A)	Intensity I(λ)* 1	2	3	4	Wavelength (A)	Intensity I(λ)* 1	2	3	4
4310	9.41	6.36	17.20	14.19	3995	11.05	6.77	19.61	20.65
4300	9.59	6.50	17.31	14.49	3990	11.67	6.52	19.20	20.30
4290	9.89	6.32	17.52	14.87	3985	12.91	8.05	18.40	19.08
4280	9.23	5.71	17.60	15.08	3980	15.40	10.60	17.32	17.51
4270	10.58	6.49	17.79	15.23	3975	21.72	15.09	14.99	15.00
4260	10.10	6.14	17.75	15.38	3973	---	---	13.27	14.04
4250	10.11	6.20	17.80	15.47	3970	24.09	19.42	14.54	14.46
4240	10.12	6.32	17.89	15.60	3968	24.10	18.30	---	---
4230	10.19	6.06	17.97	15.69	3967	---	17.45	14.26	---
4220	10.28	6.33	18.04	15.79	3966	---	17.48	14.45	15.60
4210	10.35	6.67	18.15	15.90	3965	23.00	16.13	14.86	15.60
4200	10.39	6.52	18.21	16.24	3964	---	---	---	15.15
4190	10.70	6.65	18.14	16.58	3960	18.48	11.49	17.10	17.02
4180	10.80	6.79	18.10	16.85	3955	13.91	8.50	18.40	18.60
4170	10.86	6.87	18.33	16.88	3950	12.18	7.32	19.44	19.59
4160	10.71	6.77	18.51	17.00	3945	11.85	6.84	19.94	20.10
4150	10.91	6.81	18.69	17.47	3943	---	---	19.67	---
4140	11.21	7.08	18.61	18.10	3940	12.48	7.30	18.18	19.62
4130	11.84	7.44	18.69	17.50	3939	---	---	17.82	19.43
4120	13.26	8.46	18.43	17.22	3938	12.88	8.16	17.90	---
4115	14.40	9.76	17.85	16.42	3937	13.11	8.76	18.24	---
4110	18.62	12.39	16.97	15.37	3936	13.37	9.18	18.60	---
4105	21.65	16.90	15.43	14.20	3935	13.60	9.51	18.77	---
4102	---	---	15.86	13.90	3934	13.67	9.51	18.89	20.50
4101	23.75	18.80	---	---	3933	13.55	9.36	19.00	---
4100	---	---	15.55	14.11	3932	13.42	8.95	19.00	---
4099	---	---	15.30	---	3931	13.51	9.14	18.79	---
4095	20.85	13.78	16.11	15.09	3930	13.77	9.36	18.42	---
4090	15.00	9.65	17.98	16.34	3929	13.77	9.12	18.26	---
4085	13.11	8.25	18.67	17.71	3928	13.73	---	18.17	18.95
4080	12.30	7.41	19.05	18.50	3927	13.49	---	18.31	---
4070	11.40	6.89	19.59	19.30	3926	13.23	---	19.07	---
4060	10.98	6.59	19.80	19.40	3925	12.80	7.46	19.94	---
4050	10.92	6.22	19.92	19.58	3923	---	---	---	20.60
4040	11.29	7.03	20.05	19.81	3920	11.93	6.85	19.84	20.56
4030	13.42	8.50	20.05	20.00	3915	11.87	6.81	19.70	20.20
4025	13.29	9.08	20.10	---	3910	12.18	7.24	19.12	19.96
4020	12.51	8.17	20.05	20.15	3905	12.84	7.83	18.42	19.10
4010	11.13	6.72	20.10	20.25	3900	14.24	9.26	16.90	17.99
4000	10.61	6.59	19.84	20.50	3895	18.10	12.50	14.81	16.23

* The times of the four intensity traces are (1) J D$_\odot$ 2438962.8426; (2) J D$_\odot$ 2438962.8503; (3) J D$_\odot$ 2438979.7482; (4) J D.$_\odot$ 2438980.0026. Traces 1 and 2 were made with the same microphotometer settings, so that the recorded intensities are on the same (arbitrary) system and are directly intercomparable.

TABLE 8 (continued)

Wavelength (A)	Intensity I(λ)* 1	2	3	4	Wavelength (A)	Intensity I(λ)* 1	2	3	4
3894	---	---	14.51	---	3780	15.01	9.30	16.30	18.59
3893	---	---	14.32	---	3776	---	---	14.02	---
3892	---	---	14.19	---	3775	16.98	11.11	13.85	16.93
3891	---	---	14.31	---	3774	---	---	13.82	---
3890	22.68	15.61	14.53	15.72	3773	---	---	13.90	---
3889	23.05	16.24	14.60	15.67	3772	---	---	13.95	---
3888	---	---	14.55	---	3771	---	---	13.92	---
3887	---	---	14.36	---	3770	18.47	12.32	13.70	16.07
3886	---	---	14.25	---	3769	---	---	13.47	16.00
3885	22.62	15.72	14.28	16.55	3768	18.55	12.45	13.32	---
3884	---	---	14.54	---	3767	---	---	13.31	---
3883	---	---	15.14	---	3766	---	---	13.61	---
3882	---	---	15.91	---	3765	18.30	11.77	13.85	16.85
3881	---	---	16.48	---	3761	---	---	14.65	17.49
3880	17.69	11.85	16.95	18.12	3760	16.46	10.71	14.42	---
3875	14.40	8.99	18.54	19.98	3757	16.24	10.48	14.01	---
3870	13.72	7.37	19.28	20.79	3755	16.35	10.67	13.30	16.02
3868	---	---	19.52	---	3753	---	---	13.33	---
3865	---	---	19.60	21.00	3750	18.35	12.21	13.91	17.00
3860	12.86	7.30	19.30	21.02	3745	18.42	11.99	13.55	---
3855	12.60	7.41	19.07	21.25	3740	18.09	11.41	13.19	16.48
3850	13.61	8.00	18.38	20.70	3738	---	11.40	---	---
3845	14.82	9.06	16.50	18.42	3735	18.10	11.69	13.00	---
3840	18.22	13.05	13.89	16.41	3730	18.18	12.30	12.95	16.17
3839	---	---	13.69	---	3725	---	---	13.20	---
3838	---	---	13.52	---	3720	18.41	11.44	12.31	16.10
3837	---	---	13.90	---	3715	---	11.98	12.40	---
3836	---	---	13.99	15.88	3710	18.72	12.60	12.28	16.36
3835	20.90	15.02	13.79	---	3705	---	---	11.89	---
3834	---	---	13.51	---	3700	18.98	13.37	12.13	16.62
3833	---	---	13.52	---	3695	---	---	12.15	---
3832	---	---	13.80	---	3690	19.01	12.66	11.73	16.62
3830	19.29	15.50	14.71	17.16	3680	18.90	12.50	11.65	16.37
3825	17.17	10.72	16.52	19.26	3670	13.01	12.36	11.83	15.95
3820	15.82	9.52	17.83	20.20	3660	13.08	12.30	11.87	16.00
3818	---	---	---	20.30	3650	13.09	12.39	11.74	15.82
3815	14.91	9.15	18.20	20.25	3640	13.11	12.13	11.78	15.91
3810	14.73	8.88	17.25	19.38	3630	13.08	11.85	11.82	15.91
3805	15.22	9.72	15.29	17.32	3620	13.02	11.72	11.80	15.75
3801	---	---	13.72	---	3610	12.94	11.58	11.75	15.82
3800	17.90	12.55	13.96	16.28	3600	12.72	11.07	11.58	16.17
3798	---	---	14.29	16.30	3590	12.75	10.61	11.67	16.17
3797	---	13.58	---	---	3580	12.53	10.44	11.57	16.29
3796	---	---	13.83	---	3570	12.40	9.85	11.51	16.32
3795	19.50	13.62	14.30	16.62	3560	---	---	11.57	16.39
3790	18.30	11.53	15.74	19.22	3550	---	---	11.50	---
3786	---	---	---	19.52	3540	---	---	11.30	---
3785	15.32	9.35	16.90	---	3530	---	---	11.27	---

in intensity as a function of wavelength between the energy curves for minimum and maximum. A plot of these differences is shown in Figure 5. The curved line represents the black-body curve for a temperature of 50000° K and is seen to fit the observed difference curve quite well, at least down to 3670 Å.

Inspection of the spectrograms obtained on July 21 reveals another phenomenon not observed in SS Cyg on the other nights or in any of the other rapid variables that have been observed. This is the occurrence of rapid "flares" having their maximum amplitude

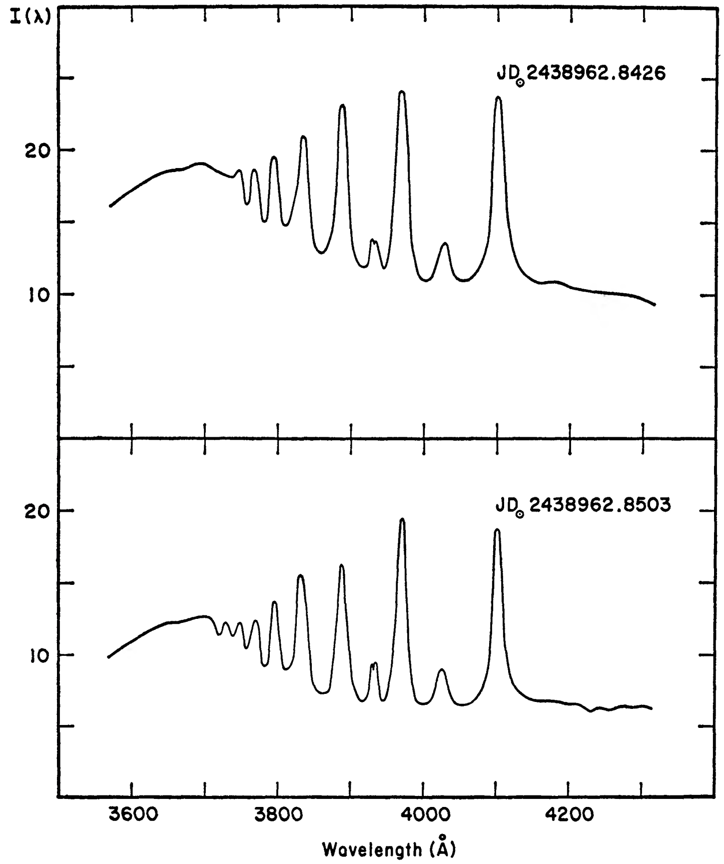

FIG. 4 —Energy curves of SS Cyg during a maximum (*top*) and a minimum (*bottom*) of the rapid light variations at minimum light. *Ordinate:* intensity per unit wavelength interval; *abscissa:* wavelength with the effect of the star's radial velocity removed. These two curves are on the same arbitrary intensity system, so that the curves are directly comparable.

in the far-ultraviolet and decreasing rapidly in intensity with increasing wavelength, becoming invisible—or nearly so—around 4100 or 4200 Å. The two best examples of these "ultraviolet flares" occur in the middle of the top spectrogram in Figure 1 at J.D.⊙ 2438962.8530 and following the brightest maximum in the middle of the second spectrogram at J.D.⊙ 2438962.8857. A third flare, occurring *immediately* after the strong light-maximum at J.D.⊙ 2438962.8822, causes that maximum to appear broader in the far-ultraviolet than in the blue. Unlike the other light variations, these flares are accompanied by a small increase in hydrogen emission intensity; little or no change in the intensity of the Ca II K-emission occurs.

The nature of these events is not clear. Since the observations were made with a slit spectrograph, there is always the possibility that the "flares" are the result of some transient atmospheric conditions that temporarily allowed more ultraviolet light to pass the slit. Two facts tend to support this interpretation: (1) The ultraviolet flares are not well shown in the photoelectric light curve. Flare 3 is probably shown, while flare 2 may have been missed because of an interruption to measure the sky. Flare 1, however, should appear on the U light curve and does not. The ultraviolet light curve is rather complex at the time of this first flare, and it is possible that this feature was lost in some smoothing process in the reduction of the observations. Unfortunately, this possibility cannot be investigated, as the original recorder sheet was lost in the course of the move from

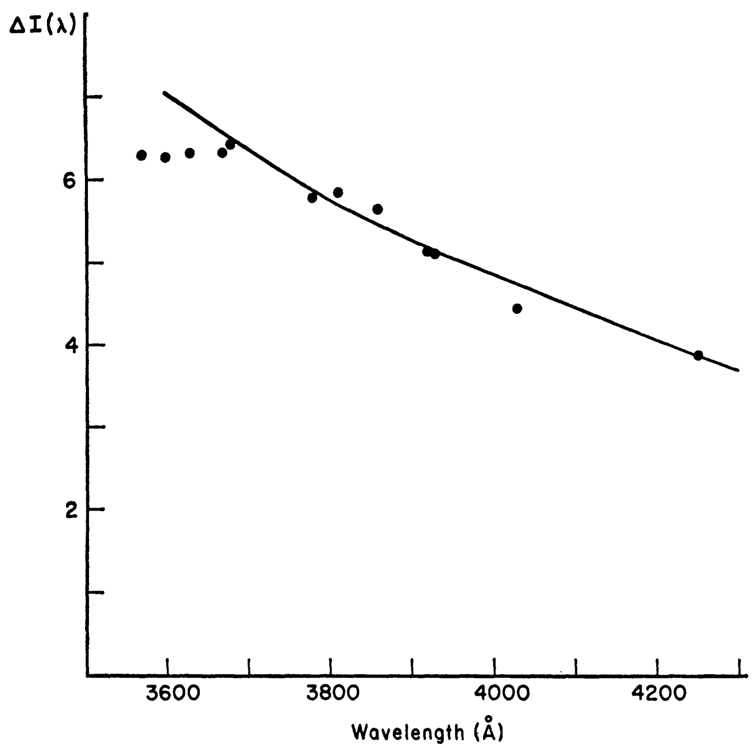

FIG 5.—Intensity difference between the two energy curves shown in Fig. 4

Mount Hamilton to Santa Cruz. (2) There is the same *percentage* increase in intensity during the flares in the emission lines plus continuum as there is in the nearby continuum. This is what we would expect if the "flare" were due to a variation in the amount of light entering the slit.

Against the atmospheric interpretation is the fact, discussed above, that the seeing conditions were relatively constant during the observations, and the fact that during these exposures the zenith distance of SS Cyg was $1.02 \leq \sec Z \leq 1.07$, so that the effects of differential light loss at the slit due to atmospheric dispersion should be negligible. Also, as stated above, similar observations of AE Aqr, covering a total interval of about 30 hours, show no events of this type, nor do observations of other rapid variables totaling 12 hours. Since most of these plates were taken under much less favorable conditions of seeing and zenith distance, we would expect them to show the same "ultraviolet flares" if these are of atmospheric origin. Many of the plates do show variations in plate density due to changes in seeing. These "normal" seeing effects produce intensity changes that are approximately constant in amplitude with wavelength. Such seeing effects are visible on the spectrogram of SS Cyg shown in Figure 7 (Plate 4), discussed in the following section. On this plate the seeing effects are difficult to trace out into the ultraviolet due to the strong intensity gradient from blue to ultraviolet and to the poorer focus of the ultraviolet end of the spectrum on this night.

The energy curve of the light of the first two ultraviolet flares discussed above has been derived from microphotometer traces perpendicular to the dispersion at a number

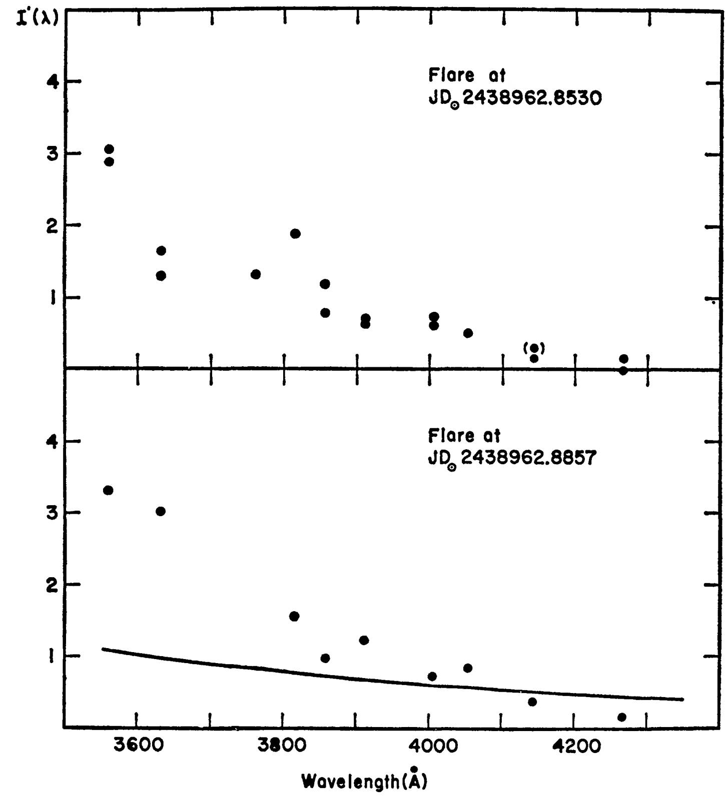

FIG. 6.—Energy curves of two of the "ultraviolet flares" observed in SS Cyg on July 21, 1965. *Ordinate:* intensity per unit wavelength interval in arbitrary units; *abscissa:* wavelength with the effect of the star's radial velocity removed. Two sets of measures of the flare at J.D.$_\odot$ 2438962.8530 are included in the figure, while the observations of the flare at J.D.$_\odot$ 2438962.8857 represent single measurements. The curve in the lower section of the figure is the energy curve of a black body of infinite temperature.

of different wavelengths between the emission lines. The energy of the flare at each wavelength was taken to be the peak of the maximum on the trace, referred to the interpolated level of "undisturbed" light before and after the flare. The results of these measurements, corrected for extinction and the sensitivity functions of telescope, spectrograph, and photocathode, are shown in Figure 6. It will be seen that if the flares are real, they represent some heretofore unknown phenomenon, since their rate of increase toward shorter wavelengths is too large to be accounted for by any known process. For comparison purposes, a curve representing the black-body distribution for infinite temperature is shown in the lower section of the figure.

Until it can be definitely established whether these flares result from some instrumen-

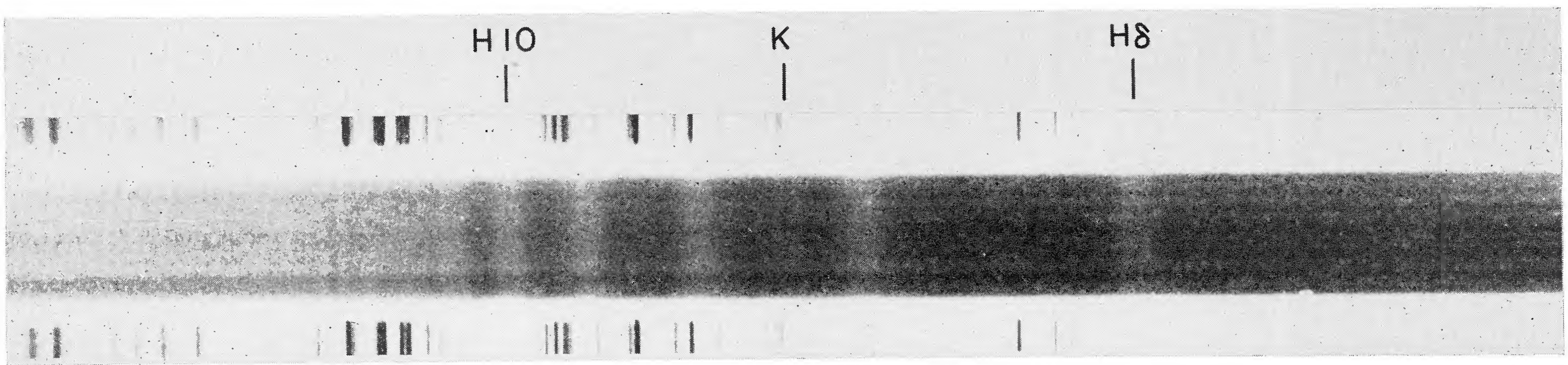

FIG. 7.—Single-trail spectrum of SS Cyg on August 7, 1965, during rising light of one of the 4-mag nova-like outbursts. Time increases uniformly from top to bottom of the spectrum. Time interval covered by this plate (ECL 371), 22 min.

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tal or seeing effect or originate in the star, speculation on their nature is useless. It is clear that single-trail spectrograms of SS Cyg should be taken using a wide slit or a "slitless" spectrograph in order to determine the reality of the phenomenon.

IV. OBSERVATIONS DURING RISING LIGHT

a) *Appearance of the Spectrum*

By chance, the observations on August 7, 1965, were made during rising light of one of the characteristic 4-mag outbursts of SS Cyg. Unfortunately, the exposure times (trailing rates) were incorrectly estimated, so that, except for plates ECL 371 and ECL 375B, the spectrograms are so heavily exposed that only radial-velocity measures were possible. Spectrogram ECL 371 is reproduced in Figure 7 (Plate 4). As in Figure 1, time increases linearly from top to bottom; the time interval covered by this spectrogram is 22

TABLE 9

RADIAL VELOCITIES OF SS CYGNI DURING RISING LIGHT

J D ⊙ 2438979+	PHASE* ($P=1$)	Absorption-Line Velocity: Hydrogen (km sec^{-1})	Ca II K (km sec^{-1}): 1	2	Av
0 763	0 969	− 16	−448	+417	− 15
823 .	186	+ 58	−309†	+480†	+ 86†
882 . .	.399	− 18	‡	‡	‡
951	649	−114	−511	+306	−102
0.990. . .	0 790	− 79	‡	‡	‡

* Zero phase = J D ⊙ 2430267 770 + 0ᵈ2762440E + 9ᵈ54 × 10^{-11} E^2

† Low weight; plate overexposed

‡ Invisible; plate overexposed

min. The spectrum has the appearance first described by Fleming (1912) and discussed in detail by Zuckermann (1962): an A-type absorption spectrum with central emission visible in the hydrogen lines. A feature of these spectra not previously reported is the doubling of the Ca II K-absorption line. As discussed earlier, these spectra show irregularities in density with time. These are not related to variations in the photoelectric light curve and are the result of changes in seeing during the observations; on this night the seeing disk varied constantly during the exposures from $1\frac{1}{2}''$ to $3''$ diameter.

b) *Radial-Velocity Measurements*

The values of the radial velocity measured on the plates taken August 7, 1965, are given in Table 9. For the hydrogen lines, only the velocity corresponding to the center of the line was measured. Both components of the K-line were measured wherever they were visible. Although the measurements are of low weight, due to the broadness of the features and the overexposure of most of the plates, we find that (1) the average of the velocities of the two components of the K-line agrees reasonably well with the hydrogen-line velocity for a given plate and (2) the velocities of the hydrogen absorption lines agree fairly well with the velocity curve of the emission lines at minimum light; these velocities have not, however, been included in Figure 2. The fact that the velocity curve matches that of the emission lines leads us to two important conclusions: (1) the nova-like outburst is associated with the hot star and not with the G-type component, as has been suggested by Bartaya (1966). (2) At least up until that phase of the outburst covered by these observations, no large outward motion of the photosphere had occurred; the dimensions of the system are so small that even a relatively small ejection velocity would carry the material beyond the radius of the orbit in only a few hours, after which time it would no longer display the orbital motion of the parent star. Judging by the slope of that portion of the light curve of the outburst obtained during the night of August 7, it would appear that the outburst probably began soon after the single photometric observation of SS Cyg made on the preceding night (see Tables 2–4). Thus any photospheric expansion velocity in excess of about 10 km sec^{-1} would have carried the material out to or beyond the radius of the orbit of the hot star by the time of our observations.

c) *Energy Curve*

Energy curves for SS Cyg were derived from plates ECL 371 and ECL 375B, using the same technique described above in § III*c*. In this case, however, the intensity scales for the two plates are unrelated. The measurements are listed in columns numbered "3" and "4" in Table 8, and smooth curves drawn through the observed points are reproduced in Figure 8. In comparing the two energy curves, it must be kept in mind that ECL 371 is a

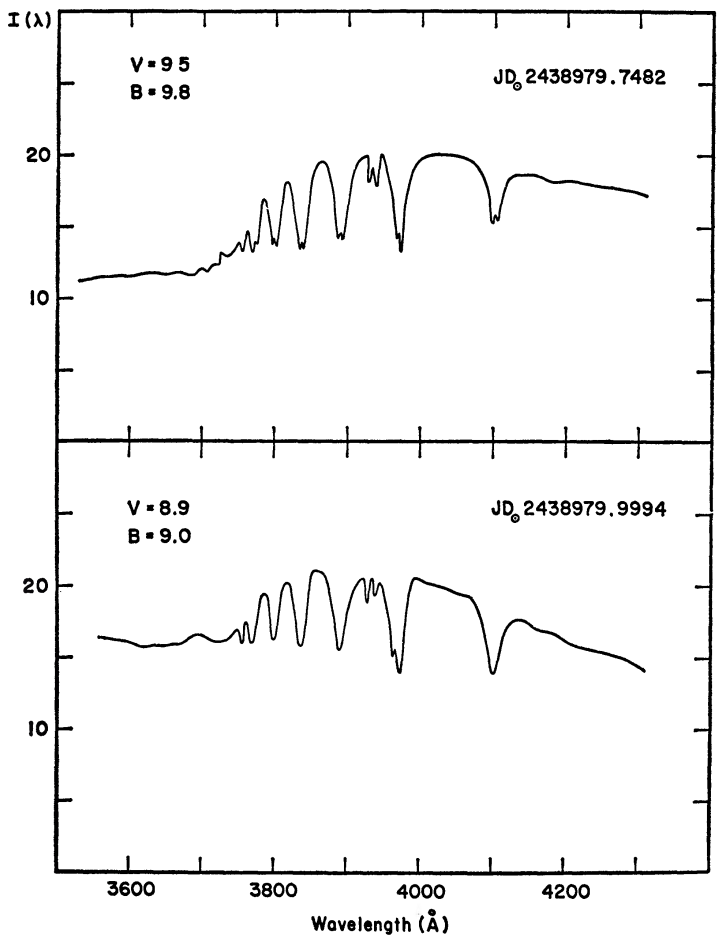

FIG. 8.—Energy curves of SS Cyg on August 7, 1965, during rise to maximum of one of the nova-like outbursts. *Ordinate:* intensity per unit wavelength interval in arbitrary, independent units; *abscissa:* wavelength with the effect of the star's radial velocity removed.

slit spectrogram, the slit width being 0″.8 and the seeing disk $1\frac{1}{2}''$–$3''$ in diameter during the observation, while ECL 375B was made with a slit width of 4″, as was the spectrogram of the standard star BD+28°4211, to avoid light losses at the slit. The tracings show that the emission cores in the center of the hydrogen lines, present on ECL 371, have disappeared on ECL 375B. The magnitude of these cores and their disappearance on ECL 375B are consistent with the interpretation that they represent the emission features present at minimum light and that the intensity of these lines did not change as the system brightened. A similar result was obtained earlier by Elvey and Babcock (1943). The two energy curves show a change in slope with time that is consistent with an increase in temperature as the system brightened. The change in $B - V$ during the interval of these observations confirms an increase in effective temperature, but a portion of the change in the energy curves could result from the different slit widths used. Hinderer (1948) found a gradient at maximum corresponding to a temperature of 15000° K. On ECL 371, the continuum gradient between 4000 and 4300 Å is fairly consistent with such a temperature, but on ECL 375B, it is not. Here, the slope between 4000 and 4300 Å corresponds to a black body of almost infinite temperature. However, the wavelength range involved is very short, and over this range the slope may very well depart from the true thermal gradient, so that it is not clear how much significance can be attached to this result; energy curves covering a large wavelength range would clearly be very desirable.

The energy curves show clearly the doubling of the K-absorption line and an irregularity in the profile of Hϵ which is most probably due to the presence of a double Ca II H-line. It will be seen from Tables 6 and 9 that the velocity separation of the two components of the K-line is much greater for the double-absorption feature seen during rising light than for the double emission visible at minimum. The most reasonable interpretation of the double K-absorption line would appear to be that it is a single absorption feature with a very strong emission core. However, it is not clear why the outburst of the system should trigger an intense emission only of Ca II and of no other atoms or ions.

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