THE LIGHT VARIATIONS OF THE TRIPLE SYSTEM HD 165590

G. A. Bakos
Department of Physics, University of Waterloo, Waterloo, Ontario, Canada

J. Tremko
Astronomical Institute, Slovak Academy of Sciences, Skalnaté Pleso Observatory, 059 60 Tatranská Lomnica, Czechoslovakia

Received 8 September 1983

ABSTRACT. Photometric observations of HD 165590 extending over a period of six years have shown that the eclipsing system undergoes systematic light variations in the form of flares and short time- and long time-scale changes. An attempt has been made to analyse and to interprete these changes.

ИЗМЕНЕНИЯ БЛЕСКА ТРОЙНОЙ СИСТЕМЫ HD 165590. Фотометрические наблюдения HD 165590 получены на протяжении шести лет показали, что затменная переменная в системе показывает систематические изменения блеска в форме вспышек и изменений в коротковременной и долговременной шкале. Сделана попытка объяснить изменения блеска.

ZMENY JASNOSTI TROJNÁSOBNEJ SÚSTAVY HD 165590. Fotometrické pozorovania HD 165590 získané v časovom intervale šesť rokov ukázali na prítomnosť zmien jasnosti v zákrytovej dvojhviezde, ktorá je zložkou sústavy. Pozorujú sa erupcie a zmeny jasnosti v krátkodobej i dlhodobej časovej škále. Skúmali sa možné príčiny svetelných zmien.

1. INTRODUCTION

Batten et al. (1979) have discussed some interesting properties of the triple system HD 165590 (ADS 11060). The visual companion has a high eccentricity (e=0.958) and a period of 20 years. The primary component was found to be a spectroscopic binary with a period of only 0.88 days. Scarfe (1977)

and the present authors, independently, found that the short-period pair is also an eclipsing binary. In addition to eclipses other features have shown that the system is quite young. Bakos and Tremko (1982) estimated the upper limit of its age at 1×10^9 years. Fekel (1981) studied the stability of the system and concluded that it is quite stable. Stern and Skumanich (1983) found that the primary component was a source of X-ray emission. The visual companion past through its periastron in June, 1978 at which time the separation between the components was only 0.4 A.U. Our observations, which cover the time interval before and after the perihelion passage, have not shown any observable change in the brightness of the system. However, large light variations were observed at other times which will be the subject of this investigation.

2. PHOTOMETRIC OBSERVATIONS

Photoelectric observations were conducted at both the University of Waterloo Observatory and at the Skalnaté Pleso Observatory between 1977 and 1983. A description of the instruments used and method of reduction were described in some of our earlier publications. The two-colour observations, in the B and V spectral bands, are in the instrumental system, however, they are quite close to the international B, V system. The variable was compared with the star HD 165570 (sp. type F0) and the star HD 166230 (101 Her, sp. A4) served as a check star. The original check star, HD 165569 turned out to be slightly variable with an amplitude 0.05 mag and a possible period of 36 days. Because of the closeness of the variable and its comparison star no correction for differential extinction was applied. The observations have been listed in Table 1 in which each entry represents the mean of five deflections measured on a strip chart. The mean error of this average is typically ± 0.005 mag. The successive columns in Table 1 are as follows: the heliocentric J.D., the magnitude difference, ΔV, in the visual pass band, the difference of the colour index, $\Delta(B-V)$, between the variable and the comparison star and in the last column, the phase. The phase was computed by means of the following formula:

$$\text{Phase} = (\text{J.D. hel.} - 244\,3656.6635) \times 1.137009\ d^{-1}$$

where the reciprocal corresponds to the improved period P = 0.8794998 days.

Table 1

Photoelectric Observations of HD 165590

J.D. hel	V	B-V	Phase	J.D. hel	V	B-V	Phase
244 3357.6810	-0.547	+0.247	0.0542	244 3357.6950	-0.548	+0.249	0.0701
.6881	.545	.241	.0622	3368.6562	.506	.238	.5331

Table 1 continued

J.D. hel	V	B-V	Phase
3368.6665	-0.506	+0.231	0.5448
.6756	.525	.243	.5537
3373.6834	.558	.214	.2490
.6956	.552	.217	.2562
.7011	.548	.235	.2704
3374.6675	.566	.256	.3680
.6767	.564	.250	.3784
.6875	.566	.254	.3907
3380.6848	.552	.234	.2097
.6948	.555	.228	.2211
.7044	.556	.229	.2320
3398.5787	.555	.227	.5552
.5880	.569	.240	.5658
.5981	.577	.243	.5773
3597.7769	.548	.238	.0454
.7908	.550	.236	.0612
.8116	.547	.238	.0848
.8255	.552	.246	.1006
.8485	.553	.248	.1268
.8602	.550	.246	.1401
3607.7324	.577	.232	.3649
.7484	.574	.231	.3831
.7679	.574	.232	.4052
.7818	.571	.233	.4210
3620.7472	.579	.239	.1628
.7688	.575	.225	.1874
.7910	.580	.226	.2126
.8056	.574	.238	.2292
3621.7736	.545	.239	.3298
.7882	.547	.240	.3464
.8070	.551	.238	.3678
3625.7413	.542	.228	.8411
.7559	.547	.238	.8577
3627.7525	.545	.231	.1279
.7650	.550	.224	.1421
3632.7327	.549	.247	.7904
.7409	.551	.243	.7997
3650.6828	.575	.232	.1998
.6953	.570	.229	.2141
3656.6628	.459	.221	.9992
.6719	.460	.220	.0095
.6809	.465	.218	.0197
.6920	.482	.224	.0324
3665.6575	.547	.229	.2264
3665.6665	-0.547	+0.229	0.2365
3682.6632	.510	.246	.5619
.6736	.545	.265	.5737
3684.6611	.547	.242	.8335
.6695	.545	.240	.8430
3696.6541	.538	.248	.4696
.6628	.522	.250	.4799
.6648	.494	.238	.4818
3701.6151	.540	.243	.1103
.6241	.545	.233	.1206
3949.8857	.550	.245	.3962
.8913	.550	.245	.4026
.9052	.545	.230	.4184
.9093	.545	.230	.4231
.9197	.545	.230	.4349
.9253	.546	.230	.4413
3981.7685	.556	.218	.6473
.7733	.559	.223	.6527
.7837	.560	.230	.6646
.7886	.558	.231	.6701
.8004	.556	.235	.6835
.8053	.556	.238	.6891
.8261	.556	.241	.7128
.8310	.552	.240	.7183
3984.8131	.530	.200	.1090
.8166	.529	.202	.1130
.8256	.534	.210	.1232
.8305	.534	.209	.1288
3998.7827	.490	.235	.9926
.7882	.488	.233	.9988
.7993	.506	.241	.0114
.8049	.512	.237	.0178
4010.7187	.549	.219	.5639
.7235	.550	.223	.5694
.7326	.552	.233	.5797
.7367	.553	.233	.5844
.7902	.559	.243	.6452
.7944	.565	.248	.6500
.8041	.570	.250	.6610
.8076	.570	.250	.6650
4011.7319	.549	.211	.7159
.7360	.552	.214	.7206
.7444	.556	.216	.7301
.7485	.555	.215	.7348

Table 1 continued

J.D. hel	V	B-V	Phase
244 4011.7615	.566	.222	.7498
4012.7159	.576	.225	.8347
.7270	.573	.228	.8474
.7312	.573	.231	.8521
.7492	.570	.245	.8726
4037.7076	.553	.255	.2505
4040.6624	.568	.258	.6102
.6652	.573	.251	.6133
.6770	.649	.224	.6268
.6798	.637	.206	.6299
.6944	.600	.225	.6465
.6971	.589	.221	.6496
.7083	.566	.232	.6624
.7117	.551	.224	.6662
4043.6777	.553	.252	.0386
.6881	.557	.240	.0504
.6916	.552	.232	.0544
.7013	.561	.229	.0654
.7041	.565	.230	.0686
4044.6771	.576	.274	.1749
.6799	.574	.270	.1781
.6910	.562	.255	.1907
.6931	.560	.252	.1931
.7077	.546	.233	.2097
.7111	.543	.230	.2136
4050.6174	.563	.243	.9291
.6223	.562	.237	.9347
.6348	.565	.240	.9489
.6389	.564	.239	.9535
.6493	.552	.227	.9654
.6660	.508	.221	.9843
.6709	.500	.226	.9892
.6806	.495	.241	.0009
.6841	.502	.247	.0049
.6959	.531	.239	.0183
.7007	.533	.223	.0238
.7098	.560	.215	.0341
.7139	.560	.209	.0388
.7334	.546	.236	.0610
.7354	.546	.236	.0633
.7452	.539	.235	.0744
.7486	.531	.231	.0783
.7625	.526	.216	.0941
.7667	.525	.215	.0988
.7771	.536	.226	.1107

J.D. hel	V	B-V	Phase
244 4050.7806	-0.543	+0.227	0.1146
4061.6048	.555	.231	.4219
.6083	.552	.227	.4258
.6215	.555	.230	.4409
.6235	.556	.231	.4431
.6333	.558	.232	.4543
.6360	.560	.236	.4573
.6465	.560	.232	.4693
.6506	.560	.233	.4739
.6583	.559	.231	.4827
.6617	.560	.230	.4866
.6722	.582	.252	.4985
.6749	.590	.260	.5016
.7006	.594	.229	.5308
.7048	.595	.230	.5356
.7145	.583	.218	.5460
.7187	.574	.211	.5514
.7312	.555	.200	.5656
.7353	.555	.200	.5702
.7458	.576	.212	.5822
.7485	.575	.211	.5853
.7610	.575	.220	.5995
.7645	.575	.220	.6034
.7749	.571	.221	.6161
.7791	.590	.238	.6200
.7888	.601	.226	.6311
.7930	.602	.225	.6358
4364.7264	.578	.253	.0738
.7389	.575	.250	.0881
.7556	.573	.258	.1071
.7834	.570	.245	.1387
.7959	.568	.238	.1529
.8090	.565	.239	.1678
.8257	.562	.242	.1868
4375.6984	.559	.258	.5491
.7123	.576	.280	.5649
.7297	.608	.381	.5847
.7422	.608	.258	.5989
.7554	.585	.259	.6139
.7727	.571	.246	.6336
.7866	.568	.254	.6494
.8019	.571	.255	.6668
.8144	.568	.252	.6810
4451.5922	.579	.252	.8410
.6033	.582	.251	.8537

Table 1 continued

J.D. hel	V	B-V	Phase
244 4451.6221	-0.578	+0.248	0.8750
.6325	.577	.249	.8869
.6422	.580	.262	.8979
.6540	.576	.249	.9113
.6672	.572	.244	.9263
.6887	.570	.238	.9508
.7019	.556	.241	.9658
.7123	.555	.251	.9776
.7248	.546	.250	.9902
.7380	.525	.242	.0068
4459.5891	.579	.250	.9336
.6002	.579	.234	.9462
.6176	.573	.246	.9660
.6280	.541	.233	.9778
.6384	.525	.241	.9896
.6530	.495	.210	.0062
.6648	.562	.216	.0197
.6780	.562	.210	.0347
.6891	.588	.261	.0473
.7037	.597	.248	.0639
4467.5727	.556	.243	.0110
.5825	.578	.238	.0222
.5929	.588	.235	.0340
.6095	.591	.221	.0529
.6193	.608	.218	.0640
.6304	.615	.235	.0766
.6408	.614	.246	.0884
.6505	.616	.232	.0995
4470.3141	.599	.287	.1280
.3331	.591	.275	.1496
.3511	.590	.282	.1701
.3659	.582	.294	.1869
.3841	.590	.277	.2076
.3999	.593	.282	.2256
.4167	.594	.275	.2447
.4358	.591	.276	.2664
.4551	.603	.260	.2883
.4712	.603	.260	.3066
4488.6069	.575	.251	.9271
.6173	.574	.256	.9389
.6312	.568	.258	.9547
.6694	.524	.236	.9982
4489.5359	.541	.206	.9834
.5505	.529	.225	.0000
.5651	.535	.231	.0166

J.D. hel	V	B-V	Phase
244 4489.5741	-0.570	+0.238	0.0268
.5845	.590	.250	.0386
.5970	.595	.244	.0528
4493.5405	.545	.245	.5363
.5516	.572	.234	.5493
.5641	.582	.247	.5635
.5766	.585	.229	.5777
.5953	.547	.247	.5989
4522.5371	.561	.246	.5060
.5475	.563	.247	.5179
.5545	.567	.248	.5258
.5670	.589	.269	.5400
.5725	.590	.275	.5463
.5822	.592	.228	.5573
7494.6179	.540	.233	.8644
.7085	.486	.202	.9674
.7283	.463	.217	.9899
.7443	.496	.209	.0081
.7582	.498	.230	.0239
.7728	.513	.239	.0405
.7866	.519	.229	.0562
.8005	.524	.235	.0720
4808.6960	.543	.233	.8713
.7265	.544	.236	.9060
.7383	.544	.233	.9194
.7508	.539	.225	.9336
.7668	.540	.229	.9518
.7779	.531	.236	.9644
4816.6124	.559	.245	.8723
.6326	.549	.239	.8953
.6465	.536	.241	.9111
.6590	.527	.225	.9253
.6756	.525	.225	.9442
.7013	.526	.244	.9734
.7166	.472	.228	.9908
.7291	.457	.202	.0050
.7423	.519	.236	.0200
4822.3705	.524	.279	.4193
.3797	.532	.285	.4298
.3888	.529	.297	.4401
.4004	.520	.276	.4533
.4225	.531	.271	.4784
.4326	.511	.282	.4899
.4433	.526	.277	.5021
.4550	.537	.279	.5154

Table 1 continued

J.D. hel	V	B-V	Phase
244 4822.4647	-0.538	+0.288	0.5264
4832.3613	.520	.251	.7789
5107.5376	.531	.294	.6569
.5466	.549	.299	.6671
.5556	.556	.273	.6776
5144.7460	.521	.227	.9632
5151.7060	.517	.216	.8767
.7254	.529	.221	.8988
.7305	.530	.229	.9046
.7450	.532	.215	.9211
.7569	.529	.216	.9346
.7631	.526	.214	.9410
.7798	.521	.217	.9606
.7847	.508	.213	.9662
.7937	.473	.228	.9765
.7999	.462	.231	.9835
.8103	.468	.224	.9953
5152.6701	.497	.232	.9729
.6946	.489	.226	.9990
.7027	.490	.230	.0100
.7090	.495	.232	.0172
.7189	.504	.233	.0284
.7252	.508	.239	.0356
5158.7545	.561	.228	.8909
5194.3224	.539	.303	.3320
.3326	.548	.298	.3436
.3510	.563	.285	.3510
.3544	.566	.285	.3684
.3750	.556	.275	.3750
.3787	.568	.295	.3960
.3967	.558	.287	.4164
.4017	.550	.281	.4017
.4202	.564	.298	.4432
.4247	.567	.285	.4483
.4419	.568	.286	.4678
.4454	.561	.298	.4718
.4628	.543	.283	.4916
.4662	.541	.283	.4955
.4822	.523	.266	.5137
.4853	.528	.243	.5172
.5022	.561	.262	.5364
.5057	.553	.224	.5404
5230.3607	.564	.283	.3078
5487.7920	.384	.256	.0095
.8024	.388	.246	.0214

J.D. hel	V	B-V	Phase
244 5487.8052	-0.393	+0.251	0.0246
.8080	.402	.251	.0277
.8094	.402	.255	.0293
5493.7609	.490	.222	.7963
.7762	.498	.237	.8136
.7915	.479	.232	.8310
5494.7300	.473	.257	.9470
.7950	.441	.242	.9720
.8012	.420	.239	.9791
.8110	.389	.240	.9902
5506.6985	.539	.222	.5064
.7173	.532	.227	.5278
.7395	.555	.230	.5530
.7513	.525	.208	.5664
.7647	.542	.222	.5817
.7777	.550	.222	.5964
5507.7180	.493	.230	.6656
.7319	.500	.230	.6814
.7527	.497	.246	.7050
.7662	.504	.249	.7204
5508.7073	.477	.249	.7905
.7245	.495	.253	.8099
.7454	.463	.270	.8338
.7579	.456	.258	.8480
.7711	.482	.241	.8630
5509.6995	.496	.257	.9185
.7161	.497	.268	.9375
.7374	.519	.275	.9617
.7541	.488	.279	.9806
.7763	.452	.244	.0059
5521.6924	.480	.215	.5546
.7068	.506	.272	.5710
.7294	.484	.254	.5967
.7429	.487	.247	.6120
5522.6790	.490	.230	.6764
.6943	.496	.216	.6938
.7151	.488	.241	.7174
.7290	.480	.228	.7332
.7470	.506	.228	.7537
5525.6636	.505	.235	.0699
.6798	.493	.253	.0768
5527.6508	.524	.205	.3294
.6747	.504	.242	.3565
.6952	.493	.208	.3798
5528.6386	.503	.284	.4525

Table 1 continued

J.D. hel	V	B-V	Phase	J.D. hel	V	B-V	Phase
244 5528.6539	-0.490	+0.259	0.4699	244 5549.6296	-0.479	+0.223	0.3195
.6775	.487	.255	.4967	.6449	.480	.231	.3368
.6914	.456	.254	.5125	.6643	.471	.231	.3589
.7122	.458	.231	.5362	.6810	.472	.222	.3779
5529.6414	.476	.220	.5927	5554.5988	.511	.234	.9695
.6567	.487	.230	.6101	.6224	.463	.237	.9963
.6806	.468	.223	.6373	.6405	.457	.259	.0169
.6952	.470	.227	.6539	.6558	.489	.219	.0343
.7206	.455	.215	.6827	.6738	.521	.252	.0548
5541.6160	.523	.247	.2079	.6891	.523	.254	.0721
.6304	.519	.244	.2243	.7086	.506	.217	.0943
.6521	.483	.221	.2490	.7178	.501	.236	.1048
.6656	.504	.250	.2643	5555.5900	.450	.249	.0965
.6834	.508	.258	.2846	.6030	.496	.249	.1113
.6966	.474	.232	.2983	.6238	.481	.232	.1349
5543.6063	.498	.239	.4709	.6388	.475	.229	.1520
.6229	.527	.241	.4898	5556.6015	.500	.240	.2466
.6438	.479	.232	.5135	.6168	.483	.247	.2640
.6563	.490	.242	.5278	.6418	.490	.266	.2924
				.6571	.495	.220	.3098

Observed epochs of primary minima have been listed in Table 1 of the quoted paper (Bakos and Tremko, 1982). In Table 2 below three more recent epochs are listed.

Table 2
Recent Epochs of Primary Minima of HD 165590

J.D. hel	E	O-C
244 5151.8097	1700	-0.0034
5554.6280	2158	+0.0040
5555.5863	2159	+0.0082

The first epoch is rather uncertain because the observations were terminated at that time. Otherwise the plot of the residuals (Fig.1a) has the tendency to become more positive with progressing cycles. Therefore a new value of the period using the program for period finding was derived. The individual observations of all primary minima were used. The new value of the period amounts to $0^d.915150$ which value had the highest variance when a step of 0.00001 was applied.

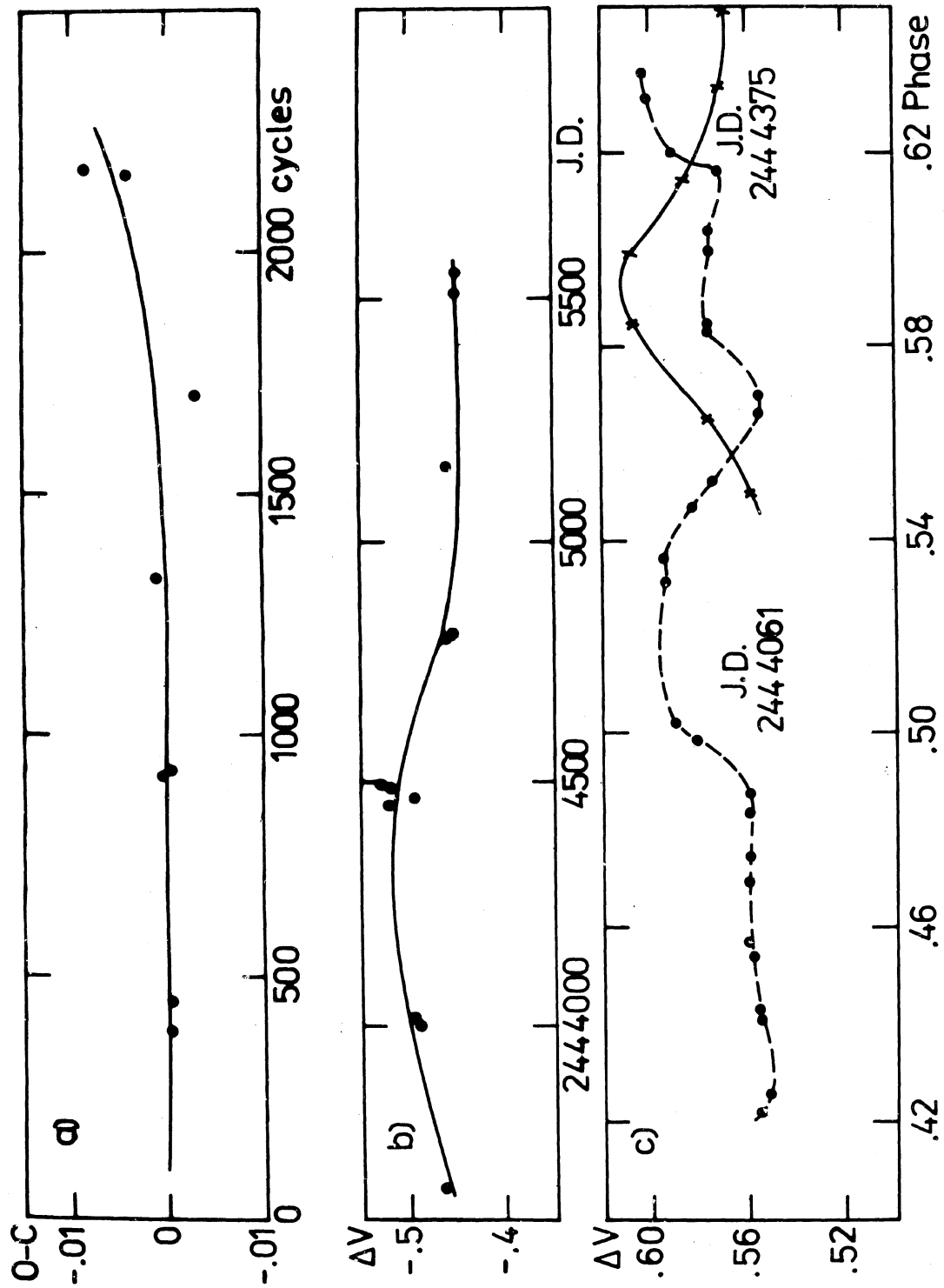

Fig. 1: a) A plot of the residuals, O-C, as a function of time, P=$0^{d}.8794998$.
b)Stellar activity measured in terms of the depth of the primary minima.
c)Two examples of flares in HD 165590. Dashed line on J.D. (244) 4061 and continuous line on J.D. 4375.

3. DISCUSSION

Variations of the light curve can be subdivided into the following three groups: a) Long time-scale variations, b) short time-scale variations and c) flares. In category a) the variations of brightness can be measured by the mean brightness of the system outside eclipses. It appears that the brightness of the system kept increasing from 1977 to 1980 (J.D. 4500) by at least 0.07 mag. Having reached its maximum the brightness declined the following year by 0.08 mag and remained steady until the present time (Fig. 1b). Synchronized with these changes were also the brightness of the primary minima as well as the depth of minima. With increasing brightness of the system the depth of minima decreased.

b) We tried to find the possible period of light changes in short time-scale. The whole set of observations was divided according to observational seasons and the period was searched in the limits between 1 and 100 days. The calculator EMG 666 was used and the program for the finding of periods was written by Dr. J.Zverko. Several periods with a significant variance were found but none of them persisted over the whole observational interval. The spurious period over 12 days appeared when observations only from one observatory were taken into account. It disappeared in sets combined from both observatories well separated in longitude. Some short term variations occured at time intervals of about 8 days as measured by the height of maxima of the light curve and the depth of minima. However, these changes are not well established because of scarcity of observations.

c) An important indicator of stellar activity are flares. The most spectacular flare in HD 165590 was described and plotted in our previous paper (Bakos and Tremko, 1982). The flare activity was most pronounced in the years 1979 and 1980 appearing at the time of the secondary minimum or soon after the minimum. In addition to the flare described in the above reference two more flares were observed. These have been plotted in Fig. 1c. Changes of the colour index during a flare were observed and correlated with the observed changes of brightness. At the height of a flare the star becomes much redder. It should be pointed out that because of the frequent flare activity the secondary minimum remained mostly unobserved. However, more recently, when the flare activity subsided three reasonably well defined secondary minima were observed /J.D. (244) 5194, 5521, 5528/. The depth of these minima is about 0.05 mag. This observation, of course, would cast some doubt in the adopted spectral type for the secondary star (Batten et al., 1979). If the depth of the secondary minimum is indeed 0.05 mag while that of the primary is 0.07 mag then the spectral types of the two stars differ but a little. The spectral type of the primary is G0 V. From the depths of the minima the secondary is expected to be of spectral type about G5 and not, as suggested by Batten et al. (1979) M1.

It seems to us that the flare activity of the system is localized on the G-type star and on the side averted from the companion. This activity has its

confirmation in the observed X-ray flux (Stern and Skumanich, 1983) since during primary eclipse the X-ray radiation is substantially lower. It would also indicate a non-uniform distribution of the X-ray flux over the surface of the G star.

The observed light variations are so complicated that a simple model of flare activity on the G star cannot explain them. We have to keep in mind the fact that we are dealing with a young system of stars in which non-stationary phenomena can be expected.

One of us (J.T.) would like to acknowledge the support received from the Natural Sciences and Engineering Research Council of Canada while he participated in the program of Exchange of scientists between Canada and Czechoslovakia, and the hospitality given to him at the University of Waterloo.

We would like to thank staff members of the stellar department of the Skalnaté Pleso Observatory for their activity in obtaining the photoelectric observations and Mrs. D.Petríková for the operation of EMG 666 calculator.

REFERENCES

Bakos, G. A., Tremko, J.: 1982, in Binary and Multiple Stars as Tracers of Stellar Evolution, ed. Z. Kopal and J. Rahe, Reidel Publ. Co., Dordrecht, 67.

Batten, A. H., Morley, C. L., Fekel, F. C., Tomkin, J.: 1979, Publ. Astron. Soc. Pacific 91, 304.

Fekel, F. C.: 1981, Astrophys. J. 246, 879.

Scarfe, C. D.: 1977, Inf. Bull. Var. Stars, Comm. 27 IAU, No. 1357.

Stern, R. A., Skumanich, A.: 1983, Astrophys. J. 267, 232.