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Astron. Astrophys. 270, 200–203 (1993)

ASTRONOMY AND ASTROPHYSICS

Research Note

Multicolour photometry of SS 433 during the monitoring campaign in May/June 1987

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Received January 23, accepted November 18, 1992

Abstract. An international multifrequency monitoring campaign on SS 433 was held in the spring of 1987. We present the results of multicolour photometry, as well as photographic and photoelectric V-band measurements. The broad-band optical luminosity generally conformed to the predicted (eclipsing) behaviour, but on May 24 and 25 a strong flare was observed.

Key words: SS 433 – binaries: eclipsing – stars: flare

1. Introduction

Photometric observations of SS 433 were obtained during the 1987 international monitoring campaign (see also Vermeulen et al. 1993a, b, c). Here we report on data taken by the Sternberg Institute at the observatories in Crimea, and by the Institute of Astrophysics of the Tadjik Academy of Sciences on Mount Sanglok in Central Asia. The campaign was planned near a time when the beams of SS 433 were closest to the line of sight; at JD 2446919.3, the Doppler shifted lines were predicted to reach their maximum wavelength separation (parameters from Margon and Anderson 1989). That is also the phase of the $\sim$164 day precession cycle when the optical brightness of the object is greatest. In the 13.081 day binary cycle, a primary photometric eclipse was predicted at JD 2446936.36 (parameters from Kemp et al. 1986).

2. The observations

In Crimea, photoelectric observations were only made on JD 2446945 (May 29/30), due to unfavourable weather. A.A. Aslanov obtained three V and R measurements with a single-channel photometer at the 60 cm reflector. The results are listed in Table 1.

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A total of twenty-four photographic observations were carried out in Crimea between JD 2446931 and JD 2446945 (May 15 to 29) using the 50 cm Maksutov photographic camera. The measurements were converted to standard V-band magnitudes through observations of the photographic V-band standard star in the field of SS 433; this procedure is described by Gladyshev et al. (1987). A systematic difference of 0.16 mag between the modern photoelectric system and the old photographic one was subtracted to obtain the values which are listed in Table 2. The photographic V-band magnitudes have an rms error of 0.1 mag.

Table 1. Photoelectric measurements from Crimea in the V and R bands

JD hel	V	(V−R)
2446945.485	13.81	2.09
.490	13.82	2.09
.496	13.86	2.11

On Mount Sanglok, multicolour photometry was obtained on six days in the period between JD 2446939 and JD 2446951 (May 23 to June 4) by V.Yu. Rakhimov, using the 1 m reflector with a single-channel photoelectric photometer. A set of standard photometric UBVRI filters was used. In addition, narrow band filters called H_α and H_α^{cont} were employed to monitor the "stationary" H_α line in the spectrum of SS 433. The properties of all filters are listed in Table 3. The H_α filter is the same as the S filter in the Vilnius photometric system (see for instance Straižys and Sviderskienė 1972; filter parameters are given by Straižys and Zdanavičius 1970). The red star labeled C5 by Goranskij (1986, 1987), which was later found to be a long period variable, was used as a control star for the accuracy of the atmospheric extinction curve at low elevations. Its photometric magnitudes are summarised in Table 4, along with those of star 1 of Kemp et al. (1981), which was called star C1 by Gladyshev et al. (1980),

Table 2. Photographic measurements in the V-band from Crimea. σ_m is the mean dispersion of the characteristic curve; however, the rms error of each measurement is 0.1 mag. t_{exp} is the exposure time in minutes

JD hel	V	σ_m	t_{exp}	JD hel	V	σ_m	t_{exp}	JD hel	V	σ_m	t_{exp}
2446931.451	13.78	0.10	6	2446936.471	14.54	0.05	14	2446937.514	14.08	0.07	15
33.420	13.82	0.04	10	37.351	14.27	0.02	15	.525	14.23	0.10	15
34.417	14.11	0.07	21	.369	14.37	0.08	15	41.402	13.51	0.07	22
35.385	14.27	0.04	15	.381	14.32	0.08	15	.523	13.49	0.05	20
.404	14.27	0.03	15	.397	14.20	0.05	15	42.455	14.03	0.02	15
.478	14.26	0.04	15	.453	14.12	0.03	15	43.517	14.19	0.02	15
.497	14.36	0.03	18	.471	14.07	0.02	20	44.499	13.95	0.06	10
.511	14.33	0.04	10	.498	14.12	0.03	16	45.521	13.74	0.08	15

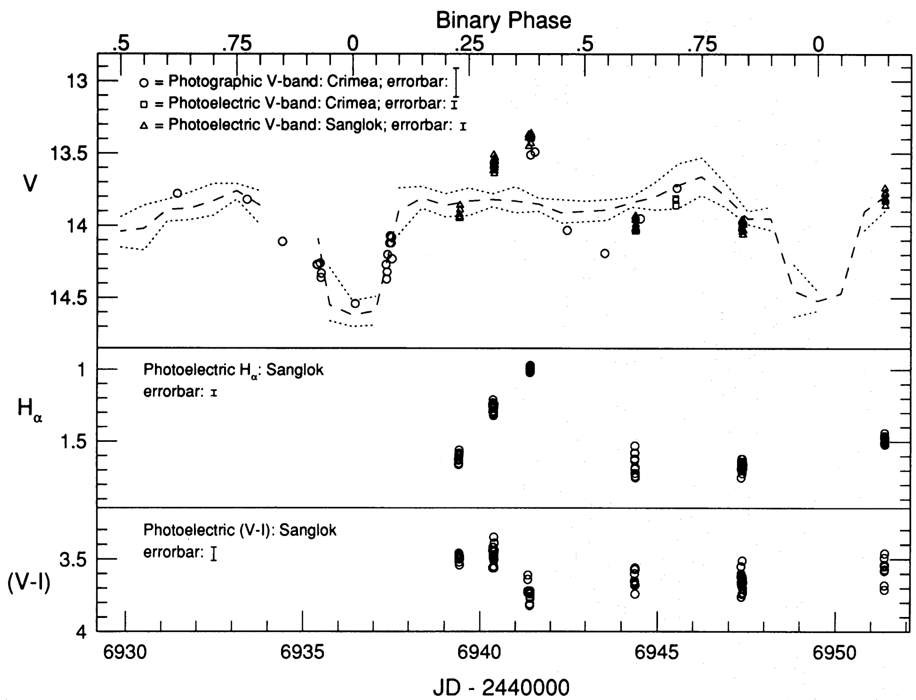

Fig. 1. Photometry showing some unusual behaviour of SS 433 during the international monitoring campaign in 1987. Top part: all V-band data from Tables 1, 2, and 5. Middle: the H_α data from Table 6. Bottom: the (V − I) data from Table 5. The $\pm 1\sigma$ error bar is shown for each data type. The top axis is labeled with the binary phase following the convention of Kemp et al. (1986). The dashed line through the V-band observations indicates the V-magnitude predicted by Gladyshev et al. (1987), and the dotted lines are the $\pm 1\sigma$ uncertainties of that prediction

Table 3. Mount Sanglok filter properties: the central wavelength, the transmission FWHM, and the rms error of an individual observation

	U	B	V	R	I	H_α	H_α^{cont}
$\langle\lambda\rangle$ (Å)	3680	4360	5520	6850	7700	6550	6370
FWHM (Å)	430	1020	820	1080	1040	200	30
rms (mag)	0.30	0.06	0.023	0.013	0.04	0.02	0.08

Table 4. Photometric magnitudes of the reference stars

	(U − B)	(B − V)	V	(V − R)
C1	1.19	1.46	11.42	1.34
C5	2.61	2.42	12.21*	2.12

*Varies from V=12.10 to V=12.24

and is the northernmost member of the diamond-shaped asterism near SS 433. Table 5 lists the UBVRI photometry obtained at Mount Sanglok. The measurements with the H_α and H_α^{cont} filters are given in Table 6. The latter are relative magnitudes compared to star C1. Note that Kemp et al. (1986) preferred a value V $\simeq$ 11.25 for star 1, but that some of their measurements also pointed to V $\simeq$ 11.45, closer to the value in Table 4. This discrepancy should be taken into account when comparing our results to the earlier data accumulated by Kemp et al. (1986).

3. Discussion

All V-band observations are displayed in Fig. 1. We also show the mean light curve of SS 433 with $\pm 1\sigma$ margins, for the precession phase of the present observations. These curves are based on the analysis of a large photometric database by Gladyshev et al. (1987), who showed that at this phase SS 433 is Algol-like, displaying deep wide primary eclipses and shallow secondary ones.

Figure 1 shows that on JD 2446940 and JD 2446941 there was a flare. At its peak, the V-band magnitude reached at least

Table 5. Photometric UBVRI data obtained at Mount Sanglok

JD hel	(U − B)	(B − V)	V	(V − R)	(V − I)
2446939.406	0.53	2.17	13.92	2.18	3.46
.408	0.77	2.13	13.94	2.19	3.50
.409	0.71	2.24	13.95	2.19	3.48
.411	0.77	2.21	13.94	2.18	3.50
.412	0.71	2.21	13.94	2.17	3.47
.418	0.78	2.16	13.94	2.19	3.52
.420	0.62	2.22	13.86	2.09	3.48
.421	0.64	2.21	13.89	2.15	3.49
.423	1.13	2.04	13.86	2.17	3.54
.424	0.64	2.18	13.86	2.12	3.50
40.351	1.04	2.11	13.62	2.23	3.56
.353	0.73	2.15	13.59	2.18	3.44
.354	1.00	2.10	13.55	2.15	3.44
.356	0.83	2.15	13.58	2.19	3.42
.357	0.83	2.12	13.56	2.19	3.56
.363	0.83	2.30	13.51	2.11	3.42
.364	1.16	2.11	13.56	2.20	3.49
.366	0.91	2.17	13.55	2.19	3.45
.367	0.91	2.13	13.54	2.14	3.48
.369	0.91	2.04	13.56	2.20	3.47
.380	0.99	2.12	13.64	2.24	3.48
.381	1.05	2.19	13.59	2.15	3.35
.383	0.85	2.16	13.62	2.19	3.55
.384	0.96	2.18	13.60	2.18	3.51
.386	0.95	2.06	13.62	2.20	3.47
.392	0.87	2.06	13.58	2.21	3.50
.394	0.95	2.20	13.56	2.18	3.45
.395	1.01	2.09	13.56	2.18	3.56
.397	0.92	2.18	13.55	2.17	3.39
.398	0.76	2.16	13.53	2.20	3.44
41.345	0.56	2.22	13.37	2.33	3.64
.346	0.97	2.17	13.39	2.35	3.72
.347	0.73	2.18	13.39	2.35	3.73
.348	0.74	2.25	13.37	2.27	3.64
.349	0.99	2.12	13.45	2.36	3.61
.401	0.80	2.17	13.38	2.34	3.74
.403	0.84	2.15	13.43	2.40	3.81
.404	0.70	2.19	13.40	2.36	3.82
.406	0.68	2.20	13.39	2.36	3.76
.407	0.84	2.07	13.43	2.38	3.81
.413	0.70	2.22	13.36	2.31	3.72
.414	0.90	2.13	13.38	2.34	3.74
.416	0.59	2.19	13.39	2.35	3.73
.418	0.89	2.21	13.38	2.37	3.77
.419	0.69	2.22	13.37	2.34	3.72
2446944.364	1.04	2.21	14.02	2.22	3.65
.366	0.42	2.29	13.93	2.20	3.60
.367	1.00	2.18	13.95	2.26	3.57
.369	0.80	2.20	13.96	2.24	3.67
.370	0.61	2.36	13.94	2.22	3.66
.375	0.84	2.14	14.01	2.12	3.56
.377	1.25	2.15	13.99	2.19	3.68
.378	1.16	2.24	14.04	2.20	3.57
.380	0.75	2.20	14.03	2.21	3.74
.381	0.96	2.30	14.02	2.17	3.57
47.348	0.53	2.34	13.97	2.22	3.62
.349	0.43	2.27	13.97	2.21	3.55
.351	0.91	2.16	13.96	2.23	3.66
.353	0.64	2.18	14.01	2.32	3.60
.354	0.82	2.17	13.96	2.29	3.61
.359	0.88	2.11	14.02	2.33	3.76
.360	0.91	2.04	13.99	2.25	3.68
.362	0.72	2.23	13.99	2.30	3.68
.364	0.78	2.17	13.99	2.27	3.63
.366	0.84	2.02	14.04	2.30	3.66
.380	0.55	2.18	14.06	2.36	3.74
.381	0.48	2.16	14.02	2.31	3.67
.383	0.18	2.09	13.96	2.26	3.51
.385	0.83	2.16	13.98	2.29	3.68
.386	0.88	2.15	13.96	2.29	3.62
.397	0.70	2.14	13.99	2.30	3.66
.399	0.67	2.11	14.06	2.38	3.73
.400	0.86	2.07	14.06	2.37	3.70
.402	0.67	2.18	14.03	2.33	3.64
.403	0.46	2.12	13.97	2.26	3.66
51.367	1.09	2.18	13.78	2.25	3.54
.369	0.55	2.17	13.78	2.24	3.54
.370	1.03	2.21	13.74	2.21	3.49
.374	0.68	2.16	13.77	2.22	3.58
.375	0.78	2.17	13.77	2.24	3.68
.378	1.06	2.23	13.78	2.21	3.55
.379	1.02	2.09	13.81	2.24	3.71
.381	0.95	2.24	13.83	2.30	3.46
.382	0.96	2.17	13.82	2.24	3.54
.384	1.36	2.16	13.86	2.29	3.57

13.4 mag, which exceeds the usual ("quiescent") level at that phase by about 0.4 mag. Note that the strongest observed flare of SS 433 reached ∼ 13.1 mag in the V-band on JD 2445553 (Kemp et al. 1986), and that only 12 of the 835 measurements presented by Kemp et al. (1986) exceed the brightness of the flare in our present dataset (we have taken V = 11.42 for star 1). The onset of the flare is constrained to fall between JD 2446939.4 and JD 2446940.4 . From the shape of the light curve, it appears that the data on JD 2446941.4 could well have been taken near the peak of the event. There is one measurement on JD 2446942 and one on JD 2446943. While these points probably confirm that the flare was over by then, it should be noted that those data were taken during the secondary eclipse, making it hard to distinguish between the end of the flare and the onset of the eclipse. Furthermore, Fig. 1 gives the impression that the secondary eclipse was unusually deep, but this conclusion again hinges on only a few data points.

Table 6. Narrow band photoelectric observations from Mount Sanglok. The magnitudes are relative to star C 1. H_α and H_α^{cont} are defined in the text

JD hel	H_α	H_α^{cont}	JD hel	H_α	H_α^{cont}	JD hel	H_α	H_α^{cont}	JD hel	H_α	H_α^{cont}
2446939.406	1.63	2.29	2446940.380	1.31	1.84	2446944.364	1.63	2.04	2446947.380	1.72	2.10
.408	1.62	2.19	.381	1.32	1.81	.366	1.58	2.15	.381	1.68	2.25
.409	1.66	2.26	.383	1.30	1.88	.367	1.62	2.10	.383	1.66	2.20
.411	1.65	2.21	.384	1.29	1.83	.369	1.53	2.27	.385	1.62	2.20
.412	1.60	2.17	.386	1.29	1.92	.370	1.58	2.21	.386	1.64	2.25
.418	1.62	2.17	.392	1.24	1.79	.375	1.69	2.27	.397	1.69	2.13
.420	1.59	2.20	.394	1.26	1.82	.377	1.72	2.30	.399	1.67	2.06
.421	1.58	2.22	.395	1.25	1.81	.378	1.68	2.28	.400	1.68	2.12
.423	1.56	2.16	.397	1.25	1.78	.380	1.74	2.28	.402	1.65	2.12
.424	1.58	2.20	.398	1.24	1.81	.381	1.75	2.35	.403	1.66	2.16
40.351	1.25	1.77	41.401	0.98	1.60	47.348	1.69	2.26	51.367	1.51	1.94
.353	1.25	1.76	.403	1.00	1.56	.349	1.75	2.16	.369	1.46	1.96
.354	1.24	1.81	.404	1.01	1.56	.351	1.64	2.15	.370	1.47	1.92
.356	1.25	1.84	.406	1.02	1.51	.353	1.64	2.20	.374	1.46	2.04
.357	1.29	1.80	.407	0.98	1.54	.354	1.66	2.17	.375	1.44	1.93
.363	1.24	1.83	.413	0.97	1.54	.359	1.65	2.26	.378	1.49	1.96
.364	1.21	1.78	.414	1.01	1.58	.360	1.70	2.16	.379	1.50	2.02
.366	1.23	1.80	.416	0.97	1.48	.362	1.62	2.26	.381	1.48	2.04
.367	1.27	1.82	.418	0.99	1.41	.364	1.67	2.25	.382	1.49	1.99
.369	1.25	1.77	.419	0.99	1.59	.366	1.70	2.29	.384	1.52	1.97

The flare was evident in all the filters; in the narrow band H_α filter, which is dominated by the stationary H_α line, its amplitude was 0.7 mag (see Fig. 1). This indicates that both the continuum and the stationary lines brightened during this flare. As an example of the behaviour in the other bands, Fig. 1 also shows the light curve in (V – I). This is the colour which exhibits the most pronounced changes from day to day (see Table 5), and yet even here it is difficult to ascertain their significance. It is possible that SS 433 was somewhat redder than usual at the peak of the optical flare; the largest amplitude of the flare was 0.76 mag in I, and 0.43 mag in B.

It is intriguing that the optical flare discussed here coincided to within a day with the first radio flare in a series monitored by Vermeulen et al. (1993a); these followed a relatively quiescent period. However, further similar coincidences would need to be observed before a physical relationship can be safely assumed to exist. Similarly, while extensive spectroscopic monitoring by Vermeulen et al. (1993b) reveals that a substantial reduction in the intensity of the moving spectral lines coincided to better than a day with the optical flare, other so-called switch-off episodes were not accompanied by an optical flare. It would be useful to obtain further simultaneous photometric, spectroscopic, and radio data of SS 433.

Acknowledgements. We are grateful for comments by Dr. R.T. Schilizzi on an earlier version of this paper. We thank the anonymous referee for some useful suggestions. RCV received support from NWO, the Netherlands Foundation for Scientific Research, through grant 782–373–030.

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