The orbital and superhump periods of the deeply eclipsing dwarf nova SDSS J150240.98+333423.9

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During 2009 July we observed the first confirmed superoutburst of the eclipsing dwarf nova SDSS J150240.98+333423.9 using CCD photometry. The outburst amplitude was at least 3.9 magnitudes and it lasted at least 16 days. Superhumps having up to 0.35 mags peak-to-peak amplitude were present during the outburst, thereby establishing it to be a member of the SU UMa family. The mean superhump period during the first 4 days of the outburst was P_{sh}= 0.06028(19)d, although it increased during the outburst with dP_{sh}/dt= +2.8(1.0)×10^{-4}. The orbital period was measured as P_{orb}= 0.05890946(5)d from times of eclipses measured during outburst and quiescence. Based on the mean superhump period, the superhump period excess was ε= 0.023(3). The FWHM eclipse duration declined from a maximum of 10.5 min at the peak of the outburst to 3.5 min later in the outburst. The eclipse depth increased from ~0.9 mag to 2.1 mag over the same period. Eclipses in quiescence were 2.7 min in duration and 2.8 mag deep.

Introduction

SDSS J150240.98+333423.9 (hereafter 'SDSS 1502') was first identified spectroscopically as a dwarf nova in the Sloan Digital Sky Survey (SDSS) database.[1] A deep doubling of its Balmer emission lines suggested that it was a high inclination system with the likelihood of eclipses. Follow-up photometry confirmed the presence of 2.5 mag deep eclipses.[1] Subsequently the orbital period was measured as 0.05890961(5)d (~84.8 min) and the mass ratio, q, of the secondary to the white dwarf primary was determined as 0.109, with the white dwarf having a mass of about 0.82 solar masses.[2]

The orbital period placed SDSS 1502 well below the so-called period gap in the distribution of orbital periods of dwarf novae, suggesting it was likely to be a member of the SU UMa family.

Outbursts of SDSS 1502

Figure 1 shows the lightcurve of SDSS 1502 between 2005 Mar 15 and 2009 Oct 10. Most of the data are from the Catalina Real-Time Transient Survey (CRTS),[3] supplemented with data from the authors. The lightcurve shows that at quiescence the star varied between mag 17 and 17.5 with a mean of 17.2, although clearly there were excursions to fainter magnitudes which presumably coincided with eclipses. At least two outbursts are apparent: one detected by CRTS in 2007 March reaching mag 14.1, and a further one in 2009 July reaching mag 13.3.

Time resolved photometry of the latter outburst is presented in this paper. It is interesting to note that CRTS did not cover this field during the 2009 July outburst, there being an observational gap between 2009 May 27 and July 31. Two further brightening events reaching mag 16.0 and 16.1 were detected, which may represent further outbursts. Other outbursts might have been missed due to incomplete observational coverage, so the 853-day interval between the two recorded main outbursts may be much longer than the actual outburst period.

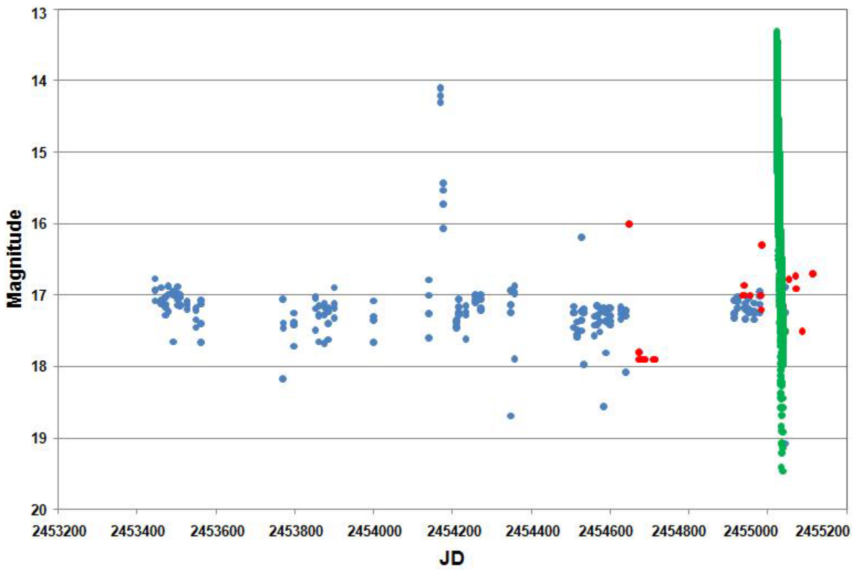


Figure 1. Lightcurve of SDSS 1502 between 2005 Mar 15 and 2009 Oct 10. Data sources: blue= CRTS, red= the authors (discrete measurements), green= the authors (time-series photometry from the 2009 July outburst as presented in Figure 2).

Table 1. Equipment used

Observer	*Telescope*	*CCD*	*Filter*
Campbell	0.3m SCT	SBIG ST-9XE	None
Foote	0.60m reflector	SBIG ST-8E	None
Garrett	0.35m SCT	SBIG ST10-XME	None
Hager	0.25m SCT	SBIG ST-9E	None
Julian	0.3m SCT	SBIG ST10XME	None
MDM telescope team	1.3m reflector	SITe 1024×1024 back illuminated detector[15][*]	Schott BG-38[17]
Masi	0.36m reflector	SBIG ST8-XME	None
Miller	0.35m SCT	Starlight Xpress SXVF-H16	None
Richmond	0.3m SCT	SBIG ST-8E	None
Ringwald	0.4m reflector	SBIG STL-11000M	None
Ruiz	0.4m SCT	SBIG ST-8XME	None
Sabo	0.43m reflector	SBIG STL-1001	None
Shears	0.1m refractor	Starlight Xpress SXV-M7	None
Stein	0.35m SCT	SBIG ST10XME	None

*except on JD 2454611 & 2454612 when STA0500A detector was used[16]

Photometry and analysis

The authors conducted photometry using the instrumentation shown in Table 1 and according to the observation log in Table 2. Most of the data from the 2009 July outburst were obtained at the observing stations of the Center for Backyard Astrophysics (CBA), a worldwide network of small telescopes. Data on eclipses at quiescence were obtained with the 1.3m MDM telescope on Kitt Peak. All images were dark-subtracted and flat-fielded prior to being measured using differential aperture photometry relative to the sequence in AAVSO chart 1432hli.[4] Heliocentric corrections were applied to all data.

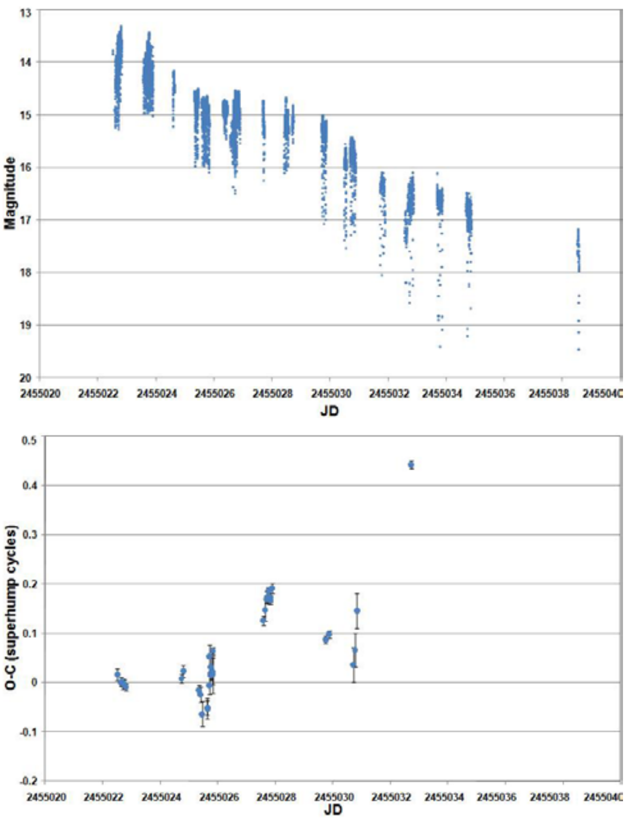


Figure 2. Lightcurve of the outburst (top) and O–C diagram of superhump maxima relative to the ephemeris in Equation 2 (bottom).

The 2009 July outburst

The outburst of SDSS 1502 discussed in this paper was detected by JS on 2009 July 9.949 at 13.7C (C, Clear, =unfiltered CCD).[5] The overall lightcurve of the outburst is shown in the top panel of Figure 2. The apparent scatter in the magnitudes is of course mainly due to the presence of eclipses. SDSS 1502 was observed to be at its brightest on discovery night at 13.3C, representing an amplitude of 3.9 magnitudes above mean quiescence. Sixteen days later the star was almost back at quiescence; the beginning of the outburst is not well constrained since the latest observation prior to the detection was on July 3.942 (<16.7C), some six days earlier. Considering the average magnitude outside eclipses, the brightness showed an approximately linear decline at 0.25 mag/d, although there is some evidence that there was a steeper decline near

Table 2. Log of time-series photometry

Start time (HJD)	*UT (dd:hh:mm:ss)*	*Duration (h)*	*Observer*
Photometry during the 2009 July outburst			
2455022.448	Jul 09:22:45:07.2	2.01	Shears
2455022.597	10:02:19:40.8	3.65	Richmond
2455022.662	10:03:63:16.8	4.10	Foote
2455022.678	10:04:16:19.2	2.35	Campbell
2455023.576	11:01:49:26.4	1.51	Ruiz
2455023.605	11:02:31:12.0	4.97	Garrett
2455023.680	11:04:19:12.0	3.72	Stein
2455023.705	11:04:55:12.0	4.94	Sabo
2455024.595	12:02:16:48.0	1.30	Ruiz
2455024.672	12:04:07:40.8	4.13	Stein
2455025.337	12:20:05:16.8	3.50	Masi
2455025.583	13:01:59:31.2	4.03	Richmond
2455025.631	13:03:08:38.4	5.35	Julian
2455025.657	13:03:46:04.8	4.22	Stein
2455025.738	13:05:42:43.2	3.86	Ringwald
2455026.314	13:19:32:09.6	3.94	Masi
2455026.574	14:01:46:33.6	4.27	Richmond
2455026.577	14:01:50:52.8	1.20	Hager
2455026.650	14:03:36:00.0	4.44	Stein
2455026.704	14:04:53:45.6	4.58	Ringwald
2455027.572	15:01:43:40.8	4.32	Richmond
2455027.678	15:04:16:19.2	5.16	Ringwald
2455027.717	15:05:12:28.8	3.14	Sabo
2455028.432	15:22:22:04.8	3.48	Miller
2455028.704	16:04:53:45.6	0.89	Sabo
2455029.715	17:05:09:36.0	4.13	Ringwald
2455030.493	17:23:49:55.2	2.02	Miller
2455030.689	18:04:32:09.6	4.68	Ringwald
2455031.725	19:05:24:00.0	4.08	Sabo
2455032.567	20:01:36:28.8	2.40	Richmond
2455032.683	20:04:23:31.2	4.70	Ringwald
2455033.685	21:04:26:24.0	4.54	Ringwald
2455034.690	22:04:33:36.0	4.32	Ringwald
2455038.530	26:00:43:12.0	1.13	Ruiz
2455081.358	Sep 06:20:35:31.2	1.06	Ruiz
Photometry during quiescence (1.3m MDM telescope)			
		Dur.(h)	
2453849.898	2006 Apr 24:09:33:07.2	2.62	
2453850.649	25:03:34:33.6	8.54	
2453851.648	26:03:33:07.2	8.64	
2453852.639	27:03:20:09.6	5.88	
2453876.651	May 21:03:37:26.4	1.22	
2454179.820	2007 Mar 20:07:40:48.0	4.97	
2454611.811	2008 May 25:07:27:50.4	3.24	
2454612.651	26:03:37:26.4	7.80	

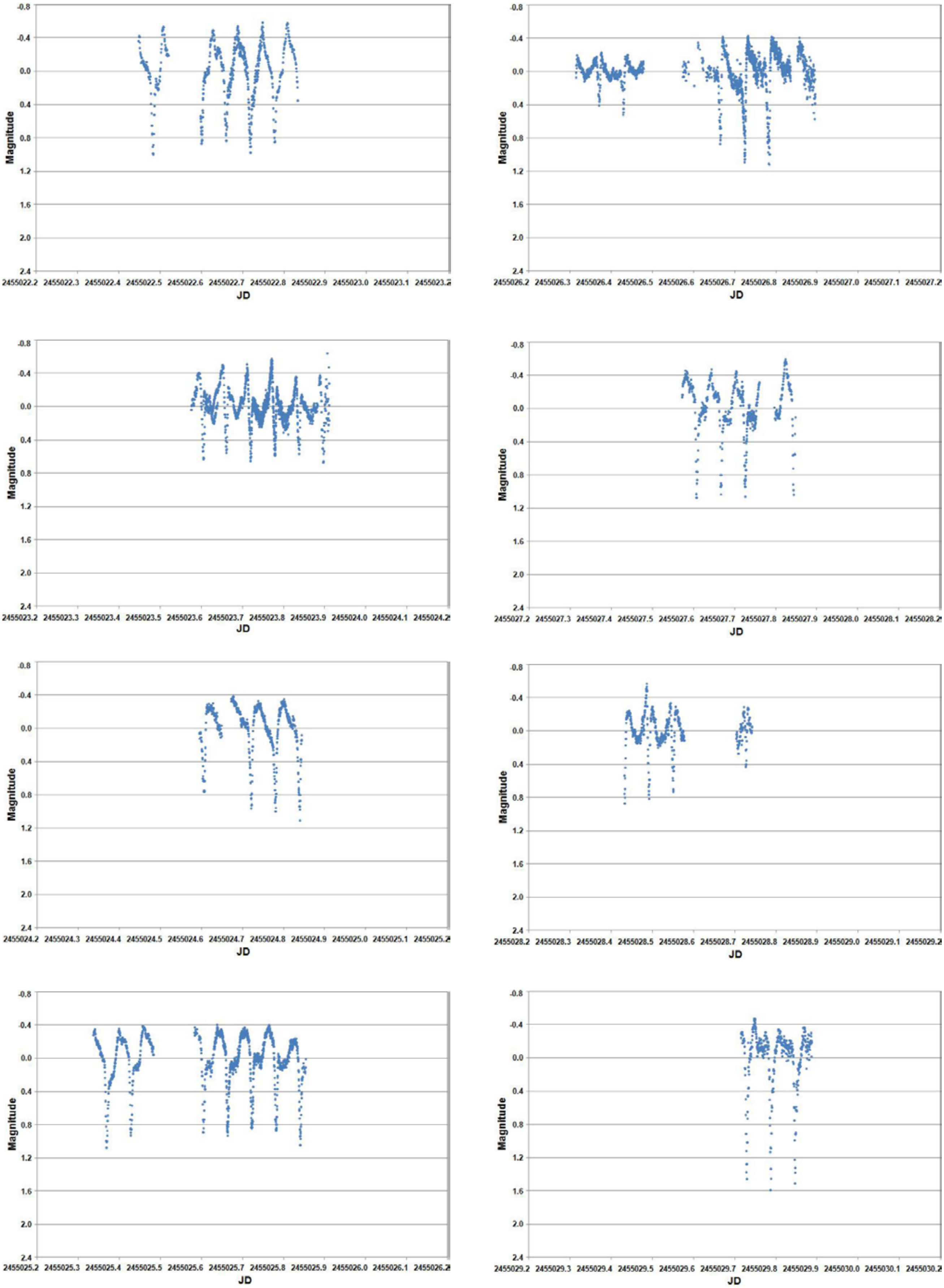
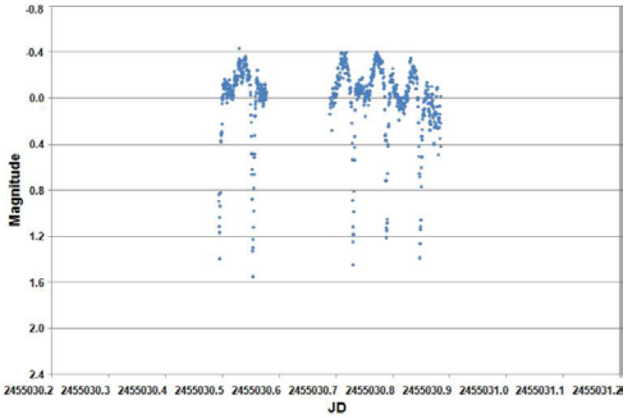
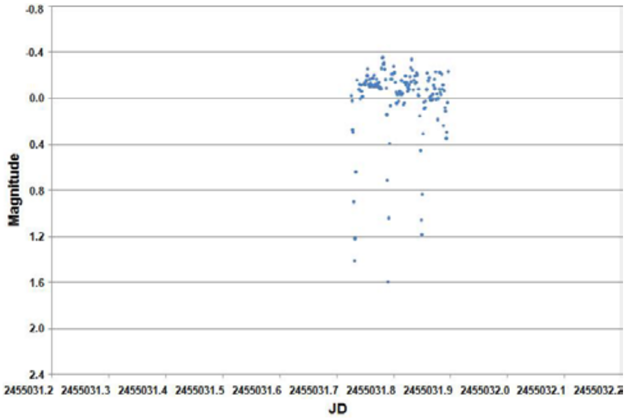


Figure 3. Time series photometry during the outburst of SDSS 1502 from 2009 July 9 to July 25, with each panel showing one day of data.





the beginning of the outburst (JD 2455022 to 2455025), followed by a plateau (JD 2455026 to 2455028) then a faster decline towards quiescence.

In Figure 3 we plot expanded views of the time series photometry, having subtracted the linear trend, where each panel shows one day of data drawn to the same scale. This clearly shows recurrent eclipses superimposed on an underlying superhump modulation, each of which will be considered in more detail later. The presence of superhumps is diagnostic that SDSS 1502 is a member of the SU UMa family of dwarf novae, making this the first confirmed superoutburst of the star.

Measurement of the orbital period

Times of minimum were measured for eclipses observed during the outburst using the 5-term Fourier fit in the *Minima* software package.[6] We supplemented these with times of minimum measured from quiescence photometry obtained using the 1.3m MDM telescope on Kitt Peak. Table 3 lists the times of minimum, where the 104 observed eclipses are labelled with the corresponding orbit number

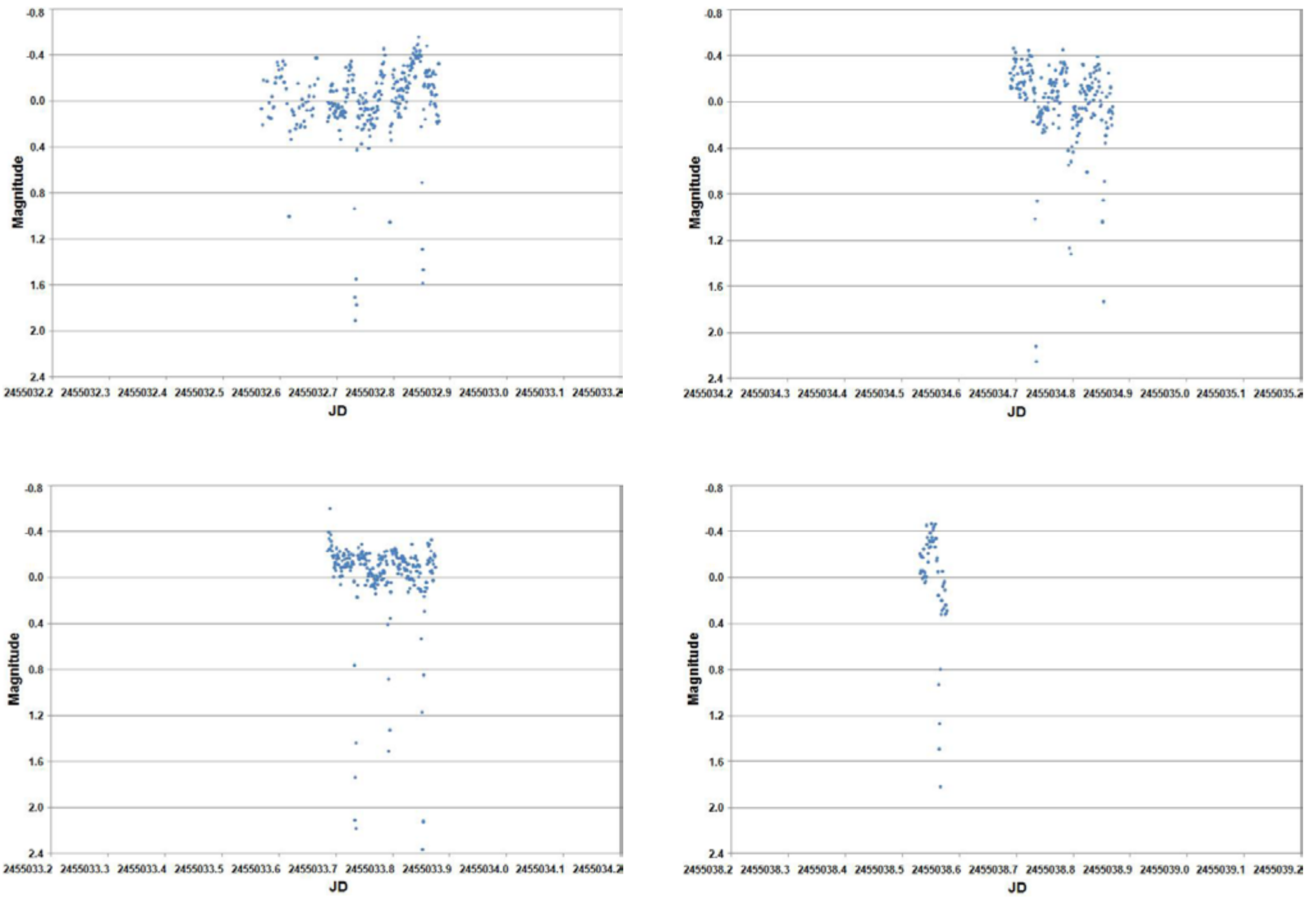


Figure 3 *(continued).* Time series photometry of the 2009 July outburst.

starting from 0. The orbital period was then calculated from a linear fit to these times of minima as P_{orb}= 0.05890946(5)d. The eclipse time of minimum ephemeris is:

$$HJD_{min} = 2453849.94908135(2) + 0.05890946(5) \times E$$ [Eqn 1]

The O–C (Observed–Calculated) residuals of the eclipse minima relative to this ephemeris are shown in Figure 4. This suggests that the period remained constant during the period of observations. However, we note that there is considerable scatter in the O–C values which were measured during the 2009 outburst of up to 0.02 cycles (~1.7 min). This is due to the difficulty in isolating eclipse minima relative to other large-scale changes in the lightcurve in the form of the underlying superhumps, and the fact that each eclipse was defined by rather few data points.

Our value of P_{orb} is consistent at the 2-sigma level with the one reported in reference 2, which was derived from observations obtained over a shorter period of time.

Table 3. Eclipse minimum times, depth and duration

Note: depth and duration were only measured during the outburst. ND= not determined

Orbital cycle no.	Eclipse minimum (HJD)	O–C (orbital cycles)	Error	Eclipse depth (mag)	Eclipse duration FWHM (m)
0	2453849.94908	–0.0001	0.0059		
1	2453850.00684	–0.0196	0.0016		
12	2453850.65615	0.0026	0.0020		
13	2453850.71498	0.0013	0.0018		
14	2453850.77384	0.0004	0.0035		
15	2453850.83284	0.0020	0.0021		
16	2453850.89165	0.0002	0.0023		
17	2453850.95066	0.0020	0.0022		
29	2453851.65760	0.0024	0.0024		
30	2453851.71630	–0.0012	0.0023		
32	2453851.83417	–0.0002	0.0028		
33	2453851.89333	0.0040	0.0023		
34	2453851.95249	0.0083	0.0023		
46	2453852.65899	0.0013	0.0031		
47	2453852.71800	0.0029	0.0026		
48	2453852.77661	–0.0021	0.0018		
49	2453852.83568	0.0006	0.0023		
454	2453876.69411	0.0023	0.0007		
5600	2454179.84201	–0.0008	0.0016		
5601	2454179.90009	–0.0149	0.0016		
5603	2454180.01900	0.0036	0.0019		
12933	2454611.82513	0.0000	0.0020		
12934	2454611.88410	0.0010	0.0020		
12935	2454611.94324	0.0050	0.0029		
12948	2454612.70875	–0.0003	0.0032		
12949	2454612.76794	0.0043	0.0020		
12950	2454612.82684	0.0043	0.0030		
12951	2454612.88550	0.0000	0.0021		
12952	2454612.94455	0.0023	0.0045		
19904	2455022.48416	0.0202	0.0008	0.93	10.50
19906	2455022.60181	0.0173	0.0043	0.93	10.40
19907	2455022.66054	0.0143	0.0040	0.94	10.35
19908	2455022.71933	0.0123	0.0026	0.95	10.35
19908	2455022.71925	0.0109	0.0063	0.96	9.90
19908	2455022.71904	0.0073	0.0037	0.94	10.35
19909	2455022.77860	0.0183	0.0053	0.92	9.60
19923	2455023.60296	0.0121	0.0034	0.89	8.25
19924	2455023.66137	0.0035	0.0047	0.93	9.75
19925	2455023.72090	0.0141	0.0016	0.94	10.50
19925	2455023.72081	0.0125	0.0068	0.93	9.60
19926	2455023.77969	0.0121	0.0037	1.00	9.75
19926	2455023.77951	0.0089	0.0032	0.99	10.05
19926	2455023.77946	0.0081	0.0035	0.98	9.60
19927	2455023.83812	0.0039	0.0024	0.82	9.30
19928	2455023.89723	0.0073	0.0090	0.85	9.75
19940	2455024.60310	–0.0104	0.0085	0.87	10.35
19942	2455024.72186	0.0056	0.0057	1.08	10.35
19943	2455024.78086	0.0072	0.0038	1.10	9.60
19944	2455024.83943	0.0014	0.0052	1.13	9.75
19953	2455025.37019	0.0111	0.0043	0.98	8.85
19954	2455025.42911	0.0113	0.0028	0.96	8.40

Measurement of the superhump period

Analysis of the superhumps was complicated by the presence of the eclipses, which often distorted the shape of the superhumps. The peak-to-peak superhump amplitude was ~0.35 mag on the first night (JD 2455022), declining to ~0.2 mag on 2455026 and subsequently increasing again gradually until the final night of time series photometry (JD 2455038) when the amplitude was 0.2 mag.

To study the superhump behaviour, we first extracted the times of each sufficiently well-defined superhump maximum by fitting a quadratic function to the individual light curves. We omitted superhumps whose maxima coincided with eclipses. Times of 37 superhump maxima were found and are listed in Table 4. An analysis of the times of maximum for cycles 0 to 55 (JD 2455022 to 2455026) allowed us to obtain the following linear superhump maximum ephemeris:

$$HJD_{max} = 2455022.50822(24) + 0.06028(19) \times E$$ [Eqn 2]

This gives the mean superhump period for the first four days of the superoutburst P_{sh}= 0.06028(19)d. The O–C residuals for the superhump maxima for the complete outburst relative to the ephemeris are shown in the bottom panel in Figure 2. There is a suggestion that the superhump period remained constant during the first four days of the outburst and then gradually increased through the rest of the outburst. The data are also consistent with a period increase during the outburst with $dP_{sh}/dt = +2.8(1.0) \times 10^{-4}$.

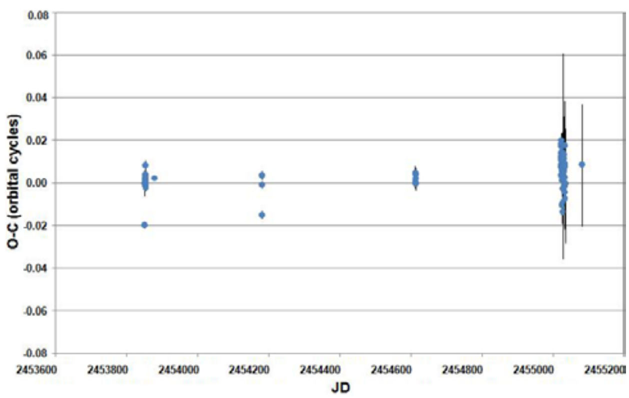


Figure 4. O–C residuals for the eclipses.

Table 3. (continued)

Orbital cycle no.	*Eclipse minimum (HJD)*	*O–C (orbital cycles)*	*Error*	*Eclipse depth (mag)*	*Eclipse duration FWHM (m)*
19957	2455025.60577	0.0101	0.0035	0.96	8.70
19958	2455025.66470	0.0105	0.0134	0.97	8.25
19958	2455025.66476	0.0114	0.0041	0.96	8.70
19958	2455025.66454	0.0077	0.0046	0.96	10.05
19959	2455025.72346	0.0079	0.0013	0.99	10.20
19959	2455025.72353	0.0091	0.0020	0.98	9.60
19959	2455025.72335	0.0061	0.0033	1.00	9.90
19960	2455025.78253	0.0107	0.0013	0.96	9.60
19960	2455025.78255	0.0109	0.0013	0.95	6.15
19960	2455025.78271	0.0137	0.0018	0.97	9.00
19961	2455025.84149	0.0115	0.0022	1.00	8.55
19961	2455025.84167	0.0146	0.0041	1.01	7.50
19970	2455026.37155	0.0093	0.0045	0.63	9.75
19971	2455026.43029	0.0064	0.0048	0.60	6.30
19974	2455026.60730	0.0112	0.0019	ND	ND
19975	2455026.66539	−0.0026	0.0058	1.07	8.70
19976	2455026.72392	−0.0092	0.0196	1.24	10.95
19976	2455026.72392	−0.0091	0.0055	1.23	10.05
19976	2455026.72478	0.0054	0.0111	1.25	9.75
19977	2455026.78257	−0.0135	0.0095	1.29	10.95
19991	2455027.60878	0.0116	0.0067	1.04	8.55
19992	2455027.66745	0.0075	0.0053	1.07	7.35
19993	2455027.72653	0.0105	0.0063	1.11	8.55
19993	2455027.72639	0.0081	0.0044	1.10	8.10
19993	2455027.72649	0.0097	0.0025	1.12	9.45
19994	2455027.78564	0.0138	0.0038	1.10	8.85
19995	2455027.84456	0.0141	0.0050	1.13	7.50
19995	2455027.84448	0.0126	0.0484	1.12	7.35
20006	2455028.49234	0.0102	0.0362	1.12	7.50
20007	2455028.55092	0.0046	0.0036	1.07	7.80
20010	2455028.72746	0.0013	0.0214	ND	ND
20027	2455029.72931	0.0081	0.0021	1.56	7.35
20028	2455029.78814	0.0067	0.0030	1.61	7.80
20029	2455029.84733	0.0115	0.0038	1.51	6.00
20040	2455030.49545	0.0134	0.0179	1.56	7.05
20041	2455030.55408	0.0087	0.0040	1.70	6.60
20044	2455030.73050	0.0034	0.0023	1.52	5.70
20045	2455030.78955	0.0057	0.0014	1.47	6.00
20046	2455030.84850	0.0066	0.0027	1.50	5.40
20061	2455031.73191	0.0026	0.0107	1.47	5.85
20062	2455031.79041	−0.0043	0.0073	1.58	5.70
20063	2455031.84955	−0.0005	0.0184	1.22	4.35
20078	2455032.73313	−0.0015	0.0082	1.69	4.05
20078	2455032.73321	−0.0001	0.0163	1.87	4.20
20078	2455032.73313	−0.0015	0.0200	1.98	3.90
20079	2455032.79204	−0.0015	0.0171	1.95	3.60
20080	2455032.85150	0.0079	0.0079	2.05	3.30
20080	2455032.85207	0.0176	0.0210	1.85	3.15
20095	2455033.73521	0.0090	0.0163	2.02	3.00
20096	2455033.79404	0.0076	0.0171	2.06	2.90
20097	2455033.85207	−0.0073	0.0210	2.18	3.10
20112	2455034.73613	−0.0002	0.0200	ND	ND
20904	2455081.39294	0.0086	0.0286	ND	ND

To confirm our measurements of P_{sh}, we carried out a period analysis of the data using the Date Compensated Discrete Fourier Transform (DCDFT) algorithm in *Peranso*.[7] To investigate the stability of the period, we divided the light curve into three sections and analysed each section separately. Figure 5 shows the power spectrum of the data from JD 2455022 to 2455025, which has its highest peaks at a period of 0.050891(13)d and 0.06024(15)d. The period error estimate is derived using the Schwarzenberg–Czerny method.[8] We interpret the shorter period signal as P_{orb} and the longer one as P_{sh}. Both values are consistent with our earlier measurements from the times of eclipse minima and superhump maxima. Removing P_{orb} by pre-whitening gave the power spectrum in Figure 6. In this case the strongest signal was at 0.06024(15)d (plus its 1, 2 and 3 c/d aliases), which had also been present in the original power spectrum as the strongest peak, and which corresponds to P_{sh}. We performed a similar analysis for the remaining sections of the light curve, and for the combined outburst data, with the following results:

JD 2455022 to 2455025 P_{sh}= 0.06024(15)d
JD 2455026 to 2455029 P_{sh}= 0.06029(12)d
JD 2455030 to 2455038 P_{sh}= 0.06098(28)d
Combined data P_{sh}= 0.06042(9)d

These results are also consistent with an increase in P_{sh} during the outburst.

The nature of the eclipses

One of the most interesting aspects of SDSS 1502 is its deep eclipses. We measured the eclipse duration as the full width at half minimum (FWHM; Table 3). Figure 7 shows that the eclipse duration was greatest at the peak of the outburst (10.5 min) and declined as the outburst progressed, with the final eclipses being about one-third the duration (3.5 min) of the first ones observed. This is a common feature of eclipses during dwarf nova outbursts and is due to the accretion disc being largest at the peak of the

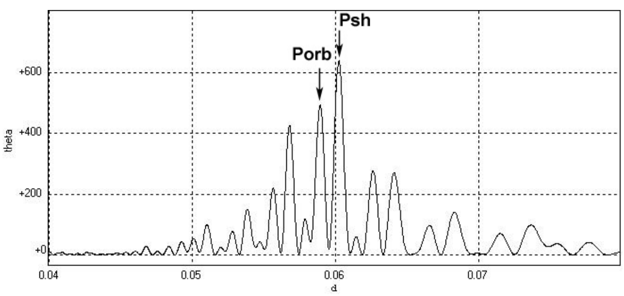


Figure 5. DCDFT power spectrum of data from JD 2455022 (2009 July 9) to 2455025 (July 12).

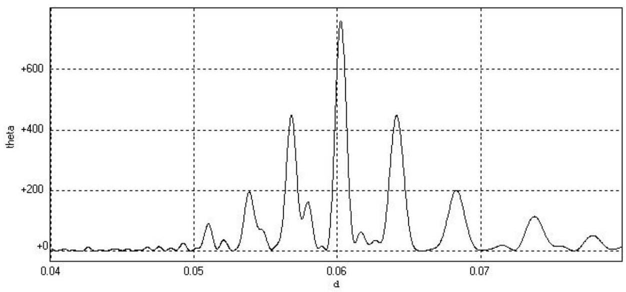


Figure 6. DCDFT power spectrum of the data after pre-whitening with P_{orb}.

Table 4. Superhump maximum times

Superhump cycle	*Superhump maximum (HJD)*	*O–C (superhump cycles)*	*Error*
0	2455022.5092	0.0160	0.0124
2	2455022.6288	0.0009	0.0087
3	2455022.6890	−0.0004	0.0082
3	2455022.6888	−0.0034	0.0106
3	2455022.6892	0.0026	0.0027
4	2455022.7489	−0.0066	0.0079
4	2455022.7492	−0.0023	0.0079
5	2455022.8090	−0.0097	0.0074
37	2455024.7391	0.0078	0.0088
38	2455024.8003	0.0231	0.0122
47	2455025.3404	−0.0153	0.0086
48	2455025.4001	−0.0246	0.0154
49	2455025.4579	−0.0641	0.0250
52	2455025.6396	−0.0512	0.0144
52	2455025.6394	−0.0535	0.0212
53	2455025.7027	−0.0055	0.0187
53	2455025.7063	0.0523	0.0229
54	2455025.7645	0.0189	0.0119
54	2455025.7653	0.0315	0.0179
54	2455025.7653	0.0146	0.0108
55	2455025.8260	0.0222	0.0270
55	2455025.8256	0.0159	0.0382
55	2455025.8287	0.0643	0.0063
84	2455027.5806	0.1253	0.0092
85	2455027.6423	0.1477	0.0226
86	2455027.7038	0.1677	0.0075
86	2455027.7042	0.1739	0.0114
87	2455027.7653	0.1859	0.0069
88	2455027.8247	0.1730	0.0094
88	2455027.8244	0.1675	0.0080
89	2455027.8862	0.1913	0.0090
120	2455029.7483	0.0870	0.0074
122	2455029.8695	0.0982	0.0075
136	2455030.7095	0.0357	0.0348
137	2455030.7717	0.0656	0.0343
138	2455030.8370	0.1457	0.0367
169	2455032.7243	0.4425	0.0081

outburst and subsequently shrinking from the outside inwards as material drains from the disc as the outburst progresses.[9] We measured the eclipse duration at quiescence, when the accretion disc diameter is expected to be at a minimum, as 2.7 min (average of five quiescence eclipses on 2006 Apr 25).

Figure 8 shows that there was also a trend of increasing eclipse depth during the outburst from ~0.9 mag near the beginning to ~2.1 mag towards the end (data are given in Table 3). During quiescence the eclipses were ~2.8 magnitudes deep. A cursory examination of the time series lightcurves presented

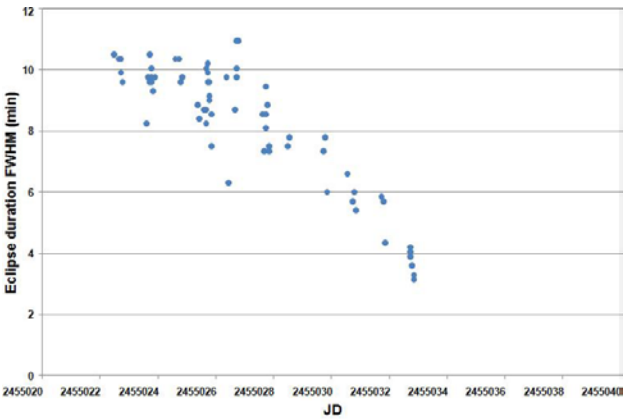


Figure 7. Duration of eclipses during the outburst.

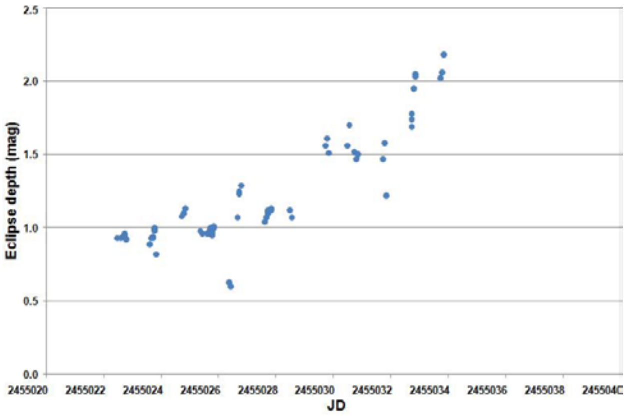


Figure 8. Depth of eclipses during the outburst.

in Figure 3 shows that the eclipse depth is also affected by the location of the superhump: in general eclipses are shallower when hump maximum coincides with eclipse. This is commonly observed in eclipsing SU UMa systems including DV UMa, IY UMa and SDSS J122740.82 +513925[9,10,11] where there is a relationship between eclipse depth and the precession period, P_{prec} (*i.e.* the beat period of the superhump and orbital periods). However, we could find no such correlation in SDSS 1502, presumably because any variation in depth associated with the beat period would have been masked by the much larger increase in depth as the star faded. According to the relation $1/P_{prec} = [1/P_{orb} - 1/P_{sh}]$, the precession period should be about 2.6d, based on our measured values of P_{sh} and P_{orb}. However, we searched for such a signal corresponding to the precession period in the DCDFT power spectrum in the interval 1 to 5d without success.

A typical example of a quiescence lightcurve is shown in Figure 9, where 6 eclipses each 2.8 mag deep are present. Another prominent feature is an orbital hump which occurs just before each eclipse. Orbital humps are due to the presence of a 'bright spot' which forms where the material flowing from the secondary star hits the edge of the accretion disc.[12] To study the eclipse profile in more detail, we took the flux intensity data from Figure 9 (rather than the magnitude data, as is standard practice when investigating deep eclipses) and folded it on P_{orb}. This gave the average eclipse profile shown in Figure 10, where we plot the mean value of bins containing five separate intensity measurements. The eclipse was not

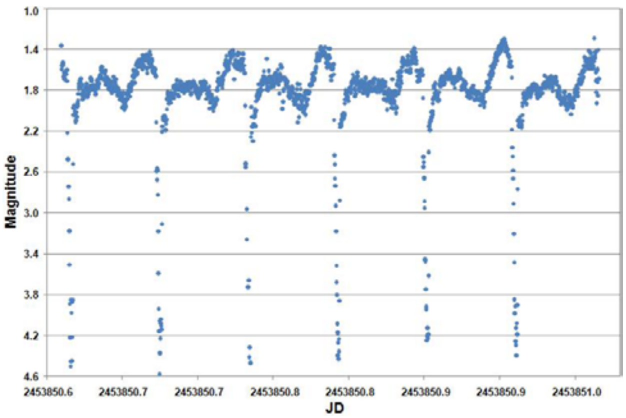


Figure 9. Eclipses at quiescence (2006 Apr 25). In this plot, *Magnitude* is the differential magnitude relative to the comparison star.

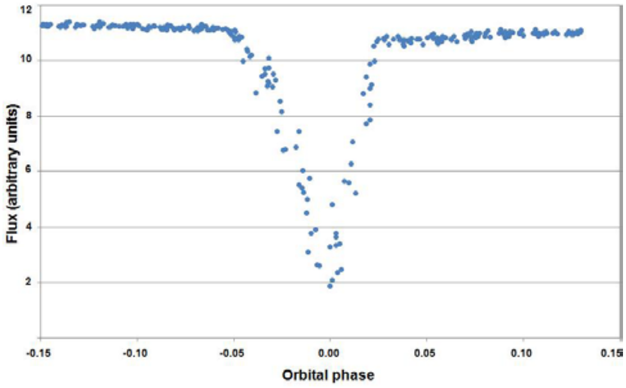


Figure 10. Average quiescence eclipse.

quite symmetrical. Littlefair *et al.*[2] also found an asymmetric eclipse in SDSS 1502 and they used multicolour eclipse mapping and modelling to associate different parts of the eclipse profile with different parts of the system undergoing eclipse, including the white dwarf, the bright spot and the accretion disc. Unfortunately, the resolution of our data was not sufficient to identify with certainty the different parts of the system undergoing eclipse, although the rapid rise in brightness at the end of the eclipse, at a phase of 0.2, may be due to the white dwarf coming out of eclipse.

Discussion

Taking our mean superhump period for the first four days of the superoutburst, P_{sh}= 0.06028(19)d, and our measured orbital period, P_{orb}= 0.05890946(5)d, we calculate the superhump period excess ε= 0.023(3). Such value is consistent with other SU UMa systems of similar orbital period.[12]

Patterson *et al.*[13] established an empirical relationship between ε and q, the secondary to primary mass ratio: $\varepsilon = 0.18*q + 0.29*q^2$. This assumes a white dwarf of ~0.75 solar masses which is typical for SU UMa systems, but which is slightly smaller than the white dwarf in SDSS 1502. Taking q= 0.109 for SDSS 1502, this empirical relationship predicts ε= 0.023. Such value is the same as our measured value of ε, again confirming that SDSS 1502 is a typical SU UMa system.

Kato *et al.*[14] have studied the superhump period changes in a large numbers of SU UMa systems and in general find three distinct stages: an early evolutionary stage (A) with longer superhump period, a middle stage (B) for a large part of the outburst in which systems with P_{orb}< 0.08d have a positive period derivative, and a final stage (C) with a shorter P_{sh}. In the case of the outburst of SDSS 1502, it is possible that we missed stage A. The bulk of our observations were probably from stage B and our positive superhump period is consistent with Kato *et al.*'s observations. Stage C usually occurs towards the end of the outburst, during which we were unable to measure the superhump period since the superhumps occurred too close to the eclipses during this phase.

Although we reported a continuous period increase during the outburst (dP_{sh}/dt= +2.8(1.0)×10^{-4}), close inspection of the trend in the O–C data in Figure 2 suggests that the situation may actually be more complex. From the beginning of the outburst to about JD 24455028 the period is generally increasing, but there then appears to be a period decrease between JD 24455028 and JD 24455030, following which it increases again. By comparing the O–C diagram with the lightcurve it is tempting to speculate that the changes in O–C may correspond to the inflexions in the lightcurve (such as the plateau between JD 2455026 to 24550228) mentioned in the section on the 2009 July outburst. These inflexions may indicate that the accretion disc is not shrinking at a constant rate during the outburst, which may in turn affect the precession of the disc and hence the form of the O–C curve.

The plot in Figure 7 suggests that there may be a discontinuity in the eclipse duration data between JD 2455028 and 2455030 which in turn could indicate a change in the rate of contraction of the disc. A similar possible discontinuity at about the same time can also be seen on the eclipse depth plot (Figure 8). Whilst these observations are intriguing, a link between them and the physical state of the accretion disc must remain speculation. Observations of future outbursts may reveal further information.

Conclusions

Analysis of the first confirmed superoutburst of SDSS 1502 during 2009 July has shown that it is a member of the SU UMa family of dwarf novae. The outburst amplitude was at least 3.9 magnitudes and it lasted at least 16 days. Analysis of eclipse times from outburst and quiescence yielded an orbital period of P_{orb}= 0.05890946(5)d. Time-series photometry during the outburst revealed superhumps with a maximum peak-to-peak amplitude of 0.35 magnitudes. The mean superhump period during the first 4 days of the outburst was P_{sh}= 0.06028(19)d, although the superhump period increased during the outburst with dP_{sh}/dt = +2.8(1.0)×10^{-4}. Based on the mean superhump period, the superhump period excess was ε= 0.023(3). The FWHM eclipse duration declined from a maximum of 10.5 min at the peak of the outburst to 3.5 min later in the outburst, indicating a shrinking accretion disc. The depth of the eclipses increased from ~0.9 mag near the beginning of the outburst to 2.1 mag at the end. Eclipses in quiescence were 2.7 min in duration and 2.8 mag deep. Long term monitoring of the star between 2005 March and 2009 October has revealed at least one, and possibly three, additional outbursts.

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