Superoutbursts and grazing eclipses in the dwarf nova V1227 Herculis

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We present photometry obtained during the 2012 May and September outbursts of the frequently outbursting dwarf nova, V1227 Her. Superhumps were present in both cases with a peak-to peak amplitude of up to 0.28 mag, showing these events to be superoutbursts. We show for the first time that the system undergoes small eclipses with a depth of up to 0.08 mag, lasting 11 to 14 min, which are likely to be grazing eclipses of the accretion disc. The September outburst was the better observed of the two and lasted at least 14 days with an outburst amplitude of approximately 4 magnitudes. The mean superhump period was P_{sh}= 0.065103(20)d. Analysis of eclipse times of minimum gave an orbital period P_{orb}= 0.064419(26)d, although there is some ambiguity due to the relatively short time over which the eclipses were observed. The fractional superhump period excess, ε, was 0.0106(7).

Introduction

V1227 Her was identified as a dwarf nova by Szkody *et al.*,[1] with the ID of SDSS J165359.06+201010.4, during their search for cataclysmic variables in data from the Sloan Digital Sky Survey (SDSS). Their follow-up photometric observations occurred at a time when the system was in outburst and revealed a periodic hump feature superposed on a declining trend, which they interpreted as superhumps during the decline from an outburst. The superhump period of the three observed humps was 0.0658d. These results are consistent with the system's being a dwarf nova of the SU UMa class. Kato *et al.*[2] performed photometry during an outburst in 2010 May which also revealed superhumps with P_{sh}= 0.065032d.

Table 1. Outbursts of V1227 Her between 2004 August and 2012 October

Date (UT) of detection	*JD*	*Days since start of prev. outburst*	*Maximum mag.*	*Detection of outburst*	*Confirmed superoutburst?*
2004 Aug 24	2453241.6		14.9	Ref 1	Yes[1]
2005 Jul 16	2453567.7	326	14.9	CRTS	
2006 Oct 20	2454028.6	461	16.3	CRTS	
2007 Apr 23	2454214.0	185	15.0	CRTS	
2008 Mar 23	2454549.0	335	15.0	CRTS	
2008 Jun 8	2454625.9	77	16.2	CRTS	
2009 Feb 13	2454876.0	250	14.9	CRTS	
2009 May 4	2454955.8	80	15.5	CRTS	
2009 Sep 29	2455103.6	228	15.0	CRTS	
2010 Apr 15	2455302.0	198	14.5	CRTS	Yes[2]
2010 Jun 16	2455363.8	62	15.2	CRTS	
2010 Sep 17	2455457.5	94	15.4	AAVSO	
2010 Oct 27	2455497.4	40	15.2	AAVSO	
2011 Jan 28	2455590.0	93	16.4	CRTS	
2012 May 14	2456062.4	472	14.6	IM	Yes: this study
2012 Sep 10	2456181.5	119	14.6	JS	Yes: this study

CRTS= detection by CRTS;[3] AAVSO= outburst recorded in the AAVSO International Database.

Table 1 lists 16 outbursts of V1227 Her, in which the object became brighter that magnitude 16.5, using data from Catalina Real-Time Transient Survey (CRTS),[3] the AAVSO International Database and the present authors. Four of the outbursts were confirmed as superoutbursts; others might well have been, but no time series photometry was conducted to check for superhumps. The short interval between several of the outbursts, as short as 40 days, suggests that V1227 Her is a frequently outbursting dwarf nova. The interval between the 2012 May and September superoutbursts points to a superoutburst period of around 120d. In this paper we report photometry during these two superoutbursts.

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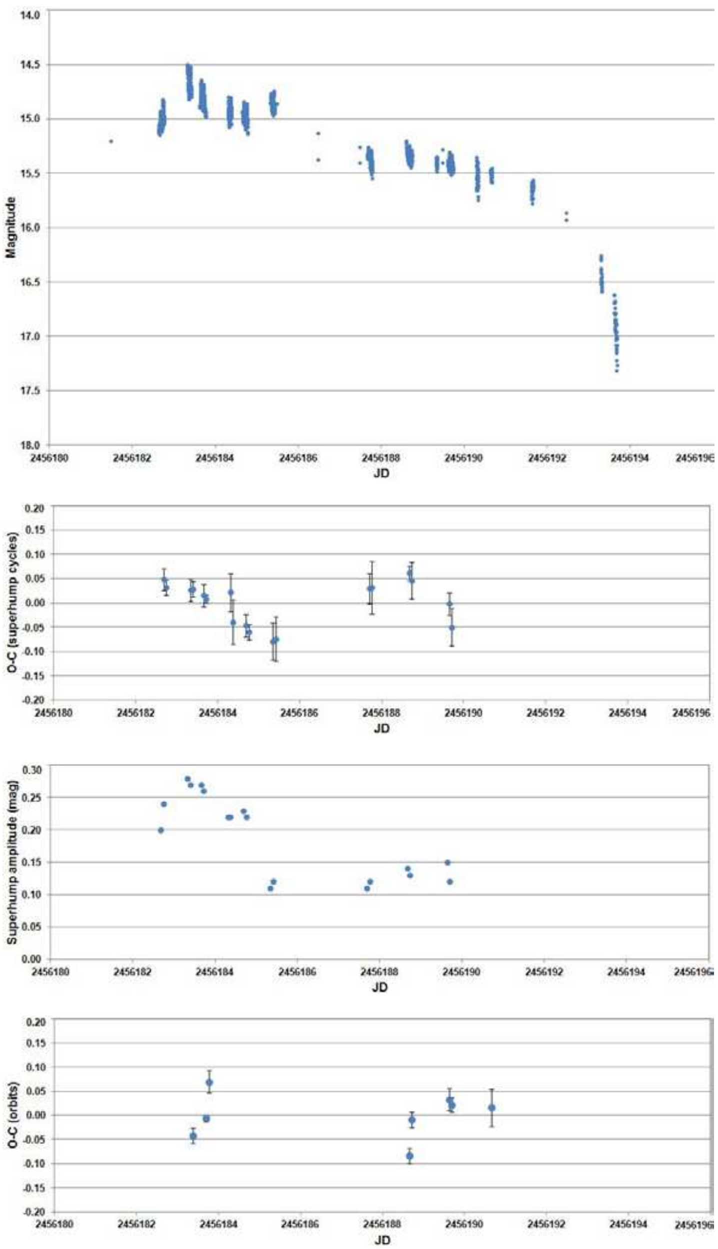

Figure 1. The 2012 September outburst. **(a)** Outburst lightcurve. **(b)** O–C diagram of the superhumps. **(c)** Superhump amplitude. **(d)** O–C diagram of the eclipses.

Photometry

We performed 18h of photometry during the 2012 May outburst of V1227 Her and 31h during the September outburst. Our instrumentation is shown in Table 2 and the observation log in Table 3. All but one of the photometry runs were 3.3hrs or less due to the rather short nights in May at our temperate latitudes, and the object's poor location in the western sky in September. Images were dark-subtracted and flat-fielded prior to being measured using differential aperture photometry relative to the BAA VSS V-band sequence P100617.[4]

Table 2. Equipment used

Observer	*Telescope*	*CCD*	*Filter*
Miller	0.35m SCT	Starlight Xpress SXVR-H16	None
Pickard	0.4m SCT	Starlight Xpress SXVF-H9	V
Sabo	0.43m reflector	SBIG STL-1001	None
Shears	0.28m SCT	Starlight Xpress SXVF-H9	None

Table 3. Log of time-series observations

Date (UT)	*Start time(JD)*	*Duration(h)*	*Observer*
2012 September			
September 12	2456182.631	3.3	Sabo
September 12	2456183.328	2.4	Miller
September 13	2456183.630	3.3	Sabo
September 13	2456184.310	1.8	Shears
September 14	2456184.653	3.0	Sabo
September 14	2456185.335	2.3	Miller
September 17	2456187.660	3.0	Sabo
September 18	2456188.603	3.3	Sabo
September 18	2456189.327	0.3	Shears
September 19	2456189.599	3.3	Sabo
September 19	2456190.299	0.7	Shears
September 20	2456190.628	1.1	Sabo
September 21	2456191.618	1.1	Sabo
September 22	2456193.292	0.7	Shears
September 23	2456193.614	1.6	Sabo
2012 May			
May 15	2456063.403	2.5	Miller
May 15	2456063.421	2.6	Pickard
May 16	2456064.394	1.8	Pickard
May 20	2456068.476	2.1	Miller
May 21	2456069.429	3.2	Miller
May 22	2456070.409	4.4	Pickard
May 22	2456070.451	1.1	Miller

The 2012 September outburst

The outburst lightcurve is shown in Figure 1a. The outburst was detected on Sep 10.986 by JS,[5] using the 35 cm Bradford Robotic Telescope, when the star was still brightening. It reached maximum magnitude of 14.6 two days later and faded at a rate of 0.6 mag/d over the next two days to mag 15.0. This marked the beginning of the plateau phase. There was then a brief rebrightening to mag 14.8, followed by a gradual decline at 0.1 mag/d for the rest of the plateau phase, which lasted about 7 days. Some 14 days after the outburst was detected, a rapid decline set in, although the approach to quiescence itself was missed. SDSS lists the system at g=18.66 in quiescence. Thus the outburst amplitude was approximately 4 mag and its duration was at least 14 days.

Figure 2 shows expanded plots of some of the longer photometry runs. Superhumps were present throughout the outburst, confirming it to be a superoutburst. We measured the times of maximum of 18 superhumps, and their uncertainties, using the Kwee & van Woerden method[6] in the *Minima* v2.3 software.[7] These are listed in Table 4. Following a preliminary assignment of superhump cycle numbers to these maxima, an unweighted linear analysis of the times of maximum between HJD 2456182 and 2456189 allowed us to obtain the following superhump maximum ephemeris:

$$HJD_{max} = 2456182.6755(11) + 0.065103(20) \times E \qquad \text{[Eqn 1]}$$

Thus the mean superhump period in this interval was P_{sh}= 0.065103(20)d. The observed minus calculated (O–C) residuals for all the superhump maxima relative to the ephemeris are shown in Figure 1b. The downward trend at the beginning of the O–C diagram suggests that the superhump period was very slightly shorter during the first part of the outburst: analysing the times of maximum between HJD 2456182 and 2456185 gave P_{sh}= 0.064905(31)d.

The superhumps increased in size up to a maximum peak-to-peak amplitude of 0.28 mag (Figure 1c), which corresponded to the time of maximum brightness. They then gradually reduced in amplitude during the first part of the plateau corresponding to the more rapid fade described above. We note that the interval over which this occurred also corresponds to the slightly shorter superhump regime. After this point the superhump amplitude remained at 0.11 to 0.15 mag for the rest of the outburst.

Close inspection of the lightcurve revealed the presence of several small V-shaped dips superimposed on the superhumps, examples of which are shown in Figure 3. The shape and regularity of these leads us to interpret them as eclipses. The eclipses were only obvious when they coincided with superhump minima. We measured eight times of eclipse minimum, again using the Kwee & van Woerden method in the *Minima* software, and these are shown in Table 5. We obtained the following eclipse ephemeris from an unweighted analysis of these times of minimum:

$$HJD_{min} = 2456183.3720(19) + 0.064419(26) \times E \qquad \text{[Eqn 2]}$$

Taking the eclipses as a measure of the orbital period means that P_{orb}= 0.064419(26)d. An O–C diagram relative to this ephemeris is shown in Figure 1d.

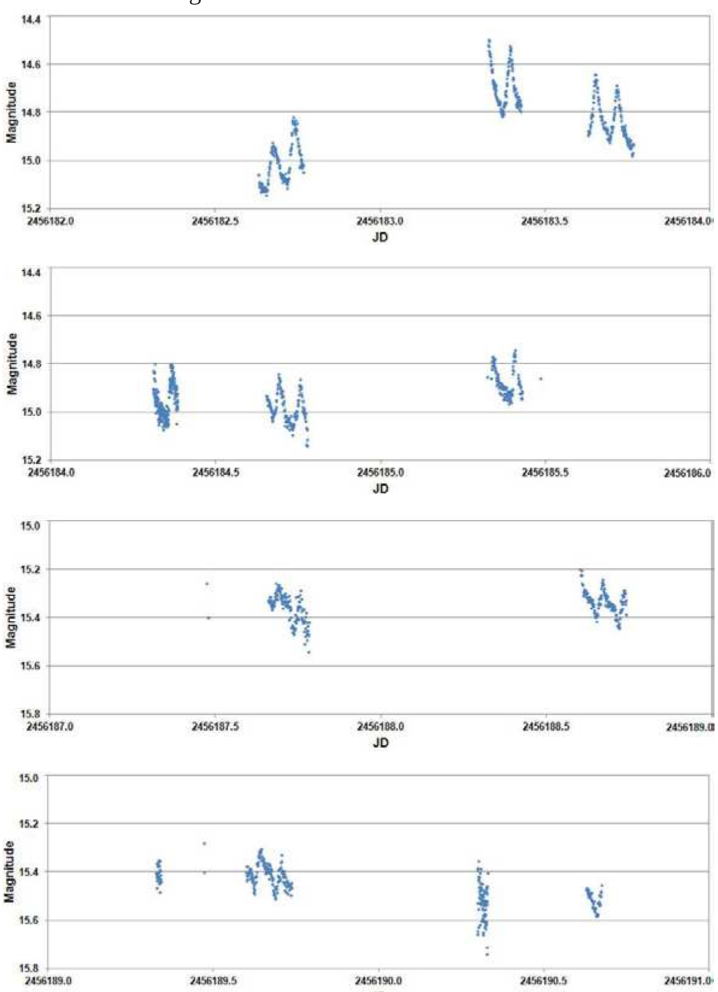

Figure 2. Time resolved photometry during the 2012 September outburst.

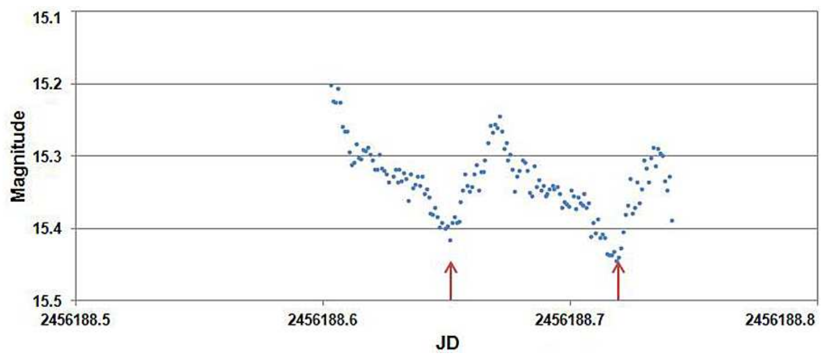

Figure 3. Photometry on HJD 2456188 from the 2012 September outburst showing two eclipses.

The depth and duration of the eclipses was hard to determine accurately due to the difficulty of isolating the eclipses from the superhump profile. The eclipse depth varied between 0.03 and 0.08 mag with a mean of 0.06 mag (Table 5) and the eclipse duration varied between 11 and 14 min.

The 2012 May outburst

The 2012 May outburst was detected by IM on May 14.934,[8] but was much less well observed than the September event. The lightcurve is shown in Figure 4a. It appears to have been caught near maximum brightness, at mag 14.7, and part of the plateau phase was followed over an interval of eight days. The mean rate of fading during the plateau was 0.11 mag/d, the same as was found in the 2012 September outburst. Superhumps were present (Figure 5) confirming that this was also a superoutburst. Times of eight superhump maxima were measured as previously and are shown in Table 4.

Table 4. Superhump maximum times

Superhump cycle no.	*Superhump max (HJD)*	*Uncertainty (d)*	*O–C (d)*	*Superhump amplitude (mag)*
2012 September				
0	2456182.6787	0.0015	0.0032	0.20
1	2456182.7427	0.0010	0.0021	0.24
10	2456183.3283	0.0015	0.0017	0.28
11	2456183.3935	0.0010	0.0018	0.27
15	2456183.6531	0.0015	0.0010	0.27
16	2456183.7177	0.0005	0.0005	0.26
25	2456184.3045	0.0025	0.0014	0.22
26	2456184.3656	0.0030	−0.0026	0.22
31	2456184.6907	0.0015	−0.0030	0.23
32	2456184.7549	0.0010	−0.0039	0.22
41	2456185.3396	0.0025	−0.0052	0.16
42	2456185.4050	0.0030	−0.0049	0.20
77	2456187.6904	0.0020	0.0019	0.11
78	2456187.7556	0.0035	0.0020	0.12
92	2456188.6690	0.0010	0.0040	0.14
93	2456188.7331	0.0025	0.0030	0.13
107	2456189.6414	0.0015	−0.0001	0.15
108	2456189.7034	0.0025	−0.0033	0.12
2012 May				
0	2456063.4330	0.0010	0.0003	0.21
0	2456063.4331	0.0010	0.0004	0.22
1	2456063.4978	0.0010	0.0000	0.21
1	2456063.4981	0.0020	0.0003	0.21
15	2456064.4083	0.0020	−0.0011	0.20
78	2456068.5118	0.0015	0.0002	0.16
93	2456069.4896	0.0015	0.0013	0.10
94	2456069.5522	0.0015	−0.0012	0.09

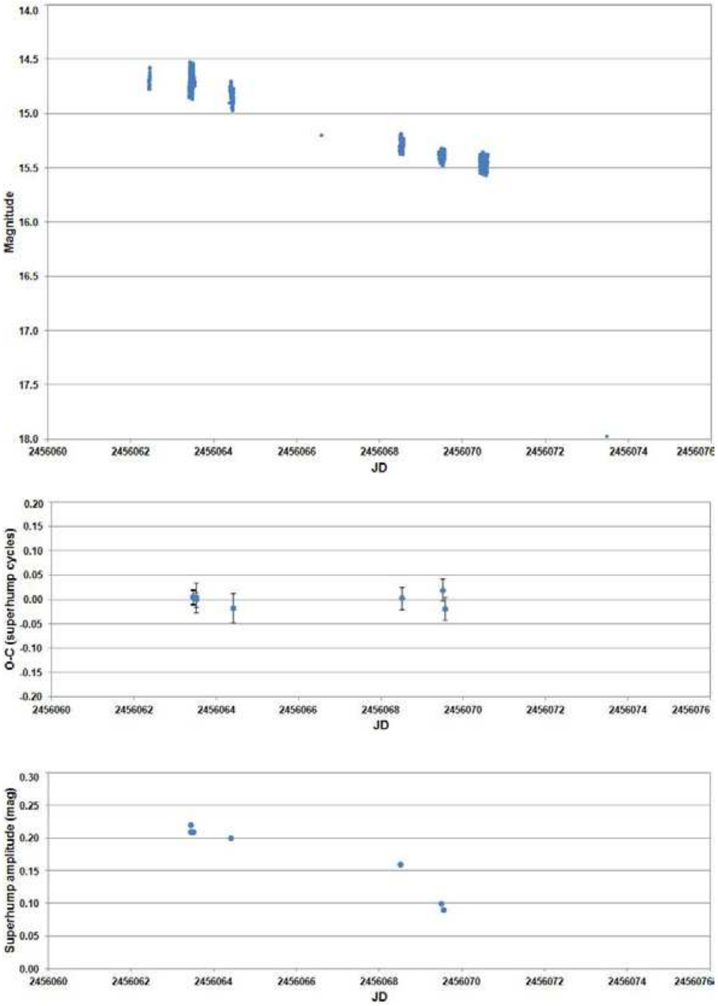

Figure 4. The 2012 May outburst. **(a)** Outburst lightcurve. **(b)** O–C diagram of the superhumps. **(c)** Superhump amplitude.

An unweighted analysis of the times of superhump maximum gave:

$$HJD_{max} = 2456063.4327(4) + 0.065114(8) \times E \qquad \text{[Eqn 3]}$$

Thus the superhump period, P_{sh} = 0.065114(8)d, was consistent with the one measured in 2012 September. The O–C diagram (Figure 4b), shows that the superhump period was constant during the observed part of the outburst. The superhump amplitude declined from 0.22 mag to 0.09 mag (Figure 4c and Table 4).

We carefully examined the lightcurves from this outburst for the presence of eclipses, but could be certain of only two such events (Table 5), with a depth of approximately 0.08 mag. Extending the 2012 September eclipse ephemeris back to May, using all the eclipse timings, gives the following eclipse ephemeris:

$$HJD_{min} = 2456069.4600(20) + 0.0644295(12) \times E \qquad \text{[Eqn 4]}$$

Given the long gap between the two sets of eclipses, we considered the change in period that would be caused by a difference of one cycle count during this period:

+1 cycle different

$$HJD_{min} = 2456069.4598(22) + 0.0643944(13) \times E \qquad \text{[Eqn 5]}$$

–1 cycle different

$$HJD_{min} = 2456069.4601(25) + 0.0644647(15) \times E \qquad \text{[Eqn 6]}$$

Table 5. Eclipse times

Eclipse no.	Eclipse min (HJD)	Uncertainty (d)	O–C (d)	Eclipse depth (mag)	Eclipse duration FWHM (m)
2012 September					
0	2456183.3693	0.0010	–0.0027	0.05	11
5	2456183.6937	0.0005	–0.0004	0.05	11
6	2456183.7630	0.0015	0.0045	0.07	13
82	2456188.6490	0.0010	–0.0054	0.08	14
83	2456188.7182	0.0010	–0.0006	0.08	14
97	2456189.6228	0.0015	0.0021	0.06	12
98	2456189.6865	0.0010	0.0014	0.08	11
113	2456190.6524	0.0025	0.0010	0.04	11
2012 May					
	2456069.4598	0.0045		0.08	14
	2456069.5245	0.0025		0.08	12

FWHM= full width at half-minimum

The difference in period is only about 1.5 times the error on the period in Eqn 2, so there is a strong possibility that our cycle count could be out by ± 1. There also remains a remote possibility that there is a 2-cycle error in the count. Clearly timings of eclipses during future outbursts would help to confirm the period and refine the ephemeris.

The nature of the eclipses

The short duration and shallowness of the eclipses suggests that these are grazing eclipses of the accretion disc, with the binary system being only slightly above the critical inclination for eclipses to occur. The fact that the eclipses were only evident at some stages of the superoutburst is also consistent with a marginal graze occurring only when the accretion disc is sufficiently expanded. The eclipse depth in eclipsing SU UMa systems is often strongly affected by the location relative to the superhumps: eclipses are shallower when hump maximum coincides with eclipse, such as is found, for example, in the case of DV UMa.[9]

Close examination of Szkody *et al.*'s lightcurve of V1227 Her, which appears as Figure 6 of their paper,[1] shows inflections in the minima of the superhump lightcurves which might be indicative of very shallow eclipses. Moreover, there is a suggestion of a third event at the end of their photometry. They did not draw

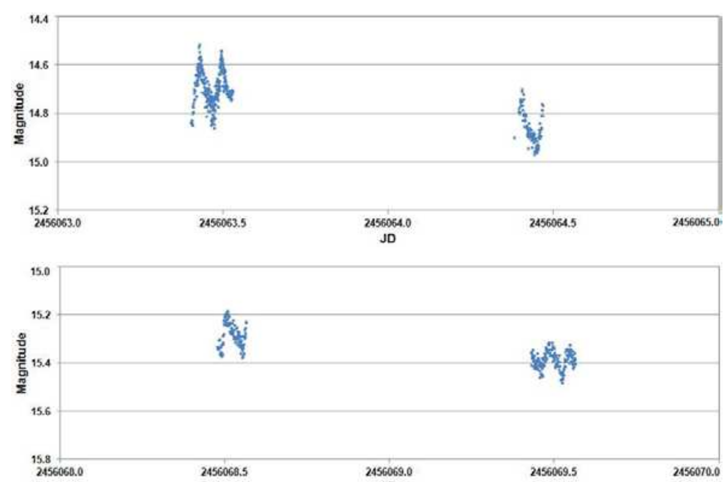

Figure 5. Time resolved photometry during the 2012 May outburst.

attention to these events and our suggestion that they are eclipses is highly tentative.

The emission spectra of high inclination dwarf novae often show double-peaked and broadened emission lines due to the Doppler shift associated with the rotation of the accretion disc. However, the emission spectrum of V1227 Her, shown in Figure 6, appears to be single-peaked and there is no obvious peak broadening. Although the absence of these features might be due to the inclination being close to the critical value, this is not diagnostic, as some high inclination systems have single-peaked spectra. For example, the SU UMa dwarf nova SDSS J081610.84+453010.2 shows 0.4 to 0.6 mag eclipses, but has a single-peaked emission spectrum.[10]

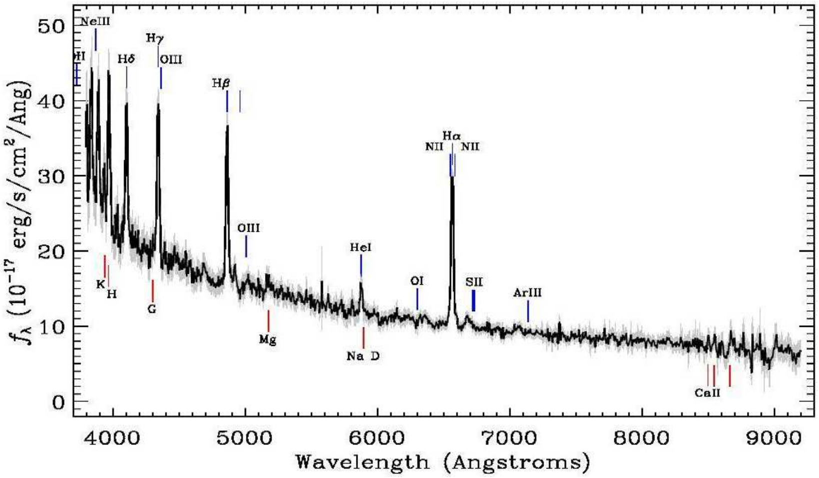

Figure 6. Spectrum of V1227 Her.[12]

Superhump period excess

Taking our measured values of P_{orb}= 0.064419(26)d and P_{sh}= 0.065103(20)d from the 2012 September superoutburst, allows the fractional superhump period excess $\varepsilon = (P_{sh}-P_{orb})/P_{orb}$ to be calculated as 0.0106(7). We note that this value of ε is rather small compared with the values observed in other SU UMa dwarf novae with similar P_{orb}, which are typically in the range 0.020 to 0.036.[11]

Patterson *et al*.[11] developed an empirical relationship between ε and the mass ratio of the secondary to the white dwarf primary, $q = M_{sec}/M_{wd}$, in a range of cataclysmic variables. Measuring ε provides a way of estimating the mass ratio, $q = M_{sec}/M_{wd}$, of a cataclysmic variable and using this relationship we find q= 0.054. Such value of q is at the lower end of the range of q for the cataclysmic variables listed in Patterson *et al*.[11] and suggests either an improbably low-mass secondary or a relatively high-mass primary.

Conclusions

Our photometry of the 2012 September and May outbursts of V1227 Her shows the presence of superhumps with a peak-to peak amplitude of up to 0.28 mag, confirming these events to be superoutbursts of an SU UMa type dwarf nova. The September outburst was the better observed of the two and lasted at least 14 days with an outburst amplitude of approximately 4 magnitudes. The mean superhump period was P_{sh}= 0.065103(20)d. We show for the first time that the system undergoes small eclipses with a depth of up to 0.08 and lasting 11 to 14 min. These are likely to be grazing eclipses of the accretion disc. Analysis of eclipse times of minimum gave an orbital period of P_{orb}= 0.064419(26)d. Thus the fractional superhump period excess, ε, was 0.0106(7).

V1227 Her appears to undergo frequent outbursts, at intervals as short as 40d. We propose further monitoring of the system to confirm its outburst period and the length of the supercycle, which may be around 120 days. Furthermore, measurement of additional eclipse times will help to refine the measurement of P_{orb}. It would also be worthwhile to conduct photometry during quiescence to ascertain whether eclipses persist when the accretion disc would be at its minimum diameter. This would require a sizeable telescope given the faintness of the system at quiescence.

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