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An irradiation effect in Nova DN Gem 1912 and the significance of the period gap for classical novae

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ABSTRACT

Continuous CCD photometry of the classical nova DN Gem during 52 nights in the years 1992–1998 reveals a modulation with a period of 0.127844 d. The semi-amplitude is about 0.03 mag. The stability of the variation suggests that it is the orbital period of the binary system. This interpretation makes DN Gem the fourth nova inside the cataclysmic variable (CV) period gap, as defined by Diaz & Bruch, and it bolsters the idea that there is no period gap for classical novae. However, the number of known nova periods is still too small to establish this idea statistically. We eliminate several possible mechanisms for the variation, and propose that the modulation is driven by an irradiation effect. We find that model light curves of an irradiated secondary star fit the data well. The inclination angle of the system is restricted by this model to $10° \lesssim i \lesssim 65°$. We also refine a previous estimate of the distance to the binary system, and find $d = 1.6 \pm 0.6$ kpc.

Key words: accretion, accretion discs – radiative transfer – stars: individual: DN Gem – stars: individual: V1974 Cyg – novae, cataclysmic variables.

1 INTRODUCTION – HISTORY OF OBSERVATIONS ON DN GEM

Nova DN Geminorum is an old classical nova, which erupted in 1912, and reached a peak magnitude of $m_V \approx 3.5$. The visual light curve of the nova a few months after the outburst was characterized by two maxima, and by strong oscillations. The nova was recognized as a fast one, with $t_{2V} \approx 16$ d, and $t_{3V} \approx 37$ d (McLaughlin 1960).

The spectrum of the nova at quiescence shows a strong continuum, with weak emission lines (Hummason 1938; Williams 1983). Warner (1986) deduced an inclination angle of about 50° from a comparison of the emission-line widths of the nova with a few other classical novae, the inclination angles of which are known from eclipses, assuming that the lines emanate from an accretion disc. Duerbeck, Lemke & Willerding (1979) deduced a distance of $d = 450 \pm 70$ pc, $A_V = 0.27 \pm 0.13$ and $M_{V(\max)} = -5.3 \pm 0.5$ from interstellar lines in the nova spectrum.

Robinson & Nather (1977) failed in their search for rapid oscillations in DN Gem and nine more classical novae. Retter & Leibowitz (1996), however, reported the detection of a sinusoidal variation with a period of 0.12785 ± 0.00005 d and a peak-to-trough amplitude of about 0.06 mag. In this work, we present the results of the photometry of Nova Geminorum, and discuss in detail the possible mechanisms that can generate the light modulation. Nova DN Gem 1912 is the fourth nova of which the period is close to the upper edge of the period-gap distribution of CVs. In Section 4.7 we discuss the implications of this fact.

2 OBSERVATIONS

We observed Nova DN Gem during 14 nights in the years 1992–1993 through an *R* filter, in the *I* filter during 34 nights in 1995–1997, and continuously switched between the *I* and *B* filters during four nights in 1998. Table 1 presents a summary of the observation schedule. The photometry was carried out with the 1-m telescope at the Wise Observatory, with the Tektronix 1K charge-coupled device (CCD) camera. Our *R*, *V* and *B* filters are the standard Cousins filters. The *I* filter is pseudo-Johnson, i.e. its red end is determined by the CCD response. The typical exposures times were 3–4 m in the *I* and *R* bands, and 7 m in the *B* band. We note that most of our observations in 1995–1998 were obtained during bright phases of the moon.

In addition, one snapshot through each of the *B*, *V*, *R* and *I* filters was taken during each of the nights of 1996 October 4 and 1997 November 27, together with a series of exposures of nearby standard stars. Unfortunately, the photometric solutions were poor during both occasions. The magnitudes of Nova Gem 1912,

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Table 1. The observations timetable.

UT Date	Time of start (HJD)	Run time (h)	Points number	Filter/s
230192	244 8645.198	6.8	37	R
240192	244 8646.213	0.5	4	R
250192	244 8647.186	9.3	53	R
230492	244 8735.238	0.5	6	R
240492	244 8736.233	1.6	17	R
250492	244 8737.228	2.3	23	R
280193	244 9016.490	1.3	14	R
110293	244 9030.208	7.6	39	R
120293	244 9031.204	0.4	3	R
130293	244 9032.194	1.4	8	R
140293	244 9033.196	7.8	39	R
020493	244 9080.247	2.3	10	R
030493	244 9081.233	3.6	19	R
090493	244 9087.241	3.0	21	R
111295	245 0063.442	0.3	8	I
121295	245 0064.475	3.2	85	I
131295	245 0065.492	2.7	46	I
020196	245 0085.416	4.8	83	I
030196	245 0086.507	3.6	57	I
090196	245 0092.398	5.8	106	I
100196	245 0093.423	2.5	25	I
130196	245 0096.411	4.5	84	I
140196	245 0097.522	2.8	53	I
300196	245 0113.269	7.6	46	I
030296	245 0117.192	9.3	124	I
050296	245 0119.189	6.4	87	I
080396	245 0151.234	2.7	36	I
090396	245 0152.195	2.8	37	I
110396	245 0154.189	0.6	9	I
290396	245 0172.214	5.2	52	I
310396	245 0174.209	5.3	76	I
041096	245 0361.202	0.3	1, 1, 1, 1	I, R, V, B
231196	245 0411.493	3.2	54	I
151296	245 0433.431	3.8	55	I
201296	245 0438.375	4.9	70	I
221296	245 0440.310	6.9	100	I
150197	245 0464.251	1.6	24	I
170197	245 0466.194	6.8	92	I
250297	245 0505.274	3.5	50	I
260297	245 0506.188	3.0	43	I
270297	245 0507.199	7.5	94	I
280297	245 0508.197	7.6	107	I
010397	245 0509.295	3.3	7	I
260397	245 0534.196	4.2	55	I
270397	245 0535.216	4.3	36	?
290397	245 0537.206	4.7	61	I
300397	245 0538.202	5.6	78	I
210497	245 0560.216	3.5	48	I
230497	245 0562.259	1.7	21	I
271197	245 0780.303	0.3	1, 1, 1, 1	I, R, V, B
090198	245 0823.253	8.3	47, 45	I, B
100198	245 0824.279	4.0	8	I
130198	245 0827.509	0.6	3, 3	I, B
140198	245 0828.255	1.3	6, 7	I, B

measured during the latter night, are: $m_B = 15.8$, $m_V = 16.0$, $m_R = 15.7$, $m_I = 15.4$. Error is about 0.2 mag globally.

Aperture photometric measurements were performed using the DAOPHOT program (Stetson 1987). Instrumental magnitudes of the nova, as well as of 3–20 reference stars, depending on each image quality were obtained from the frames. An internally consistent series of nova magnitudes was obtained by using the Wise Observatory reduction program DAOSTAT (Netzer et al. 1996).

We did not consider the points of 1997 March 27 in our analysis, because it seems that a wrong filter was accidentally used. Thus, the number of remaining frames obtained in each filter on our programme was: 2039 (I), 295 (R), 2 (V) and 57 (B).

3 DATA ANALYSIS

A variation at $P \approx 3$ h and a full amplitude of about 5–10 per cent can be seen by simple visual inspection of the light curve during a few of our best nights. In addition, the nightly mean varied by a few tenths mag from night to night with $\sigma \approx 0.09$ mag – more than three times larger than the mean error for a single data point. In Fig. 1 the observations in the I band during 1995–1998 are plotted. The points represent the raw data, while the circles display nightly means.

The power spectrum of the 1995–1998 data obtained through the I filter is shown in Fig. 2. The de-trending was carried out by subtracting the mean from each night. The highest peak in the graph corresponds to the periodicity of $0.127\,844 \pm 0.000\,001$ d. This period also appears in the power spectrum of each of the

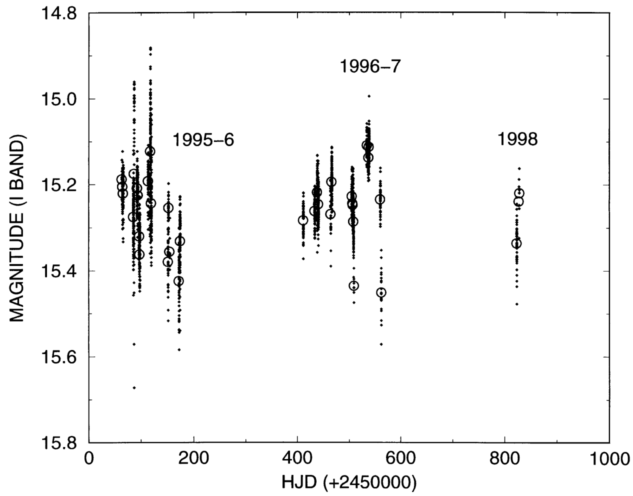

Figure 1. All 1995–1998 data points (I band) are presented. The empty circles display the mean of each night. There is a variation of the order of a few tens per cent between adjacent nights.

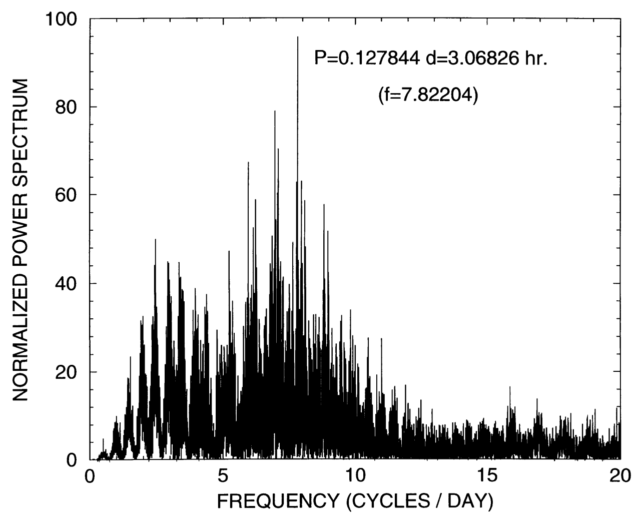

Figure 2. The power spectrum of the 1995–1998 points (I band). The highest peak at the frequency 7.822 04 d^{-1}, marked as P, corresponds to the period 0.127 844 d.

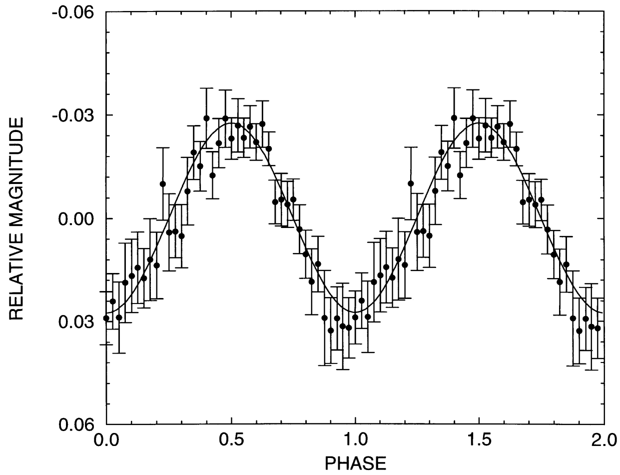

Figure 3. The *I*-filter light curve of the nights in 1995–1998, folded on to the 3.1-h period and binned into 20 equal bins.

years 1992, 1993, 1995–1996 winter and 1996–1997 winter separately. The peak is many σ above the noise level. The fact that it is detected even in the light curves of most of our long-duration nights makes it also highly significant. The other peaks seen in the graph around the highest peak are identified as aliases. The group of peaks on the left-hand side of the diagram corresponds to periodicities that are longer than the typical interval of observations in each night, and might reflect the noise added to our data by the presence of the moonlight. A consistent search for a second real periodicity in the light curve with the various techniques discussed by Retter, Leibowitz & Ofek (1997) was not fruitful.

In Fig. 3 we present the mean light curve of the 1995–1998 observations. We omitted from the data the nights in which the duration of the observations was shorter than one full cycle. The light curve shows a symmetrical sinusoidal variation. The first harmonic fit to the data yields a semi-amplitude of 0.028 ± 0.005. The error corresponds to a 99 per cent confidence level, and it was calculated by a sample of 1000 Bootstrap simulations (Efron & Tibshirani 1993).

The semi-amplitude of the periodicity in the 1992–1993 data is very similar to this value in the 1995–1998 data – 0.031 ± 0.008 – and the shape of the mean light curve is sinusoidal, too. It seems that there is no systematic difference in the amplitude of the variation in the two bands (*I* and *R*). However, the amplitude of the period in the *B* band, which is derived only from a single night (1998 January 9) is consistent with zero. Taking into account the interval length of the observations during this night (8.3 h), and the fact that the variation is clearly detected in the *I*-band data of the same night, we believe that this result is significant.

The best-fitted ephemeris of the periodicity is:

$$T_{\min} = \mathrm{HJD}\ 245\ 0823.2866 + 0.127\,844\ E$$
$$\pm 0.0005 + 0.000001.$$

4 DISCUSSION

4.1 The distance problem

Duerbeck et al. (1979) found a distance of $d = 450 \pm 70$ pc, $A_V = 0.27 \pm 0.13$ and $M_{V(\max)} = -5.3 \pm 0.5$ (Section 1). The latter value is very faint compared with typical values of novae (Warner 1986, 1995). Adopting these numbers and using the current visual magnitude of the nova ($m_V \approx 16$ – Section 2), we can use the distance modulus equation (Allen 1976):

$$m_V = M_V - 5 + 5\log(d) + A_V \tag{1}$$

and find $M_{V(1997)} = 7.4 \pm 0.6$ for DN Gem. This brightness is relatively faint for old novae (Warner 1986; Naylor & Somers 1997), and suggests a very low rate of mass transfer. Alternatively, the distance estimate might be wrong. In addition, when we use equation (7) of Retter & Leibowitz (1998), with a typical white dwarf mass of $1\,\mathrm{M}_{\odot}$, we find that Duerbeck et al.'s values put Nova Gem well below the critical line for the thermal stability limit. This means, that as a probable non-magnetic CV (see arguments for this below), the system should have regular dwarf nova outbursts such as those observed in Nova V446 Her 1960 (Honeycutt, Robertson & Turner 1995; Honeycutt et al. 1998). We, therefore, estimate the distance to the system in a different manner – using the t_2–M_V relation (Warner 1995). From $t_{2V} \approx 16$ d (McLaughlin 1960), we obtain $d = 1600 \pm 600$ pc. We adopt this value, which is much larger than the previous estimate, in this work. The corresponding absolute magnitude of DN Gem in outburst and in 1997 are $M_{V(\max)} = -7.7 \pm 1.0$, and $M_{V_{\mathrm{current}}} = 4.5 \pm 1.0$. These values are almost identical to the estimates of Warner (1986), using the same method but with a slightly different value of t_2. They are typical of absolute magnitudes of novae.

4.2 Identification of the photometric period

We propose that the periodicity that prevails in the light curve of DN Gem through more than 5 yr of photometric observations, $P \approx 3.1$ h, is the orbital period of the underlying binary system. This suggestion is based mainly on the fact that this period was present in all yearly light curves, with no apparent change in its value, amplitude or shape. Typical orbital periods of nova systems range between $P_{\mathrm{orb}} = 1.5$–9 h with a peak around 4 h (Diaz & Bruch 1997), so the proposed orbital period of DN Gem fits in the observed orbital period distribution of novae. Naturally, radial–velocity measurements are required in order to confirm this suggestion.

4.3 Classification of the system and identification of the variation – general remarks

There are a few mechanisms that can generate such variations in old novae. In many cases the various forms of accretion (i.e accretion disc, accretion columns and bright spot) cause modulations in the light. Accretion plays an important role in the light curve of novae after only a few months to years after outbursts (Retter et al. 1997; Retter, Leibowitz & Kovo-Kariti 1998) and certainly many decades afterwards (Bode & Evans 1989). We observed fluctuations of up to 20–30 per cent in the mean magnitude of adjacent nights presented in the light curve of DN Gem (Fig. 1). Such modulations in CVs are usually interpreted as fluctuations of the accretion source.

A major question is whether the white dwarf has a strong magnetic field (the accretion is maintained through accretion column/s) or whether the system is non-magnetic (the accretion stream forms an accretion disc around the white dwarf). We believe that based on the spectrum of DN Gem, which is characterized by a strong continuum and only weak absorption lines (Hummason 1938; Williams 1983), the first scenario can be eliminated, because AM Her systems have strong emission lines in their spectra (Warner 1995). The typical optical spectra, radiated from accretion discs, are characterized by a strong continuum, because the disc is usually optically thick in classical nova systems a few decades after their eruptions (Retter, Naylor & Leibowitz 1999).

In the next few sections we examine a few models for the nova and the variation, and analyse them in the light of our data. One option of an eclipse of one of the light sources of the system (for example the accretion disc), can be immediatedly ruled out from an inspection of the shape of the mean light curve (Fig. 3), which is sinusoidal and does not resemble an eclipse.

4.4 An intermediate polar model?

Intermediate polars (for reviews see Patterson 1994; Hellier 1995, 1996, 1998) are a subclass of CVs. In intermediate polar systems the rotation of the primary white dwarf is not synchronized with the orbital motion of the binary system, unlike the AM Her systems. The spin periods found in intermediate polars are much shorter than their orbital periods (Patterson 1994; Hellier 1996), and range between 33 s in AE Aqr (Hellier 1996) and 1.44 h in Nova V1425 Aql 1995 (Retter et al. 1998). It is believed that in most intermediate polars the accretion is maintained most of the time through an accretion disc (Patterson 1994; Hellier 1996).

The power spectrum of Nova Geminorum (Fig. 2) is inconsistent with a significant second periodicity in addition to the main period (Section 3). Our relatively long (3–4 m) exposure times do not, however, allow us to eliminate the possibility of a very short spin period of the order of a few tens of seconds. Nevertheless, Robinson & Nather (1977) made a high speed photometric search in unfiltered light for very short periods in a sample of 10 novae, including DN Gem. No such period was found in Nova Gem 1912 up to 0.0022 mag and up to the Nyquist frequency (0.1 Hz). This fact suggests that unless the spin period of Nova Gem 1912 is shorter than all known intermediate polar periods, there is no short spin period in Nova Gem.

The intermediate polar model cannot be definitely ruled out. We could consider the observed 3.1-h period as the spin period itself, speculating that a possible longer period (the orbital period) has not been detected so far. If this suggestion were true, the spin period of this system would be the longest among all known intermediate polar systems. However, we believe that a better interpretation for the 3.1-h period is that it is the orbital period of the binary system (Section 4.2).

We conclude that it is very unlikely that an intermediate polar model fits the nova.

4.5 A permanent superhump system?

Permanent superhumps are quasi-periodic oscillations that appear in the light curve of relatively bright CV systems (Osaki 1996; Retter & Leibowitz 1998; Patterson 1999; Retter & Naylor in preparation), with short orbital periods ($P_{\rm orbital} = 17$–225 m). The superhump period is a few per cent longer than the orbital period (la Dous 1993). The precession of the accretion disc, which surrounds the white dwarf, is believed to be the reason for the light variation (Osaki 1989, 1996).

As a bright, short orbital period CV, Nova Gem 1912 is a natural permanent superhump candidate. The fact that the power spectrum of the nova (Fig. 2) does not reveal two periodicities in the light curve does not rule out this hypothesis. First, we believe that we can reject the possibility that the periodicity we detect in Nova Geminorum is a superhump period, based on the stability of the observed period (Sections 3 and 4.2) and on the fact that the superhump variation is believed to be stronger in the blue bands (Warner 1995). Observationally, in one well-investigated object (Nova V1974 Cygni 1992), the amplitude of the permanent superhump variation was very similar in the *B*, *V* and *I* bands (Semeniuk et al. 1994, 1995; Olech et al. 1996; Skillman et al. 1997; Retter et al. 1997). This is unlike the variation in DN Gem, which is below our detection limit in the *B* band (Section 3).

Even if we interpret the detected periodicity as the orbital period of the binary system, the permanent superhump scenario could be applied to the nova. Permanent superhumps, unlike the strict meaning of their name, are not permanently present in the light curves of systems bearing this name. An example is again V1974 Cyg, a well-established permanent superhump system (Skillman et al. 1997; Retter et al. 1997), which is probably the best observed of its kind. The superhump variations were detected in 1994, and since then have been present most of the time in the nova light curve. During a few weeks in 1995 July–August, the superhump modulation either decreased sharply in amplitude or completely disappeared from the light curve (Retter et al. in preparation). Other permanent superhump systems show similar behaviour (Patterson, private communication). We should also keep in mind that, as already mentioned in Section 2, most of the observations presented in this work were not obtained in ideal conditions, but are rather low quality data because they were carried out during bright phases of the moon. The resulting high noise level in the power spectrum (Fig. 2) may, therefore, hide a possible permanent superhump periodicity of low amplitude, or the orbital period itself, if the observed periodicity is interpreted as a superhump period.

We try here to test the permanent superhump hypothesis. Based on the tidal-disc instability model (Osaki 1989, 1996), and assuming that the accretion disc is the dominant light source in the visual band, Retter & Leibowitz (1998) developed a way to check the thermal stability of CVs. Permanent superhumps are supposed to be developed in thermally stable discs, while SU UMa systems (performing regular superhumps in their light curves) are thermally unstable. In this method, the current mass transfer rate of the CV system is estimated by a few system parameters, and compared with the critical thermal instability value.

We use the parameters of DN Gem in the equations of Retter & Leibowitz. The current visual magnitude of DN Gem is $m_V \approx 16.0$ (Section 2), and the distance, $d = 1600 \pm 600$ pc (Section 4.1). We use the interstellar reddening, $A_V = 0.27 \pm 0.13$, which was determined by Duerbeck et al. (1979), although it should be somewhat higher as we believe that they underestimated the distance (Section 4.1). To our knowledge, there is no cited value in the literature for the white dwarf mass; however, $M_{\rm WD} \approx 1\,{\rm M}_\odot$ is a typical value for nova primaries, and a large change in this value does not alter our final conclusion. Inserting all these values into equation (8) of Retter & Leibowitz (1998), we get $\dot{M} \approx 4 \pm 3 \times 10^{17}\,{\rm g\,s^{-1}}$. The critical value of the mass transfer, which we get from equation (1) of Retter & Leibowitz, is about $2 \times 10^{17}\,{\rm g\,s^{-1}}$, so the system is very close to the thermal instability borderline. A definite conclusion cannot be made.

As a concluding remark for this section, we say, that unless a superhump periodicity is found in the light curve of Nova Gem

1912 in the future, in addition to the observed (orbital) period, this scenario cannot be applicable for the system and seems to be excluded by the observations.

4.6 Light from the companion

In this section we test the idea that the variation is generated by light from the red dwarf. We discuss two models.

4.6.1 An ellipsoidal variation?

The ellipsoidal variation is caused by the distorted shape of the secondary star in the binary system, because of the tidal forces exerted by the primary white dwarf. The result is a change in the surface area of the companion, seen by the observer at different phases of the cycle. Such light curves typically have two maxima at phases -0.25 and $+0.25$ relative to conjugation. We believe that there is only a small chance that such a model fits the observational features of DN Gem, because a typical ellipsoidal light curve has a double asymmetrical structure. The mean light curve of Nova Gem 1912 is sinusoidal (Fig. 3). When the mean light curve is folded on to the double period (6.14 h), there is no difference between the two minima within the error limit. An ellipsoidal variation model may, thus, fit the nova only if the change in the light at the two different phases of the cycle mentioned above is coincidentally similar to each other.

A very strong argument against the ellipsoidal variation effect as an explanation for the observed periodicity, is that the secondary star is very faint, and thus does not contribute significantly to the overall light curve of the nova. Using equation (2.102) of Warner (1995) with the alleged period of 6.14 h (twice the periodicity), we find that the visual absolute magnitude of the red dwarf is only about $M_V \approx 8.0$. This value, and the current absolute magnitude of DN Gem (Section 4.1) suggests that the secondary star contributes insignificantly to the light in the binary system – only about 4–10 per cent. Using the code that we apply for the irradiation effect in the next section, we find that the amplitude of the ellipsoidal modulation can be only about 20 per cent of this value or less than 2 per cent of the total flux. This value is inconsistent with the observed peak-to-trough amplitude of about 6 per cent (Section 3).

Based on the above two arguments, we conclude that it is unlikely that the variation is an ellipsoidal effect.

4.6.2 An irradiation effect?

The observed variation in Nova Gem can be simply explained by light coming from the secondary star in the system, illuminated by the vicinity of the white dwarf, or from the various forms of accretion, i.e. an accretion disc, a bright spot, or an accretion column. The typical shape of such a modulation is sinusoidal, which fits the folded light curve of Nova Gem 1912 (Fig. 3).

We investigated the plausibility of the modulation originating from the irradiation of the secondary star using the model described in Somers, Mukai & Naylor (1996) and Ioannou et al. (1999). The model consists of a steady-state accretion disc, flared so as to be triangular in cross-section, with a hot central source that irradiates a Roche-lobe filling secondary star. We chose the white dwarf to be 1 $M_\odot$, and the secondary star to be 0.34 $M_\odot$, appropriate for a main-sequence star that would fill the Roche lobe at a binary period of 3.07 h (Bode & Evans 1989). The chosen pole temperature was 3440 K. The semi-opening angle of the disc was 10°. The disc radius was set at 70 per cent of the Roche lobe of the white dwarf, $0.7R_{L_1}$, close to the tidal radius. For a flat disc, we then searched a two-dimensional χ^2 space in irradiating luminosity and binary inclination. At each point in the grid, we set the mass transfer rate to match the observed *I*-band magnitude, assuming three distances of 1.0, 1.6, 2.2 kpc (Section 4.1). Unsurprisingly, the resulting χ^2 space showed that low inclinations required high irradiating luminosities, while high inclinations required low luminosities. The resulting light curves are almost indistinguishable from sine waves, and hence are good fits to the data, until the inclination is greater than about 60°, when the mutual eclipses of the disc and secondary star begin to affect the shape. Thus, we can rule out these higher inclinations.

The irradiating luminosity is not outrageous for a flat disc (at a luminosity of about 10 $L_\odot$), even at an inclination of only about 10°. This is similar to the accretion luminosity, and therefore could be supplied even without a hot white dwarf. For a flared disc, the flare shadows the secondary star, and so higher luminosities are required. In this case, 10 $L_\odot$ is required at 25°. Finally, we simulated light curves in the *B* band for typical parameters that fit the *I*-band data. These have modulations of around 2 per cent, which are consistent with the one *B*-band light curve we have (Section 3).

In Fig. 4 we display an example of the constraints on the inclination angle, deduced from our model. The overall shape of the χ^2 space varies little with reasonable changes to the chosen parameters, although the position of the contour depends on the parameters chosen. The distance used was 1.6 kpc, which fixed the mass transfer rate by the requirement to match the overall flux level. The χ^2 minimum was rescaled to give a reduced χ^2 of 1, and the contour shown is the 90 per cent confidence region for three parameters of interest (inclination, irradiating luminosity and mass transfer rate). High inclination angles are prevented because of the absence of an eclipse in the mean light curve. Low inclination angles are favoured only for very high luminosities of the irradiated source. In this example we found $10° \lesssim i \lesssim 60°$; however, taking into account the permitted range of the relevant input parameters, we adopt the constraints: $10° \lesssim i \lesssim 65°$. This result is consistent with a previous estimate of $i \approx 50°$ (Warner 1986).

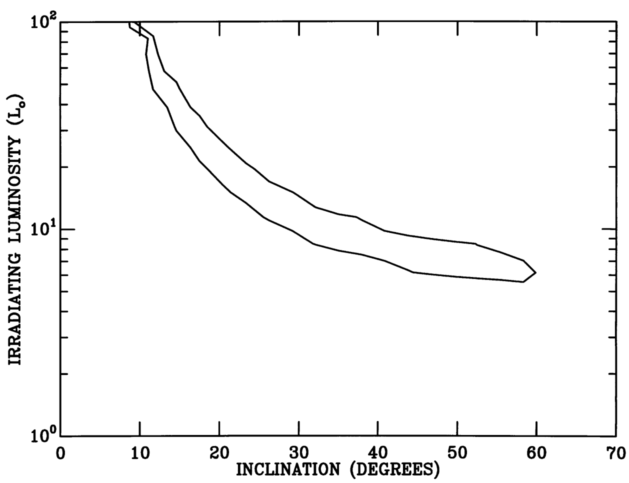

Figure 4. An example χ^2 space for a 2D grid search of inclination and irradiating luminosity, for the *I*-band data. The contour in the (i, L) plane defines the 90 per cent confidence region. See text for more details.

In summary, an irradiated secondary star seems a likely source of the modulation. It reproduces the orbital light curve well, for reasonable irradiating fluxes, which could be provided either by a hot white dwarf, or by accretion luminosity.

4.7 DN Gem as a nova inside the period gap

The observed orbital period distribution of CVs presents a deficiency of systems between about 2 and 3 h, which is termed 'the period gap' (Warner 1995). Diaz & Bruch (1997) used the updated data of Ritter & Kolb (1998), and limited the gap to between 2.11–3.20 h. This interval encompasses the period of Nova Gem 1912. So far, the orbital periods of three other novae are inside the period gap – V Per 1891, QU Vul 1984 and V2214 Oph 1988 (Wood, Abbott & Shafter 1992; Baptista et al. 1993; Shafter et al. 1995; Diaz & Bruch 1997).

Our suggestion that the period observed in the light curve of DN Gem is its orbital period (Section 4.2), makes DN Gem the fourth case of classical nova in the gap, as defined by Diaz & Bruch (1997). The number of nova systems with orbital periods inside the period gap increases, then, to more than 10 per cent of the overall distribution (see Diaz & Bruch 1997). It was suggested (Baptista et al. 1993) that the period gap in the orbital-period distribution of CVs does not exist for novae. The detection of the period in DN Gem supports this claim; however, we will show below that it cannot be backed up statistically. As there is no period gap for systems of which the primaries harbour strong magnetic fields – AM Her systems (Warner 1995) – Baptista et al. also argued that magnetic systems are favoured among novae with orbital periods that lie inside the period gap. Our findings (Section 4.3) do not support this idea.

Undoubtedly, the period distribution of novae is different from that of all CVs, because there is a lack of nova systems below the period gap (Diaz & Bruch 1997; Ritter & Kolb 1998). We here subject to statistical testing the idea of Baptista et al. (1993) that novae do not show a period gap at all. The small number of systems below the gap make it hard to be quantitative about the period gap in novae. We, therefore, ask the question 'Is there a significant change in the number of systems per unit period interval at the upper end of the period gap, somewhere around 3 h?' The answer to this question must be yes, if the gap exists, and so the question is interesting. Furthermore, it turns out to be a well posed question in the statistical sense.

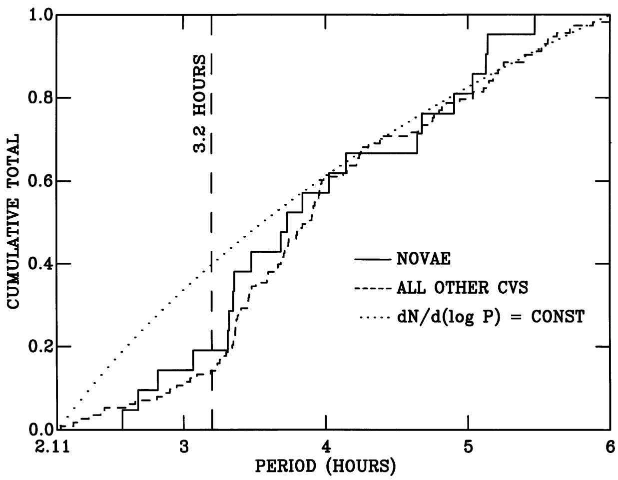

Figure 5. The accumulative distribution of novae, CVs, and a theoretical model of constant distribution, versus the orbital period. The *x*-axis ranges are plotted from the lower end of the period gap until an arbitrary chosen period of 6 h. The distribution of nova systems is not significantly different from the other two distributions.

To answer this question we performed a one-sided Kolmogorov–Smirnov test (Press et al. 1992) of the cumulative distribution of novae between 2.11 h (the bottom of the gap) and 6 h (arbitrarily chosen), against a model distribution with a constant number of systems per unit log period. This gave a 17 per cent chance that the two distributions arise from the same parent population, i.e. the existing data are still consistent with a smooth change of population density with a period around the upper edge of the period gap. In other words, the data are consistent with no gap.

Obviously, with just four systems in the gap the statistics are rather poor, so the next question we asked was if the data were consistent with a period gap. To answer this question, we performed a two-sided Kolmogorov–Smirnov test of the distribution of novae against all CVs (excluding novae) between 2.11 and 6 h. Again, the distributions are consistent, with a probability of 75 per cent of being from the same population. So the answer to the question 'Is there a period gap for novae?' is as yet unsettled. There are simply too few systems to decide.

As primary stars in novae show a variety of magnetic behaviour (Warner 1995), we should not, perhaps, expect that the distribution of classical novae will resemble that of AM Her systems, but rather be similar to that of all CVs.

In Fig. 5 we plot the discussed distribution. It is clear that the distribution of nova systems is not far removed from the all-CVs distribution, or from a constant-period distribution.

5 SUMMARY

The observed sinusoidal variation in DN Gem with the period $P \approx 3.1$ h is interpreted as the orbital period of the nova binary system. This suggestion places Nova Gem near the upper edge of the period gap. Three other novae have orbital periods in the period gap as well. However, the rather poor statistics prevent a verification of the claim that there is no such gap for classical novae.

All possible explanations for the variation, we can think of, seem not to fit the observational data, except for the irradiation effect. We used this model to constrain the inclination angle to $10° \lesssim i \lesssim 65°$.

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