Visual observations of TT Crateris at minimum

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Visual observations of the faint dwarf nova TT Crt at minimum show the orbital lightcurve and enable a period to be determined. The most likely period is 0.2686 days but the two periods suggested by Szkody *et al.* are also revealed in the analysis.

Introduction

The variability of TT Crateris (TT Crt) was discovered by Fleet in 1986 while he was preparing photometric comparison stars for Halley's Comet.[1,2,3] The early observations suggested that this star was an eruptive variable, and spectroscopic confirmation as a dwarf nova was provided by Filippenko[4] in 1989. Further observations by amateur astronomers from all around the world showed that it spends most time near magnitude 16.0 but may reach 13.1 during outbursts. The mean outburst interval is around 100 days and it takes about a week to return to the quiescent level.[5,6]

Szkody *et al.*[7] carried out a campaign of CCD photometry and spectroscopy on this star over the years 1989–1991. They found that, at minimum, it shows a periodic variation in brightness with an amplitude of about 0.35 in V (Figure 1). They interpreted this as an ellipsoidal variation arising from the rotation of the gravitationally distorted cool component of the system. The orbital period of the binary system is about seven hours, during which the lightcurve goes through two maxima and two minima. However, they were unable to determine the period unambiguously; their best estimate was 0.30428 days, but they also found that 0.309 days fits nearly as well.

The observations

In an attempt to detect these periodic variations visually, Fleet made 73 visual observations between 1992 April 21 and May 8, when the star was at minimum. During this period of nearly three weeks the star was observed on most nights, typically five or six times. The observations were made from Harare, Zimbabwe with a 52cm Newtonian reflector at ×150 magnification. Magnitudes were estimated against comparison star G (Figure 2) which has been assumed to have a visual magnitude of 16.0. Heliocentric corrections were applied to the times of the observations before they were analysed.

Periodogram analysis

A period search was performed on the visual observations using the classical Fourier transform method of Deeming.[8] Figure 3 shows the periodogram for frequencies in the range 1 to 10 cycles per day (equivalent to periods from 1.0 to 0.1 days). This shows several large peaks which may correspond to true periods. However, first the possibility has to be investigated that they could have arisen by chance, due to noise in the data, or that they might be artefacts of the time-spacing of the observations.

The probability that the peaks could have arisen by chance was estimated using Fisher's Method of Randomisation, as explained by Nemec & Nemec.[9] One hundred simulations were performed. In each of these, the observation magnitudes were first randomly shuffled (keeping the

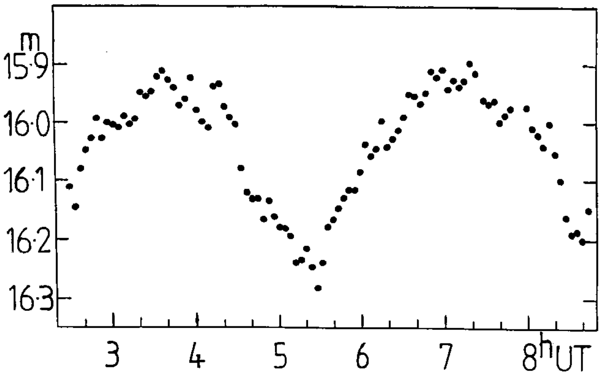

Figure 1. Lightcurve of TT Crt on 1990 Feb 18 from CCD photometry by Szkody *et al.*[7] The zero-point on the magnitude axis has been determined from data given in their paper, but is only approximate.

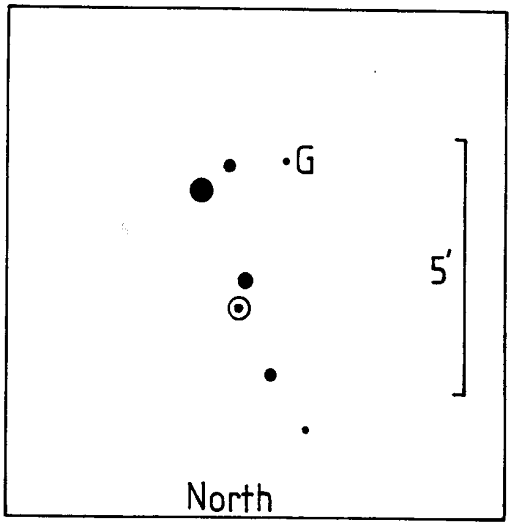

Figure 2. Chart of the field of TT Crt showing the location of comparison star G. The brightest star in the field has a visual magnitude of 12.3.

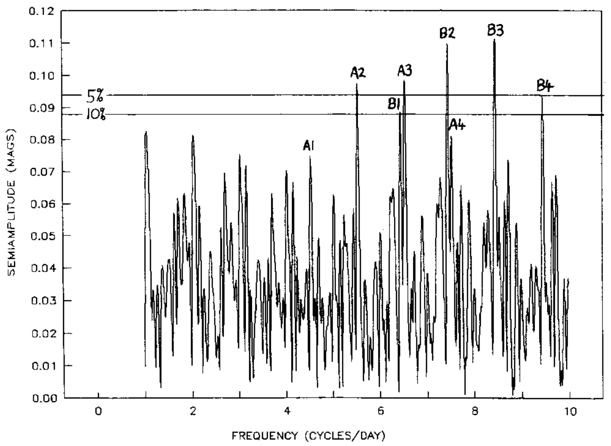

Figure 3. Periodogram of the visual observations of TT Crt. The labels A1 to A4 and B1 to B4 indicate members of the two series of peaks mentioned in the text. The horizontal lines indicate the 5% and 10% significance levels as estimated by the Method of Randomisation.

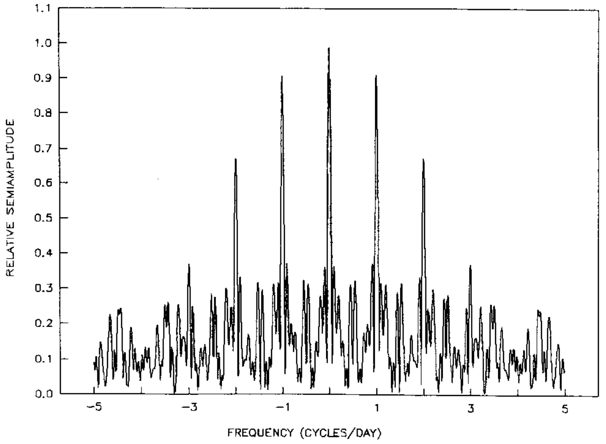

Figure 4. Spectral window function of the times of the visual observations of TT Crt.

times fixed), and then the periodogram was recalculated and the height of the highest peak recorded. In only 5 percent of these simulations was the highest peak above 0.094 magnitudes in height; in all the rest it was below that level. As the highest peaks in the original periodogram are above this 5 percent 'significance' level, it is unlikely (less than 1 chance in 20) that they would have appeared if only random variations had been present in the data. It is therefore most probable that these peaks are the product of a genuine underlying periodicity in the observations.

The possibility that some of the peaks might be artefacts of the time-spacing of the observations was investigated by computing the spectral window function (Figure 4). The window function is the signature of a sinusoidal variation in the data and may be used to identify spurious peaks in the periodogram that arise as a result of the spacing of the observations. Ideally, the spectral window function should consist of a single narrow peak at zero frequency but real data isn't like that. Figure 4 shows that in the present case the central peak has several 'alias' peaks on either side, separated from one another by intervals of 1 cycle per day. These are a result of the observation times being strongly clumped at 1 day intervals.

Table 1. Properties of the four highest peaks in the periodogram

Peak	*Frequency (cycles/day)*	*Semiamplitude (magnitudes)*	*Epoch of min. (JD Hel)*	*Period (days)*
A2	5.535	0.088	2448742.340	0.361337
A3	6.537	0.098	2448742.489	0.305951
B2	7.447	0.110	2448742.382	0.268565
B3	8.449	0.111	2448742.493	0.236714

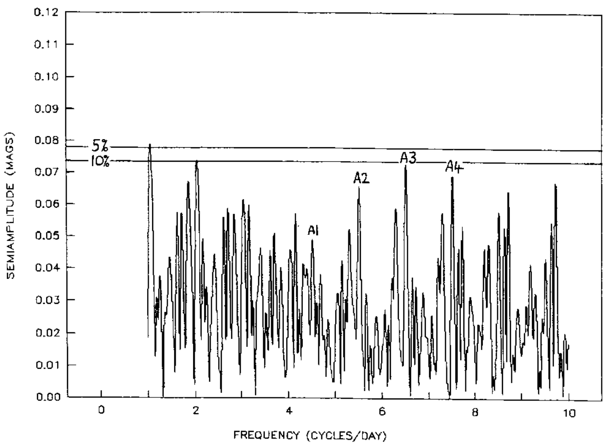

Figure 5. Periodogram of the visual observations of TT Crt after they have been prewhitened by subtracting from them the sine wave corresponding to peak B2. Peaks of the A series are still present but are only just above the background level. The horizontal lines indicate the 5% and 10% significance levels.

Turning back to Figure 3, it can be seen that several of the highest peaks in the periodogram are also separated from one another by intervals of 1 cycle per day. These peaks form two series which have been labelled A1 to A4 and B1 to B4. The properties of the four highest members of these two series are listed in Table 1. The periods given there are the 'double' values corresponding to the orbital period found by Szkody *et al.*[7] The epochs are the times of minimum closest to the mean of the observation times. No attempt has been made to distinguish primary and secondary minima because their depths are so similar. The photometric periods found by Szkody *et al.* appear to correspond to the peaks labelled A3 and B1.

Note that there is no clear central peak in either of the two series – the relative heights of the peaks appear to be slightly distorted when compared with the spectral window function. The most likely cause of this is cycle-to-cycle variations and irregularities in the light-curve which are clearly visible in the photometry of Szkody *et al.* (Figure 1).

The relationship between the peaks in Table 1 was investigated by taking each in turn and subtracting the corresponding sine wave from the original observations. The periodograms of these 'prewhitened' sets of observations were then compared with the original periodogram. As expected, subtracting one member of either series caused all of the other members of that series to disappear, demonstrating that the members of each series are indeed aliases of each other. Subtracting A2 or A3 also caused the heights of the B series to be reduced, but only slightly. However, subtracting B2 or B3 caused a more drastic reduction in the

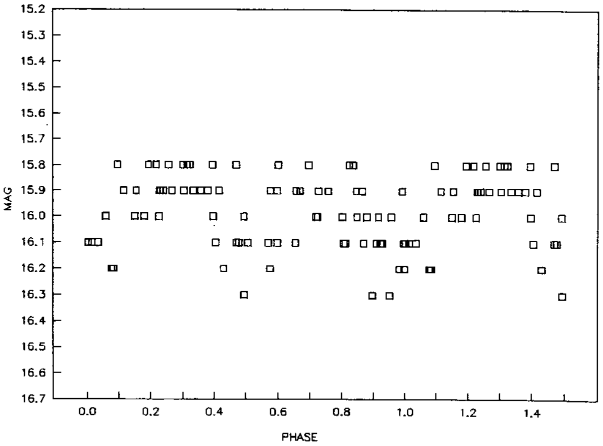

Figure 6. Lightcurve of the visual observations of TT Crt plotted against phase relative to the epoch and period of peak B2.

A series peaks to the level where they almost disappear into the background noise (Figure 5).

The Method of Randomisation was again used, this time on the prewhitened observations, to estimate significance levels. This showed that, while B2 and B3 are still significant at the 5 percent level when A2 or A3 is removed, none of the A series are significant, even at the 10 percent level, when B2 or B3 are removed (Figure 5).

The visual observations therefore clearly favour a period from the B series, B2 or B3 being the most likely. Peak B3, at a frequency of 8.449 cycles per day is marginally larger but corresponds to a period of 0.2367 days, or 5.68 hours. The lightcurve in Figure 1 covers a slightly longer interval and is not compatible with such a short period. Peak B2, on the other hand, corresponds to an orbital period of 0.2686 days, or 6.45 hours, and is consistent with the photometric and spectroscopic data of Szkody *et al.* Figure 6 shows the lightcurve produced by folding the visual observations on the 0.2686-day period. This value is a one-day alias of Szkody *et al.*'s alternative period. Their preferred period is a member of the A series but it is not clear why these two periods should both appear in two such completely different sets of observations. In the visual observations the A series is an alias of the B series, corresponding to the second highest series in the spectral window function (Figure 4), and is reduced to the noise level when members of the principal series are removed (Figure 5). Under the circumstances it does not seem appropriate to seek a physical explanation for the A series.

Conclusions

The visual observations of TT Crt at minimum show the orbital lightcurve and enable a period to be determined. The most likely value for the period is 0.2686 days but either of the periods suggested by Szkody *et al.* must remain a possibility and both appeared in this analysis. Further observations, visual or CCD, will be required to unambiguously determine the period of this interesting system.

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