V973 Cygni – an overlooked semi-regular variable?

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The giant spectral-type-M star V973 Cygni has appeared in various surveys over the past 50 years and is listed in many catalogues, but its variability has not always been recognised. This paper analyses 1,543 visual observations submitted to the BAAVSS over the past 23 years, confirms the 40-day period listed in the GCVS and identifies several longer-term ones.

Background

The star V973 Cygni (=SAO 48789, HR 7523, BD+40 3866, HD 186776, IRAS 19431+4035, BV 286, HIP 97151) has RA 19h 44m 49.0s, Dec +40° 43' 01" (2000) and is listed in GCVS[1] as a variable of type SRb and spectral type M3IIIa, though other sources give M4III. The period is given as 40 days (approximate). The range of variation is given in Sky Catalogue 2000[2] as 6.10 to 6.62V. In 1953 the object came to the attention of Keenan & Keller[3] in their 'Spectral Classification of High-Velocity Stars', and was listed as being intermediate between normal low velocity stars and stars which are members of globular clusters. The relative speed was given as 101 km/sec. In this study V973 Cyg was included as an instance of a 'non-variable' star. Nikulina[4] presented it in 1962 as one of '16 Unstudied Variable Stars in the Records of Bamburg Observatory'. The observations evidently comprised 225 plates taken over the period 1941–1960 inclusive. Nikulina concluded that there was no fixed period, just an irregular variation in light.

In 1967 Eggen[5] conducted broadband photometry of certain red giant stars. Ten observations of V973 Cyg, made between August 1964 and June 1966, confirmed its variability, and exhibited a range of 6.15–6.77 magnitude, a greater range than has been reported by many later observers. In 1971 Eggen[6] again considered V973 Cyg and placed it in the 'Arcturus Group', a group of stars supposed to be moving with Arcturus, alleged to be amongst the oldest of the galactic disc population. He gave orthogonal velocity components of –29, –116 and +47km/sec, consistent (within error bounds) with the speed given earlier by Keenan & Keller. By analogy with similar stars in the other old disc population groups, and from the amplitude he had observed in 1967, Eggen speculated that the period was 80–90 days. McWilliam and Lambert[7] demonstrated in 1984 that V973 Cyg had a CO-band intensity typical of an M giant. In 2001 Percy *et al.*[8] listed the periods of 25 pulsating red giants. He gave periods of 35 and 376 days for V973 Cyg, based upon observations made over an interval of 1,950 days as part of the AAVSO photoelectric photometry programme. They gave an amplitude of 0.4 magnitude. Interestingly, V973 Cyg was identified by Hipparcos as a 'suspected non-single' object, and was on a list of objects passed to groups specialising in speckle interferometry (Mason et al, 1999[9]). Observation with the Mount Wilson 2.5 metre telescope could not however resolve the object further (the resolution limit was estimated at 0.054") so it intriguingly remains an 'unresolved Hipparcos problem star'.

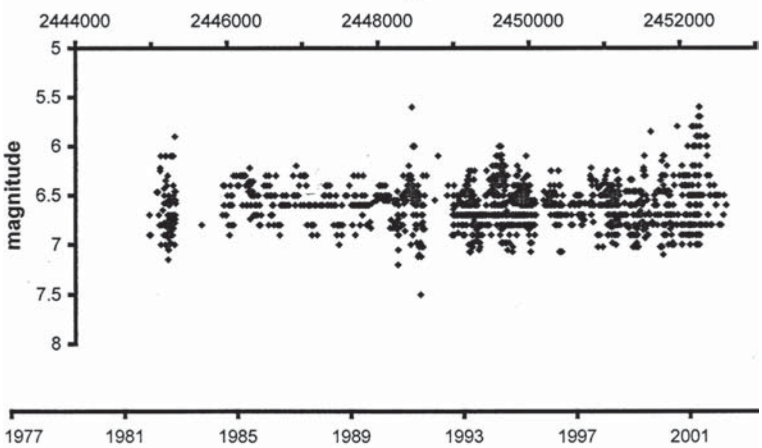

Figure 1. BAAVSS observations plotted against Julian date (top) and calendar years (bottom).

Observations

The BAAVSS recorded a total of 1,543 observations of V973 Cyg from 1982 to 2003 inclusive. These were digitised and checked as part of the Archive Computerisation Project.[10] The mean value of the data was 6.6 magnitude and the standard deviation was 0.24 magnitude. The raw estimates are shown in Figure 1. It can be seen that prior to 1990 (JD 2447890) the observations were rather sparse. They show a distinct 'tramline' effect, caused by the rounding of observations or by the preferred use of certain fractional estimates. This tends to obscure any variation because the eye cannot easily detect subtle preferences toward one 'rail' or the other. Careful inspection of the whole data set suggests varia-

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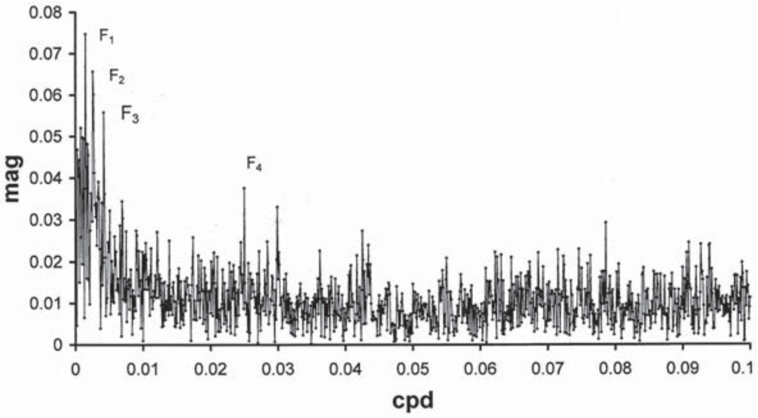

Figure 2. Semi-amplitude spectrum (half peak-to-peak) plotted against frequency (cycles per day) to resolution 0.0001cpd. The marked peaks correspond to the frequencies discussed in the text.

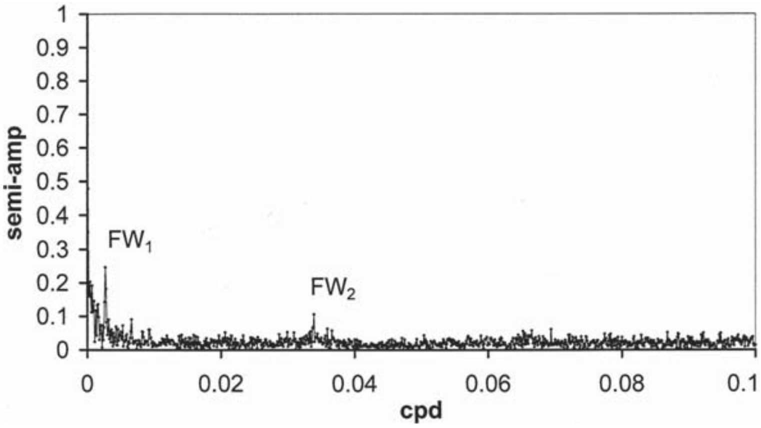

Figure 3. The spectral window function plotted against frequency (cycles per day) to resolution 0.0001cpd. The marked peaks correspond to the frequencies discussed in the text. (The vertical axis is scaled to give 1 at zero frequency.)

tion of the order 400–700 days (*e.g.* around 400 days between about JD 2447000 and 2450400 and 700 days circa 2452000) though more exact calculation is clearly required to determine this periodicity precisely. The data seem free of obvious seasonal gaps. This was to be expected as Cygnus is visible from Northern Europe for at least part of the night all year round. Bearing this in mind, and noting that short (*i.e.* < 40 day) periodicities might be present, it was decided not to pool the data into bins, but to analyse it in its raw form. A spectral window function (SWF) would be calculated later to assess the effect, if any, of the pre-1990 sparsity.

Analysis of the BAAVSS data

A Fourier analysis was carried out on the data and the result is shown in Figure 2. Fourier analysis (or Fourier Transform) is a powerful method of extracting periodic signals from noisy data, and is able to detect effects that would otherwise be obscured by noise or 'tramlining'. It involves splitting a light curve into a series of periodic components. Frequencies up to 0.1 cycles per day (cpd) (*i.e.* a period of 10 days) were examined in increments of 0.0001cpd. The greatest peak is shown at F_1 = 0.00149229cpd (period 670.1 days) with smaller peaks at F_2 = 0.00263981cpd (378.8 days) and F_3 = 0.00421251cpd (237.4 days). All three peaks are significant, by a method discussed by Koen,[11] at the 99.9% level (that is, the probability of each having arisen by chance is < 0.1%). Their respective semi-amplitudes (half peak-to-peak) are $A_1 = 0.075$, $A_2 = 0.072$ and $A_3 = 0.056$. Error bounds for these periods were calculated as, respectively, 1.89, 0.63 and 0.32 days using a formula given by Kovacs,[12] assuming a worst case standard error of 0.24 magnitude, the standard deviation given earlier. Several other high values of semi-amplitude were recorded around F_1 but it is thought that these are caused by phase and amplitude variation in the aforementioned periodicities. The phase and amplitude variation of these periods is investigated later in the *Discussion* section. Further to the right there is an isolated peak, F_4 = 0.02500761 (period 39.988 days) with error bound 0.013 day and semi-amplitude A_4 = 0.038 mag. This turns out to be just statistically significant,[11] at about the 90% level, and more will be said about this later.

To check for possible aliasing, particularly in view of the sparsity already mentioned, the SWF was calculated and is shown in Figure 3. The SWF is calculated similarly to the Fourier Transform except that all observations are set to the same constant value so that peaks represent periodicities in the observation *times*. Peaks are noted at FW_1 = 0.00274 cpd (period 1 year) and at FW_2 = 0.0339 cpd (period 29.5 days) of semi-amplitudes $AW_1 = 0.25$ and $AW_2 = 0.1$ magnitude respectively, but there is little else. FW_2 corresponds to the *synodic* month, which indicates that there is an aversion to observing at full moon. This is not quite so trivial as it seems, as correspondence with the *sidereal* month would have indicated aversion to the moon's proximity in the sky, which would have been slightly different! Aliases can be expected in Figure 2 at frequencies $| F_i \pm FW_j |$ and semi-amplitude $A_i \times AW_j$ (where i = 1, 2, 3, 4 and j = 1, 2). Upon calculation, all such frequencies prove to be well below the noise threshold.

Discussion

The peaks in Figure 2 corresponding to the frequencies F_1, F_2, F_3 and F_4 appear to be quite sharp which suggest periods with little variation in phase over the span of the data. To test this further, the computer program AMPSCAN[13] was run for each of the four frequencies F_1, F_2, F_3 and F_4 separately. AMPSCAN enables phase and amplitude to be derived for each frequency as a function of time, by means of a moving window whose size is generally based on the frequency under investigation. The results are shown in

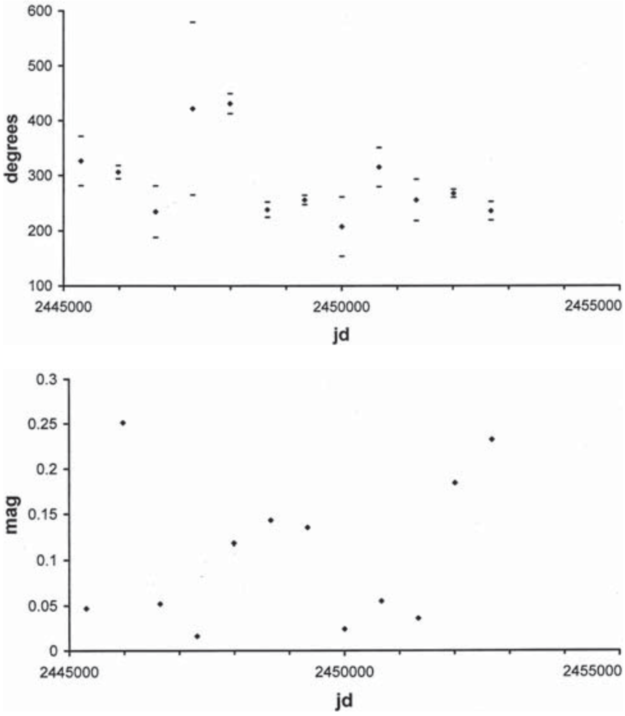

Figure 4. Plot of (a, *top*) phase (with standard error bars) and (b) semi-amplitude of the 670.1-day period versus Julian date.

Figures 4(a)–7(b), the figure numbers denoting, respectively, frequencies F_1, F_2, F_3 and F_4 and (a) denoting phase and (b) denoting semi-amplitude. The phase plots have error bars to show standard errors in the estimates. For frequencies F_1 and F_2 the window size was set to equal the respective period, and the step size was set to the window size, so all estimates of phase and amplitude would be statistically independent of each other. For F_3 the window and step size were still equal, but to *twice* the period (474.8 days), as a narrower window would not have included enough data points. For F_4 the window and step size were again equal, but this time set to equal exactly 10 periods (399.88 days).

Figure 4(a) shows the phase of frequency F_1, the 670.1-day period, to be quite steady at around 260°. The outliers correspond, as expected, to the episodes of small semi-amplitude in Figure 4(b), and the error bars in Figure 4(a) widen accordingly. From Figure 5(a) it can be seen that the phase of frequency F_2, the 378.8-day period, is around 330° but with a considerable amount of scatter. Figure 6(a) shows that the 237.4-day period has a phase centred at about 215°. Over time this phase shows stability. Figure 6(b) shows that the amplitude is not constant, however, experiencing a surge around JD 2448600 (late 1991). Finally, the phase of F_4 (the 40.0-day period) in Figure 7(a) also shows considerable phase stability around 170°, especially since some of the outliers again correspond to the smaller semi-amplitudes (see Figure 7(b)). The semi-amplitude itself fluctuates around 0.04 magnitude, consistent with the earlier calculation of A_4, but with occasional, brief migrations up to over twice this value. The gaps in Figures 5, 6 and 7 between the first and second values of abscissa correspond to windows which did not contain enough data points for phase and amplitude to be reliably calculated.

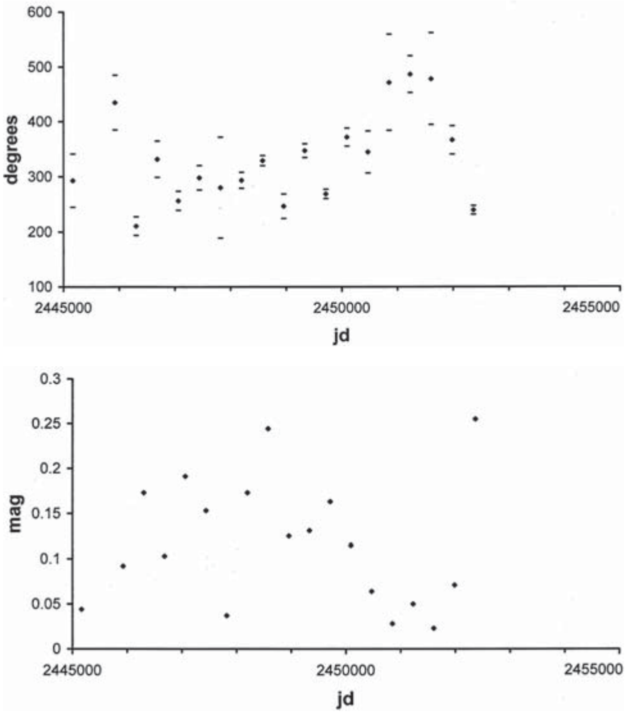

Figure 5. Plot of (a, *top*) phase (with standard error bars) and (b) semi-amplitude of the 378.8-day period versus Julian date.

Although the F_4 frequency is only marginally significant, if frequencies below 0.005cpd are removed from the data, then F_4 becomes significant at the 99.9% level. The value 0.005, which effectively serves here as the boundary between 'short' and 'long' periods, is, of course, quite arbitrary. However, the F_4 period also agrees with that of the GCVS,[1] though this could be considered fortuitous as their period was only approximate.

Percy & Polano[14] identified two groups of bi-periodic M giants, characterised by the ratio of periods: the first has a

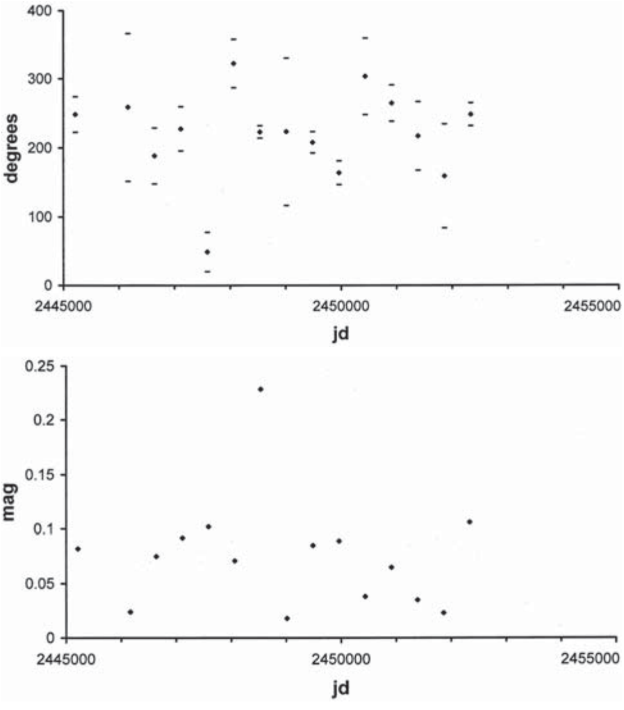

Figure 6. Plot of (a, *top*) phase (with standard error bars) and (b) semi-amplitude of the 237.4-day period versus Julian date.

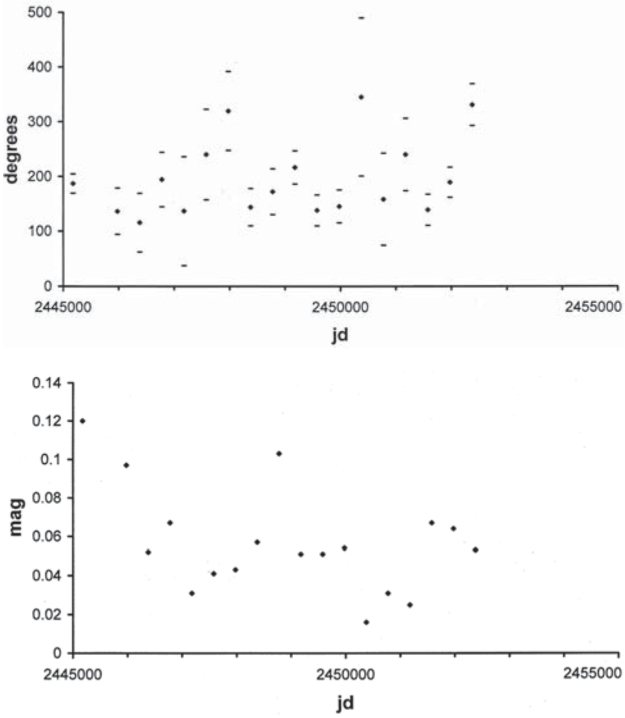

Figure 7. Plot of (a, *top*) phase (with standard error bars) and (b) semi-amplitude of the 40.0-day period versus Julian date.

ratio roughly in the range 10–15, and the second has a ratio of 1.5–2. For V973 Cyg (which is not a star they examined in this work) $F_4/F_1 = 16.76$ and $F_4/F_2 = 9.47$ suggest the former group, whilst $F_2/F_1 = 1.77$ and $F_3/F_2 = 1.60$ fall into the latter. Interestingly, the periods for V973 Cyg given in the IBVS (Percy et al.[8]) yield a ratio of 10.7, inside the former category. Houk[15] also gives many examples of bi-periodic spectral-type-M variables, having an average period ratio of 11.7. A further example is furnished by BR CVn, photoelectrically studied and analysed by West, Howarth & Kiss,[16] which yielded periods of 711.8 and 70.9 days, giving a ratio of 10.04.

Conclusions

V973 Cyg has had various periodicities ascribed to it in the literature, even having been used as a non-variable ‘control’ object. This has been mainly due to lack of observational data, either in density or in time-span. The question of its being a binary is still unresolved. Analysis of BAAVSS data from 1982 to 2003 has shown that it has a cluster of long-term periodicities, most significantly at 610.1, 378.8 and 237.4 days, and a shorter-term periodicity of 40.0 days, this last being in accordance with the GCVS. Despite some variation in the density of the observations, aliasing was not a problem, and none of the main periods is an alias of any other. There is no evidence of any phase shift in any of the periods, and it is this consistency in phase that helps to pull these very low amplitude periods out of the data. This variable appears to conform to a substantial group of spectral-type-M variables which possess long and short periods with a ratio of approximately 10, and shows characteristic ratios between the longer periods of 1.5–2. Both of these are documented characteristics of small-amplitude SR variables.

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