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Archival photographic light curves of the red semiregular star CPD –80°966 [1964–1976], and modern CCD multicolor photometry

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We used digitised scans of plates from the Bamberg Observatory Southern Photographic Patrol Survey to study the variation of the recently discovered semiregular variable star CPD −80°966 from 1964 to 1976. We present evidence to show that the star was varying during the course of the Bamberg survey, but was apparently overlooked at the time. We also present multicolour CCD photometry of CPD −80°966 from 2006 July to 2007 March.

1 Introduction

The star CPD −80°966 was included in the ASAS catalogue of variable stars, being classified as 'miscellaneous' with a characteristic period of 87.6 d (Pojmanski and Maciejewski, 2005) and amplitude ∼0.3 mag in V. The variation was also independently noted by some of the present authors, serendipitously, when performing CCD observations of the known variable CF Oct in 2006 (Innis et al., 2006) – CF Oct and CPD −80°966 are separated by less than 30 arc min on the sky. These CCD data confirmed the semiregular nature of the CPD −80°966. Inspection of the ASAS database and our CCD data (which is now more extensive than that which appears in Innis et al., 2006) show that the interval between successive maxima typically varies from ∼70 to ∼120 d, and possibly can be as short as ∼50 d as shown in our most recent data.

The full range of the long-term variation (i.e. over many cycles of the 90 d period) of CPD −80°966 in the ASAS database approaches one magnitude. This is large enough to be detectable on photographic surveys. We recently obtained scanned digitised images of the Bamberg Southern Photographic Patrol Survey (BSPPS) plates from 1964–1976 for a study of CF Oct (Innis et al., 2004). We reanalysed these scans to extract the historical light curves of CPD −80°966. We present evidence indicating that CPD −80°966 was varying during the course of the BSPPS, and conclude that the variation was overlooked at the time.

2 The Bamberg Southern Photographic Patrol Survey (BSPPS)

The BSPPS was conducted by the Dr Remeis–Sternwarte, Bamberg (Bamberg Observatory) at three southern hemisphere sites (South Africa, New Zealand, and Argentina) between 1962 and 1976, with the specific aim of discovering new variable stars. A description of the program can be found in Strohmeier (1965). A modern description and summary of the BSPPS is given by Tsvetkov et al. (2005). The main work was carried out by a bank of six cameras (of 10 cm aperture) on a common mount, which photographed a swath of declination near meridian transit. Typically the plates reached 14th magnitude for a 1 h exposure, and covered $13° \times 13°$.

We digitised a $2.75° \times 2.75°$ area of the BSPPS plates of the field of CF Oct for a study of that star (Innis et al., 2004). A total of 375 plates were scanned for that study. The scanned images included CPD −80°966, hence we have remeasured these plates for the present study.

3 Analysis and Results

We follow the procedures described in detail in Innis et al. (2004). In outline, we determined plate magnitudes of the target star (CPD −80°966) and five nearby field stars, of comparable magnitude but with a range of $B - V$, using aperture photometry in IRAF. We use the field stars to form, for each plate, a transformation between plate magnitude and B magnitude. (B and V for the field stars were found by transforming Tycho VT and BT magnitudes.) For each set of 5 field stars for each plate we solve, via a least squares Singular Value Decomposition (SVD) method, for the β parameters in the equation

$$B = \beta_1 M_p + \beta_2 M_p^2 + \beta_3(B - V) + \beta_4, \tag{1}$$

where M_p is the plate magnitude.

We then solve for B for CPD −80°966 given the β-terms, the plate magnitude, M, and the star's $B - V$. Our recent photometry indicates the $B - V$ change in CPD −80°966 during a pulsation cycle is only a few hundredths of a magnitude, so for the purposes of the work presented here it can be treated as a constant.

We were able to measure CPD −80°966 on 344 of the 375 scanned plates. In the other cases cloud, tracking errors (e.g. from wind) or other effects (such as plate scratches) interfered. We also measured CPD −80°980 as a control star to check our method. These data are not used in the derivation of the β values. We determine the B magnitudes of the control star in exactly the same way as for CPD −80°966.

The values of the β parameters for the 344 plates we measured are shown in Fig. 1. There is generally good consistency in the value of a given β term within a season. The step near JD 24539500, particularly obvious in the β_2 data, corresponds to the shift of the programme from South Africa to New Zealand (see Innis et al., 2004 for further discussion). The colour term, β_3, (i.e. $B - V$ term) is discussed below.

We use a $B - V$ for CPD −80°966 of 1.7, found from transforming BT and VT. Our recent CCD measurements, which cover several pulsation cycles, give a mean $B-V = 1.78$. We calibrated our CCD filter set from observations of Cousins E-region standards, but we were not able to observe any standard stars redder than $B-V = +1.55$. Hence our $B-V$ determination relies on a slight extrapolation of the calibration equation. In a similar way the reddest field star we used in deriving the β parameters is $B - V = +1.46$ (for CPD −80°965). Hence we require an extrapolation of the $B - V$ dependence of the plate transformation equation (equation 1) in determining the B magnitude for CPD −80°966.

The high declination of the field often meant several plates that included CPD −80°966 were available on a given night, centred at different right ascension. Hence we have averaged all measurements available on given night to reduce observational scatter.

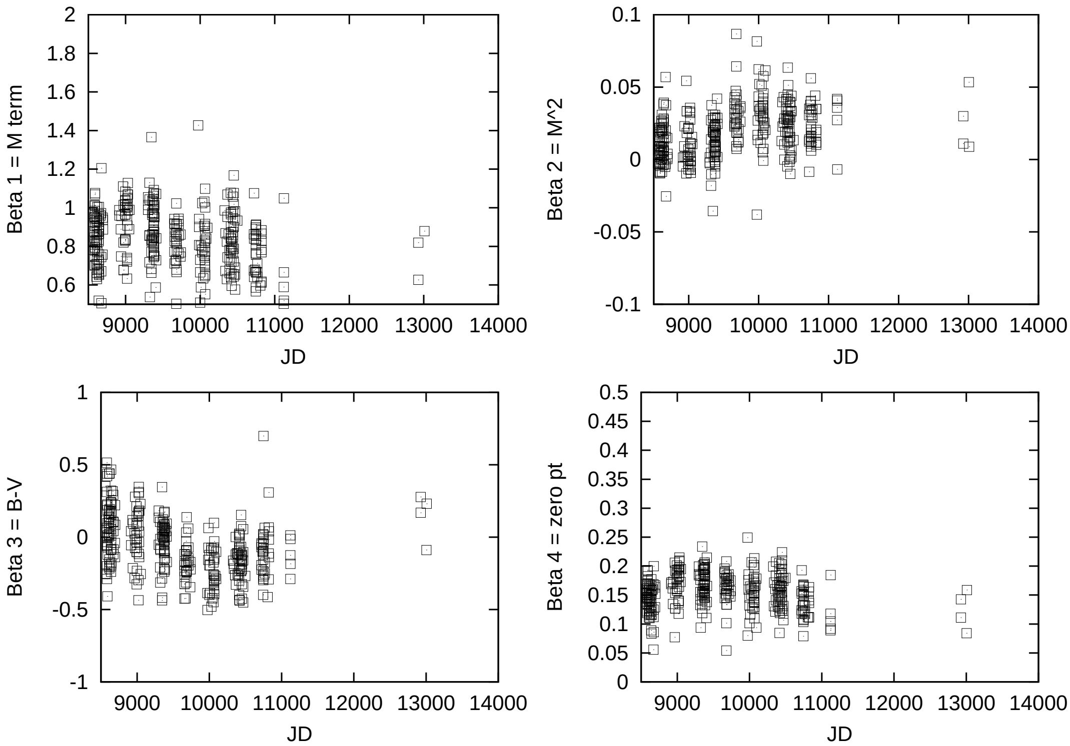

Figure 1. β parameters derived for the 344 plates with useable images of CPD −80°966, plotted versus JD-2430000. Top left: β_1, the term linear in plate magnitude, M_p; top right: β_2, the M_p^2 term; bottom left: β_3, the $B-V$ term; bottom right: β_4, the zero-point.

Figure 2 shows the resulting transformed B data for CPD −80°966 (circles) and the control star CPD −80°980 (upright crosses) for data from 1964 to 1976. The control star measurements show no overall trend, and relatively little scatter. In contrast, the data for CPD −80°966 show a dimming then brightening, as well as an increased noise level. An initial conclusion that could be drawn from Fig. 2 is that CPD −80°966 shows a long-term variation. Such a long-term change in mean magnitude is consistent with the behaviour of the star as seen in the ASAS-3 database. It is important to attempt to rule out artifacts as the cause of the long-term variation in the photographic data.

For example, the colour-term, β_3, shows a possible small decline for the first three seasons, a further, possible step-like decrease between the third and fourth seasons, a small decrease in the fifth season, then an increasing trend thereafter (Fig. 1). However, the derived B magnitudes for CPD −80°966 (Fig. 2) do not show a similar form, but appear to reach a minimum in the second and third seasons, then brighten each season after this. Further, it is difficult to attempt to account for the long-term brightness change of CPD −80°966, which is around 0.5 mag in the seasonal means, purely in terms of a calibration error in the β_3 term. The β_3 term is in the range −0.5 to +0.5, and is simply not large enough to bring about such a result. Based on this analysis, and the fact that the control star CPD −80°980 shows no similar long-term trend, we believe it is likely that CPD −80° 966 did indeed show a long-term variation in brightness during 1964–1976.

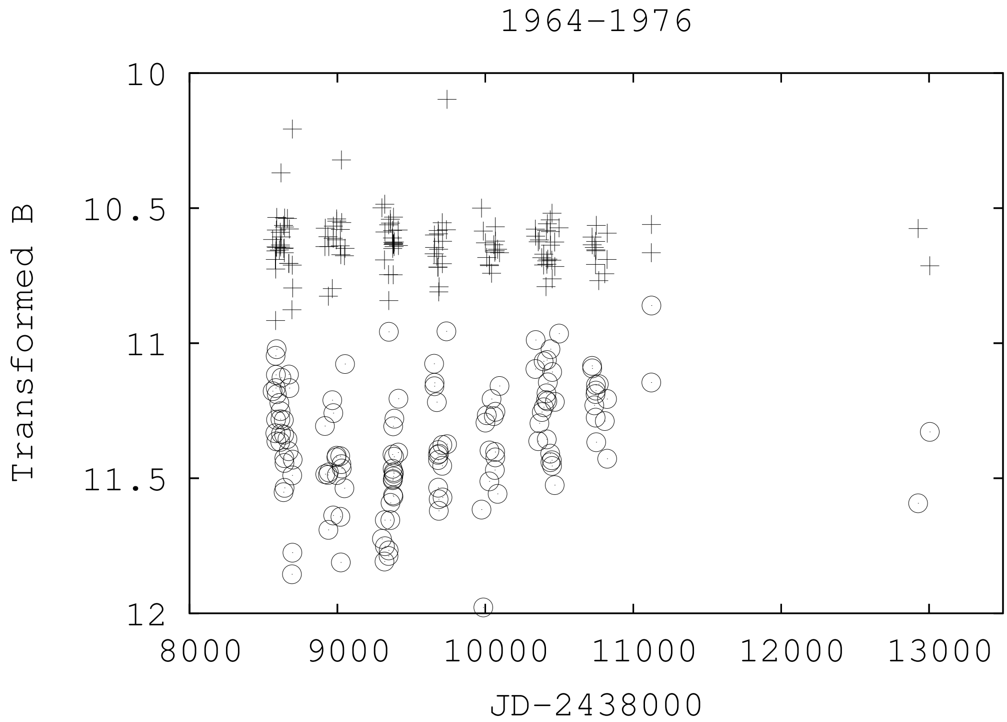

Figure 2. Light curves for CPD −80°966 (circles) and the control star CPD −80°980 (upright crosses) from the analysis of the digitised Bamberg plates, for 1964 to 1976. The data are transformed to standard B magnitudes. Each data point represents an average from all plates taken on that night. Although the light curve for CPD −80°966 shows more scatter than for the control star, probably due to it being fainter, there are also long-term systematic changes that we believe arise from a real variation in the magnitude of this known semiregular variable.

4 Current CCD photometry

CCD photometry obtained at the Brightwater Observatory from 2006 July to 2007 March are shown in Fig. 4. Details of the equipment and observing method are available in Innis et al. (2007). Typically, four exposures were made in a given filter (B, V, and R) and were then combined into normal points, with at least 4 such normal points being collected on a given night. As CPD −80°966 varies only slowly, we present nightly averaged points in this figure and in the tabulated data. The figure shows V and B versus HJD, and $B - V$ versus V in the upper, middle and lower panels respectively. The total range in V is near 0.5 mag. Even in this short interval of data, the time between successive maxima is seen to be very variable, being ∼95 d, ∼75 d, and ∼50 d for the four maxima we have observed. $B - V$ is largest when the star is brightest. This effect is the reverse of that expected from a simple pulsation theory, and was noted by Wisse (1981) to occur in SRb stars of spectral type M. The explanation lies in extreme line blanketing by TiO in spectra of stars of this type, so that $B - V$ is no longer a measure of the star's effective temperature (Smak, 1964; Torres et al., 1993).

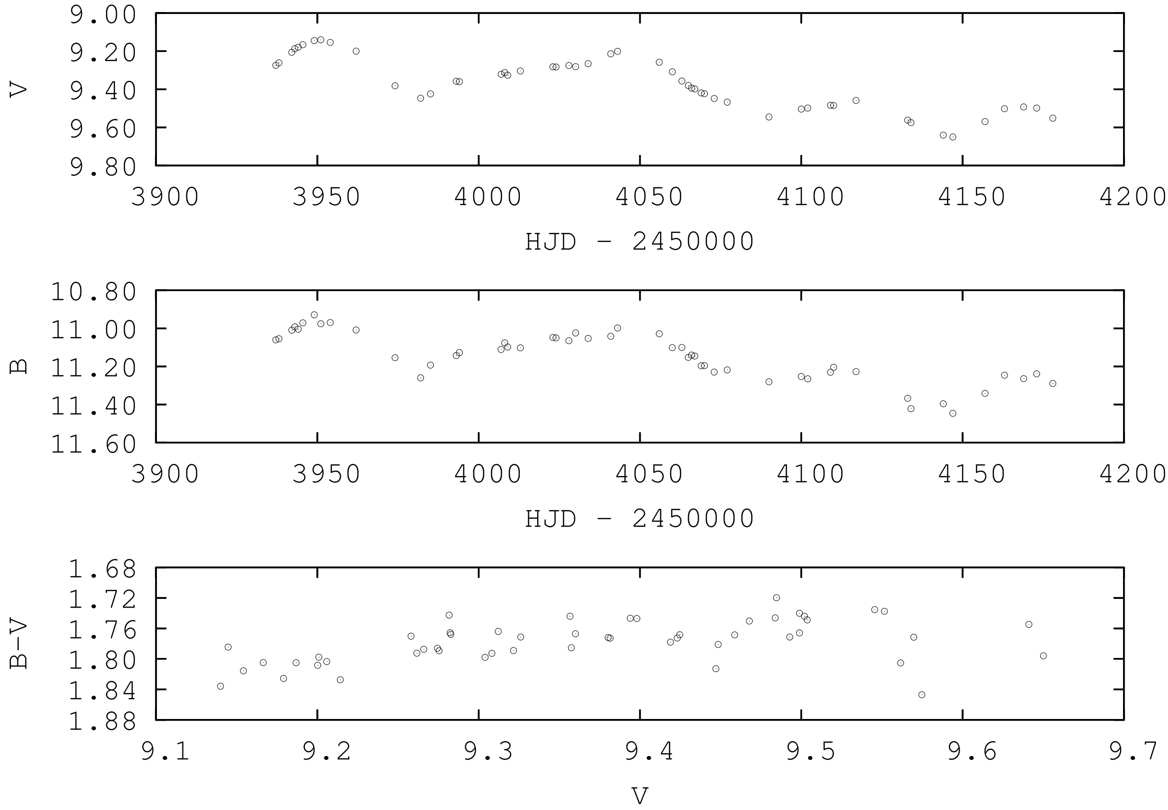

Figure 3. CCD V and B light curves for CPD −80°966 from the Brightwater Observatory, 2006 July to 2007 March (upper and middle panels), and $B-V$ versus V (lower panel).

5 Discussion

Our analysis shows there is little indication of a characteristic ∼90 d periodicity for CPD −80°966 in the Bamberg data, which is however seen in the ASAS-3 database and is supported by our recent CCD photometry. In two seasons, 1964 and 1966, there is evidence for a monotonic decrease and increase respectively over at least ∼120 to 150 d. There may be slight evidence for a ∼100 d periodicity in the 1967 data. In general, the scatter in the data (of order 0.05 to 0.1 mag per averaged point) makes it difficult to see a ∼0.3 mag peak-to-peak variation, which is fairly typical of a given pulsation cycle in the ASAS database and our CCD observations. However, the long–term variations of CPD −80°966 are larger, up to 1 magnitude (ASAS-3 data). We believe that we have good evidence that we have detected long-term changes of similar character in this star in the 1964–1976 interval (Fig. 2).

We have performed a period analysis of all the transformed B data for CPD −80°966 we obtained from the Bamberg plates using both the Phase Dispersion Minimum (PDM) method of Stellingwerf (1978) and the string length method of Dworetsky (1983), with very similar results. Searching in the range from 50 to 1000 d we find the most significant period is near 305 d. Evidence of periodicity from many seasons for a semiregular star of this type, whose light curve varies greatly (e.g. as shown by the ASAS-3 data and our CCD observations), does not necessarily mean that the period has any physical significance: when searching over a large enough period range, some periods will fit the data better than others by random chance. The 305 d period appears to arise mostly from a combination of the monotonic decline in 1964 and the increase seen in 1966, but the 1965 data do not obviously support this. A period search on the post-1966 data reveals only weak evidence for a period near 300 d.

We have also performed a period search on the $\sim$2000 d of data from ASAS-3 CCD photometry for CPD $-80°966$. There is slight evidence for a period near 285 d, but the resulting phase plot is very scattered. Hence we cannot confirm the existence of a $\sim$300 d periodicity in CPD $-80°966$ in these modern data, although the presence of the dominating $\sim$ 90 d period complicates the analysis. If the $\sim$300 d period for CPD $-80°966$ is not an artifact, the period ratio 305 d to 90 d is about 3.4, which is close to the period ratios of a possible sequence of semiregulars considered by Kiss et al. (1999). Continued observations of CPD $-80°966$ would be required to study this, and to see if the star exhibits mode switching (e.g. Kiss et al., 2000).

6 Conclusion

Our analysis of the archival Bamberg photographic plates, via aperture photometry of digitised scans, indicates that CPD $-80°966$ was varying in the interval 1964–1976. We are unable to clearly identify any seasons where the star shows a $\sim$90 d periodicity, which it typically exhibits at the present time. There is marginal evidence for a $\sim$300 d periodicity from the Bamberg data, but this does not appear to be confirmed from modern CCD photometry. Further observations are planned.

Acknowledgments

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