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The photometric variability of the Be star NW Serpentis

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Abstract. NW Ser is a bright ($V = 6\overset{\mathrm{m}}{.}1$–$6\overset{\mathrm{m}}{.}2$), active Be star which is known to vary photometrically on a time scale of hours to days. Using both *Hipparcos* and ground-based photometry, and using light curve, autocorrelation, power spectrum analysis and phase dispersion minimalization techniques, we have concluded that the period is close to $0\overset{\mathrm{d}}{.}46$ – a period typical of stars of this type, and in good agreement with the value of $0\overset{\mathrm{d}}{.}488$, recently determined by Hubert & Floquet from *Hipparcos* data. It is possible that the period is near twice this value, but the evidence is not strong. We also find a period of about $5\overset{\mathrm{d}}{.}5$ from both the ground-based and *Hipparcos* data.

Key words: stars: early-type – stars: emission-line, Be – stars: variables: general

1. Introduction

NW Ser (HR 6873, HD 168797, BD+5°3704, MWC 601; V=$6\overset{\mathrm{m}}{.}1$-$6\overset{\mathrm{m}}{.}2$, $B-V$=$-0\overset{\mathrm{m}}{.}02$, $U-B$=$-0\overset{\mathrm{m}}{.}62$) is a bright, active B3-4Ve star, the brightness of which has been systematically monitored for over two decades (Pavlovski et al. 1997 (the data are published in Harmanec et al. 1997), Percy et al. 1997 and references therein). Variations in V and B on time scales of months to decades appear to be $0\overset{\mathrm{m}}{.}05$ or less (see Pavlovski et al. 1997, Fig. 8, and Percy et al. 1997, Fig. 4). Also earlier UBV observations, found in the astronomical literature, do not indicate any pronounced long-term brightness or color changes. However, there are variations of up to $0\overset{\mathrm{m}}{.}10$ on time scales of hours to days. Many Be stars show variations on time scales of 0.3 to 3 days (see, for example, Percy 1983); they may be either due to non-radial pulsation (Bolton 1982, Percy 1987), or rotation (Harmanec 1983, 1984, 1991, Balona & Engelbrecht 1986, Balona 1990); see Baade & Balona (1994) and Baade (1998) for brief reviews. Such time scales can be difficult to identify and study using ground-based photometry from one site. Even combining data on NW Ser from Europe and North America, we had difficulty identifying the period, if any. The H_p photometry from the *Hipparcos* mission (Perryman et al. 1997) provides new information about the time scale of the variability (though this photometry is not without problems of its own: the distribution of the time intervals between observations is often quite non-random). Hubert & Floquet (1998) have very recently derived periods for many bright Be stars (including NW Ser) from *Hipparcos* data.

2. Analysis

We have used two sets of photometric data: overlapping ground-based UBV data from Hvar Observatory (Pavlovski et al. 1997) and North America (Percy et al. 1997), and photometry which was obtained in a wide-band H_p system by the *Hipparcos* satellite between 1989.85 and 1993.21. For some purposes, the *Hipparcos* photometry was transformed to Johnson V with the help of Harmanec's (1998) formula.

The data were analyzed using four techniques: (i) inspection of the long-term ground-based and *Hipparcos* light curves, and the short-term *Hipparcos* light curves, in cases in which the photometry was continuous over a day or two; (ii) the date-compensated discrete Fourier transform (DCDFT) (Ferraz-Mello 1981), as implemented in a computer program kindly provided by Dr. E.P. Belserene; (iii) autocorrelation analysis (AC; see Percy et al. 1993, for instance); and (iv) phase dispersion minimalization technique (PDM hereafter; Stellingwerf 1978).

3. Results

There are two intervals in which the *Hipparcos* photometry is sufficiently continuous, over one to two days, to define a short-term light curve. (i) JD 2448656.3-57.7: There are 14 observations. The cycle-count period is $0\overset{\mathrm{d}}{.}44$ (Fig. 1). The DCDFT gives two peaks of comparable height: $0\overset{\mathrm{d}}{.}106$ and $0\overset{\mathrm{d}}{.}245$. (ii) JD 2448661.2-62.4.: There are 12 observations. The cycle-count period is $0\overset{\mathrm{d}}{.}43$. The DCDFT gives several peaks of comparable height: 0.143, 0.220, and 0.459 day. The DCDFT of the combined data gives several peaks of comparable height: 0.142 and 0.147, 0.224 and 0.238, 0.433 and 0.476 day. These pairs of peaks reflect the 5-day interval between the two groups of observations, and the first two pairs are submultiples of the third.

The most useful result was the autocorrelation analysis of the *Hipparcos* data (Fig. 2). There is a clear minimum at $0\overset{\mathrm{d}}{.}47 \pm 0\overset{\mathrm{d}}{.}01$, and a minimum near $0\overset{\mathrm{d}}{.}88$; this one is less well

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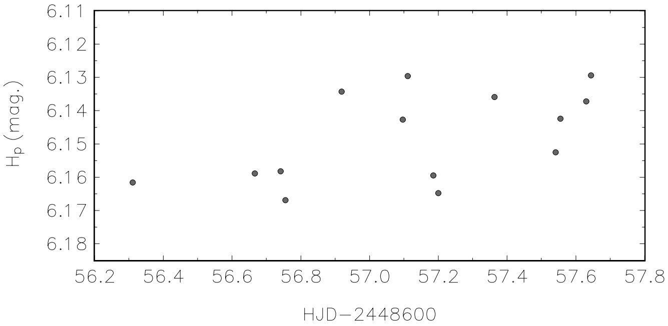

Fig. 1. The light curve of NW Ser, in the *Hipparcos* photometric system, over slightly more than one day

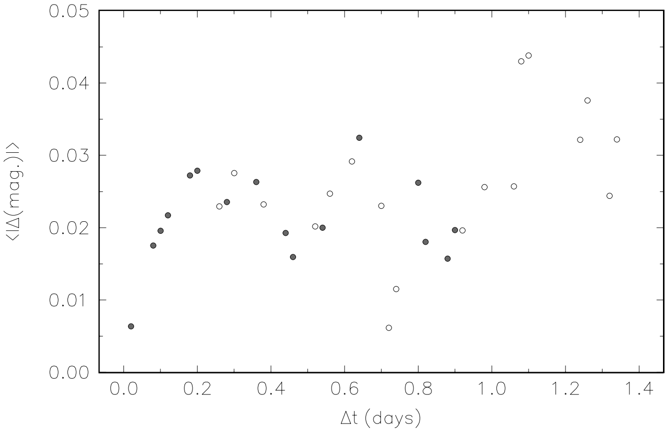

Fig. 2. The autocorrelation diagram for NW Ser, using the *Hipparcos* data. The filled circles have higher weight. The minima suggest a period of about $0\overset{\mathrm{d}}{.}46$

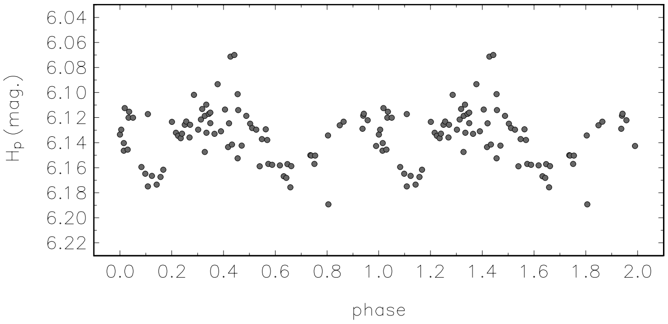

Fig. 3. The phase curve of NW Ser, using the *Hipparcos* data, and a period of twice $0\overset{\mathrm{d}}{.}477622$. The double-wave appearance of the phase curve is more apparent than real

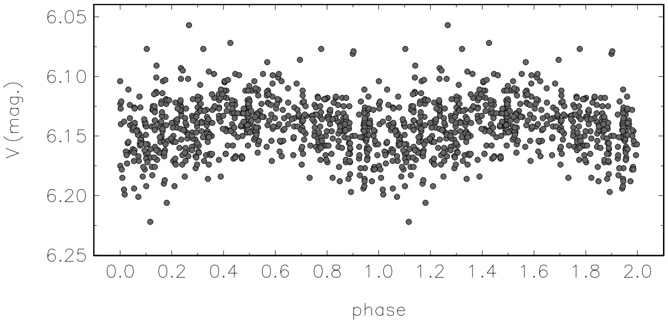

Fig. 4. The phase diagram of the merged ground-based *V* data and the transformed *Hipparcos* data (Harmanec 1998), for a period of $5\overset{\mathrm{d}}{.}491$

defined because there are relatively few pairs of observations which are $0\overset{\mathrm{d}}{.}9$ to $1\overset{\mathrm{d}}{.}1$ apart. Note that autocorrelation analysis produces minima at integral multiples of the basic time scale. The autocorrelation diagram clearly rules out time scales less than $0\overset{\mathrm{d}}{.}4$.

The autocorrelation analysis of the ground-based data was complementary in the sense that, although there were no pairs of observations $0\overset{\mathrm{d}}{.}4$ apart, there were many pairs $0\overset{\mathrm{d}}{.}9$ to $1\overset{\mathrm{d}}{.}1$ days apart. The minimum occurs at $0\overset{\mathrm{d}}{.}925 \pm 0\overset{\mathrm{d}}{.}025$. All of the autocorrelation results are consistent with variation on a time scale of $0\overset{\mathrm{d}}{.}46 \pm 0\overset{\mathrm{d}}{.}01$.

The DCDFT of the *Hipparcos* data has a highest peak at $0\overset{\mathrm{d}}{.}477996$, but there are peaks at periods from $0\overset{\mathrm{d}}{.}406$ to $0\overset{\mathrm{d}}{.}522$ which are almost as high. In particular, the peak at $0\overset{\mathrm{d}}{.}477662$ was only marginally lower. All of them give reasonably clean phase curves.

In Fig. 3, we show the phase curve for a period of twice $0\overset{\mathrm{d}}{.}477622$. The two highest points give the impression of a double-wave curve, but the mean curve shows little evidence for such behavior.

The DCDFT of the ground-based data is strongly affected by aliasing, because of the one-day spacing of the data. The highest peak is around $0\overset{\mathrm{d}}{.}84$, depending on the segment of data used, but the alias peaks are almost as high. The PDM method has also been used to search for periods in the V data; the best period between $0\overset{\mathrm{d}}{.}45$ and $0\overset{\mathrm{d}}{.}50$ is $0\overset{\mathrm{d}}{.}4958887$. Analysis of the merged ground-based V and transformed *Hipparcos* data gives a best period near $0\overset{\mathrm{d}}{.}459$.

We also used the PDM, autocorrelation and power spectrum analysis to search for periods greater than 2 days. A period close to $5\overset{\mathrm{d}}{.}5$ was found by all techniques, independently in both the ground-based and *Hipparcos* data. This suggests that the period is not an artifact. Using the ground-based V data, merged with the transformed *Hipparcos* data (Harmanec 1998), we found a best period of $5\overset{\mathrm{d}}{.}491$. The phase diagram for this period is shown in Fig. 4.

The long-term light curve of the *Hipparcos* photometry is dominated by the short-term variations. Autocorrelation analysis of this and the ground-based data shows a weak minimum at 100 days, but the corresponding full amplitude is less than $0\overset{\mathrm{m}}{.}01$. There is also a weak minimum at 250 days, with comparable amplitude. In the power spectra, the peak at $5\overset{\mathrm{d}}{.}5$ was much higher than any peak for longer periods. Furthermore, there was no evidence for longer-term variations, in the *Hipparcos* photometry, greater than about $0\overset{\mathrm{m}}{.}01$. The mean "$V$" magnitude derived from transformation of the *Hipparcos* photometry was about $6\overset{\mathrm{m}}{.}15$. The seasonal mean V magnitudes found by Pavlovski et al. (1997) and Percy et al. (1997) varied from $6\overset{\mathrm{m}}{.}12$ to $6\overset{\mathrm{m}}{.}17$.

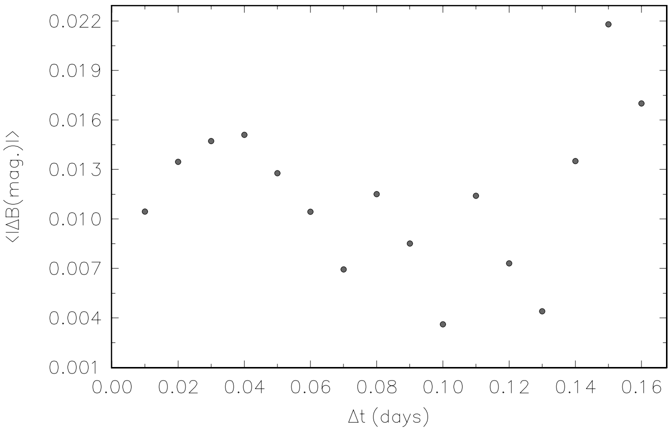

Fig. 5. The autocorrelation diagram for the ground-based *B* data for HR 6900, showing the minimum at a period of $0\overset{\rm m}{.}07$. In autocorrelation diagrams, the first minimum is the most significant; higher minima may or may not occur, depending on the coherence of the variations. Therefore the significance of the minima at $0\overset{\rm d}{.}10$ and $0\overset{\rm d}{.}13$ is not clear. A similar minimum is seen in the *Hipparcos* photometric data at a period of about $0\overset{\rm d}{.}06$

4. Possible variable comparison star

Three comparison stars were used in the ground-based photometry: HR 6900, HR 6925, and HR 6928. The scatters (*s*) in their *Hipparcos* photometry were, respectively $0\overset{\rm m}{.}010$, $0\overset{\rm m}{.}007$, and $0\overset{\rm m}{.}008$. HR 6925 was classified as "constant", the other two were unclassified. For the magnitudes of these stars, such a scatter corresponds more or less to that found for constant stars, perhaps with the exception of HR 6900.

We, therefore, examined the *Hipparcos* photometry of HR 6900 (B9V) in more detail. The light curves for individual days suggested that the time scale of variability – if real – was of the order of hours. The autocorrelation diagrams confirmed this; there were significant minima at $0\overset{\rm d}{.}07$ and its multiples. The power spectrum showed peaks at about $0\overset{\rm d}{.}064$, $0\overset{\rm d}{.}137$, $0\overset{\rm d}{.}204$, and $0\overset{\rm d}{.}255$. The best period near $0\overset{\rm d}{.}07$ was $0\overset{\rm d}{.}064138$. This period gave an acceptable phase curve, with a peak-to-peak range of $0\overset{\rm m}{.}02$ in H_p. Autocorrelation analysis of the ground-based (Hvar Observatory) V and B data (Fig. 5) also showed a minimum at a period of about $0\overset{\rm d}{.}06$. The PDM technique finds $0\overset{\rm d}{.}203$ as the best one. We urge observers at good photometric sites to check on this suspected variability. If really variable, the star might be a δ Scuti variable, though such stars tend to have spectral types of A5 to F2, or even a member of the elusive "Maia variables" – short-period variables with spectral types around A0 IV-V. Two apparent members of this class have recently been discovered by Balona & Laney (1995, 1996).

5. Discussion

Unlike most Be stars, NW Ser appears to show little or no long-term variability. Hubert & Floquet (1998) noted that there was a relation between the amplitude of long-term brightness increases and decreases, and the projected rotational velocity of the star. According to Briot (1986), NW Ser has a v sin i of 295 km s^{-1}– a projected rotational velocity at which some other Be stars show little or no long-term variability (Hubert & Floquet 1998, Fig. 7). See also Moujtahid et al. (1998) for a comprehensive survey and discussion of long-term spectrophotometric behavior of Be stars.

According to our results, NW Ser has a period between $0\overset{\rm d}{.}45$ and $0\overset{\rm d}{.}50$. There is some evidence that the period may be twice this value, and the light curve may be double-wave, but the evidence is not compelling.

Very regrettably, the Hipparcos parallax of NW Ser, π = $0\overset{\prime\prime}{.}00097 \pm 0\overset{\prime\prime}{.}00083$ (Perryman et al. 1997) cannot be used to a reliable radius determination because of its large error. Following Harmanec (1991), we can only estimate the minimum and maximum period of rotation of NW Ser using its spectral type (B4V; Moujtahid et al. 1998), projected rotation velocity (295 km s^{-1}) published by Briot (1986) and the mass and radius calibration derived by Harmanec (1988), which is the best currently available. The minimum period is $0\overset{\rm d}{.}83$ for the Roche model or $0\overset{\rm d}{.}45$ if the radius of the star is not modified by the rapid rotation while the maximum period is $0\overset{\rm d}{.}56$. These values are rather uncertain since we know neither the radius nor the mass accurately enough. Note also that other sources give B3 for the spectral type of NW Ser. It is interesting to note, however, that the observed period (about $0\overset{\rm d}{.}46$) is close to the expected period of Keplerian rotation near the stellar surface ($0\overset{\rm d}{.}55 \pm 0\overset{\rm d}{.}15$).

Although there are stars like NW Ser which have periods in the same range (μ Cen, for instance, see Rivinius et al. 1998), the double period would fall closer to Balona's (1990) period – rotational velocity relation for early B stars.

The short period is not strict enough to appear, clearly, in the power spectra of the large body of ground-based data from various sources, but this is not surprising, given the complexity of the photometric variations in Be stars. It is also possible that the short "period" is only a pseudo-period, which would not show up clearly in a Fourier analysis of a very long dataset.

Periods as long as $5\overset{\rm d}{.}5$ days are not found among the "short-term" variability of Be stars, but are occasionally found (as phase-locked light variations) in binary systems such as CX Dra (period $6\overset{\rm d}{.}696$; Koubský 1978). In this case, the period would be a strict one, but the variability might be complicated by non-periodic phenomena such as episodic mass ejection or transfer.

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