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Research Note

53 Piscium: peculiar amplitude modulation or transient variability?*

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Abstract. Photoelectric observations of this small-amplitude variable, carried out in 1973, 1979, 1987 and 1988, are presented. Much attention is given to atmospheric extinction corrections, which are by no means negligible in most series of observations of the star. No evidence is found for the $0\overset{\mathrm{d}}{.}096$ light variation of 53 Piscium, reported by other workers. Instead, it is shown that 34 Psc, one of the comparison stars used for 53 Psc by most observers, is slightly variable with a similar period. This, however, does not explain the large amplitude observed recently by Wolf (1987). The latter result is also difficult to understand in terms of a beat phenomenon. A peculiar amplitude modulation or transient variability may better account for all observations of the star.

Key words: photoelectric photometry – atmospheric extinction corrections – amplitude modulation – transient variability – β Cep stars – δ Sct stars

1. Introduction

The variability of 53 Psc = AG Psc = HR 155 (B2.5 IV, $V = 5\overset{\mathrm{m}}{.}89$) was first reported by Williams (1954). He concluded, from photoelectric observations carried out on one night, that the star is variable in yellow light with an amplitude of less than $0\overset{\mathrm{m}}{.}01$ and a period on the order of $0\overset{\mathrm{d}}{.}097$. Subsequent observations of 53 Psc by Percy (1971) and by Sareyan et al. (1979) led these authors to conflicting conclusions. Whereas Percy (1971) found the star to be constant, Sareyan et al. (1979) maintained that it should be classified as a β Cep variable.

Recently, Wolf (1987) published a well-defined V light curve of 53 Psc with a range of $0\overset{\mathrm{m}}{.}035$ and a period of about $0\overset{\mathrm{d}}{.}096$, obtained on a single night in 1985. This prompted two teams to report their hitherto unpublished photometric observations of the star. In both cases the results were negative. Le Contel et al. (1988) found no variation larger than $0\overset{\mathrm{m}}{.}01$ on two nights in 1982 and on six nights in 1987, while Balona and Marang (1988) concluded from a periodogram analysis of an observing run in September 1986, spanning 27 days, that 53 Psc showed no significant periodic variation with an amplitude larger than $0\overset{\mathrm{m}}{.}002$.

In the present paper we report observations of 53 Psc, obtained by M.J. in 1973 at Lowell Observatory, and by C.S. in 1979 at the European Southern Observatory, and in 1987 and 1988 at the High Alpine Research Station Jungfraujoch.

2. Observations and reductions

2.1. *The equipment*

At Lowell Observatory the observations were obtained with a photoelectric photometer, attached to the 42-inch reflecting telescope. An EMI 6256SA photomultiplier tube, refrigerated at − 20° C, served as the detector. The signal was fed to the LeCroy Research Systems pulse-counting electronics and the output was recorded by a computerized data-acquisition system, developed by Albrecht et al. (1971).

At ESO the equipment consisted of the Bochum 61-cm telescope and a DC photoelectric photometer with an EMI 9502SA photomultiplier tube, cooled with dry ice. A voltage-to-frequency converter provided digital readout of the output.

At Jungfraujoch the observations were obtained with a 76-cm reflecting telescope and the Geneva P1 photoelectric photometer. A Lallemand S-11 photomultiplier, refrigerated at −23° C, was used as the detector. The system was equipped with a DC amplifier and a strip chart recorder.

2.2. *The observing scheme*

The observations were carried out according to the following scheme:

$$C_1 P C_2 C_1 \ldots, \tag{1}$$

where P, C_1, and C_2 denote measurements of the program and comparison stars, respectively. At Lowell each measurement consisted of five 10-sec integrations, viz., two integrations for the star, one for the sky background, and again two for the star. The comparison stars were C_1 = HD 2714 (A0, $V = 6\overset{\mathrm{m}}{.}9$) and C_2 = 64 Psc = HR 225 (F8 V, $V = 5\overset{\mathrm{m}}{.}07$). All measurements were taken with a Strömgren y filter.

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* Based on observations obtained at the European Southern Observatory, La Silla, Chile, the High Alpine Research Station Jungfraujoch, Switzerland, and Lowell Observatory, Flagstaff, Arizona, USA

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At ESO the comparison stars were C_1 = 34 Psc = HR 26 (B9 Vn, $V = 5^{\mathrm{m}}.51$) and C_2 = 26 Psc = HR 9048 (B9 V, $V = 6^{\mathrm{m}}.21$). Strömgren u and b filters were used. All measurements were made with an integration time of about one minute.

At Jungfraujoch, the Geneva B1 filter was used. The comparison stars were C_1 = 34 Psc and C_2 = 66 Psc = HR 254 (A1 Vn, $V = 5^{\mathrm{m}}.7$). Each measurement lasted about one minute.

2.3. *The atmospheric extinction coefficients*

The observations were corrected for the effect of atmospheric extinction, and then differential magnitudes, ΔP = "P minus a mean of C_1 and C_2" and ΔC = "C_2 minus C_1", were formed.

The Lowell data were corrected using a mean seasonal value of the y band extinction coefficient. This procedure was certainly adequate, because differential air masses never exceed 0.015 for ΔP, and 0.04 for ΔC, so that the extinction corrections were accurate to within $\pm\,0^{\mathrm{m}}.0005$ and $\pm\,0^{\mathrm{m}}.0015$ for ΔP and ΔC, respectively, provided that actual extinction coefficients did not differ by more than 30% from the seasonal mean value. At ESO and Jungfraujoch the differential air masses were, unfortunately, much larger than at Lowell. We therefore made an attempt to derive nightly extinction coefficients from observations of the program and comparison stars. This turned out to be possible on three nights, one at ESO and two at Jungfraujoch. We used the following two methods.

The first method consisted in plotting raw magnitudes of P, C_1, and C_2 as a function of air mass, shifting the magnitudes vertically in order to make them agree at the same abscissae, and then fitting the Bouguer lines to the data by the method of least squares. In the second method, raw *differential* magnitudes, ΔP_1 = "P minus C_1", ΔP_2 = "P minus C_2", and ΔC = "C_2 minus C_1", and the corresponding *differential* air masses were used instead of the magnitudes and air masses. How these methods work is illustrated in Figs. 1 and 2, where they are applied to the Jungfraujoch observations of 21 September 1988. Note that both methods assume constant extinction coefficient over the period of observations. The first method assumes, in addition, that the photometer sensitivity stays constant.

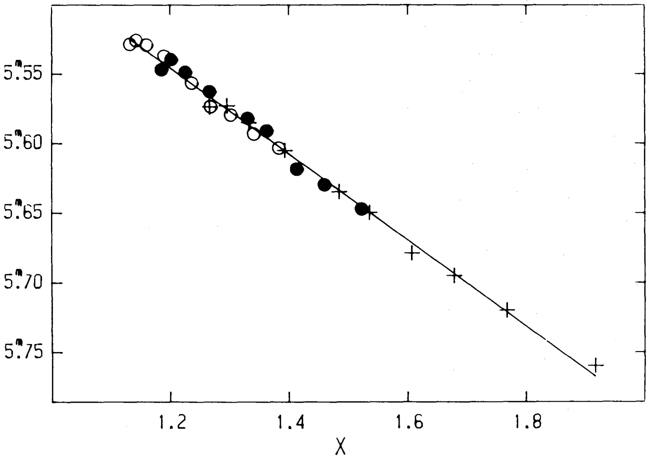

Fig. 1. An illustration of the "mag vs. X" method of deriving the atmospheric extinction coefficient. The raw B1 magnitudes of 53 Psc (filled circles) and the comparison stars, C_1 = 34 Psc (plus signs) and C_2 = 66 Psc (open circles), obtained at Jungfraujoch on 21 September 1988, are shown plotted as a function of air mass, X. The C_1 and C_2 magnitudes were shifted vertically downward relative to P by $0^{\mathrm{m}}.202$ and $-0^{\mathrm{m}}.138$, respectively. Also shown is the Bouguer line, fitted to the data by the method of least squares. The slope of the Bouguer line is equal to 0.309 ± 0.005 mag/a.m.

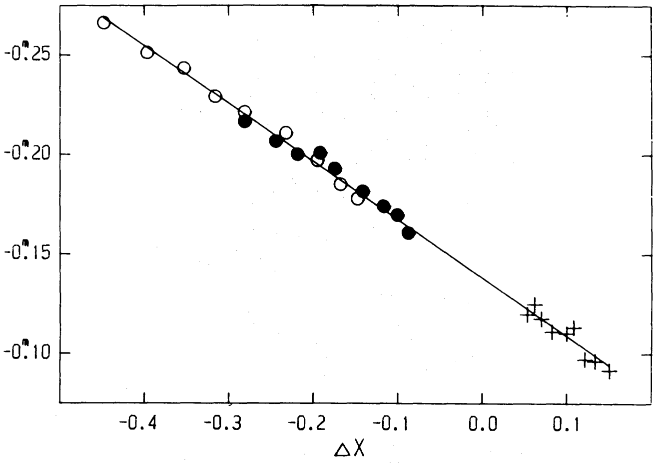

Fig. 2. An illustration of the "Δmag vs. ΔX" method of deriving the atmospheric extinction coefficient. The raw B1 differential magnitudes, ΔP_1 = "53 minus 34 Psc" (filled circles), ΔP_2 = "53 minus 66 Pcs" (plus signs), and ΔC = "66 minus 34 Psc" (open circles), obtained at Jungfraujoch on 21 September 1988, are shown plotted as a function of differential air mass, ΔX. The ΔP_1 and ΔC differential magnitudes were shifted vertically upward relative to ΔP by $0^{\mathrm{m}}.336$ and $0^{\mathrm{m}}.473$, respectively. Also shown is the straight line, fitted to the data by the method of least squares. The slope of the straight line is equal to 0.292 ± 0.004 mag/a.m.

The extinction coefficients, in magnitudes per air mass (mag/a.m.), derived by means of the above-mentioned two methods, are listed in Table 1. On 17 September 1987, the only night with observations on both sides of the meridian, we found a linear variation of the photometer sensitivity, amounting to 0.013 mag h^{-1}. This effect was removed from the data before using the "mag vs. X" method. On the remaining nights the measurements were taken on one side of the meridian, so that small, linear sensitivity variations could not be detected. If present, they affected the slope of the Bouguer lines, and therefore introduced errors into extinction coefficients derived by the "mag vs. X" method. The reasonably good agreement, seen in Table 1, between extinction coefficients, obtained on the same nights by the two methods, shows that these errors were insignificant.

3. Results

3.1. *Lowell Observatory*

At Lowell, 53 Psc was observed on four nights in September and October 1973. Observations spanned an interval of 18 days. The results are shown in Fig. 3, plotted as a function of phase of Wolf's (1988) period of $0^{\mathrm{d}}.096$. Each plotted point is a mean of two or three successive differential magnitudes. As can be seen from the figure, the program and both comparison stars are remarkably constant in light. The entire light-range amounts to about $0^{\mathrm{m}}.004$ and $0^{\mathrm{m}}.005$ for ΔP and ΔC, respectively.

3.2. *The European Southern Observatory*

At ESO, the observations were obtained on four nights: 13, 16, 17, and 18 October 1979. The mean values of the 16 October

Table 1. The atmospheric extinction coefficients, derived by means of the two methods described in the text

Date	F	"mag vs. X"	"Δmag vs. ΔX"	Site
16 Oct. 1979	u	0.578 ± 0.004	0.587 ± 0.005	La Silla
	b	0.163 ± 0.004	0.204 ± 0.004	
17 Sept. 1987	$B1$	0.382 ± 0.004	0.394 ± 0.005	Jungfraujoch
21 Sept. 1988	$B1$	0.309 ± 0.005	0.292 ± 0.004	

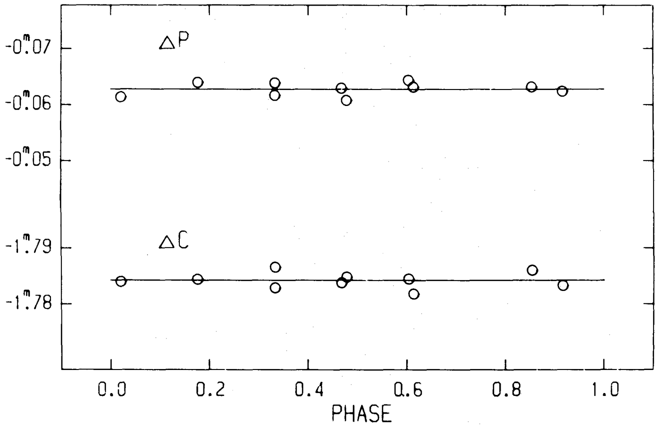

Fig. 3. The Lowell differential photometry of 53 Psc, shown as a function of phase of the $0^{\rm d}.096$ period. Zero phase corresponds to JD 2441953. The observations were obtained with a Strömgren y filter. Each plotted point is a mean of two or three successive differential magnitudes, ΔP = "P minus a mean of C_1 and C_2" (top), and ΔC = "C_2 minus C_1" (bottom), where P = 53 Psc, C_1 = HD 2714, and C_2 = 64 Psc. The mean level lines are also shown. They fit the data with standard deviations equal to $0^{\rm m}.0012$ and $0^{\rm m}.0014$ for ΔP and ΔC, respectively

1979 extinction coefficients of Table 1 were used in the reductions. Results of the u and b observations are plotted in Figs. 4 and 5, respectively, also as a function of phase of the $0^{\rm d}.096$ period. In both cases, the scatter around the mean level lines, measured by the standard deviations given in the captions to the figures, is substantially larger than in the case of the Lowell data. This was caused mainly by the following two circumstances: (1) air masses at ESO ranged from about 1.2 to almost 2.0, while at Lowell all observations were obtained through air masses not exceeding 1.2, (2) differential air masses, very small at Lowell, at ESO ranged from -0.16 to 0.41.

The relatively large air masses and differential air masses, in connection with the much larger atmospheric extinction in u than in b, explain also why the u standard deviations (Fig. 4) are substantially larger than the b ones (Fig. 5). Finally, the somewhat larger scatter of ΔP, as compared with that of ΔC, seen especially in the u data on 16 October (filled circles in Fig. 4), can be accounted for by the fact that the air masses and the differential air masses were larger for P than for C_1 and C_2.

In spite of these circumstances, which made observing 53 Psc from ESO much more difficult than from Lowell, our ESO observations put quite stringent limits on the amplitude of the $0^{\rm d}.096$ variation. As can be seen from Figs. 4 and 5, the amplitude (half range) did not exceed $0^{\rm m}.010$ in u and $0^{\rm m}.005$ in b.

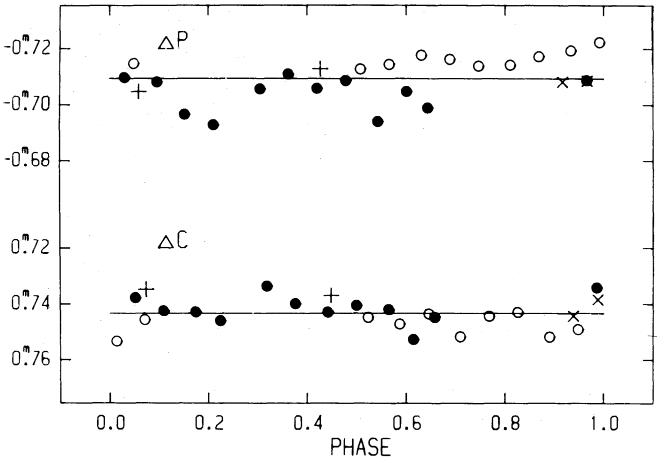

Fig. 4. The ESO differential photometry of 53 Psc, obtained with a Strömgren u filter, shown as a function of phase of the $0^{\rm d}.096$ period. Phase zero corresponds to JD 2444159. Plotted are differential magnitudes, ΔP = "P minus a mean of C_1 and C_2" (top), and ΔC = "C_2 minus C_1" (bottom), where P = 53 Psc, C_1 = 34 Psc, and C_2 = 26 Psc. Observations made on different nights are indicated with different symbols: JD 2444159 (open circles), JD 2444162 (filled circles), JD 2444163 (crosses), and JD 2444164 (plus signs). The mean level lines fit the data with standard deviations equal to $0^{\rm m}.0075$ and $0^{\rm m}.0055$ for ΔP and ΔC, respectively

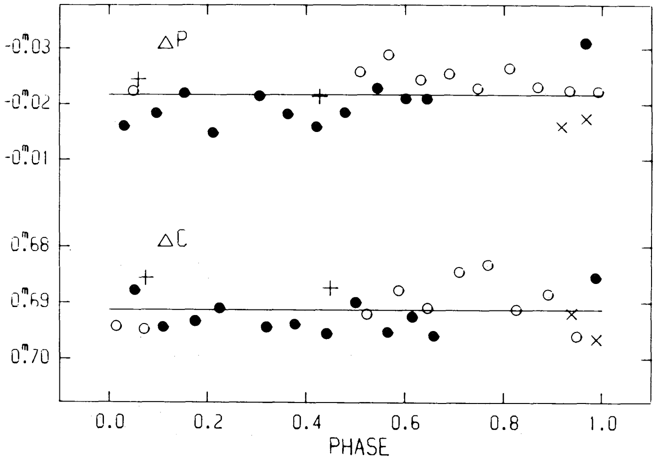

Fig. 5. The ESO differential photometry of 53 Psc, obtained with a Strömgren b filter. The abscissae and symbols are the same as in Fig. 4. The mean level lines fit the data with standard deviations equal to $0^{\rm m}.0041$ and $0^{\rm m}.0039$ for ΔP (top) and ΔC (bottom), respectively

3.3. The High Alpine Research Station

At Jungfraujoch, 53 Psc was observed on two nights in September 1987, and also on two nights in September 1988. The 1987 data were reduced using the mean value of the 17 September 1987 extinction coefficients of Table 1. The results are shown in Fig. 6. The first night, 16 September (filled circles), was cloudy at the beginning. It cleared later, but very soon the observations were stopped by cirrus. The second night, 17 September (open circles), was clear all the time, but with some transparency variations during the first couple of hours. As can be seen from Fig. 6, there is no reason to suspect variability of either the program or the comparison stars. In particular, the upper limit for the amplitude of the $0^{\rm d}.096$ variation, estimated from the second night's observations, is equal to $0^{\rm m}.005$.

In reducing the 1988 data we tried a similar approach as before, that is, we used for both nights the mean value of the 21 September extinction coefficients, equal to 0.300 mag/a.m. This turned out to be adequate for ΔP, but not for ΔC. The latter showed a difference in the mean level between the two nights, amounting to $0^{\rm m}.006$. By increasing the extinction coefficient for 20 September to 0.320 mag/a.m. we removed this difference, without affecting ΔP. The large sensitivity of ΔC to extinction coefficient resulted from the fact that differential air masses corresponding to ΔC ranged from 0.19 to 0.29, whereas those corresponding to ΔP did not exceed 0.04.

The results of the 1988 observations are shown in Fig. 7. As before, there is no evidence for a $0^{\rm d}.096$ variation of 53 Psc. However, a $0^{\rm d}.096$ variation seems to be present in the comparison stars observations. Fitting a $0^{\rm d}.096$ sine-curve to ΔC by the method of least squares confirms this impression: the resulting amplitude is equal to $0^{\rm m}.005 \pm 0^{\rm m}.001$, and the standard deviation of the fit amounts to $0^{\rm m}.0024$, much less than the mean level standard deviation, given in the caption to Fig. 7. A closer examination of the differential magnitudes "53 minus 34 Psc" and "53 minus 66 Psc" showed that the star responsible for the variation is 34 Psc.

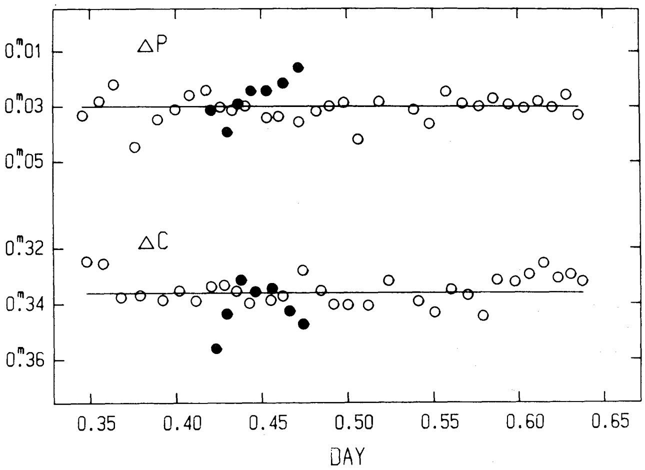

Fig. 6. The 1987 Jungfraujoch differential photometry of 53 Psc, shown as a function of heliocentric Julian day. The observations were obtained with the Geneva B1 filter on two nights, JD 2447055 (filled circles) and JD 2447056 (open circles). Plotted are differential magnitudes, ΔP = "P minus a mean of C_1 and C_2" (top), and ΔC = "C_2 minus C_1" (bottom), where P = 53 Psc, C_1 = 34 Psc, and C_2 = 66 Psc. The mean level lines fit the data with standard deviations equal to $0^{\rm m}.0055$ and $0^{\rm m}.0066$ for ΔP and ΔC, respectively. If the JD 2447055 points were rejected, these numbers would reduce to $0^{\rm m}.0047$ and $0^{\rm m}.0052$

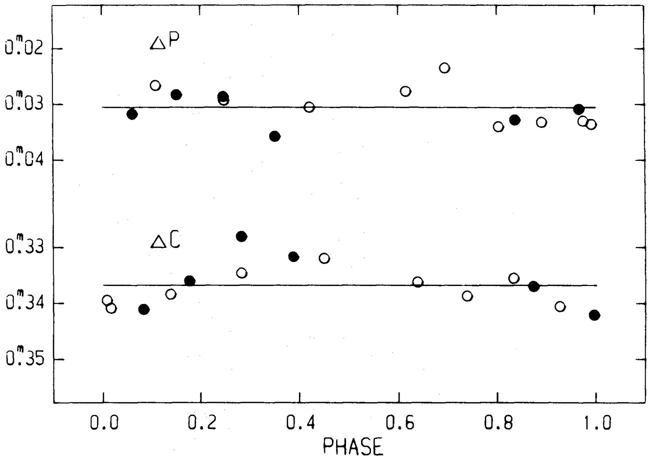

Fig. 7. The 1988 Jungfraujoch differential photometry of 53 Psc, shown as a function of phase of the $0^{\rm d}.096$ period. Phase zero corresponds to JD 2447425. The observations were obtained with the Geneva B1 filter on two nights, JD 2447425 (filled circles) and JD 2447426 (open circles). Plotted are differential magnitudes, ΔP (top), and ΔC (bottom), defined in the same way as in the caption to Fig. 6. The mean level lines fit the data with standard deviations equal to $0^{\rm m}.0033$ and $0^{\rm m}.0040$ for ΔP and ΔC, respectively

Because of this unexpected result, we re-examined the 1979 and 1987 observations of the comparison stars. A clear evidence for a variation with a period equal to about $0^{\rm d}.096$ was found in the u filter differential magnitudes "26 minus 34 Psc" (lower panel of Fig. 4). This confirms the above conclusion that 34 Psc is responsible for the variation.

4. Discussion

Apart from Williams' (1954) discovery paper and the recent report by Wolf (1987), the only evidence for short-period light variability of 53 Psc was presented by Sareyan et al. (1979). These authors observed the star on four nights in September 1971. The observations were carried out from ESO, using a Geneva type photometer and two filters, similar to Strömgren's u and b. On two nights, judged by Sareyan et al. to be of excellent quality, they saw a variation with a period of $0^{\rm d}.08 \pm 0^{\rm d}.02$ and an amplitude of $0^{\rm m}.005$ in u and less than $0^{\rm m}.002$ in b. They could not see this variation on the other two nights, which they rated "good" and "very good".

Sareyan et al. (1979) used only one comparison star, 34 Psc. In this they were probably guided by the circumstance that the star was found rigorously constant on two nights in 1971 by Sareyan et al. (1976). The same comparison star was also used by Williams (1954). However, in view of the evidence presented in Sect. 3.3, the variation attributed by these observers to 53 Psc may in fact have been due to 34 Psc. Consequently, Wolf's (1987) V light-curve, obtained with two comparison stars, 34 and 66 Psc, becomes the only strong evidence for the light variability of 53 Psc. It is thus somewhat unfortunate that Wolf's (1987) note contains no details of his observations and reductions.

Whether the earlier reports of variability of 53 Psc are taken at their face value or ignored, the relatively large amplitude observed by Wolf (1987) needs accounting for. Wolf (1987) himself suspects interference between two oscillations of different periods, resulting in a beat phenomenon. This explanation, although feasible in principle, becomes very unlikely if the negative results of Balona and Marang (1988), Le Contel et al. (1988), and the present paper are taken into account.

In order to prove this, we shall first estimate the minimum length of the beat-period from the duration of the longest interval over which the star was found nonvariable.

Interference of two oscillations, represented in the following by two sinusoids of the same amplitude, A, and periods equal to P_1 and P_2, leads to amplitude modulation of the form:

$$A_{\rm beat} = A\sqrt{2[1 + \cos(2\pi t/P_{\rm beat})]}, \qquad (2)$$

where $P_{\rm beat} = 1/(1/P_1 - 1/P_2)$ is the beat-period. From this equation it follows that the time required for the amplitude to reach a certain value $A_{\rm obs}$, counted from the epoch of $A_{\rm beat} = 0$, is equal to

$$\Delta t_{\rm min} \approx \frac{P_{\rm beat}\, A_{\rm obs}}{2\pi A}. \qquad (3)$$

Assuming $A = 0^{\rm m}\!.010$, that is, about half the amplitude (one-fourth the range) found by Wolf (1988), and taking into account Balona and Marang's (1988) results, that is, $A_{\rm obs} = 0^{\rm m}\!.004$ (twice their upper limit of the observed amplitude to compensate for the amplitude increase from $A_{\rm beat} = 0$) and $\Delta t_{\rm min} = 13^{\rm d}\!.5$, we get $P_{\rm beat} > 210^{\rm d}$. The Lowell results, presented in Sect. 3.1, lead to $P_{\rm beat} > 130^{\rm d}$.

From Eq. (2) it also follows that the interval over which the amplitude in the beat cycle stays within Δm of its maximum value amounts to

$$2\Delta t_{\rm max} \approx \frac{2P_{\rm beat}}{\pi}\sqrt{\Delta m/A}\,. \qquad (4)$$

Two conclusions can be drawn from the last equation. First, each beat cycle the amplitude of the light variation will stay within 0.1 of its maximum value for about $P_{\rm beat}/3.5$. Second, the probability of observing the amplitude within 0.1 of its maximum value is about 3.5 times the probability of finding that it does not exceed 0.1 of the maximum value. These conclusions, together with $P_{\rm beat} > 210^{\rm d}$, derived above, make it indeed difficult to understand why 53 Psc showed its (presumably) maximum amplitude only in 1985, while remaining apparently constant, or very nearly so, in 1973, 1979, 1982, 1986, 1987, and 1988.

Thus, in order to understand the available observations of 53 Psc in terms of amplitude modulation, one may have to postulate that the amplitude stays below the detection threshold most of the modulation cycle. Another possibility is that the star shows transient short-period variations, an alternative suggested by Balona and Marang (1988). Either case will be very difficult to verify observationally. In view of the atmospheric extinction problems, discussed at some length in the preceding section, future reports of variability of 53 Psc should include details of observations and reductions. Hopefully, details of Wolf's (1987) observations will also become available. This would help to eliminate the possibility that his result was due to short-term atmospheric extinction variations, not uncommon at most sites in Europe.

5. Conclusions

From observations carried out in 1973, 1979, 1987 and 1988 at three observatories we find no evidence for the $0^{\rm d}\!.096$ light variation of 53 Psc, reported by other workers. Instead, we suspect that 34 Psc, one of the comparison stars used for 53 Psc, is slightly variable with a similar period. This, however, does not explain the large amplitude observed recently by Wolf (1987). The latter result is also difficult to understand in terms of a beat phenomenon. A peculiar amplitude modulation or transient variability may better account for all observations of the star.

Neither of the two stars can be easily fit into a common class of variable stars. 53 Psc is considerably cooler and less luminous than such cool and low luminosity β Cep variables as, for instance, γ Peg or V2052 Oph. In its effective temperature it is, however, rather similar to 22 Ori and ι Her, two puzzling small-amplitude variables. The first of these objects shows transient milimagnitude oscillations in the Strömgren b band with a time scale of $0^{\rm d}\!.10$ (Balona and Engelbrecht 1985). The second has a period equal to either $0^{\rm d}\!.12$ or $0^{\rm d}\!.14$ and an amplitude (half range) equal to $0^{\rm m}\!.004$ in an optical ultraviolet band at 3500 Å (Chapellier et al., 1987). In both cases, however, longer period variations of unknown origin are also present. Chapellier et al. (1987) have suggested that 22 Ori and ι Her represent a low temperature extension of the β Cep instability strip. A similar suggestion was made in connection with 53 Psc by Williams (1954) and by Sareyan et al. (1979). If all stars in this hpothetical low-temperature extension have such small amplitudes as ι Her or such peculiar photometric behaviour as 53 Psc, the evidence in favour of the suggestion will indeed be very difficult to come by.

As far as 34 Psc is concerned, it is similar in its observed variability to small amplitude δ Sct stars. However, with the MK type of B9 Vn (Hoffleit, 1982), the star is somewhat too hot to be a normal δ Sct variable.

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