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53 Persei: a slowly pulsating B star⋆

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Abstract. A new investigation of the behaviour of the star 53 Per was performed. New photometric observations allow to confirm two dominant periods p_1=2.16 d, p_2= 1.67 d. A third one p_3= 3.64 d is detected. These long period variations are present in our radial velocities data and in old equivalent width data. The amplitude of the p_1 = 2.16 d period increases from 1977 to 1991, while the amplitude of the 1.67 d period remains constant. Considering the observational characteristics of the star since 1997, 53 Per clearly belongs to the Slowly Pulsating B stars group as defined by Waelkens (1991) and North & Paltani (1994).

Key words: stars: variables: general stars: oscillations stars: individual: 53 Persei

1. Introduction

53 Per (HR 1350, HD 27396, B4 IV, m_V = 4.85) was proposed by Smith (1977) as the prototype of the group of B type line profile variables. Photometric variability was detected by Percy & Lane (1977) and Africano (1977).

Smith & Mc Call (1978) found a complex period behaviour in the profile variations: five different periods (0.150, 0.188, 0.304, 0.476, 0.608 d) were present at different times over a time scale of two years (1975 to 1977). Using Strömgren *u* and *y* observations, obtained from November 1977 to January 1978, Buta & Smith (1979) found that the light variations could be fitted by a pair of sinusoidal components having closely spaced periods near 1.7 and 2.1 d and respective amplitudes of 0.03 and 0.04 mag. Simultaneous line profile observations confirmed this light behaviour. On the basis of their new 1981-82 photometric and 1983 line profile data combined with the 1977 - 1978 observations, Smith et al. (1984) showed the presence of two stable periods of nearly equal amplitude at 1.681 and 2.155 d. They attributed these variations to non-radial modes of high overtone (l = 3, m = -3 and -2). Although these periods were dominant in the light variations during 1977-1981, the overall fits are still fairly unsatisfactory and point to the presence of additional periods. The authors were unable to fit the earlier line-profile observations with these two periods. They suggest that 53 Per changed its pulsational characteristics sometime during 1977. Balona (1987) re-analysed the 1981-82 photometry and claimed that a complex double wave curve with a period of 3.45 d could fit the data. In 1983 Le Contel et al. (1989) observed 53 Per spectroscopically during seven consecutive nights. Night to night variations are present in their radial velocity measurements and also in the ratios of line central depths. These variations could be fitted by a single sinusoidal period of 2.36 d as well as by the previous two periods. This 2.36 d period also fits the photometric data of Buta & Smith (1979). On the basis of UBV (Johnson filters) observations obtained during an international photometric campaign in January 1991, Huang et al. (1994) showed that the light variations of 53 Per could be fitted by two sinusoids of period 1.67 and 2.17 d. Smith & Huang (1994) reported a new modal l identification of pulsation modes (l = 2 or 1) using the ratio between the Voyager Far-UV amplitudes and Huang et al. U, V amplitudes.

Since the new OPAL opacities (Iglesias et al. 1992) became available the stellar models predict the existence of two instability zones for the B stars. In the first zone between B0 and B2 the low order *p* and *g*-modes are destabilised (Dziembowski & Pamyatnykh 1993). In the second one the high-order *g*-modes of low harmonic degree l are destabilised over a large region around the main-sequence between B3 and B8 (Dziembowski et al. 1993). These two zones correspond respectively to the β Cep and SPB stars.

The aim of the present study is to investigate the photometric and spectroscopic variability of 53 Per. A photometric campaign was made simultaneously in Pico del Veleta (Spain) and in San Pedro Martir (Mexico) in September- October 1988. Spectroscopic observations were also performed at the Haute-Provence Observatory (France) in September- October 1989. This paper

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⋆ spectroscopic observations performed at the Haute Provence Observatory reports on the results of the period analysis of these data. We also discuss whether or not 53 Per belongs to the group of SPB stars.

2. Observations and reductions

2.1. Photometry

The observations were performed with the 'Danish' photometer on the 150 cm telescope at San Pedro Martir Observatory (Mexico) during 10 nights (from September 26 to October 8, 1988) and with the photon-counting photometer (described in Sareyan et al. 1992) on the 62 cm telescope at Pico del Veleta Observatory (Spain) during 11 nights (from September 23 to October 28, 1988). Five stars were observed at both stations, i.e. 53 Per (m_v = 4.85, B4 IV), two comparisons C_1 = HR 1261 (m_v = 4.29, A0 IVn), C_3 = HD 27795 (m_v = 7.39, B1 V), and two check stars C_2 = HR 1482 (m_v = 5.67, A0 V) and C_4 = HR 1328 (m_v = 6.22, B8 V). HR 1328 turned out to be variable (Chapellier et al. 1996). The measurements were carried out through the *u* and *v* Strömgren filters. The observing sequence was C_1- C_4- C_3- sky- 53 Per- C_2- C_3- sky- 53 Per. We made the reductions using C_3 which is the closest to 53 Per.

The observational uncertainties were larger for San Pedro Martir than for Pico del Veleta. According to the Bouguer curve behaviour, we believe that the larger scatter at San Pedro Martir was mainly caused by an instrumental drift.

To determine the main differential magnitudes in each site we made a preliminary period analysis of the two sets of observations. Then these main magnitudes have been subtracted from the individual values of the differential magnitudes before we added the two files. The similarity of magnitudes measured during the two common nights in both observatories confirms the reliability of this reduction scheme. The light curves are shown in Fig. 1 (the data are available in electronic form at CDS).

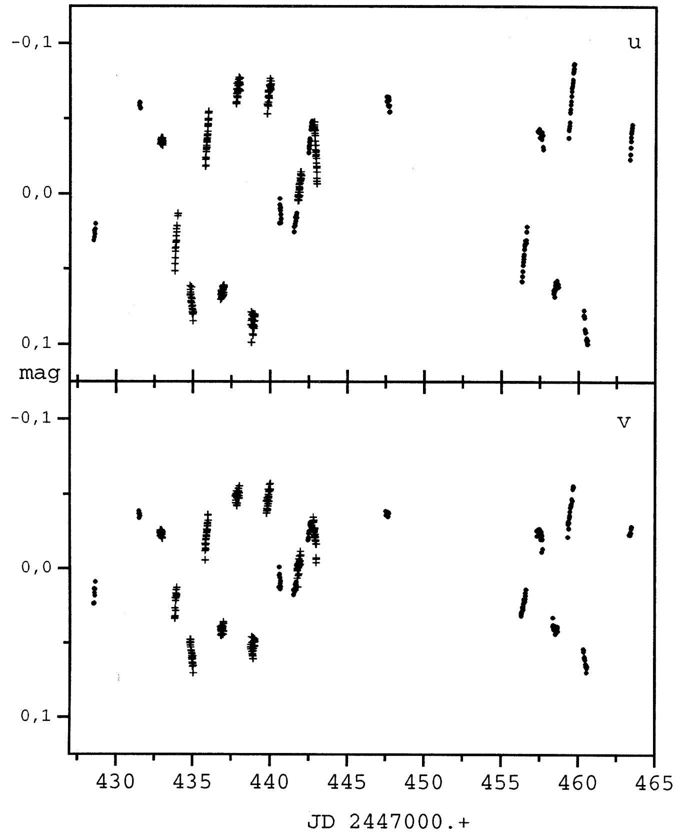

Fig. 1. Differential magnitudes 53 Per minus C3 for *u* and *v* filters (crosses: Mexico data, dots: Spain data)

2.2. Spectroscopy

The observations were performed at the Haute Provence Observatory in October 1989 (9 nights). We obtained 80 spectra using the 'Aurelie' spectrograph attached to the coudé focus of the 152 cm telescope. This spectrograph is equipped with a linear detector of 2048 × 13 pixels. We used a 1200 lines mm^{-1} grating. The resolution element is about 2.94 pixels (FWHM). We observed a 192 Å wide domain centred at 4101 Å, at a reciprocal dispersion of 8 Å/mm. The resulting resolution is about 15,000. The wavelength calibration was derived from measurements of a thorium spectrum and the flat field corrections made with a tungsten lamp. The final files obtained with the STII reduction package on the VAX computer at Nice Observatory consist of line profiles reduced to the continuum of the star, the radial velocity values were obtained by taking the means of the measures on each wing at half intensity of the profile. The signal to noise ratio is always over 100. We checked the stability of the spectrograph by observing at least one time every night the standard star γ Equ (HR 8099 = HD 201601). On 53 Per we measured for radial velocity determination the following six lines: He I (4026 Å), H_δ (4101 Å), He I (4120 Å), the Si II doublet (4128 Å, 4130 Å) and He I (4143 Å).

The radial velocities of the singlet He I line (4143 Å) depart widely from the mean radial velocities derived from the two other lines of He I (4026 Å and 4120 Å). This fact was previously pointed out by Le Contel et al. (1989) and was also observed in γ Peg (Ducatel et al. 1981), no explanation was found for this phenomena. The precision on a given night for each measurement is ±1.8, ±1.6, ±1.5, ±1.3, ±1.0 and ±1.8 Kms^{-1} for the respective following lines: He I (4026 Å), H_δ (4101 Å), He I (4120 Å), the Si II doublet (4128 Å, 4130 Å) and He I (4143 Å). The amplitudes of the radial velocity variations are identical on all the lines (all the individual values are available in electronic form at CDS).

To minimise the dispersion due to differential velocities between different elements and to have lines which are formed at the same level in the stellar atmosphere, we used only the Si II doublet line velocities in our period analyses. Fig. 2 shows the means of two Si II line velocities.

3. Period analysis

The period analysis of our data was performed using the program package 'Period' (Breger 1990). Its main program provides Fourier transforms and the best fits of sinusoids by mul-

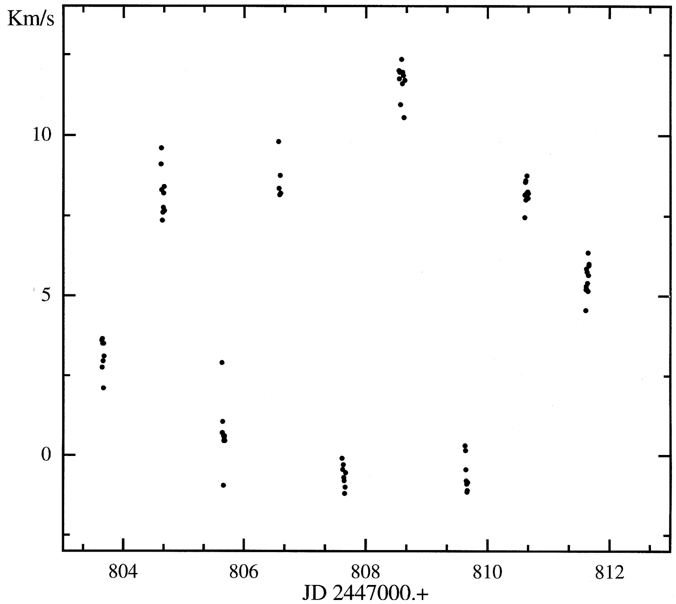

Fig. 2. Radial velocity variations (means of the two Si II lines)

tiple least squares. The best fits are determined by minimising the squares of the residuals between the fits and the data.

3.1. Photometry

3.1.1. Filter *u*

The dominant peak in the Fourier transform was close to 2 d, a least square sine fit gave a value of $p_1 = 2.17$ d with an amplitude (half range) a = 0.058 mag. After prewhitening for this period the least square sine fit gave p_2 =1.67 day, a = 0.033 mag. Then we used both periods simultaneously in a new least square sine fit. The results are listed in Table 1. These two periods were the same as found by Buta & Smith (1979), Smith et al. (1984) and Huang et al. (1994).

To look for other periods we prewhitened the data for these two periods and performed a Fourier transform. A new peak appeared, the least square sine fit gave $p_3 = 3.66$ d with an amplitude a = 0.017 mag. When we computed the three periods simultaneously the residual decreased from 0.024 mag to 0.020 mag (the results are listed in Table 1).

3.1.2. Filter *v*

As in filter *u* the dominant peak in the Fourier transform was close to 2 d. A least square sine fit gave a value of $p_1 = 2.16$ d with an amplitude a = 0.038 mag. After prewhitening the second highest peak appeared. The least square sine fit gave $p_2 = 1.67$ day, a = 0.022 mag. The results of the least square sine fitted by both periods simultaneously, are listed in Table 1. After a prewhitening for these two periods the largest peak of the Fourier transform was again near 4 d, the least square sine fit gave p_3 = 3.64 d with an amplitude a = 0.015 mag. When we computed the three periods simultaneously the residual decreased from 0.017 mag to 0.015 mag (the results are listed in Table 1).

To measure an eventual phase lag sine fits between *u* and *v* filters, data were analyzed with the same time zero point JD 2447428.53711. No effect was detected within the error bars.

3.2. Radial velocities

As previously found in photometric analysis, the most distinct feature of the analysis of the spectroscopic data was the peak close to 2 d. After cleaning with $p_1 = 2.16$ d, two periods of nearly equal amplitude remain at 3.3 and 1.65 d. Owing to the limited number of nights, we preferred to fit the radial velocity data with our well-determined photometric periods. When we forced the two periods $p_1 = 2.164$ and $p_2 = 1.674$ d we obtain the results listed in Table 1. After a prewhitening with these two periods the largest peak of the Fourier transform was again close to 4 d, the least square sine fit gave $p_3 = 4.09$ d with an amplitude K = 0.51 Kms^{-1}. When we computed the three periods simultaneously the residual decreased from 0.77 to 0.68 Kms^{-1} (the results are listed in Table 1).

3.3. Observations prior to 1977

Smith & McCall (1978) detected short period line profile variations in 53 Per. Their material consisted of 35 high resolution spectra distributed over 6 observational sessions between December 1975 and August 1977 (each session had a duration between 2 and 5 d with 3 to 8 profiles). They found 5 different periods (0.150, 0.188, 0.304, 0.476, and 0.608 d). Only two of these periods (0.304 and 0.608 d) occurred twice. The authors conclude to the presence of non radial gravity modes. Same variations discovered in some other stars lead Smith and co-authors to create the 53 Per group of variables.

Africano (1977) obtained photometric data on 53 Per during one of the observing sessions of Smith & McCall. According to Smith & McCall (1978) their 0.309 d period fits Africano's data well. These relatively short period variations have never been detected again since 1977 neither in spectroscopy nor in photometry. Smith et al. (1984) concluded that 53 Per changed its pulsational characteristics to excite the present pair of dominant periods (1.7 and 2.1 d) somewhere in 1977.

We reanalysed the Africano's photometric data of 23 and 24 December 1976. The best least square fit corresponds to p = 2.31 d with a 0.024 mag. while the 0.304 d peak has only a 0.004 mag. amplitude.

We also reanalysed the Smith & McCalls data. From their tables of equivalent width variations, we obtained by Fourier and least square analysis a mean peak at p = 1.89 d with an amplitude of a = 6 mÅ. Though rapid variations appeared in the line profiles we do not detect any significant peak corresponding to Smith & McCalls periods. Although our analysis method is much simpler than Smith's one, it appears that the long period variations were already present in the 1977 spectroscopic and photometric data.

Table 1. Results of fitting using 2 and 3 periods. P is the period, A the half range amplitude, M the time (2447000.+) of maximum luminosity or radial velocity, R the residual after fitting.

Filter *u*				Filter *v*				Radial velocity			
P (days)	A (mag.)	M 445.+	R (mag.)	P (days)	A (mag.)	M 445.+	R (mag.)	P (days)	A (Kms^{-1})	M 806.+	R (Kms^{-1})
2.164	0.046	0.4421	0.024	2.164	0.030	0.4534	0.017	2.164	5.75	1.8694	0.77
1.672	0.038	0.3832		1.676	0.025	0.3885		1.674	3.27	1.8814	
2.157	0.047	0.4415	0.020	2.157	0.031	0.4416	0.015	2.164	5.04	1.8099	0.64
1.669	0.036	0.3954		1.673	0.025	0.4000		1.674	2.66	1.8562	
3.651	0.017	0.6418		3.623	0.013	0.6178		3.643	0.77	0.3922	

4. Discussion

4.1. Amplitude variations

Huang et al (1994) showed that the amplitude ratio of the two main modes has increased from 0.9 to 2.5 between 1977-1981 and 1991. In our observations the amplitude ratios of the two dominant periods for *u* and *v* filters were highly similar and the mean is equal to 1.19.

To study precisely the behaviour of each mode we examined all the observations of 53 Per. We dispose now of four photometric series of observations: 1977-1978, filter *v*, 1981-1982, filter *y* (Smith et al. 1984), 1989 filters *u*, *v* (this paper), 1991 filters U,B,V (Huang et al. 1994). Nevertheless these series correspond to different filters and are hardly comparable. To avoid this problem we plot A = f(λ) curves with the U, B, V amplitudes from Huang et al. and then deduce from the curves the corresponding values of the amplitudes in the Strömgren *v* filter. Table 2 gives the list of the values. Within the error bars, these values confirm the increase of the amplitude of the 2.16 d period and the stability of the 1.67 d period.

4.2. The other periods

Smith et al. (1984) and Huang et al. (1994) claimed that the deviations of their data from the two-period fits may imply the existence of additional periods that cannot be recovered from their data. Therefore the detection of a third period (other periods could also exist) is not surprising, but does the p_3 = 3.65 d peak we found correspond to a real pulsation mode or is it only an alias? Several arguments can be advanced in favour of the reality of this pulsation:

– After prewhitening for the two classical periods the largest peak in the periodograms of the *u* and *v* data corresponds to the same period.

– The maxima of luminosity for the two filters are in phase.

– The amplitudes of the light variations of p_3 are relatively large and the residuals are significantly reduced when we used the three periods simultaneously.

– We find the same third period in the radial velocity data.

Analysing Smith et al. (1984) data, Balona (1987) found a major peak at p = 3.45 d, so he concluded that:"the light variation of 53 Per can be interpreted as a rather complex double wave light curve with a period of 3.45 d". If we consider that the Balona's period is the same as our p_3, then it means that the third period was also present in Smith et al.'s data.

From Dziembowski et al (1993), the excited non-radial modes in a B4 IV star are in a period range between 1 and 3 d. The p_3 value found is larger than the upper limit, but it is not an isolated case. Three others SPB stars discovered by Waelkens (1991) show larger periods than three day: HD 74195 (p_5 = 4.42 d), HD 143309 (p_6 = 3.45 d), HD 160124 (p_6 = 3.18 d). As for 53 Per, there are secondary modes with small amplitudes. Perhaps coupling phenomena can destabilise some non excited modes.

Mills & Dukes (1994) detected another photometric period from four years of observations. The value of their period (2.13 d) is too close to p_1 to be detectable in our data set.

4.3. Is 53 Per a slowly pulsating B star?

The relation between 53 Per type stars and the SPB stars is not clear: Waelkens & Rufener (1985) proposed first to include the 53 Per stars in their "mid-B variables" group, but Waelkens (1991) divided the two groups and classified only the long period photometric variables in a new group called "slowly pulsating B stars" (SPBs).

Historically the stars composing the two groups have been detected by different instrumental techniques. Smith & Karp (1976) detected the 53 Per stars by studying the line shape variations of a number of sharp-lined early to mid-B stars known for their profile variations. They used high spectral resolution which requires relatively long expositions (up to one hour). So the profile variable stars must have a relatively long period and a low v*sini* to be detected.

On the contrary SPBs have been discovered in the course of a systematic photometric programme of a large sample of B stars as free from observational bias as possible (Waelkens & Rufener 1985). Dziembowski et al. (1993) showed the existence of an instability zone in the same region of the H-R diagram; the main characteristics of these stars (periods, multiperiodicity...) are in agreement with the observations of Waelkens and co-authors.

Dziembowski et al. (1993) and Waelkens (1994) suggested that 53 Per itself belongs to the SPBs class, but in the latest study on 53 Per, Huang et al. (1994) did not mention any relation with the SPBs.

Table 2. Amplitude variations of the two periods in filter *v*

Date of the observation	half range amplitude (mag)		reference
	2.16 days period	1.67 days period	
1977 - 78	0.024	0.020	Smith et al. (1984)
1981 - 82	0.019	0.021	Smith et al. (1984)
1988	0.030	0.025	This paper
1991	0.040	0.016	Huang et al. (1994)

North & Paltani (1994) summarised the six main observational characteristics of the SPB stars: spectral types between B3 and B8, presence and long-term stability of several photometric periods, periods much longer than radial pulsations would produce, amplitudes of a few thousandths or hundredths of a magnitude, increasing with decreasing wavelength, no phase lag between the variations in different colours and a slowly axial rotation.

The spectral type of 53 Per (B4 IV) puts it in the middle of the observational and theoretical instability zone of SPB stars. The stability of at least two photometric periods is clearly established over 14 years, with periods much longer than radial pulsation would produce. Huang et al., as ourselves, found significantly larger amplitude in the UV than in the visible for both periods. The phase lag between the variations in different colours is always smaller than 0.06 period, which is a value within the observational errors. The axial rotation is very small ($v sini$ = 15 to 20 Kms^{-1}).

Another characteristic of 53 Per is the presence since 1977 of line profile variations with the same periods as in photometry. Such line profile variations have also been observed in several SPB stars: HD 74195 and HD 74560 (Waelkens 1987) and HD 37151 (North & Paltani 1994), so they are probably a frequent phenomenon in SPBs.

Thus, as all the criteria of North & Paltani are fulfilled, 53 Per itself could be considered as a SPB star.

5. Conclusion

A new investigation of the behaviour of the star 53 Per was performed. New photometric and radial velocity observations allow to confirm two stable dominant periods p_1= 2.16 d, p_2= 1.67 d. We also detect another low amplitude period, p_3= 3.64 d, both in our photometric and spectroscopic data. The amplitude of the p_1 = 2.16 d period increases from 1977 to 1991 while the amplitude of the 1.67 d period remains constant.

Smith et al. (1984) claimed that the behaviour of this star changed somewhere in 1977. Before 1977, several periods from 0.150 to 0.607 d were present in the line profile variations and the photometric data. After 1977 only the two long periods (p_1 and p_2) were present. We reanalysed the data prior to 1977 and showed that a long period p = 2.3 d fits much better the photometric observations than Smiths 0.304 d period. Concerning the line profile variations we showed the presence of a p = 1.89 period in equivalent width data. However more rapid variations which could correspond to Smith's periods were also present.

If we consider only the long periods observed since 1977, 53 Per belongs to the Slowly Pulsating B stars group defined by Waelkens (1991) and North & Paltani (1994).

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