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Extreme amplitude variations in 28 And

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Abstract. New simultaneous observations using the four *uvby* filters of the Strömgren photometric system have been collected in the year 1996 for the low amplitude δ Sct star 28 And. During the course of these observations, the observed amplitude of the light curves is very small as compared with any other data set available in the literature for this star. In particular, the actual amplitude is about 19 times less than during the last observing run, five years before. The frequency analysis of the data also reveals the existence of a secondary frequency ν_2. Hence, the monoperiodicity is not confirmed with the new data. In addition, the analysis of the phase shifts between observed light variations confirms the nonradial nature of the main pulsation of this star.

Key words: δ Scu – stars: individual: 28 And – stars: oscillations – techniques: photometric

1. Introduction

28 And is a bright low amplitude δ Sct type star with V=5.^{m}23, ΔV=0.^{m}05 (full amplitude) and P=0.^{d}0693 (Rodríguez et al. 1994). Its variability was discovered by Nishimura (1969) during the course of photometric observations. The observational history of 28 And is relatively short. Photometrically, this star has been observed by Breger (1969), Nishimura & Watanabe (1969), Garrido et al. (1985) and Rodríguez et al. (1993, hereafter Paper I). Some additional data were published in Elliott (1974), Tunca et al. (1981) and Ibanoglu et al. (1983).

From these works it seems that 28 And is a monoperiodic pulsator. In Paper I, the authors carried out frequency analyses on the different data sets available in the bibliography. In all the cases they find similar results to those obtained with their own data, that is, when the main frequency is prewhitened the resulting periodograms do not show any trace of another peak. In particular, using the 1982 B data set of Garrido et al. (1985), the best case, the white noise level appears nearly constant and smaller than 0.^{m}001, and they conclude that there are probably no remaining periodicities in the light variation of 28 And, at least with amplitudes greater than the limit of $\sim$0.^{m}001. Then, 28 And is one of the very few known low amplitude δ Sct stars where only a single pulsation frequency has been detected. However, 28 And could pulsate with additional frequencies with amplitudes too small to be detected photometrically. On the other hand, it is known that its amplitude is variable with a time scale of years similar to that occurring in many multimode low-amplitude δ Sct pulsators showing variable amplitudes in a number of frequencies. Moreover, similar to the dominant frequency, these possible additional frequencies could present amplitude variability showing, in some cases, amplitudes greater than the limit of $\sim$0.^{m}001 found in the 1982 B data set of Garrido et al. (1985). Moreover, in Paper I, the authors suggest that 28 And is a nonradial pulsator with *l*=2 and p_3 on the basis of the phase shifts and amplitude ratios between observed light and colour variations. The main aim of this work is to further investigate the frequency content of 28 And and the behaviour of the long term amplitude variations using new simultaneous *uvby* photometry.

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2. Observations

The observations were carried out on fifteen nights during September and October, 1996, using the 90 cm telescope at the Sierra Nevada Observatory, Spain. The photometer attached to this telescope is a six-channel *uvby*β spectrograph photometer for simultaneous measurements in *uvby* or in the narrow and wide H_β channels, respectively, using uncooled EMI photomultipliers type 9789 QA (Nielsen, 1983), but only *uvby* measurements were obtained in this session.

As in Paper I, HR 133=HD 2924 (V=6.^{m}67, A2V) was used as the main comparison star. In addition, HD 2019 (6.^{m}74, B8V) was used as check star. Because high time resolution is necessary, the sequence was, generally, C1,C2,var,var,C1,var,var. Sky measurements were made every 2 or 3 cycles. In total, 1708 *uvby* measurements were collected for the variable, about 900 for C1 and about 400 for C2. Each integration consisted of 40 s for the variable and 50 s for any of the comparison stars. This gives us, for any of the stars, an internal error in each observation better than 0.^{m}0017 for the *u* filter and C2, namely the worst case. This precision is very important for the frequency analysis of the variable and to analyse the phase shifts and amplitude ratios between different filters, especially when the amplitudes of the pulsations are very small.

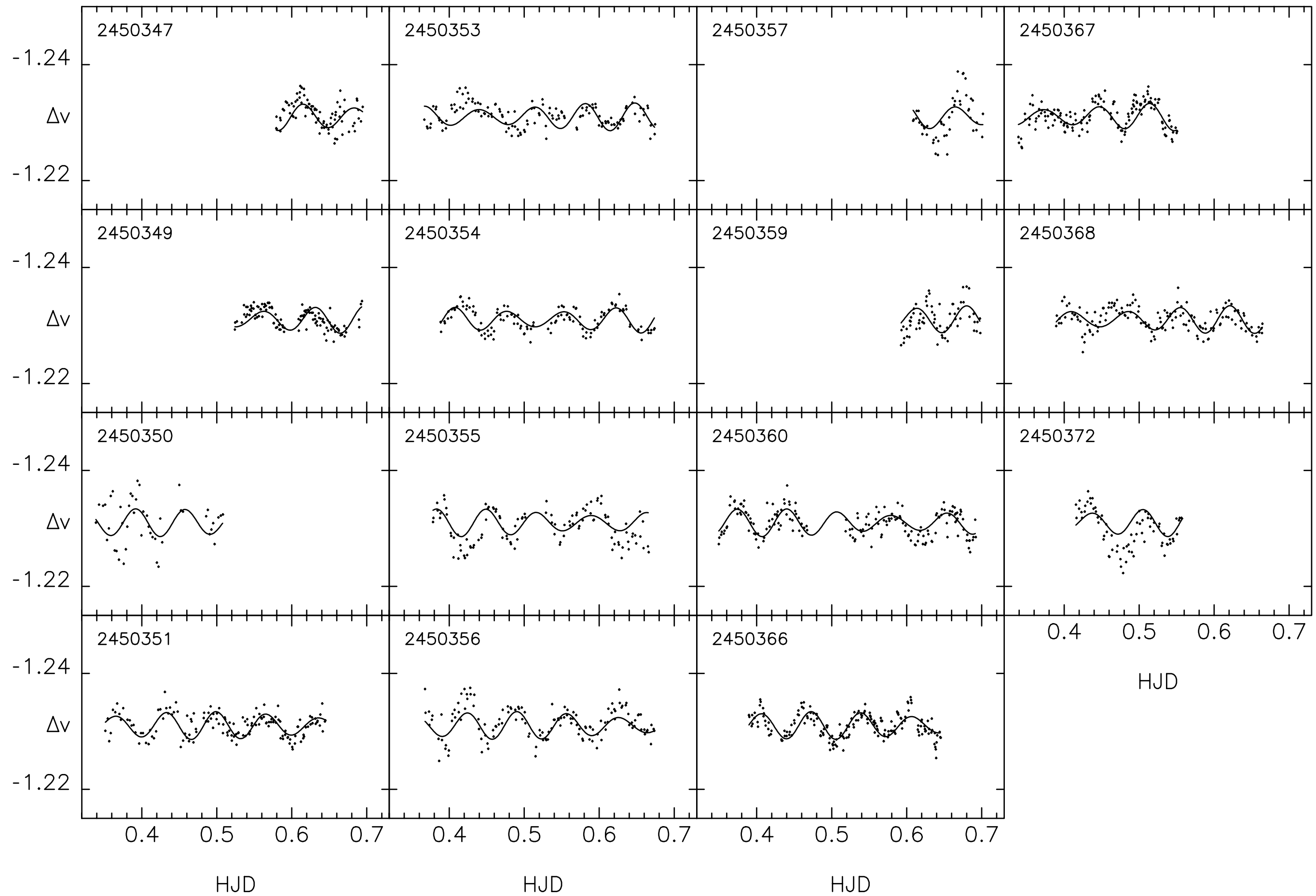

Fig. 1. Observed light curves of 28 And in the *v* band with the Fourier fitting versus Heliocentric Julian Day

During the observations reported here, neither of the comparison stars showed any sign of variability. On every night, the standard deviations for C2-C1 differences were always better than $0.^{m}006$, $0.^{m}003$, $0.^{m}003$ and $0.^{m}003$ for *u*, *v*, *b* and *y* filters, respectively. This demonstrates the excellent quality of the sky during this campaign. Moreover, the stability of the instrumental system was very good. In fact, the mean values obtained for differences C2-C1 on the fifteen nights were always the same within $0.^{m}001$, as standard deviation, for any of the filters and colour indices. Futhermore, when the Fourier analysis is applied to C2-C1, no sign of variability within about $0.^{m}0006$, in the range from 0 to 40 cd^{-1} and filter *v*, is found for C2 and C1. The standard deviation of C2-C1 was found to be 2.2 mmag and the noise level, as the average amplitude in an oversampled amplitude spectrum (as defined in Handler et al. 1996), is about 0.20 mmag. That is, the significance level, as defined by Breger et al. (1996), is of about $0.^{m}0008$.

To transform our data into the standard system we have used the same procedure described in Rodríguez et al. (1997). The data obtained, as magnitude differences variable minus C1=HD 2924 in the standard system versus Heliocentric Julian Day, have been deposited in the Commission 27 IAU Archives of Unpublished Observations, file 334E, and can also be requested from the authors. As an example, the *v* observed light curves are plotted in Fig. 1 with the Fourier fitting obtained in Sect. 3.1. This shows the amplitude of the light curve to be very small, less than 4 mmag ! (from peak to peak) in the filter *v*, being the filter with largest amplitude. Thus, a very strong decrease has occurred in the pulsational amplitude of 28 And during the last few years.

3. Results

3.1. Frequency analysis

The frequency analysis of 28 And was carried out using the Discrete Fourier Transform method, as described in López de Coca et al. (1984) where recently combined single frequency and multiple frequency techniques have been implemented using both Fourier and multiple least squares algorithms. When one significant peak is detected using the single frequency Fourier technique we can refine the frequency value using least squares algorithms. In the case of multiperiodic behaviour, the computer program is also able to simultaneously optimize all the frequencies by nonlinear least squares fits. Moreover, the multiple frequency least squares technique does not depend on successive prewhitening, but calculates the best fit to the data with all given frequencies simultaneously by minimizing the resid-

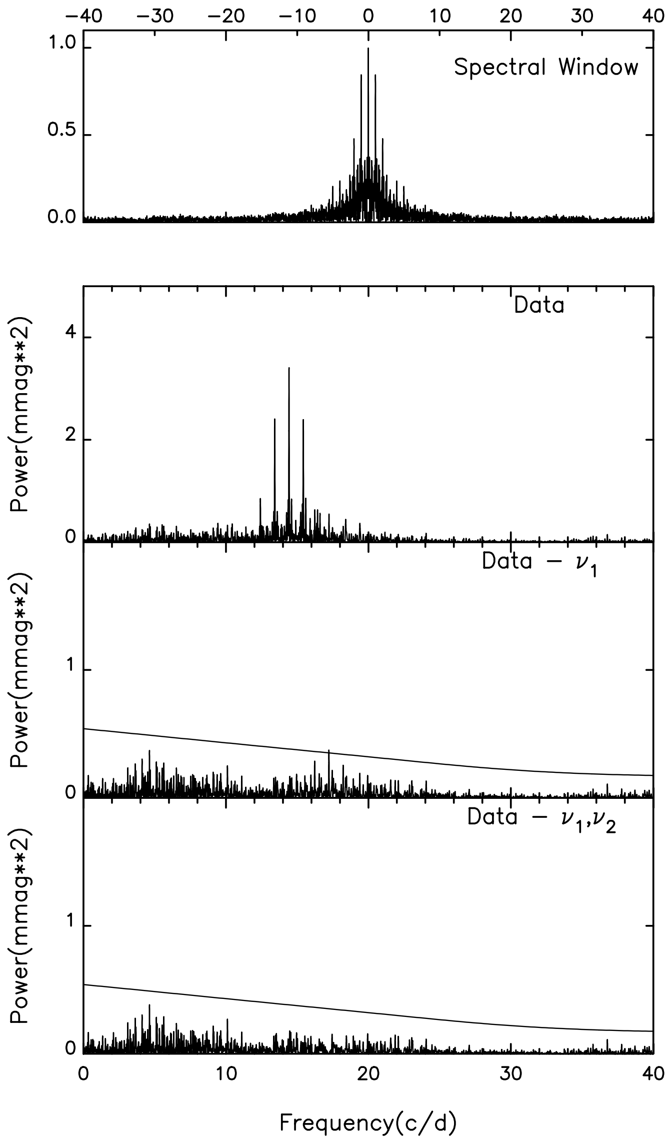

Fig. 2. Power spectra of 28 And in the *v* filter before and after prewhitening the frequencies ν_1 and ν_2 to our data

uals between light curve and fit. Nevertheless, prewhitening is required for purposes of presentation in order to show the low amplitude modes. Therefore, the various power spectra are commonly presented as a series of panels, each showing the results of subsequent removal of additional frequencies relative to the panel above.

When the frequency analysis is applied to 28 And in the *v* filter, the periodograms showed a principal peak at ν_1=14.4272 cd^{-1} in good agreement with the period P=0.^{d}0693 derived by earlier authors. Fig. 2 shows the spectral window and power spectra of 28 And in the *v* filter before and after (second and third panel) prewhitening for ν_1. The aliases are seen to be high in power (about 80% in a first order) due to the data being collected from only one site. This represents a great problem when we are dealing with complex pulsating stars, but this is not the case for 28 And. The last panel shows the power spectrum after removing ν_1 and ν_2 (Table 1). The line in the last two panels of Fig. 2 indicates the significance level as described by Breger et al. (1996). After subtracting for the main frequency, the periodograms show some other peaks at about 4.63, 10.11 and 17.23 cd^{-1}, but only the last one seems to be statistically significant with an amplitude signal-to-noise (S/N) ratio equal to 4.1. The mean noise level in the region from 12 to 22 cd^{-1} is 0.15 mmag. This peak was also confirmed in the other two *b* and *y* filters, but not in the *u* band (in this last filter, the noise level is too high), and the amplitudes seem to be consistent with a pulsation mode. The other two peaks above mentioned are not significant. In both cases, the amplitude S/N ratio is smaller than 4.0 (3.4 and 2.9, respectively) and their positions in the periodograms are not confirmed in any of the other filters. The noise level between 2 to 7 cd^{-1} and between 7 to 12 cd^{-1} is 0.18 and 0.17 mmag, respectively. Thus, only the frequency of 17.23 cd^{-1}, corresponding to the last peak, was included into the final solution.

When the two above derived significant frequencies were simultaneously optimized, this led to the following results: ν_1=14.4282 cd^{-1} and ν_2=17.23 cd^{-1}. The error estimated in the determination of ν_1 is of about 0.001 cd^{-1} and three times larger for ν_2. The same analysis was performed on the other filters and the results were consistent with each other. In Fig. 1 we plot the resulting Fourier fitting, in the filter *v*, with the observed light curves. The results of the frequency analysis are listed in Table 1.

We also tried to make use of the data collected by the Hipparcos satellite (Hipparcos 1997) in order to gain some insight on the frequency content of 28 And through the years from 1989 to 1993. Unfortunately, this data set contains very few points on this star, randomly distributed in time with a time span of 3.15 years. Therefore, not reliable results can be obtained.

3.2. Amplitude variations

It is known, from earlier authors, that long term amplitude variations take place in 28 And. During the observing run of 1996, it was shown, in the above section, that the amplitudes of the light curves of 28 And are always smaller than 2 mmag, for any of the four *uvby* bands as determined by means of the Fourier fitting (that is, semiamplitudes). This value is very small when compared with any other data set found in the bibliography. In Paper I, the authors homogeneously analysed all the reliable data sets available in the literature in order to determine the amplitude of 28 And during each run of collected observations between the years 1967 to 1991. The results showed strong amplitude variations varying from 6.8($\pm$0.6) mmag in 1977 to 31.9($\pm$0.1) mmag in 1991, in the B band of the Johnson photometric system. Both values are much larger than the amplitude shown during 1996. When we average the *b* and *v* measurements to approximate the variations in B, a value of 1.72($\pm$0.07) mmag is derived for the main frequency. In particular, a very strong decrease has taken place in the amplitude of the main pulsation between the years 1991 to 1996. By comparing the results listed in our Table 1 with those corresponding to Table 2 in Paper I,

Table 1. Results from Fourier fitting

	u		*v*		*b*		V	
Frequency	A (mag)	φ (rad)	A (mag)	φ (rad)	A (mag)	φ (rad)	A (mag)	φ (rad)
ν_1=14.4282	0.00181	1.487	0.00181	1.085	0.00160	1.168	0.00152	1.211
	13	71	7	36	6	37	7	45
ν_2=17.23	0.00071	2.023	0.00061	1.408	0.00053	1.522	0.00052	1.517
	13	179	7	110	6	113	7	131
mean value (mag)	-1.4329		-1.2310		-1.3621		-1.4740	
	1		1		1		1	
residuals (mag)	0.0037		0.0019		0.0017		0.0020	
T_{or}(HJD)	2450347.5793							

we can see that the latter amplitude is about 19 times smaller than five years before.

3.3. Pulsation modes identification

It is possible to gain some insight into the pulsation modes identification by using the method of the phase shifts and amplitude ratios between observed light and colour variations as described in Garrido et al. (1990). In this way, in Paper I a nonradial nature was suggested with *l*=2 for the main pulsation of 28 And. However, in our case the error bars in the determination of the amplitudes and phases are much larger than in Paper I (see our Table 1) due to the very small amplitude present in these observations. Moreover, no reliable results can be obtained for b-y. Nevertheless, Table 1 shows again that the phase shifts for ν_1 and *v*, *b* and *y* bands are in the same order as in Paper I, that is, the light maximum occurs later when the wavelength is longer. Thus, a nonradial nature is again suggested for ν_1, with *l*=2 as the most probable value. In the case of ν_2, the phase value in the filter *v* gives us some indication in favour of nonradial pulsation. However, the error bars are even larger than in the former case and the light maxima in the *b* and *y* filters seem to be occurring at the same time. Following this, a definitive conclusion can not be made at this moment for ν_2.

In Paper I, a Q value of $0.^d018(\pm0.003)$ was derived for ν_1. Hence, the third overtone was suggested as the most reliable identification. On the other hand, the period ratio for ν_1 and ν_2 is of P_2/P_1=0.837. This leads to a fourth overtone, radial or nonradial, for ν_2. Another possibility is a nonradial p_2 mode for ν_1 and a third overtone for ν_2.

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