1993JAVSO..22..110P

THREE SELECTED LOW-AMPLITUDE CEPHEIDS

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Presented at the October 1993 Meeting

Abstract

A recent publication concerning the continuing decrease in the pulsation amplitude of Polaris, and the prediction that this star will soon become nonvariable raises the question of similar behavior in other low-amplitude Cepheids ($\Delta V < 0.5$ magnitude). In this paper we use the Fourier decomposition of light curves to obtain rigorous estimates of the pulsational amplitude. A limited sample of three s-Cepheids, SU Cas, SZ Tau, and V1726 Cyg, was chosen to demonstrate the capabilities of this technique. The pulsation amplitude shows no decisive changes as a function of time in any of the three Cepheids. Adequate follow-up photoelectric photometry of these and other low-amplitude Cepheids is clearly needed to make more definite conclusions as to their pulsational (in)stability. Another issue we briefly address here is whether other parameters derived from the Fourier decomposition, like the phase difference vs. period, do unambiguously indicate the pulsational mode. The answer is probably negative since in the case of SU Cas and V1726 Cyg the pulsational mode deduced from the Cepheids' cluster/star association membership is different from that suggested by their Fourier parameters.

1. Introduction

Recently a goodbye to Polaris as a Cepheid was announced (Fernie *et al.* 1993), predicting that Polaris will stop pulsating in 1994.[2] Polaris is known as a short period (P = 3.97 days) and low-amplitude Cepheid. About a hundred years ago it was spotted having a pulsational amplitude of $\Delta V \approx 0.12$ magnitude, which by now has declined to 0.01 magnitude. Not so long ago Fernie (1990) suggested that another Cepheid, Y Oph, has undergone a secular decline in amplitude. A comprehensive study of V473 Lyr shows that the amplitude of this Cepheid varies periodically on a time scale of about 1400 days (for references see Burki *et al.* 1986). Clearly, these compelling facts will renew the interest in the properties of other low-amplitude Cepheids with short pulsation periods. A number of studies, such as that of Szabados (1977), have been devoted to the Cepheid period stability; however, with a few exceptions stated above, the pulsational amplitude was not scrutinized for possible trends and secular evolution. Here, we present an analysis of the pulsational amplitude stability, utilizing the Fourier fits of light curves, for three low-amplitude Cepheids, namely SU Cas, SZ Tau, and V1726 Cyg. The first two have reasonably long photoelectric observation histories. Since any

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[1] On leave of absence from Radioastrophysical Observatory, Latvia.

[2] As of September 1994, Polaris was still pulsating.

kinds of pulsations are temporal in a star's life, intuitively one feels that the low amplitude might indicate a transition from a solid resonant pulsation into non-variability or vice versa. In other words, in s-Cepheids we perhaps have an opportunity to observe this transition phenomenon even in our lifetimes, as in Polaris.

All Cepheids mentioned above belong to a relatively rare type of so-called s-Cepheids. According to the *General Catalogue of Variable Stars* (Kholopov *et al.*, 1985) (GCVS), 42 Cepheids with amplitudes less than $\Delta V = 0.5$ magnitude and almost symmetrical light curves are classified as DCEPS (s-Cepheids). In contrast, the classical Cepheids have higher amplitudes and asymmetric light curves. Although the amplitude is an important discriminator between the two types of Cepheids, an artificially low amplitude may also be caused by the presence of a companion star.

Recently Antonello *et al.* (1990a) proposed to use certain combinations of the light-curve Fourier decomposition parameters in order to classify a sample of Cepheids. This technique does show better classification features over the vague GCVS definition but cannot give an interpretation of the essential differences between classical and s-Cepheids. Antonello *et al.* (1990b) proposed that the s-Cepheids are the first overtone pulsators. However, Simon (1990) casts doubts on whether all s-Cepheids are pulsating in the first overtone mode. We do not see any simple, direct technique to establish correctly a pulsational mode of s-Cepheids in the Galaxy, except for those in open clusters. Therefore, in addition to SU Cas, which is a possible member of a poorly-populated association of B and A type stars (Turner and Evans 1984), and SZ Tau, which is an outlying member of NGC 1647 (Turner 1992), we also included in our sample V1726 Cyg. This Cepheid is a likely member of the open cluster C2128+488 (Turner *et al.* 1994). According to Antonello *et al.*'s (1990) criteria all three Cepheids belong to the s-Cepheid type and, presumably, are first overtone pulsators. Notably, if the cluster membership is confirmed, it can unambiguously indicate the actual pulsational mode.

2. Fourier decomposition technique

Following Antonello *et al.* (1990), we applied the Fourier decomposition technique to the light curves in V-bandpass. It is based upon Fourier decomposition of the light curves by series:

$$m(t) = A_o + \sum_{i=1}^{n} A_i \cos[2\pi i(t - T_o)/P + \phi_i] \qquad (1)$$

where A_i is a semi-amplitude of light variation, ϕ_i is the phase shift, T_o and P are the adopted epoch of light maximum and period. In the plane of the phase difference ϕ_{ij} *vs.* P, where $\phi_{ij} = j\phi_i - i\phi_j$; i = 2,3; j = 1; the s- and classical Cepheids form separate sequences. Also useful for the discrimination between these two types of Cepheids is the amplitude ratio $R_{ij} = A_i/A_j$. In this paper we used the Fourier parameters for two reasons. First, since the light curve might not have a good phase coverage, especially at its extremes, the simple eye-ball estimates of the amplitude might be distorted. In order to detect small secular changes in the amplitude one must consistently use rigorous estimates of amplitude after a least-squares Fourier fit. Each data set should be analyzed separately in a manner as described above. Second, we formed mean data sets for each Cepheid and solved once again for the Fourier parameters. In this case the different data sets must be synchronized, i.e., any period change should be accounted for. The mean Fourier decomposition parameters are provided in Table 1 and are mainly used in context of the pulsational status of Cepheids. The uncertainties in the Fourier parameters listed in Table 1 are the formal standard errors.

Table 1. Mean Fourier decomposition parameters.

SU Cas	SZ Tau	V1726 Cyg
$P = 1^{d}.94933$	$P = 3^{d}.14873$:	$P = 4^{d}.23704$
$A(V) = 0^{m}.40$	$A(V) = 0^{m}.34$	$A(V) = 0^{m}.19$
M-m = 0.38	M-m = 0.47	M-m = 0.50
$R_{21} = 0.187 \pm 0.006$	$R_{21} = 0.029 \pm 0.008$	$R_{21} = 0.06 \pm 0.02$
$R_{31} = 0.041 \pm 0.007$	$R_{31} = 0.006 \pm 0.008$	$R_{31} = 0.04 \pm 0.02$
$\phi_{21} = 4.21 \pm 0.03$	$\phi_{21} = 4.62 \pm 0.28$	$\phi_{21} = 3.81 \pm 0.33$
$\phi_{31} = 2.95 \pm 0.14$	$\phi_{31} = 4.70 \pm 1.36$	$\phi_{31} = 6.72 \pm 0.50$

3. SU Cas

SU Cas has an extensive and long observational history (see Szabados 1977; Szabados 1991 for references), but only a few sources can be used for amplitude stability studies. The observations must be photoelectric and they should cover evenly the light curve's minimum and maximum parts to ensure a reliable amplitude estimate using the Fourier decomposition technique. The only sources of data which meet these requirements (though not completely!) are indicated in Table 2.*

Table 2. Mean V-amplitudes for SU Cas and SZ Tau.

SU Cas		SZ Tau		
JD	Mean V-Amplitude	JD	Mean V-Amplitude	Reference
2437439	$0^{m}.39$	2437620	$0^{m}.40$	Mitchell *et al.* (1964)
2438385	0.41	2438530	0.32	Wisniewski and Johnson (1968)
2439055	0.40	2439055	0.34	Milone (1970)
2441646	0.37	2439808	0.33	Szabados (1977)
2441930	0.40	...	...	Gieren (1976)
2444178	0.41	2443927	0.34	Moffett and Barnes (1984)
2447150	0.40	...	...	Rhode (1990)

The combined light curve of SU Cas deviates from the sinusoidal shape but the Cepheid's position in the ϕ_{21} *vs.* P and ϕ_{31} *vs.* P planes fits the s-Cepheid sequence. The light-curve parameters derived from combined Mitchell *et al.* (1964), Wisniewski and Johnson (1968), Milone (1970), Szabados (1977), Moffett and Barnes (1984) data sets are listed in Table 1. The approximate normal maximum moments adopted from

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* Comparison and check stars for photoelectric photometry of SU Cas are, respectively, BD+67°215 (V = 6.64, B-V = 0.47, U-B = 0.25), and BD+67°224 (V = 5.95, B-V = 0.21, U-B = 0.17) (Szabados 1977).

Szabados (1991) and mean *V*-amplitudes for each data set (see Reference column) are presented in Table 2. The observations by Gieren (1976) and Rhode (1990) are available only in graphical form, therefore, in Table 2 we quote the amplitude from Gieren's paper and present our best eye-ball estimate from Rhode's (1990) light curve. As can be seen from Table 2, the mean *V*-amplitude, $\Delta V = 0.40$ magnitude, is remarkably stable over a quarter of a century. A least-squares fit of the mean-amplitude as a function of time, assuming that all points have equal weights, yields a secular brightening of 0.00015 ± 0.00065 magnitude/year. Given the formal fitting error, we believe that the pulsational amplitude of SU Cas has not changed over the last 25 years.

The pulsational mode of SU Cas is a subject of certain controversy. Gieren (1976) and Antonello *et al.* (1990a) provide strong support for SU Cas as an overtone pulsator, whereas its B and A star association membership (Turner and Evans 1984) indicates the fundamental mode pulsation. To some extent the correct interpretation is aggravated by the presence of a companion (Turner and Evans 1984). With the existing observations on hand, we do not pretend to resolve the issue.

4. SZ Tau

In contrast to SU Cas in the previous section, SZ Tau has a sinusoidal, s-Cepheid-like light curve. Similar to SU Cas, it also has a fairly long observational history (Szabados 1977). The high quality photometric data we used for the Fourier decomposition are presented in Table 2.* Fortunately, both SU Cas and SZ Tau were observed equally frequently by the same authors. Yet reported phase jumps and period changes of SZ Tau (Szabados 1977; Szabados 1991) created additional difficulties in calculating the mean Fourier parameters which are provided in Table 1. The mean light curve was composed by taking out these phase jumps from individual data sets used for the calculations, namely, from Mitchell *et al.* (1964), Wisniewski and Johnson (1968), Milone (1970), Szabados (1977), Moffett and Barnes (1984). Still unaccounted-for effects of period changes are probably responsible for considerably higher errors in the decomposition parameters of SZ Tau. It must be noted that the mean period of SZ Tau in Table 1 is given just for the sake of completeness. Individual values of the SZ Tau pulsation period can be found in Szabados (1991). The Cepheid SZ Tau fits nicely along the s-Cepheid sequence in the ϕ_{21} *vs.* *P* and ϕ_{31} *vs.* *P* planes. As for SU Cas, the normal maximum moments and mean *V*-amplitudes of SZ Tau are presented in Table 2. The *V*-amplitudes from different sources, except that of Mitchell *et al.* (1964), are fairly consistent at a value of around $\Delta V = 0.33$ magnitude. One may notice that the data from Mitchell *et al.* (1964) also include earlier observations by Eggen which originally were not in the UBV system. Considering this, as well as a larger scatter of data points and a poor coverage at light minimum, it is unlikely that SZ Tau had undergone a real amplitude drop at JD ~ 2438000. A least-squares fit to the mean amplitudes indicates an amplitude decline at the rate -0.0016 ± 0.0025 magnitude/year. This amplitude decline rate is mainly determined by Mitchell *et al.*'s (1964) observations, which might have a problem as mentioned above. Therefore, we are inclined to adopt a constant pulsational amplitude for SZ Tau over the time span indicated in Table 2.

SZ Tau is a very likely member of the open cluster NGC 1647 (Turner 1992). The derived luminosity from the cluster membership and that of a period-luminosity relation for cluster Cepheids implies a first overtone mode. This is consistent with a common belief in the s-Cepheid pulsational mode. On the other hand, SZ Tau is located far from the cluster nucleus—at a distance of 2°1, which corresponds to a linear separation of

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* Comparison and check stars for photoelectric photometry of SZ Tau are, respectively, BD+19°744 (V = 6.34, B-V = 0.74, U-B = 0.33), and BD+19°731 (V = 7.11, B-V = 0.46, U-B = 0.08) (Szabados 1977).

~20 pc (Turner 1992). Although the radial velocity, age, and (less convincingly) proper motion of SZ Tau match very well the values for NGC 1647 members, it still has to be proved that the Cepheid is within the tidal radius of the cluster.

5. V1726 Cyg

This Cepheid was discovered by Platais (1979) during photometric studies of the nearby open cluster NGC 7092 = M39. The star BD +48°3398 = SAO 050939 was measured photoelectrically by McNamara and Sanders (1977), and therefore was used as a standard along with others in order to calibrate the photographic photometry. It had small but obvious brightness variations from plate to plate. Fortunately, the sky area containing V1726 Cyg was observed quite frequently with the Schmidt camera at Baldone (Latvia) during the outburst of Nova Cygni = V1500 Cyg in September 1975. The B-magnitudes derived from this plate material enabled us to determine the Cepheid nature of BD +48°3398 and, despite the small amplitude $\Delta B = 0.27$ magnitude, to establish correctly the period $P = 4.24$ days and other parameters. The basic references to the history of the follow-up photoelectric observations and the best set of parameters of V1726 Cyg can be found in Turner *et al.* (1994), where the best combined V-light curve is also presented. Existing photoelectric observations cover about 12 years of photoelectric observations, or ~1000 pulsational cycles. A finder chart for V1726 Cyg can be found in Turner *et al.* (1994).

In Table 1 we simply reproduced the Fourier parameters from Turner *et al.* (1994), since no additional observations are available to improve them. The Fourier decomposition parameters of V1726 Cyg fit very well within the domain occupied by s-Cepheids, although Antonello *et al.* (1990a) discarded this Cepheid as having an almost sinusoidal light curve. V1726 Cyg could be an appropriate s-Cepheid to examine its amplitude stability due to very low pulsational amplitude $A(V) = 0.19$ magnitude. From the currently available light curve analysis we cannot find any amplitude or period changes. Probably, the observational history of 12 years is too short to detect long-term changes.

A very interesting question is whether V1726 Cyg pulsates in fundamental or the first overtone mode. The evidence presented by Turner *et al.* (1994) strongly suggests that V1726 Cyg is a very likely member of the open cluster C2128+488. The cluster's evolutionary status, and the Cepheid's intrinsic color and luminosity imply that V1726 Cyg is a fundamental mode pulsator, despite the conclusion drawn from its Fourier decomposition parameters.

6. Conclusions

Based upon the observational data available from different sources we have found no decisive traces of the amplitude change for SU Cas, SZ Tau, and V1726 Cyg. With a few exceptions it must be noted that the observations are not quite adequate to test the amplitude stability rigorously. Ideally, there must be well-observed cycles of light variation (especially at the extreme magnitudes) approximately once in two years. Instead, observations have been casual and not well planned. Therefore, we encourage observers possessing adequate equipment to make coordinated follow-up observations for at least the next decade. The lists of well-established low-amplitude Cepheids (in total of ~ 20) are available in papers by Arellano Ferro (1984) and Antonello *et al.* (1990a) and references therein. We hope that in a few years the Hipparcos astrometric satellite data will provide invaluable information for new, insofar, undetected low-amplitude Cepheids.

We confirmed that in the Fourier parameter space, all three Cepheids occupy the domain of supposedly well-established s-Cepheids; however, the matter of their pulsational mode still has to be resolved. If one adopts luminosities based on cluster membership for these Cepheids, then only SZ Tau appears to be an overtone pulsator. At present, the available data indicate that each Cepheid is a probable cluster member, although it could be desirable to re-examine their cluster membership using better proper motions. This mentioned, the three cases analyzed here seem to provide evidence that not all s-Cepheids are overtone pulsators. If we have such an uncertainty in the pulsational mode of a given Cepheid, then we may have almost a guaranteed uncertainty in the luminosity estimate—a key issue in establishing the extragalactic distance scale. This only stresses the importance of continuing the observations in a variety of approaches, including the simplest optical monitoring.

7. Acknowledgments

We are grateful to Dr. D. G. Turner for stimulating discussions and for a number of invaluable suggestions. We also appreciate helpful comments from two anonymous referees. This research made use of the SIMBAD database, operated at CDS, Strasbourg, France.

References

Arellano Ferro, A. 1984, *Mon. Not. Roy. Astr. Soc.*, **209**, 481.
Antonello, E., Poretti, E., and Reduzzi, L. 1990a, *Astron. Astrophys.*, **236**, 138.
Antonello, E., Poretti, E., and Reduzzi, L. 1990b, in *Confrontation Between Stellar Pulsation and Evolution*, eds. C. Cacciari and G. Clementini, *Astron. Soc. Pacific Conf. Ser.*, **11**, 209.
Burki, G., Schmidt, E.G., Arellano Ferro, A., Fernie, J.D., Sasselov, D., Simon, N.R., Percy, J.R., and Szabados, L. 1986, *Astron. Astrophys.* **168**, 139.
Gieren, W.P. 1976, *Astron. Astrophys.*, **47**, 211.
Fernie, J.D. 1990, *Publ. Astron. Soc. Pacific*, **102**, 905.
Fernie, J.D., Kamper, K.W., and Seager, S. 1993, *Astrophys. J.*, **416**, 820.
Kholopov, P.N., *et al.* 1985, *General Catalogue of Variable Stars*, 4th ed., Moscow.
McNamara, B.J., Sanders, W.L. 1977, *Astron. Astrophys. Suppl.*, **30**, 45.
Mitchell, R.I., Iriarte, B., Steinmetz, D., and Johnson, H.L. 1964, *Bol. Obs. Ton. Tacubaya*, **3**, 153.
Milone, E.F., 1970, *Inform. Bull. Var. Stars*, No. 482.
Moffett, T.J., and Barnes III, T.G. 1984, *Astrophys. J. Suppl.*, **55**, 389.
Platais, I. 1979, *Astron. Circ.*, No. 1049, 4.
Rhode, K.L. 1989, *J. Amer. Assoc. Var. Star Obs.*, **18**, 119.
Simon, N.R. 1990, in *Confrontation Between Stellar Pulsation and Evolution*, eds. C. Cacciari and G. Clementini, *Astron. Soc. Pacific Conf. Ser.*, **11**, 193.
Szabados, L. 1977, *Comm. Konkoly Obs., Budapest*, No. 70, 1.
Szabados, L. 1991, *Comm. Konkoly Obs., Budapest*, No. 96, 125.
Turner, D.G., and Evans, N.R. 1984, *Astrophys. J.*, **283**, 254.
Turner, D.G. 1992, *Astron. J.*, **104**, 1865.
Turner, D.G., Mandushev, G.I., and Forbes, D. 1994, *Astron. J.*, **107**, 1796.
Wisniewski, W.Z., and Johnson, H.L. 1968, *Comm. Lunar Planet. Lab.*, **7**, No. 112.