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ASTRONOMY AND ASTROPHYSICS

Cyclicities in the light variations of LBVs*

I. The multi-periodic behaviour of the LBV candidate ζ^1 Sco

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Abstract. Differential Strömgren $uvby$ photometry of ζ^1 Sco collected during the time interval 1982-1995 is analysed together with new $VBLUW$ photometry with a complementary discussion of unpublished $JHKLM$ data. We report the discovery of a $\sim$ 1750-2200 d regular oscillation of amplitude $\sim 0\overset{\rm m}{.}01$ in all bands, and pulsation-like oscillations with at least one frequency $f_1 = 0.03155$ ($P \sim 32$ days) and a possible second frequency $f_2 \sim \frac{5}{4} f_1 \sim 0.03891 (P \sim 25.7$ days). Most likely, all such stars exhibit multi-periodic light variability. A strong noise component remaining in the prewhitened signal leads us to postulate that the driver for LBV-like eruptions is stochastic resonance. This hypothesis is supported by the historic light curve of ζ^1 Sco which shows that two centuries ago the star was about 2 magnitudes brighter, while a millenium ago it was only 1 magnitude brighter than today, an indication that ζ^1 Sco should be regarded as a candidate Luminous Blue Variable.

Key words: stars: variables – stars: oscillations – stars: LBVs – stars: individual: ζ^1 Sco – techniques: photometric

1. Introduction

ζ^1 Sco (HD 152236 = HR 6262, $V \sim 4.74$, B1.5Ia$^+$) is one of the best studied early-B type α Cyg variables and is a member of the Sco OB1 association. This superluminous star belongs to the open cluster NGC 6231 (van Genderen et al. 1984). Line-strength variability was reported by Jaschek & Jaschek (1973); the photometric variability of ζ^1 Sco as an extreme supergiant was described by Sterken (1977), who derived a pseudo-period of $\sim$ 16.5 days with an amplitude of $0\overset{\rm m}{.}05$ in the Strömgren y band. The amplitude of the variation is changing with time. The star may also be regarded as variable at near-infrared wavelengths: unpublished $JHKLM$ measurements by one of us (C.S.) at ESO reveal significant differences with the results obtained by Leitherer & Wolf (1984) shortly after, and by Whittet et al. (1976), see Table 1. Note that the former results are in the ESO system, which is–notably in the J and L bands–photometrically incompatible with the system used by Whittet et al. (1976).

The star also has a variable β index, and has an extreme photometric index β = 2.582 (Hauck & Mermilliod 1990). Using the Geneva photometric colours taken from Rufener (1988), we obtain for the emission-free calculated β index (see Cramer 1994) $\beta_{calc} = -0.103$, a signature of very strong emission in Hβ, a situation that reflects the observed variable Hβ line profiles as shown, for example, in Fig. 1 of Rivinius et al. (1997). These authors presented a study based on extensive high-dispersion spectroscopic observations carried out in the framework of the "Long-Term Spectroscopy of Variables" program (LTSV, Wolf 1994, see also Stahl et al. 1995). They show that the photospheric variability displays a pulsation-like pattern extending over several cycles covering a time interval of about 2 months, followed by a quite random pattern. Their analysis shows, for the first time, that disturbances which affect the wind of ζ^1 Sco (and other early B hypergiants) are generated very deep in the photosphere and are causally connected to pulsation-like motions seen in the shape of radial-velocity variations. They derive typical time scales of 15 days for the emission-line intensities, 24 days for the absorption-line intensities, and $11\overset{\rm d}{.}8$ for the radial velocities of photospheric lines, while the Hα emission shows both the 15 and 11.8 day time scale. These time scales indicate a possible connection with the photometric variations reported by Sterken (1977) and later by Burki et al. (1982). We also note that their Fig. 9 shows a mean emission-line time scale of about 13 days. This is about half the time scale of 24 days for the absorption lines and almost exactly half our time scale of $25\overset{\rm d}{.}7$ for the photometric variations (see Sect. 4 below). Using $E_{\rm B-V}$ = 0.64, Rivinius et al. (1997) derive the following stellar parameters for

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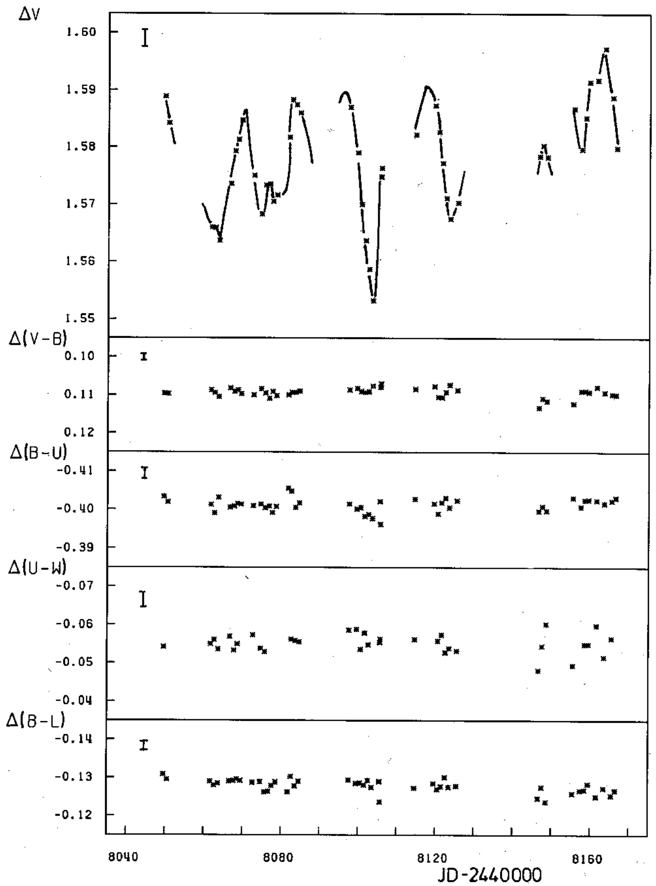

Fig. 1. An example of a series of observations in the $VBLUW$ system (ζ^1 Sco relatively to the comparison star, data from 1990). Magnitude scale is in $\log I$ units, error bars are two times m.e.

Table 1. Near-infrared photometry of ζ^1 Sco from different sources. WvBG refers to Whittet et al. (1976), LW to Leitherer & Wolf (1984) and S to unpublished measurements by CS (mean errors do not exceed 0$^{\rm m}_{.}$03 in all bands). Note that the ESO L band results are, in fact, L', whereas the WvBG corresponding magnitudes are on the L scale

Date	J	H	K	L	M	Source
April 1974	3.47	3.27	3.11	2.94		WvBG
2445088.12	3.64	3.45	3.23	3.07	2.96	S
2445092.21	3.43	3.36	3.18	2.98	2.97	S
Aug. 1982	3.58	3.32	3.18	2.98	2.90	LW

ζ^1 Sco: T$_{\rm eff}$ = 19700, $log\, g$ = 2.30, $R/R_\odot$ = 91, $M/M_\odot$ = 60, $logL/L\odot$ = 6.05, $M_V = -9.09$, $M_{\rm bol} = -10.39$ and a distance d = 1.90 kpc.

Burki et al. (1982) established a unique relation between the time interval T (in days, between maximum and subsequent minimum or vice versa) and the associated total amplitude of light variation A in the Geneva V band, viz. $A = 0.28(10.4 - P/2)^{-1}$ with $P = 2T$, a relation that holds for $6 < P < 16$ and that implies that the pseudo-period derived by Sterken (1977) only holds for the variations with the largest amplitude.

In this paper we present a study of the light variations of ζ^1 Sco involving all available photometric data originating from photometric monitoring during the last 23 years. Throughout this paper we discuss differential photometry, in the sense that the variability of ζ^1 Sco is discussed in terms of the differential magnitude (Var - Comp) in each Strömgren band, and in the Walraven and Johnson V bands.

2. The data

2.1. *uvby photometry, ESO*

The data were collected by CS in 1972-1973 and have been discussed by Sterken (1977). 35 measurements are available, the comparison star was HD 152234.

2.2. *VBLUW photometry, ESO*

The $VBLUW$ photometry of ζ^1 Sco was made in 1989 and 1990 using the 90 cm Dutch telescope equipped with the simultaneous $VBLUW$ Walraven photometer. A general description of the monitoring campaign (including the observing strategy and reduction procedures) of luminous and massive stars that included ζ^1 Sco, is given by van Genderen et al. (1985). A total of 145 nightly averages were obtained with a very small mean error of $\sim$ 0$^{\rm m}_{.}$003 in V. The sole comparison star used is HD 152941 (V = 8.71 $\pm$ 0.01, A0V). In order to bring the Walraven V data to the same scale as the Strömgren y magnitudes, the difference between simultaneously obtained (i.e. within 0$^{\rm d}_{.}$1) differential magnitudes was calculated. 39 such measurements are available, and yield a mean $\Delta y - \Delta V_W = 2.396 \pm 0.002$ (the corresponding mean time difference between simultaneous measurements is 0$^{\rm d}_{.}$02 $\pm$0$^{\rm d}_{.}$06). This correction was then applied to all the Walraven V data. Fig. 1 shows an example of a series of observations in the $VBLUW$ system.

2.3. *LTPV uvby photometry, ESO*

These $uvby$ data were obtained at ESO in the framework of the "Long-Term Photometry of Variables" (LTPV) project which was initiated more than a decade ago (Sterken 1983, 1994). A total of 399 datapoints (i.e. nightly averages of 1-3 measurements) have been collected. Table 2 gives the most important results for each star, as well as the overall averages in $y(V)$, $b-y$, m_1 and c_1, together with the corresponding standard deviations of individual measurements. The data in Table 2 are based on data from "System 7" (see Sterken 1993) only, and they give a general impression of the photometric accuracy of the LTPV program. A quick look confirms variability: in all cases the standard deviations of the program star largely exceed those of the comparison stars. The comparison stars, being supergiants themselves, are variable too, but with an amplitude that is about half that of the program star; the colours have very similar ranges. From an inspection of the non-differential measurements, we came to the conclusion that A5010 = HD 152424 is the most stable comparison star. There are no dramatic changes, except for one event on HJD 2445907.6 when HD 152147 weakened by about 0$^{\rm m}_{.}$3

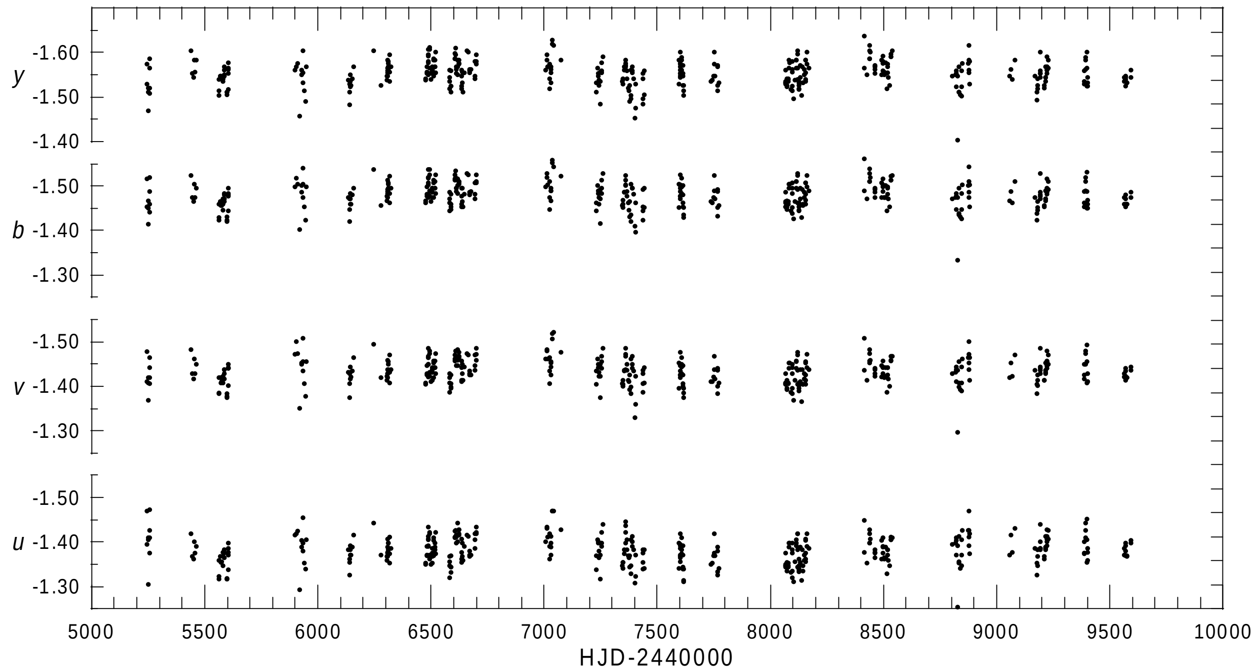

Fig. 2. Differential $uvby$ light curves of ζ^1 Sco (P *minus* A) in the instrumental system

Table 2. Program star ζ^1 Sco (P) and comparison Stars (A, B): average $y(V), b-y, m_1, c_1$ magnitudes and their standard deviations σ (in millimag.). N denotes the total number of observations of each star. Note that the results are based solely on data belonging to System 7 (Sterken et al. 1993, see also Sterken 1993)

LTPV	HD	MK type	$y(V)$	$b-y$	m_1	c_1	N	σ_y	σ_{b-y}	σ_{m_1}	σ_{c_1}
P5010	152236	B0.5Ia	4.737	0.444	-0.087	-0.108	279	24	4	5	7
A5010	152424	O9I	6.294	0.371	-0.051	-0.111	265	15	4	5	7
B5010	152147	B0I	7.267	0.360	-0.039	-0.115	264	14	4	6	6

in u and about $0\overset{m}{.}1$ in y and v. On that night, it appeared that all stars were slightly fainter than on the following night, but the effect should cancel out in any differential evaluation. The remainder of our discussion of LTPV data is restricted to those time intervals where the differences between both comparison stars can be regarded as constant.

Despite the variability of the LTPV comparison star, we stick to differential data, because the latter are free from variations in the zero points and extinction coefficients that might otherwise affect the results.

The photometric data were published by Manfroid et al. (1991, 1994) and Sterken et al. (1993, 1995), and we refer to these papers for more details on the observing strategy and reduction procedure. All our figures are based on data in the instrumental photometric system.

3. The light curves

Fig. 2 reveals, besides short-term variability, also some sign of a low-frequency variability in the form of a wave-like pattern with a cycle length of about 1500 to 2000 days. The colour variations are relatively modest, but the similarities in the pattern of variability, especially in c_1 and m_1, suggest that some deviations might be of non-physical origin–that is, due to conformity errors that arise when combining data from non-congruent photometric systems. Indeed, some of these effects disappear after JD 2447600, when data have been collected in System 7 only.

4. Search for periodicities

In order to avoid bias during the quest for frequencies, a careful inspection of the differential magnitude of the comparison stars (LTPV data only) was carried out. The following outlying data were removed: JD 5562.6-63.6, 5907.6, 6518.9, 6603.7-6607.6, 6634.6-6635.7, 7011.5, 7246.9, 7752.6, 7765.6, 7766.6, and 8833.6-8846.5. A period search was carried out using Fourier analysis (using programs described by Sterken 1977 and Breger 1990) on the differential P *minus* A data in the frequency range 0.0001-0.2c d^{-1}. The spectral window is dominated by two very strong peaks at 0.00273 and 0.00552 c d^{-1}, respectively corre-

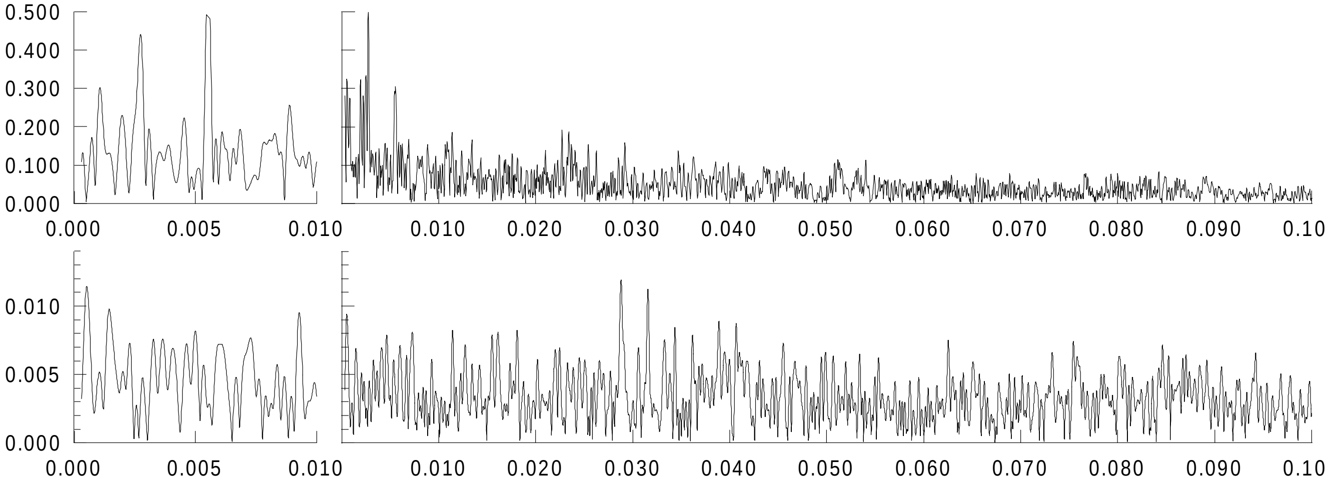

Fig. 3. Amplitude spectrum of ζ^1 Sco (bottom) and corresponding spectral window in the frequency range 0.0001-0.1 c d^{-1}. The left part of the graph (at higher frequency resolution) is based solely on LTPV y data, the right part is based on the LTPV y + Walraven V measurements

Table 3. Amplitude A_V (in mag) and phase ϕ_V (in degrees) from the Fourier analysis of all $y \equiv V$ data, and the corresponding results for the 3-frequency fit to the $uvby$ LTPV photometric data. Phase zero corresponds to JD=2440000

Frequency	Period (d)	A_V	ϕ_V	A_y	ϕ_y	A_b	ϕ_b	A_v	ϕ_v	A_u	ϕ_u
f_0 = 0.00054	1835	0.010	5.4	0.011	6.0	0.011	5.9	0.011	7.0	0.014	5.2
f_1 = 0.03156	31.7	0.011	35.4	0.012	35.7	0.011	35.5	0.012	35.8	0.011	35.2
f_2 = 0.03894	25.7	0.009	1.4	0.008	2.1	0.009	2.7	0.008	2.5	0.008	3.3

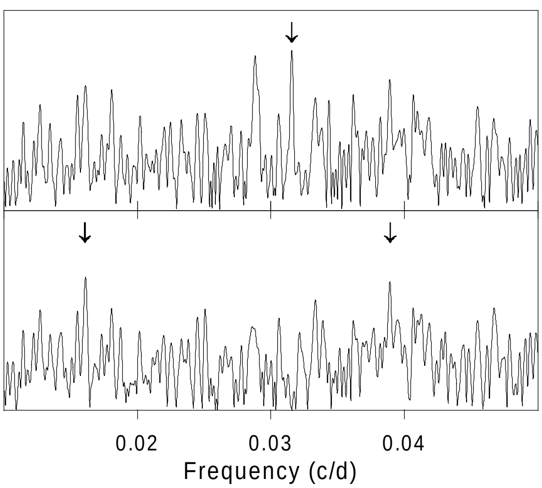

Fig. 4. Amplitude spectra for two successive steps of the frequency analysis. The top diagram is the spectrum obtained after prewhitening for the lowest frequency as seen in Fig. 3; the selected frequency f_1 is indicated by an arrow. The other graph shows the result after prewhitening for f_1, the arrows give the positions of f_2 and f_1/2

sponding to P = 363$^{\rm d}_{.}$6 and P = 181$^{\rm d}_{.}$1 originating from the annual cycle of our measurements.

A strong low-frequency amplitude in the frequency spectrum for the y data is at f_0 = 0.00052 (see Fig. 3). This frequency is also present in the v, b and u data, and is also visible in the non-differential data. At the same time, it is absent in the spectral window, and in the data of the comparison stars. A new period analysis of all combined $y \equiv V$ data reveals, again, the 0.002735 annual frequency, and the resulting low-frequency f = 0.00045 ($\sim P$ = 2200 d) cycle.

The long cycle is clearly visible in Fig. 2. After prewhitening with this frequency (an operation which reduces the standard deviation of the residual light curve from an initial R = 0$^{\rm m}_{.}$0265 to 0$^{\rm m}_{.}$0256), a new search was initiated in the same frequency domain. The highest peak is at f_1 = 0.03156 (see Fig. 4), and is flanked by the one cycle per year alias 0.02872. We removed the f = 0.03156 frequency, and obtained a noisy spectrum that is dominated by two relatively strong peaks at f_2 = 0.03894c d^{-1}and 0.01605c d$^{-1}\sim$ $f_1/2$. The latter frequency may be an artifact of prewhitening a non-sinusoidal signal by a sinusoidal function with frequency f_1, but the former ($P \sim$ 25.7) could be a real frequency representing the oscillatory behaviour as seen in Fig. 1 and in the light curves obtained by Sterken (1977) and Burki et al. (1982). Furthermore, f_2 does correspond to what Rivinius et al. (1997) call "the repetition time of the absorption features of approximately 24 days".

Because the spectra are quite noisy, we have sought additional arguments to support our view that the frequencies f_1 and possibly f_2 are real. An independent periodogram analysis kindly performed by Dr. A. Kaufer using the CLEAN method as applied by Kaufer et al. (1996) indicates that the level of significance of both f_1 and f_2 exceeds 3σ. Fig. 5, representing the phase diagram obtained after folding the f_0-prewhitened V

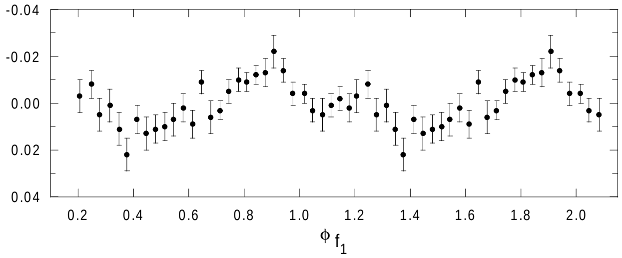

Fig. 5. Phase diagram of LTPV + Walraven V data (prewhitened with the low frequency f_0 and folded by f_1 = 0.03156

data over f_1 (data have been averaged in phase bins of 0.03 [$\sim$ 1 day], the maximum time resolution of our observations) adds convincing evidence that a stable frequency f_1 is present in our data covering a time interval of more than 12 years.

A frequency analysis of two subsets of data of comparable time span (viz. all LTPV and Walraven data collected before and after JD 2447500–respectively, 200 and 317 measurements) yields f_1 and f_2 in the second dataset, whereas the first dataset leads to f_1, f_2 with a strong additional frequency at 0.0455 c d^{-1}, a frequency that also shows up when the CLEAN method is applied. One should, however, not conclude from this that a change in one or more of the frequencies is seen, since the resulting periodicities are very sensitive to the time interval over which the analysis is carried out, to the distribution of the data points over time, and to the spectral distribution of the noise component (see Sect. 5.3). We conclude that the significance of f_2 and $f_1/2$ as derived from our data is marginal at present, and needs to be confirmed by additional photometric measurements.

We have made a simultaneous three-frequency fit to the homogenised data set consisting of the LTPV and Walraven $y \equiv V$ data, which led to a solution with f_0 = 0.000545, f_1 = 0.03155 and f_2 = 0.03891 $\sim$ $\frac{5}{4}f_1$. These frequencies were then fitted to the LTPV u, v, b and y magnitudes, and the resulting amplitudes and phases (in degrees, according to $m(t)$ = $m_o + \sum_{i=0}^{2} A_i \sin(2\pi f_i t + \varphi_i)$, where m_0 is the mean differential magnitude in the appropriate band, and t is HJD-2440000) are given in Table 3. We also repeated this step for all LTPV-system 7 data (for details on the nomenclature of the LTPV photometric configurations, see Sterken 1993), and obtained very similar results. The longest period seems to range from $\sim$ 1750 to 2000 d, depending on the (extent of the) data set being used. The higher frequencies, however, are affected very little by the value adopted for the low frequency.

Another interesting feature is also visible in the light curves: at JD 2445251.5, 5918.6, 7400.6 and 8825.6, there are rather pronounced minima. These features occur with a regularity of $\sim$ 725 d. Unfortunately, the time resolution of our observations does not allow us to say anything about the duration of these minima, except that they can last a couple of days at most. In order to see whether these features have any effect on the value found for the low frequency f_0 = 0.00054, we repeated the period search with the same data, after removal of the features. This, however, does not change the above-derived frequencies.

5. Discussion

5.1. The $\sim$ 2000 day oscillation

A first-hand explanation could be found in an interpretation in terms of a large rotating disk, where the minimum features could be partial eclipses of a migrating spot, in the sense of the "dimples" seen by van Genderen et al. (1995) in the light variations of η Carinae.

Another possible interpretation of the low-frequency light variation could be in terms of an ellipsoidal configuration where tidal deformation in a binary with period $2/f_0 \sim 4000$ days causes the light variations. Using the stellar parameters of ζ^1 Sco, such a binary configuration would entail an orbit with semi-major axis of 19-23 A.U. (for the sum of the masses $M/M_\odot$ = 60-100). The distance of the star being 1.9 kpc (Rivinius et al. 1997), this would correspond to $\pm 0''\!.01$ on the sky. To our knowledge, ζ^1 Sco is not a member of such a wide binary system; moreover, ellipsoidal effects in the light curve of such a wide configuration can be ignored. The trend of the associated amplitudes of the light variation does not support the hypothesis of ellipsoidal variability by a solid companion.

Fig. 6 shows the long-term variation in the V-band. The dotted line is the extrapolation of the fit to the new data described in this paper. It is obvious that it fits the Geneva visual magnitudes very well, though it falls short by about $0^{\rm m}\!.05$ of the data collected by CS in 1972. We stress that these deviating data were taken in a photometric setup that was very similar to the one used by LTPV, while the Geneva data do correspond notwithstanding they having been obtained in a completely different photometric system. This may support the picture that this oscillation is a typical pulsation wave with a total range of $\geq 0^{\rm m}\!.02$ in all bands and with variable amplitude. Note that the (slight) long-term colour variation is in the sense that the system becomes bluer when it is brighter, lending some support to the above-expressed idea of a rotating disk probably with something like a "hot spot".

5.2. The regular light variations of ζ^1 Sco on a time scale of several weeks to one month

Three independent studies, viz. this paper, the work by Burki et al. (1982) and the discovery light curve by Sterken (1977), clearly show that ζ^1 Sco appears to be a rather uneventfully-varying hypergiant. The (pseudo-) cycles of variation–with the exception of the $\sim$ 2000 d periodicity reported here–are very similar, and no signs of eruptive behaviour have been observed. In view of the results of the frequency search, it is clear that the variability in amplitude and period of the star's continuum radiation could be understood in terms of the interplay between two (or more) "short" periods as listed in Table 3. Indeed, there is the dominant $32^{\rm d}\!.0$ period with its amplitude of about $0^{\rm m}\!.01$ to which a weaker wave is added, and this signal is modulated by the long-wave periodicity. As a result of this composite pattern, at times the light curve typically shows a couple of consecutive maxima and minima of almost equal amplitude at about 32-

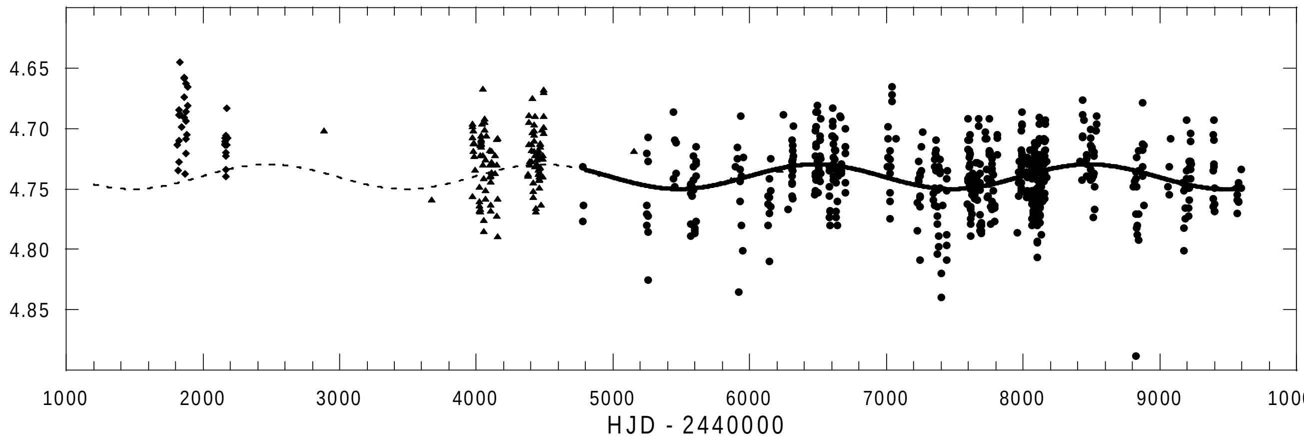

Fig. 6. All available V-band photometry of ζ^1 Sco: Sterken (1977): filled ◇, Burki et al. (1982): filled △, new data reported in this paper: •. The solid line is the 1-frequency sinusoidal fit described in Table 3. The dotted line is the extrapolation of the solid line towards earlier times

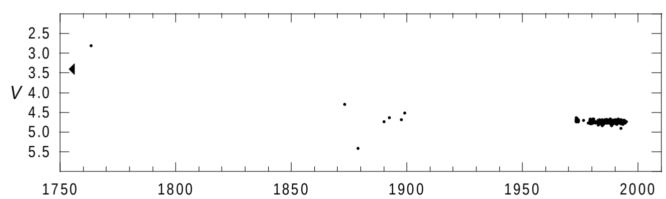

Fig. 7. Light history of ζ^1 Sco combining historic data and new data discussed in this paper. The filled triangle near the Y-axis gives the V magnitude derived from the estimates reported by al-Sûfi in A.D. 962

day intervals, while at other times longer intervals of lower-amplitude variability do occur.

5.3. The stochastic variability

It is clear that the formal Fourier expression of the more rapid light variations does not account for the full variability in all bands–indeed, deviations up to $0^{m}.05$ between the observed and computed light curve do remain. Not all of this excess fluctuation can be ascribed to the comparison star, since its variability is of a smaller magnitude than that of ζ^1 Sco itself.

The remaining large residuals and the broad band of noise extending over a wide frequency range open, in fact, an interesting possibility: the presence of a rather strong noise component–unpredictable, but to some degree in step with the microvariations–could from time to time amplify the regular long-term oscillation beyond expectation and, as such, lead to an eruption. Such amplification of weak signals by associated noise is known as *stochastic resonance*–for an introduction, see Moss & Wiesenfeld (1995). It can lead to unexpected triggerings, especially when combined with a long-period oscillation like the 2000 d period, or even to conceivable very-long-term multi-periodic variations, such as the S Dor phases (“VLT-SD phases”) as seen by van Genderen et al. (1997) in S Dor and AG Car. Variations of such regularity have not been seen in ζ^1 Sco because the light history of the star barely covers two decades, but they might be present (see Fig. 7). Such a scenario would open the possibility of ζ^1 Sco being a dormant (or ex-) LBV. Considerations supporting this idea are given in the following section.

5.4. ζ^1 Sco as a candidate LBV

Hertzog (1992) surveyed the histories of blue supergiants not currently thought to be large-amplitude variables, and pointed out that today ζ^1 Sco, when compared to ζ^2 Sco = HD 152334, apparently is more than one magnitude brighter than a century ago. However, ζ^2 Sco being a K5III star, the direct comparison of its visual magnitude with that of a B1 supergiant leaves much room for doubt on the resulting magnitude difference when measured with a detector that has a passband as wide as the photometric passband of the human eye.

The oldest-known recorded photometric measurement of ζ^1 Sco undoubtedly is the estimate ($4^{m}.1$) registered by the tenth-century Persian astronomer Abd-Al-Rhaman al-Sûfi (903-986, mostly referred to as Al-Sufi) in his catalogue of 1022 stars published in 962. Such pre-telescopic measurements, though, cannot be taken at face value for more than one reason (the major source of error not only is the human eye as a non-calibrated detector, but also the star’s position close to the Milky Way and the fact that his observations were made at 30° northern latitude).

De La Caille (1763) lists ζ^1 Sco as a 4$^{\rm th}$ magnitude star, and gives m_V= 4 both for σ and τ Sco. Gould (1879), on the other hand, gives m_V = 5.8 for ζ^1 Sco, and m_V = 3.4, respectively 3.2, for the nearby stars σ and τ Sco, and Houzeau (1878) lists ζ^1 Sco as a $4^{m}.5$ star, while for ζ^2 Sco $3^{m}.4$ is given with τ Sco as a third magnitude star. σ and τ Sco may be regarded as nearly constant (σ Sco, B1III, is a β Cep star with an amplitude of a few $0^{m}.01$; τ Sco is a B0V star); currently they have, respectively, m_V = 2.9 and 2.8. Transforming these magnitude data to a homogeneous scale, we obtain for ζ^1 Sco $m_V \sim 2.8$ around the middle of the 18$^{\rm th}$ century, and m_V = 4.3 (Houzeau) and 5.4 (Gould), respectively in 1875.2 and 1878. It should be noted that

Houzeau's data–and even more so Gould's data–are to be considered as very reliable (each entry is based on several calibrated measurements), whereas in de La Caille's work only a few stars were observed more than once, using a meridian instrument (no standard stars were observed, and de La Caille observed more than 10,000 stars during only 127 nights in 14 months). Still, the comparisons with the nearby bright stars guarantees that our transformations are reliable. Another source of measurements of ζ^1 Sco during the last two decades of the 19th century are the four measurements listed by Zinner (1926) which, together with measurements of σ Sco, provide us with a more complete account of the light history of ζ^1 Sco. These data clearly show that in the past centuries ζ^1 Sco has experienced large-amplitude variations (see Fig. 7). However, no evidence of strong S Dor eruptions is available. Since Al-Sufi also observed σ Sco, we can apply the same approach to homogenise his data, which yields $V = 3.4$ for ζ^1 Sco in the 10th century.

The only indication about the colour of ζ^1 Sco in the past is by Gould (1879)[1] who described the colour as "not red", i.e. as if the star was less red than expected, thus in full agreement with the expected behaviour of LBVs in the sense that in the S Dor cycle the faint state is associated with a bluer colour of the system.

Thus, ζ^1 Sco has all the characteristics of LBVs as mentioned by Humphreys & Davidson (1994), but it has not been observed sufficiently frequently in past centuries to answer the question whether it has ever gone through an eruption "à la η Carinae", nor is it listed in Humphreys & Davidson's Table 2 of candidate LBVs. It is clear, though, that in the remote past, the star has been, at times, almost two full magnitudes brighter than we see it now.

6. Conclusions

We have shown that the light variations of ζ^1 Sco look very much like those seen in other α Cygni variables, i.e. non-LBVs as well as LBVs (at minimum phase), another indication that, most likely, all such stars exhibit multi-periodic light variability. It is clear that only large sets of carefully collected photometric data will allow to extend the existing sample to a size that is statistically meaningful.

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[1] lack of colour estimates for data preceding 1972 prevents us from applying colour corrections to the estimated visual magnitudes

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