PERIODOGRAM AND WAVELET ANALYSIS OF THE SEMI-REGULAR VARIABLE SUPERGIANT Y CVN

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ABSTRACT. Time series analysis of the bright cold carbon SR-type star Y CVn was studied. The star belongs at a rare subclass "J" and has a separate asymmetric envelope. It is assumed that no "s" process takes place in this star. Due to this, Y CVn may belong not to the AGB, but to the RGB stage, or to a stage of helium burning in a nucleus after a helium flash. The data from the published international databases of AFOEV (France) and VSOLJ (Japan) were studied using the periodogram and wavelet analysis and the "running sine" approximation. The cycle of variations is 267^d (varying from 247^d to 343^d which are superimposed on 1000^d -10000^d waves.

Key words: Variable stars: pulsating: Semi-regular: Y CVn.

The star Y CVn has other designations HR 4846 =HD 110914 =SAO 44317 =PPM 53169 =HIP 62223 =BD +46 01817 =GC 17342 =TYC 03459-2147 1 =GSC 03459-2147.

This bright carbon cold star of rare J-type has an isolated asymmetric envelope. The star is located not precisely in the center, brightness of an envelope in the western part is smaller. Thickness of an envelope is $(2-5)\cdot 10^{17}$ cm, and an internal radius of the envelope is $7\cdot 10^{17}$ cm. Distance to the star is 250 parsecs. Rate of mass loss has decreased during recent 14,000 yrs by two orders. Similar variations are present in stars U Hya, U Ant. But Y CVn does not show absorbtion line of technetium. It is suggested, that there is no s-process in the star. Due to this, Y CVn may be classified not as AGB, but as RGB or being at a stage of stationary burning of helium in nucleus after a helium flash (Izumiura et al., 1996).

Models of stellar pulsations were reviewed by Zhevakin (1963, 1975), Cox (1983).

For the analysis, we have used the observational database of visual observations of the French Association of Variable Star Observers (AFOEV, ftp://cdsarc.u-strasbg.fr/pub/afoev) and of the Variable Star Observers League of Japan (VSOLJ, http://vsolj.cetus-net.org) and methods of analysis of multi-periodic oscillations published by Andronov (1994, 2003). Totally, after filtration of "bad" and "fainter than" points, we analyzed 7428 observations obtained during the time interval from JD 24 23904 to 24 51081 (1924-1998 yrs). The observations are distributed in time very irregularly. Especially rare are observations are from JD 24 30115 to 24 38875 (1940-1965 yrs.) with an obvious absence of observations during the Second World war.

Periodogram analysis was carried out using the sine approximation for a trial period. As the test function, we have used $S(f) = r^2$, where r is a correlation coefficient between the observed and calculated values. For the analysis, we have used the programs FO (Four-1), FDCN (Four-N) described by Andronov (1994) and MCV (Andronov and Baklanov, 2004). The periodogram are shown in Fig. 1. The most prominent peak corresponds to a long period of 5150^d. However, it seems to be not a "true" (relatively stable) photometric cycle, but a characteristiv value of the cycle length. There are also some other peaks at the periodogram which are listed in Fig. 1. There are two peaks near the value of 365^d, the year duration. These peaks may be interpreted as beat periods between the annual period of observations and a long-term photometric cycle. Interesting peaks occur at 985^d, 159^d.

To check their reliability, we have made a same analyzis of artificial data defined at the same moments, as real observations have. The magnitudes were computed as $m(t_i) = m_0 - r\cos(2\pi(t_i - T_0)/P + \varepsilon_i$. where the mean m_0, semiamplitude r, initial epoch T_0 and period P are model parameters, and ε_i is normally distributed random value with variance σ_ϵ^2. For our analysis, we adopted the period of $P = 267^d$, which is statistically optimal for the wavelet periodogram (see below) and a corresponding initial epoch of JD 24 42114.7. The formal semi-amplitude is $0.^m046(5)$ is statistically significant, but seems to be underestimated, if the period is not stable. The characteristic (r.m.s.) amplitude was arbitrarily set to $\sigma_\epsilon = r$.

The periodogram for this artificial data set is also shown in Fig 1. One may note a strong peak corresponding to the model period, but also bias peaks at 995^d and 154^d. Thus we assume that the peaks seen at the periodogram for the observations of Y CVn close to these periods, are just biases and do not correspond to real physical variability of the star.

As the artificial signal did not contain a $\sim 5000^d$ periodicity, nothing significant was seen at the periodogram for the artificial set.

Assuming that the variations may show significant (and multiple) period variations, we have made additional analysis. THe initial data set was splitted into 3 intervals of similar duration, which are releatively good covered by the observations, namely JD 2400000+ (24910 - 29965), (41059 - 46384), (46413 - 50718). The corresponding periodograms are shown in Fig. 2. The peaks are often occur at close (but not equal) periods. In this paper, we have used a "mean" periodogram computed as $S(f) = W(t)/(1 + W(t))$, where $W(t)$ is a geometric mean of $W_i(f) = S_i(f)/(1 - S_i(f))$, and $S_i(f))$ is the value of the test-function $D(f)$ for the interval i. The test function $W_i(f)$ has a sence of "signal-to-noise" ratio, i.e. ratio of variance of computed data to the variance of residuals. As the peaks at the periodograms show some shift, the resulting "mean periodogram" seems to be very close to zero (except the $\sim 5500^d$ "period"). The three other peaks again correspond to $\sim 264^d$ period and its annual biases.

Next method was the wavelet analysis using the program WWZ based on the algorithm by Andronov (1998). The "Morlet-based" wavelet periodograms (weighted averages of the wavelet map over time interval) are shown in Fig. 3. Besides a "standard" value of the decay coefficient $c = 0.0125$, we also have used smaller values 0.00125 and 0.000125, which correspond to increasing period resolution. Generally, the structure of peaks is in an agreement with that at the periodogram. Also annual biases are present at the wavelet periodogram for the "artificial data". So we adopted the value of the period of $P = 267^d$, which was used for the artificial data set. The number of peaks increases with decreasing c, indicating that the periods are not stable.

To check stability of period and other characteristics, we have used finally another complementary algorithm, So the "rectangular weight function" wavelet with a fixed period (="running sine", Andronov (2003)) was computed. The local fit $m_C(t) = m_0 - r\cos(2\pi((t - T_0)/P - \phi))$ was computed for each trial value of t_0 using the data in the interval from $(t_0 - \Delta t)$ to $(t_0 + \Delta t)$. For such a "running approximation", we have used a filter half-width of $\Delta t = 0.5P_1$. The "initial epoch" for maximum magnitude (minimum brightness) is $T_0 = 24\,41981.2$, and $P = 267^d$. The parameter ϕ is the phase of maximum brightness (minimum magnitude).

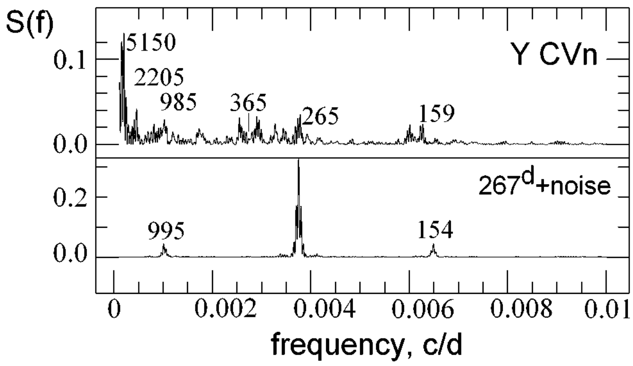

Figure 1: Periodograms for observations of Y CVn for all data (up) and for simulated "sine+noise" data. The numbers mark period values corresponding to some prominent peaks.

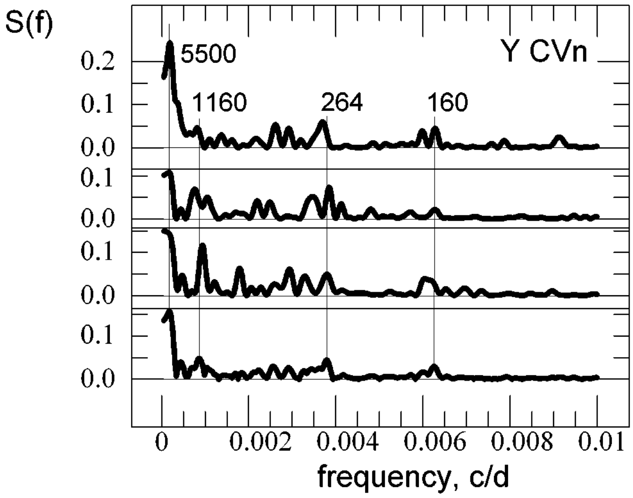

Figure 2: Periodograms for observations of Y CVn for three time intervals best covered by the observations. At bottom, there is a "mean" periodogram. The numbers mark period values corresponding to some prominent peaks at the "mean" periodogram.

The dependence of characteristics of the "running sine" approximation on trial time are shown in Fig. 4 as well as the original observations at the same scale. To study long-term variations, the best variable parameter is m_0. It shows drastic variations from $5.^m43$ to $6.^m15$ at most prominent timescales of 1000^d and 10000^d. The semi-amplitude r sometimes reaches $r = 0.^m44$, but also vanishes down to $0.^m001$. Not unexpectedly, at these times of "constancy", the phase may undergo jumps. The variations of phase show "linear parts" corresponding to "stable period," but the values differ from 247^d (JD 24 45322-46499) to 343^d (JD 24 24362-27129).

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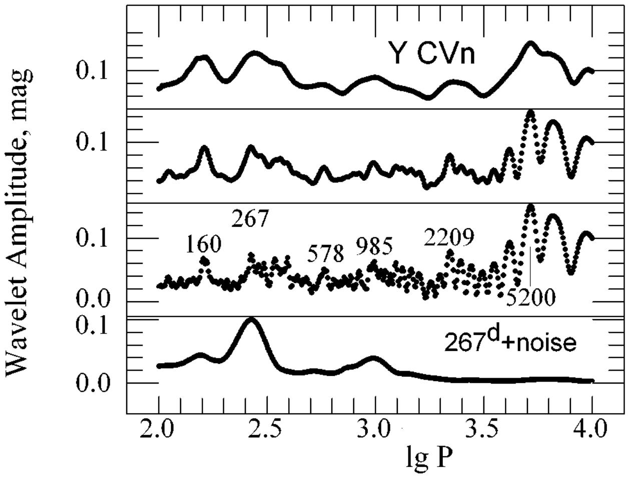

Figure 3: "Wavelet periodogram" for all data values for different values of the decay coefficient c (0.0125, 0.00125 and 0.000125 from top to bottom, respectively. The bottom curve corresponds to the noisy periodic data and $c = 0.0125$.) The numbers mark period values corresponding to some prominent peaks for $c = 0.000125$ - the wavelet with best period resolution.

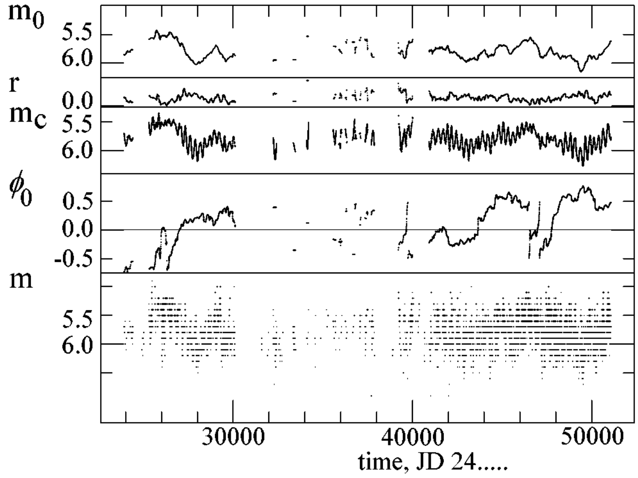

Figure 4: Dependence of the characteristics period and amplitude on trial time for different values of c.

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