WAVELET ANALYSIS OF 173 SEMI-REGULAR VARIABLES

L.L. Chinarova

Research Institute "Astronomical Observatory"
Odessa National University, Odessa 65014, Ukraine

ABSTRACT. We made the wavelet analysis of 173 semi-regular pulsating variable stars of different sub-types. For the analysis, we have used 1,000,000 individual brightness estimates from the published international databases of the VSOLJ (Japan) and AFOEV (France). They were visually checked using the program OL (I.L.Andronov, 2001OAP....14..255A), and bad points were removed from the data files. The wavelet analysis was performed using the program WWZ (I.L.Andronov, 1998KFNT...14..490A) which improves the discrete Morlet-type wavelet transform to the case of irregularly spaced data. Mean weighted wavelet periodograms are presented, as well as wavelet maps. Dependences of the wavelet-based periods and amplitudes on time are presented for the investigated stars. Some stars exhibit switchings between preferred periods, which are interpreted as switchings of the pulsation mode. Additional criteria for classification of the pulsating variables based on the stability of periods and amplitudes are discussed. Results are shown for the semi-regular star RU And, for which the semi-amplitude varies drastically from 0.027 ("nearly constant star") to 1.204 mag ("Mira"- type pulsating variable. The phase of pulsations also varies drastically by 0.7P, and the wavelet estimates of the period - from 210 to 270 days.

Key words: Variable stars: pulsating: Semi-Regular: RU And; Data analysis.

We introduce the "Atlas and Catalogue ..." which is an extended version of the "Catalogue of main characteristics of pulsations of 173 semi-regular stars" by Chinarova and Andronov (2000) taking into account observations from the AFOEV international databases obtained during 10 more years of photometric monitoring. Statistical study of semi-regular variables using scalegram-based characteristics was made by Andronov and Chinarova (2003). Comparison of different methods for determination of characteristic time scales in semi-regular stars was made by Andronov and Chinarova (2001). In this work, we use for the analysis improved values of the parameters based on more extensive time series and more individual pulsation cycles.

Results are shown for one of the stars from our sample - RU And.

For the analysis, we have used 1446 observations from the AFOEV (2010) international database. Also we have used the data from the VSOLJ (2000) international database, which were analyzed by Chinarova and Andronov (2000). After the filtering of the merged dataset for bad points (or groups of points by some observers) using the program OL (Andronov, 2001), the final number of data points covering the time interval from October 14, 1979 to March 13, 2010, is 1638.

The wavelet analysis was performed using the program WWZ (I.L.Andronov, 1998, 1999) using a standard decay coefficient $c = 0.0125$. The wavelet periodogram is shown in Fig.1. The test function computed as a time-weighted mean of the function WWZ proposed by Foster (1995) and improved by Andronov (1999). The highest peak at the periodogram corresponds to the period of 247^d, although some smaller peaks are present. Consequently, we used another value of the decay coefficient $c = 0.003125$, which corresponds to a twice larger time interval for each trial period and time. The corresponding periodogram has become higher and thinner. And finally, we made a periodogram analysis using the sine fit for all data (i.e. $c = 0$ using the programs Four (Andronov 1994) and MCV described by Andronov and Baklanov (2004). The test function S is a square of the correlation coefficient between the observed and calculated (for a given period) values. It is also shown in Fig. 1. Because of larget time base, the peaks at this periodogram are more narrow than for the wavelet periodograms, and some peaks are splitted, what is not seen at the local wavelet fits.

The statistically optimal sine fit to the observations corresponds to a mean value $C_1 = 11.^{\rm m}775 \pm 0.^{\rm m}012$, semi-amplitude $r = 0.^{\rm m}493 \pm 0.^{\rm m}017$, period $P = 246.^{\rm d}99 \pm 0.^{\rm d}11$ and initial epoch for maximum brightness $T_0 = 2450577.8 \pm 1.3$.

Using the wavelet analysis, we have determined best fit values of the period and semi-amplitude as functions of trial time. They are shown in Fig. 2. Both these parameters show significant variations. The wavelet period varies mainly from 210 to 270 days, sometimes formally going out of this interval. This is caused by observational gaps between annual seasons.

To avoid this problem, we used $c = 0.003125$, which corresponds to twice better period resolution in cost of twice worse time resolution. For such a parameter, the problem of seasonal gaps is solved, however, the smoothing function has wider and less prominent peaks. Thus we conclude that the variations are present and significant. The third wavelet-related method is the method of "running sine" with a rectangular weight function (see Andronov 1997, 1998b for a description). We used the filter half-width $\Delta t = P/2$.

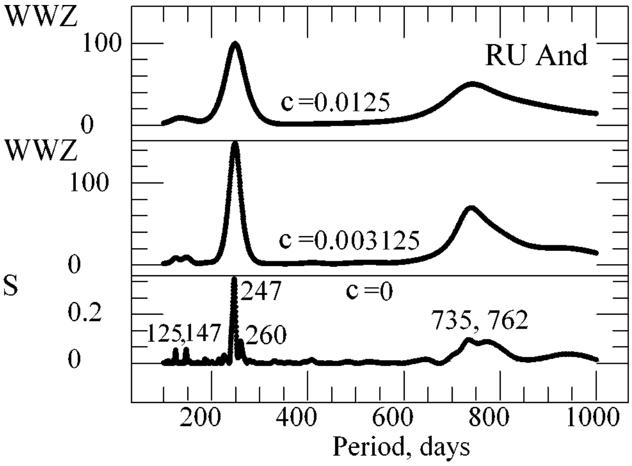

Figure 1: Wavelet periodograms for observations of RU And for different values of the decay coefficient c.

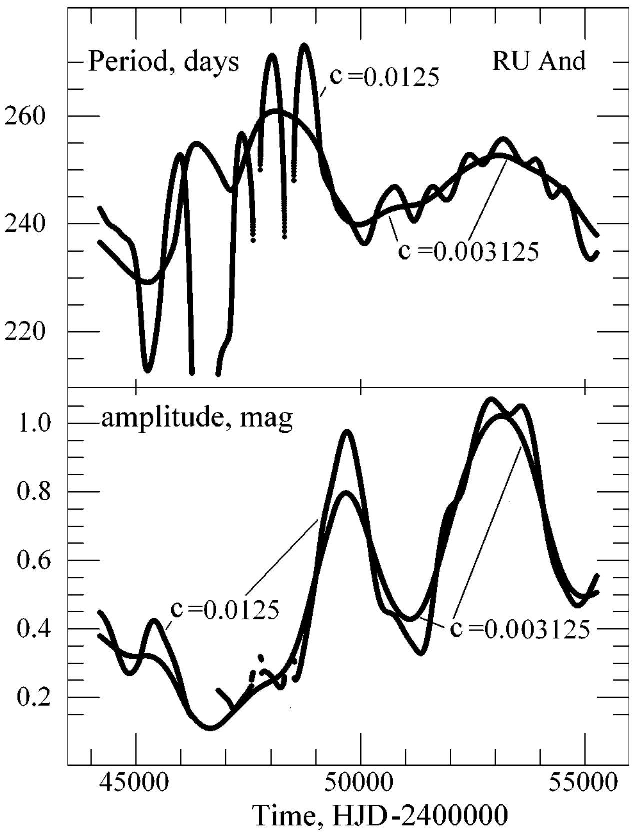

Figure 2: Dependence of the period and amplitude on trial time for different values of the decay coefficient c.

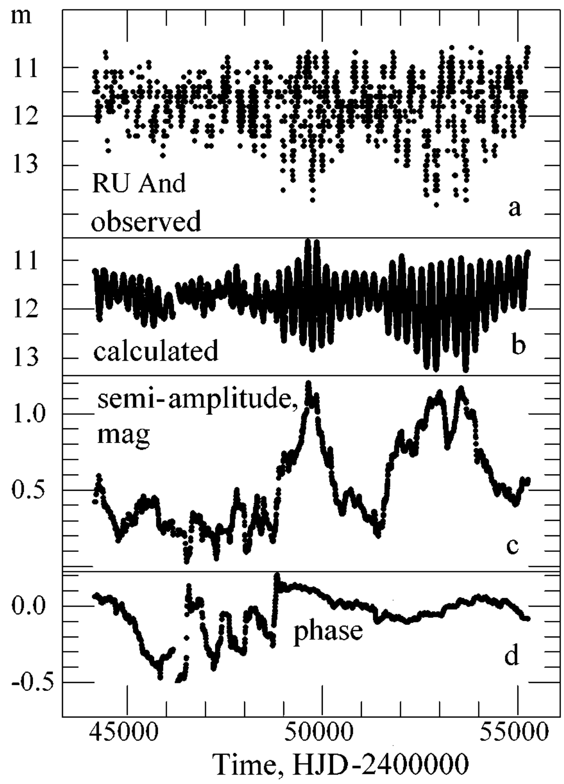

Figure 3: "Observed" and "calculated" data and time variations of the semi-amplitude and phase of individual pulsation cycles using the method of 'running sines" according to the ephemeris Max.HJD= $2450577.8 + 246.99 \cdot E$.

The semi-amplitude varies drastically from 0.027 ("nearly constant star") to 1.204 mag ("Mira"- type pulsating variable. The phase of pulsations also varies drastically by 0.7P, indicating transitions between relatively stable periods.

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