THE CLASSIFICATION OF CEPHEIDS BY PULSATION MODES AND THE PROBLEM OF THE DISTANCE SCALE

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ABSTRACT

The neural network algorithm and analysis of the 'period–radius' diagram are used to classify the classical cepheids of our Galaxy by pulsation modes. The LMC cepheids with I – band photometry from OGLE have been used as a training sample. Infrared and V-band photometric data for Galactic cepheids have been taken from Berdnikov's data base. We calculated the radii of cepheids using our original and published radial velocities, V- and I-band photometry.

Key words: Cepheids; Classification; Neural networks.

1. WHY WE DO IT?

Classical Cepheids can be regarded as the most important stars that define the distance scale in the Universe due to the presence of the 'period–luminosity' relation for these variables. The ratio of first-overtone to fundamental tone pulsation periods is ≈ 0.7 (Alcock et al. 1995). But only for cepheids with very well known distance could we in principle determine the pulsation mode directly. As for bulk cepheids, the problem seems to be more complex. Considerable contamination of the sample by unrecognized first-overtone pulsators could make the observable distance scale shorter. For the Berdnikov et al. (1996) 'period–luminosity' relation and the Dean et al. (1978) 'period–intrinsic colour' relation adopted distances of these unrecognized first-overtone cepheids should be multiplied by the factor of 1.35. So, it's very important to know the pulsation modes of cepheids before calculating the distance scale factor (the ratio of observable to true distances).

2. HOW TO CLASSIFY?

One way to do this lies in photometric data, i.e., light curves. For example, the cepheids with small amplitudes and almost symmetrical light curves were classified as probably first-overtone pulsators in the General Catalog of Variable Stars (GCVS; Kholopov et al. 1985).

In early works attempts have been made to improve the classification (Connolly 1980; Antonello & Poretti 1986; Antonello et al. 1990; Mantegazza & Poretti 1992; Buchler & Moskalik 1994; Zakrzewski et al. 2000). Commonly the cepheid's light curve was presented as a Fourier-decomposition:

$$m(t) = R_0 + \sum_{i=1}^{N} R_i \cos[2\pi i (t - T_0)/P_{\rm pls} + \phi_i] \quad (1)$$

and some ratios of Fourier-coefficients and phases

$$R_{ij} = R_i/R_j, \qquad \phi_{ij} = j \cdot \phi_i - i \cdot \phi_j \quad (2)$$

have been used for classification.

3. THE DATA

After the OGLE (Optical Gravitational Lensing Experiment) photometric survey appeared, with large numbers of LMC and SMC cepheids' light-curves mostly in the infrared photometric band (Udalski et al. 1999), new perspectives opened to continue the classification work. Because all cepheids in the Magellanic Clouds are nearly at the same distance from the Sun, they can be classified by pulsation mode directly from $I - \log P_{\rm pls}$ diagram. In Figure 1 such a diagram for LMC cepheids (1228 stars) is shown. Because we have chosen only the most reliably classified pulsators in fundamental tone and first overtone, our Figure 1 is slightly different from Figure 2 in the paper of Udalski et al. (1999). Here the extinction insensitive index $W_I = I - 1.55(V - I)$ used instead of I to correct photometric data for differential extinction.

Standard light curves in I and V band have been taken from Berdnikov's data base. To classify cepheids by pulsation modes we used V-band photometry because the number of light curves in the V band (441 stars) is four times as many as in the I band, and Fourier-coefficients for both bands show good correlation (see Figure 2).

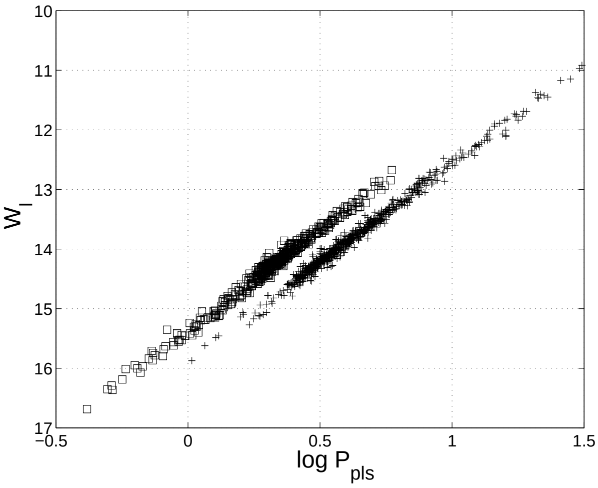

Figure 1. The $W_I - \log P_{\rm pls}$ relation for LMC cepheids. Plus signs are for the fundamental tone, squares are for the first overtone pulsators.

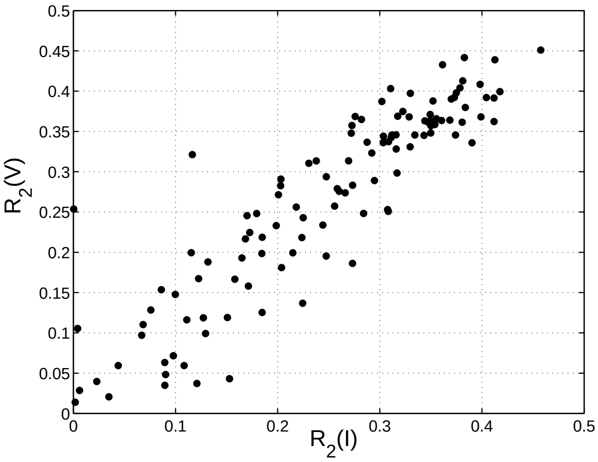

Figure 2. The correlation between Fourier-coefficients R_2 for light curves in I and V bands.

4. NEURAL NETWORK

We used the neural network technique to classify the Galactic cepheids by pulsation modes. It has at least two advantages. Often we don't know which parameters are crucial for classification. We can preset all available inputs, and network itself searches the input variables considered as most important. For example, our network with LMC cepheids as the training sample has found Fourier-coefficient R_2 as the most crucial input parameter (the exclusion R_2 from inputs will lead to the increase of RMS errors of the network by the factor of 4-5). The possibility of estimating the classification errors is another advantage of neural network.

In our case the multi-layer perceptron neural network has been trained using a back propagation algorithm. The training sample contains the set of input data ($\log P_{\rm pls}$, the Fourier-coefficients and phases up to 5th order) together with corresponding output (the classification of the cepheid as fundamental tone or first-overtone pulsator).

5. RESULTS

First, you can see the confirmation of good classification by our network. The correlation coefficient between the predicted and target values is 0.98. Widely used by many authors, relation $R_{21} - \log P_{\rm pls}$ is plotted in Figure 3 for the LMC cepheids. Although the set of input data don't include R_{21}, two groups of cepheids are very well separated on this diagram. It means that we can classify cepheids by our neural network without involving R_{ij}, ϕ_{ij} or other ratios, but only using Fourier-coefficients and phases itself.

The results of the Galactic cepheids classification can be seen in Figure 4. It is of special interest to analyze the pulsation modes of 9 cepheids – members of open clusters that have been used by Berdnikov et al. (1996) as the basis of the 'period–luminosity' relation. Fortunately, our classification of seven cepheids and their classification in the GCVS are the same, but for CE Cas (a) and CE Cas (b) there are yet no good separate photometric data because of their close binarity.

Table 1. Cepheids with wrong classification in GCVS (if DCEP are fundamental tone pulsators and DCEPS are first-overtone pulsators). Notation: 'NN' is neural network, 'PR' is 'period-radius' diagram, '0' is first overtone, '1' is fundamental tone, 'err(NN)' is deviation from adopted classes.

star	classification			
	GCVS	NN	err(NN)	PR
IR Cep	DCEP	0	0.13	0
AV Cir	DCEP	0	0.02	-
V465 Mon	DCEP	0	0.04	0
DK Vel	DCEP	0	0.03	-
V496 Aql	DCEPS	1	0.01	1
V1162 Aql	DCEPS	1	0.00	1
GH Car	DCEPS	1	0.04	-
SZ Cas	DCEPS	1	0.00	-
V378 Cen	DCEPS	1	0.00	1
V419 Cen	DCEPS	1	0.08	0
V924 Cyg	DCEPS	1	0.26	-
X Lac	DCEPS	1	0.00	0
Y Oph	DCEPS	1	0.00	-

The Cepheids V419 Cen and X Lac lie on the border between two classes in the $R_{21} - \log P_{\rm pls}$ relation and therefore their classification by the neural network may be wrong.

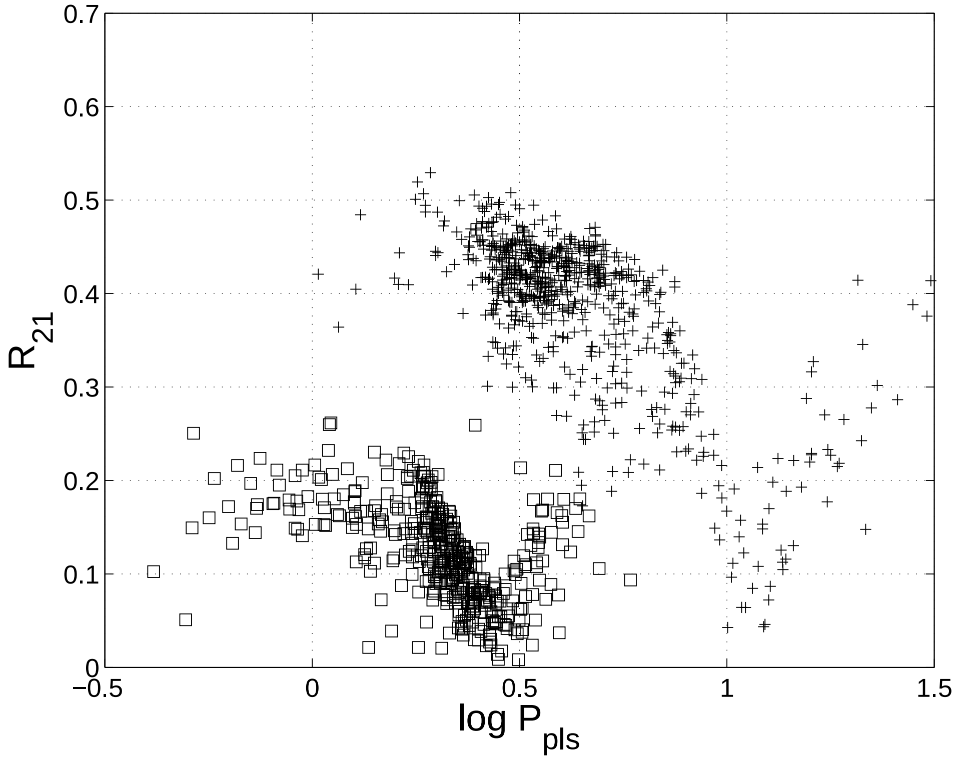

Figure 3. The $R_{21} - \log P_{\rm pls}$ relation for LMC cepheids. Plus signs and squares show fundamental tone and first-overtone pulsators respectively. Only stars with classification error < 30% are shown.

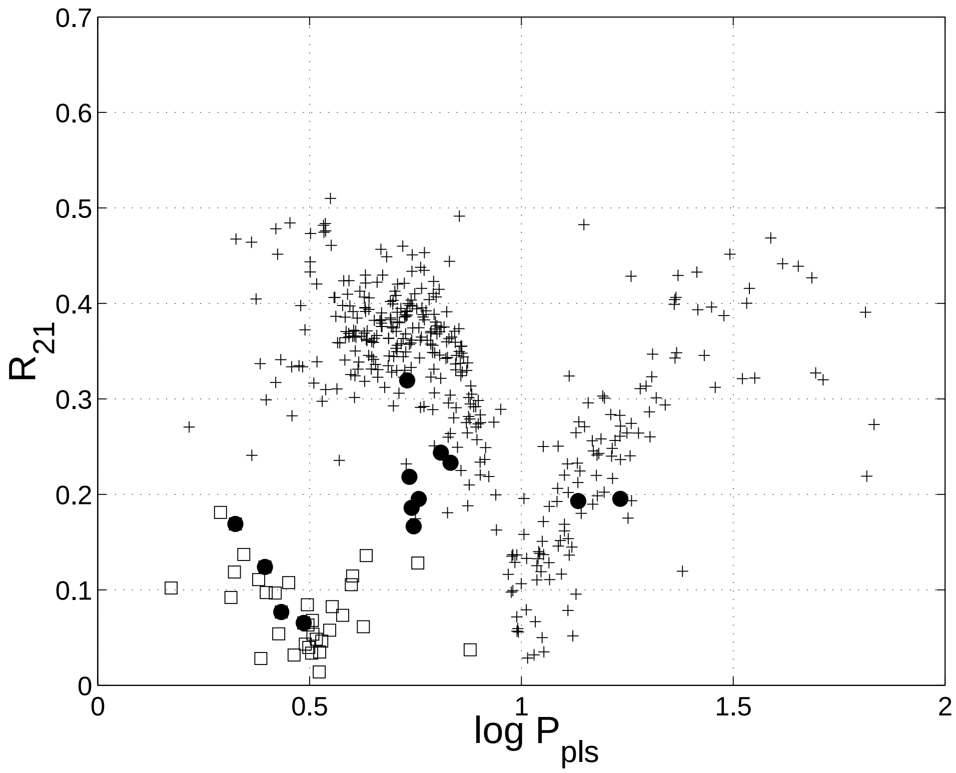

Figure 4. The $R_{21} - \log P_{\rm pls}$ relation for cepheids in our Galaxy. Plus signs and squares show fundamental tone and first-overtone pulsators respectively. Only stars with classification error < 30% are shown. Cepheids with wrong classification in GCVS are marked by black circles.

6. ‘PERIOD–RADIUS’ DIAGRAM

For many Galactic cepheids we collected long sets of precise observations of radial velocity. We used these spectroscopic data together with photometric data (magnitude V and colour index $V-I$) from Berdnikov’s data base to estimate the radii of such cepheids using the Baade-Wessilink method (Balona 1977). Note that Balona’s radii are independent of interstellar extinction. In the ‘period–radius’ diagram the first-overtone and fundamental tone pulsators are separated into two relations directly (see Figure 5). The relation for fundamental tone pulsators is:

$$\log R = 1.08(\pm 0.01) + 0.74(\pm 0.01)\log P_{\rm pls} \qquad (3)$$

and for first-overtone pulsators:

$$\log R = 1.19(\pm 0.01) + 0.74(\pm 0.01)\log P_{\rm pls} \qquad (4)$$

The ‘period–radius’ diagram analysis is in general agreement with our results obtained by the neural network (see Table 1).

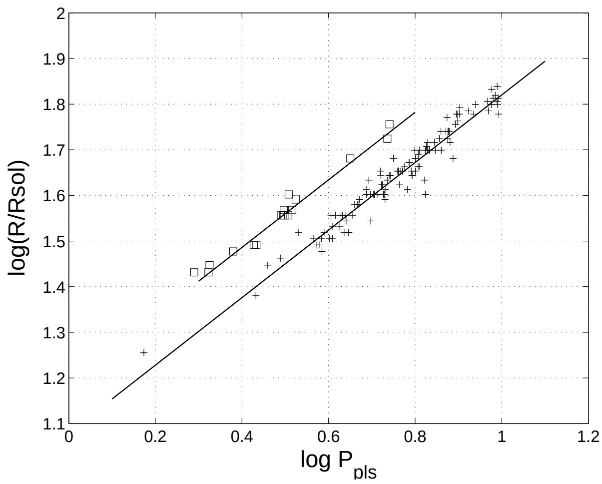

Figure 5. ‘Period–radius’ diagram for two groups of the cepheids: plus signs are for the fundamental tone, squares are for the first-overtone pulsators.

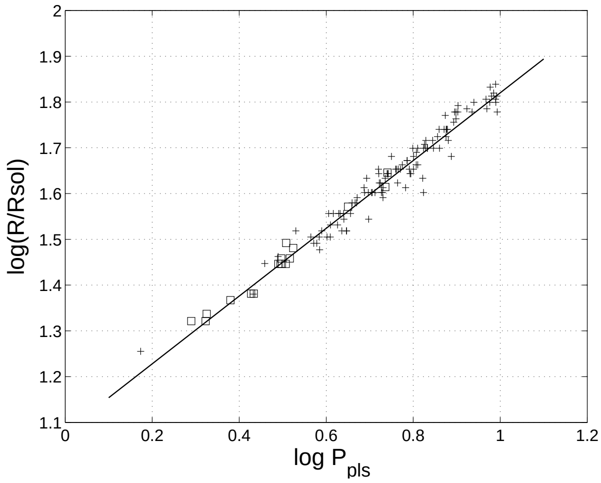

Figure 6. ‘Period–radius’ diagram taking into account the ratio of first-overtone to fundamental tone pulsation periods ≈ 0.7.

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