PHASE DISPERSION MINIMISATION AS A TOOL FOR ANALYSIS OF LONG-TERM BRIGHTNESS VARIATIONS IN LIGHT CURVES

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Abstract

Long-period variables such as Mira stars often show long-term variations in brightness superimposed on their periodic changes caused by pulsations. Long-term variations can be periodic or non-periodic, caused by orbital motion, presence of dust or by some other physical mechanism. In order to remove periodic short-term variations and study only the long-term component, we propose Phase dispersion minimization (PDM) method as an efficient tool and a method of choice. PDM is a very robust and precise method, capable of efficiently removing short-term periodic variations regardless of the shape of the light curve. It greatly reduces the number of free fitting parameters usually used by other techniques as the pulsation period is the only parameter to be determined. If the phase diagram is fitted to the Fourier polynomial, other pulsational parameters can be also determined. We have successfully applied PDM method in analysis of light curves of symbiotic Miras HM Sge and RR Tel, and compared the results with the values obtained by Discrete Fourier Transform (DFT), another widely used method. Our results show that PDM method is efficient in reducing the light curves for short-term periodic variations and can be applied in larger stellar samples expected to be obtained by surveys such as LSST.

Introduction

Long period variables (LPV) such as the Mira-type stars often show long-term non-periodic brightness variations that can be caused by different physical mechanisms and/or phenomena. Long-term variations can be periodic or non-periodic, caused by orbital motion, presence of dust or by some other physical mechanism. Symbiotic Miras are a perfect example of such behaviour, where short-term periodic brightness variations due to the pulsations are superimposed on long-term non-periodic changes caused by dust obscuration (Jurkic & Kotnik-Karuza 2012). In order to study such long-term variations, it is important to remove and analyse the short-term variations as they can be correlated with each other. The parameters of the short-term periodic variations, mainly due to pulsations, can also help to determine the origin of any long-term brightness variations caused by possible changes in the pulsation behaviour of the LPV.

Methods

Complete determination of all possible frequencies and modes in periodic brightness variations usually demand application of Fourier analysis and longer computational times. This is especially true if the shapes of periodic variations are highly asymmetric and can be represented only by a number of frequencies. In order to remove periodic short-term variations and study only the long-term component, we have used Phase dispersion minimisation (PDM) method based on work of Lafler & Kinman (1965) and Stellingwerf (1978) as an efficient, very robust and precise method. It is capable of efficiently removing short-term periodic variations regardless of the shape of the light curve and even if significant long-term variations are present. PDM greatly reduces the number of free fitting parameters usually used by other techniques as the pulsation period is the only parameter to be determined.

Details of application of PDM method are presented in Jurkic & Kotnik-Karuza (2012). For a chosen pulsation period, the observational times are subdivided into bins of duration determined by the period and number of bins. Observations falling in the same bins are grouped together and phase diagram is constructed. The pulsation period and the number of bins, and hence the duration of each bin, are varied until the least scattering in the phase diagram is achieved. Additionally, the phase diagram can be fitted to the Fourier polynomial and subtracted from the observed light curves, thus obtaining the light curves corrected for short-term variations. The pulsation amplitude and initial epoch for the light curve variations can be determined from the best-fitted phase diagram.

Analysis based on discrete Fourier transforms (DFT) was used to verify and confirm the results of PDM method. For this purpose, we applied the publicly available program SigSpec (Reegen 2007) which computes a significance spectrum for a time series by evaluating analytically the Probability Density Function (PDF) of a given DFT amplitude level. No significant differences between properties of short-term variations determined by PDM and DFT methods were found.

HM Sge and RR Tel

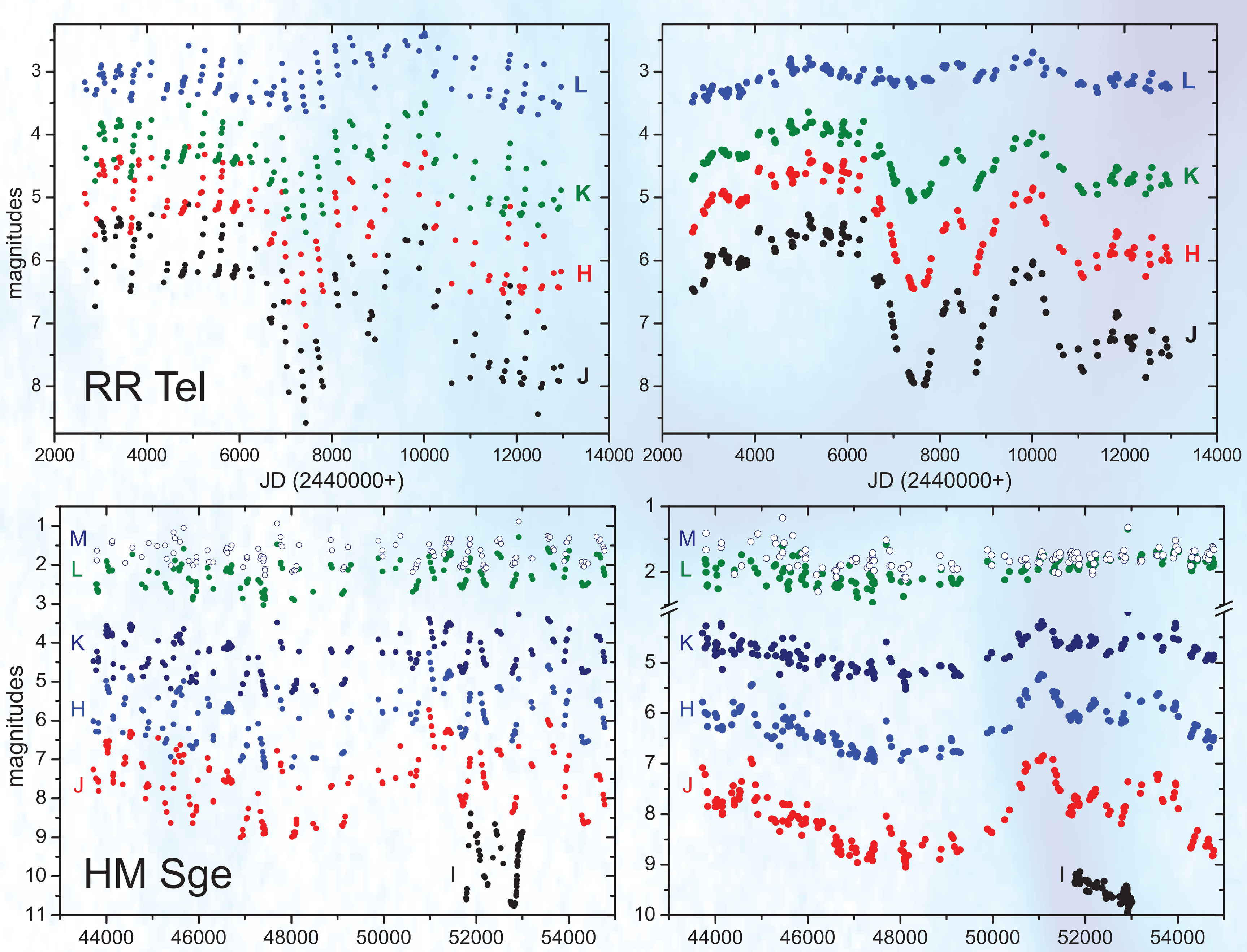

Figure 1. Light curves of RR Tel and HM Sge with (right) and without (left) corrections for short-term variations obtained by PDM method. Obscuration episodes are clearly visible.

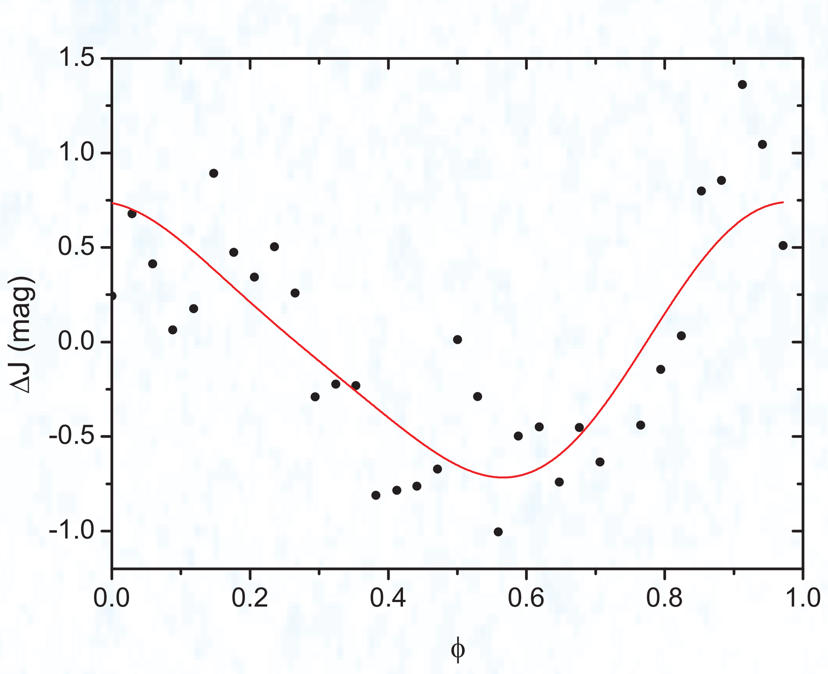

Figure 2. Phase diagram of long-term (~25 years) brightness variations detected by PDM method and probably caused by dust.

HM Sge and RR Tel are among the best studied symbiotic binary systems in which the hot component is a white dwarf that ionizes the surrounding nebula, while the cold component is an AGB star of a Mira-type. The light curves show the presence of short-term brightness variations caused by Mira pulsations superimposed on long-term changes. These long-term variations have been explained by obscuration of dust formed around the Mira component (Jurkic & Kotnik-Karuza 2012, 2016). In order to analyse the long-term variations with different theoretical dust shell models, it is important to correct the light curves for short-term variations. The corrected light curves clearly show different epochs of minimum brightness (obscuration events) that have been caused by absorption in circumstellar dust. Analysis of phase diagrams of short-term variations can show correlation between possible changes in pulsational parameters (period, amplitude, phase of short-term variations) and the onset of obscuration events, but no such correlations were found. Instead, we have found a very long-period brightness variation (~25 years) that could be related to dust.

Results

The method has been tested on several artificially produced light curves with both short- and long-term variations, including non-periodic variations caused by phenomena such as an eclipse or a dust obscuration episodes. In order to simulate the real data as realistically as possible, we have added random noise in the light curves with a maximum value corresponding to ~20% of the amplitude of periodic short-term variation. Some of the artificial light curves are presented here and include different types of short-term brightness variations such as

- sinusoidal variation,
- non-sinusoidal variation as expected for Miras
- more complex brightness variations.

Long-term variations included sudden brightness changes due to an eclipse, or longer, more gradual variations that can be caused by circumstellar dust. As the number of measurements can influence the results, we have performed analysis with small (200 data points) and large (450 data points) datasets consisting of observations scattered randomly in time.

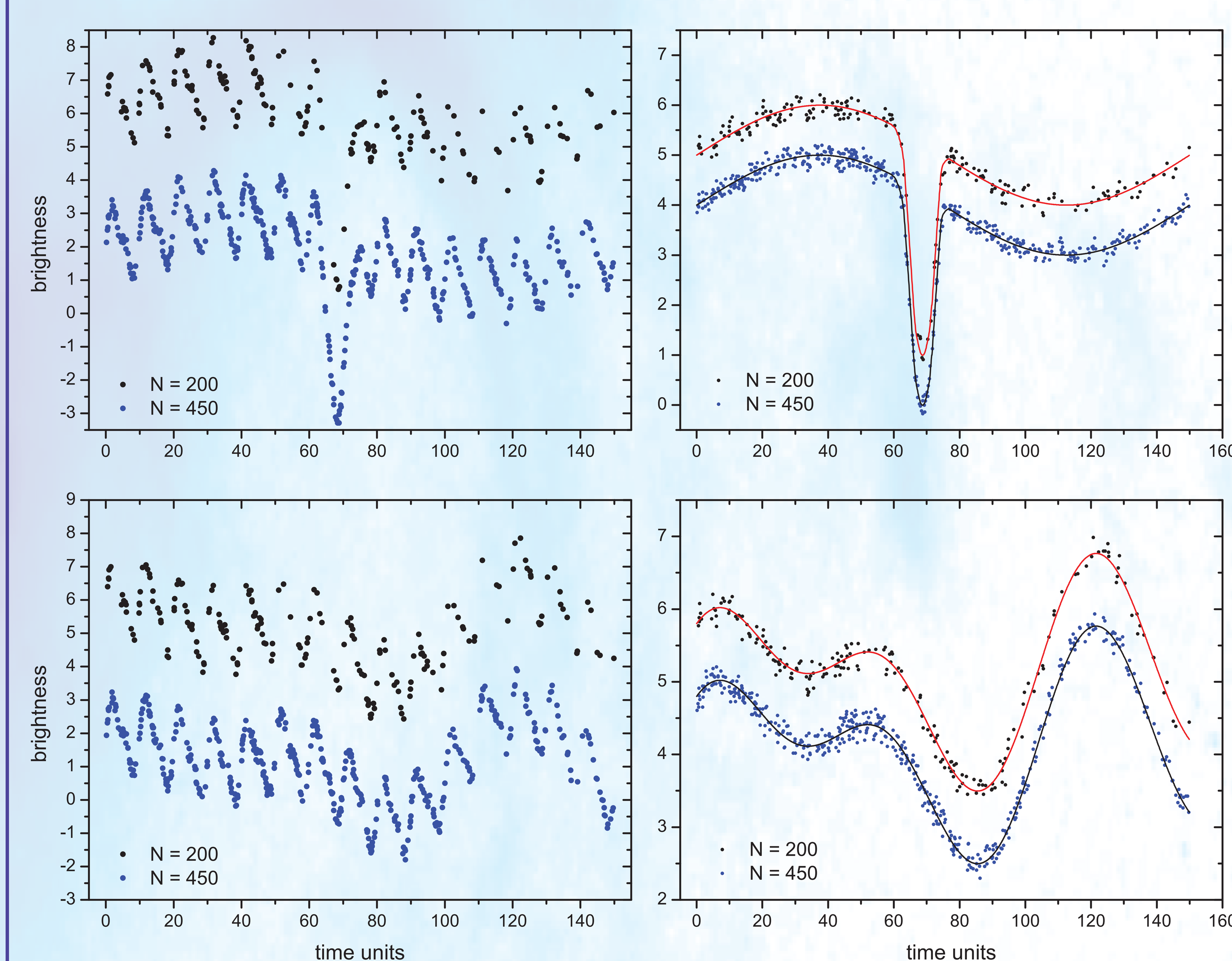

Figure 3. Artificial light curves used for testing of PDM method before (left) and after (right) the correction for short-term brightness variations by PDM. Upper light curve with black dots has 200 observations while lower curve with red dots has 450 observations. Full lines represent the original long-term brightness variation. Upper panel shows eclipse-type long-term variations, while the light curve in lower panel has longer monotonous brightness variations.

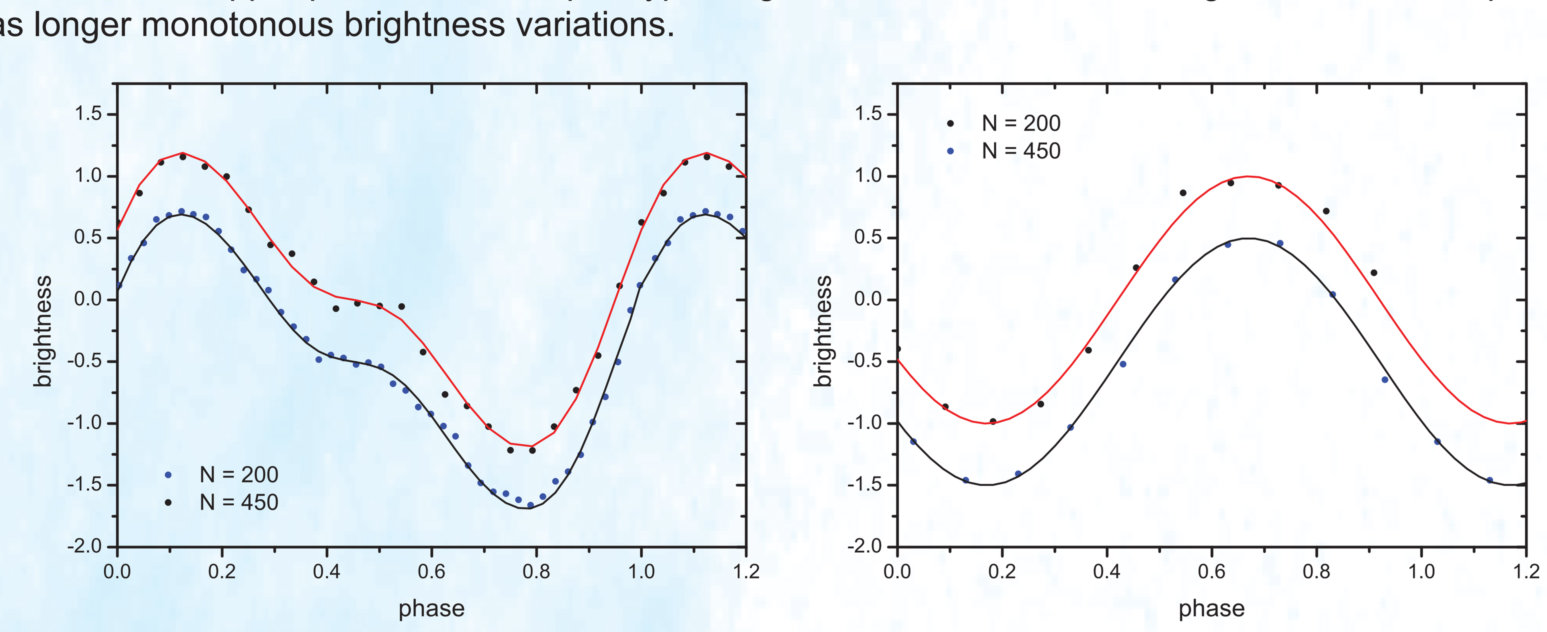

Figure 4. Phase diagrams of short-term brightness variations obtained by PDM method from artificial light curves. Upper diagram was determined from a dataset containing 200 measurements and lower diagram from a dataset of 450 measurements. Full lines represent the original shape of the short-term variations used in generating the artificial light curves. Left panel shows periodic non-sinusoidal short-term variations present in Fig. 3, while right panel shows sinusoidal variations.

Despite different types of short- and long-term variations, PDM method has always found the correct period of short-term variations with a precision of the order of 0.02 time units. The obtained phase diagrams and light curves corrected for short-term variations agree very well with the original theoretical shapes. As expected, agreement is better for light curves with larger number of data. The differences in brightness between obtained and original light curves after the removal of the short-term variations are fully random and at the level of the noise we have introduced in the artificial data. Thus, this difference can be attributed fully to the noise.

Conclusion

We have shown that Phase dispersion minimisation (PDM) technique can be successfully applied in determination of the properties of periodic variations in light curves of long period variables. PDM method is an effective, robust and precise method for removal of short-term brightness variations in order to study the long-term non-periodic changes in light curves.

This essential procedure allows determination of the physical origins of such long-term variations. The method was successfully used in correction of light curves of symbiotic Miras and determination of their pulsational properties, as well as in detection of very long-term brightness variations. PDM could be of interest in reduction of light curves in large surveys such as LSST.

References

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