SEARCH FOR LONG-TERM BRIGHTNESS VARIATIONS IN LIGHT CURVES

HRZZ Croatian Science Foundation

Tomislav Jurkić, Lovro Pavletić, Dubravka Kotnik-Karuza

Department of Physics, University of Rijeka, Croatia

SVEUČILIŠTE U RIJECI

Abstract

Some types of variable stars often show long-term variations superimposed on the dominant short-period changes in brightness. Removal of the short-term component is crucial if we are interested to study the long-term variations. We propose Phase Distribution Minimisation (PDM) method as a tool for removal of short-term periodic brightness variations and for the study of the residual brightness variations. We have shown that this method is robust, precise and efficient in removing short-term variations, as well as in the determination of the periods. This method can analyse and remove any periodic brightness variations regardless of the shape of the light curve, which greatly reduce the computing time, and can detect periods of the order of the observational time interval. The method was successfully applied in the study of irregular long-term variations caused by dust in symbiotic Miras. PDM method was also used to detect Blazhko effect in RR Lyrae and Cepheids as changes in pulsational amplitudes. Our results show that PDM method can be successfully applied to detect and analyse long-term changes in light curves of variety of variable stars, from short-period RR Lyrae to long-period Miras. This means that the method can be used to analyse a large number of different light curves expected to be obtained by LSST survey.

Introduction

Long-term variations superimposed on the dominant short-period changes in brightness can be found in many light curves of variable stars. These long-term variations can be periodic or non-periodic, regular, semi-regular or completely irregular, including variations in the amplitude or in the period of the short-term component. Determination and removal of the short-term component is crucial if we are interested in the study of the long-term variations. Such variations can be caused by orbital motion, stellar pulsations and resonances, dust obscuration, or by some other 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). Blazhko effect is another example of long-term variations in pulsational amplitudes found in dominant short-term changes in many RR Lyrae variables, and recently in two Cepheids. This effect is still poorly understood, and further research is needed.

Methods

Analysis of light curves of variable stars usually demand use of methods such as Fourier analysis which can be time consuming and require substantial computing power. This is especially true if the shapes of periodic variations are highly asymmetric and can be represented only by a number of frequencies. Methods such as Fourier transforms show setbacks when both short and long period variations are present in the light curves. We propose Phase dispersion minimisation (PDM) method based on work of Lafler & Kinman (1965) and Stellingwerf (1978) as an efficient, very robust and precise method, suitable for analysis of both periodic short- and long-term brightness variations. Light curves can be corrected for short-term variations, leaving only long-term component for further study. Its main advantage is efficient removal of short-term periodic variations regardless of the shape of the light curve, and further analysis of any long-term variations. PDM reduces the number of free fitting parameters usually required by other techniques as the pulsation period is the only parameter to be determined.

The method is based on determination of the phase diagram by dividing the observational times into bins for a trial pulsational period. Observations falling in the same bin are grouped together and phase diagram is constructed. The trial period and number of bins which determine the duration of each bin, are varied until the least scattering is achieved. The phase diagram can be also fitted to the Fourier polynomials and subtracted from the observed magnitudes in order to obtain O - C, i.e. the ligh curve corrected for the short-term variation. Other pulsational parameters such as pulsation amplitude and initial epoch for the light curve variations can be also determined.

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.

Symbiotic Miras

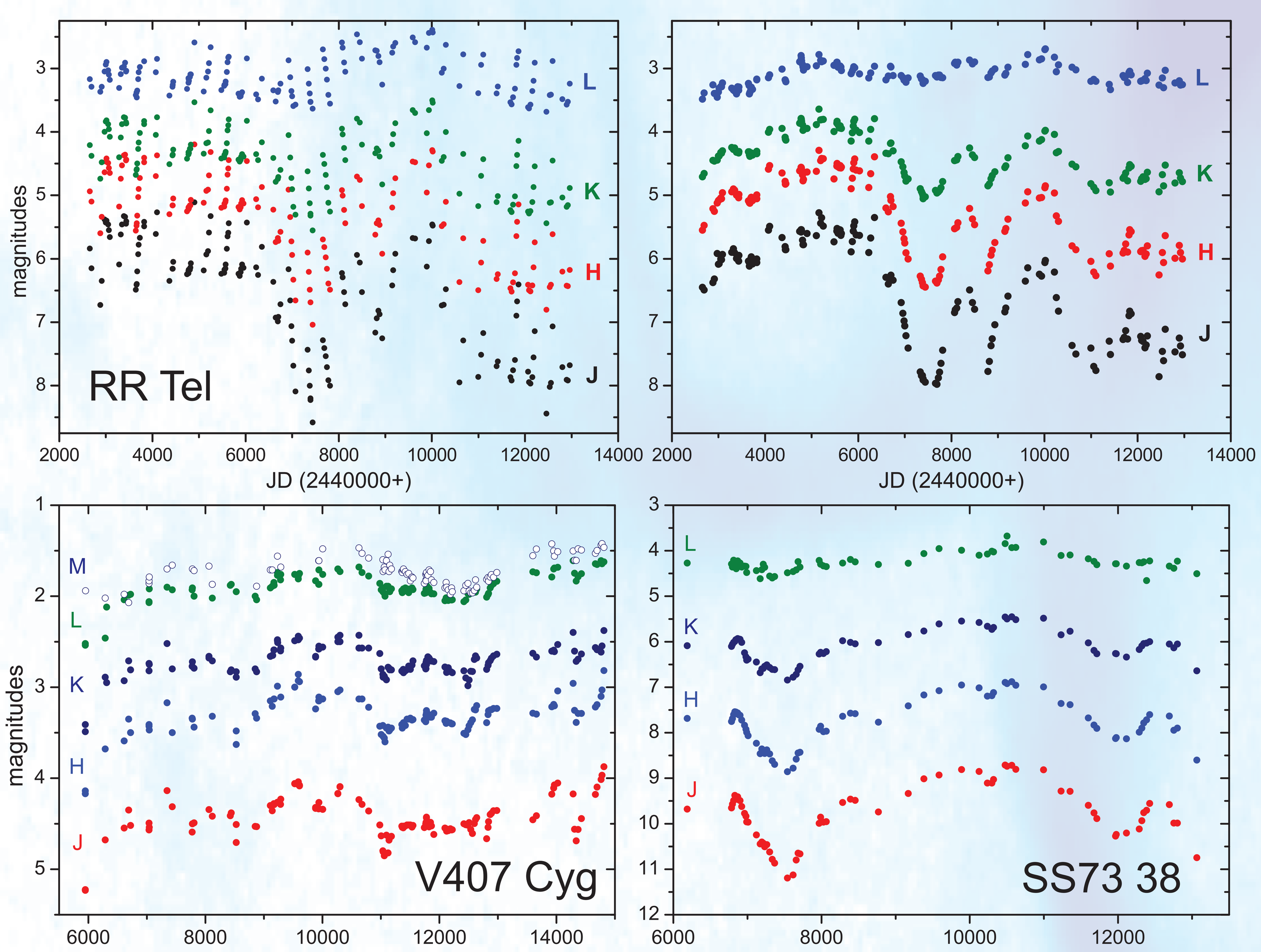

Figure 1. Light curves of RR Tel with (top right) and without (top left) corrections for short-term variations obtained by PDM method. Corrected light curves of V407 Cyg symbiotic nova and SS73 38 C-rich symbiotic Mira are also shown (bottom). Obscuration episodes are clearly visible.

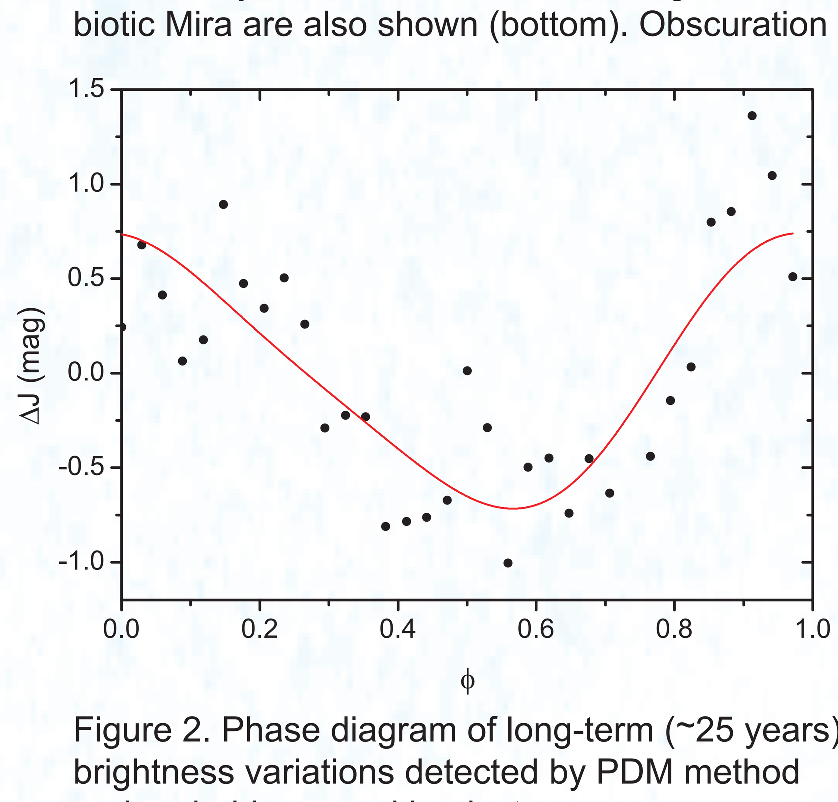

Figure 2. Phase diagram of long-term (~25 years) brightness variations detected by PDM method and probably caused by dust.

Symbiotic Miras are semi-detached binary systems consisting of a compact hot component such as white dwarf and of a cold AGB giant of a Mira-type. The presented light curves show the presence of short-term variations due to the 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, 2018a, 2018b). Short-term variations due to the Mira pulsations should be removed in order to study the long-term component. The corrected light curves clearly show different obscuration epochs caused by absorption in circumstellar dust. Further analysis can also detect periodic very long-term variations (~20-30 years). We have analysed light curves of 15 symbiotic Miras, including 5 symbiotic novae and two rare C-rich symbiotic Miras, and detected such long-term variations in 5 of them that could be related to orbital motion of the dust shell or to the dust formation.

Blazhko effect

Modulations of amplitude and phase in the pulsations of RR Lyrae variables are known as Blazhko effect. This effect consists of a number of pulsational phenomena such as period doubling, resonances or chaotic behaviour. It is still poorly understood and remains one of the challenges in stellar astrophysics as RR Lyrae are important distance indicators. Detection of Blazhko effect is further complicated by its low amplitude, presence of both amplitude and phase modulation, and large differences between the periods of the short- and long-term (Blazhko) component which restrict the application of Fourier analysis. If data sampling is low, and seasonal and daily biases and gaps are present, the analysis is further complicated.

We have applied PDM method on a number of RR Lyrae with already detected Blazhko effect, and successfully confirmed the Blazhko period, including the most problematic HH Tel variable. ASAS observations were used in order to mimic the least favourable dataset expected to be provided by LSST observations that includes up to 900 observations during ~9 years, or cadence of ~4 days.

Object					PDM		DFT	
	P_{puls} (days)	P_{BL} (days)	A_{BL} (mag)	Ref.	P_{BL} (days)	A_{BL} (mag)	P_{puls} (days)	P_{BL} (days)
HH Tel	0.4821	143	--	1	141.80	0.069	0.4821	125.66
RY Psc	0.5297	154.53	0.12	2	154.20	0.132	0.5297	142.07
ASAS 160125-5150.3	--	1242	--	3	1311	0.18	5.0202	n.d.

Table 1. Blazhko period (P_{BL}) and full amplitude (A_{BL}) determined by PDM method for two RR Lyrae and one Cepheid variables. Blazhko and pulsational periods (P_{puls}) were also determined by DFT method. Results of PDM and DFT methods are compared with the periods and amplitudes obtained by other authors and methods: (1) Skarka, 2014, A&A, 562, A90; (2) Szczygiel & Fabrycky, 2007, MNRAS, 377, 1263; (3) Berdnikov et al. 2017, ApSS, 362, 105).

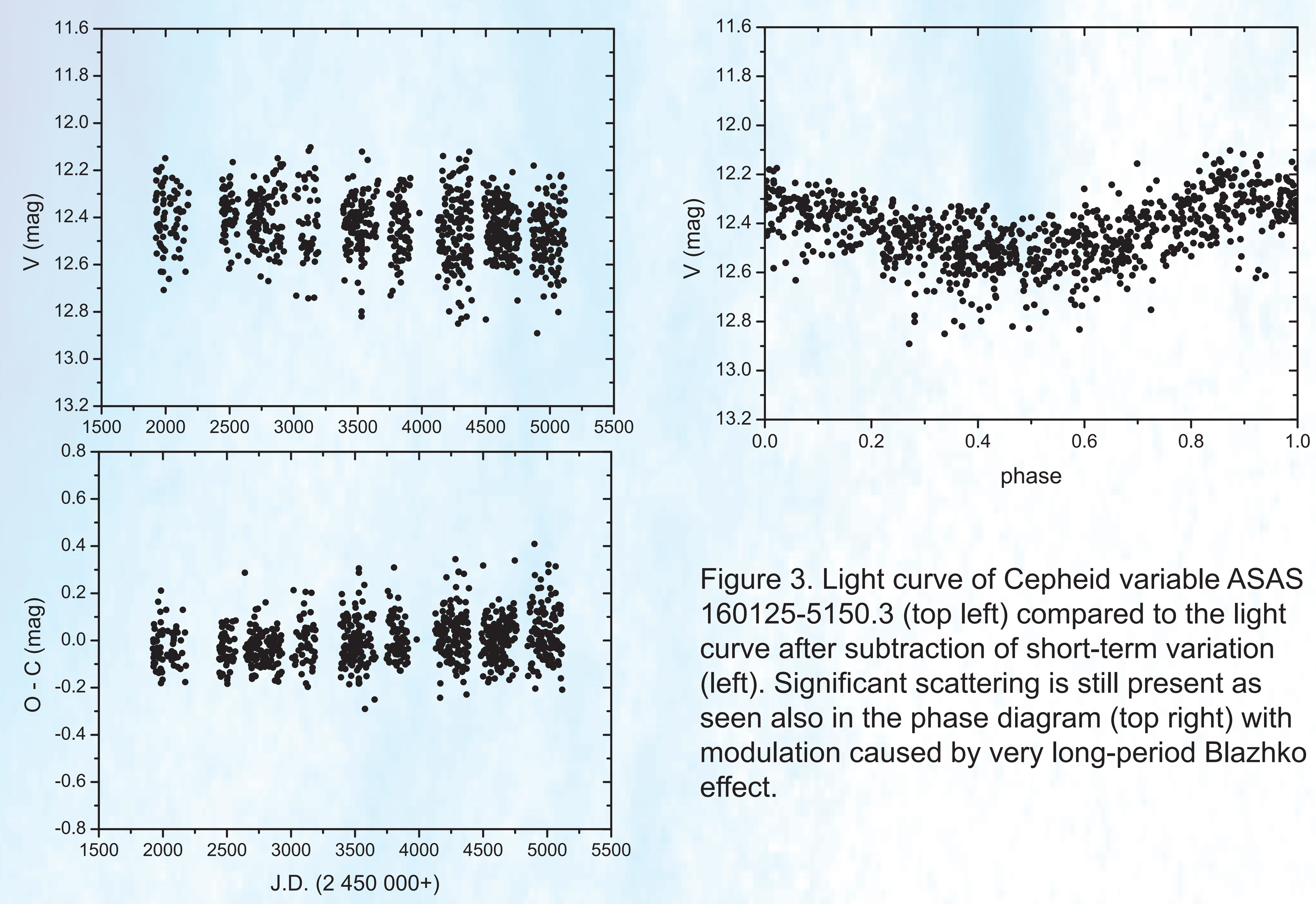

Figure 3. Light curve of Cepheid variable ASAS 160125-5150.3 (top left) compared to the light curve after subtraction of short-term variation (left). Significant scattering is still present as seen also in the phase diagram (top right) with modulation caused by very long-period Blazhko effect.

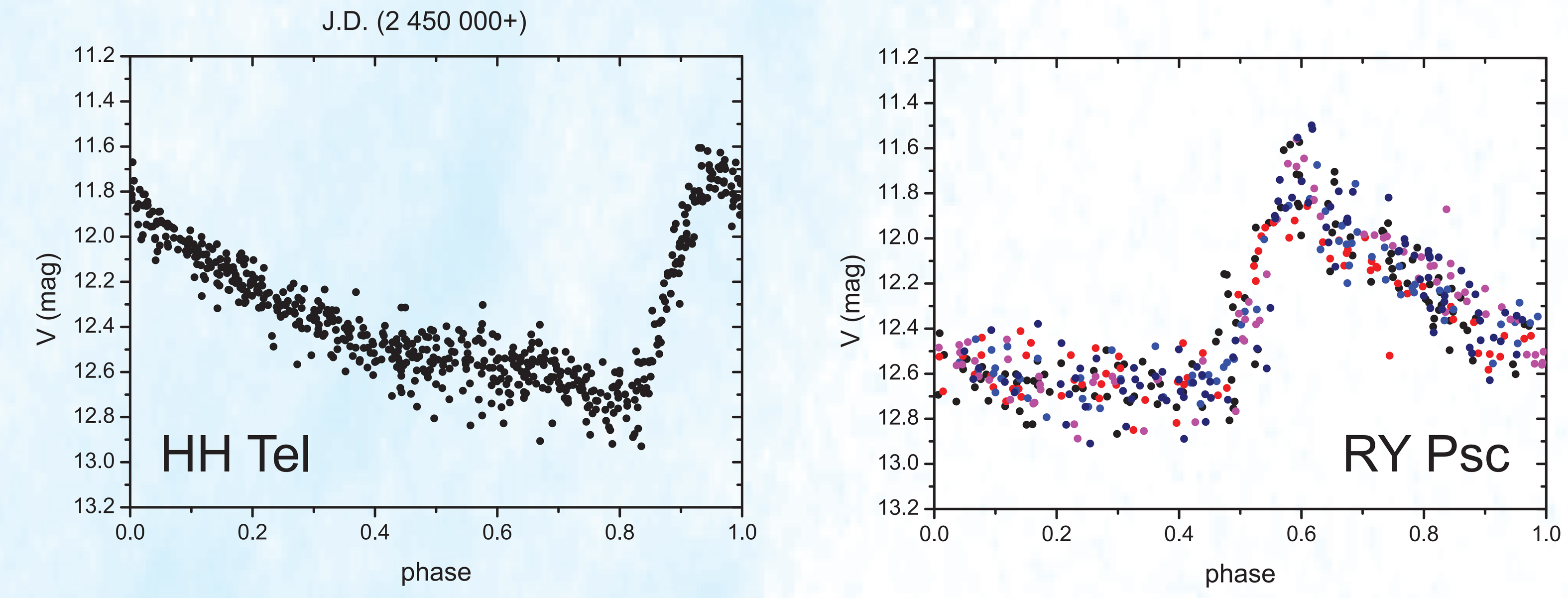

Figure 4. Phase diagrams of short-term brightness variations of HH Tel and RY Psc, two RR Lyrae variables. Scattering is present in both diagrams and caused partially by Blazhko effect. Scattering is higher in RY Psc (right) than in HH Tel (left) which can be explained by higher Blazhko amplitude in RY Psc. Observations shown in the same colour in phase diagram of RY Psc belong to the same Blazhko phase, indicating significant scattering due to the Blazhko effect.

PDM method was successful in detecting and obtaining Blazhko periods that are similar to the values determined by more complex analysis that used observations of higher cadence such as SuperWASP survey. Both RY Psc and HH Tel have periods of ~0.5 days which causes observational gaps due to the Earth rotation. HH Tel has low Blazhko amplitude so Blazhko effect is hard to detect as shown by Skarka (2014) who didn't succeed to obtain Blazhko period from ASAS observations only. Contrary to that, PDM method derived similar Blazhko period as the period obtained from SuperWASP observations. We have also analysed ASAS 160125-5150.3 Cepheid and derived Blazhko period of 1311 days which is longer than 1242 days reported by Berdnikov et al. (2017) who detected Blazhko effect for the first time in this Cepheid.

Conclusion

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

The method was successfully used in correction of light curves of symbiotic Miras and in detection of long-term brightness variations, including detection of Blazhko effect in RR Lyrae and Cepheid variables. Such method could be of interest in reduction of light curves in large surveys such as LSST.

References

Jurkic, T., Kotnik-Karuza, D. 2012, A&A, 544, A35
Jurkic, T., Kotnik-Karuza, D. 2018a, Astr.Lett., 44, 265
Jurkic, T., Kotnik-Karuza, D. 2018b, A&A, submitted
Lafler J., Kinman T. D., 1965, *ApJS*, 11, 216
Reegen, P. 2007, *A&A*, 467, 1353
Stellingwerf, R. F. 1978, *ApJ*, 224, 953