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Dynamical investigation of modulated *Kepler* RR Lyrae stars

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Abstract. We performed a non-linear dynamical analysis on the Blazhko modulation for the first time. Our results suggest that the detection of chaotic nature behind the phenomenon is limited by the instrumental effects and the data processing problems of the *Kepler* pipeline concerning high-amplitude variable stars.

1 Introduction

The Blazhko modulation shows irregular behaviour. Significant cycle-to-cycle changes of the Blazhko cycles are detectable among the *Kepler* RR Lyrae stars. These rule out any explanation that predicts strictly periodic modulation. The study of the nature of the irregularity may lead us to the solution of this mysterious effect. Possible chaotic dynamics support the resonant coupling model [1] while the stochastic nature favours the convective cycle model [2]. Our aim is to distinguish which behaviour characterizes the RR Lyrae modulations.

Because of the lack of any suitable data, non-linear dynamical analysis has not been performed on the Blazhko modulation before. However, the *Kepler* photometry may be useful for dynamical studies, because it provides unprecedentedly high accuracy, quasi-continuous time series and the highest number of adjacent modulation cycles ever detected.

2 Analysis

We found V783 Cyg (KIC 5559631) to be the most suitable for the non-linear analysis. Its ~27.7-day Blazhko period is the shortest amplitude modulation in the *Kepler* field, providing the most (51) modulation cycles with long cadence data collected between Q1 to Q16. We used the tailor-made photometric data provided by [3] that collects the flux from a given target as accurately as possible.

The used analyser tool, the global flow reconstruction method is able to detect chaos by searching for a non-linear map that connects the neighbouring points of phase space trajectory [4]. Once we found the map, arbitrary long synthetic data can be iterated, from which we can determine the quantitative properties of the system. Chaotic systems always have fractional dimensions that tell about their complexity. The Lyapunov dimension can be easily determined from the Lyapunov characteristic exponents that describe the divergence of trajectories in different orientation of the phase space. This method proved to be useful to detect low dimensional chaos not only in artificial but in real observational data [5].

Our non-linear investigation focused on the Blazhko effect of V783 Cyg itself, so we separated the modulation from the light-curve. We used different techniques to determine modulation curves. The magnitude of the pulsation maxima display the amplitude variation curve, the time of the maxima minus a calculated time of the main pulsation period provide the O-C diagram that shows the phase

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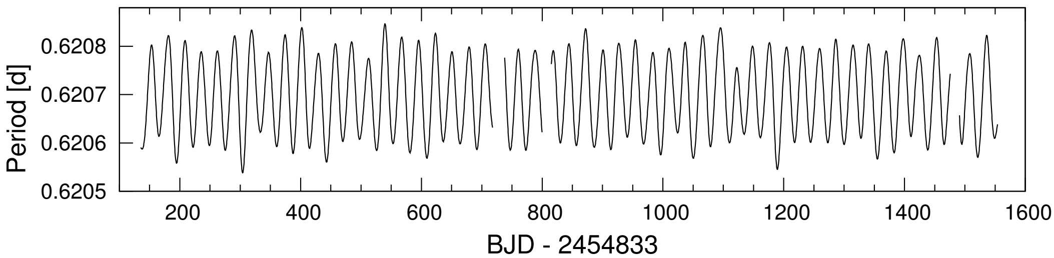

Fig. 1. The modulation curve of the main pulsation period of V783 Cyg derived by the analytical signal method.

modulation. An alternative modulation curve determination is provided by the analytical signal method [6]. It is a powerful tool to derive the time dependence of amplitudes and frequencies of the pulsation modes [7]. In Figure 1 we display the modulation curve derived by the analytical function of the main pulsation period.

3 Results

During the analysis we faced the problem that the determination of the modulation curve is ambiguous. The pulsation amplitudes are highly sensitive to quarter-stitching techniques. The sparse, 30-min long-cadence sampling causes a very low signal to noise ratio in the O–C diagram. The stochastic cycle-to-cycle change caused by observational noise distorts the shape of the analytical signal of the period.

However, we could fit all the modulation curves with chaotic signals with a Lyapunov dimension between 2.001-3.635. The large scatter in the quantitative properties shows that the results are very uncertain. Furthermore, our control tests showed that a similar, but stochastic dataset can also be fitted with chaotic signals. We believe that this is due to the shortness of the data and the low amplitude irregularity of modulation. Detailed description of the analysis can be found in a recent paper [8].

We intend to continue the search of non-linear dynamics in RR Lyrae modulation on other possible candidates of the *Kepler* stars.

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