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The long term behaviour of RR Gem

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Abstract
The photometric observations of RR Gem obtained at the Konkoly Observatory during the last 70 years have been analysed in search of the signs of Blazhko modulation. The analysis showed that RR Gem was modulated nearly all the time with the same 7.21 d period as nowadays. The amplitude of the modulation varied inversely with the variation of the pulsation period.
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1 Introduction

The phenomenon of the periodic light curve variation of some fraction of the RR Lyrae stars is known for about a century. Blazhko (1907) and Shapley (1916) discovered that RW Dra and RR Lyr showed periodic oscillation in the phase and height of light maxima on a timescale of tens of days. Nowadays the light curve modulation of RR Lyrae stars is called Blazhko effect.

There are signs suggesting that the Blazhko modulation changes in time. For example the most extensively studied Blazhko star, RR Lyr itself, changes the modulation amplitude with about a 4 year long period (Detre & Szeidl, 1973). Unfortunately, there are only a few Blazhko stars for which long term photometry are available. RR Gem is one of these stars. At the Konkoly Observatory RR Gem has been observed more or less continuously since 1935. The most accurate photometric technique of the time was always applied. Between 1935 and 1953 photographic, from 1954 to 1983 photoelectric, and in 2004 and 2005 CCD observations were made.

Considering its modulation properties, RR Gem is a peculiar Blazhko star. Detre (1970) found that it showed Blazhko modulation with a period of 37 days in the 1930s from photographic observations. The modulation had, however, disappeared for the 40s. Based on CCD observations Jurcsik et al. (2005) have found recently that the true modulation period of RR Gem is 7.2 d. This was the shortest Blazhko period known and the 0.1 mag B band amplitude of the modulation was also the lowest observed. On the ground of these surprising results it seemed worthwhile to reinvestigate the long term behaviour of the modulation of RR Gem, i.e., to reanalyse the photographic and photoelectric data collected at the Konkoly Observatory with the help of new computer aided techniques.

2 The data

In this paper we report the results of the analysis of the photographic, photoelectric and CCD light curves obtained at the Konkoly Observatory in the last 70 years. We also used about 300 published times of maxima from different authors collected in the GEOS[1] database.

The photographic observations. More than 1000 exposures were taken on more than 100 photographic plates. Unfortunately, many of the plates have been damaged or disappeared. We could measure 671 data points from 37 nights, 20 of them covered phases around light maximum.

The photoelectric observations were obtained and reduced by Béla Szeidl. No filter was used before 1958. At that time the new photometer was in test phase and due to the different settings these observations were too inhomogeneous to study the low amplitude Blazhko modulation. More than 1000 data points covering 31 maxima were obtained in B and V colours on 41 nights after 1958.

The CCD observations were obtained with a Wright CCD camera attached to the refurbished and automated 60 cm Heyde telescope of the Konkoly Observatory, Budapest. We obtained more than 3200 frames in each passbands of the $BV(RI)_c$ filters. Altogether 32 light maxima were observed on 63 nights. The analysis of the CCD light curve from 2004 has been already published (Jurcsik et al., 2005). In 2005 we continued the observations to refine the pulsation and modulation periods.

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3 The $O-C$ diagram

The variation of the pulsation period during the last 115 years is presented on the $O-C$ diagram shown in Fig. 1. We determined the maximum times for the observations by polynomial fit to the data points around the maxima. These fits also yielded the magnitudes of maximum brightnesses. We corrected some mistyped GEOS data according to the original publications and left out a few outlying points where no cause of the deviation was found. We have also found additional published maximum times from two authors (Waterfield, 1927; Graff, 1906). The $O-C$ diagram shown in the top panel of Fig. 1 was constructed using the following ephemeris:

$$t_{\max} = 2412077.521\,[\mathrm{HJD}] + 0.397291066 \cdot E.$$

This period is the average pulsation period of RR Gem over the last 115 years.

The diagram shows many changes in the pulsation period, among them the most abrupt and the most remarkable happened just at the middle of the Konkoly photographic observations, around 1938. This section of the $O-C$ is enlargened in the lower left panel of Fig. 1. During the photoelectric observations a slow and nearly constant period decrease occurred. This linear period change is demonstrated in the lower right panel of Fig. 1. The fitted parabolic curve is also drawn. To plot this diagram we used a different ephemeris:

$$t_{\max} = 2435062.216\,[\mathrm{HJD}] + 0.3973106 \cdot E.$$

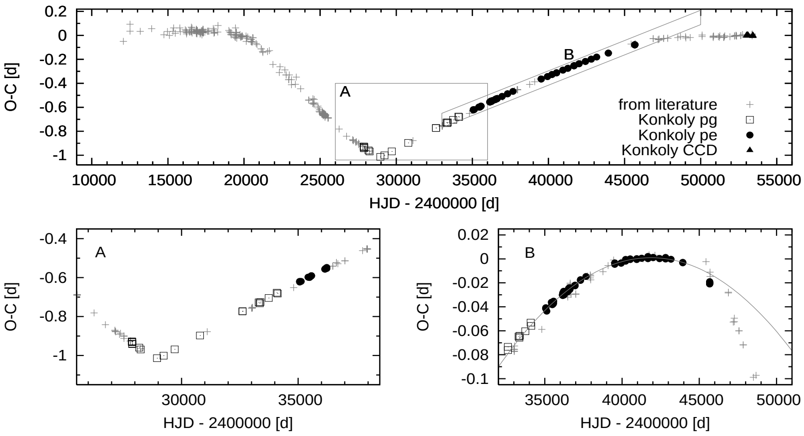

Figure 1: *The $O-C$ diagram of RR Gem for the last 115 years.*

4 Light curve analysis

4.1 The CCD light curve

A detailed study of the CCD photometry from the 2004 season has been published by Jurcsik et al. (2005). We give here the refined parameters of the modulation and the pulsation based on the light curve from 2004 and 2005.

The pulsation period was determined from nonlinear Fourier fit of the light curve with 15 harmonics. The yielded period is $P_{\mathrm{puls}} = 0.39728930 \pm 2.4 \cdot 10^{-7}$ d.

After the removal of the pulsation frequencies the prewhitened Fourier spectra showed the modulation peaks clearly, symmetrically around the pulsation frequencies (see Fig. 2 in Jurcsik et al. (2005)). The frequency separation of the modulation and pulsation peaks corresponds to a modulation period of $P_{\mathrm{Bl}} = 7.216$ d.

As the modulation of the maximum light is nearly sinusoidal, the amplitude and period of the maximum light modulation can be determined from a simple sine fit to the maximum points. Data folded with the modulation period and the fit are shown in Fig. 2. The maximum magnitude modulation in B band has an amplitude of $A_{\mathrm{m}} = 0.114 \pm 0.004$ mag, with a period of $P_{\mathrm{Bl}} = 7.214 \pm 0.0025$ d.

We derived the following normal maxima times for the two observing seasons:

$$t_{\mathrm{max}}^{(2004)} = 2453063.6492 \pm 0.0007\,\mathrm{HJD}, \qquad t_{\mathrm{max}}^{(2005)} = 2453424.4003 \pm 0.0016\,\mathrm{HJD}.$$

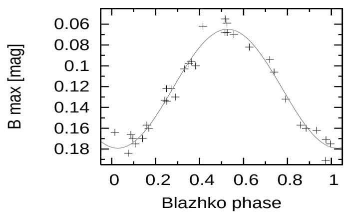

Figure 2: *The maximum magnitudes of the CCD B observations folded with the 7.214 d modulation period.*

4.2 The photoelectric light curve

Due to the period change and the uneven data distribution of the photoelectric observations we analysed only the data of the first 3 seasons in search for the signs of modulation. About the half of the observations were obtained during this time, which covered 15 light maxima. In the next 18 years altogether 16 maxima were only observed. The effect of period change was negligible in the first 3 years of the photoelectric observations. The B and V observations were made simultaneously, however, we analysed only the B light curve as its S/N ratio was better.

The observations were made only around rising branch and maximum brightness what makes Fourier analysis difficult. To stabilize the Fourier fit and to reduce the $\pm f_p$ aliases in the amplitude spectrum we inserted 2 synthetic descending branches based on the CCD B mean light curve. The analysis of the CCD light curve which showed that the modulation practically has no effect on the descending branch (see Fig. 9 in Jurcsik et al. (2005)) validates this procedure.

As the modulation peaks in the Fourier spectra of the light curves of Blazhko stars follow the same pattern around the harmonics of the pulsation frequency, the S/N ratio can be improved if we sum up the appropriate sections of the spectrum around the harmonics of the pulsation frequencies. The formula to calculate this *aggregated spectrum*, $A'(f)$ for n harmonics is:

$$A'(f) = \sum_{i=1}^{n} A(f + i \cdot f_{\mathrm{p}}), \text{ where } -\Delta f > f > \Delta f,\ \Delta f > f_{\mathrm{mod}},$$

f_{p} is the pulsation frequency, $A(f)$ is the original amplitude spectrum and the examined range extends to $2 \cdot \Delta f$ symmetrically around the pulsation peaks.

The Fourier analysis of the photoelectric B light curve and of the B maximum points showed that RR Gem was modulated at this time also, but the modulation was even weaker than today.

4.3 The photographic light curve

The available photographic plates were digitized and aperture photometry was applied. To construct the density–magnitude curves for every exposure we used the Johnson B magnitudes of 16 comparison stars measured with the Wright CCD camera on the 60 cm telescope. As the sensitivity range of the photographic emulsion is near to the B band this way we transformed the photographic measurements to B magnitudes.

Due to the abrupt period change during the time of the photographic observations the photographic light curve had to be divided into two parts before the analysis.

We had 8 light maxima from the first 2 seasons and 12 maxima from the next 15 years. The modulation was detected in the first part of the data in spite of the large uncertainty of the photographic observations. Its amplitude was much larger than today, 0.25 mag in the B passband while the modulation period was the same as today. On the other hand no sign of the modulation was found in the second part of the data. As the observations at this period were very sparse and the period of the modulation was very short it does not mean that RR Gem was not modulated then. We estimate the upper limit of the modulation amplitude to be 0.06 mag in B band from the scatter of the maximum points of this dataset.

5 Discussion

The analysis of the light curves from the last 70 years showed that RR Gem was modulated nearly all the time. When modulation was detected, its period was always the same as recently, 7.21 d. The amplitude of the modulation, however, changed significantly from the undetectable level to 0.25 mag amplitude in the maximum brightness in the B passband. The modulation amplitude changed in reverse to the pulsation period.

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