Flavours of variability: 29 RR Lyrae stars observed with Kepler

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ABSTRACT
We present our analysis of Kepler observations of 29 RR Lyrae stars, based on 138-d of observation. We report precise pulsation periods for all stars. Nine of these stars had incorrect or unknown periods in the literature. Fourteen of the stars exhibit both amplitude and phase Blazhko modulations, with Blazhko periods ranging from 27.7 to more than 200 days. For V445 Lyr, a longer secondary variation is also observed in addition to its 53.2-d Blazhko period. The unprecedented precision of the Kepler photometry has led to the discovery of the the smallest modulations detected so far. Moreover, additional frequencies beyond the well-known harmonics and Blazhko multiplets have been found. These frequencies are located around the half-integer multiples of the main pulsation frequency for at least three stars. In four stars, these frequencies are close to the first and/or second overtone modes. The amplitudes of these periodicities seem to vary over the Blazhko cycle. V350 Lyr, a non-Blazhko star in our sample, is the first example of a double mode RR Lyrae star that pulsates in its fundamental and second overtone modes.

Key words: stars: oscillations — stars: variables: RR Lyrae

1 INTRODUCTION
The ultraprecise photometry by the Kepler space telescope opens up the possibility of discovering new phenomena and shedding new light on long-standing astrophysical problems (Gilliland et al. 2010). One of the most interesting unsolved problems is the physical origin of the Blazhko (1907) effect, an amplitude and/or phase modulation of RR Lyrae stars. The leading explanations are: (1) an oblique rotator model that invokes a magnetic field (Shibahashi 2000); (2) a model with resonant coupling between radial and non-radial mode(s) (Dziembowski & Mizerski 2004); and (3) a mechanism invoking a cyclic variation of the turbulent convection caused by a transient magnetic field (Stothers 2006). At present none of these models explains all the observed properties of stars showing the Blazhko effect. It is not even clear whether a modification of the above ideas or new astrophysical processes are needed to solve the problem. Comprehensive discussions of the observational and theoretical properties of Blazhko RR Lyrae stars are given by Szeidl (1988) and Kovács (2009).

This paper paper describes new properties of RR Lyrae stars revealed by early data from the Kepler photometer. Here we concentrate on the results based mostly on Fourier analyses. A detailed study of all observed stars is beyond the scope of the present paper.

2 DATA
A detailed technical description of the Kepler Mission can be found in Koch et al. (2010) and Jenkins et al. (2010,8). At the time of this writing three long cadence (29.4-min integration time) photometric data sets have been released to the KASC (Kepler Asteroseismic Science Consortium). Altogether 29 RR Lyrae stars were

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Table 1 shows the available data sets for each star observed during the commissioning phase (Q0) and the runs Q1 and Q2. The commissioning phase data (Q0) included six of the CoRoT RR Lyrae stars observed between 2009 May 2 to 11 (9.7 d), the observations were made on 2009 May 13 and ended on 2009 June 15 (33.5 d). The first full quarter of data (Q2) ran from 2009 June 19 to 2009 September 16 (89 d). At present, the combined number of data points for a given star is between 4096 and 6175. Column 8 in Table 1 contains the main pulsation periods and the Fourier amplitude of the main frequencies obtained from our SPEC analysis. These two basic parameters ($P_0$ and $A_1$) were previously unknown or wrong for nine stars (signed by an ‘n’ in the last column). The columns of the table shows the ID numbers, J2000 positions (RA, DEC), and apparent magnitude ($K_p$) for nine stars (signed by an ‘n’ in the last column).

The telescope is rotated by 90 degrees four times per orbital period for best exposure of the solar panels. Accordingly, the Q0 and Q1 data sets were observed at one position and the first roll was executed between Q1 and Q2. The different apertures applied to a given star in the two positions caused the zero points of the raw fluxes and the amplitudes of a star to be different for the two rolls. We applied simple linear transformations to fit the amplitudes and zero points for combining the data. The long-time-scale trends were removed from the raw fluxes by a trend filtering algorithm prepared for CoRoT RR Lyrae data (Chadid et al. 2010), then fluxes were transformed into a magnitude scale, where the averaged magnitude for an individual data point.

Some basic parameters of the observed stars are summarized in Table 1. The columns of the table shows the ID numbers, J2000 positions (RA, DEC), and apparent magnitude ($K_p$) for CoRoT RR Lyrae data (Chadid et al. 2010), then fluxes were transformed into a magnitude scale, where the averaged magnitude for an individual data point.

3 ANALYSIS AND RESULTS

As a first step Fourier analyses were performed on the data sets. To this end we used the software packages MUFRAN (Kolláth 1990), PERIOD04 (Lenz & Breger 2005) and SSPEC (Reegen 2007), all of which gave similar frequency spectra with similar errors. Some basic parameters of the observed stars are summarized in Table 1. The columns of the table shows the ID numbers, J2000 positions (RA, DEC), and apparent magnitude ($K_p$). From the results we have observed several additional RR Lyrae candidates with short cadence (1-min integration); results from these data will be discussed in a forthcoming paper.

1. http://keplergo.arc.nasa.gov/GOProgramDDT.shtml
2. We have observed several additional RR Lyrae candidates with short cadence (1-min integration); results from these data will be discussed in a forthcoming paper.
3. Public Kepler data can be downloaded from the web page: http://archive.stsci.edu/kepler/
4. http://www.konkoly.hu/HAG/Science/index.html
5. http://archive.stsci.edu/kepler/kic10/search.php
Figure 1. The gallery of Kepler Blazhko stars. The figure shows the complete light curves of eight stars observed with long–cadence during the periods Q0 through Q2. Further light curves are given in Fig. 2 and Fig. 5 and in our parallel papers (Szabó et al. 2010; Kolenberg et al. 2010b). Lines seen running through these light curves are visual artefacts caused by beating of the sampling frequency with the pulsation frequencies. They cause no problems in the Fourier analysis. *For better visibility the scale of KIC 11125706 is increased by a factor of 1.5.

Table 2. Period, amplitude and phase properties of the Blazhko stars

| KIC     | GCVS      | P (d) | σ(P) (d) | ΔA1 (mag) | Δφ1 (deg) | Q | Addition freq. |
|---------|-----------|-------|----------|-----------|-----------|---|----------------|
| 3864443 | V2178 Cyg | > 200 | > 0.488  | > 0.0014  | 0.153     | F2, (PD) |
| 4484128 | V808 Cyg  | > 90  | 0.304    | 0.01214   | −0.045    | PD   |
| 5559631 | V783 Cyg  | 0.4   | 0.071    | > 0.00159 | 0.156     |     |
| 6183128 | V354 Lyr  | 0.25  | > 0.245  | > 0.00245 | −0.139    | F2, (F1, PD, F') |
| 6186029 | V445 Lyr  | 53.2  | 2.8      | 0.968     | 0.022442  | 0.540 | PD, F1, F2 |
| 7176080 | V349 Lyr  | > 127 | > 0.060  | > 0.00175 | −0.251    |     |
| 7198959 | RR Lyr    | 39.6  | 1.8      | 0.461     | 0.013836  | 0.676 | PD   |
| 7505345 | V355 Lyr  | 31.4  | 0.1      | 0.107     | 0.003518  | 0.136 | PD   |
| 7671081 | V450 Lyr  | 125   | 0.391    | 0.004882  | 0.235     |     |
| 9001926 | V353 Lyr  | 60.0  | 7.1      | 0.157     | 0.004026  | 0.033 |     |
| 9578833 | V366 Lyr  | 65.6  | 2.6      | 0.171     | 0.003205  | −0.102 |     |
| 9697825 | V360 Lyr  | 51.4  | 4.3      | 0.356     | 0.008228  | 0.279 | F1, (PD) |
| 11125706|           | 39.4  | 2.0      | 0.030     | 0.001420  | 0.540 |     |
| 12155928| V1104 Cyg | 53.1  | 0.3      | 0.105     | 0.002451  | −0.063 |     |

(a) The star shows a longer time-scale variation than its Blazhko modulation as well.
(b) The pattern of additional frequencies: PD means period doubling; F1 indicates first overtone frequency and its linear combination with fundamental one; F2 is as F1, but with second overtone; F' indicates frequencies with unidentified modes; brackets indicate marginal effects.

except RR Lyr itself. In most of the cases these stars are mentioned in the literature apropos of their discoveries and in some cases due to the determination of their position and/or ephemeris. The radial velocity measurements of NR Lyr and V894 Cyg were used for kinematic study of the Galaxy (Layden 1994; Beers et al. 2000; Jeffers et al. 2007). The Northern Sky Variability Survey (NSVS) included NR Lyr, V355 Lyr and V2470 Cyg. Their NSVS light curves – together with more than 1100 other ones – formed the basis of the statistical study of Kinemuchi et al. (2006). The most specific investigations were carried out on V783 Cyg by Loser (1979) and Cross (1991), who found a period increase between 1933 and 1990 with the ephemeris of $JD_{\text{max}} = 2436394.332 + 0.62069669E + 7.5 \cdot 10^{-11}E^2$. According to Table 1 the period is still increasing with a good agreement of the rate of Cross’s value: $0.088 \pm 0.023$ d My$^{-1}$.

The standard errors of the main period and amplitude (in columns 6 and 8) were estimated from the accuracy of non-linear least-square fits. The last three columns of the table indicate other identifications of the stars, the observing runs analysed and the presence of a Blazhko effect, respectively. All the periods, amplitudes and light curve shapes of the 29 stars are typical for RRab
Blazhko cycle.

Figure 2. **Top left:** Light curve of V445 Lyr (KIC 6186029). **Bottom left:** Fourier spectrum after the data are prewhitened with the main frequency and its harmonics. The insert is a zoom around the positions of the main frequency $f_0$ and its first harmonics $2f_0$ (showed by green arrows) after the 20 highest amplitude frequencies were removed. The complex structure of additional frequencies is clearly seen.

3.1 RR Lyrae stars with amplitude modulation

Generally, it is an easy task to distinguish amplitude modulated and non-modulated *Kepler* RR Lyrae light curves. A gallery of modulated light curves is shown in Fig. 1. It is obvious at first glance that the modulation cycles are predominantly long and the amplitude of the effect is clearly visible. Non-sinusoidal envelopes of the light curves (see, e.g., V2178 Cyg: KIC 3864443) or moving bumps (e.g., V366 Lyr: KIC 9578833) are also conspicuous.

The interesting light curve of V445 Lyr (KIC 6186029) is shown separately in Fig 2. The two observed Blazhko cycles are surprisingly different. The high amplitude of the Blazhko modulation extremely distorts the shape of the light curve. This is demonstrated in the small panels of Fig 2. Signs of complex variations are detectable from the Fourier spectrum as well. The spectrum of the data prewhitened with the main pulsation frequency and its harmonics shows four peaks around each of the harmonics (Fig 3). Two outer peaks at the harmonics can be identified as elements of the Blazhko triplets $(f_0 \pm f_3)$. Two other side peaks closer to the harmonic frequencies show the possible variation of the Blazhko effect on a time-scale longer than the observation run. This may be a result of a cyclic variation (existence of more than one Blazhko modulation), a secular trend, or random changes.

Several papers have reported multiperiodic and/or unstable behaviours in the Blazhko effect (e.g., LaCluyze 2004; Collinge et al. 2006; Kolenberg et al. 2006; Nagy & Kovács 2006; Sódor et al. 2006; Szeczygiel & Fabrycky 2007; Wils et al. 2008; Jurcsik et al. 2009). After investigating the two Blazhko cycles noted here, we are not in the position to decide on the nature of this variation, but the 3.5–5 year long time base of *Kepler*’s observations will provide an excellent opportunity to study this strange behaviour.

We were systematically searching for low amplitude Blazhko RR Lyrae stars. Instrumental trends of the observed fluxes that are not properly removed could cause apparent amplitude changes in the non-linear magnitude scale. A decreasing trend of the averaged fluxes results in increasing amplitudes in magnitudes and vice-versa. Therefore, we always checked the amplitude variation using the raw fluxes. We divided the data sets into small sections (typically 2–3 d in length), then calculated the amplitude difference $\delta A_1(t)$ of the first Fourier component and its averaged value $\Delta A_1$ over the whole time span for all sections by a non-linear fit. These calculated functions reflect well the variation of pulsation amplitude seen in the light curves.

With the help of this tool we found in KIC 11125706 the lowest amplitude modulation ever detected in an RR Lyrae star. Full amplitude of the maximum light variation $A(K_p)_{max} = 0.015$ mag, and the amplitude of the highest side peak in the Fourier spectrum is only $A_{K_p}(f_0 + f_3) = 0.0022$ mag. The lowest published amplitude of a Blazhko effect previously found was the case of DM Cyg (Jurcsik et al. 2009) where $A(V)_{max} = 0.07$ mag, $A_V(f_0 + f_3) = 0.0096$ mag and $A_V(f_0 + f_3) = 0.0061$ mag. The two measurements are not strictly comparable because *Kepler* pass-
band is broad in white light. However, the maximum of its spectral response function (see Koch et al. 2002) is about 6000 Å between Johnson–Cousins filters V and R.

All the Blazhko RR Lyrae stars found in our sample are listed in Table 2. The estimated lengths of the Blazhko cycles are indicated in the third column. For the shorter periods than the total time span they were calculated from the averaged frequency differences of the highest side peaks \((f_0 + f_B)\) and \((f_0 - f_B)\), otherwise a minimum period is given. The fourth column shows the amplitude modulation parameter \(\Delta A_1\) defined above.

We note here, the triplet structure has always appeared for all Blazhko stars, i.e. no stars show frequency doublets. The amplitude of the high frequency peak is higher than the lower for 9 stars. The remaining 5 show the opposite pattern. The asymmetry parameter \(Q\) defined by Alcock et al. (2003) as \(Q = \frac{A(f_0 + f_B) - A(f_0 - f_B)\sqrt{A(f_0 + f_B) + A(f_0 - f_B)}}{\sqrt{A(f_0 + f_B) + A(f_0 - f_B)}}\) varies from -0.251 to 0.676 (see the 6th column in Table 2), however, these values are rather preliminary due to the long Blazhko cycles.

In the past few years, thanks to high precision ground- and space-based observations, the known occurrence rate of the Blazhko effect among RR Lyrae stars has increased from the former estimate of 15–30% to a ratio close to 50% (see Jurcsik et al. 2005, 2006; Chadid et al. 2008; Kolenberg et al. 2010d). It is even possible that all RR Lyrae stars may show a Blazhko modulation with an increasing frequency of Blazhko stars at lower modulation amplitude. The Kepler measurements provide an ideal tool to test this hypothesis. From our \(\Delta A_1\) values in Table 2 it can be seen that we found only two stars with modulation amplitude lower than 0.1 mag.

To test our detection limit of the amplitude modulation, artificial light curves were generated. Two sets of grids were constructed: one for V368 Lyr (KIC 7742534) and another for KIC 7030715. These stars have the shortest and the longest pulsation periods (0.45649 \(d\) and 0.68204 \(d\)) in the sample, respectively. In both cases the Fourier parameters of the main pulsation frequencies and their significant harmonics were used to build the artificial light curves. These were modulated by a simple sinusoidal function with amplitudes ranging between \(10^{-4}\) and \(5 \times 10^{-4}\). The light curves were always calculated at the observed points of time.

In our tests, we reckoned the amplitude modulation as detectable if the highest Fourier side peak connected to the modulation exceeds the spectral significance \(\sigma_s\) 5. (For the definition of the \(\sigma_s\), we refer Reegen 2007: the correspondence between more popular amplitude signal-to-noise ratio \(S/N\) and \(\sigma_s\), is yielded as \(\sigma_s = 5 \approx S/N = 3.83\)). The obtained limiting values are \(A(f_0 + f_B) > 0.001 - 0.002\) mag (or \(\Delta A_1 > 0.005 - 0.01\) mag) depending on the brightness, but highly independent of the periods \((P_0\) and \(P_B\)). Higher sampling rate (i.e. short cadence) does not decrease our detection limit because the present sampling frequency 48.98 \(d^{-1}\) is much higher than a typical Blazhko frequency \((0.1 - 0.01\) \(d^{-1}\)), hence each Blazhko cycle is covered sufficiently.

Notwithstanding our efforts, we did not detect any modulation for 15 RR Lyrae stars in our Kepler sample, however, some very small amplitude modulation with long period might remain undetected.

Using the same number (14) of Blazhko stars Jurcsik et al. (2009a) found an exponential-like distribution of their modulation amplitude strengths. Our sample shows a similar behaviour (top in Fig 4) when we divide it up into the same 0.025 mag size of bins as were used by Jurcsik et al. (2009a). However, the distribution seems be to more uniform, when we split our sample into smaller bins (bottom in Fig 4). Although, our sample is affected by small number statistics in this respect, we checked the uniformity of the modulation amplitude distribution. We carried out a one-sample Kolmogorov–Smirnov (K-S) test over the intervals of \((0, \Delta A_1^{\text{max}})\) and \((0, A(f_0 + f_B)^{\text{max}})\), respectively. (The extremely modulated star V445 Lyr was omitted from the sample.) Both tests allowed the uniform distribution hypothesis with 99 per-cents of probabilities. We note that the K-S test uses data directly, without any binning.

3.2 Phase modulation

Without any “a priori” knowledge about the nature of the modulation, frequency modulation (period changes over the Blazhko cycle) and phase modulation can not be distinguished: a detected phase variation indicates period changes, and vice-versa. From now on we refer to this phenomenon as phase modulation.

We searched for phase modulation in all of our RR Lyrae stars in the same way as was described in the case of amplitude modulation. We calculated the \(\Delta T\) values from the phase variation function \(\delta \varphi_1(t)\). We expressed the phase differences relative to the

\[
\Delta \varphi_1(t) = \int \frac{A_1(f)}{S(f) + A_1(f)} df
\]

Figure 4. Modulation amplitude distribution of the Blazhko variables in the Kepler sample using 0.025 mag (top) and 0.005 mag (bottom) size of bins. The modulation amplitude corresponds to the Fourier amplitude of the largest amplitude modulation frequency component \(A(f_0 + f_B)\).
in all Blazhko stars both amplitude and phase variation are present. The total cycle, that is $\Delta \phi_1 = \Delta \phi / 2\pi = \delta P / P_0$. The results can be seen in the 5th column of Table 2.

We detected clear phase modulation for all the studied Blazhko RR Lyrae stars. The hardest task was to find it in the case of V2178 Cyg, where the Blazhko cycle is longer than the data set and the phase variation during the observed time span was only 0.0014 (≈ 1 min). The reality of this small phase variation was checked and confirmed by the sensitive analytical function method (Kolláth et al. 2002). We can detect period variations smaller than 1.5 min for three further stars: V783 Cyg (KIC 5559631), V349 Cyg (KIC 7176080), and KIC 1125706. The other extremity is represented by V445 Lyr and RR Lyr itself with their values of 0.0224 (≈ 16.6 min) and 0.0138 (≈ 11.3 min), respectively. There is no clear indication for any connections between the strengths of the two type of modulations.

As was shown by Szeidl & Jurcsik (2009) and Benkő et al. (2009), phase modulation always causes multiplet structures of higher order than triplets in the Fourier spectrum around the main frequency and its harmonics. These multiplet peaks were most clearly detected for V808 Cyg, RR Lyr and V360 Lyr, the Blazhko stars with the strongest phase modulation in our sample.

The precise and almost continuous observation of 14 Blazhko RR Lyrae stars measured by Kepler convincingly demonstrates that in all Blazhko stars both amplitude and phase variation are present.

### 3.3 Additional frequencies

Besides the modulation components that occur in multiplet structures around the main frequency and its harmonics, we found additional frequencies. In the cases of V808 Cyg, V355 Lyr and RR Lyr these frequencies are located around $f_0/2, 3f_0/2, 5f_0/2, \ldots$, where $f_0$ denotes the main pulsation frequency. This very interesting period doubling effect has already been discussed briefly in Kolenberg et al. (2010a) for RR Lyr itself, and a separate paper (Szabó et al. 2010) is dedicated to it. Here we just remark that the presence of these frequencies in the spectra seems to be variable in time and connected to particular Blazhko phases. The phenomenon can be described in a purely radial framework of pulsation theory.

Similarly, time-dependent phenomena might also be important for the four further stars V354 Lyr, V2178 Cyg, V360 Lyr and V445 Lyr, where we discovered additional frequencies with small amplitudes. The light curves of V354 Lyr and V360 Lyr are plotted in the top left panels of Fig. 6. The last column of Table 2 indicates the possible identification of the additional frequencies.

In the Fourier spectrum of V354 Lyr (KIC 6183128) the highest ($\sigma_0 = 34.4$) additional peak is at $f_2 = 3.0369 \pm 0.0002 \text{ d}^{-1}$ (see insert in Fig. 6). Its ratio to the fundamental frequency ($f_0 = 1.78037 \pm 0.00004 \text{ d}^{-1}$) is 0.586, which is close to the canonical ratio of the fundamental and second radial overtone modes. Furthermore, many linear combinations in the form $kf_0 \pm f_2, k = 0, 1, 2, \ldots$ are present in the spectrum. As the period dou-
models (Fig. 6). We used the Florida–Budapest code (Yecko et al. 1998; Kolláth et al. 2002) to fit the observed frequencies by the fundamental and second overtone modes in linear pulsation. We have to note, however, that the width of these regions matching star can be determined by numerical model calculations.

The other star where we found highly significant additional frequencies is V360 Lyr (KIC9697825). The dominating extra peak in its spectrum is located at $f_1 = 2.4875 \pm 0.0001 \text{d}^{-1}$ with $\sigma_1 = 51.9$ (bottom right in Fig. 7). The ratio of this frequency to the fundamental mode frequency ($f_0 = 1.79344 \pm 0.00003 \text{d}^{-1}$) is 0.721. This value is a bit smaller than the generally accepted ratio of fundamental to first radial overtone frequencies ($f_1/f_0 = 0.745$), but some model calculations with higher metallicity (see Fig. 8 in Chadid et al. 2010) allow double mode pulsation with this ratio as well. We also detect a low-amplitude, but significant ($\sigma_1 = 18.9$), peak at the frequency of $f' = 2.6395 \pm 0.0002 \text{d}^{-1}$. Its ratio $f_0/f' = 0.679$ is almost the same as was found for V1127 Aql, a Blazhko RR Lyrae star observed with CoRoT and explained there by a non-radial pulsation mode (Chadid et al. 2010).

V445 Lyr (KIC6186029) has a very complex structure of frequencies at the low-amplitude level (see right panel in Fig. 2). Here, the three types of frequency patterns (connected to the first and second overtone modes and period doubling effect) show similarly significant peaks. In decreasing order of amplitude: $3f_0/2 = 2.9231 \pm 0.0002 \text{d}^{-1}$ ($\sigma_1 = 24.5$), $f_1 = 2.7725 \pm 0.0002 \text{d}^{-1}$ ($\sigma_1 = 21.1$) and $f_2 = 3.331549 \pm 0.0002 \text{d}^{-1}$ ($\sigma_1 = 13.5$).

If the global physical parameters are varying over the Blazhko cycle as demonstrated by Jurcsik et al. (2009), excitation of a radial (or maybe a non-radial) mode temporally, (when the physical conditions of excitation are realized) would be a natural explanation for these patterns.

The frequency spectra of non-Blazhko stars were checked to see whether any of them possesses additional frequencies. This search resulted in the discovery the double mode nature of V350 Lyr (KIC9508655). Its Fourier spectrum (see Fig. 7) contains a significant ($\sigma_0 = 11.5$) peak at $f_2 = 2.8402 \pm 0.0002 \text{d}^{-1}$ with the amplitude of $A(f_2) = 0.001$ mag. The ratio of this frequency to the fundamental mode frequency ($1.682814 \pm 0.00003 \text{d}^{-1}$) is 0.592. That is, V350 Lyr is the first example of a non-Blazhko double mode RR Lyrae star, where the fundamental and second overtone modes are excited. The extremely high amplitude ratio, $A(f_0)/A(f_2) = 316$, points out why we have not been able to find such stars from the ground.

The residual peaks around the main frequency and its harmonics raise the possibility of the presence of the Blazhko effect close to the detection limit. However, neither the $A_1(t)$ function nor the amplitude of the overtone frequency show clear time variation. In the future, calibrated Kepler data gathered over a longer time span may clarify the nature of this interesting object.

In the case of V350 Lyr, the match of the observed frequencies to the theoretical model is a tougher problem than the case of V354 Lyr. High mass or luminosity is required to fit the empirical data even at low metallicity (Fig. 5). However, a small shift in the period ratio results in a better agreement with the canonical mass and luminosity values. 0.001 difference in the observed period ratio and the linear model values can be accounted to observational errors and non-linear effects of stellar pulsations.
The forthcoming long time base of the We found a long term variation of the Blazhko cycle in V445 Lyr. secondary modulation cycles were also reported in the literature. data were prewhitened with the main frequency Fourier amplitude spectrum of V350 Lyr around the highest peaks after the is well known, such as the 4-year cycle of RR Lyr itself. Further on the used size of bins. Our sample supports the uniform distribution. The measured modulation amplitudes proved to be highly dependent on the size of bins. Our sample supports the uniform distribution.

The possibility of multiple modulations of an RR Lyrae star is well known, such as the 4-year cycle of RR Lyr itself. Further secondary modulation cycles were also reported in the literature. We found a long term variation of the Blazhko cycle in V445 Lyr. The forthcoming long time base of the Kepler data will allow us to investigate this phenomenon in detail.

The Kepler data made it possible to find the Blazhko modulation of KIC 1125706 with an amplitude as small as 0.03 mag. This is by far the smallest modulation amplitude ever detected for a Blazhko star. The same is true for phase modulations: we found small but clear phase variations for stars V2178 Cyg, V783 Cyg, V349 Cyg, and KIC 1125706. For these cases the $\delta P_0 < 1.5$ min period variation again have the smallest known values.

- The sensitivity both in amplitude and phase made it possible to detect phase variation for all Blazhko stars. Although our sample is small, it is notable that all of our Blazhko stars are modulated both in their amplitude and phase simultaneously. The relative strength of the two types of modulation varies from star to star, but always has a common period. Therefore, a plausible explanation for the Blazhko effect must account for both amplitude and phase variations.

- We found additional frequencies, beyond the main frequency, its harmonics and expected modulation components, in the Fourier spectra of 7 Blazhko type stars. These additional frequencies concentrate around $f_0/2, 3f_0/2, \ldots$ for three stars, while they appear around the first and second overtone frequency and its linear combination with the harmonics of the main frequency in the the case of V354 Lyr, V2178 Cyg and V360 Lyr, respectively. A special case is V445 Lyr where all of the above-mentioned types of frequencies are present.

If the basic physical parameters, such as mean radius, luminosity, effective temperature, are varying over the Blazhko cycle, a radial (or maybe non-radial) mode could be excited temporally. This would be a natural explanation for these transients.

- As a by-product of our frequency search for additional frequencies, we may have found the first double mode RR Lyrae star, V350 Lyr, which pulsates in its fundamental and second overtone mode simultaneously.

Comprehensive and more detailed study of the increasing Kepler RR Lyrae data sets are in progress and will be discussed in the near future.

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4 SUMMARY

In this paper we have outlined some results obtained for RR Lyrae stars based on the first 138-d long data sets of the Kepler Mission:

- We have determined the main pulsation periods and amplitudes for all stars in this sample. These parameters were previously unknown or wrong for 9 stars.

- We have found 14 certain Blazhko stars among the 29 stars of the observed sample (48%), and we could not find any deviations from monoperiodicity for 15 stars (52%). Statistical distribution of the measured modulation amplitudes proved to be highly dependent on the size of bins. Our sample supports the uniform distribution.

- The possibility of multiple modulations of an RR Lyrae star

Figure 7. Top: Phase diagram of V350 Lyr (KIC 9508655). The Kepler light curve is folded by the main period of $P_0 = 0.59424$ d. Bottom: Fourier amplitude spectrum of V350 Lyr around the highest peaks after the data were prewhitened with the main frequency $f_0$. For these cases the $\delta P_0 < 1.5$ min period variation again have the smallest known values.


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