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RR Lyrae Stars in M4

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Abstract. Observations by Kepler/K2 have revolutionized the study of RR Lyrae stars by allowing the detection of new phenomna, such as low amplitude additional modes and period doubling, which had not previously been seen from the ground. During campaign 2, K2 observed the globular cluster M4, providiing the first opportunity to study a sizeable group of RR Lyrae stars that belong to a single population; the other RR Lyrae stars that have been observed from space are field stars in the galactic halo and thus belong to an assortment of populations. In this poster we present the results of our study of the RR Lyrae variables in M4 from K2 photometry. We have identified additional, low amplitude pulsation modes in both observed RRc stars. In 3 RRab stars we have found the Blazhko effect with periods of 16.6d, 22.4d, and 44.5d.

1 Introduction

The globular cluster M4 was observed during K2's Campaign 2, making it the first globular cluster, along with M80 observed during the same campaign, to be observed by Kepler/K2. These globular clusters represent the first opportunity to use Kepler/K2 to study single populations of RR Lyrae stars. While many RR Lyrae had perviously been observed by Kepler/K2, these were all field stars in the Milky Way halo and thus came from a variety of different populations.

Only a portion of M4 fell on silicon during Campaign 2 with most of the cluster falling in the gap between CCDs. A large superstamp measuring approximately $300x150$ pixels ($\approx 20x \approx 10$ arcminutes), Figure 1, was obtained in long cadence mode. These superstamps are similar to those obtained for the open clusters NGC 6791 and NGC 6819 in the original Kepler mission.

2 Photometry

Studying star clusters with Kepler/K2 is a challenge due to the crowded nature of the clusters, especially their centers, and the large pixel size scale (3.98 arc seconds on a side) of the telescope. This results in a large number of the stars in M4 being at least partially blended with the degree of blending increasing toward the cluster center. M4 is one of the two nearest globular clusters and thus will appear more spread out on the sky, making it the best chance for us to study the stars in a globular cluster with K2. In order to obtain photometry for these blended stars, we performed image subtraction using Wojtek Pych's DIAPL2 package[1]; DIAPL2 is an improved version of the DIAPL package [1].

Despite the best efforts to minimize the drift of the telescope, K2 still suffers from a slow drift that necessitates thruster firing to repoint the telescope approximately every six hours. This drift and repointing presents complications for photometry with K2 compared to the original Kepler mission. The differing pixel sensitivies result in an additional signal as the stars drift across the pixels. Figure 2 shows some of the systematic effects seen in the lightcurves of stars in M4 including a general increase in the differential flux across the entire campagn (left panel) which is due to a change in the sky brightness. The effects of the drift and repointing every 6 hours can be seen in the right panel.

The large pulsational amplitudes of RR Lyrae stars meant that these systematic effects had little impact on our ability to identify the main pulsation frequencies in these stars though they likely reduced our ability to find all low amplitude frequencies. We attempted to remove the systematics from the lightcurves using a Principle Component Analysis (PCA) code that we adapted from one originally written by Tom Barclay and Daniel Huber for performing photometry on K2 postage stamps. This produced mixed results but did not lead to the reliable detection of any additional frequencies.

3 RR Lyrae Variables

3.1 RRab Stars

Nine RRab stars in M4 fell on silicon during the K2 observations. We detected the Blazhko effect in three of those

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[1] http://users.camk.edu.pl/pych/DIAPL/

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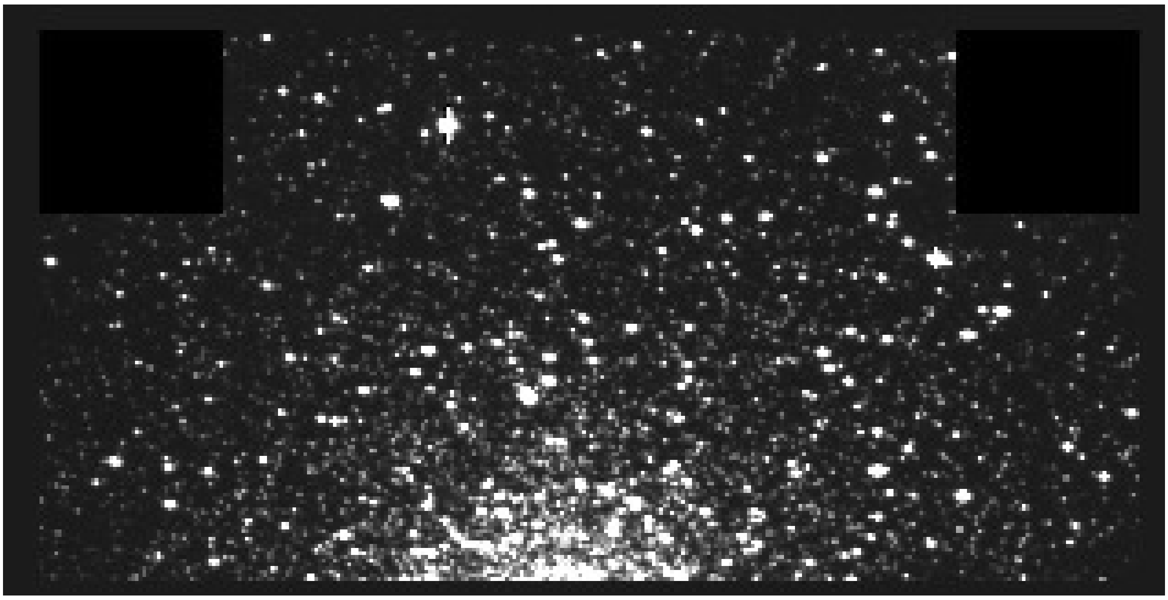

Figure 1: Superstamp of M4 observed by K2.

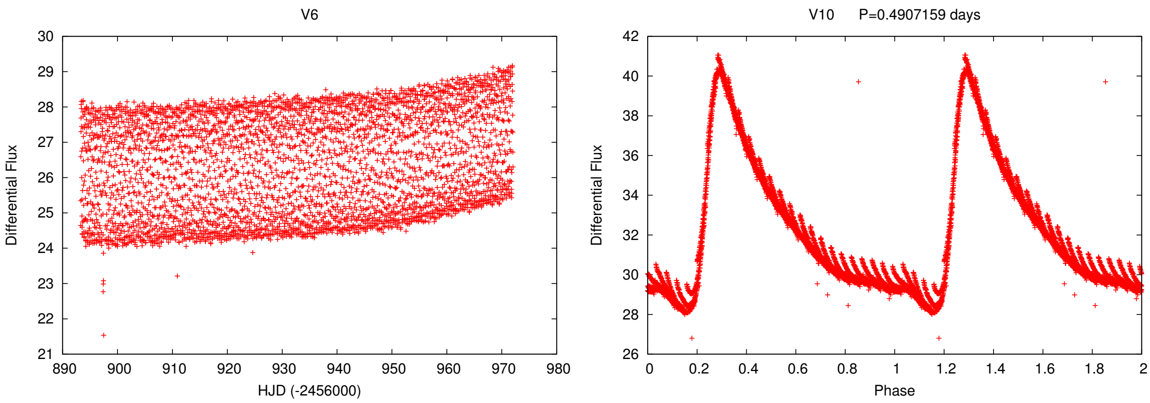

Figure 2: (Left panel) Lightcurve of the RRc star V6. A general increase in the differential flux can be seen over the course of the observing period. (Right panel) Phase-folded lightcurve of RRab star V10; the effects of K2's drifting and repointing every 6 hours is clearly visible. Similar systematics are seen in all of the M4 lightcurves.

stars (V19, V29, V35). V29 and V35 had previously been identified as candidate Blazhko stars [2] while V19 had not previously been considered a Blazhko star. Figure 3 shows the amplitude spectra for the three Blazhko RR Lyrae stars; the measured fluxed were converted to magnitudes prior to the frequency analysis being performed. The fundamental radial mode and its harmonics have been subtracted making the characteristic Blazhko sidepeaks visible. We found Blazhko periods of 16.554 days for V19, 22.419 days for V29, and 44.514 days for V35; this is the first time that Blazhko periods have been determined for these stars.

3.2 RRc Stars

Two RRc stars fell on silicon and both showed additional modes. Figure 4 shows the amplitude spectrum for V42; the first radial overtone and its harmonics have been removed, their locations are marked by dotted lines. The thruster firing frequency at 4.08 cycles per days and its harmonics (8.16 d^{-1}, 12.24 d^{-1}) can be easily seen in amplitude spectrum. We detected three secondary oscillation frequencies with frequencies of $f_{2a} = 5.218d^{-1}$, $f_{2b} = 5.298d^{-1}$, and $f_{2c} = 5.373d^{-1}$; this triplet of peaks corresponds to nonradial modes (see however [3]). The period ratios between these modes and the first radial overtone are 0.631, 0.622, and 0.613, and fall perfectly well on the three sequences in the Petersen diagram established by [4]. Nonradial modes with similar period ratios have been found in many RRc stars but excitation of all three modes in a single star is rare. The three peaks around $8.6d^{-1}$ are combination peaks of the first radial overtone and the triplet of nonradial modes. We also see subharmonics of the nonradial modes (two peaks at around $8.0d^{-1}$ and two weak peaks at around $2.6d^{-1}$) and a combination peak involving one of the subharmonics ($11.345d^{-1}$). Table 1 shows the detected frequencies for

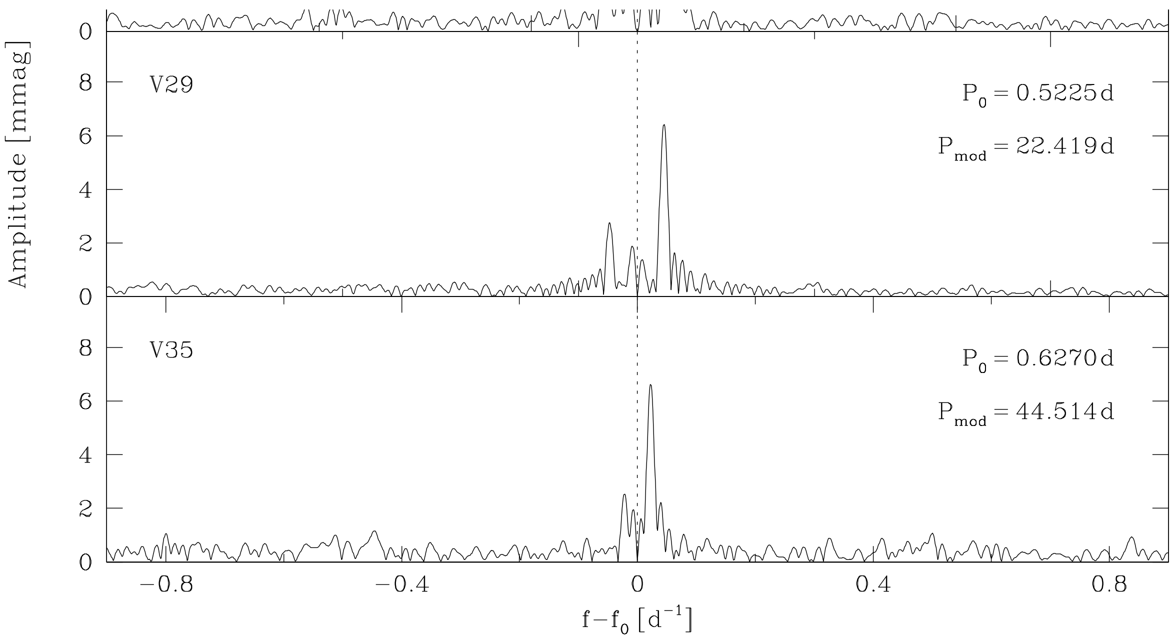

Figure 3: Amplitude spectra for the three RRab stars in M4 observed by K2 that show the Blazhko effect. The fundamental radial mode has been removed and its location is marked with a dotted line. The characteristic Blazhko sidepeaks are visible.

Table 1

V42 f (d^{-1})	Identification	V6 f (d^{-1})	Identification
3.293	f_1	3.120	f_1
5.218	f_{2a}	2.474	f_2
5.298	f_{2b}	4.952	$2f_2$
5.373	f_{2c}	7.415	$3f_2$
8.511	$f_{2a}+f_1$	8.072	$2f_2+f_1$
8.590	$f_{2b}+f_1$	8.714	f_2+2f_1
8.665	$f_{2c}+f_1$	10.535	$3f_2+f_1$
11.803	$f_{2a}+2f_1$		
11.958	$f_{2c}+2f_1$		
2.600	$\approx 0.5f_{2a}$		
2.687	$\approx 0.5f_{2c}$		
7.980	$\approx 1.5f_{2b}$		
8.052	$\approx 1.5f_{2c}$		
11.345	$\approx 1.5f_{2c}+f_1$		

V42 and identifies the combination frequencies.

Figure 5 shows the amplitude spectrum for V6; the first radial overtone and its harmonics have been subtracted and their locations are marked by dotted lines. As was the case with V42 the thruster firing frequency and its harmonics are clearly seen in the amplitude spectrum. A second frequency at 2.47 d^{-1} and its harmonics are clearly detected. The period ratio of $P_1/P_2 = 0.7928$ is tricky to explain. This ratio would suggest that P_1 and P_2 correspond to the second and first radial overtones, respectively. This scenario is contradicted by the shape of the lightcurve of the dominant mode (P_1) which is very typical for first overtone pulsators. Thus, P_2 must be interpreted as corresponding to a nonradial mode. Alternateively, variability with period P_2 could be contamination from another star but the presence of combination peaks with the dominant mode at frequencies $f_1 + 2f_2$, $f_1 + 3f_2$, and $2f_1 + f_2$ makes this explanation less likely. Table 1 shows the detected frequencies for V42 and identifies the combination frequencies.

References

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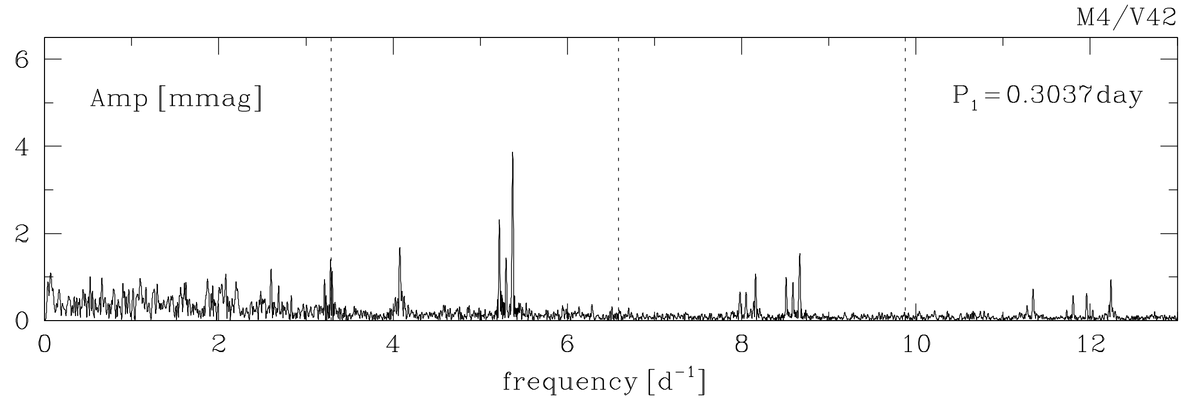

Figure 4: Amplitude spectra for the RRc star V42. The first radial overtone and its harmonics have been removed but their locations are marked with dotted lines. The thruster firing frequency (4.08d^{-1}) and its harmonics (8.16d^{-1}, 12.24d^{-1}) are visible. The triplet of peaks around 5.3d^{-1} correspond to nonradial modes. Combination peaks, subharmonics of the nonradial modes, and a combination peak involving one of the subharmonics are also seen.

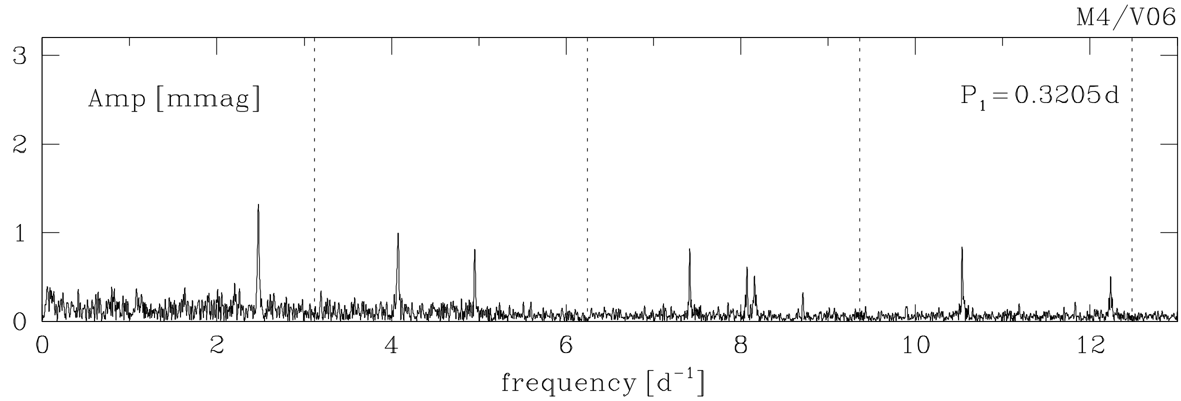

Figure 5: Amplitude spectra for the RRc star V6. The location of the first radial overtone and its harmonics are marked with dotted lines. As was the case in Figure 4 the thruster firing frequency and its harmonics are visible. A secondary frequency at 2.47d^{-1} and its harmonics (4.95d^{-1}, 7.42d^{-1}) are detected as are several combination peaks of the dominant and secondary mode.