RR Lyrae Stars in M4

Charles A Kuehn III[1], Pawel Moskalik[2], Jason Drury[3,4]

1 – University of Northern Colorado, 2 – Copernicus Astronomical Center, 3 - Sydney Institute for Astronomy, University of Sydney, 4 – Stellar Astrophysics Centre

Abstract: Observations by Kepler/K2 have revolutionized the study of RR Lyrae stars by allowing the detection of new phenomena, 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, providing 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.

Superstamps

M4 was observed during K2's Campaign 2. Only a portion of the cluster fell on silicon, with most of it falling in a gap between the CCDs. In order to study M4, a large superstamp measuring approximately 300x150 pixels (~20 x ~10 arcminutes, see Figure 1) was obtained in long cadence mode. These superstamps are similar to those obtained for NGC 6791 and NGC 6819 in the original Kepler mission.

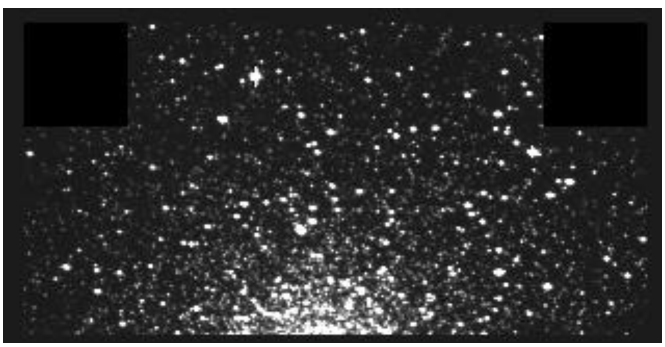


Fig. 1. Superstamp of M4

Image Subtraction

The crowded nature of the cluster center and the large pixel scale (3.98 arc seconds per pixel) result in a large number of the stars in M4 being at least partially blended, with the degree of blending increasing toward the cluster center. In order to obtain photometry for these blended stars, we performed image subtraction using Wojtek Pych's DIAPL2 package (http://users.camk.edu.pl/pych/DIAPL/), which is an improved version of the DIAPL package (Woźniak 2000, AcA, 50, 421).

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 6 hours. This drift and repointing presents complications for photometry with K2 compared to the original Kepler mission. The differing sensitivities between K2 pixels results in an additional signal as the stars drift across the pixels. Figure 2 shows some of the systematic effects in the lightcurves including a general change across the entire campaign (left panel) and the effects of the drift and repointing every 6 hours (right panel). These effects did not impact our ability to recover the main pulsation frequencies from the RR Lyrae stars though they likely reduced the ability to find all low amplitude frequencies. Attempts were made to remove these systematic effects 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 and did not lead to the reliable detection of any additional frequencies.

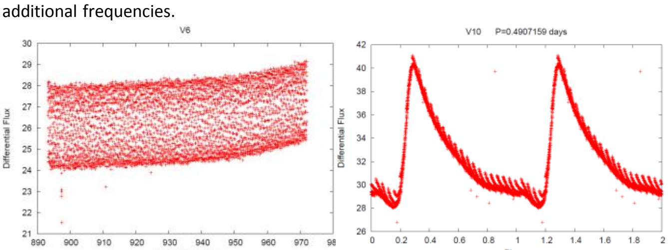


Fig. 2 (Left panel) Light curve of V6, an RRc star. A general increase in the differential flux can be seen over the course of the campaign. (Right panel) Phase-folded lightcurve of RRab star V10; the effects of K2's drifting and repointing every 6 hours are clearly visible. Similar systematics are seen in all of the lightcurves.

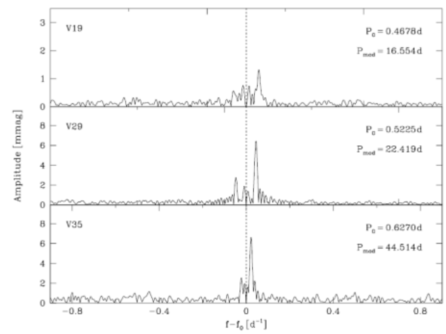
RR Lyrae Variables

While there were many RR Lyrae stars in the original Kepler field, M4 represents the first chance to use Kepler to study a group of RR Lyrae stars belonging to a single population. Combining the M4 RR Lyrae stars with those in the globular cluster M80, also observed by K2 during Campaign 2, has the potential to provide insight into the Oosterhoff phenomenon (Catelan 2009, IAU Symp. 258, 209). Eleven of the RR Lyrae stars in M4 fall on silicon and all were clearly detected in our photometry.

RRab Stars

9 RRab stars in M4 fall on silicon. Three of those stars (V19, V29, V35) show the Blazhko effect. V29 and V35 had previously been identified as candidate Blazhko stars by Stetson et al. 2014 (PASP, 126, 521) while V19 had not been previously thought of as a Blazhko star; Stetson did not calculate Blazhko periods for any of these stars. Figure 3 shows the amplitude spectra for the three Blazhko RR Lyrae stars; the fundamental radial mode and its harmonics have been subtracted making the characteristic Blazhko sidepeaks visible.

Fig. 3 Amplitude spectra for the 3 RRab stars that show the Blazhko effect. The fundamental radial mode and its harmonics have been subtracted; the location of the subtracted mode is indicated by the dotted line. The characteristic Blazhko sidepeaks are visible.



RRc Stars

Two RRc stars fell on silicon and both showed additional modes. Figure 4 shows the amplitude spectrum for V42 while Figure 5 shows the same thing for V6. In V42 we detected three secondary oscillations with, now very familiar, period ratios of 0.61-0.63 to the first overtone. The amplitude spectrum of V6 is different and somewhat puzzling.

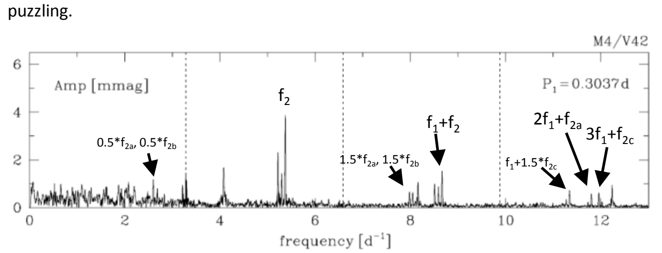


Fig. 4 Amplitude spectrum for RRc star V42. The first overtone radial mode and its harmonics have been removed, their locations are marked by the dotted lines. The thruster firing frequency at 4.08 c/d and its harmonics (8.16 c/d, 12.24 c/d) are very strong. A triplet of peaks is visible at f_{2a}=5.218 c/d, f_{2b}=5.298 c/d, and f_{2c}=5.373 c/d and corresponds to nonradial modes (see however Dziembowski 2016, Comm, Konkoly Obs., 105, 23). 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 Netzel et at. 2015 (MNRAS, 453, 2022). 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 first peaks at around 8.6 c/d 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 8.0 c/d and two peaks at around 2.6 c/d) and a combination peak involving one of the subharmonics (at 11.345 c/d).

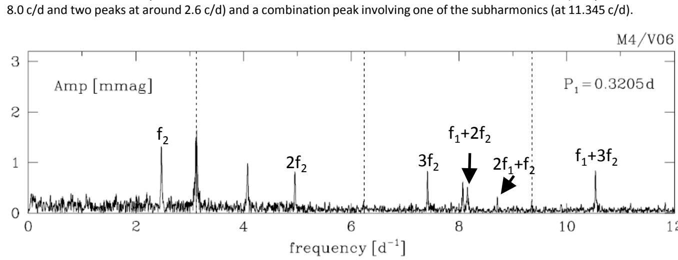


Fig. 5 Amplitude spectrum for RRc star V6. The location of the first radial overtone and its harmonics are marked with dotted lines. A second frequency is found at f_2=2.47 c/d, its harmonics (4.95 c/d, 7.42 c/d) are also clearly detected. The period ratio of P_1/P_2=0.7928 is tricky to explain. This ratio would suggest that P_1 and P_2 correspond to the second and the 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 the first overtone pulsators. Thus, P_2 must be interpreted as corresponding to a nonradial mode. Alternatively, variability with period P_2 could be a 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.