

**First year report
NKFIH K-115709**

**Investigation of dynamical phenomena in pulsating variable stars with
space telescopes**

K2 and TESS target selection and data reduction. During the reporting period our group submitted four K2 proposals on Cepheids and RR Lyrae stars. The selection of RR Lyrae and Cepheid targets for Campaigns 14,15,16 is also in progress. The already observed and adopted K2 targets amount to over 2000 RR Lyrae stars and dozens of Cepheids that will form the base of an unprecedented sample of classical variable stars with extreme-precision space photometry. We prepared the light curves of 522 RR Lyrae stars of C0-C6 campaign fields. The data will be published in a data release paper. A thorough statistical analysis of the light curves (such as nonradial mode frequencies, period doubling, modulation) is in progress. The NASA Senior Review extended the K2 Mission for not just the usual two years, but until onboard fuel lasts, probably till Campaign 17 (mid-2018). The PI presented the K2 RR Lyrae survey in Santa Barbara, CA, USA at the K2 Science Conference in November, 2015. He was selected to be a member of the K2 Users' Panel, which was set up to provide support, insight, and perspectives on K2 mission policies, progress, and products in order to facilitate community exploitation of K2 data. The selection of NASA's TESS Mission short cadence targets is also in progress. The targetlist is due in December, 2016. E. Plachy became the subgroup leader for target selection for classical pulsators in the TESS Asteroseismic Science Consortium.

RR Lyrae stars. We presented the first observations of extragalactic pulsating stars in the K2 ecliptic survey. Variability of all three known RR Lyrae stars in the dwarf spheroidal galaxy Leo IV were successfully detected, at a brightness of $K_p \sim 21.5$ mag, from data collected during Campaign 1. We identified one modulated star and another likely Blazhko candidate with periods of 30 days and more than 80 days, respectively. EPIC 210282473 represents the first star beyond the Magellanic Clouds for which the Blazhko period and cycle-to-cycle variations in the modulation were unambiguously measured. The photometric [Fe/H] indices of the stars agree with earlier results that Leo IV is a very metal-poor galaxy. The image subtraction method we used will be useful for future space photometric missions to reliably extract photometry from faint confused sources (Molnár et al. 2015).

In the framework of the SERMON project we investigated 1234 fundamental mode RR Lyrae stars observed by the All Sky Automated Survey (ASAS) to identify the Blazhko effect. A large control sample was collected from the literature to compare the modulation-period distribution with stars newly identified in our sample. Altogether we identified 87 Blazhko stars (48 new detections), 7 candidate stars, and 22 stars showing long-term period variations. The distribution of modulation periods of the newly identified Blazhko stars corresponds well to the distribution of modulation periods of stars located in the Galactic field, Galactic bulge, Large Magellanic Cloud, and globular cluster M5. The pulsation periods of the Blazhko stars follow a Gaussian distribution with a mean period of 0.54 days, while 99.7% of all known modulated stars have modulation periods between 7.6 and 478 days. The next step will be to compare these results with K2 Blazhko sample (Skarka et al. 2016).

Based on space photometric observation we posited that overtone (RRc) and modulated fundamental (RRab) RR Lyrae stars ubiquitously show additional modes, while non-Blazhko RRab stars never do. Two Kepler stars seemed to be exceptions: these were classified as non-Blazhko RRab stars showing additional modes. We reprocessed Kepler pixel photometric data of these stars and detected a small amplitude (but significant) Blazhko effect for both stars by using the resulting light curves and O–C diagrams. This finding strengthens the apparent connection between the Blazhko effect and the excitation of additional modes. In addition, it yields a potential tool for detecting Blazhko stars through the additional frequency patterns (Benkő & Szabó, 2015).

The RR Lyrae census observed by the CoRoT satellite has not been complete for years. To remedy this situation, we thoroughly checked the CoRoT public database and found nine unstudied RR Lyrae stars, seven of which are new discoveries. We identified three new Blazhko stars. The Blazhko effect shows non-strictly repetitive nature for all stars. One of the stars contains second overtone frequency with the highest known period ratio. CM Ori displays significant random period fluctuations. The sample can be divided into two subgroups with respect to the metallicity but otherwise the physical parameters are in the canonical range of RR Lyrae stars (Benkő et al. 2016).

Cepheids. We revisited the 4-year-long continuous Kepler observations of the bright Cepheid-type variable star V1154 Cygni, the only one in the original Kepler field. We identified modulation of the main pulsation frequency and its harmonics with a period of ~ 159 d. We detected another modulation with a period of about 1160 d. The star shows significant power in the low-frequency region that we identified as granulation noise. The effective timescale of the granulation agrees with the extrapolated scaling from red giant stars. Non-detection of solar-like oscillations indicates that the pulsation inhibits other oscillations. We obtained new radial velocity observations which suggest that V1154 Cygni has no high mass star companion (Derekas et al. 2016).

In a series of ongoing investigations, we are investigating the physical properties of Type II Cepheids and Anomalous Cepheids in the LMC and SMC, and we studied the question of the binarity of RV Tauris subtype of Type II Cepheids using the OGLE-III sample. So far we do not see evidence of more than usual percentage of binaries among them. Based on ground-based and our K2 survey data we started to investigate the Galactic population membership of the Type II Cepheids (Jurkovic, 2016).

Synergies with galactic archeology missions. As both our K2 survey and the ongoing and upcoming large sky-survey programs, such as Gaia (space-borne astrometric), SDSS-IV and LSST (ground-based photometric) have strong classical pulsators components, we built professional connections toward these endeavors. Members of this project are part of the Gaia team, investigate classical pulsators, and are on the author list of two Gaia instrumental papers. The PI gave a talk on the synergies between K2 and LSST at the 2nd LSST in Europe conference in Belgrade in June, 2016, and he was awarded the SDSS-IV external collaborator status to work on RR Lyrae stars and galactic archeology.

Hybrid main-sequence pulsators. We used the time-delay method to identify binarity in hybrid gamma Dor (g-mode) – delta Sct (p-mode) pulsators. We found signs of binarity in nine stars from the total sample of 50 candidates by using this method. Currently we work on more than 1700 hybrid candidates in the Kepler sample trying to find signs of binarity in the Kepler data. In addition, an extensive spectroscopic campaign is being conducted by the team in the Piszkés-tető Observatory to investigate the rotational properties of the hybrid candidates. The photometric properties (light curve analysis, frequency and period spacings) are being investigated in order to better understand the nature of these intriguing objects and establish their true occurrence rate in the Galaxy.

Binaries. We are in the process of obtaining high resolution spectra of a few eclipsing binary systems with pulsating components we have been monitoring during this project. We are working on a method to disentangle the spectra of a hybrid variable of which we detected a component with the frequency-modulation (FM) method. The results are promising, but we need more spectra to get definite result. We participated in the publication of the seventh catalog of the Kepler eclipsing binary catalog (Kirk et al. 2016), and contributed to the discovery of a unique quintuple star system containing two eclipsing binaries (Rappaport et al. 2016).

Publications and conferences. During the reporting period we have published 19 papers with impact factor (IF), 2 papers without IF, and 7 papers in conference proceedings. The sum of the impact factor of the papers is over 100. We have submitted three IF papers related to the topic of the project, and several are close to submission. Members of our team gave 9 conference talks, and 9 poster presentations at various relevant conferences. E. Plachy gave an invited review talk at the 2nd BRITE Science Conference, in Innsbruck, in August, 2016 (Cepheid investigations in the era of space photometric missions). We organized an international conference (RRL2015 conference, *High-precision studies of RR Lyrae stars, from dynamical phenomena to mapping the galactic structure*) in Visegrád, 19-22 October 2015, with 60 registered participants. The conference was a pioneering undertaking, but it was so successful that it became the starting point of a conference series, and more conferences on the same topic will follow biannually (in Poland, USA, etc.)

Other. The following grants were awarded during the reporting period: NKFIH Postdoctoral Excellence Program (E. Plachy), Postdoctoral National Excellence Program (E. Plachy, rejected), MTA Junior International Conference Grant (E. Plachy, A. Derekas), Eötvös Fellowship of the Hungarian State (A. Derekas). One PhD degree was awarded (E. Plachy October, 2015) and the PI has submitted his DSc thesis (February, 2016) with a topic closely related to this project.