Second year report
NKFIH K-115709
Investigation of dynamical phenomena in pulsating variable stars with space telescopes

K2 target selection and data reduction. During the reporting period, our group submitted additional K2 proposals on Cepheids (CEP) and RR Lyrae stars (RRL). The selection of RRL and CEP targets for the last K2 Campaigns (C16-C17-C18) is in progress. The already observed and adopted K2 targets amount to over 3000 RRL stars and dozens of CEPs that will form the base of an unprecedented sample of classical variable stars with extreme-precision space photometry. The first data release paper is close to submission on K2 C0-C6 RRL stars, where we present our photometric solutions using extended apertures in order to conserve the flux of the stars to the highest possible extent. With this method, we are able avoid most of the problems that RRL light curves produced by other pipelines suffer from.

TESS target selection. All of the targets from NASA's TESS Mission (scheduled to launch in March 2018) will be available on the Full Frame Images taken with a cadence of 30 minutes. However, short cadence (2-minute) observations will also be available for a limited sample of stars. Members of our group lead the target selection for classical pulsators in the TESS Asteroseismic Science Consortium. A preliminary short-cadence target list has been compiled and submitted. Refinement and amendment of this list is currently underway.

RR Lyrae stars. We discovered a new form of double-periodic pulsation in RRL stars. In four long-period (P > 0.6 d) RRab stars observed by OGLE, we detected additional, low-amplitude variability. The period ratios fall in a range of ordinary double-mode RRL stars, with the exception of one object. The observed period ratios can be well modelled with high-metallicity pulsation models. Five other candidates share the same characteristics (Smolec et al. 2016). Another group of RRab stars with additional periodicities was also discovered in the OGLE Galactic bulge photometry. Here the period ratios are much lower than the canonical RRd period ratio. The amplitudes of the extra periodicities are also lower than for regular RRd stars. Some of these stars show the sign of Blazhko-modulation. It is not clear whether radial or non-radial pulsational modes can be invoked to explain these oddballs (Prudil et al. 2017).

We studied the incidence rate of the Blazhko effect in RRab stars in the Galactic bulge. The number of Blazhko stars we identified is 3341, which is the largest sample ever studied. We found that at least 40% of the stars show modulation. Many stars show unresolved peaks close to the main pulsational component. Fifty percent of them were identified as Blazhko stars with extremely long periods. No correlation was found between the occurrence of the Blazhko-modulation and photometric metallicities, intrinsic colors and absolute magnitudes (Prudil & Skarka, 2017).

We explored a new mathematical formalism to describe Blazhko light curves. Almost periodic functions describe well light curves that are modulated and predict an observable shift of the Fourier harmonics of the main pulsation frequency from the exact harmonic position. This phenomenon was observed in two Kepler Blazhko RRab stars. The effect is detectable only if the phase variation part of the Blazhko effect is of large amplitude and non-periodic enough,

additionally, the time span of the observed light curve is sufficiently long. These conditions explain why this effect has not been discovered up to now (Benkő, 2017).

Cepheids. We investigated two CEPs with the MOST space telescope. V473 Lyrae is a second-overtone, strongly modulated Cepheid, in which we discovered period doubling, being the first case in any classical CEPs. Ground-based photometry and spectroscopy were obtained to follow two modulation cycles. The simultaneous data yielded the phase lag parameter (the phase difference between maxima in luminosity and radial velocity, a good pulsation mode diagnostics) of a second-overtone CEP for the first time. Period doubling provides a strong argument that mode interactions do occur in some Cepheids and we may hypothesize that it could explain the amplitude modulation, as recently proposed for Blazhko RRL stars. We found no evidence for a period change in the double-mode U TrA or an energy exchange between the fundamental mode and the first overtone during the last 50 years, contrary to earlier indications (Molnár et al. 2017).

We studied a large sample of Type II and anomalous Cepheids in the Small and Large Magellanic Clouds detected in OGLE-III data. The spectral energy distributions were constructed from photometric data available in the literature and fitted with a dust radiative transfer model, leading to a determination of luminosity and effective temperature. Building on these results, we studied the period-luminosity (PL) and period-radius relations of these sources. We derived the period-luminosity-mass-temperature-metallicity relations and estimated the pulsation mass. These relations are useful to measure cosmic distances, and are complementary to the best studied classical CEP and RRL PL relations. We also investigated the evolutionary status of these often-neglected objects. In addition, a subsample of targets was investigated for possible binarity by looking for the light-time travel effect. This study revealed 20 systems that may be new binaries (Groenewegen & Jurković 2017a,b).

We presented the first analysis of W Vir stars observed by the K2 mission. Cycle-to-cycle variations were detected in the light curves of KT Sco and the globular cluster member M80-V1. While the variations in the former star seemed to be irregular on the short time-scale of the K2 data, the latter appears to experience period doubling in its pulsation. Ground-based color data confirmed that both stars are W Vir-type pulsators, while historical photometric time series data revealed drastic period changes in both stars. These results support the notion that non-linear dynamics plays an important role in the pulsation of W Virginis-type stars (Plachy et al. 2017).

We analyzed the light variations of DF Cygni, the only RV Tauri-type star in the original Kepler field. The four years of high-quality Kepler photometry was complemented with almost half a century of visual data from the AAVSO database. DF Cygni shows a rich behavior on all timescales. There is a remarkably coherent slow variation, whereas the 49.85-d period pulsation shows alternating minima, characteristic of the RV Tau class. Both types of light variation fluctuate in time, with a constantly changing interplay of amplitude and phase modulations. By comparing the pulsation patterns with the latest models of Type-II Cepheids, we found evidence of strong non-linear effects (Bódi et al. 2016).

A CEP candidate (KIC 2569073) located on one of the Kepler 200x200 pixel superstamps was investigated in detail. It turned out to be a particularly interesting variable Ap star, with one of the largest peak-to-peak variations of any known representative of its class. Color photometry revealed an antiphase correlation between the B band, and the V, R and I bands. This Ap star is a rotational variable (α^2 CVn type), and is one of only a handful of Ap stars observed by Kepler. While no change in spot period or amplitude is observed within the 4-year Kepler time series, the amplitude shows a large increase compared to ground-based photometry obtained two decades ago (Drury et al. 2017).

Hybrid main-sequence pulsators. We continued to analyze hybrid gamma Dor (g-mode) – delta Sct (p-mode) pulsators found in the Kepler data in order to detect binarity. Based on the time-delay method and spectroscopic observations (some of them taken at the Piszkés-tető Observatory), a significant fraction (27%) was found to be in binary systems.

Binaries. We continued the investigation of RRL stars in binary systems. We discovered a new RRc binary candidate in the original Kepler field. The systematic phase variations of KIC 2831097 can be interpreted as light travel time effect caused by orbital motion in a binary system with a possible black hole companion. The assumed eccentric orbit with the period of 2 years is the shortest among the non-eclipsing RRL binary candidates (Sódor et al. 2017).

Publications and conferences. During the reporting period, we have published 17 papers with impact factor (IF), 2 papers without IF, and 8 papers in conference proceedings. Several papers have been submitted for peer review. The sum of the impact factor of the papers is over 80 (180 since the start of the project). Members of our team participated at 6 major international conferences, where they gave 5 talks and 11 poster presentations. E. Plachy gave an invited review talk at the TASC3/KASC10 Conference in Birmingham ("*Cepheid and RR Lyrae studies with TESS: what could 27 days give us"*). The PI served as a SOC member of two conferences: (1) RRL2017 conference, *Revival of the Classical Pulsators: from Galactic Structure to Stellar Interior Diagnostics*, to be held in Niepolomice, Poland, 19-22 September 2017, (2) *TESSting Stellar Astrophysics* TASC3/KASC10 Conference, Birmingham, UK, 16-21 July 2017. Konkoly Observatory is part of the LSST Consortium. The PI participated in the LSST Community and Project workshop in Tucson, Arizona for the first time, representing Hungarian astronomy, as a whole.

Other. The following grants were awarded during the reporting period: NKFIH Postdoctoral Excellence Program (Zs. Bognár), MTA Junior International Conference Grant (E. Plachy, A. Bódi), Bolyai Fellowship (A. Derekas), National Excellence Fellowship (Á. Juhász), Campus Mundi (A. Bódi). R. Szabó defended his DSc thesis (June, 2017) with a topic strongly aligned with this project. We purchased a high-performance server for archival purposes and to speed-up the process of analysis of K2 space photometric data.