The After SDSS-IV, Letter of Intent: Andrew Tkachenko on behalf of the KU Leuven Gaia/K2/TESS/PLATO2.0 team
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High precision stellar astrophysics: an avant-guard look at the asteroseismology of binary systems

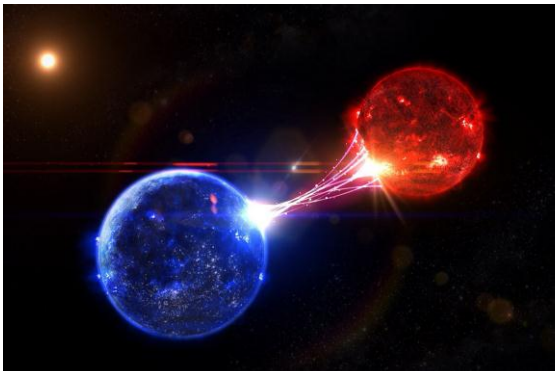

Fig. 1 An artist image of an interacting binary star system (taken from www.cozydark.com).

State of the art. Asteroseismology is a powerful tool in modern astrophysics that allows us to “look” inside the stars and to study their interiors in great detail. Thanks to the fact that pulsating stars are found everywhere in the Hertzsprung-Russell (HR) diagram, asteroseismic studies become possible for stars over a large range in mass and ages. Despite the huge success of asteroseismology (largely driven by the launch of space missions such as MOST, CoRoT, and *Kepler*) in the past decade, it still remains a model-dependent research field, in which the model dependency is significantly larger for intermediate- and high-mass stars than for sun-like stars. Photometric data sets delivered by the space missions are often complemented by high quality ground-based spectroscopic data to study different types of stars, including those in binary systems. Nowadays, we talk about model-independent measurements of fundamental properties of stars obtained from binary dynamics reaching a precision of about 1% in a wide range of stellar mass and ages (e.g., Gillen et al. 2014; Tkachenko et al. 2014). The vast majority of the discovered binary systems are found to contain pulsating stellar components. By studying different types of pulsating stars in binary systems, we have the unique opportunity of supplying the asteroseismic investigations with additional observational constraints, in terms of the dynamical masses and radii of stars.

Objectives. Scaling relations in asteroseismology are the relations between stellar fundamental and pulsation properties of stars exhibiting solar-like oscillations (Kjeldsen & Bedding 1995). Some uncertainties are associated with the use of these relations, such as using the Sun as the reference star for the objects that differ from the Sun in their fundamental properties and model dependence of the relations. Miglio et al. (2013) pointed out that masses obtained from the scaling relations are on average accurate to about 10%, which results in about 30% uncertainty on stellar age. Chaplin et al. (2014) come to a similar conclusion, emphasizing that these uncertainties are due to the combined effects of models and adopted analysis methodology. The most obvious and precise way of testing and tuning the scaling relations is to study solar-type stars and solar-like pulsating red giants in binary systems, where the fundamental, model-independent properties of stars inferred from binary dynamics can be confronted to the values obtained by means of asteroseismic analysis. Thanks to the fact that different types of pulsating stars are often found in binary systems, similar methodology will be used to establish empirical relations for other types of pulsating stars in large ranges of stellar mass and ages. Thus, the current LoI calls on combining the two complementary fields in stellar astrophysics, asteroseismology and binary stars, with the ultimate goal to push the current limit of precision for the determination of fundamental parameters of stars up to the level of a few percent or better.

The net result is two-fold: 1) an improved understanding of the evolution and internal structure of intermediate- to high-mass stars (the mass range between 1.5 and some 15 solar masses); 2) an efficient tool for the determination of precise, model-independent fundamental characteristics of single stars directly from their observed asteroseismic properties. The latter is particular important in the view of the upcoming exoplanet search space missions such as TESS and PLATO2.0, which very much rely on precise fundamental parameters of host stars to measure the properties of exoplanets with high precision.

Star samples and observations. The goals will be achieved by providing homogeneous analyses of statistically significant samples of pulsating stars in binary systems residing at different places in the HR-diagram and covering a large range in stellar mass and ages. Binarity (or multiplicity) has been discovered from the *Kepler* photometric data for about 40 evolved red-giant stars having pulsation properties similar to those of the Sun. These stars are found in the samples compiled by Gaulme et al. (2013) and by Beck et al. (2014), and represent a good starting point for the proposed project. The sample will be increased by searching for solar-type stars and evolved solar-like pulsators in binary systems in the catalogs of different space missions, including those of TESS and PLATO2.0. Similarly, the samples of stars exhibiting γ Dor, δ Sct, SPB, and β Ceph-type pulsations will be compiled from the objects available in the literature as well as from those that will be detected within the proposed project. In total, about 150-200 (or more) binary systems will be characterized from combined spectroscopic and photometric data. Fig. 2 illustrates the individual star samples in the effective temperature-surface gravity diagram with an indication of the stellar mass ranges covered by different space-based missions (shaded areas).

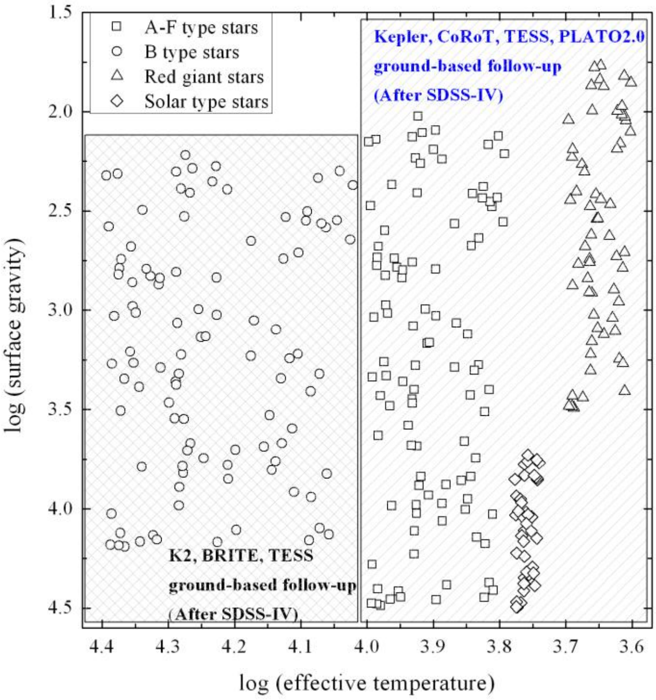

Fig. 2 Star samples on the log(Teff)-log(g) diagram. Symbols refer to different types of stars; the mass ranges (with more massive stars at the hotter age) covered by different space-based missions are indicated by the shaded regions.

The project will rely on space-based photometric data that are readily available (CoRoT, *Kepler*, BRITE, and K2 missions) and the ones that will be delivered by TESS and PLATO2.0. The high-precision space-based photometry needs to be complemented with medium- to high-resolution spectroscopic material obtained with ground-based facilities. The After SDSS-IV activity, with its specific focus on time-domain astronomy, is an ideal tool for collecting spectroscopic observational material required for the success of the proposed project. Since the project focuses on the brightest binary stars, the desired signal-to-noise ratio (S/N) of ~100 per pixel can be obtained with 2m class telescopes. A certain instrument set-up is essential for the success of the proposed research: 1) medium- to high-resolution (30 000 and above) instrument is needed to resolve in detail spectral lines of our targets, in particular of slowly rotating solar-like pulsators and of the individual stellar components that are spinning synchronously with their intermediate-/long-period orbits. 2) The wavelength coverage should extend to the visible range (down to ~400 nm) where the majority of spectral lines of OBAF-type stars are found. Essentially, the ideal instrument set-up for the realization of our project is the wavelength range of current eBOSS/BOSS, but about twice the resolving power of APOGEE.

Methodology. To reach the main goal of establishing empirical (scaling) relations for pulsating stars, a homogeneous analysis of all the selected stars will be performed. A semi-automated methodology was recently developed by us for the analysis of pulsating stars in binary systems, which includes three basic analysis steps. The three steps are: 1) *classification of stars* (Fourier decomposition-based method which relies on comparison of the seismic properties of the target stars with the ones of the prototype stars, taking into account the effects of binarity), 2) *photometric analysis* (modelling the binarity signal with the aim to extract precise fundamental parameters of stars; the extraction of individual pulsation modes to further establish the empirical relations), 3) *spectroscopic analysis* (spectral disentangling and interpretation of the obtained spectra to infer atmospheric parameters and chemical compositions of stars). As soon as all data are collected and individual stars are analysed as described above, a *statistical analysis* will be performed to establish empirical relations between fundamental and seismic properties of stars using multivariate analysis methods.

Impact of the proposed research. The novelty of this project is situated in the fact that it will 1) deliver a tool for the determination of model-independent fundamental parameters of stars directly from their pulsation properties, and 2) provide a valuable input for testing and improving the current theories of stellar structure and evolution, in terms of precise, model-independent fundamental properties of stars in a wide range of stellar mass and ages. This will become possible thanks to the empirical (scaling) relations between fundamental and seismic properties of stars that will be established within the proposed project. All the data will be homogeneously reduced and analyzed, which will yield unbiased observational information on stellar fundamental and pulsation properties of stars, such as masses, radii, ages, spectral characteristics, frequencies and amplitudes of individual pulsation modes, etc. Due to similar dynamics with binary stars and due to the fact that the characterization of exoplanets requires a good knowledge about host stars in terms of their fundamental parameters, the proposed project is extremely important in the view of the upcoming exoplanet search missions, like TESS and PLATO2.0. Besides that, the fundamental stellar parameters obtained by means of the empirical relations can be confronted to their model-dependent counterparts obtained by means of detailed asteroseismic analysis of selected stars. Such an exercise will provide a valuable input for revealing possible shortcomings in the current theories of stellar structure and evolution, which the seismic modelling heavily relies on.