In the project we plan to study the properties of classical variable stars: Cepheids and RR Lyrae stars. Cepheids are young, giant stars, typically few times as massive as the Sun. RR Lyraes are old and low mass stars. Brightness of these stars changes periodically due to pulsation. Both Cepheids and RR Lyrae stars are very important – they are so called standard candles, used in distance determination. Dynamics of their pulsation, a subject of this project, is very interesting on its own.

What are pulsations? Pulsations are periodic oscillations of gas in the form of standing waves. There are many analogies with musical instruments. Strings in string instruments, air in wind instruments or stretched membrane, e.g. in a drum, oscillate. These oscillations produce sound, frequency of which depends on the oscillation mode – the way string, air or membrane vibrates. Lets focus on a drum. If struck vertically, exactly at the center, only radially symmetric vibrations of the drumhead are possible. In stars, such oscillations are called radial. Of course stars are not forced to oscillate by any external force. Their oscillations are self-excited, the mechanism is similar to a heat engine. In the lowest frequency oscillation mode the whole drumhead moves periodically up and down; only the circular edge of the drumhead does not oscillate – it is a circular oscillation node. Other spherically symmetric vibrations are possible. In the first harmonic vibration mode, of higher frequency, there is one additional circular node located symmetrically in between drumhead edge and its center. Vibrating drumhead looks like sombrero periodically turned inside out and back. In stars these two vibration modes are called radial fundamental a radial first overtone modes. If drum is hit at an acute angle vibrations are no longer symmetric. Straight nodal lines may appear on a drumhead next to circular nodes. In stars such oscillation modes are called non-radial. Frequency of such vibrations depends on the mode geometry: on the location and type of the nodes. Multi-mode vibrations can also develop in a membrane – drum can produce a variety of sounds of different timbres. What else affects the frequency of sound that drum produces? Clearly the material of which the drumhead is made; other sound is produced by leather membrane, other by plastic one. New drum sounds differently than aged one. This is also what we observe in stars. Oscillation frequency of given mode depends on star's chemical composition (metallicity) and its age.

Till very recently, Cepheids and RR Lyrae stars were regarded as simple, single-periodic, radial pulsators. Majority of these stars were known tu pulsate either in radial fundamental mode or in radial first overtone. Less numerous was a group of double-mode pulsators, oscillating in the two radial modes simultaneously. This simple picture has changed recently, thanks to precise observations of space telescopes and massive and dedicated ground-based observations. Many new double-periodic stars were discovered pulsating in higher order overtones, and, most interestingly, in non-radial modes. In the latter stars the radial mode oscillation always dominates, non-radial oscillations are of much lower amplitude. Space observations indicate that this form of oscillations may be common, at least in RR Lyrae stars in which the dominant radial mode is first overtone. Stellar oscillation may deviate from strict periodicity. Quite often fast and irregular period changes are observed, faster than expected due to star ageing, the evolution. As in the case of non-radial modes, such changes are more frequent in first overtone pulsators. Stellar pulsations, both amplitude and period, may be periodically modulated. This is the Blazhko effect, observed nearly exclusively in RR Lyrae stars, more frequently in fundamental mode pulsators. All the above phenomena, excitation of non-radial modes, period changes or Blazhko effect, are not well understood. We do not know the geometry of non-radial modes and the mechanism behind their excitation. The cause of fast period changes is unclear. Blazhko modulation remains a puzzle for more than 100 years now. We do not understand why first overtone pulsators are less stable against excitation of non-radial modes and are prone to fast period changes.

To understand and explain the above phenomena we first have to study their observational properties, how they depend on chemical composition of stars, their age, evolution history and the dominant radial mode. More stars pulsating in additional non-radial modes must be discovered, as now their number does not allow reliable statistical analyses. We have to check whether this form of pulsation is indeed predominantly connected with dominant pulsation in first overtone. The outlined phenomenological study, coupled with interpretation work, are the main goals of the proposed project. The knowledge we have so far is fragmentary, based on analysis of non-homogeneous observations from diverse sources and for relatively small samples of stars. Our project will change this situation.

Our project will be based on analysis of brightness measurements (photometry) of classical pulsators gathered by the Optical Gravitational Lensing Experiment, OGLE. Data are available for more than hundred thousand classical pulsators in three different stellar systems: in the Galactic bulge and in the Large and Small Magellanic Clouds. These systems, and so their stars, differ in metallicity and evolution history – it is a perfect resource to study the dependencies outlined above. The top quality OGLE photometry guarantees that interesting effects will be detected, in particular we anticipate the discovery of hundreds of stars pulsating simultaneously in radial and in non-radial modes. Indeed, our analysis of photometry for a small fraction of RR Lyrae stars (4.5%) towards the Galactic bulge led to the detection of 140 new stars of this type, including the discovery of a new group of double-mode stars with specific period ratio of the excited modes. OGLE observations have a long time-base, some sky areas are observed for more than 20 years now. Using the OGLE photometry we will determine the oscillation frequencies and amplitudes, we will check whether they remain stable or vary in time. We will study period changes in classical pulsators and look whether some regularities or patterns that repeat in different stars can be recognized. We will study the modulation of pulsation, the Blazhko effect. We will check whether the modulations are single periodic or variations on other time-scales are also present. We will search for additional modes in modulated stars and will study how light curve changes over the modulation cycle. By studying stars in three different stellar systems we will learn how the above properties depend on metallicity of stars or on their evolution state. Using pulsation models we will try to constrain the geometry of non-radial modes. Our results, based on analysis of homogeneous, top-quality OGLE observations, will help to understand the wealth of pulsations we observe in classical pulsators. This knowledge is essential to propose and test the theoretical models explaining the diverse pulsation forms.