Classical Cepheids as testbeds for stellar evolution and pulsation theories

Classical Cepheids are among the most important tools of modern astrophysics and cosmology. In the Hertzsprung-Russell (HR) diagram, these helium burning giants are located in a well defined vertical stripe – the classical instability strip – in which they undergo large amplitude radial oscillations. The star expands and contracts with a well defined period that is inversely proportional to the mean density of a star. The route of a star in the HR diagram can be followed with evolutionary calculations. The higher the mass of the star, the larger its luminosity during core-helium burning phase, when star oscillates as a Cepheid. The above outlined relations and well defined position in the HR diagram, underlie the period-luminosity relation that makes the Cepheids most famous standard candles. They are used to measure distances and are an indispensable rung of the cosmic distance ladder allowing to compute the expansion rate of the Universe.

Still, we are far from complete understanding of Cepheids' evolution and pulsation. One of the long standing problems is Cepheid mass discrepancy – evolution theory predicts masses of the Cepheids that are 10–20% too large as compared to determinations done using other methods, e.g. arising from the pulsation theory. While the Cepheid evolves across the instability strip its mean dimension changes, and so is its pulsation period. However, the observed period change rates do not agree with model predictions. In additions, irregular variability of pulsation period on a short time scale is observed. The origin of such changes is unknown.

How to solve these and other problems related to modeling of classical Cepheids? We need a rich and diverse observational constraints that then can be used to test and constrain the theory. In particular, precise determination of physical parameters of Cepheids, such as metallicity, mass, intrinsic luminosity or effective temperature are needed. Such precise determinations are possible for a limited sample of Cepheids only. On the other hand, the values of physical parameters may be hidden in the shape of the light variation. We will investigate such possibility in detail. We will gather new photometric observations of Cepheids to characterise their light curves and we will check and calibrate the relations, e.g. between the metallicity and light curve shape. With such relations at hand, we will be able to characterise much larger samples of Cepheids. We will then compute large grids of Cepheid evolutionary models assuming different scenarios (e.g. including rotation, increased mass loss or increased overshooting from the convective core) and we will compute pulsation models, including light curves, on top of them.

Models will be confronted with observations using two methods. In the first, we will consider only a few Cepheids, components of the eclipsing binary systems, for which physical parameters (masses, location in the HR diagram) are precisely determined. In the second approach, we will focus on Cepheids in the Magellanic Clouds, sample of which is now complete. Magellanic Clouds offer a unique, global view on stellar populations of different chemical composition. Thanks to relations derived in the project, we will be able to map the Cepheids into theoretical HR diagram. We will also compare the observed period change rates with model predictions, as well as observed and computed light curve shapes. By confronting the models with the observations we hope to learn which physical processes are essential and indispensable in the evolution of Cepheids. We will investigate the limitations of the current stellar pulsation and evolution theories and we will try to point where improvements are needed. We stress that these results will be important not only for Cepheids, but for our understanding of the evolution and structure of medium mass stars in general. Stellar pulsations are only a relatively short episode in the life of a star, but they offer an unique insight into physical processes acting inside the stars.