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Review of the Ph.D. thesis

"Kepler photometry of two open clusters NGC 6791 and NGC 6819"

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This Ph.D. thesis focuses on the search and analysis of variable stars in the two open clusters NGC 6791 and NGC 6819. Both clusters are relatively old with 9 and 2.5 Gyr. The main focus was on finding and studying hot subdwarf B-type pulsators. Those are stars that were stripped on the tip of the red giant branch. There are various formation channels to form such objects. In the field, most likely binary evolution is responsible for the mass loss, whereas in globular clusters, most likely collisions cause it. A significant number of those objects show p-mode pulsations of the order of minutes or g-mode pulsations of the order of hours. Only three pulsating hot subdwarfs, which were already known before, were found in NGC 6791 and none in NGC 6819. Therefore, the region around these clusters was searched for all kinds of variable stars. Those were classified into different groups: eclipsing binaries (eclipsing, active eclipsing, contact), pulsators, and rotational variables. For all targets, the probability of cluster membership was determined.

The thesis is a collection of four thematically similar refereed articles (three first-author publications and one second-author publication). For all four articles, the contribution of the Ph.D. candidate was at least 60-70%. The thesis is structured in an introduction, which consists of a short introduction and motivation to the subject, as well as a summary of the main results followed by the four papers.

The Introduction begins with introducing hot subdwarf B (sdB) stars. Those objects were found to be the main source of the UV excess observed in old elliptical galaxies. They are characterized by a helium burning core, a helium shell, and a very thin hydrogen envelope that cannot sustain hydrogen shell burning. In the Hertzsprung-Russell diagram, they are found on the extreme horizontal branch (EHB). They are descendants of low-mass main-sequence stars with masses between 0.7 and 1.9 solar masses in the degenerate channel. Their mass depends on the progenitor mass and can be down to 0.3 solar masses, with most subdwarfs having a mass around 0.47 solar masses. In the next section, the current knowledge about the pulsations in hot subdwarf stars is presented. Pulsations are driven by the κ-mechanism due to an iron opacity bump and can drive p- or g-modes or both depending on the temperature and surface gravity of the subdwarf. The next section presents the current knowledge on hot subdwarfs in clusters. The advantage of such objects is that for the cluster members additional information is available that is not available for stars in the field. As all stars have formed out of the same cloud, they have the same age, distance, and chemical content. Several globular clusters have been studied to find a hot subdwarf population. However, the high stellar density makes it difficult. Most of the open clusters are not old enough to have developed a horizontal branch yet. The oldest open cluster NGC 6791 is known to have a distinct EHB. The possibility and limitation of asteroseismic modeling of hot subdwarf pulsators in open clusters is the main goal of the thesis. For this goal, data from the Kepler space mission were used, as described in the fourth section. Most of the work in this thesis was the processing of data from the "superstamps" observed by the Kepler mission, which contain complete images of the central region of different clusters. The next sections (5-11) give a summary of the search for pulsating hot subdwarf stars and an analysis of them in the two open clusters NGC 6791 and NGC 6819. In addition, mode identification and analysis of the known pulsating hot subdwarfs in NGC 6791. The search for other variable stars is just briefly mentioned. It is a summary of what is presented in the papers later. No additional details are given, and it is poorly structured, jumping from one topic to the next. More details would have been helpful for an easier understanding of the methods. The Introduction ends with a summary of the most significant results and caveats.

For the Introduction, I would have expected not a summary of the results that are discussed later but a broader background and more detailed explanation of the methods, as well as a discussion that puts all papers in a common context and demonstrates the impact on the field. I am missing a Conclusion chapter. A comparison of the results, e.g. with globular clusters would have been desirable. The references are not always up-to-date and do not include the latest observational results, and are sometimes narrowed down to one specific group. Moreover, the introduction does not completely fit the topic of the thesis. It covers mainly the properties of hot subdwarf stars; most of the thesis is, however, about variable stars in open clusters, mainly cool main-sequence stars or red giants. This should have been reflected in the Introduction and e.g. the criteria for the classification of the variable star types explained. Some details are presented in a somewhat simplified and superficial way. This makes it difficult to understand the introduction. The motivation of the thesis and the broad impact to open questions in stellar astrophysics does not become clear, especially due to the fact that no new sdB pulsators were found, and therefore the topic shifted additionally to variable stars in general.

Paper I aims at the analysis of three known pulsating subdwarf B stars and the unsuccessful search to find new ones. Archival spectra were used to derive the atmospheric parameters of the four known hot subdwarf stars. The spectral parameters were compared to previous determinations, which show significant differences that were not always in agreement within the errors. A more detailed discussion of these differences is missing. Multiple spectra allowed the authors to check for radial velocity variations for three targets, which are found for all of them. The next step was to determine the cluster membership and extract the light curves of the blue objects near the open cluster from the Kepler data. It is not clear from the text for which targets the light curves were checked. The authors performed a reanalysis of the three pulsating sdB stars using more Kepler quarters. The amplitude spectrum, which revealed significantly more frequencies than detected before, was derived and mode identification was performed for all derived frequencies using rotational multiplets and asymptotic period spacing. However, it is not clear to me, how n was derived. The description of the analysis is hard to follow. A proper discussion of the results and how they compare with previous studies of the same objects is missing.

In Paper II asteroseismic modeling of two stars from the previous paper and two additional field stars was performed using the codes MESA and GYRE. The previously derived frequencies are fitted using a calculated grid of models with different parameters of stars on the EHB with different constraints. At first, a fit with no constraints was performed. Secondly, the atmospheric parameters derived previously by spectroscopy and finally the age and metallicity of the cluster were used as a constraint for the fit of the observed frequencies. The different constraints resulted in deviating models for the targets. No errors are determined. The difference in the quality of the fit is not given, but it would have been interesting to judge the differences between models. Moreover, the new method could have been compared with other targets in which astroseismic modeling has been performed before to verify it.

Paper III describes the search and analysis of the variable star population of NGC 6791. Several searches for variable objects have been performed before. In this work, the authors used Kepler photometry. Fluxes for all pixels from the Kepler "superstamps" covering the most central part of the cluster have been extracted and investigated for flux variations. In addition, atmospheric parameters for some targets have been derived using archival spectra. Using the Gaia parallax and proper motion, the probability of a cluster membership is derived. 278 variable objects have been found, 129 of them are cluster members. The variable stars were classified into different groups (binaries, rotational variables, pulsators). The definition of a star as variable, as well as the classification criteria for the variability types, is not properly explained. For the eclipsing binaries, period variations have been investigated by deriving eclipse times. For three binaries, significant period variations have been found. However, a discussion of possible causes was not properly done. By fitting isochrones to the color-magnitude diagram of the cluster, the distance and age of the cluster were derived. A discussion of the results, together with a comparison with previous determinations, is missing. The purpose of the paper is not clear. Why were not only variable cluster members studied, but also random foreground or background variable stars? What additional knowledge do those variable stars bring to learn more about open clusters? In Paper IV the same method was applied to NGC 6819. For some stars, spectroscopic follow-up was done. The target selection is not described. No hot subdwarfs were found in the cluster. 385 variable stars were found, but only 128 of them were cluster members.

In these four papers, of which this thesis is composed, the data from the Kepler mission have been used to search and analyze variable stars in two open clusters. The same data was also used by another group at the same time. However, they used another method for the data extraction and used strong detrending, which can lead to the removal of stellar variations. Moreover, this group concentrated only on the light curves. Sanchu Sanjayan included different methods to perform a much more thorogh analysis of the variable stars in these open clusters. He demonstrated that he can independently conduct a scientific project and developed methods for the complicated extraction of photometric data in crowded fields. He performed an investigation of different aspects of stars in an open cluster using additional techniques such as the determination of the cluster membership using astrometric data from Gaia and the determination of atmospheric parameters and radial velocities using spectroscopy from different instruments, as well as the determination of the age from isochrones. As most of the original aim of the project, which was to find more hot subdwarf pulsators, could not be achieved, he found alternative ways to get meaningful results from the data. However, a clear focus of the thesis is lacking, as it was not adapted to the changed goals. More effort could have been made to put everything in a consistent picture. The discussion of the results is mostly missing, especially a conclusion section that brings all four papers together.

The thesis resulted in several interesting results. The variability classifications provided in this thesis may help people for selecting interesting targets. The further investigation of the previously known hot subdwarf binaries with a much longer data set provides a very useful mode identification for many more frequencies. For two of the targets and two known targets, these frequencies were used to successfully attempt asteroseismic modeling. This suggests that the results of this thesis will be useful for more detailed asteroseismic modeling in the future, as well as for the more detailed study of variable stars in open clusters. According to the statements of the other authors, Sanchu Sanjayan did at least 60 to 70% of the work for the four articles. He showed that he gained knowledge of many different techniques widely used in stellar astrophysics and demonstrated a good understanding of the theory of pulsations of hot subdwarf stars.

Summing up, I consider the doctoral thesis of Sanchu Sanjayan to be a valuable contribution and to meet the criteria prescribed by the law for a doctoral dissertation. Therefore, I request that this dissertation be admitted to a public defense.

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