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Supervisor's report on Mgr. Jakub Cehula's Doctoral Thesis

The doctoral thesis of **Jakub Cehula** titled "Theory of stellar mass loss: from binary stars to magnetars" investigates stellar mass loss, which is an important part of a broader field of stellar evolution. This field has been an active topic of research in astronomy for a long time, but the importance and timeliness of this line of research has recently increased due to advances in gravitational-wave and time-domain astronomy, where stellar mass loss plays crucial role at various stages of evolutionary pathways.

Jakub's thesis is divided into five Chapters and the final Conclusion section. The first Chapter is about 20 pages long and provides basic context for the two main topics addressed within the thesis: mass transfer in Roche-lobe overflowing binary stars and magnetar giant flares. For both topics, there is first an introduction to the problem accessible to non-specialists followed by description of the computational methods used in subsequent parts of the thesis. Specifically, the thesis is based on computations performed with the open-source state-of-the-art stellar evolution code MESA, custom-built two-point boundary value relaxation solver for wind-like problems, and special-relativistic explicit hydrodynamic open-source code PLUTO. The Chapter is generally very clearly written and logically organized, it is accompanied by several figures specifically made for this Chapter, and a sufficient number of relevant references.

The second Chapter presents a new theory of mass transfer through the L1 point in binary stars. L1 mass transfer is a fundamental astrophysical process, which can greatly affect evolution of both stars in a binary through the exchange of mass and angular momentum. In stellar evolution codes, this process is typically implemented using a prescription that connects structure of the stellar layers above the Roche lobe with the mass transfer rate. In this work, Jakub developed a new model, which calculates the mass transfer rate as an eigenvalue of a two-point boundary value wind-like problem. He found analytic solutions, developed code for numerical solution, and assessed the effects on stellar evolution with MESA. This work was published in MNRAS in 2023.

In the third Chapter, Jakub further develops this model by including radiation. This is a non-trivial change, because radiative processes can affect the result on various levels. In this work, Jakub carefully isolated various relevant physical effects (convection, advection, radiation

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pressure, von Zeipel theorem, etc.) and synthesized a model that can be used in one-dimensional simulations. Specifically, the predictions include Eddington correction to optically thin mass transfer rates and a relaxation of photon-tiring constraints on super-Eddington outflows near L1. The second result has the potential to help explain non-terminal outbursts of Luminous Blue Variables. The paper with these results is currently under review in MNRAS. Jakub's work on mass transfer in binaries is already internationally recognized, for example, he was invited as one of the invited speakers at Stable mass transfer workshop at the Center for Computational Astrophysics in New York in 2025.

The fourth Chapter presents a project on magnetar giant flares, which Jakub executed without my direct participation together with Prof. Todd Thompson (Ohio State University) and Prof. Brian Metzger (Columbia University). The paper, published in ApJ, presents a new model explaining baryon ejection during magnetar giant flares and the astrophysical implications for transient detection in optical and radio, synthesis of r-process elements, and environments of fast radio bursts. All of these are some of the hottest topics in contemporary high-energy astrophysics. The work in this paper is based on semi-analytic considerations and numerical simulations with PLUTO. The leadership in this project earned Jakub collaboration on two follow-up papers described in the last supplementary Chapter, which covers two papers published in ApJ in 2025. This work consists of observations and theoretical modeling of MeV emission from the SGR 1806-20, providing direct evidence for r process nucleosynthesis in giant magnetar flares. This result was also announced in an international press release coordinated by NASA.

To summarize, during his PhD studies Jakub has become familiar with a number of advanced theoretical concepts and numerical tools in stellar and high-energy astrophysiscs. He has two distinct and viable topics for further research and both have been already internationally recognized. He has experience with presenting his research with contributed and invited talks as well as dedicated seminars. He obtained funding for his magnetar research from the Grant Agency of Charles University. In my opinion, **Jakub's work presented in this thesis and his papers show that he can perform independent creative scientific work**. I strongly recommend his thesis for acceptance and awarding him the PhD degree and I wish him success during his postdoc.

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