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For: Council of the Discipline of
Astronomy of NCU in Torun,
Poland

Object: Evaluation of the Habilitation work of Dr. D. Szecsi

Nice, January 24, 2024

Dear Dr. hab. Krzysztof Katarzynski prof. NCU, Chairman of the Council,

It has been a pleasure to review Dr. Dorottya Szécsi's application for the Habilitated doctor's degree on the "Role of Gravitational Wave Progenitors in the Universe". In her "Summary of Professional Accomplishments' ', Dr Szecsi explains why low-metallicity massive stars are crucial objects in our Universe in a very straightforward yet accurate fashion. Dr Szecsi presents a compelling story, around two types of massive stars she has specifically studied: cold supergiants and chemically-homegeously evolving stars.These categories of stars are both evolved massive stars, but they have a different rotational velocity and end up behaving and looking very differently. Dr Szecsi convincingly explains that these rare stars are key ingredients in the Universe, especially at early times, as they are likely shaping globular clusters, finishing their lives in gamma-ray bursts, and when in binaries, they can lead to GW events.

Dr Szecsi's main results and future projects build on the 5 main publications she is describing in her application. They describe the evolutionary stages and observational properties of low metallicity evolved massive stars as well as their impact on the chemical enrichments observed in globular clusters.

Hab 1: "Bonn Optimized Stellar Tracks (BoOST)
Simulated populations of massive and very massive stars for astrophysical applications"

presents newly computed evolutionary tracks of massive stars, including very low metallicity models and very massive stars which are usually not presented in the literature although they have a strong impact. This work shows under which conditions the cold very luminous supergiants form. This work presents a grid of stellar tracks, and presents physical and numerical arguments as to why they can be reliably extrapolated, which is a challenging aspect in the field. The numerical difficulties related to modeling the inflated envelopes near the Eddington limit are clearly explained, with a solid description of the options proposed in the literature. This work proposes a different solution, where the envelopes are modeled in postprocessing. Although the simulations stop at the end of core helium burning, like most

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stellar evolution codes, the connection to the final outcome of stellar evolution in terms of supernova type and compact object mass is clearly explained and the community can use these models for further evolution. The evolutionary tracks are publicly available, including yields for 34 isotopes and will be a baseline for many of the studies Dr. Szecsi plans to undertake, and for the broader community as well. The publication gathered 30 citations in less than two years, proving the importance of this work and the need in the community. I can safely predict that this work will be the basis of many key studies about low-metallciity massive stars in the future.

Hab 2 "Explaining the differences in massive star models from various simulations". This publication, the first one from Dr. Szecsi directly building on the BoOST models, mainly highlights that there are major discrepancies between 5 different stellar evolution codes when it comes to stars beyond 40 solar mass. The publication clearly explains that this mostly relates to the techniques used to overcome numerical difficulties near the Eddington limit, and can lead to up to 20 Msun difference in the estimates for the final remnant mass, and up to 20% difference in the ionising radiation of a stellar population. The publication is very well written and clearly explains how different choices lead to different stellar parameters, it can be used as a compass to guide people when interpreting stellar evolution results. The comparison is done with the 5 main stellar evolution codes, in collaboration with several of the initial designers of the stellar evolution grids. This publication is a clear warning to the broader community that massive stellar evolution is not a solved problem and that population inference should be done with caution.

Hab 3. " Role of supergiants in the formation of globular clusters" and Hab 4. " Supergiants and their shells in young globular clusters" both present how cold supergiants could be responsible for the chemical enrichment observed in second-generation stars in globular clusters. The unexpected chemical diversity observed in globular clusters is still an unsolved problem within the GC community, and no explanation can explain both the spread in abundances and the fraction of second versus first generation stars convincingly. In these papers, Dr Szecsi and collaborators propose that the second generation of stars could have formed in an ionised shell surrounding the cold supergiants. Hab 3 specifically explains that cold supergiants naturally enrich the surrounding gas with the appropriate abundances, on short timescales, and with the mass-loading that seems necessary to form a significant second generation of stars. The paper presents a thorough description of the different mechanisms leading to mass loss and its properties and then delves into a detailed description of the cluster abundances and the comparison between models and data. Hab 4. is more focused on the hydrodynamical conditions in the shell, and how they can lead to the formation of a new generation of (low-mass) stars. The paper explains that the stars in the globular cluster likely present a distribution in terms of rotational velocity, and naturally contain massive stars evolving into cold supergiants as well as the chemically homogeneously evolving stars which will drive a strong UV field. This work studies how the interaction of the ionising radiation with the wind-driven shell around the supergiant can create the conditions that allow gravitational collapse. This publication is mostly based on "textbook" hydrodynamics, and

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presents an additional expertise for Dr. Szecsi, with an application to star formation. Again, the publication presents a convincing discussion on the implications and further possibilities of this work. These two studies highlight how Dr. Szecsi's approach really makes the difference; she has brought together expertise and experts of two separate communities (massive stars and globular clusters), to propose an explanation to a long standing problem. The publications present thorough discussions on the limits of the work, and within those limits, the model fits the observations. Several pathways are also proposed to confirm (or invalidate) the model with future observations. The computations are based on initial stellar evolution models, prior to the BoOst project, and updating them with the BoOST stellar track is a natural extension.

Hab 5. " Low metallicity massive single stars with rotation. II Predicting spectra and spectral classes of chemically homegeneously evolving stars". This presents another collaborative work, around the TWUIN stars, which result from rapid rotation. The publication clearly explains how these stars have different "names" in different works, depending on the focus of the publication. This work focuses on their spectral appearance, and how these stars would be classified by an observer. The work confirms that these stars do not look like Wolf Rayet (except in certain cases) stars (although they live in the right area of the HR diagram), but mostly look like early O-type stars.

Throughout these publications, Dr. Szecsi presents a coherent body of work on massive low metallicity stars. Her work is remarkably thorough, numerically solid, and the caveats are always described in depth. From her international experience (Hungary, the UK, Germany, the Czech Republic and now Poland), Dr. Szecsi brings back a wide range of expertises and collaborators. In the main document, she presents a clear path forward with the tools she has developed, including a population synthesis approach. Her next step will be the study of binary interactions and other multiples, and I am sure she will produce very strong scientific results.

In conclusion, I have a very positive opinion of the work presented here, and I recommend that Dr. Szecsi be awarded a Habilitated Doctor's degree.

Best regards,

Astrid Lamberts