THE ANNUAL REPORT

Name and surname	mgr. Hanno Stinshoff
Project title	Expanding the BoOST massive star models to explain the formation of globular clusters
Scientific disciplines	Astronomy
Supervisor	dr. hab. Dorottya Szécsi, prof. UMK
Foreign scientific supervisor*	Not Applicable
Assistant supervisor*	Not Applicable

Year of study: . 3rd . (academic year 2024/2025)

1. Description of the progress in the preparation of the doctoral dissertation and the progress in conducting scientific research
[Please, also refer to your Individual Research Plan]

Project 1: Expanding the BoOST model grids

This is the project I am working on with Dr. Szécsi to update the Bonn Optimized Stellar Tracks (BoOST) model grids from [1] Szécsi et al. (2022).
The original grid features stellar evolutionary models, created with the so-called Bonn Code, which follow the evolution of (single) massive stars, ranging from 9 to 500 solar masses and metallicities from the Milky Way (Z_{MW}) down to a fraction of the Small Magellanic Cloud (0.02 Z_{SMC}). With that, they cover a broad parameter space, enabling the user to investigate the differences in evolution. These public and user-friendly libraries allow the stellar evolutionary models to be applied in a wide range of astrophysical scenarios like e.g. star formation simulation, chemical evolution studies of galaxies, cluster formation research, gravitational wave astrophysics and more. Some works that employed the BoOST models so far include [2] Lahén et al. (2023), [3] Lahén et al. (2024), [4] Franeck et al. (2022), [5] Agrawal et al. (2023) and [6] Romagnolo et al. (2023).

The goal of this project is to expand on the parameter space by adding a range of initial rotational velocities (0 to 500 km/s) as initial parameter and creating new grids based on these configurations (cf. Also annual reports from 2022 and 2023). Just like its predecessor, the models are supposed to be converted into a format that is easy to use further in other applications.
Scientifically, my goal is to employ the BoOST models in exploring open questions in globular cluster research (as explained under Project 2).

Scientific Goals and Achievements:

1.) Model progression
The first goal of the year was to push the models further, including the post-processing into the BoOST format
→ Partially achieved
Choosing the correct equivalent evolutionary points (EEPs) for evolutionary pathways that diverge from the normal form is now done automatically instead of the previous manual process. This includes all the models undergoing Chemically Homogeneous Evolution (cf. For example [7] Szécsi et al., 2015), where the transition into the BoOST format stayed an issue that needed resolution last year. We have fixed this issue for now, although some more testing is still required to assure that the results are satisfactory in all cases.

2.) Data management strategy updates and data back-ups
In order to avoid data loss due to connection issues of an external hard drive (which has been hinted at in previous reports already), I decided to use a second high-performance device to run the models rather than on the device that stores the backups. The first device I used (which is the stationary machine in the office workplace) also doesn't have enough storage space and computation power to reliably let the models run solely on there, so an alternative solution was preferable.

→ Achieved
I acquired a high-performance work-station laptop as my second machine, paid by Dr. Szécsi's OPUS grant. In order to set it up, I had to perform IT management steps like installing a working Linux System (Ubuntu 24) with dual boot next to the already existing Windows 11 (which had to be preserved since it legally belongs to the university). Then I successfully installed the Bonn Code via the "beci" interface and also managed to set up a version of the WINDCALC code (see project 2). Installing the Bonn Code was also connected to the next step 3), using a newly setup online repository of the code, so step 2) could be used to help locate and fix many small bugs in the compilation software of "beci". With this second machine ready for work, I am now running my simulations and data analysis/visualization in a more reliable and more secure way.
On top of that, the new machine also helps with working from abroad, in case of going to conferences or workshops, which I made use of already when going to the JWST workshop (see below).

3.) Setting the Bonn Code up to be accessible online and introducing proper version control via git.
In general, and especially during the work to fix the computational errors on my side, the Bonn Code was modified repeatedly over short periods of time, which presented the issue that it could only be distributed manually, physically instead of via internet, which made every change present a new hurdle of updating the code. So we decided that we need a method of distributing the code more easily, and a way to assure a way to document changes in the code.
→ Achieved
Dr. Szécsi and I have set up a repository online in a gitlab environment to ensure the remote access and version control via git, which is the number one software to do that and used widely in the field. The expertise to use it was in parts acquired by attending a course two years ago offered at the university.
This portation of the code not only included actually copying the files, but also checking for issues with the re-installation/upgrading of existing versions and the modification of the code to be portable. The access is now possible for everyone who has the rights to access it.

Project 2: Investigating the winds of stellar populations in Globular Clusters with varying wind descriptions:

This second project is work I am collaborating on with Dr. Richard Wünsch (Astronomical Institute of the Czech Academy of Sciences, Bocní II 1401/1, 141 00 Praha 4, Czech Republic). It is international collaboration which grew out of the Internship I did at their institute for a month in 2024, where I worked to improve the WINDCALC code.
We are working on getting a better explanation for abundance anomalies observed in Globular Clusters, which is an observational riddle that is actively investigated (cf. For example [8] Carretta et al., 2009). I am utilizing a scenario of multiple generation of stars, with the first creating the observed patterns and then passing them on to the newly-created second generation. It is a scenario that is widely researched (e.g. in [9] Bastian & Lardo, 2018, [10] Gratton et al., 2012 and in [11] Szécsi & Wünsch, 2019), with many facets still in question; the mass budget that a second generation of stars could form of is limited by various factors, which still need more investigation to find out the limits of the scenario.
I analyze the winds of stellar populations in Globular Clusters to determine which parameter configurations lead to circumstances benefiting the formation of a second generation of stars that inherited abundance patterns from their parent generation, which is an observational riddle that is actively investigated.
For now I am using the already published BoOST models ([1] Szécsi et al., 2022), but it is possible to do the same with the models I am creating in project 1 to investigate additional dependencies (e.g. the rotational velocity, which is not a vastly varied parameter in the current models).

Scientific Goals and Achievements:

1.) There was some uncertainty whether the models I had previously used to work with WINDCALC were the most up-to-date ones, so I needed to redo the process of setting up the trackfiles and their BoOST format.
→ Successfully achieved
As I already had the experience from the first time I had undergone this process, the application to the new models was not problematic and I could work on them in the following steps. This included the usage of the determined EEPs to create tracks with filtered data, that can then be used in applications like WINDCALC.

2.) For the parameter study, I needed to determine which parameters could have an influence and could be varied with the code I used. I also needed to determine, in what way I would vary them to make sure that I didn't just blindly create far too much unnecessary data.
→ Successfully achieved
I determined a broad range of many different parameters to investigate, which included the cluster core radius and cutoff

radius (cf. For example [12] Palouš et al., 2013), the Initial Mass Function (IMF, cf. For example [13] Kroupa, 2001) slope in the high-mass-end, the total cluster mass, the metallicities that the BoOST models had provided and the highest mass-bin for the creation of the population (to draw comparisons to a different population synthesis code, STARBURST99, cf. [14] Leitherer et al., 1999). I decided on two hyper-crosses around the examplary metallicities of [11] Szécsi & Wünsch (2019) to isolate the effect that each of the parameters has on the outcome.

3.) The synthetic populations needed to be created.
→ Partially achieved
I used the first part of the WINDCALC code, SYNSTARS, to create the synthetic populations with the parameter configurations mentioned in step 2. I verified that the process worked and the results make sense. This verification is ongoing, as the data could still show some issues that need correcting, but so far the results look as expected.

4.) The winds of the populations needed to be computed.
→ Successfully achieved
I used the second part of the WINDCALC code, WINDEVOL, to determine the winds of said populations from 3), depending not just on the parameters chosen in 2), but also for multiple wind prescriptions that I had implemented last year to compare them to each other and to a different population synthesis code called STARBURST99. STARBURST99 is commonly used in the field, and currently in the progress of being upgraded to pySTARBURST99 (a python port that also features new physics with higher mass stellar models as base, cf. [15] Hawcroft et al., 2025), and since the higher masses are a big part of said portation and my work explicitly covers how the winds of the population react to high mass stars, this project can be very useful for the community.
The results already hinted at there being quite a difference in Mechanical Cluster Luminosity depending on the wind prescription, which could mean that the mass accumulation might have been underestimated previously, which would be a hopeful result for the mass budget problem.

Notes:

It should be noted that the progress was halted due to sickness for +2 months from 18.02.2025 until 22.04.2025 (with sick leave report handed it at the university).

References (in order of appearance):

[1] D. Szécsi, P. Agrawal, R. Wünsch and N. Langer, “Bonn Optimized Stellar Tracks (BoOST) - Simulated populations of massive and very massive stars for astrophysical applications”, *Astronomy & Astrophysics*, vol. 658, A125, 2022, https://doi.org/10.1051/0004-6361/202141536

[2] N. Lahén, T. Naab, G. Kauffmann, D. Szécsi, J. M. Hislop,A. Rantala, A. Kozyreva, S. Walch and C. Hu, “Formation of star clusters and enrichment by massive stars in simulations of low-metallicity galaxies with a fully sampled initial stellar mass function”, *Monthly Notices of the Royal Astronomical Society*, vol. 522, Issue 2, pp. 3092–3116, 2023, https://doi.org/10.1093/mnras/stad1147

[3] N. Lahén, T. Naab and D. Szécsi, “Star clusters forming in a low-metallicity starburst - rapid self-enrichment by (very) massive stars”, *Monthly Notices of the Royal Astronomical Society*, vol. 530, Issue 1, pp. 645–667, 2024, https://doi.org/10.1093/mnras/stae904

[4] A. Franeck, R. Wünsch, S. Martínez-González, I. Orlitová, P. Boorman, J. Svoboda, D. Szécsi, and V. Douna, “X-Ray Emission from Star-cluster Winds in Starburst Galaxies”, *The Astrophysical Journal*, vol. 927, Issue 2, p. 212, 2022, https://dx.doi.org/10.3847/1538-4357/ac4fc2

[5] P. Agrawal, J. Hurley, S. Stevenson, C. L Rodriguez, D. Szécsi and A. Kemp, “Modelling stellar evolution in mass-transferring binaries and gravitational-wave progenitors with metisse”, *Monthly Notices of the Royal Astronomical Society*, vol. 525, Issue 1, pp. 933–951, 2023, https://doi.org/10.1093/mnras/stad2334

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[7] D. Szécsi, N. Langer, S. Yoon, D. Sanyal, S. de Mink, C. J. Evans and T. Dermine, “Low-metallicity massive single stars

with rotation - Evolutionary models applicable to I Zwicky 18", *Astronomy & Astrophysics*, vol. 581, A15, 2015, https://doi.org/10.1051/0004-6361/201526617

[8] E. Carretta, A. Bragaglia, R. G. Gratton, S. Lucatello, G. Catanzaro, F. Leone, M. Bellazzini, R. Claudi, V. D'Orazi Y. Momany, S. Ortolani, E. Pancino, G. Piotto, A. Recio-Blanco and E. Sabbi, "Na-O anticorrelation and HB - VII. The chemical composition of first and second-generation stars in 15 globular clusters from GIRAFFE spectra", *Astronomy & Astrophysics*, vol. 505, Issue 1, pp. 117–138, 2009, https://doi.org/10.1051/0004-6361/200912096

[9] N. Bastian and C. Lardo, "Multiple Stellar Populations in Globular Clusters", *Annual Review of Astronomy and Astrophysics*, vol. 56, pp. 83-136, 2018, https://doi.org/10.1146/annurev-astro-081817-051839

[10] R. G. Gratton, E. Carretta and A. Bragaglia, "Multiple populations in globular clusters - Lessons learned from the Milky Way globular clusters", *The Astronomy and Astrophysics Review*, vol. 20, p. 50, 2012, https://doi.org/10.1007/s00159-012-0050-3

[11] D. Szécsi and R. Wünsch, "Role of Supergiants in the Formation of Globular Clusters", *The Astrophysical Journal*, vol. 871, Issue 1, p. 20, 2019, https://dx.doi.org/10.3847/1538-4357/aaf4be

[12] J. Palouš, R. Wünsch, S. Martínez-González, F. Hueyotl-Zahuantitla, S. Silich and G. Tenorio-Tagle, "YOUNG STELLAR CLUSTERS WITH A SCHUSTER MASS DISTRIBUTION. I. STATIONARY WINDS", *The Astrophysical Journal*, vol, 772, Issue 2, p 128, 2013, https://dx.doi.org/10.1088/0004-637X/772/2/128

[13] P. Kroupa, "On the variation of the initial mass function", *Monthly Notices of the Royal Astronomical Society*, vol. 322, Issue 2, pp. 231-246, 2001, https://doi.org/10.1046/j.1365-8711.2001.04022.x

[14] C. Leitherer, D. Schaerer, J. D. Goldader, R. M. González Delgado, C. Robert, D. F. Kune, D. F. de Mello, D. Devost and T. M. Heckman, "Starburst99: Synthesis Models for Galaxies with Active Star Formation", *The Astrophysical Journal Supplement Series*, vol. 123, Issue 1, p. 3, 1999, https://doi.org/10.1086/313233

[15] C. Hawcroft, C. Leitherer, O. Aranguré, J. Chisholm, S. Ekström, S. Martinet, L. P. Martins, G. Meynet, C. Morisset, A. A. C. Sander and A. Wofford, "pySTARBURST99: The Next Generation of STARBURST99", *The Astrophysical Journal Supplement Series*, vol. 280, Issue 1, p. 5, 2025, https://doi.org/10.3847/1538-4365/adddb6

2. Information on courses passed within the Framework Program of Education (all classes must be included in your USOS account; those which are not cannot be included in this report)
[Title of courses, amount of hours, ECTS credits].

1. Name of the course: Supervisory mentoring
Course code on USOS: 7405-AC-SMEN-1
Form of classes: Supervisor mentoring
Final grade: ZAL
Number of hours: 10 hours
Number of ECTS points: 1 ECTS credit

3. Participation in scientific conferences** (confirmations required/ must be enclosed to the report)
[name of conference, organizer, dates; form of participation; title of abstract, authors, etc.]

Conference name: VFTS meeting 2024 (Handed in, but not yet confirmed by UMK - AC)
Date: 16 - 18 September 2024
Type of participation: Talk (Title: Cluster winds and how they depend on the stellar population parameters)
Link to Presentation Slides:
https://wwwold.astro.umk.pl/~hanno/Hanno/presentations/seminars_conferences_workshops_internships/004_VFTS2024_HannoStinshoff.pdf
Venue: ESAC, Madrid, Spain

Conference name: I-HOW JWST Hands-On Workshop for Central & Eastern Europe 2025 (Handed in, but not yet confirmed by UMK - AC)

Website: https://jwst-ihow2025.faj.org.pl/index.html
Date: 14 - 25 July 2025
Type of participation: Workshop including group presentation (Title: P7: Exoplanets)
Topic of presentation: Distinguishing Exoplanets from Background Stars and Galaxies by means of Ammonia absorption, at the example of archive data from JWST
Presentation slides:
https://wwwold.astro.umk.pl/~hanno/Hanno/presentations/seminars_conferences_workshops_internships/006_WorkshopJWST2025_HannoStinshoff.pdf
Venue: Institute of Physics, Astronomy and Informatics, Nicolaus Copernicus University, 87-100 Toruń, Poland

4. Research trips or internships (confirmations required/ must be enclosed to the report)
[Name of the institution, place, dates, description of the internship].

Not applicable

5. Submission of the doctoral dissertation – yes/no [delete as appropriate].

no

6. Teaching practice with students*** (confirmations required/ must be enclosed to the report)
[Title of courses, amount of hours]

Not applicable

7. Applying for a research grant. (confirmations required/ must be enclosed to the report)
[name of the grant, application's status, confirmation of submitting the application].

The research of the student in question is covered by the National Science Center (NCN), Poland under grant No. OPUS 2021/41/B/ST9/00757. There is no need for the application for a research grant anymore.

8. Scientific publications. (confirmations required/ must be enclosed to the report)

Not applicable

9. Other achievements: (confirmations required/ must be enclosed to the report)

Since the stellar evolution code that I use has been handed down manually between people, every change in the code meant a lot of infrastructural problems to update the version on local machines. Dr. Szécsi and I spent a considerable amount of time and energy on updating the code, introducing a proper version control via git and facilitating the provision of the code over online access in a gitlab environment. This is good practice and common in our field, and it gives freedom from artificial barriers in the distribution process and a more smooth collaboration opportunity in the future.

I also continued to work with Dr. Wünsch to further improve the WINDCALC code. After having implemented various wind prescriptions for it last year, there were issues with the bigger context of them in the code that still needed to be fixed. This meant checking the transition from the first part of the code (SYNSTARS), in which I had implemented the prescriptions, to the second part of the code (WINDEVOL), that used the output of the first step to further process it.
On top of that we worked on keeping the code updated regarding new versions of python, which the code is built upon.

10. Plans for further work on the doctoral dissertation.

Two papers are in the work for the two projects mentioned above, and a tentative plan is to write a third creating a more solid connection between the two.
The first paper will exhibit the newly-created BoOST grids, showing features of the parameter space interesting for further investigation, discussing the limits of Chemically Homogeneous Evolution, and how the initial rotational velocity impacts the stellar evolution of the models.
In the second paper I will discuss how synthetic populations created by WINDCALC are affected by wind velocity prescriptions, total cluster mass, IMF slope and many other parameters, and which of these provides advantageous circumstances for mass accumulation for a second generation.
Finally, depending on the results of the first two papers, it is possible to undergo the process of the second project again with the models of the first project, adding initial rotational velocity and Chemically Homogeneous Evolution into the factors to consider. It might be possible to further investigate the circumstances needed for sufficient mass accumulation.

...27.08.2025.....
Date

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PhD student's signature Supervisor's signature Signature of the Head of ISD AC

Attachments:
1. Opinion of the supervisor(s)
2. Opinion of the doctoral student

THE ANNUAL REPORT/ Appendix 2

Opinion on the supervisor–doctoral student relationship and cooperation

Name and surname of the supervisor(s)	dr. hab. Dorottya Szécsi, prof. UMK
Project title	Expanding the BoOST massive star models to explain the formation of globular clusters
Scientific discipline	Astronomy
Name and surname of the doctoral students	mgr. Hanno Stinshoff

Please provide a constructive feedback of supervisor–doctoral student relationship and cooperation during the past year of education (support, guidance, help in the implementation of the tasks indicated in the Individual Research Plan, frequency of meetings, supervision-related issues or challenges, etc.)

I feel very supported by Dr. Szécsi.
I enjoy working with her, learning a lot from her expertise about the code I am using and the models I am comparing my own ones to. The work together doesn't feel too distanced to be accessible, while still offering proper structure in the meetings.
Especially in the last year I felt very supported, since my work is still facing issues that seem to be solved very slowly. These are mostly connected to issues with computations, and Dr. Szécsi put in the time to work with me through the issues. We worked together to improve the code that we used and to make it accessible for usage due to newly-established online access. This also included the usage of git structure and version control to be able to follow the changes applied to the code.
On top of that she facilitated the contact to my other collaborator, Dr. Richard Wünsch (Astronomical Institute of the Czech Academy of Sciences, Bocní II 1401/1, 141 00 Praha 4, Czech Republic) with whom I am closely collaborating in my second project. The two projects have strong links between them (they both rely on BoOST-formatted models and require the deep understanding of the physics of massive stars), meaning they will nicely fit together into my final thesis. I feel like her help in establishing the contact and keeping it productive was very important to my progress.
Additionally, we as a group have a weekly meeting called "Journal club", enabling us PhD students to learn more about recent developments in astronomy in a group setting, and Dr. Szécsi encourages us to actively take part in that, not only by means of discussion, but by means of reading and presenting new papers ourselves.
Finally and apart from offering support in terms of content of the work itself, she also is a person I feel safe to address personal matters to as well. She is putting a lot of effort and energy in making sure that we as PhD students don't feel alone with struggles that we face.

I am honestly very happy to work with Dr. Szécsi, and consider myself lucky to have a person like her for guidance.

…….. 27.08.2025 ……
Date

Hanno Stinshoff
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Doctoral student's signature