De revolutionibus orbium coelestium

Über die Umlaufbahnen der Himmelssphären

Nicolaus Copernicus

June 23, 2022

KARL-FRANZENS-UNIVERSITÄT GRAZ
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Bachelor's / Master's / PhD Thesis

De revolutionibus orbium coelestium

Über die Umlaufbahnen der Himmelssphären

Nicolaus Copernicus

in partial fulfillment of the requirements for the degree of
Bachelor / Master of Science – BSc / MSc

Supervisors Prof. Dr. Aristach von Samos
Johannes Kepler, PhD

June 23, 2022

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De revolutionibus orbium coelestium – Über die Umlaufbahnen der Himmelssphären

Thesis in partial fulfillment of the requirements for the degree of Bachelor / Master of Science – BSc / MSc;

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Department for Geophysics, Astrophysics and Meteorology,
Institute for Physics, NAWI Graz, University of Graz.

Supervisors: Prof. Dr. Aristach von Samos[1] and Johannes Kepler, PhD[1,2]
External Readers: Dr. Hypatia[1], Doz. Dr. Galileo Galilei[2], and Prof. Dr. Carl Sagan[1,2]

[1] Institut für Physik, Institutsbereich Geophysik, Astrophysik und Meteorologie,
NAWI Graz, University of Graz, Universitätsplatz 5/II, 8010 Graz, Austria.
[2] Instituto de Astrofísica de Canarias, E-38200 La Laguna, Tenerife, Spain.

0 Writing and formatting guide for your thesis

Dear colleague,

Scientific writing is the number one skill of a successful scientist. Mastering this proficiency requires extensive practice, iteration, and feedback. To support you in the first steps to master this essential skill, we provide you with a summary of the essential style rule and some writing style guidelines. We are happy that you are taking those first steps on this demanding but exciting journey with us.

Success in writing your thesis,
Your thesis advisers at IGAM

The following notes were written by Paul Beck, PhD, with addenda by the teachers and advisers at IGAM. (Living document, Version: April 2021)[1]

Writing

The language has to be clear and objective. Science requires quantifying things and putting results into context. The following items will give you a first impression of where to be on your toes.

- Avoid qualitative adjectives (e.g., very, a lot, little, many) and refrain from expressing personal beliefs or using sarcasm. Following the maxim of *'show, don't tell'* a sentence like *'Sample A is much better than sample B'* should be rewritten into something like *'The statistical uncertainty of the measurements of parameter X in sample A is three times smaller than in sample B.'*

- Consider your *'Why?'*. A sentence like *'Studying stars is important'*, is a general statement which says everything and nothing at once. Following the principle, *Show, don't tell* you can implicitly show *why* something has significance, rather than saying so, *'Stars are the building blocks of the galaxy. Studying these objects allows for a better understanding of how our milky way evolved'*.

[1] Comments or feedback on the IGAM thesis template should be directed to paul.beck@uni-graz.at.

- Avoid wordy sentences. A typical sentence should be less than two full lines. A good trick is to mark each sentence longer than that with a text marker on a printout. Then split such sentences into two or three shorter sentences.

- Write in an active form. For example, write *'Galileo has found 4 Jovian satellites'* instead of *'The four Jovian satellites have been found by Galileo'*. The active form will help you write more precise and shorter sentences. Remember that your text may need to be read and understood by people with lower language skills than yours. Make the reader's life easier.

- Use abbreviations sparsely and only for your most important phrases or key terms. At first use in the text body, they need to be defined. The use of abbreviations or acronyms is highly de-appreciated by editors in a paper's title and abstract. Consequently, colloquially used acronyms, such as HRD, RV, ZAMS, or TAMS, need to be spelled out in the title and abstract.

- Similar applies for each mathematical symbol used in the text and equation must be defined at first use – an occasional reminder of the meaning throughout the paper doesn't hurt.

- Only use footnotes to indicate webpage links, e.g., for MESA, PHOEBE, AstroPy, data catalogs portals, or as demonstrated above for a specific document of high relevance to your work.

- References to papers are fundamental for your work's scientific integrity and placing your work into the broader context of timely and relevant research. The examples below and in the next section and Chapter 1 demonstrate the use of the implemented BibTex-package.

- Short notes on grammar. Always put a "," before the word "which", but never before "that". Remember the "s" at the end of the verbs in the third singular person. If possible, try to keep the tenses of the verbs always the same throughout the text. Write all numbers between zero and ten as a word while keeping the others in number.

- Plagiarism and doctoring the data are the cardinal sins of a scientist. Such behavior is not tolerated. Be aware of the automated plagiarism check during the submission process. If detected, we would consider this a major abuse of our trust in you and reserve the right to take academic action.

Additional self-study resources on scientific writing

- The best way to improve your writing is to read much scientific literature. Different authors write differently, though, so you have to find your own style. You can do this by exercising your writing and reading and identifying authors who write in a way you like. Keep notes on the content of the papers you read. We also recommend reading the article on reading papers by Cooke et al. (2020).

- Concise collections of lecture notes on the topic are available in the books by Prof. Arnold Hanslmeier[2] and Mack (2018)[3].

- You may use modern software, such as Grammerly.com, to check your thesis's grammar and spelling. Doing so allows us to focus on discussing science and content and streamline the iteration process.

- Play around with LaTeX. Writing in this scripting language will become second nature to you. You are encouraged to search LaTeX-documentation and advance your thesis beyond this template, e.g., defining your own frequently used symbol-groups. A good source of documentation about working with LaTeX is provided by Overleaf: https://www.overleaf.com/learn.

  Commented text, using '%' allows you to keep hidden notes. This is particular helpful to keep notes or an earlier version of a sentences or paragraph, you wanted to reword. Use colors to mark action items or text during the iteration phase. Some examples are shown at the end of this chapter.

A very common mistake beginners make is to write meaningless sentences. This happens because you know well what you want to say, write it down in a sentence in a meaningless way due to lack of practice. Yet, because you know what you want to say, the sentence you have just written looks useful to you. There is a straightforward strategy that you should apply to avoid this. Write a piece of text, then read it aloud or (even better) record it, and finally listen to it, trying to understand what you want to say from listening to what you read. If you cannot understand the meaning of what you said, then there is something wrong with that text.

A final piece of advice. Write something, then leave it aside without reading it for a few days and then returning to it. The more times you do this process, the better the text will become.

[2] The PDF of the book (in German) is available at https://bookboon.com/de/wissenschaftliches-arbeiten-ebook
[3] The PDF of the book (in English) is available at https://spie.org/samples/9781510619142.pdf

Elements of a scientific work

In general, the style in this thesis template follows the formatting guidelines[4] of *Astronomy & Astrophysics (A&A)*, the European workhorse journal for astrophysics. The only divergence from these guidelines is the more extensive bibliographic information of cited papers and how you can present your programming code in the appendix.

Below, we summarize the essential guidelines to follow in your writing. Examples for typical elements, such as including citations, cross references, and the inclusion of figures and tables are shown in Chapter 1 and Chapter 2. Each content element (e.g. abstract, table of contents, chapter, bibliography) starts on the right page (recto). This means that in some cases the left side (verso) will be left blank. LaTeX will take care of this.

Structure of your thesis

- **Abstract:** It follows the structured abstract of A&A. Write a few sentences for each of the indicated blocks. The length of the abstract should be about half a page. Do not use abbreviations, acronyms, or formulae in this block. Typically this section is written as last.

- **Acknowledgements:** This section allows you to give explicit credit to people, institutions, programs, or projects. This template shows typical examples. Many telescopes, space missions or software projects provide predefined sentences for the acknowledgements which you simply should copy. Make sure that you cite the requested instrumental-reference papers in the text body.

- **Text body:** consists of the main content of the paper. It starts with the first chapter, the *Introduction*, where you explain, how your research question connects to the bigger picture of the field. Do not write a review on the whole field. Rather follow the recipe depicted in Fig. 0.1. Ideally, you pick up the argumentative thread again in the the final section on *Discussions & Conclusions* and demonstrate how your work has advanced on the addressed topics.

- Name and content of the following chapters are not defined. However, it should loosely follow the logic: *Methodology*, *Observing techniques* (or simply) *Data – Analysis – Results – Discussions & Conclusions.* Optimally, you have a LaTeX file per chapter, as demonstrated in this template.

[4] The PDF version of the editorial guidelines: https://www.aanda.org/doc_journal/instructions/aadoc.pdf

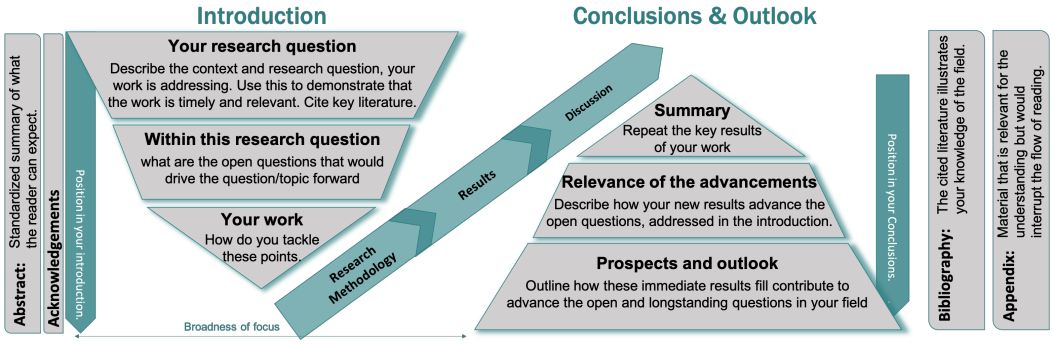

Fig. 0.1.: Schematic structure of the elements of a thesis or research paper. The cones depict the ideal logical flow of the chapters of the *Introduction* and *Conclusions & Outlook*.

- Sections or subsections will follow the logic of your work. Use lower case for all words in chapter and section title headings, except for the first character. Do not introduce subsubsections.

- **Bibliography:** This section provides all information to find and retrieve your cited literature unambiguously. If you are using the recommended BibTex package to manage your references, this part will be taken care of for you by LaTeX. How to work with BibTex is demonstrated below.

- **Appendix** is used to place extensive content, which would otherwise interrupt the reader. It can have several sections, labeled with capital letters. You typically would place code, additional figures, or large tables. Content in the appendix, such as figures, tables, or supplementary method descriptions in sections, needs to be referenced at least once in the main text body.

- For a master or PhD thesis, include the **Curriculum Vitae**. Complete the predefined sections. List what is relevant to your studies and research activity.

- List your scientific publications in the **List of publications**.

As the first step in your writing process, we recommend that you lay out the anticipated structure and approximate content by crafting chapter and perhaps the main section titles. This first structure can already be implemented in the template and be discussed with your adviser early on. Doing this will allow you to have a more straightforward path to assess the thesis's content and expected workload.

Literature references & managing your bibliography

- A citation is needed whenever a bibliographic reference to published content is required. The leading astronomical journals use the style of inter-textual citations. In this format, you see the first author's name in the text, most likely to be followed by *et al.* to indicate that more than two authors have signed the paper and the publication year of the paper. The *Bibliography* section in the rear provides all the information on how to retrieve the cited article. Each item listed in the bibliography needs to be referenced at least once in the paper.

- BibTex is a powerful software package that will help you to easily manage your bibliographic references and the respective bibliography. By using the citation commands \cite{}, \citep{}, \citep[]{}, and \citep[][]{} you create inter-textual references. The following examples show how the above mentioned macros can be used in the syntax of a sentence:

  – It was shown by Beck et al. (2015) that the long-periodic variations of the radial-velocity signal of θ^1 Tau originates from stellar activity.
  – Combining remote-sensing image data with in-situ measurements have lead to an improved flare-CME characterization (Temmer et al., 2017).
  – The extreme-ultraviolet Radiation from A-stars has significant implications for the formation of (Fossati et al., 2018, and references therein).
  – This topic has been discussed in the recent literature (e.g. see Hanslmeier, 2018; Veronig, 2020, and references therein).

- To cite from a monography use the \citep[]{} command to reference the book you are citing. If of relevance you can note to which chapter or page you are referring to in the squared brackets of the makro.

- Those macros access the content of the file *bib-refs.bib*. To add references, copy the content from *'export citation'* on the NASA ADS webpage of a paper into the bib-file. Experience has shown that it will improve the readability of your LaTeX code if you change the predefined bibcode (e.g., 2017SoPh..292...93T) into a more user-friendly keyword (e.g., Temmer2017), which is then used in the macros mentioned above to cite the paper.

Cross references to elements inside your thesis

- Each Figure, Table, and Equation presented in the paper needs to be referenced at least once in the text body. The objects of each group (figures, tables,

equations) must be introduced in the paper in consecutive order: Reference Fig. 1 in the text before you mention Fig. 2.

- Abbreviate the following expressions unless they appear at the beginning of a sentence: *Sect., Sects., Fig., Figs., Col., Cols.*. *Table* and *Listing* are never abbreviated in a paper. Write the object abbreviation in the upper case if used as a numbered reference. Otherwise, object names should not be abbreviated and written in lower case.

  – Figure 1.1 shows the position of 18 eccentric binary in the HR diagram.
  – As shown in Fig. 1.1, the 18 eccentric binary are found on the low-luminosity red-giant branch (RGB).
  – The 18 eccentric binary are found on the low-luminosity RGB (see Fig. 1.1).

- To generate an automated numbering, you need to create a reference-able label, using *label*{*keyword*}. Calling the keyword through the reference macro, *ref*{*keyword*} will create the reference in the text. You can freely choose the keyword. Experience has shown that it is good practice to encode what kind of object you are referencing into the keyword, e.g. *label*{*fig:HRD*}, *label*{*tab:redGiantCatalogue*}, *label*{*eq:pythagoras*}, or *label*{*sec:introduction*}.

  Note that the template contains customized macros in the *main.tex* for all full and abbreviate element names. This way, you only need to type, e.g. *Fig*{*fig:HRD*}, instead of *Fig.*\,*ref*{*fig:HRD*}

Figures

Example of single and multi-panel figures and their caption format are given in Fig. 1.1 and Fig. 2.1, respectively.

- **Position:** to be placed on top of the page, using the figure attribute *[t!]*. Do not place a figure on the first page of a chapter.

- **Message:** be clear to yourself, what take away message is, which you want to give to the reader of your paper by showing this figure. Now optimize your figure to maximize the storytelling: use different symbols, line styles, and colors. A good test for a colored figure is if it is still readable on a black-and-white printout.

- **Caption**: The first sentence of the figure's caption should be a sentence describing the figure. This sentence should start without 'The' / 'This', 'A / An',

or similar. Describe all symbols and line styles used in the figure. Express no physical or scientific interpretation of the depicted context.

- Refer to the figure's axes as the *'horizontal'* and the *'vertical axes'*, instead of the x- and y-axis, respectively.

- For multi-panel figures, you should refer to the individual panels by using *'top left panel'*, *'middle bottom panel*, or *'bottom right panel'*.

- In case you show additional figures depicting different data but using the identical symbol and color scheme, you can refer to the first figure explaining the meaning. State something like *'Meaning of the colors and symbols is similar to Fig. XY'*.

- If you show a figure previously published in another article, you need to indicate the source, such as *(Figure taken from REFERENCE)*. In case somebody provided you an unpublished figure, you would state *(Figure provided by PERSON)*.

- **Axis labels**: produce plots with readable axes, labels, and ticks. Unreadable labels are the easiest way of getting into trouble with the referee (or adviser).

- Format: preferably use PNG to avoid excessive file sizes for figures depicting many datapoints.

Tables

An example of a simple, complex and a multi-page table are given in Tab. 2.1, Tab. 2.2, and Tab. A.1 respectively.

- **Position:** to be placed on top of the page, using the table attribute *[t!]*. Do not place a table on the first page of a chapter.

- **Caption:** (on top of the table): The table caption should be a one-line sentence, describing the table and placing it into the work or paper context. This sentence should start without 'The' / 'This', 'A / An', or similar.

- **Layout:** Tables start from above with a double vertical line, followed by the table header, followed by a single line, followed by the table's content. A final horizontal line is closing the table.

If appropriate, you can use horizontal lines in the table body to mark separations. In this case, the A&A guidelines refer to the separated blocks as panels. An example is given in Table 2.1.

- The content of the table is typically formatted to the left or right of the column. If you wish to do the extra work for a nice looking table, you can center the header, as shown in Tab. 2.2.

- **Tablefoot:** (text block below the actual table starting with **Notes.**) should contain all relevant information for each column should be provided in the table foot. If you use abbreviated references, you should give the connection to the inter-textual references here. Express no physical or scientific interpretation here. The tablefoot-macro requires an empty line between the text and the table to avoid layout issues.

- **Extensive tables** can be presented in the landscape format and / or be split over several pages (longtable). Consider placing it in the Appendix. In this case, you could place the tablefoot-block into the text body of the Appendix as demonstrated in Appendix A

- Tables are usually not used in the Introduction or Conclusions chapter.

Equations

- Treat equations as part of the sentence and place them like a subordinate clause. See Eq. 1.1 and 1.2 for an example.

- All mathematical symbols used in the equation need to be defined near the equation, if not defined before in the text. Mention the physical units of the parameter used in the equation.

- Text in equations or math mode is written in italics per default. In case you want to place a subscript text, which is not an index, you need to force it to be non-italic, e.g., P_{orb}.

Presentation of code and code snippets

One of the bricks of the fundament of science is the replicability of disseminated results. Therefore, the modern standard of research journals that any elaborated code that is used for the data analysis presented in the paper should be made available to

the reader. Such code is typically distributed on pages such as GitHub.com. For your thesis, we simulate such public distribution of code by presenting your code in the appendix. Discuss with your adviser if or what part of your code should be part of the thesis work. Listing 2.1 and Appendix B demonstrate how code (snippet) or pseudo-code is to be presented in the textbody and appendix your thesis, respectively.

Presentation in the text body

- Only essential code parts or concepts (via snippets or pseudo code, respectively) should be presented in the main body of your thesis.

- The `verbatim` command is a very severe command, which cannot be used within the iteration tools. Instead of `verb` or `verbatim`, please use *\texttt{}*.

- Treat the code listing like a table. The **caption** should be a one-line sentence, describing the table and placing it into the work or paper context. This sentence should start without 'The' / 'This', 'A / An', or similar. Explain the environment and variables in the **tablefoot**. See Listing 2.1 for an example.

Presentation in the Appendix

- Before listing the code, provide a preamble outlining your system dependencies of your code (scripting language, version, etc.) Any necessary information should be given in the preceding preamble. An expamle is shown in Appendix B.1 and Table B.1.

- Provide a caption as described above, to create a referencable object.

- Each program should be listed in a separate section of the Appendix. Before listing the source code, provide an abstract of the tasks and functions of the program. Also, give a brief characterization (name, version, download information) of any non-standard package that you have used imported and used.

- Listing B.2 provides an example. For the reader's benefit, provide in-code comments and documentation.

- If you have built-in options, provide a table explaining the options' functionality and how they are called. Table B.2 provides an example for the necessary documentation. For those tables, use the positioning argument [h!].

- To see how to include MESA inlists, activate Appendix C. For those use 'language= Fortran'.

Abfassen einer Arbeit auf Deutsch

- Sollten Sie diese Arbeit auf Deutsch verfassen, so sind auch die Elemente auf Titelseite, Elementnamen (Abstract, Acknowledgements, Table, Figure) sowie der Colophon zu übersetzen. Die Endung 'et al.' verbleibt als solches.

- Fachbegriffe müssen in ihrer deutschen Übersetzung ausgeschrieben werden, da eine Mischung zwischen Deutsch und English nicht zulässig ist.

- Die Erfahrung hat jedoch gezeigt dass es dem Verständnis des Textes zuträglich ist, wenn in Klammer nach der ersten Verwendung eines Begriffes die englische Originalbezeichnung so wie die in der Literatur übliche Abkürzung angegeben wird. Geben Sie im Appendix ein Glossar der englischen Fachbegriffe sowie der in der Arbeit verwendeten Übersetzung wieder (siehe das auskommentierte Bsp. *appendix_DeutschesGlossar.tex*). Im Text können die Abkürzungen Verwendung finden, wobei bei der ersten Abkürzung im Text eine Fußnote zu setzten ist um auf die Tabelle im Appendix zu verwesien, z.B:

  Der rote Riesensternast (in der englischsprachigen Fachliteratur auch als red giant branch oder abgekürzt RGB[5] bezeichnet) ist das Stadium des Wasserstoffschalenbrennens. Dieses RGB-Sterne besitzen einen degenerierten Heliumkern.

[5] In diesem Text werden der Fachliteratur entsprechend die Abkürzungen des englischsprachigen Fachbegriffes verwendet. Siehe ebenfalls Table **??** im Anhang.

Submitting your thesis at the University of Graz

Once your thesis is ready to be submitted, do the following steps:

- **Finalize your manuscript:** in the file *titlepages.tex*,
  – change the updated date (*today*) on page i and iv to the date of the submission.
  – delete the red line on Page iv and fill out the actual date of your submission.
  – The corporate-design manual[6] of the University of Graz has assigned the *blue-green*, you find throughout the thesis. Please make sure that you have deactivated or deleted all other text-coloring macros, except for *physbf*{} and *physit*{}.

- **Submission of a Bachelor thesis:** Send the final PDF of your thesis at least a week before you final presentation to your adviser(s). At *University of Graz* you also have to upload your thesis to UNIGRAZonline in order to do the mandatory plagiarism check. A detailed description of the upload process can be found here. You will receive feedback from your supervisor about the outcome. When your adviser gave you their approval, please provide a signed hard copy of your thesis to (each of) your advisers. We ask you to produce these copies with a thermal and not a spiral binding.

- **Submission of a Master thesis:** This summary describes the main steps for the formal submission of your Master thesis at the *University of Graz*. Detailed instructions are found on the webpage[7] the University of Graz. For submission of a thesis manuscript at the TU Graz, please refer to their webpage[8].

  – You first need to *register the title of your thesis in the university systems*. Ideally, you do this in the final stage of your writing process, about one month before the actual submission to avoid unnecessary delays in the process. To file in your thesis title at the dean's Office, download and complete the latest form[9]. You, your advisers and the head of the Physics Institute must sign this form and it has to be submitted directly (in paper) at the Dean's office for study Affairs ("Prüfungsreferat der Naturwissenschaftlichen Fakultät").

[6] https://presse.uni-graz.at/de/services/corporate-design/
[7] https://nawi.uni-graz.at/de/studieren/informationen-und-formulare-fuer-studierende/einreichen-von-diplom-masterarbeiten-und-dissertationen/
[8] https://tu4u.tugraz.at/studierende/mein-studienabschluss/masterarbeit/
[9] https://nawi.uni-graz.at/de/studieren/informationen-und-formulare-fuer-studierende/bekanntgabe-des-diplom-oder-masterarbeitsthemas/

– For the *actual submission of your manuscript*, you have to register and upload your final thesis in your personal UNI GRAZ ONLINE account. After your adviser has confirmed your thesis online, you have to hand in two hard copies of your work (plus a form[10]), including the abstract but without the declaration, into the Dean´s office. The electronic upload automatically initiates the obligatory *plagiarism check*.

For your planning, please consider that it takes **at least four weeks** (from the submission of your thesis) before your the date of the Master´s exam can be scheduled. After your adviser has officially graded your thesis, you are done with your thesis.

Detailed instructions and up-to-date forms for the submission process of master and PhD thesis can be found on the webpage[11] the University of Graz.

For the submission of a thesis of students who are main inscribed at the TU, it is important that you replace *'titlepageKFU.tex'* with *'titlepageTU.tex'* and adapt it accordingly.

- **Submission of a PhD thesis:** Detailed instructions and up-to-date forms for the submission process of a PhD thesis are found on the webpage[11] of our Alma Mater, the University of Graz.

[10] "Ansuchen um Beurteilung der Masterarbeit oder Diplomarbeit", to be downloaded at 11

[11] https://nawi.uni-graz.at/de/studieren/informationen-und-formulare-fuer-studierende/einreichen-von-diplom-masterarbeiten-und-dissertationen/

Color scheme and implemented tools for iteration

The implemented blue-green color in section headings and text markup agrees with the corporate-design manual[6] of the University of Graz and the assigned scheme for the Institute for Physics. You can use these comments to highlight important text. This is the only color to be used for text as markup in the submitted version.

Macro name	Example & Explanation
physbf{}	**bold text with CI color.**
physit{}	*italic text with CI color.*

You will find the following macros useful to mark text or place action items and comments in the iteration phase. This approach adopts typical elements of a paper's revision phase, indicating changes requested by the referee.

myComment{}	*[StudentPlaceYourInitialsHere: Macro marking a comment with your initial.]*
myRevision{}	**This macro is to mark text, revised according to your adviser comment.**
myToDo{}	*[*TODO*: describe your identified action item.]*

If you and your adviser choose to communicate via a shared project on overleaf, then your adviser has the following defined tools at their disposal to mark and comment. Typically, you can expect an explanation next to *Markover* or *Cossout* why this text requires further attention or should be deleted.

adviserComment{}	*[AdviserPlaceYourInitialsHere: Macro marking a comment of your adviser]*
adviserAddition{}	**Macro marking an textual addition to your thesis.**
adviserHighlighted{}	Macro highlighting a text in yellow.
longSentence{}	Same as above, printing *'long sentence'* to the right.
adviserMarkover{}	*Macro marking a text that requires a makeover.*
adviserMarkoverComment{}{}	*Marking text. [AdviserPlaceYourInitialsHere: Placing a comment]*
adviserDelete{}	~~*Text to be deleted.*~~

You are free to change the iterative tools' color settings if you do not like the chosen colors. If so, please make sure that your and your adviser's macros remain well distinguishable in color.

Abstract

Context.

Aims.

Methods.

Results.

Conclusions.

Acknowledgement

This thesis made use of the infrastructure, resources and observational facilities of the Department for Geophysics, Astrophysics and Meteorology (IGAM) at the Institute of Physics of the University of Graz. I thank DI Roland Maderbacher and Mag. Klaus Huber for maintaining the IT-infrastructure, software installations, the server farm and providing technical support, whenever needed. The team of UniIT is thanked for maintaining and supporting the use of the high performance cluster (HPC), used for computations presented in this thesis. I thank Dr. Rainer Kuschnig, Mag. Robert Greimel, Josef Ramsauer, and Dr. Martin Leitzinger for their technical support and expertise at the Lustbühel Observatorium Graz (OLG) operated by the University of Graz. This thesis made use of infrastructure, which was supported by NAWI Graz.

I thank the people behind the space missions, whose data we were using in this thesis. This thesis includes data collected by the *Kepler* and the *TESS* missions. Funding for the *Kepler* mission is provided by the NASA Science Mission directorate. Funding for the *TESS* mission is provided by the NASA Explorer Program. This work also has made use of data from the European Space Agency (ESA) mission *Gaia*, processed by the *Gaia* Data Processing and Analysis Consortium (DPAC). Funding for the DPAC has been provided by national institutions, in particular, the institutions participating in the *Gaia* Multilateral Agreement. Based on data collected by the BRITE Constellation satellite mission, designed, built, launched, operated and supported by the Austrian Research Promotion Agency (FFG), the University of Vienna, the Technical University of Graz, the University of Innsbruck, the Canadian Space Agency (CSA), the University of Toronto Institute for Aerospace Studies (UTIAS), the Foundation for Polish Science & Technology (FNiTP MNiSW), and National Science Centre (NCN). This work has utilized the MESA stellar evolutionary code package, Modules for Experiments in Stellar Astrophysics (MESA Paxton et al., 2011; Paxton et al., 2013; Paxton et al., 2015; Paxton et al., 2018; Paxton et al., 2019). The MESA EOS is a blend of the OPAL (Rogers and Nayfonov, 2002), SCVH (Saumon et al., 1995), FreeEOS (Irwin, 2004), HELM (Timmes and Swesty, 2000), PC (Potekhin and Chabrier, 2010), and Skye (Jermyn et al., 2021) EOSes. Radiative opacities are primarily from OPAL (Iglesias and Rogers, 1993; Iglesias and Rogers, 1996), with low-temperature data from Ferguson et al. (2005) and the high-

temperature, Compton-scattering dominated regime by Poutanen (2017). Electron conduction opacities are from Cassisi et al. (2007). Nuclear reaction rates are from JINA REACLIB (Cyburt et al., 2010), NACRE (Angulo et al., 1999) and additional tabulated weak reaction rates Fuller et al. (1985), Oda et al. (1994), and Langanke and Martinez-Pinedo (2000).Screening is included via the prescription of Chugunov et al. (2007). Thermal neutrino loss rates are from Itoh et al. (1996). This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France. This research has made use of the Exoplanet Follow-up Observation Program website, which is operated by the California Institute of Technology, under contract with the National Aeronautics and Space Administration under the Exoplanet Exploration Program.

Software: `Python` (Van Rossum and Drake, 2009), `numpy` (Oliphant, 2006; Harris et al., 2020), `matplotlib` (Hunter, 2007), `scipy` (Virtanen et al., 2020), `pandas` (team, 2020; McKinney, 2010). This research made use of `astropy` (Astropy Collaboration et al., 2013; Astropy Collaboration et al., 2018)., a community-developed core Python package for Astronomy.

I gratefully acknowledge the Austrian Science Fund (FWF): P30949-N36 (PI: Temmer) for supporting this project. This work was supported with funding of the Dr. Heinrich-Jörg Foundation at the Faculty of Natural Sciences at the Karl-Franzens University of Graz. The authors acknowledge the support from ERASMUS+ grant number 2017-1-CZ01-KA203-035562.

Contents

1 Introduction

Binary stars play a major role in astrophysics since their analysis by different means enables astronomers to deduce various stellar properties. In this thesis the binary system KIC 10614012 is analysed by combining asteroseismic techniques with radial velocity measurements and light curve analysis. This star system, also referred to as TYC 3561-1138-1, is part of the Kepler Input Catalog (KIC), a catalogue for potential target stars of the *Kepler* mission. KIC 10614012 is an eclipsing binary (EB), i.e. an eclipse is visible in its light curve (as written in Kirk et al., 2016). Furthermore, Beck et al. (2014) has shown that this star exhibits tidally induced flux modulations during periastron passage, on its eccentric ($e = 0.71$) orbit. Such binary stars, theorized by Kumar et al. (1995), are colloquially referred to as *Heartbeat stars*, a term coined by Thompson et al. (2012).

This case study is divided into 7 sections. The first section (Sec. 1) gives a brief introduction into some of the underlying astrophysics of this analysis. Sec. 2 presents the three datasets used for this case study (light curves, asteroseismic power spectra and radial velocity measurements) and the instruments which obtained them (*Kepler* and HERMES). The analysis of KIC 10614012 by means of asteroseismology is described in Sec. 2, while the next chapter (Sec. 3) deals with the system's analysis regarding its binary features. The fifth section (Sec. 3) combines results from the previous two sections and estimates stellar properties of both, the primary and the secondary. A discussion of those results and a comparison to other studies are given in Sec. 4. Eventually, in Sec. 5 some conclusions are drawn, suggestions for further analysis of KIC 10614012 are given and a brief outlook on future prospects in asteroseismology is provided.

Calculating the hypotenuse follows the sentence of Pythagoras,

$$c^2 = a^2 + b^2, \tag{1.1}$$

$$c = \sqrt{a^2 + b^2}, \tag{1.2}$$

whereby a and b are the cathetus and c the hypotenuse of a right-angled triangle. Please note that a and b are typically in the range of $10^{-9} \lesssim \mathrm{R/R_\odot} \lesssim 10^{6}$.

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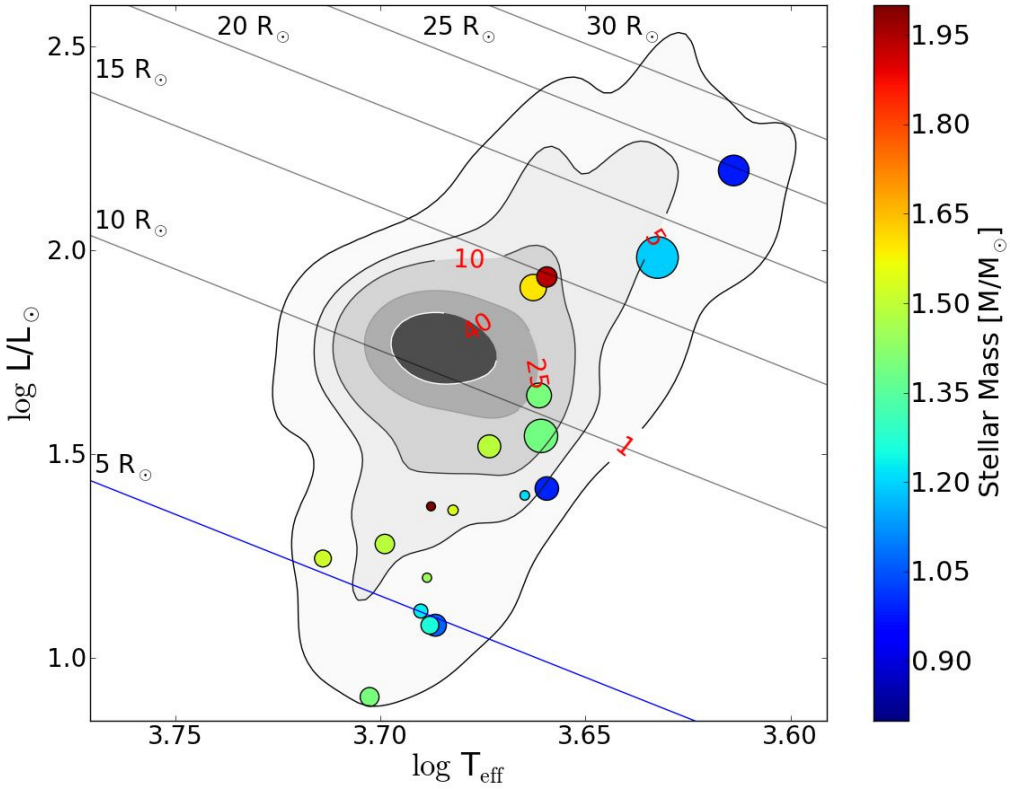

Fig. 1.1.: Position of the 18 red giant heartbeat stars from Tables 1 and 2 in the HR diagram, where the colour shows the mass of the red giant, derived from seismology. The size of the dots represents the orbital period, ranging between 20 and 438 d. The contour surfaces reflect the density distribution of 1000 pulsating red giants. The darkest areas mark the position of the densely populated red clump. Numbers in red indicate the star count per bin, for which the contour surfaces have been drawn. Lines of equal radii in the HR diagram have been drawn for selected stellar radii between 5 and 30 R. (Figure taken from Beck et al., 2014)

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2 Methodology

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2.1 This is a section

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Table 2.1.: Training sample of false-positive planet candidates for the clustering algorithm.

Star's identifier	$T_{\rm eff}$ [K]	Lum [$L/L_\odot$]	Luminosity cluster	Reference
π Her	4170	1320	High	Hatzes and Cochran (1999)
μ UMa	3899	1150	High	Lee et al. (2016)
HD 18438	3871	830	High	Delgado Mena et al. (2018)
γ Dra (Eltanin)	3990	510	High	Hatzes et al. (2018)
α Tau (Aldebaran)	4055	440	High	Hatzes et al. (2015)
θ^1 Tau	5000	70	Low	Beck et al. (2015)
NGC2423 No.3	4592	65	Low	Delgado Mena et al. (2018)
γ Psc	4909	60	Low	Beck et al. (2015)
β Gem (Pollux)	4865	40	Low	Delgado Mena et al. (2018)
IC4651 No.9122	4720	35	Low	Delgado Mena et al. (2018)
γ Cep A	4900	10	Low	Hatzes and Cochran (1999)

Notes. The star's identifier is given. For the most prominent stars, the name of the star is amended in brackets. The next columns report on the effective temperature and the luminosity of the star in units of the solar luminosity $L_\odot$. The typical uncertainty of the reported temperature and luminosity are 150K and $\sim$10%, respectively. The top and bottom panel report classification of the clustering. The cluster name refers to the position in the red-giant phase. The literature references are provided in the last column. (Table taken from Elisabeth Höldrich bachelor thesis, 2020)

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2.1.1 This is a subsection

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Listing 2.1: Example for setting the tidal mechanisms in the *star_star* inlist.

```
1 &binary_controls
2          do_tidal_circ = .true.
3          circ_type_1 = 'Hut_conv'
4          circ_type_2 = 'Hut_conv'
5
6          do_tidal_sync = .false.
7          sync_type_1 = 'Hut_conv'
8          sync_type_2 = 'Hut_conv'
```

Notes. A part of *&binary_controls* environment in the *star_inlist* is shown. The true/false-statements in line 2 and 6 determine if the models defined below takes into account the defined mechanism. The keywords for defining the formalistic description for circularization and synchronization mechanism are defined in lines 2-4 and 6-8, respectively. The number at the end of the keyword indicates which formalism is set for the primary (1) and secondary (2) stellar component.

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2.2 Example of a code snippet

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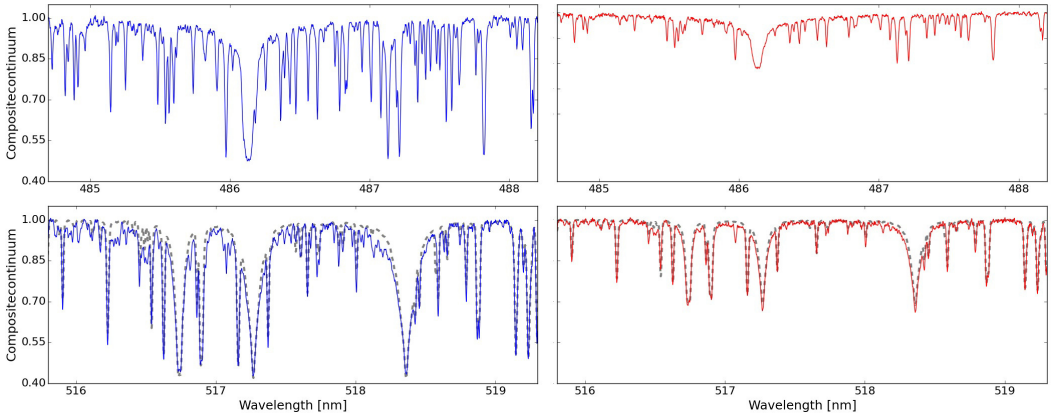

Fig. 2.1.: Disentangled spectra of KIC 9163796. The spectra of the primary in blue and secondary in red are shown in the left and right spectrum, respectively. Top panel: the region around the Hβline, while bottom panel: magnesium triplet at 518 nm, normalised to the continuum flux of the composite spectrum. The synthetic model of the best fit of the determination of fundamental parameters and metallicity is shown as dashed grey line is shown depicted in the region of the Mg triplet. (Graphic taken from Beck et al., 2018)

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Table 2.2.: Seismic and fundamental parameters for 14 oscillating red giant heartbeat stars, ordered by descending orbital period.

Star KIC	$\nu_{\max}$ [μHz]	$\Delta\nu$ [μHz]	$\Delta\Pi_1$ [sec]	$\delta f_{\max}$ [nHz]	Evol. Phase	R [$R_\odot$]	M [$M_\odot$]	$\log g$ [dex]	L [$L_\odot$]	$T_{\rm eff}$ [K]	$P_{\rm orbit}$ [d]	A [ppt]	$\lvert\Delta$RV$\rvert$ [km s^{-1}]
9151763	13.8±0.2	1.98±0.01	–	–	RGB?	17.6±0.4	1.19±0.08	2.01	96±16	4290	437.5	+7.1	32.2
7431665	54.0±0.7	5.46±0.02	∼67	–	RGB	9.4±0.1	1.39±0.05	2.62	35±2	4580	281.4	-3.0	[37.8]
5039392	6.2±0.1	1.13±0.01	–	–	RGB	24.0±0.7	0.98±0.07	1.67	157±24	4110	236.7	-6.0	42.3
9540226⋆	27.4±0.4	3.18±0.01	–	–	RGB	14.1±0.3	1.6±0.1	2.37	81±13	4600	175.4	-7	45.3
8210370	44.1±0.8	4.69±0.02	–	–	RGB?	10.5±0.2	1.40±0.08	2.54	44±4	4585	153.5	-5.3	22.1
11044668	50.2±0.2	5.65±0.01	∼60	83(?)	RGB	8.18±0.09	0.99±0.03	2.59	26±3	4565	139.5	-3.8	[43.0]
10614012⋆	70.2±0.9	6.54±0.02	–	–	RGB	8.6±0.2	1.49±0.08	2.74	33±4	4715	132.1	-4.7	49.3
9163796	153.2±0.7	13.53±0.04	–	–	RGB	4.46±0.03	0.89±0.01	3.09	12±1	4820	121.3	±0.5	70.1
2444348	30.5±0.3	3.26±0.01	–	–	RGB	14.9±0.3	1.94±0.11	2.38	86±14	4565	103.5	-1.7	7.7
5006817	145.9±0.5	11.64±0.01	78	450	RGB	5.84±0.09	1.49±0.06	3.08	19±3	5000	94.8	-1.7	23.5
8803882	347±3	22.6±0.4	–	500(?)	RGB	3.68±0.1	1.4±0.1	3.45	8±1	5043	89.7	+0.5	[1.9]
8144355	179±2	13.95±0.04	∼78	210(?)	RGB	4.90±0.09	1.26±0.08	3.16	12±2	4875	80.6	+2.1	18.9
9408183	164.8±0.2	13.29±0.02	∼93	450	RGB	5.02±0.07	1.23±0.05	3.12	13±1	4900	49.7	+1.5	64.4
2720096	110.1±0.7	9.17±0.01	–	–	RGB	6.98±0.08	1.54±0.06	2.95	23±2	4812	26.7	+1.0	4.0
8095275	69.3±0.3	6.81±0.01	–	–	RGB	7.78±0.08	1.21±0.05	2.74	25±3	4622	23.0	-6.0	20.6

Notes. The star's identifier in the *Kepler* Input Catalogue (KIC) is given. Eclipsing systems are marked with an asterisk. The columns $\nu_{\max}$ and $\Delta\nu$ report the frequency of the oscillation power excess and the large frequency separation between radial modes for a given star. $\Delta\Pi_1$ quantifies the true period spacing of dipole modes. The maximum value of the detected rotational splitting δf is listed. The evolutionary phase RGB describes H-shell burning red giant. Ambiguous values are marked with '?'. The columns R, M, L, and $\log g$ report the stellar radius, mass, luminosity, effective temperature and surface gravity from scaling relations, respectively. $T_{\rm eff}$ was adopted from the KIC. The uncertainties of $\log g$ are on the order of 0.01 dex and for the temperature typically smaller than 150 K. $P_{\rm orbit}$ gives the orbital period from photometry. The column A lists the maximum amplitude of the heartbeat in a rebinned phase diagram. The error estimate for $P_{\rm orbit}$ and A from the PDM is not reliable due to the remaining contamination of the solar-like oscillations and therefore not given. $\lvert\Delta$RV$\rvert$ reports the maximum difference in radial velocity. Squared brackets mark systems for which the orbital parameters could not yet be determined from radial velocities. (Table taken from Beck et al., 2014)

3 Results

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4 Discussion

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5 Conclusion and Outlook

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A Literature values for *Kepler* systems

[This appendix has been published as Appendix C of Beck et al. (2018)].

The parameters for eclipsing binaries are taken from the dynamical solution of G16. For the list of heartbeat stars (B14), radius and mass were inferred from seismic scaling relations and corrected for the systematic mass overestimate of 15% reported by G16. Surface rotation periods were adopted from G14, B14 and B18. For four stars of B14, KIC 7431665, KIC 11044668, KIC 8803882, and KIC 7799540, no orbital parameters have yet been published.

A.1 Compilation of literature values

We refer to the cited literature for details on the applied methodology. Table A.1 contains the following parameters,

- *KIC* specifies the target identification number in the *Kepler* Input Catalog.
- *Type* indicates if a binary system is an eclipsing binary (EB), a heartbeat system (HB), or an eclipsing heartbeat system (eHB). 'NO' indicates that the star belongs to the four non-oscillating stars of G14/G16.
- $P_{\rm orbit}$ is the measured orbital period.
- e is the orbital eccentricity.
- $\nu_{\rm max}$ is the peak frequency of the excess of oscillation power.
- $R/R_{\odot}$ is the stellar radius in solar units. Values from B14 are seismically inferred and corrected for the 5% overestimate of seismic radius. Values from G16 originate from a dynamical solution.

- $M/M_{\odot}$ is the stellar mass in solar units. Values from B14 are seismically inferred and corrected for the 15% overestimate of seismic mass. Values from G16 originate from a dynamical solution.

- $q = M_2/M_1$ is the mass ratio between the two stellar components in the system. '?' indicates if q has not been determined for a given system.

- $T_{\rm eff}$ is the effective temperature.

- $P_{\rm rot}$ specifies the time scale of the flux modulation, identified as the surface rotation period. The sources of the values are G14 and B18. We round all period values to the next full day.

- The dimensionless number ε_r is proportional to the inverse of the time scale of tidal circularisation (see Eq. XX). If no value of the mass ratio is specified, ε_r is calculated for $q = 0.5$.

- REF: the last column is specifying the literature references. If several papers are reporting on a given system, values of the most recent paper are cited. Previous references are given in brackets.

Table A.1.: Literature Parameters of red-giant binaries in the *Kepler* sample.

KIC	Type	P_{orb} [days]	e []	ν_{max} [μHz]	$R/R_\odot$ []	$M/M_\odot$ []	q []	T [K]	P_{rot} [days]	ε_R []	REF
2444348	HB	103.50 ± 0.01	0.48 ± 0.01	30.5 ± 0.3	14.2 ± 0.3	1.6 ± 0.1		?	4565	-	-0.53 B14
2697935	eHB	21.50 ± 0.02	0.41 ± 0.02	~ 405.6	~ 3.1	~ 1.2		?	4883	-	-0.73 B14
2720096	HB	26.70 ± 0.01	0.49 ± 0.01	110.1 ± 0.7	6.6 ± 0.1	1.3 ± 0.1		?	4812	-	0.83 B14
3955867	EB, NO	33.65685 ± 0.00007	0.019 ± 0.002	–	7.9 ± 0.1	1.10 ± 0.06	0.84 ± 0.05	4884	33	1.14	G16 (G14)
4569590	EB, NO	41.3710 ± 0.0001	0.004 ± 0.001	–	14.1 ± 0.2	1.6 ± 0.10	0.66 ± 0.05	4706	41	1.67	G16 (G14)
4663623	EB	358.09 ± 0.0003	0.43 ± 0.01	54.1 ± 0.2	9.7 ± 0.2	1.36 ± 0.09	0.99 ± 0.08	4812	-	-4.08	G16 (G14)
5006817	HB	94.812 ± 0.002	0.71 ± 0.01	145.9 ± 0.5	5.5 ± 0.1	1.3 ± 0.1	0.199 ± 0.001	5000	-	-2.80	B14
5039392	HB	236.70 ± 0.02	0.44 ± 0.01	6.2 ± 0.1	22.8 ± 0.7	0.8 ± 0.1		?	4110	-	-0.01 B14
5179609	EB	43.93108 ± 0.000002	0.150 ± 0.001	322 ± 1.0	3.50 ± 0.03	1.18 ± 0.03	0.51 ± 0.02	5003	182	-1.96	G16 (G14)
5308778	EB	40.5661 ± 0.0003	0.006 ± 0.005	49 ± 1.1	10.1 ± 0.3	1.5 ± 0.1	0.43 ± 0.03	4900	39	0.80	G16 (G14)
5786154	EB	197.918 ± 0.0004	0.3764 ± 0.0009	29.8 ± 0.2	11.4 ± 0.2	1.06 ± 0.06	0.96 ± 0.07	4747	-	-1.85	G16 (G14)
7037405	EB	207.1083 ± 0.0007	0.238 ± 0.004	21.8 ± 0.1	14.1 ± 0.2	1.25 ± 0.04	0.91 ± 0.03	4516	-	-1.62	G16 (G14)
7377422	EB	107.6213 ± 0.0004	0.4377 ± 0.0005	40 ± 2.1	9.5 ± 0.2	1.05 ± 0.08	0.81 ± 0.07	4938	55	-0.96	G16 (G14)
7943602	EB, NO	14.69199 ± 0.00004	0.001 ± 0.003	–	6.6 ± 0.2	1.0 ± 0.10	0.78 ± 0.09	5096	15	2.70	G16 (G14)
8054233	EB	1058.16 ± 0.02	0.2718 ± 0.0004	46.5 ± 0.3	10.7 ± 0.1	1.60 ± 0.06	0.69 ± 0.04	4971	-	-6.61	G16 (G14)
8095275	HB	23.00 ± 0.01	0.32 ± 0.01	69.3 ± 0.3	7.4 ± 0.1	1.0 ± 0.1		?	4622	-	1.86 B14
8144355	HB	80.55 ± 0.01	0.76 ± 0.01	179.0 ± 2	4.7 ± 0.1	1.1 ± 0.1		?	4875	-	-2.41 B14
8210370	HB	153.50 ± 0.01	0.70 ± 0.01	44.1 ± 0.8	10.0 ± 0.2	1.2 ± 0.1		?	4585	-	-1.92 B14
8410637	EB	408.3 ± 0.5	0.689 ± 0.001	46.0 ± 0.2	10.7 ± 0.1	1.56 ± 0.3	0.85 ± 0.16	4800	-	-4.34	F13
8430105	EB	63.32713 ± 0.00003	0.2564 ± 0.0002	76.7 ± 0.6	7.65 ± 0.05	1.31 ± 0.02	0.63 ± 0.01	5042	122	-0.73	G16 (G14)

Table A.1.: Literature Parameters of red-giant binaries in the *Kepler* sample. (continued)

KIC	Type	P_{orb} [days]	e []	ν_{max} [μHz]	$R/R_\odot$ []	$M/M_\odot$ []	q []	T [K]	P_{rot} [days]	ε_r []	REF
8702921	EB	19.38446 ± 0.00002	0.0964 ± 0.0008	195.6 ± 0.5	5.32 ± 0.05	1.67 ± 0.05	0.16 ± 0.01	5058	98	0.26	G16 (G14)
8912308	HB	20.17 ± 0.01	0.23 ± 0.01	~ 350.0 0	~ 4.0	~ 1.7	?	4872	-	-0.39	B14
9151763	HB	437.51 ± 0.03	0.73 ± 0.01	13.8 ± 0.2	16.7 ± 0.4	1.0 ± 0.1	?	4290	-	-2.62	B14
9163796	HB	121.30 ± 0.01	0.69 ± 0.002	165.3 ± 1.3	5.1 ± 0.1	1.2 ± 0.1	0.985 ± 0.005	4960	130	-3.17	B18 (B14)
9246715	EB	171.27688 ± 0.00001	0.3559 ± 0.0003	106.4 ± 0.8	8.30 ± 0.04	2.149 ± 0.007	0.990 ± 0.005	5030	93	-3.54	R16 (G14)
9291629	EB, NO	20.68643 ± 0.00004	0.007 ± 0.002	–	7.99 ± 0.05	1.14 ± 0.03	0.96 ± 0.03	4713	21	2.26	G16 (G14)
9408183	HB	49.70 ± 0.01	0.42 ± 0.01	164.8 ± 0.2	4.8 ± 0.1	1.0 ± 0.1	?	4900	-	-1.18	B14
9540226	eHB	175.4439 ± 0.0006	0.3880 ± 0.0002	27.1 ± 0.2	12.8 ± 0.1	1.33 ± 0.05	0.74 ± 0.04	4692	-	-1.64	G16 (B14, G14)
9970396	EB	235.2985 ± 0.0002	0.194 ± 0.007	63.7 ± 0.2	8.0 ± 0.2	1.14 ± 0.03	0.89 ± 0.03	4916	-	-3.38	G16 (G14)
10001167	EB	120.3903 ± 0.0005	0.159 ± 0.003	19.9 ± 0.1	12.7 ± 0.3	0.81 ± 0.05	0.98 ± 0.07	4700	-	0.03	G16 (G14)
10614012	eHB	132.13 ± 0.01	0.71 ± 0.01	70.2 ± 0.9	8.2 ± 0.2	1.3 ± 0.1	?	4715	-	-2.23	B14

A.2 Tidal properties of selected systems

Table A.2 lists the following parameters for the systems' red-giant primary with known $P_{\rm rot}$,

- δ_{10} is the $10^{\rm th}$ percentile of the logarithm of the ratio between the dissipation of the equilibrium and the dynamical tide, $\delta = \log(\mathcal{D}_{\rm eq} / <\mathcal{D}>_{\omega})$.
- $\tau_{\rm conv,10}$ is the corresponding convective turnover timescale computed in the middle of the convective zone.
- $P_{\rm tide} > \tau_{\rm conv,10}$ indicates if the tidal period is longer than the convective turnover timescale (Yes / No).

Table A.2.: Evolution of δ_{10} for the systems with know rotation period.

KIC	$P_{\rm tide}$ [days]	$\tau_{\rm conv,10}$ [days]	$P_{\rm tide} > \tau_{\rm conv,10}$	δ_{10}
7943602	357	20	Y	2.3-3.4
7377422	56	20	Y	3.7-4.8
3955867	845	20-23	Y	2.6-3.7
9291629	692	20-23	Y	2.3-3.4
5179609	28	23	Y	4.7-5.8
9163796	906	23	Y	3.8-4.9
8430105	65	23-26	Y	4.4-5.5
5308778	505	12	Y	3.0-4.1
4569590	2285	12	Y	2.4-3.5
8702921	12	12	N	4.2-5.3
9246715	101	14	Y	4.1-5.2

B Example for the presentation of programming code

B.1 System dependencies

The presented code is written for Python 3.7. Table B.1 details the used standard and specialized python packages and modules and is structured as follows.

- The package and module names are listed in the first column. Specialized modules are preceeded with the abbreviation of the parent package, whose abbreviated package name is inidacted in brackets.
- The version number of the used library is indicate in the second column.
- A brief module description is provided in the third column.

The top panel reports the standard python packages, contained in the standard python distribution. The bottom panel lists specialized packages, which require individual download. (Modified table based on Table A.1 from Rafael Goldgruber's Bachelor thesis).

Table B.1.: Required Python modules for the presented code.

Package / Module	Version	Modul Description
math	–	Access mathematical functions;
os	–	Miscellaneous operating system interfaces
glob	–	Creates iterable lists from folder content
matplotlib	3.3.1	Core package for scientific computation & plotting
numpy	1.19.1	Core package for numerical computing
astropy (ap)	4.0.1	Community Python Library for Astronomy
ap.astroquery	0.4	Querying astronomical web databases
ap.vizier	0.4	Importing online data and catalogues, published along with papers
ap.io.pyfits		Reading and operating with FITS files
mesareader	–	Reading MESA history and profile output files

B.2 Program to name new Planets

Provide a short description of the following script and give a brief description of the key settings or input format. The example below shows how to insert the code of a whole program from its source file.

Listing B.1: HelloPlanet.py: Sophisticated code to name new worlds.

```
1 import sys,os,math
2 import numpy as np
3 import pylab as pl
4
5 # here we have a comment on the scripting
6
7 for iii in np.arange(0,42):
8   print('Hello new planet number {}'.format(iii+1))
```

Table B.2.: Option menu for helloWorld.py (Listing B.1),

Type	Argument	Functionality
InCode	if xY==True	Description of what will happen if this option is used.
CmdL	-n	Description of what will happen if this option is used.
ReqIn	parameter name	Description of what will happen if this option is used.

Notes. Usage options: *InCode* curial options to be set inside the code before excecution of the program, *CmdL* options set in the command line, *ReqIn* requested user input during the execution of the program;

B.3 Example for long code listing

This section presents styles to present longer code snippets. To save printing space and cost, these are typset in a two-column format.

The combined presentation of Listing B.2 and Listing B.3 show how two snippets can be shown. Listing B.4 depicts how long code snippets or full programs can be included as multi-column and multi-page element.

Also for these listings a preamble stating the system requirements is needed.

Listing B.2: inlist1

```
&star_job
      show_log_description_at_start = .true.
      pgstar_flag = .true.
/ ! end of star_job namelist

&controls
      extra_terminal_output_file = 'log1'
      log_directory = 'LOGS1'
/ ! end of controls namelist

&pgstar
      History_Panels1_win_flag = .true.
      History_Panels1_win_width = 5
      History_Panels1_win_aspect_ratio = 1.0

      History_Panels1_title = 'Orbital␣evolution'
      History_Panels1_num_panels = 2

      History_Panels1_yaxis_name(1) = 'period_days'
      History_Panels1_other_yaxis_name(1) =
      'lg_mstar_dot_1'
      History_Panels1_yaxis_name(2) = 'Jdot'
      History_Panels1_other_yaxis_name(2) =
      'binary_separation'
/ ! end of pgstar namelist
```

Listing B.3: inlist2

```
&star_job
      show_log_description_at_start = .false.

/ ! end of star_job namelist

&controls
      extra_terminal_output_file = 'log2'
      log_directory = 'LOGS2'
/ ! end of controls namelist

&pgstar

/ ! end of pgstar namelist
```

Listing B.4: Example for a multi-column and multi-page code listing.

```
! inlist to evolve a 15 solar mass star

! For the sake of future readers of this file,
! ONLY include the controls you are actually using.
! DO NOT include all of the other controls that
! simply have their default values.

&star_job

  ! begin with a pre-main sequence model
    create_pre_main_sequence_model = .true.

  ! save a model at the end of the run
    save_model_when_terminate = .false.
    save_model_filename = '15M_at_TAMS.mod'

  ! display on-screen plots
    pgstar_flag = .true.

/ !end of star_job namelist


&controls

  ! starting specifications
    initial_mass = 15 ! in Msun units

  ! options for energy conservation
     use_dedt_form_of_energy_eqn = .true.
     use_gold_tolerances = .true.

  ! stop when the star nears ZAMS (Lnuc/L > 0.99)
    Lnuc_div_L_zams_limit = 0.99d0
    stop_near_zams = .true.

  ! stop when the center mass fraction
  of h1 drops below this limit
    xa_central_lower_limit_species(1) = 'h1'
    xa_central_lower_limit(1) = 1d-3

/ ! end of controls namelist

&pgstar

  ! MESA uses PGPLOT for live plotting and
  ! gives the user a tremendous amount of control
  ! of the presentation of the information.

```

```
49    ! show HR diagram
50    ! this plots the history of L,Teff over many
51    ! timesteps
52      HR_win_flag = .true.
53
54    ! set static plot bounds
55      HR_logT_min = 3.5
56      HR_logT_max = 4.6
57      HR_logL_min = 2.0
58      HR_logL_max = 6.0
59
60    ! set window size (aspect_ratio = height/width)
61      HR_win_width = 6
62      HR_win_aspect_ratio = 1.0
63
64
65    ! show temperature/density profile
66    ! this plots the internal structure at single
67    ! timestep
68      TRho_Profile_win_flag = .true.
69
70    ! add legend explaining colors
71      show_TRho_Profile_legend = .true.
72
73    ! display numerical info about the star
74      show_TRho_Profile_text_info = .true.
75
76    ! set window size (aspect_ratio = height/width)
77      TRho_Profile_win_width = 8
78      TRho_Profile_win_aspect_ratio = 0.75
79
80  / ! end of pgstar namelist
```

Curriculum Vitae
Mag. Nikolaus Copernicus, PhD

Born	February 19, 1473
Citizenship	Poland

Research positions and academic education

Current academic position

Affilitation & academic address	Institute for Physics, Karl Franzens University Graz, Universitätsplatz 5/II, NAWI Graz, 8010 Graz, Austria
Contact	nicolaus.copernicus@uni-graz.at

Research Positions

since March 2020	Doctoral researcher at the Department for Astronomy, Inst. of Physics, NAWI Graz, University of Graz, Austria
2019, March – 2020, March	Pre-doctoral researcher at the Department for Astronomy, Inst. of Physics, NAWI Graz, University of Graz, Austria

Academic Education

2017, February – 2019, March	University of Graz, Austria: Master of Natural Sciences in Physics (Graduation: March 32, 2019), Title of Thesis
2014, October – 2017, February	University of Vienna, Austria : Bachelor of Natural Sciences in Astronomy (Graduation: February, 30, 2017)

Academic Recognition

Invited talks at conferences and seminars

- **Title of invited contribution**, title of conference or occasion, length of contribution, (date, hosting institution)

Grants & Awards

- **Name of achievement**, awarding entity or agency, (awarded amount, duration)

Service to the community & memberships in academic organization

- **Refereeing activity for scientific journals**, give concise details
- **Membership in relevant professional societies, consortia or collaborations**, give concise details
- **Function in associations**, give concise details

Extended scientific or exchange stays

- Institution, program / purpose, give concise details

Teaching Portfolio

List here the courses you have assisted in or taught until now.

- **Name of Course**, (type of course: e.g. lecture, exercises, practicum, ...) Semester 202X, ECTS of the course, Bachelor's / Master's Curriculum, list your co- or lead-lecturer, description of your responsibilities in this course.

- **Name of Course**, (type of course: e.g. lecture, exercises, practicum, ...) Semester 202X, ECTS of the course, Bachelor's / Master's Curriculum, list your co- or lead-lecturer, description of your responsibilities in this course.

Nota bene: If you use this template for your Habilitationsschrift, replace this section by the structure and content of the teaching portfolio, as recommended[1] by the *Zentrum für Lehrkompetentz (ZLK) of Graz University.*

Observing Portfolio

The candidate has obtained XXX nights of accumulated observing experience of at international facilities:

- Observatory name and location, telescope, technique, number of nights

Proposals lead as Principle investigator

- **Title of successful proposal**, awarded observing time (observing semester), observatory, telescope & instrument specification

Proposals contributed to as Co-investigator

- **Title of successful proposal**, awarded observing time (observing semester), name of PI, observatory, telescope & instrument specification

[1] https://lehrkompetenz.uni-graz.at/de/service/lehrportfolios/

List of Publications

Bibliographic information and overview

Repository identifiers	ORCID: xxx, GitHub: xxx
Bibliometric indicators	H-index: xxx, m-index: xxx
Publication record in NASA ADS	URL of your private NASA ADS library

Refereed journal publications

Published work that is available as open access through the ArXiv.org preprint server or journal policies is indicated through the abbreviation [AO].

1. **Your, N.**, Author, A., Author, B., Author, C., ... , **Title of the paper**, Journal, Volume, pages, DOI, (Year) [AO]

2. Author, A., Author, B., **Your, N.**, Author, C., ... , **Title of the paper**, Journal, Volume, pages, DOI, (Year) [AO]

Conference proceedings and other publications

1. **Your, N.**, Author, A., Author, B., Author, C., ... , **Title of the conference proceedings paper**, Conference Series, pages, DOI, (Year) [AO]

2. Author, A., Author, B., **Your, N.**, Author, C., ... , **Title of the popular paper**, Popular Journal, Volume, pages, DOI, (Year) [AO]

Colophon

This thesis was typeset with LaTeX 2_ε. It uses the *Clean Thesis* style developed by Ricardo Langner, available at http://cleanthesis.der-ric.de/. The design of the *Clean Thesis* style is inspired by user guide documents from Apple Inc.

The template was adapted by Desmond Grossmann, BSc, Stefan Janisch, BSc, Lea Schimak and Paul Beck, PhD to implement the editorial guidelines of *Astronomy & Astrophysics* and the cooperate-identity guidelines of the University of Graz for the Institute for Physics. This thesis uses the template, released on the webpage of the *Department for Geophysics, Astrophysics and Meteorology (IGAM)*[2] on *February 12, 2021*.

[2] https://physik.uni-graz.at/de/igam/

Declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources/resources, and that I have explicitly indicated all material which has been quoted either literally or by content from the sources used. The text document uploaded to UNIGRAZonline or TUGRAZonline is identical to the present master's thesis.

Graz, June 23, 2022

Nicolaus Copernicus