



binary_c-python: A Python-based stellar population synthesis tool and interface to binary_c

D. D. Hendriks *¹ and R. G. Izzard ¹

¹ Department of Physics, University of Surrey, Guildford, GU2 7XH, Surrey, UK

DOI: [10.21105/joss.04642](https://doi.org/10.21105/joss.04642)

Software

- [Review](#) 
- [Repository](#) 
- [Archive](#) 

Editor: [Eloisa Bentivegna](#) 

Reviewers:

- [@trappitsch](#)
- [@schristophe](#)

Submitted: 20 July 2022

Published: 27 May 2023

License

Authors of papers retain copyright and release the work under a Creative Commons Attribution 4.0 International License ([CC BY 4.0](#)).

Summary

We present the software package [binary_c-python](#) which provides a convenient and easy-to-use interface to the [binary_c](#) ([Izzard et al., 2004, 2006, 2009, 2018](#); [Izzard & Jermyn, 2022](#)) framework, allowing the user to rapidly evolve individual systems and populations of stars. [binary_c-python](#) is available on [Pip](#) and on [GitLab](#).

[binary_c-python](#) contains many useful features to control and process the output of [binary_c](#), like by providing [binary_c-python](#) with logging statements that are dynamically compiled and loaded into [binary_c](#). Moreover, we have recently added standardised output of events like Roche-lobe overflow or double compact-object formation to [binary_c](#), and automatic parsing and managing of that output in [binary_c-python](#). [binary_c-python](#) uses multiprocessing to utilise all the cores on a particular machine, and can run populations with HPC cluster workload managers like HTCondor and Slurm, allowing the user to run simulations on large computing clusters.

Recent developments in [binary_c](#) include standardised output datasets called *ensembles*, which contain nested histograms of binned data like supernovae rates or chemical yields. [binary_c-python](#) easily processes these datasets and provides a suite of utility functions to handle them. Furthermore, [binary_c](#) now includes the *ensemble-manager* class, which makes use of the core functions and classes of [binary_c-python](#) to evolve a grid of stellar populations with varying input physics, allowing for large, automated parameter studies through a single interface.

[binary_c-python](#) is easily integrated with other Python-based codes and libraries, e.g. sampling codes like Emcee ([Foreman-Mackey et al., 2013](#)) or Dynesty ([Speagle, 2020](#)), or the astrophysics oriented package Astropy ([Astropy Collaboration et al., 2013](#); [Astropy Collaboration et al., 2018](#)). Moreover, it is possible to provide custom system-generating functions through function hooks, allowing third-party packages to manage the properties of the stars in the populations and evolve them through [binary_c-python](#).

We provide [documentation](#) that is automatically generated based on *docstrings* and a suite of Jupyter [notebooks](#). These notebooks consist of technical tutorials on how to use [binary_c-python](#) and use-case scenarios aimed at doing science. Much of [binary_c-python](#) is covered by unit tests to ensure reliability and correctness, and the test coverage is continually increased as the package is improved.

Statement of need

In the current scientific climate Python is ubiquitous. While lower level code written in, e.g., Fortran or C is still widely used, much new software is written in Python, either entirely or as a wrapper around other code and libraries. Education in programming also often includes Python

*E-mail: davidhendriks93@gmail.com (DDH)

courses because of its ease of use and its flexibility. Moreover, Python has a large community with many resources and tutorials. We have created `binary_c-python` to allow students and scientists alike to explore current scientific issues while enjoying the familiar syntax, and at the same time make use of the plentiful scientific and astrophysical packages like Numpy, Scipy, Pandas, Astropy and platforms like Jupyter.

Over time, many (binary) stellar population synthesis codes have been created. Each one usually has a slightly different focus, like gravitational waves or spectral synthesis. Recent ones are BPASS/HOKI (Stevance et al., 2020), COMPAS (Compas et al., 2022), COSMIC (Breivik et al., 2019), MOBSE (Giacobbo & Mapelli, 2019) and SeBa (Toonen & Nelemans, 2013). Most of these have Python interfaces, which further highlights the need to develop and release a modern Python interface to `binary_c`, i.e. `binary_c-python`.

The previous interface to `binary_c`, `binary_grid` was written in Perl, where much of the logic and structure was developed and debugged. While much of the code base of `binary_c-python` has changed significantly from its Perl predecessor, the initial porting to Python and the development of `binary_c-python` greatly benefitted from the existence of this earlier interface.

Projects that use `binary_c-python`

`binary_c-python` has already been used in a variety of situations, ranging from pure research to educational purposes, as well as in outreach events. In the summer of 2021 we used `binary_c-python` as the basis for the interactive classes on stellar ecosystems during the [International Max-Planck Research School summer school 2021 in Heidelberg](#). Students were introduced to the topic of population synthesis and were able to use our notebooks to perform their own calculations. `binary_c-python` has been used in Mirouh et al. ([submitted](#)), implementing improvements to tidal interactions between stars and varying initial birth parameter distributions to match to observed binary systems in star clusters. The `binary_c-python` and Emcee packages were used in a Master's thesis project to find the birth system parameters of the V106 stellar system, compare observations to results of `binary_c`, and perform uncertainty with Bayesian uncertainty inference through Markov chain Monte Carlo sampling.

Currently, `binary_c-python` is used in several ongoing projects. These include a study on the effect of birth distributions on the occurrence of carbon-enhanced metal-poor (CEMP) stars, the occurrence and properties of accretion disks in main-sequence stars (Hendriks & Izzard, [in prep](#)), and the predicted observable black hole distribution by combining star formation and metallicity distributions with the output of `binary_c` (Hendriks et al., [in prep](#)). We also use the *ensemble* output structure to generate datasets for galacticochemical evolution over cosmological timescales, where we rely heavily on the utilities of `binary_c-python` (Yates et al., [in prep](#)).

Acknowledgements

We are grateful for the helpful discussions and testing efforts from A. Aryeapour, M. Delorme, S. Dykes, G. Mirouh, M. Matteuzzi, N. Rees, M. Renzo, L. van Son, K. Temmink, D. Tracey and R. Yates, and the early work of J. Andrews which inspired our Python-C interface code. DDH thanks the UKRI/UoS for the funding grant H120341A. RGI thanks STFC for funding grants [ST/R000603/1](#) and [ST/L003910/2](#).

References

Astropy Collaboration, Price-Whelan, A. M., Sipőcz, B. M., Günther, H. M., Lim, P. L., Crawford, S. M., Conseil, S., Shupe, D. L., Craig, M. W., Dencheva, N., Ginsburg, A., VanderPlas, J. T., Bradley, L. D., Pérez-Suárez, D., de Val-Borro, M., Aldcroft, T. L.,

- Cruz, K. L., Robitaille, T. P., Tollerud, E. J., ... Astropy Contributors. (2018). The Astropy Project: Building an Open-science Project and Status of the v2.0 Core Package. *The Astronomical Journal*, 156, 123. <https://doi.org/10.3847/1538-3881/aabc4f>
- Astropy Collaboration, Robitaille, T. P., Tollerud, E. J., Greenfield, P., Droettboom, M., Bray, E., Aldcroft, T., Davis, M., Ginsburg, A., Price-Whelan, A. M., Kerzendorf, W. E., Conley, A., Crighton, N., Barbary, K., Muna, D., Ferguson, H., Grollier, F., Parikh, M. M., Nair, P. H., ... Streicher, O. (2013). Astropy: A community Python package for astronomy. *Astronomy and Astrophysics*, 558, A33. <https://doi.org/10.1051/0004-6361/201322068>
- Breivik, K., Coughlin, S., Zevin, M., Rodriguez, C., Andrews, J., Kimball, C., mcdigman, & Inhtran. (2019). *COSMIC-PopSynth/COSMIC: COSMIC now integrated with Globular Cluster Simulation Software ClusterMonteCarlo (CMC)* (Version v3.1.0). Zenodo. <https://doi.org/10.5281/zenodo.3482915>
- Compas, T., Riley, J., Agrawal, P., Barrett, J. W., Boyett, K. N. k., Broekgaarden, F. S., Chattopadhyay, D., Gaebel, S. M., Gittins, F., Hirai, R., Howitt, G., Justham, S., Khandelwal, L., Kummer, F., Lau, M. Y. m., Mandel, I., Mink, S. E. de, Neijssel, C., Riley, T., ... Willcox, R. (2022). COMPAS: A rapid binary population synthesis suite. *Journal of Open Source Software*, 7(69), 3838. <https://doi.org/10.21105/joss.03838>
- Foreman-Mackey, D., Hogg, D. W., Lang, D., & Goodman, J. (2013). Emcee: The MCMC Hammer. *Publications of the Astronomical Society of the Pacific*, 125(925), 306–312. <https://doi.org/10.1086/670067>
- Giacobbo, N., & Mapelli, M. (2019). The impact of electron-capture supernovae on merging double neutron stars. *482*(2), 2234–2243. <https://doi.org/10.1093/mnras/sty2848>
- Hendriks, D. D., & Izzard, R. G. (in prep). Disk mass loss during mass transfer onto main sequence accretors.
- Hendriks, D. D., van Son, L. A. C., Renzo, M., & Izzard, R. G. (in prep). Pulsational pair-instability supernovae in gravitational-wave and electromagnetic transients.
- Izzard, R. G., Dray, L. M., Karakas, A. I., Lugaro, M., & Tout, C. A. (2006). Population nucleosynthesis in single and binary stars. I. Model. *460*(2), 565–572. <https://doi.org/10.1051/0004-6361:20066129>
- Izzard, R. G., Glebbeek, E., Stancliffe, R. J., & Pols, O. R. (2009). Population synthesis of binary carbon-enhanced metal-poor stars. *508*(3), 1359–1374. <https://doi.org/10.1051/0004-6361/200912827>
- Izzard, R. G., & Jermyn, A. S. (2022). Circumbinary discs for stellar population models. *Monthly Notices of the Royal Astronomical Society*. <https://doi.org/10.1093/mnras/stac2899>
- Izzard, R. G., Preece, H., Jofre, P., Halabi, G. M., Masseron, T., & Tout, C. A. (2018). Binary stars in the Galactic thick disc. *473*(3), 2984–2999. <https://doi.org/10.1093/mnras/stx2355>
- Izzard, R. G., Tout, C. A., Karakas, A. I., & Pols, O. R. (2004). A new synthetic model for asymptotic giant branch stars. *350*(2), 407–426. <https://doi.org/10.1111/j.1365-2966.2004.07446.x>
- Mirouh, G. M., Hendriks, D. D., Dykes, S., Moe, M., & Izzard, R. G. (submitted). Detailed equilibrium and dynamical tides: impact on circularization and synchronization in open clusters.
- Speagle, J. S. (2020). Dynesty: A dynamic nested sampling package for estimating Bayesian posteriors and evidences. *Monthly Notices of the Royal Astronomical Society*, 493(3), 3132–3158. <https://doi.org/10.1093/mnras/staa278>

- Stevance, H., Eldridge, J., & Stanway, E. (2020). Hoki: Making BPASS accessible through Python. *The Journal of Open Source Software*, 5(45), 1987. <https://doi.org/10.21105/joss.01987>
- Toonen, S., & Nelemans, G. (2013). The effect of common-envelope evolution on the visible population of post-common-envelope binaries. 557, A87. <https://doi.org/10.1051/0004-6361/201321753>
- Yates, R. M., Hendriks, D. D., Vijayan, A. P., Izzard, R. G., Thomas, P. A., & Das, P. (in prep). Modelling binary stellar populations & dust in cosmological-scale galaxy evolution simulations.