METISSE: METhod of Interpolation for Single Star Evolution

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Software

- Review
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Summary

METISSE is an open-source code that interpolates between pre-computed stellar models to quickly derive stellar parameters for population synthesis codes. Written in Modern Fortran, METISSE is both fast and robust. It is comparable to existing rapid stellar evolution codes, such as SEVN (Iorio et al., 2023) and Combine (Kruckow et al., 2018) but with the added advantage that it can be seamlessly integrated with any population synthesis code that currently uses popular SSE fitting formulae (Hurley et al., 2000) to calculate stellar parameters. METISSE can function as a standalone code for simulating single stellar populations as well as in conjunction with population synthesis codes for modelling binary stars and star clusters.

Statement of need

Stars, especially those with masses greater than eight solar masses (massive stars), play a pivotal role in shaping stellar populations. The best way of computing stellar evolution involves solving equations of stellar structure and evolution through detailed stellar evolution codes such as MESA. However, the inherent uncertainties in stellar evolution cause stellar codes to adopt different physical inputs, leading to significant differences in the predictions for the evolution of stars and stellar populations (Agrawal et al., 2022). Moreover, computational requirements and robustness issues render these codes impractical for direct use in large population synthesis simulations.

As a result, rapid stellar evolution codes that rely on fitting formulas, manually calibrated to specific sets of stellar models to determine the evolution of individual star systems, have been a popular alternative in the past. These methods provide a computationally efficient, fast, and reliable way to calculate stellar population properties. Unfortunately, fitting formulas must be recalculated manually each time for different stellar model sets, limiting our ability to conduct systematic studies of stellar parameters. The use of interpolation in METISSE allows input stellar models to be easily swapped and enables systematic studies of stellar parameters on the stellar populations.

METISSE has already been employed in several scientific publications. For instance, it has also been used to demonstrate the impact of core overshooting — one of the major uncertainties in stellar evolution — on the evolutionary outcomes of binary systems (Agrawal et al., 2023).

Additionally, it has been used with stellar models from MESA as well as models from the Bonn Code (via the BoOST project (Szécsi et al., 2022)) to conduct a systematic study study of how different physical parameters affect the evolutionary properties of massive single stars (Agrawal et al., 2020). Multiple ongoing projects use METISSE alongside the binary population synthesis code COSMIC(Breivik et al., 2020) to investigate the population properties of black hole-X-ray binaries, LISA white dwarf binaries, and GAIA black hole-star systems. In the era of big-data astronomy, driven by high-quality observational data from both ground-based and space-based telescopes, as well as gravitational wave and multi-messenger detectors, METISSE facilitates the seamless incorporation of updates in stellar evolution into simulations that model stellar populations and their interactions.

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