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MESAlab: a Pipeline for Mapping the Blue Loop with MESA runs

Dóra Tarczay-Nehéz [1,2]

1 HUN-REN CSFK Konkoly Observatory, Konkoly Thege M. út 15-17, Budapest, 1121, Hungary **2** CSFK, MTA Centre of Excellence, Konkoly Thege M. út 15-17, Budapest, 1121, Hungary

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Software

- Review
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Summary

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); Jermyn et al. (2023)) is a widely used open-source software for modelling stellar evolution. In many studies, the computational grids covers thousands of models (e.g., Joyce et al. (2024), which requires a tremendous amount of time and computational effort to process.

To streamline data analysis, the `mesalab` package was developed. This Python-based pipeline is designed to simplify the post-processing of MESA outputs by automatically identifying various stellar evolutionary phases, with a specific focus on the "blue loop"—a blue-ward excursion in the Hertzsprung-Russell Diagram (HRD) for intermediate-mass stars often associated with peculiar pulsational phenomena like "strange modes".

The `mesalab` pipeline

The pipeline offers several key functionalities

- It collects data on the mass and metallicity ranges of the grid.
- It calculates the necessary bolometric corrections (BCs) by utilizing the MESA Isochrones & Stellar Tracks (MIST) bolometric correction tables (Choi et al., 2016).
- It automatically generates HRDs and Color-Magnitude Diagrams (CMDs) with Gaia passbands.
- Furthermore, `mesalab` provides crucial tools for asteroseismological investigations.

The GYRE module

For blue loop crosser models, the pipeline generates GYRE (Townsend & Teitler, 2013) inlist files with user-specified parameters. In the next step, the pipeline automatically executes GYRE for these pre-filtered models, with the option to run the computations sequentially or in parallel, significantly enhance computational efficiency.

The RSP module

Similar to the GYRE module, the pipeline generates MESA RSP ((Smolec & Moskalik, 2008), (Paxton et al., 2019)) inlist files with user-specified parameters, then executes the MESA RSP module automatically. This process can also be configured to run the computations sequentially or in parallel, with the number of parallel threads also being a user-defined parameter.

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Statement of need

The pipeline `mesalab` is a fully automated, Python-based, open-source package designed to simplify the complex and often manual-driven post-processing of stellar evolution grids generated by MESA with a specific focus on blue loop analysis. It automates key, repetitive tasks, including identifying blue loop crossings, calculating bolometric corrections using the MIST tables (Choi et al., 2016), and generating standard diagrams like HRDs and CMDs with Gaia passbands.

For asteroseismological investigations, `mesalab` streamlines the workflow by automating the entire process: it generates and then executes inlist files for both GYRE (Townsend & Teitler, 2013) and MESA RSP ((Smolec & Moskalik, 2008), (Paxton et al., 2019)). This automation, along with the option for parallel execution, dramatically reduces the time and effort required to prepare models for a detailed analysis.

The pipeline operates within a broader ecosystem of open-source tools for stellar astrophysics. Foundational libraries like `py_mesa_reader` are essential for parsing and accessing raw MESA output files. While `py_mesa_reader` provides this low-level data access, `mesalab` builds upon it to offer an end-to-end pipeline that automates the entire workflow from data parsing and filtering to asteroseismological analysis. Similarly, other pipelines, such as `FOAM` (Michielsen, 2024), have different primary goals. FOAM is a powerful tool for comparing theoretical pulsation data with observations, whereas the purpose of `mesalab` is to provide a unified interface that streamlines the preparation and execution of external tools like GYRE and MESA RSP.

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