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tomso: TOols for Models of Stars and their Oscillations

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Software

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Summary

Many branches of astronomy interpret observations through approximate, one-dimensional models of stars. Furthermore, many stars are observed to undergo resonant pulsations, and the frequencies at which they do so are similarly interpreted through the predicted pulsations of the one-dimensional models. The study of these resonant pulsations in stars is known as *asteroseismology*. Since the equations of stellar structure, evolution and pulsation were defined in their modern forms around the mid-20th century, many programs have been written to produce models and predict their pulsations frequencies and correspondingly many custom data formats have been defined, with varying levels of ease-of-use and interoperability. `tomso`'s main purpose is to provide a compact interface for parsing data in these formats and simplify research that uses them.

Statement of need

Data formats for stellar models and their oscillations vary widely. Some are fixed-width plain text files with several blocks; some are Fortran binaries; and few can easily be read with standard routines for loading data. Some programs require data to be prepared in a specific format and provide tools to do so but these tools, if publicly available, are incomplete and difficult to extend. At one extreme, there are no public, open source libraries for manipulating data from the Cambridge stellar evolution code (STARS, Eggleton et al., 2011). The Aarhus adiabatic oscillation package (ADIPLS, Christensen-Dalsgaard, 2008) includes tools to convert stellar models of one particular widely-used format (FGONG) into its internal Fortran binary format but not to convert them back after they've been manipulated by other bundled tools. Other programs enjoy greater support, though often limited to that single program, e.g. PyGYRE's support for GYRE (Townsend & Teitler, 2013). The Modules for Experiments in Stellar Astrophysics (MESA, Paxton et al., 2011) in particular enjoys support from a number of packages, e.g. PyMesaReader for loading output data; pyMesa (Farmer & Bauer, 2018), which also allows access to program variables and functions; and mesaplot (Farmer, 2021), which allows advanced plotting.

`tomso` is a set of Python modules that provides a compact interface to access data in several formats. It also enables or simplifies several common tasks in analysing the stellar models and oscillations. First, it allows the user to load the data for inspection, which can be cumbersome, given the complicated specifications of some formats. The high-level interface also allows straightforward access to complicated properties that can be derived from the data. Second, it can be convenient—and, as mentioned above, is sometimes necessary—to convert files between different formats. Finally, some computational experiments involve modifying the stellar models directly, which requires reading the file in the correct format, manipulating the data, then ensuring that the data is correctly re-written in the same format. A key—and currently unique—aim of `tomso` is to provide a common interface to data stored in several different fixed-width or binary formats. When working with the input and output of a single program that is already supported by similar packages (e.g., MESA), `tomso` might not offer any benefit. `tomso` is, however, particularly useful for manipulating and converting stellar models that are inputs for frequency calculations, which is generally unsupported by any public, open-source package.

For example, two derived properties are the speed of sound c_s and acoustic depth τ, which is how long a sound wave would take to travel from a star's surface to some depth inside. The sound speed gradient $dc_\mathrm{s}/d\tau$ is useful for identifying regions where sudden changes in the star's structure might discernibly affect the frequencies at which it vibrates. Such figures are shown for models of the Sun in, e.g., Monteiro et al. (2000, fig. 1) and Aerts et al. (2010, fig. 7.30). These figures, however, require some manipulation of the source data because neither c_s nor τ are part of the data format. Figure 1 shows the same data but with `tomso` this is naturally expressed in two functional lines of Python code: one to read the data file and one to plot the relevant data using the high-level properties `cs` and `tau`. The code is the same whether the stellar model is in ADIPLS's binary format, FGONG format or GYRE's plain-text model format.

`tomso` currently includes interfaces for ADIPLS, the FGONG file format, plain-text output from GYRE, input and output from MESA, and output from STARS. `tomso`'s interfaces also aim to be easily extensible, so that in the future it can not only support more current codes and file formats, but also those that have yet to be developed.

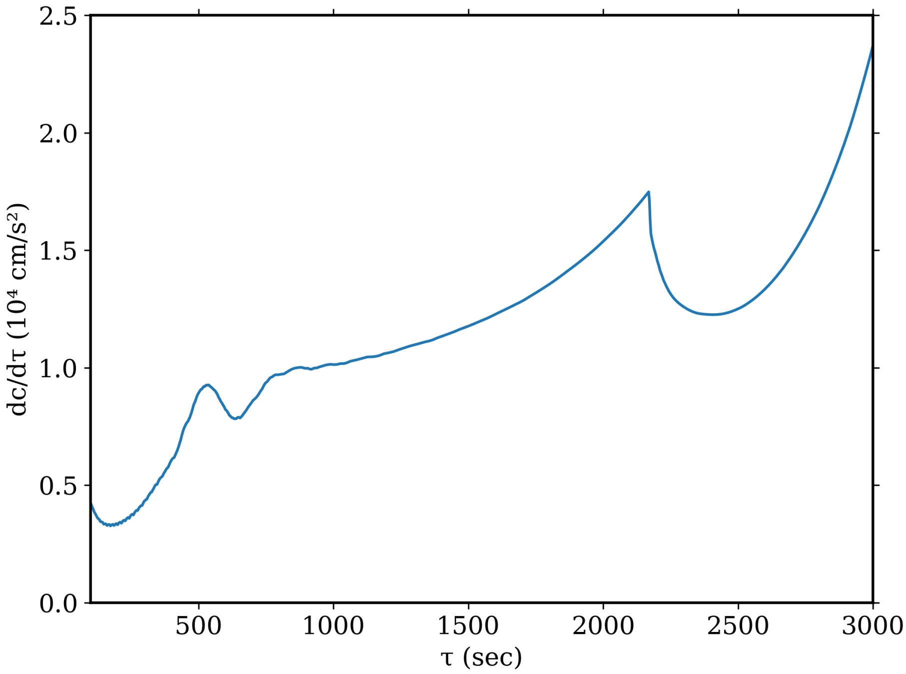

Figure 1: Plot of the sound speed gradient as a function of the acoustic depth in a standard solar model (Model S, Christensen-Dalsgaard et al., 1996), as in Fig. 7.30 of Aerts et al. (2010).

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