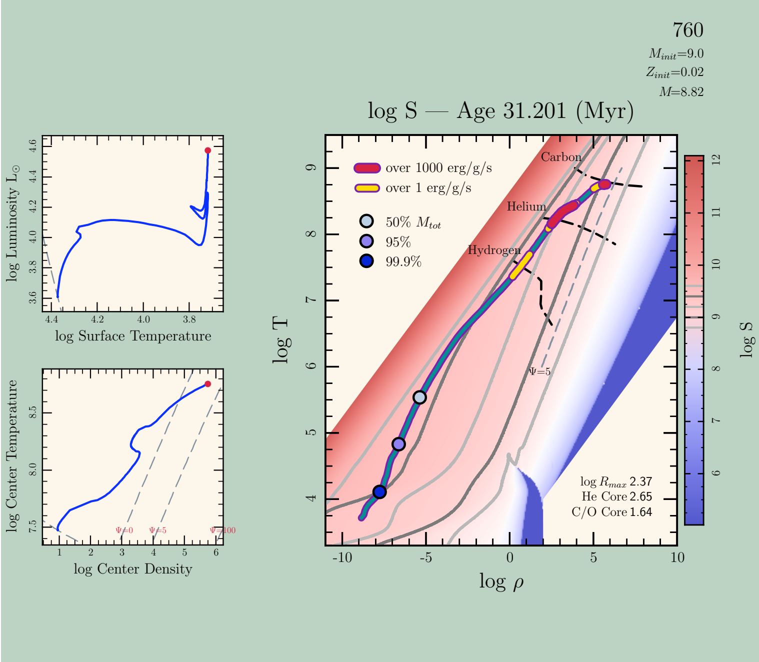
MESA - Open source stellar evolution modules and framework



State of a 9 Msun star during a second ascent of the Red Giant Branch computed with EZ. Shown are the HR track, time history of the central temperature vs central density, and the structure of the star in the temperature-density plane (large contour plot) colored by the entropy. The full movie may be downloaded by clicking on this link

The new software project MESA, Modules for Experiments in Stellar Astrophysics, aims to provide state-of-the-art, robust, and efficient open source modules, reusable singly or in combination for a wide range of applications in stellar astrophysics. It includes modules for various aspects of the physics, such as nuclear networks, opacities, and equation of state, as well as modules for various algorithmic components such as a 2nd order implicit solver and 3rd order interpolation routines. Each module is constructed as a separate Fortran 95 library to facilitate independent use and development, and each includes a test suite and an explicitly defined public interface. The modules are designed to be "thread-safe" for use with shared memory parallel processing, a mode of operation that promises to become dominant with the advent of multi-core processors.

The MESA nuclear networks module is based on Timmes' previous codes and includes options ranging from a small basic net for standard hydrogen, helium, and carbon/oxygen burning, to a large net with an alpha chain to ^{56}Ni, hot CNO reactions, and some early rp-process reactions. MESA's equation of state module combines Timmes' HELM eos for high temperature ranges with the OPAL eos for lower temperatures at typical intermediate-mass and low-mass stellar densities, and the SCVH eos (Saumon-Chabrier-van Horn) for even lower temperatures and substellar densities. MESA's opacities module combines the OPAL Type 2 tables, including options for enhanced carbon and oxygen abundances, with a special set of low temperature tables provided by Jason Ferguson that give extended coverage in the regions needed for low mass objects. MESA's neutrinos module provides a routine for calculating energy loss rates for neutrinos from sources other than nuclear burning, based on the Itoh fitting formulas.

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MESA's 2D interpolation module provides bicubic spline routines in single and double precision. The MESA 1D interpolation module includes both Steffen's piecewise monotonic cubic algorithm and Huynh's monotonicity preserving cubic interpolation scheme. The MESA modules for solver algorithms include a globally convergent Newton iteration routine and a 2nd order, fully implicit, backwards differencing solver with features specially tailored for use in stellar evolution codes.

The modules mentioned above are currently available for download from the MESA website http://mesa.sourceforge.net; they will soon be joined by others that will make use of them to do stellar evolution in a style similar to Paxton's EZ code. For example, the figure above shows the evolutionary state of 9 Msun model during a second ascent of the Red Giant Branch computed with EZ. The goal is to eventually provide several evolution codes sharing a common set of MESA modules for the physics and solver algorithms: the first will be for 1D implicit, quasi-hydrostatic evolution; it will be followed by ones for implicit and explicit hydrodynamic evolution in 1D. The use of a common set of underlying modules should greatly reduce the cost of creating such a family of codes and increase the ability to explore new alternatives for their design and implementation.

During the next few years we will add to MESA the capability to produce SNe Ia models with a variety of flame propagation algorithms and evolve pre-supernova massive stars from birth to the formation of an iron core.

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