MESA Summer School 2015: X-ray Burst Minilab

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Objectives

In this minilab, we will use the ns_h test suite included with MESA to model Type I X-ray bursts on accreting neutron stars. In Part 1, you will get the code up and running with a pgstar window tailored to this problem and generate your first sequence of flashes. In Part 2, we will study how the hydrogen and helium burning changes with accretion rate.

Part 1: Up and Running

In this part, we will use MESA to calculate what happens when matter accretes onto a neutron star and hopefully see some thermonuclear flashes!

- Copy the ns_h test suite directory from mesa/star/test_suite. Before you run it, you'll need to remove some lines that are there specifically for the test suite:
  - Edit the makefile and remove the first include line.
  - Edit the inlist and set read_extra_star_job_inlist1=.false.
  - In src/run_star_extras.f there is a termination condition for the test in the function extras_finish_step. To prevent the code from finishing early, edit that function and remove the lines after the line extras_finish_step=keep_going.

  After you've made these edits, check that you can compile and run without problems.

- We have provided a inlist_pgstar file that will make a pgstar window suitable for this problem. The window has four different panels: (1) a TRho_Profile window, (2) Abundance as a function of column depth, (3) a History_Panel showing the number of zones and $\log L$ as a function of time, and (4) another History_Panel which plots max_eps_he_lgT (the temperature at the location of maximal helium burning) against log_total_mass_he4 (the total mass of ^{4}He in the model).

  Copy the inlist_pgstar file into your directory and change the main inlist so that it points to the new file. You will need to add log_column_depth to the profile columns to be able to plot against column depth, and star_age_hr and log_total_mass he4 to the history columns.

  You can of course change the axes as you go along depending on the question you are trying to answer - you might find it helpful to plot model number as the x-axis in panel

(3) for example to see more detail during the burst. Or you can change the column depth limits for panel (2) to see the composition in more detail in part of the model.

- Run the test suite problem and see what is happening. You should see a sequence of flashes. Using the pgstar window you created, answer the following questions:
  - What is the approximate range of density and temperature in the model? What is the pressure scale height at the base? This gives you a rough estimate of the thickness of the layer we are simulating – only the very outer part of the neutron star!
  - What is the recurrence time of the flashes?
  - What is the peak luminosity? What do you think sets this physically?
  - What fuel is burning in the flash?
  - What happens to the CNO elements over time?
  - What do you think will happen if you run the simulation for a long time?

Part 2: Burning Regimes

In this exercise, we will investigate how the hydrogen and helium burning changes with accretion rate. Each table will run a different accretion rate and we will compare notes at the end to see how things change.

- Together with the other students at your table, choose an accretion rate at random uniformly distributed in $\log_{10} \dot{M}$ from $\dot{M} = 2 \times 10^{-11}$ to $2 \times 10^{-8}\ M_{\odot}\ \mathrm{yr}^{-1}$.
- To make it easier to zoom in on individual burst lightcurves, Rob has made a magic pgstar window that zooms in on each burst as it happens. To use it, copy the file `run_star_extras.f` that we provide to `src` and recompile the code using `./mk` . You will need to set `use_other_pgstar_plots=.true.` in the `&controls` part of the inlist so that MESA knows to use the new window. The window also comes with its own set of controls in the file `inlist_for_my_pgstar_plots` which you should also copy to your directory. As bursts occur, you should see the individual burst light curves appear in the new window. If some bursts don't show up in this window, try adjusting the `FLUX_CHANGE` parameter (e.g. from 10 to 5) in `inlist_for_my_pgstar_plots`.
- You may have noticed that the base of layer warms up significantly as the accreted matter burns. The initial temperature profile of the envelope is set by the luminosity at the

base L_b. Try changing the luminosity at the base using the `relax_initial_L_center` and `new_L_center` controls. Each person at the table should use a different L_b so that we can see what affect if any it has on the burning. Choose from one of the following values: $L_b = 10^{33}$, 5×10^{33}, 10^{34}, or 1.5×10^{34} erg s^{-1}.

- Run the code and see what happens! In the google doc, you should report:
  - your choice of $\dot{M}$ and L_b
  - the recurrence time
  - the type of ignition/burning regime
  - the peak luminosity of the bursts
  - the burst duration (you can measure this as the time for luminosity to fall to approximately half of its peak value).

  You should measure these quantities as best you can directly from the pgstar windows.

- Try to answer the following questions as the model runs
  - What is happening to the CNO elements at different depths?
  - What is the luminosity between bursts?
  - Do all the bursts in a sequence look the same? How many bursts have to happen before the model gets into a steady state?
  - How does the number of zones and the timestep change with time?

  We will discuss the answers at the end when we compare results.

Extras

Some extra things to try at home:

- You tried changing the base luminosity L_b. The other parameters of the initial model are the mass and radius of the neutron star. Try changing M and R using the appropriate `relax` controls in the inlist.
- The accreted material is assumed to have a metallicity of $Z = 0.02$ in the example above. What happens if you change Z?

- Run a model with a high $\dot{M}$, so that the burning is stable. How does the helium mass fraction change with column depth once the helium starts to burn (hint: it should be a power law)? Does it make sense given what you know about the triple alpha reaction?
- The base of the model changes temperature significantly when a burst goes off. You might worry that we are not modelling a thick enough layer to include the high density material currently off the grid that gets heated up during the burst. How could you change the neutron star model so that it has a thicker envelope, say 100 times more massive than the one in the test suite?