MESA Summer School 2022

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Lab 2: CPM, overshoot, and diffusion on the MS

In this lab, we will learn about convective premixing (CPM) and its current state in the MESA code. We also will explore the effects of overshooting and diffusion. You will continue your analysis with the same mass you used in lab 1 for part of the lab, but can work in the same directory as you did for lab 1. We will only investigate CPM and overshooting on the MS, so we can recycle the starting mod files (from evolving from the the pre-MS to ZAMS) that were used in lab 1.
For **quick reference** of case number to the criterion, recall that:

Case 0 = Sign + Schwarzchild
Case 1 = Sign + Ledoux
Case 2 = Predictive mixing + Schwarzchild
Case 3 = Predictive mixing + Ledoux

Comparing and Analyzing Results

We will again plot multiple cases in a single figure, and will disperse the work as in Lab 1. Here are the table assignments:

Table 1	Table 2	Table 3	Table 4	Table 5	Table 6	Table 7	Table 8
Case 4	Case 5	Case 6	Case 7	Case 4	Case 5	Case 6	Case 7

For cases 4 and 5 (Tables 1,2,5 and 6), choose one person from each mass to upload their `LOGS_caseX/history.data` file and the **last** `LOGS_caseX/profile<last>.data` to the convective boundaries dropbox.
For cases 6 and 7 (Tables 3,4,7 and 8), we will drop the $10M_\odot$ model, so only one person from your table needs to upload their files.
For all cases, **still please upload the files as:**

```
history_caseX_XM_TX.data
profile_caseX_XM_TX.data
```

Where, again, X is the case number, mass size, and table number you were assigned.

Case 4: CPM with Schwarzchild

Let's read a little about how CPM works in MESA. Open the `MESA_DIR/star/defaults/controls.defaults` file and search for 'convective premixing'. (You may also find the same documentation here, doing the same search.) Read the documentation in that section.

Assuming you made copies of your inlists for each case, copy your case 0 (sign+schwarz) inlist to `inlist_project`. **Need help?**. If you had trouble building `inlist_project_case0` in lab 1, you can copy over the solution `inlist_project_case0` for your model, located in the `conv_boundaries_2022/lab1_XM_solutions` folder.
We will again need to update the controls in the **checklist** from lab 1:

Checklist:

1. `load_model_filename` (`inlist_project`, under `&star_job`)
2. `save_model_filename` (`inlist_project`, under `&star_job`)

3. `log_directory` (`inlist_project` under `&controls`)

4. `photo_directory` (`inlist_project` under `&controls`

5. in `inlist_pgstar`, edit the `Grid1_file_dir` folder (i.e. change to "caseX" at the end of "grid_png" for your case number).

For checklist item 1, we will recycle the saved mod file from case 0 (sign + schwarz), the `1.5M_case0_to_ZAMS.mod` or `10M_case0_to_ZAMS.mod` file. Items 2-5 should be updated to the case4 number when saving, if following the assumed convention.

TIP: If using `vim`, simply type: `:%s/caseX/caseXnew/g` in `inlist_project` for items 1-4. This replaces every instance of the old 'caseX' with the new 'caseXnew', assuming each case's inlist was named by case number. Just make sure you go back and edit the `load_model_filename` to start at case 0 if you do this!

For this case, we simply want to do convective premixing on the MS with the Schwarzchild criterion. Navigate to the `&controls` section and add:

```
do_conv_premix=.true.
```

Now run the CPM case and save a copy of `inlist_project` to `inlist_project_case4`!

Reminder: Tables 1 and 5 need to upload their profiles to the dropbox ;)

If your run finishes quickly, make a movie of the Case 4 evolution!

Case 4 Questions

1. Does the evolution of the convective core look ok?

2. Ask someone from your table with the other mass what their answer is. Are the results the same?

Click here for answer.

Case 5: CPM + Ledoux

Now we want to include the Ledoux criterion. (you should know the control in `inlist_project` that does this by now ;))

Remember to go through the **checklist** items before running the case! Which saved mod file do you think we should start from for case 5? (Look at the quick reference guide at the top of the lab for help. We want to use the Ledoux criterion... Click here to make sure you load the right one :))
After completing all the **checklist** items, run the case and save a copy of `inlist_project` to `inlist_project_case5`!

Reminder: Tables 2 and 6 need to upload their profiles to the dropbox ;)

If your run finishes quickly, make a movie of the Case 5 evolution!

Case 5 Questions

1. Does the evolution of the convective core look ok?

2. Ask someone from your table with the other mass what their answer is. Are the results the same?

Click here for answer.
Discuss at your table what is happening... Is there a bug in the code? If so, what is the process to solve the issue? (See section 3.1 below!)

Using the mesa-users email list

If you believe there is a bug in the code, the first thing to do is look at known bugs on the MESA docs website. For this example, the issue is the first one listed under the r22.05.1 heading. Read the reported bug. For this MESA version, we can't do anything except for wait for the bug to ve resolved in the next MESA release.
Keep in mind: If the bug had not been reported, the user should email the users-list, with all the necessary information to describe the bug!

FOR THE REST OF THE LAB, EVERYONE WILL PROCEED WITH THE M=1.5 $M_\odot$ model!

For those with the 10 $M_\odot$ model, simply copy over the `1.5M_case0_to_ZAMS.mod` and `1.5M_case1_to_ZAMS.mod` mod files from the `conv_boundaries_2022` folder to your working directory. The instructions below will include other minor switches in `inlist_project`. Also copy (you may over-write) the `inlist_pgstar_1.5M_lab1` file to `inlist_pgstar` so that your `pgstar` plots are set up for the 1.5$M_\odot$ model.

Case 6: Sign + ledoux + overshoot (1.5 $M_\odot$)

We saw in lab 1 that when using the Ledoux criterion with the sign algorithm the core does not grow as it should. We want to start with this case (case 1) so copy your `inlist_project_case1` file to `inlist_project`. Since we are exploring the sign+ledoux algorithm for the 1.5 $M_\odot$, we want to load in the case 1 `1.5M_case1_to_ZAMS.mod` mod file for `load_model_filename`. If you had the 10$M_\odot$ model before, update to loading in this mod file!

Now, what happens if we add overshooting to this case?

Note: overshooting is an ad hoc hack that is used to obtain in particular larger convective cores (to allow in some cases stellar models to fit observations), but is not really based on physics.
Open the controls.defaults documentation (you should be familiar with how to do that now!) and search for overshooting. Spend a few minutes reading about overshoot controls. To include overshoot, you may choose step or exponential overshooting, just make sure you use reasonable values. For example, using exponential, something like:

```
overshoot_scheme(1) = 'exponential'
overshoot_zone_type(1) = 'any'
overshoot_zone_loc(1) = 'core'
overshoot_bdy_loc(1) = 'top'
overshoot_f(1) = 0.01d0
overshoot_f0(1) = 0.001d0
```

would be suitable. Add overshooting controls to `inlist_project` and follow the remaining **checklist** items and run the case. (For those switching from the 10 $M_\odot$ model, you may want to add something like '`1.5M`' after '`case6`' to your directory and file names, but that is personal preference.) Save a copy of `inlist_project` to `inlist_project_case6`.

Reminder: Tables 3 and 7 need to upload their profiles to the dropbox ;)

If your run finishes quickly, make a movie of the Case 6 evolution!

Case 6 Questions:

1. Does the evolution of the convective core look ok? Is it growing well?
2. The results should be identical when using Schwarzchild or Ledoux. Why is that?

Click here for answers.

BONUS TASK 1: Predictive mixing + Overshooting

Try adding the overshooting controls to the predictive mixing + schwarz case (`inlist_project_case2`). For good practice, follow the **checklist** items and save a copy of `inlist_project` to a name you'll recognize for this exercise ;)

Q: Do you expect the results to be different than with the sign algorithm?
Click Here for answer.

Case 7: Sign + Schwarzchild + Diffusion

Now we want to look at the effects of diffusion on the MS for the Schwarzchild criterion. Copy `inlist_project_case0` to `inlist_project`, and update the `load_model_filename` to `1.5_case0_to_ZAMS.mod` if you had the $10\mathrm{M}_\odot$ case previously. Spend a few minutes looking at the documentation on diffusion controls (from either the `controls.defaults` file or the MESA docs website).

For this case, we will use the simplest control to add the effect of diffusion:

```
do_element_diffusion = .true.
```

Add this to the `&controls` section.
Follow the **checklist** items to update to this case. Then run the case and save a copy of `inlist_project` to `inlist_project_case7` :)

Reminder: Tables 4 and 8 need to upload their profiles to the dropbox ;)

If your run finishes quickly, make a movie of the Case 7 evolution!

Case 7 Question

1. Look at the profile of ^{1}H next to the convective boundary. How is it different from what it was without diffusion?

Click here for answer.

BONUS TASK:

Try including diffusion with the sign+ledoux case (case 1) or with the predictive + ledoux case (case 3). Does diffusion help in those cases? (Follow checklist items for good practice :)). Feel free to try anything else you want to explore if there is time!

Solutions

If you'd like to compare results/files, or if you were unable to get through all the cases successfully, you can access the lab 2 solutions for both masses in the `conv_boundaries_2022/lab2_XM_solutions` folders. The solutions do not include the bonus exercises however.

Answer to Case 4 Question

Yes, we get the same result as we did with sign or predictive+Schwarzchild for both masses.
Click here to return to the Case 4 Question.

Answer to Case 5 Question

For the 1.5 $M_\odot$ model, the convective core does not grow! (Look at the gradient profiles. Do we have $\nabla_{ad} = \nabla_{rad}$ on the convective side of the boundary? Nope!

For the 10 $M_\odot$ model, things look ok because we don't have a discontinuity at the convective boundary. Click here to return to the Case 5 Questions.

Answer to Case 6 Questions

1. Yes, the core grows well. 2. They are identical because overshooting aids a smooth transition for the composition profile across the convective boundary, such that it never develops a discontinuity at the convective boundary. Click here to return to the Case 6 Question.

Answer to Bonus Task 1

No. Look at the results where we compare the sign +schw with predictive + schw: the resulting growth was identical. So with overshooting we should also get identical results as those obtained using sign algorithm. The reason is that Predictive increases the core size up to where $\nabla_{rad} = \nabla_{ad}$, which corresponds to a very small value of the overshooting. Click here to return to Bonus task.

Answer to Case 7 Question

Answer: the profile of h1 is smoother at the top of the convective boundary. There is still a discontinuity in its derivative.
Click here to return to the Case 7 Question.

Controls and mod file help

Ledoux Criterion for Case 5:
`use_Ledoux_ctriterion = .true.` (in the `&controls` section)
Click to go back.
Case 5 mod files: `1.5M_case1_to_ZAMS.mod`; `10M_case1_to_ZAMS.mod`
Click to go back.

Making movies

You can use the built-in `images_to_movie` executable in MESA to quickly make movies. Simply type in your terminal:
`images_to_movie '<grid_png_directory>/*.png' <movie_name>.mp4`
where you only need to specify the png directory to point to and the name for your movie.

A more custom-made movie can be done by utilizing flags, and pointing to ffmpeg in the `$MESASDK` folder. For instance, to slow the frame-rate, you could do something like:

```
$MESASDK_ROOT/bin/ffmpeg -framerate 24 -pattern_type glob -i '<grid_dir>/*png' -vf
"scale=trunc(iw/2)*2:trunc(ih/2)*2" -c:v libx264 -pix_fmt yuv420p -y <name>.mp4
```

All in one line haha. you can adjust the framerate from 24 to something smaller for a slower movie, or something larger for a faster movie.
Click to go back to end of case 4
Click to go back to end of case 5
Click to go back to end of case 6

Click to go back to end of case 7