EXO-PLANETS INTERIORS & ATMOSPHERES (EIA2020)

LAB ASSIGNMENT 1: MODELLING SUB-NEPTUNE MASS PLANETS INTERIOR

INTRODUCTION

In this lab, you will use the MESA code (Paxton et al. 2013) to simulate low mass planets (with an envelope made mostly by H and He) interiors and evolution. The work folder and details for this computer lab is based on work by Chen & Rogers (2016).

HOW TO RUN MESA

1. Download the folder Lab1 in your computer using this link: https://surfdrive.surf.nl/files/index.php/s/3Il2hX0c926AXcE. Enter in the folder.
2. The `inlist_project` is the file that has the information necessary to run the part of the project that you are interested in. For example, `inlist_1a_create` is the file that has the information to create the planet, this is what you have to do in the part 1a of this assigment. Make sure to copy paste `inlist_project` into `inlist` before running your code. `inlist` is the file the code will read and run.
3. Go to the directory ~`/Lab1/` and run:
   `clean` — to remove the objects introduced by the previous time the code was run.
   `mk` — to create your work version of the code
   `rn` — to run it

Then you will be running MESA!

THE ASSIGNMENT

You will have to run simulations to form and evolve 10 mini-gas planets, make plots using the output files and write an essay. The plots and the essay can be produced with any program you want. Details are given below

A. Create your planet. Create a coreless planet of 30 $M_{\oplus}$ made of H/He. For this copy paste `inlist_1a_create` into `inlist` and run MESA. This will create a file called “planet_1a_create.mod" that will be used in the next point. Make sure that the parameters defined in the file are the ones of the planet you want to run. Note: the initial radius of the planet is set up at 3 Jupiter radius. This is because planets have a large radius at the begging, so you don't have to change this parameter, MESA will find the true radius of the planet with time.

B. Add a core to your planet. Low mass planets have a core, so this is what we will add to our coreless planet formed in the previous point here. We will assume that the core has the same composition as the Earth. Then, using that an Earth-composition core satisfies a relation $(R/R_{\oplus}) = (M/M_{\oplus})^{0.27}$ (Valencia et al. 2006), estimate the mean density of a core that has 10 $M_{\oplus}$ and use this in the corresponding `inlist` file that you are going to use (`inlist_1b_core`). Also change the mass of the core to be 10 $M_{\oplus}$. Repeat this step for the following core masses: 3,5,7,10,12 $M_{\oplus}$. So then we will have 5 planets with different cores created after this point. Note: in addition to changing the input core mass and density you may want to change the file name to the core mass that you are using each time (save_model_filename and star_history_name). You should similarly adjust the corresponding lines in all subsequent inlists in the following points to make sure that you are saving the correct data for each planetary core mass that you are running.

C. Reduce the mass of your planets. We started creating a planet of 30 $M_{\oplus}$ but we want to end with a planet of a lower mass, so in this point we will reduce the mass of the planet. The planet has a core made of Earth's composition surrounded by a H/He envelope. The reduction in mass will be in the gaseous envelope only. We will explore planets with 2 different values for the envelope mass fraction: $f_{env} = M_{env}/M_p =$ 0.01 and 0.1 (for each one of the 5 core masses created above, then in the end, we will be creating 10 planets). Use this to calculate the different final mass that your planet will have, taken into account that $M_p = M_{core} + M_{env}$. Then specify the final mass of the planet in the parameter `new_mass` in the file `inlist_1c_reducemass`. Note: don't forget to change the `saved_model_filename`, `save_model_filename` and `star_history_name` to reflect your particular value of M_{core} and f_{env} in each case that you are running!

D. Set initial entropy at the base of your envelope. The next step is to change the initial conditions at the base of the envelope. We will use an entropy of S=9 kB/baryon at t=0, that is a standard value for these planets. Double check your file `history_1c_reducemass` (it should be inside the folder `LOGS`) to see what the center_entropy (MESA calls this at the entropy at the base of your envelope) is (it's listed in units k_B=baryon) for each of the models saved at the end of the last step. It should be lower than our target S = 9 kB/baryon. To change the initial entropy we need to puff our planets up. We will do this by adding an artificial luminosity that will deposit some energy inside the planets inflating them. To achieve this, then set up the artificial luminosity (`new_L_center`) equal to 2e27 erg/s (this will create the desire effect in all the different planets that you are creating). Then we use the stopping criterion `center_entropy_limit` to get MESA to quit and to save a model once our entropy limit is exceeded.

E. Evolve your planet! Finally, we will evolve the planets for 5 Gyr. This is done using `inlist_1e_evolve`. Note: we use the `relax_initial_L_center` again to turn down the artificial core luminosity, and to relax the core luminosity to a more physical (lower) value during evolution. Use a core energy generation rate of 5e−8 erg/g/s to estimate a plausible value for L_core for your assigned value of M_core. Note 2: Make sure that the final time set up in this file is the correct one!

F. After you have models made for all your 10 planets (with 5 different core masses and 2 different envelope mass fraction), then create 4 plots:
    I. one showing the evolution of the radius of each planet with time
    II. Make a figure showing the final mass (x-axis) vs. the final radius (y-axis) of all the 10 planets you created. Add in this figure some real exoplanets similar to the ones you created (from www.exoplanets.org or exoplanet.eu) as a comparison and put their names in the figure as a reference.
    III. Plot the final radiative gradient and the adiabatic gradient (both in the same plot) vs. the radius for each planet and explain how they are transporting their energy.
    IV. Plot the final temperature as a function of pressure for all your planets.

DETAILS ON THE ESSAY

Finally, you need to write an essay explaining all that you see in the 4 plots made above. The essay must be written according to the following structure:

1. Introduction
2. Methods: This section should be short. A detailed description of the code itself is not required, just explain the different cases you are running and write the parameters for each planet (M_p, M_{core}, M_{env}, mean density of the core).
3. Results: This is the main section. Here you must present the four plots, describe them and explain physically and in detail the evolution of the planet and final internal structure based on the four plots.
5. Conclusion

You can use as sources the lectures, lectures materials and any other paper you find relevant. Please cite the sources in an appropriate manner. The essay should not exceed 5 pages of A4 size, including figures (references do not count in this page limit). The figures should not be larger than half of an A4 and the 5 pages are to be counted in Times New Roman font of size 12. Please write your student number on the assignment.

IMPORTANT INFORMATION

The deadline to submit the essay is <u>October 22, 2020 at noon</u>. Submit your essay in PDF format via Brightspace. Results will be posted on November 5.

USEFUL UNITS & CONSTANTS

m_earth = 5.9764d27 earth mass (g)
r_earth = 6.37d8 earth radius (cm)
au = 1.495978921d13 astronomical unit (cm)
m_jupiter = 1.8986d30 jupiter mass (g)
r_jupiter = 6.9911d9 jupiter mean radius (cm)
semimajor_axis_jupiter = 7.7857d13 jupiter semimajor axis (cm)
msol = 1.9892d33 solar mass (g)
rsol = 6.9598d10 solar radius (cm)
lsol = 3.8418d33 solar luminosity (erg s^-1)

REFERENCES

Chen, H., & Rogers, L. A. 2016, ApJ, 831, 180
Paxton, B., Cantiello, M., Arras, P., et al. 2013, ApJs, 208, 4
Valencia, D., O'Connell, R. J., & Sasselov, D. 2006, Icarus, 181, 545