EXO-PLANETS INTERIORS & ATMOSPHERES (EIA2020)

LAB ASSIGNMENT 2: MODELLING IRRADIATED SUB-NEPTUNE MASS PLANETS

INTRODUCTION

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

THE ASSIGNMENT

You will have to run simulations to form and evolve 2 mini-gas planets highly irradiated (actually is one planet but located at 2 different semi major axis), 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. <u>Getting Started.</u> We'll start from one of the models that you created in the "Set initial entropy" step D in the Lab 1. We will use the case of Mcore = 12 $M_\oplus$ and $f_{env} = M_{env}/M_p = 0.1$. For this planet, take the file output of inlist_1d_setS (e.g. save_model_filename = “planet_1d_setS_XYZ”) and put that file as input in inlist_2a_evolve (saved_model_name = "planet_1d_setS_XYZ"). This inlist file relaxes the core luminosity, but then only evolves the planet without irradiation for 1e6 years. Then after this step, you would have created a planet model that has an appropriately core luminosity, but that hasn't evolved all the way to 5 Gyr.

B. <u>Add a source of external heating for your planet - 1) Relax irradiation.</u> In this step we add the irradiation coming from the star. This needs to be done gradually to avoid crushes in the code. Then in this step we gradually dial up the incident irradiation. We will use "inlist_2b_relaxsurfheat" to accomplish this goal. If you look inside "inlist_2b_relaxsurfheat", you see that you have two parameters that we haven’t used before: “irrad_col_depth" and another one that is “relax_to_this_irrad_flux”. The column depth for irradiation tells you how deep the irradiation penetrates into the planet before it is absorbed, and 300 cm^2/g is an appropriate value for these planets (see also Paxton et al. 2013). The other parameter is the irradiation flux coming from the star $F_\star = L_\odot/(4\pi a^2)$. Here we are going to make two runs using two different values, to model in the end 2 planets: one receives an incoming flux corresponding to 10 times more irradiation than the Earth and the other one receives an incoming flux corresponding to 100 times that of the Earth. Indicate in the essay which is the semi-major axis of the 2 planets that you are considering. Because this is a relaxation step before the real evolution, we only run this for a very short time (a few thousand years). Note: you don't need to change the time predefined in the file, or the column depth for irradiation, but you need to change the irradiation flux received by the planet.

C. Evolve the irradiated planets. In this final step, we evolve our 2 planets until the final time 5 Gyr. For this we run the file "inlist_2c_evosurfheat". Please make sure that you have the appropriate irradiation flux in the file (in this file this is the parameter called "irradiation_flux").

Note: steps B and C need to be done twice. One for each of the irradiation cases you are considering (for 10 and 100 times the Earth incoming flux). But you can use the same input file you got in A for both cases.

D. In this step you are going to create 6 plots. For each plot use the 2 models that you created in this lab and compare this with your non-irradiated planet obtained in Lab 1 (the same case that you are analysing here with Mcore = 12 $M_\oplus$ and $f_{env} = M_{env}/M_p = 0.1$).
   For these 3 planets plot:
   I. The evolution of the radius of the 3 planets with time.
   II. The evolution of the luminosity of the 3 planets with time.
   III. The final mass (x-axis) vs. the final radius (y-axis) of all the 3 planets. Are the irradiated planets inflated?
   IV. Plot the final radiative gradient and the adiabatic gradient (both in the same plot) vs. the radius normalised to the total radius of the planet for the two extreme cases (the non irradiated one and the most irradiated one). Did they change the way of transporting their energy because of the irradiation?
   V. Plot the temperature as a function of the radius normalised to the total radius of each planet (the 3 cases). How do the temperatures change with irradiation? Why?
   VI. Plot the pressure as a function of the radius normalised to the total radius of each planet (the 3 cases). How do the pressures change with irradiation? Why?

DETAILS ON THE ESSAY

Finally, you need to write an essay explaining all that you see in the 6 plots made above. The essay must be written according to the following structure:

1. Introduction
2. Methods: Explain here the equations introduced to take into account the irradiation of the planets in the MESA code. Hint: you can find more information in Paxton et al. 2013.
3. Results: This is the main section. Here you must present the six plots, describe them and explain physically and in detail the evolution of the planet and final internal structure based on the six plots indicating the effect of stellar irradiation on your planets.
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. In order to save space, put Figures I and II on the same row and the same with figures V and VI. 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>November 19, 2020 at noon</u>. Submit your essay in PDF format via Brightspace. Results will be posted on December 3.

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