Universidad Técnica Federico Santa María
Departamento de Física
Astrofísica computacional II
AST-305

Monte carlo simulation of the stars of the galaxy

Right now you are going to perform a population synthesis of single stars of the Milky way. The Milky way has around *100-400 billion* stars, which makes a number incredibly large to make simulations of each individual star with stellar evolution codes such as MESA or SSE. Therefore, we will make use of some known functions and a simple Monte Carlo simulation to get an estimate of the fraction of stellar objects there are in our Galaxy.

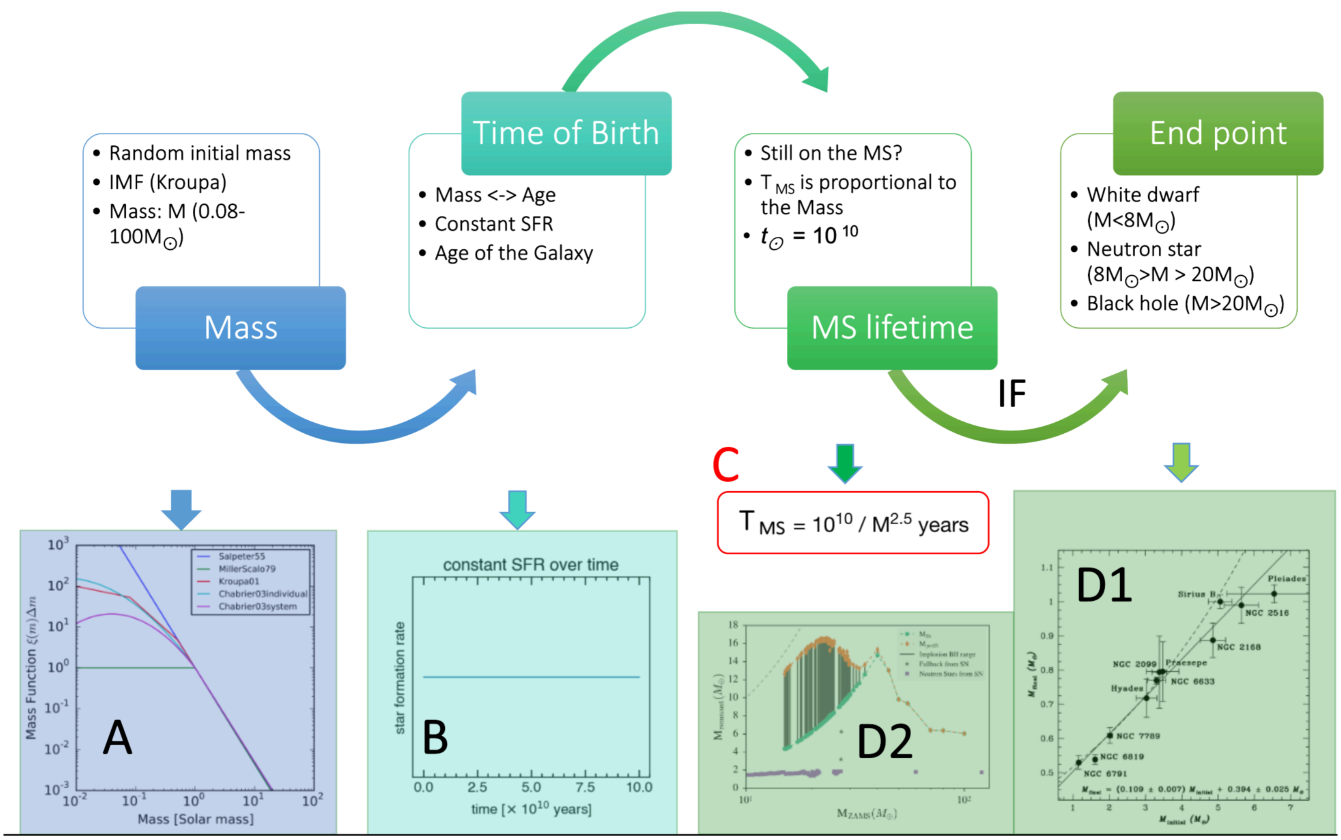

Figure 1: functions and equations needed to code a Monte Carlo simulation on the evolution of the stars in the Milky Way

Write a code in python in which you implement the following steps:
1) **choose the mass of those stars**: draw randomly the mass from the IMF from Kroupa. The IMF has been determined empirically by various authors, finding that more stars are formed with lower mass. Ultimately this leads to many more white dwarfs being formed than neutron stars and black holes (see panel A in Figure 1).
2) **choose a time for stars to form**: You can assign a birth time to the stars by randomly drawing a time from a constant star formation rate (SFR). As shown in panel B in Figure 1, the SFR can be represented with a uniform distribution on the time of birth from 0 to 10 Gyr (age of the Milky way).

3) **check the main-sequence lifetime for the drawn mass** - Calculate what would be the main sequence lifetime of your stars, if the total age of your star is longer than T_{MS}, then it will be a stellar remnant i.e. a white dwarf, a neutron star or a black hole (here we assume that the phase of the red giant is very short along the evolution of the star and therefore you can ignore the time of your star spent along the red giant branch). The main sequence lifetime can be approximated by

$$t = 10^{10} (M/L) = 10^{10} (M/M^{3.5}) = 10^{10} / M^{2.5} \text{ years}$$

with $t_{\odot} = 10^{10}$ years being the Sun MS lifetime, M the mass of the star (same equation to the one shown in C in Figure 1). So for example the main sequence lifetime of a 20 solar mass star is $10^{10} / 20^{2.5} = 6 \times 10^{6}$, or 6 million years.

4) **What stellar remnant is your star?** If your star has evolved off the main sequence you need to find out what its end point is . In order to determine the endpoint you are going to use initial-to-final mass relations (IFMR). We are going to use the formulation implemented by default of the code SPISEA (read section 4.3 of the paper of Hosek et al. 2020) which the IFMR is a combination of two IFMRs in the literature: one for white dwarfs (WD, see panel D1 in Figure 1), and another for neutron stars (NS) and black holes (BHs) which both are shown in panel D2 in Figure 1.

- For white dwarfs the IFMR is given by the formula shown in section 8.4 of Kalirai et al. (2008), where your $M_{initial}$ is the mass you have drawn in step 1.
- For neutron stars read section 5 of Raithel et al. (2018), and you will find out that the IFMR is given by their equations 11, 12, 13, and 14.
- For black holes read section 4 of Raithel et al. (2018), and you will find out that the IFMR are given by their formulas 1,2,3 and 4 (use the ejection fraction of f_{EJ}=0.9).
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CODING!!

1. Write a python code that simulates the stellar components in our galaxy (10Gyr old).
    - Be organised with our code: write a documentation about your code (what the functions do, what are the input and output of your code).
    - Try that your code is efficient: test making 100, 1000, 1000000, so on stars
    - Make a flowchart of your code! So you can have the steps of what your code makes
2. Upload your flowchart, code and documentation to github (with a private account) and send the invitation to me.

With your simulation at hand, know try to elaborate a figure which answer the following questions: **What is the FRACTION of WDs, NSs, BHs and MS stars you have in your simulation of the Milky Way? And What mass has the oldest star/WD/NS/BH and the youngest star/WD/NS/BH?**

In a presentation (max. 10 minutes + 5 of questions):

> present your flowchart (with models and parameters)
> figure that illustrates the answers to the questions

What you need to do with your code:

1. Simulate 100 stars, 1000 stars, 10000, 100000, and 1000000 stars.
2. Make a normalised histogram which displays the final masses at age of the Milky for the main sequence stars, white dwarf, neutron stars and black holes (with different colours).
3. Make a histogram of the age of the stellar bodies (with different colours). Discuss the distribution you are getting, and why does it have that shape.
4. Provide the fraction for which each of these 4 stellar bodies, are they consistent with the census of the Milky way?
5. Make a flowchart of your code,
6. write a documentation about your code (what the functions do, what are the input and output of your code).
7. Upload your flowchart, code and documentation to github (with a private account) and send the invitation to Prof. Alejandra and teaching assistants.