ASTR 400B In Class Lab 3

1 First Step

Make sure to have a cloned copy of your own repository on your computer (or on nimoy). Create a directory Labs/Lab3.

From the command line git clone the class repository. If you have already done this, git pull to update the repository. There is a directory Labs/Lab3/ with a file Lab3.ipynb, which is the template for this exercise.

Copy this template to your own repository directory Labs/Lab3

2 The Lab

The Large Magellanic Cloud is at a distance of 50 kpc from the Galactic Center. It is observed to have a stellar disk that extends to a radius of at least 18.5 kpc. See Figure 1.

In this lab we will determine the minimum mass required such the LMC can maintain the observed radius for its stellar disk in the face of the Milky Way's tidal field.

3 MW Mass Profile

In the MW-M31 simulation, both galaxies are modeled as a Hernquist sphere with the following density and mass profile:

$$\rho(r) = \frac{Ma}{2\pi r}\frac{1}{(r+a)^3} \qquad M(r) = \frac{M_{halo} r^2}{(a+r)^2} \tag{1}$$

3.1 Question 1

Create a function *HernquistM* that returns the Hernquist halo mass at a given radius. This function should take as input: the scale radius a, the halo mass M_{halo}, and the distance to the satellite, r.

Create a function *HernquistM* that returns the dark matter halo mass at a given radius in units of solar mass. This function should take as input: the distance from the Galactic center r, the scale radius a, and the halo mass M_{halo}.

For the Hernquist scale radius for the Milky Way, use the default value of $a = 60$ kpc.

For M_{halo} use your answer for the total mass of the simulated Milky Way you computed in Homework 3 as the default value (in units of 1e12).

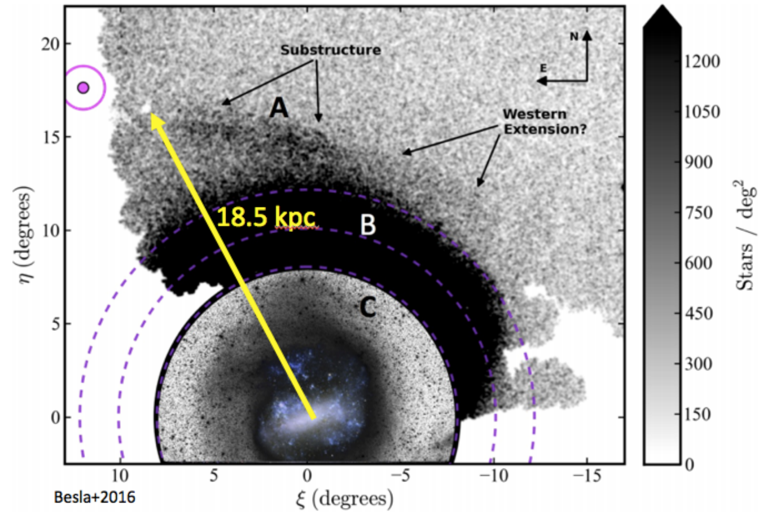

Figure 1: Deep photometric imaging reveals the faint stellar outskirts of the LMC. Outskirts: DECam data Mackey+2016 MNRAS 459, 239. Inner: shallower imaging from robotic telescopes Besla+2016 APJ 825.

3.2 Question 2

Compute the total mass of the Milky Way within 50 kpc, including its baryonic components (Dark Matter + Bulge + Disk). Use your answers from Homework 3 for the Bulge and Disk Masses. Store this as a variable called *MassMW50*.

4 M_{sat}: Mass of the LMC

The Jacobi Radius for a satellite on a circular orbit about an extended host following an isothermal sphere halo is:

$$R_j = r\left(\frac{M_{sat}}{2M_{host}(<r)}\right)^{1/3} \tag{2}$$

We are assuming that the mass of the MW within 50 kpc can be well approximated by an isothermal sphere model (which it can, if V_c = 206 km/s rather than 220 or 240). Note also that the LMC is not on a circular orbit, but it is very close to its pericentric approach, where the velocity is all in the tangential component. So this isn't a terrible approximation.

Create a function called *JacobiMass* that returns the total mass of a satellite galaxy in units of solar mass, such that it has a given size

Do this by rearranging the Jacobi Radius equation to solve for the satellite mass.

4.1 Question 2

Determine the minimum total mass of the LMC needed to maintain its radius of 18.5 kpc in the face of the Milky Way's tidal field at its current distance of 50 kpc. Store this as a variable called *LMCJacobiMass*.

4.2 Question 3

Recall that, ignoring centrifugal forces and assuming the host is a point mass, the tidal radius is given as :

$r_{tide} = r\left(\frac{m_{sat}}{4M_{host}}\right)^{1/3}$

Create a function called ‘TidalMass‘ to determine the total mass the must LMC possess to have a disk with radius 18.5 kpc. Use the function to determine the needed LMC mass and store it as a variable called ‘LMCTidalMass‘.

4.3 Question 4

Compare this to the calculation using the Jacobi Radius. How does this mass compare to the stellar mass of the LMC (3×10^9 $M_\odot$)?

5 Consistency Check

The maximal enclosed mass of the LMC at any radius can be determined by assuming a flat rotation curve.

$$V_c^2 = \frac{GM}{r} = constant \tag{3}$$

G = 4.498768e-6 $\text{kpc}^3/\text{Gyr}^2/M_\odot$ (note that 1 kpc/Gyr $\sim$ 1 km/s). The rotation curve of the LMC is observed to be 91.7 +/- 18.8 kpc (van der Marel & Kallivayalil 2014).

Create a function called *MaxMass* that takes as input Vc (km/s) and distance to from the center of the galaxy (r) and returns the maximal dynamical mass in Msun.

5.1 Question 1

What is the maximal mass enclosed by the LMC within the observed radius? Is it consistent with the minimum mass needed to explain the observed radius of the LMC given the tidal field of the MW? If not, how could the numbers be reconciled?