Practica 1 - 11/04

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We import the libraries and the differents tools of pyhton to make figures and units from astropy:

In [ ]:
```
import gala.potential as gp
import astropy.units as u
import numpy as np
import gala.dynamics as gd
from gala.units import galactic
import matplotlib.pyplot as plt
```

We make a **composite potential** using the function of gala `gp.CCompositePotential.` The potential of a galaxy contents differents substructures potentials inside:

- Disk: Miyamoto-Nagai
- Bulge: Hernquist
- Dark Matter halo: Navarro Frenk and White

In [ ]:
```
total_potential = gp.CCompositePotential()
total_potential['disk'] = gp.MiyamotoNagaiPotential(m = 1E11 , a=3, b=0.15, units=galactic)
total_potential['bulge'] = gp.HernquistPotential(m = 3E9 , c = 0.67, units=galactic)
total_potential['dm_halo'] = gp.NFWPotential.from_circular_velocity(v_c=200*u.km/u.s,
                                             r_s=10.*u.kpc,
                                             units=galactic)
```

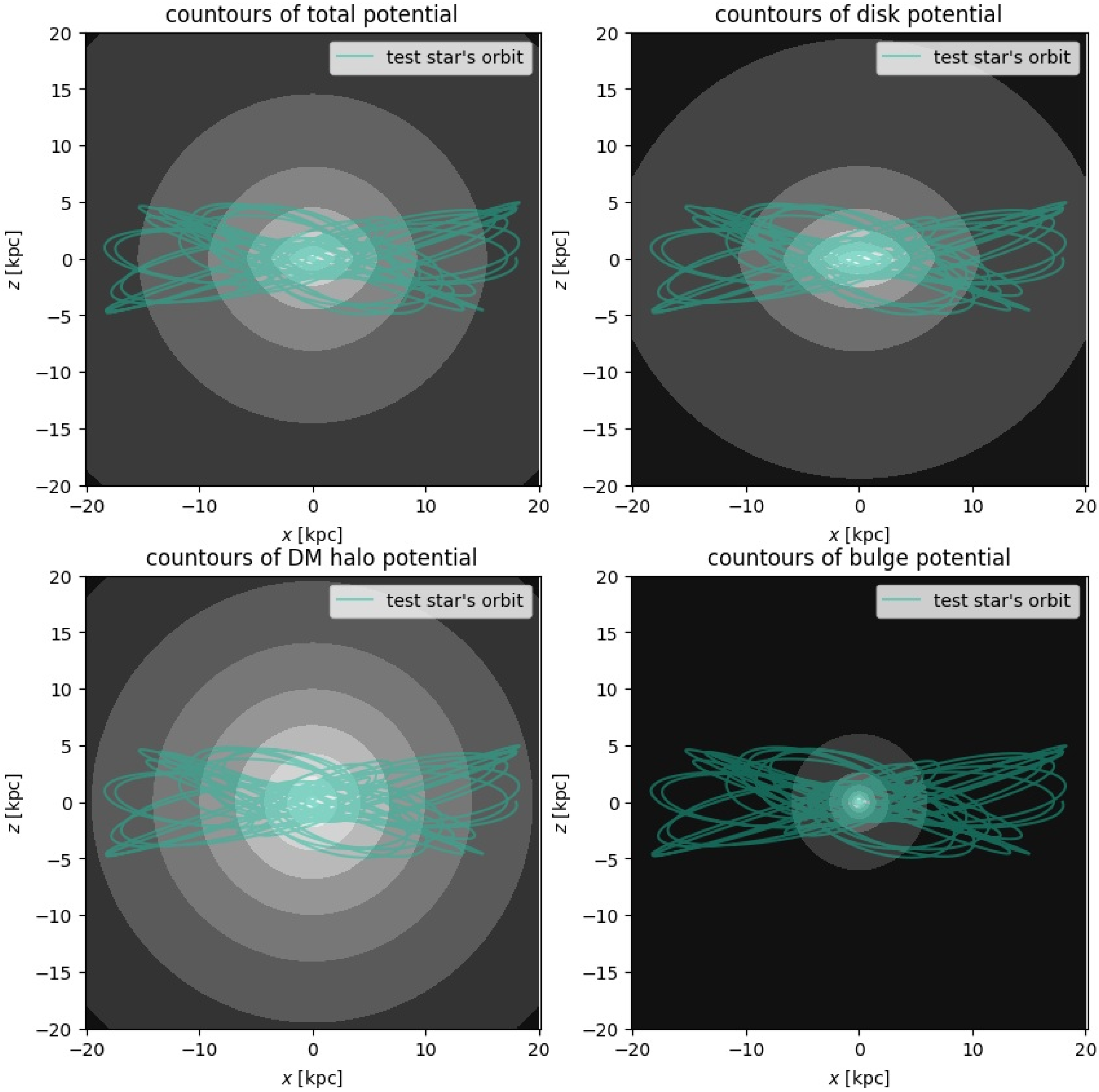
Following the tutorial of gala (https://gala.adrian.pw/en/latest/tutorials.html), we put a test star over the potential, to calculate its orbit. Also, the following plots are for the same orbit calculated with the total potential and, the countours correspond to the differents potentials shapes.

In [ ]:
```
test_star_p = [18,-4,0]
test_star_v = [20,100,-50]
```

In [ ]:
```
ics = gd.PhaseSpacePosition(pos = test_star_p*u.kpc,
                            vel = test_star_v*u.km/u.s)
#orbital matematical derivation
orbit = gp.Hamiltonian(total_potential).integrate_orbit(ics,dt=2.,n_steps=3500)
```

In [ ]:
```
grid = np.linspace(-20,20,128)
fig, ax = plt.subplots(2, 2, figsize=(10,10))


fig = total_potential.plot_contours(grid=(grid, 0, grid), cmap='Greys', ax=ax[0,0])
fig = orbit.plot(['x','z'], color='#1ABC9C',
                      alpha=0.5, axes=[ax[0,0]], auto_aspect=True, label="test star's orbit")
ax[0,0].legend()
ax[0,0].set_title('countours of total potential')

fig2 = total_potential['bulge'].plot_contours(grid=(grid, 0, grid), cmap='Greys', ax=ax[1,1])
fig2 = orbit.plot(['x','z'], color='#1ABC9C',
                      alpha=0.5, axes=[ax[1,1]], auto_aspect=True, label="test star's orbit")
ax[1,1].legend()
ax[1,1].set_title('countours of bulge potential')

fig3 = total_potential['disk'].plot_contours(grid=(grid, 0, grid), cmap='Greys', ax=ax[0,1])
fig3 = orbit.plot(['x','z'], color='#1ABC9C',
                      alpha=0.5, axes=[ax[0,1]], auto_aspect=True, label="test star's orbit")
ax[0,1].legend()
ax[0,1].set_title('countours of disk potential')

fig = total_potential['dm_halo'].plot_contours(grid=(grid, 0, grid), cmap='Greys', ax=ax[1,0])
fig = orbit.plot(['x','z'], color='#1ABC9C',
                      alpha=0.5, axes=[ax[1,0]], auto_aspect=True, label="test star's orbit")
ax[1,0].legend()
ax[1,0].set_title('countours of DM halo potential')
```

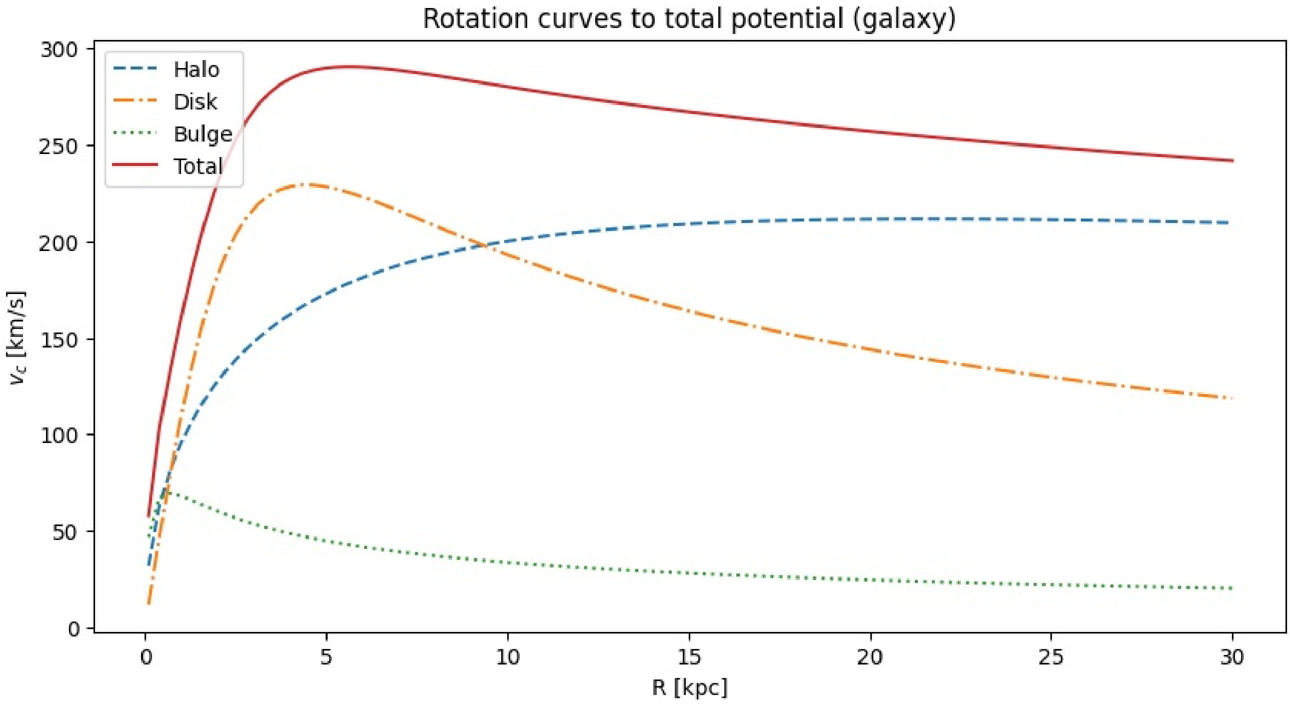
Out[ ]:
```
Text(0.5, 1.0, 'countours of DM halo potential')
```



Also, we made the rotation curve of the galaxy, considering the total potential and their components. See next figure.

In [ ]:
```
R_grid = np.linspace(0.1, 30, 100) * u.kpc
xyz = np.zeros((3,) + R_grid.shape) * total_potential['dm_halo'].units["length"]
xyz[0] = R_grid

vcirc_halo = total_potential['dm_halo'].circular_velocity(xyz)
vcirc_disk = total_potential['disk'].circular_velocity(xyz)
vcirc_bulge = total_potential['bulge'].circular_velocity(xyz)
#vcirc_core = core.circular_velocity(xyz)
vcirc_gal = total_potential.circular_velocity(xyz)

fig = plt.figure(figsize=(10, 5))
plt.plot(R_grid, vcirc_halo, label='Halo',linestyle='--')
plt.plot(R_grid, vcirc_disk, label='Disk',linestyle='-.')
plt.plot(R_grid, vcirc_bulge, label='Bulge',linestyle=':')
#plt.plot(R_grid, vcirc_core, label='Nucleus',linestyle='-.')
plt.plot(R_grid, vcirc_gal, label='Total')
plt.xlabel('R [kpc]')
plt.ylabel(f'$v_c$ [km/s]')
plt.title('Rotation curves to total potential (galaxy)')
plt.legend()
```

```
plt.show()
```



Practica 2 - 18/04

We use 2 test star to calculate different propiertes of the potential and the orbit of its. We define `a_star` and `b_star`, their initial positions in `[x,y,z]` and their initial velocities `[d_x, d_y, d_z]`

In [ ]:
```
#estrellas para probar los potenciales
a_star_p = [8,2,0.5]
a_star_v = [-20,80,-3]

b_star_p = [3,7,0]
b_star_v = [150,-80,-6]
```

Only considering the DM potential

We calcule the orbit of this tests stars, using only the DM halo potential. Also, we compute the total energy, potential energy, angular moment, angular moment per component, and eccentricity

In [ ]:
```
#Dentro del halo de materia oscura
a_particle = gd.PhaseSpacePosition(pos = a_star_p*u.kpc,
                            vel = a_star_v*u.km/u.s)
b_particle = gd.PhaseSpacePosition(pos = b_star_p*u.kpc, vel= b_star_v*u.km/u.s)

#orbital matematical derivation
a_orbit_DM = gp.Hamiltonian(total_potential['dm_halo']).integrate_orbit(a_particle, dt=0.5*u.Myr , t1=0, t2=2*u
b_orbit_DM = gp.Hamiltonian(total_potential['dm_halo']).integrate_orbit(b_particle, dt =0.5*u.Myr , t1=0, t2=2*

#calculo de parametros practica 2
a_potentialenergy = a_orbit_DM.energy() - a_orbit_DM.kinetic_energy().to(u.kpc**2/u.Myr**2)
a_totalenergy_DM = a_orbit_DM.energy()
a_angularmoment_DM = a_orbit_DM.angular_momentum
a_Lx_DM = a_angularmoment_DM()[0]
a_Ly_DM = a_angularmoment_DM()[1]
a_Lz_DM = a_angularmoment_DM()[2]
a_totalangularmoment = np.sqrt(a_Lx_DM**2 + a_Ly_DM**2 + a_Lz_DM**2)
a_eccentricity = a_orbit_DM.eccentricity

b_totalenergy_DM = b_orbit_DM.energy() + b_orbit_DM.kinetic_energy()
b_potentialenergy = b_orbit_DM.energy() - b_orbit_DM.kinetic_energy().to(u.kpc**2/u.Myr**2)
b_angularmoment_DM = b_orbit_DM.angular_momentum
b_Lx_DM = b_angularmoment_DM()[0]
b_Ly_DM = b_angularmoment_DM()[1]
b_Lz_DM = b_angularmoment_DM()[2]
b_totalangularmoment = np.sqrt(b_Lx_DM**2 + b_Ly_DM**2 + b_Lz_DM**2)
b_eccentricity = b_orbit_DM.eccentricity
```

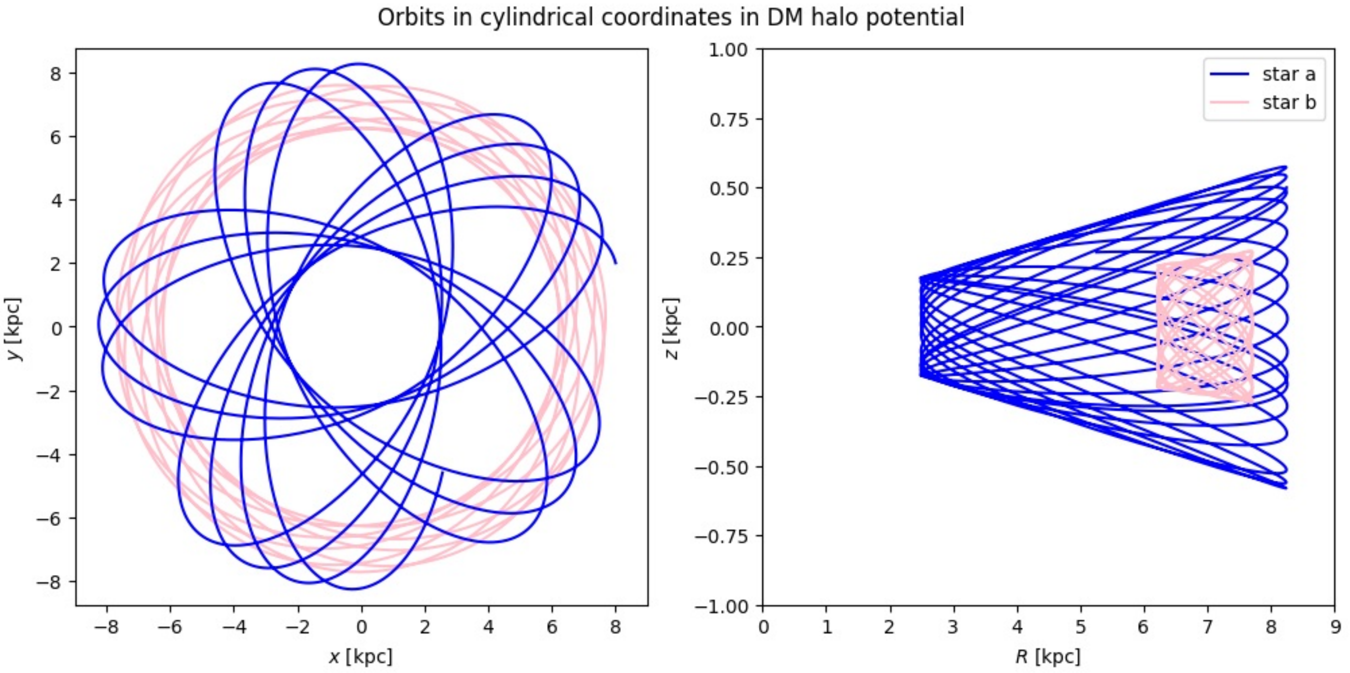
In [ ]:
```
#this is another way to integrate the orbit
a_test_orbit = total_potential['dm_halo'].integrate_orbit(a_particle, dt=0.5*u.Myr, t1=0, t2=2*u.Gyr )
b_test_orbit = total_potential['dm_halo'].integrate_orbit(b_particle, dt=0.5*u.Myr, t1=0, t2=2*u.Gyr )
```

In [ ]:
```
fig, axes = plt.subplots(1,2,figsize=(10, 5), constrained_layout = True)
```

```
fig.suptitle('Orbits in cylindrical coordinates in DM halo potential')

b_test_orbit.plot(['x','y'], color='pink', axes=axes[0])
a_test_orbit.plot(['x','y'], color='blue', axes=axes[0])
axes[0].set_xlim(-8,8)
axes[0].set_ylim(-8,8)

a_test_orbit.cylindrical.plot(
    ["rho", "z"],
    color='blue',
    axes=axes[1],
    auto_aspect=False,
    labels=["$R$ [kpc]", "$z$ [kpc]"],
    label="star a",
)
b_test_orbit.cylindrical.plot(
    ["rho", "z"],
    color='pink',
    axes=axes[1],
    auto_aspect=False,
    labels=["$R$ [kpc]", "$z$ [kpc]"],
    label="star b",
)
axes[1].set_xlim(0,9)
axes[1].set_ylim(-1,1)
axes[1].set_aspect('auto')
axes[1].legend(loc='best', fontsize=10)
```

Out[ ]:

```
<matplotlib.legend.Legend at 0x7a5da250e4a0>
```

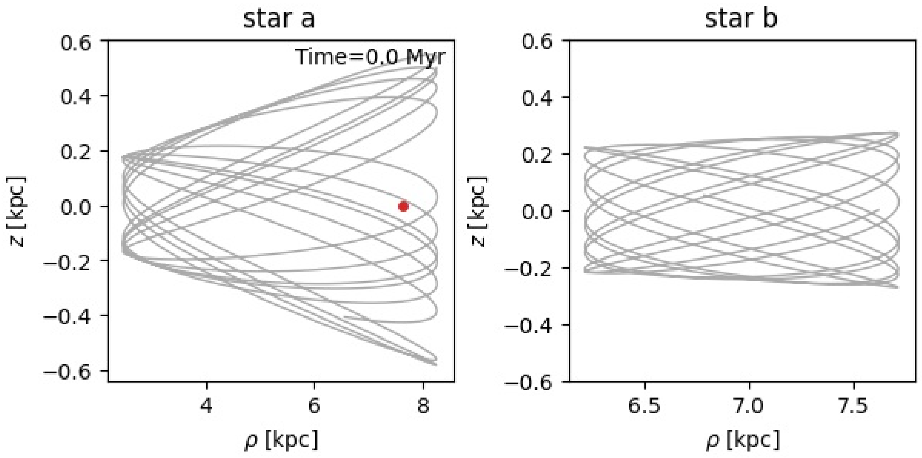


The next two cells run a script to generate a gif animation using the data of the orbits extracted previously.

In [ ]:

```
#Esto hace los gif de las orbitas
fig, axes = plt.subplots(1,2,figsize=(6, 3), constrained_layout = True)
fig, anim = a_test_orbit[:3000].cylindrical.animate(components=['rho', 'z'], stride=10, axes=axes[0])
fig, anim = b_test_orbit[:3000].cylindrical.animate(components=['rho', 'z'], stride=10, axes=axes[1])
#axes.legend(loc='best', fontsize=15)
axes[1].set_title('star b')
axes[1].set_ylim(-0.6,0.6)
axes[0].set_title('star a')
anim.save('animacion.gif')
```

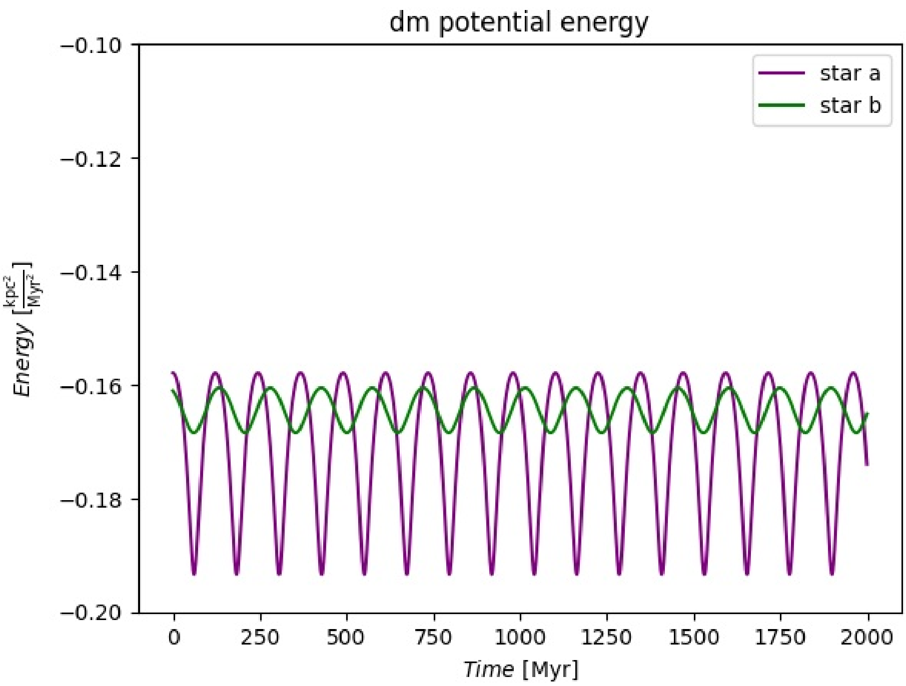
```
/home/patito/.local/lib/python3.10/site-packages/matplotlib/animation.py:892: UserWarning: Animation was deleted without rendering anything. This is most likely not intended. To prevent deletion, assign the Animation to a variable, e.g. `anim`, that exists until you output the Animation using `plt.show()` or `anim.save()`.
  warnings.warn(
```



Now we plot the potential energy of the particle on DM halo potential

In [ ]:
```
#calcular y graficar la evolucion temporal de energia

plt.plot(a_orbit_DM.t, a_potentialenergy, color='purple', label='star a')
plt.plot(b_orbit_DM.t, b_potentialenergy, color='green', label='star b')
plt.ylim(-0.2,-0.1)
#plt.yscale('log')
plt.xlabel("$Time$ [{}]".format(a_orbit_DM.t.unit.to_string(format="latex")))
plt.ylabel("$Energy$ [{}]".format(a_totalenergy_DM.unit.to_string(format='latex')))
plt.title('dm potential energy')
plt.legend(loc='best')
```

Out[ ]: <matplotlib.legend.Legend at 0x7a5da99424d0>

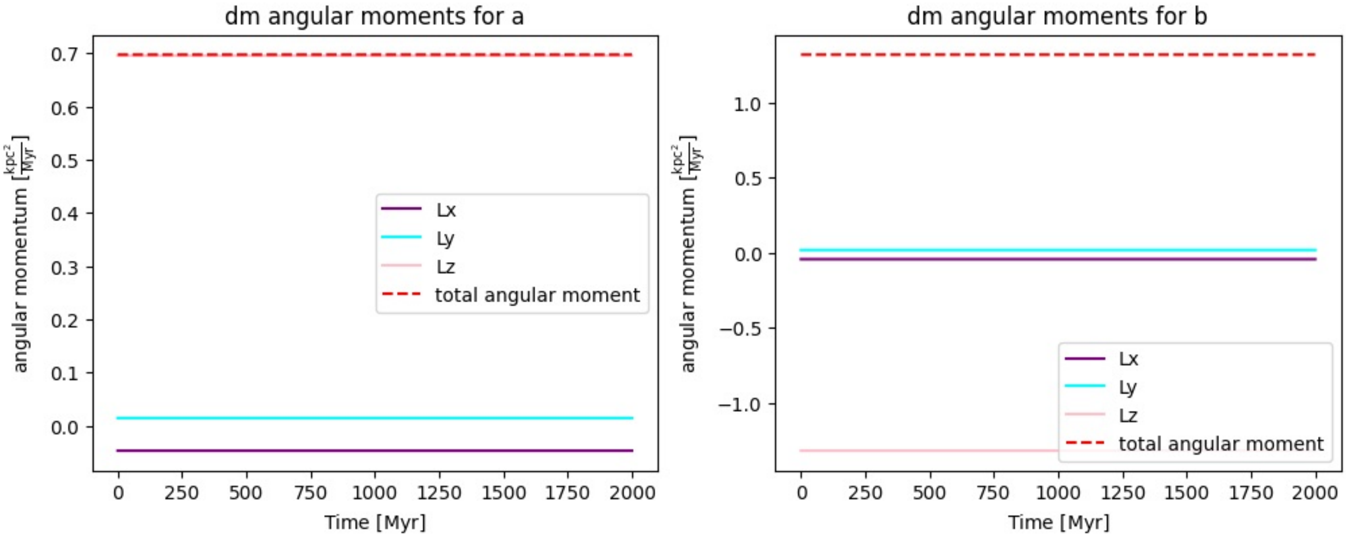


Also we plot the angular moment for the stars a and b, an their different components.

In [ ]:
```
fig, ax = plt.subplots(1,2,figsize=(10, 4), constrained_layout = True)
ax[0].plot(a_orbit_DM.t, a_Lx_DM, color='purple', label='Lx')
ax[0].plot(a_orbit_DM.t, a_Ly_DM, color='cyan', label='Ly')
ax[0].plot(a_orbit_DM.t, a_Lz_DM, color='pink', label='Lz')
ax[0].plot(a_orbit_DM.t, a_totalangularmoment, color='red', label='total angular moment', linestyle='--')

#ax[].ylim(-0.2,-0.1)
#ax[].yscale('log')
```

```python
ax[0].set_xlabel("Time [{}]".format(a_orbit_DM.t.unit.to_string(format='latex')))
ax[0].set_ylabel("angular momentum [{}]".format(a_Lx_DM.unit.to_string(format='latex')))
ax[0].set_title('dm angular moments for a')
ax[0].legend(loc='best')

#ax[].plot(b_orbit_DM.t, b_totalenergy_DM, label='total energy')
ax[1].plot(b_orbit_DM.t, b_Lx_DM, color='purple', label='Lx')
ax[1].plot(b_orbit_DM.t, b_Ly_DM, color='cyan', label='Ly')
ax[1].plot(b_orbit_DM.t, b_Lz_DM, color='pink', label='Lz')
ax[1].plot(b_orbit_DM.t, b_totalangularmoment, color='red', label='total angular moment', linestyle='--')

#ax[].ylim(-0.2,-0.1)
#ax[].yscale('log')
ax[1].set_xlabel("Time [{}]".format(b_orbit_DM.t.unit.to_string(format='latex')))
ax[1].set_ylabel("angular momentum [{}]".format(b_Lx_DM.unit.to_string(format='latex')))
ax[1].set_title('dm angular moments for b')
ax[1].legend(loc='lower right')
```

Out[ ]: <matplotlib.legend.Legend at 0x7a5da1694b50>



We compute the same parameters for the stars and the total potential (i.e. bulge, disk and dm halo)

In [ ]:
```python
#agregamos el disco y otras cosas
#orbital matematical derivation
a_orbit_total = gp.Hamiltonian(total_potential).integrate_orbit(a_particle, dt=2., n_steps=5000)
b_orbit_total = gp.Hamiltonian(total_potential).integrate_orbit(b_particle, dt = 2. , n_steps = 5000)

#calculo de parametros practica 2
a_potentialenergy_total = a_orbit_total.energy() - a_orbit_total.kinetic_energy().to(u.kpc**2/u.Myr**2)
a_totalenergy_total = a_orbit_total.energy()
a_angularmoment_total = a_orbit_total.angular_momentum
a_Lx_total = a_angularmoment_total()[0]
a_Ly_total = a_angularmoment_total()[1]
a_Lz_total = a_angularmoment_total()[2]
a_totalangularmoment_total = np.sqrt(a_Lx_DM**2 + a_Ly_DM**2 + a_Lz_DM**2)
a_eccentricity_total = a_orbit_total.eccentricity

b_totalenergy_total = b_orbit_total.energy() + b_orbit_total.kinetic_energy()
b_angularmoment_total = b_orbit_total.angular_momentum
b_Lx_total = b_angularmoment_total()[0]
b_Ly_total = b_angularmoment_total()[1]
b_Lz_total = b_angularmoment_total()[2]
b_eccentricity_total = b_orbit_total.eccentricity
```

We add a 'c star' to plot the poncaire surfaces and with the aim to have a best data visualization

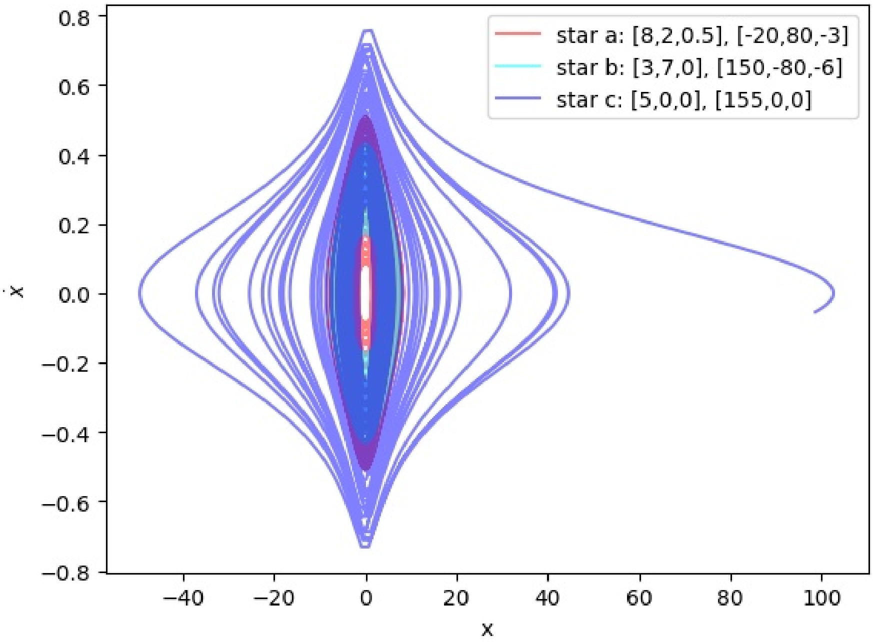
In [ ]:
```python
# ninguna de las orbitas srive, asi que hacemos una tercera

c_star_p = [5,0,0]
c_star_v = [155,0,0]

ics = gd.PhaseSpacePosition(pos = c_star_p*u.kpc,
                            vel = c_star_v*u.km/u.s)
#orbital matematical derivation
c_orbit_total = gp.Hamiltonian(total_potential).integrate_orbit(ics,dt=2.,n_steps=5000)

c_potentialenergy = c_orbit_total.energy() - c_orbit_total.kinetic_energy().to(u.kpc**2/u.Myr**2)
c_totalenergy_total = c_orbit_total.energy()
c_angularmoment_total = c_orbit_total.angular_momentum
c_Lx_total = c_angularmoment_total()[0]
```

```
c_Ly_total = c_angularmoment_total()[1]
c_Lz_total = c_angularmoment_total()[2]
c_totalangularmoment = np.sqrt(c_Lx_total**2 + c_Ly_total**2 + c_Lz_total**2)
c_eccentricity = c_orbit_total.eccentricity


poncaire_c1 = c_orbit_total[np.nonzero(c_orbit_total.pos.y > 0)]
```

Finally, we made the poincare surfaces using the condition $y = 0$ and $\dot{y} > 0$. This was the reason for the star c (the a and b stars, dont has the initial conditions to the poincares surfaces proposed)

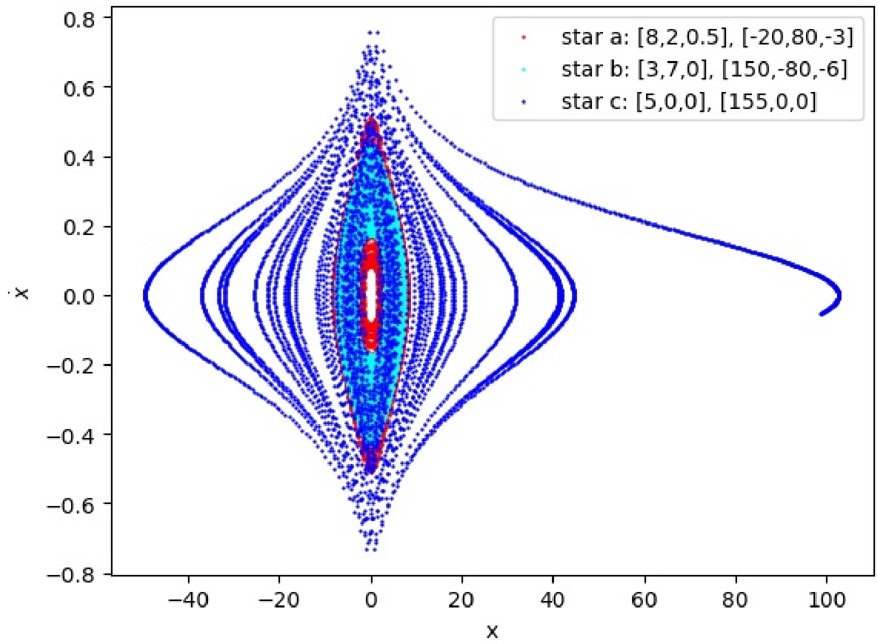
In [ ]:
```
#graficos para distintas estrellas creadas con posiciones iniciales disntintas
plt.plot(a_orbit_total.pos.x, a_orbit_total.vel.d_x, color='red', alpha=0.5, label='star a: [8,2,0.5], [-20,80,
plt.plot(b_orbit_total.pos.x, b_orbit_total.vel.d_x, color='cyan', alpha=0.5, label='star b: [3,7,0], [150,-80,
plt.plot(c_orbit_total.pos.x, c_orbit_total.vel.d_x, color = 'blue', alpha=0.5, label='star c: [5,0,0], [155,0,
plt.xlabel('x')
plt.ylabel('$\dot{x}$')


plt.legend()
```

Out[ ]: <matplotlib.legend.Legend at 0x7a5da16b8bb0>



In [ ]:
```
#graficos para distintas estrellas creadas con posiciones iniciales disntintas
plt.scatter(a_orbit_total.pos.x, a_orbit_total.vel.d_x, color='red', s=0.5, label='star a: [8,2,0.5], [-20,80,-
plt.scatter(b_orbit_total.pos.x, b_orbit_total.vel.d_x, color='cyan', s=0.5, label='star b: [3,7,0], [150,-80,-
plt.scatter(c_orbit_total.pos.x, c_orbit_total.vel.d_x, color = 'blue', s=0.5, label='star c: [5,0,0], [155,0,0
plt.xlabel('x')
plt.ylabel('$\dot{x}$')

plt.legend()
```

Out[ ]: <matplotlib.legend.Legend at 0x7a5da1545390>



In [ ]:

Processing math: 100%