practica2

April 24, 2024

1 Mejora del potencial inicial

Aqui he modificado el potencial utilizado en la practica 1, al igual que lo he generalizado mediante la importacion de un script(anidado al final del jupyter por completitud)

[1]:

```python
# import astropy.units as u
# import numpy as np
# import gala.potential as gp
# from gala.units import galactic
# import matplotlib.pyplot as plt
from constructor import *
```

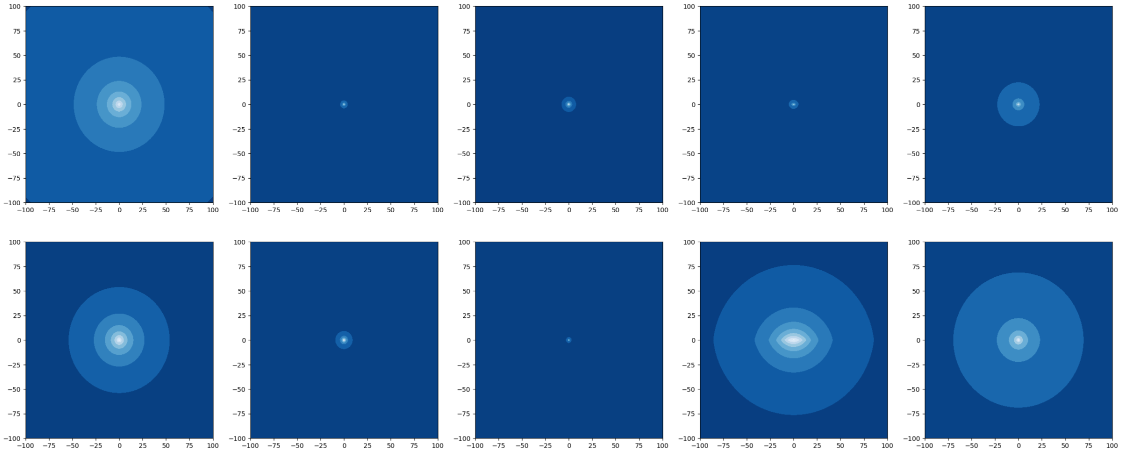
[2]:

```python
oldgalpot = create_gal_potential(total_mass=1e11*u.M_sun, r_s=5*u.kpc)
# Valores L*(M) obtenidos de (Cooray,2008)
#
newgalpot = create_complex_potential(
    total_mass=1e12*u.M_sun,
    r_s=5*u.kpc,
    dm_fraction=0.78,
    disk_total=0.7,
    bulge_total=0.29,
    nucleus_total=0.01,
    bulge_b=1.2,
    disk_a=10,
    disk_b=0.5,
    nucleus_b=0.4
)
```

[3]:

```python
grid = np.linspace(-100,100,1000)
fig, axes = plt.subplots(2,5,figsize=(30,12))

oldgalpot["halo"].plot_contours((grid,0,grid), ax=axes[0,0])
oldgalpot["bulge"].plot_contours((grid,0,grid), ax=axes[0,1])
oldgalpot["nucleus"].plot_contours((grid,0,grid), ax=axes[0,2])
oldgalpot["disk"].plot_contours((grid,0,grid), ax=axes[0,3])
oldgalpot.plot_contours((grid,0,grid), ax=axes[0,4])

newgalpot["halo"].plot_contours((grid,0,grid), ax=axes[1,0])
```

```
newgalpot["bulge"].plot_contours((grid,0,grid), ax=axes[1,1])
newgalpot["nucleus"].plot_contours((grid,0,grid), ax=axes[1,2])
newgalpot["disk"].plot_contours((grid,0,grid), ax=axes[1,3])
newgalpot.plot_contours((grid,0,grid), ax=axes[1,4])
plt.show()
```

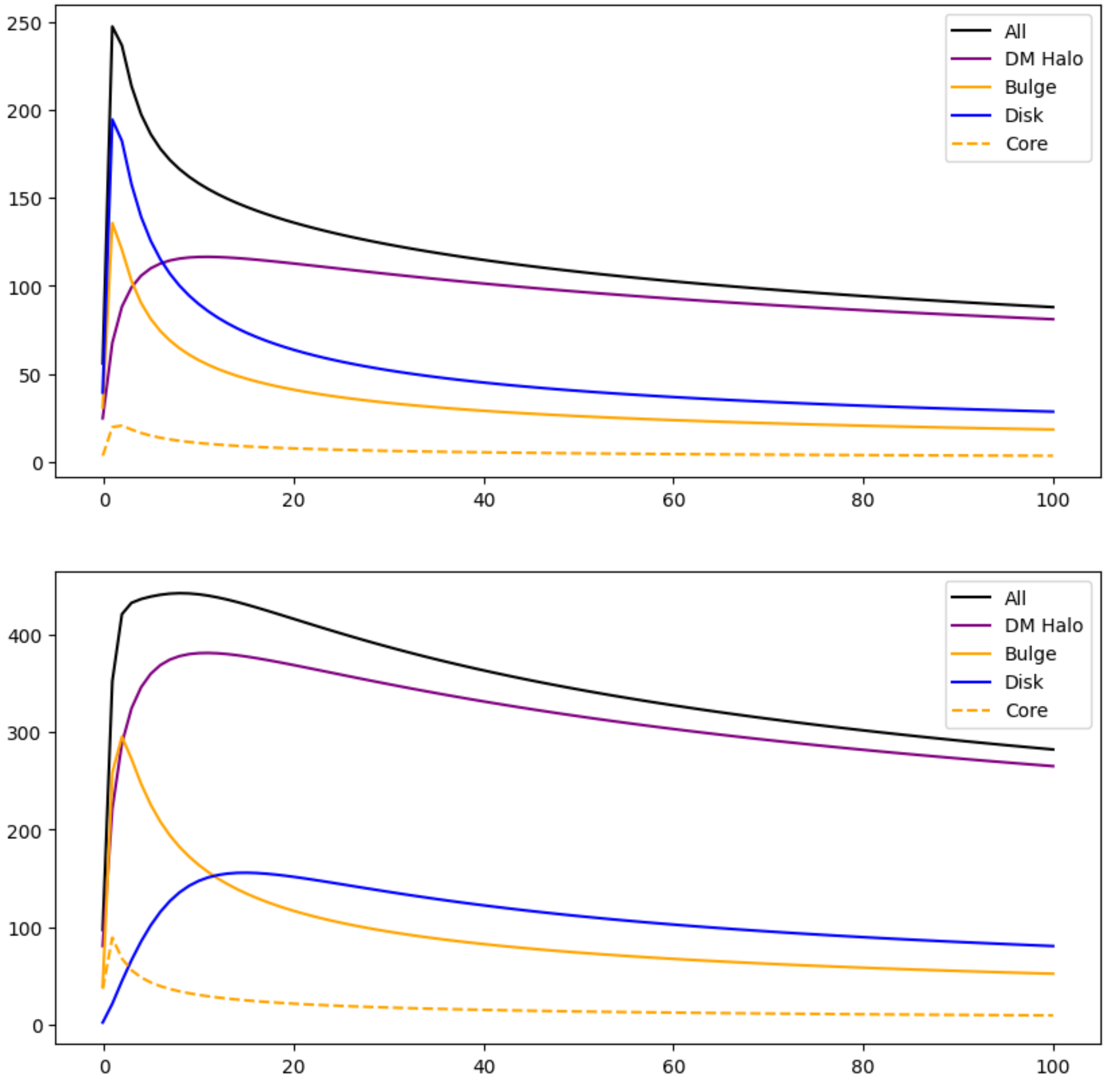


[4]:

```
# Curvas de velocidad respectivas ;D
# Es sencillo ver la curva de rotacion de las componentes y del total
grid = np.linspace(-0.1,100,100)
fig, axes = plt.subplots(2,1,figsize=(10,10))
xyz = np.zeros((3,) + grid.shape)
xyz[0] = grid

oldVcirc = {}
oldVcirc["all"] = oldgalpot.circular_velocity(xyz)
oldVcirc["halo"] = oldgalpot['halo'].circular_velocity(xyz)
oldVcirc["bulge"] = oldgalpot['bulge'].circular_velocity(xyz)
oldVcirc["nucleus"] = oldgalpot['disk'].circular_velocity(xyz)
oldVcirc["disk"] = oldgalpot['nucleus'].circular_velocity(xyz)

axes[0].plot(grid,oldVcirc["all"],c='black',label='All')
axes[0].plot(grid,oldVcirc["halo"],c='purple',label='DM Halo')
axes[0].plot(grid,oldVcirc["bulge"],c='orange',label='Bulge')
axes[0].plot(grid,oldVcirc["nucleus"],c='blue',label='Disk')
axes[0].plot(grid,oldVcirc["disk"],c='orange',linestyle='--',label='Core')

axes[0].legend()

newVcirc = {}
newVcirc["all"] = newgalpot.circular_velocity(xyz)
newVcirc["halo"] = newgalpot['halo'].circular_velocity(xyz)
```

```
newVcirc["bulge"] = newgalpot['bulge'].circular_velocity(xyz)
newVcirc["nucleus"] = newgalpot['disk'].circular_velocity(xyz)
newVcirc["disk"] = newgalpot['nucleus'].circular_velocity(xyz)

axes[1].plot(grid,newVcirc["all"],c='black',label='All')
axes[1].plot(grid,newVcirc["halo"],c='purple',label='DM Halo')
axes[1].plot(grid,newVcirc["bulge"],c='orange',label='Bulge')
axes[1].plot(grid,newVcirc["nucleus"],c='blue',label='Disk')
axes[1].plot(grid,newVcirc["disk"],c='orange',linestyle='--',label='Core')

axes[1].legend()
```

```
[4]: <matplotlib.legend.Legend at 0x7f5645b7a9f0>
```



2 Recreacion de orbitas practica 1 en potencial mejorado

Se utilizan las mismas condiciones iniciales que antes, por completitud se utiliza igualmente el potencial de la practica1, llamado oldgalpot

[5]:

```
import gala.dynamics as gd

def orbit_integrate(pot):
    txtsize = 8
    r = [7.5,0,0] * u.kpc
    v = [0, 200, 0] * u.km/u.s
    ics_closed = gd.PhaseSpacePosition(pos=r,vel=v)

    r = [100,-300,0] * u.kpc
    v = [-70, 260, 0] * u.km/u.s
    ics_hyperbolic = gd.PhaseSpacePosition(pos=r,vel=v)

    fig,axes = plt.subplots(2,4,figsize=(20,10))

    sumpot = gp.CCompositePotential()
    i = 0
    grid_closed = np.linspace(-30,30,1000)
    grid_hypebolic = np.linspace(-150,150,1000)
    components_str = ''
    for key in pot.keys():
        sumpot[key] = pot[key]
        sumpot.plot_contours(grid=(grid_closed,grid_closed,0), ax=axes[0,i])
        sumpot.plot_contours(grid=(grid_hypebolic,grid_hypebolic,0),␣
 ↪ax=axes[1,i])
        closed_orbit = gp.Hamiltonian(sumpot).integrate_orbit(ics_closed, dt=0.
 ↪6, n_steps=1e4)
        closed_orbit.plot(components=['x','y'], axes=[axes[0,i]], color='red')
        hyperbolic_orbit = gp.Hamiltonian(sumpot).
 ↪integrate_orbit(ics_hyperbolic, dt=1., n_steps=6e3)
        hyperbolic_orbit.plot(components=['x','y'], axes=[axes[1,i]],␣
 ↪color='red')
        components_str += key + '|'
        axes[0,i].set_title(f'{components_str}')
        axes[0,i].set_xlim(-30,30)
        axes[0,i].set_ylim(-30,30)
        axes[1,i].set_xlim(-100,100)
        axes[1,i].set_ylim(-100,100)
        # texto con apocentros y datos
        closed_energy = np.round(ics_closed.energy(sumpot).to(u.km**2/u.
 ↪s**2)[0],2)
        closed_apocenter = np.round(closed_orbit.apocenter(),2)
        closed_pericenter = np.round(closed_orbit.pericenter(),2)
        closed_eccentricity = np.round(closed_orbit.eccentricity(),2)
        hyperbolic_energy = np.round(ics_hyperbolic.energy(sumpot).to(u.km**2/u.
↪s**2)[0],2)
        hyperbolic_apocenter = np.round(hyperbolic_orbit.apocenter(),2)
        hyperbolic_pericenter = np.round(hyperbolic_orbit.pericenter(),2)
        hyperbolic_eccentricity = np.round(hyperbolic_orbit.eccentricity(),2)
        axes[0,i].text(0.01,0.95,f'E = {closed_energy}',transform=axes[0,i].
↪transAxes,size=txtsize,c='white')
        axes[0,i].text(0.01,0.025,f'Apocenter =␣
↪{closed_apocenter}',transform=axes[0,i].transAxes,size=txtsize,c='white')
        axes[0,i].text(0.01,0.075,f'Pericenter =␣
↪{closed_pericenter}',transform=axes[0,i].transAxes,size=txtsize,c='white')
        axes[0,i].text(0.01,0.125,f'Ecentricity =␣
↪{closed_eccentricity}',transform=axes[0,i].transAxes,size=txtsize,c='white')
        axes[1,i].text(0.01,0.95,f'E = {hyperbolic_energy}',transform=axes[1,i].
↪transAxes,size=txtsize,c='white')
        axes[1,i].text(0.01,0.025,f'Apocenter =␣
↪{hyperbolic_apocenter}',transform=axes[1,i].transAxes,size=txtsize,c='white')
        axes[1,i].text(0.01,0.075,f'Pericenter =␣
↪{hyperbolic_pericenter}',transform=axes[1,i].
↪transAxes,size=txtsize,c='white')
        axes[1,i].text(0.01,0.125,f'Eccentricity =␣
↪{hyperbolic_eccentricity}',transform=axes[1,i].
↪transAxes,size=txtsize,c='white')
        # Podemos saber si seleccionamos dt correcto si vemos que la energia se␣
↪conserva
        print('-'*84)
        print(components_str)
        print('-'*84)
        print('Std deviation of Energy')
        print(np.std(closed_orbit.energy()),'\n',np.std(hyperbolic_orbit.
↪energy()))
        print('Std deviation of Ang.Mom')
        # Y que tambien el momentum angular lo hace
        print(np.std(closed_orbit.angular_momentum()[2,:]),'\n',np.
↪std(hyperbolic_orbit.angular_momentum()[2,:]))
        i += 1
    return(fig,axes)
```

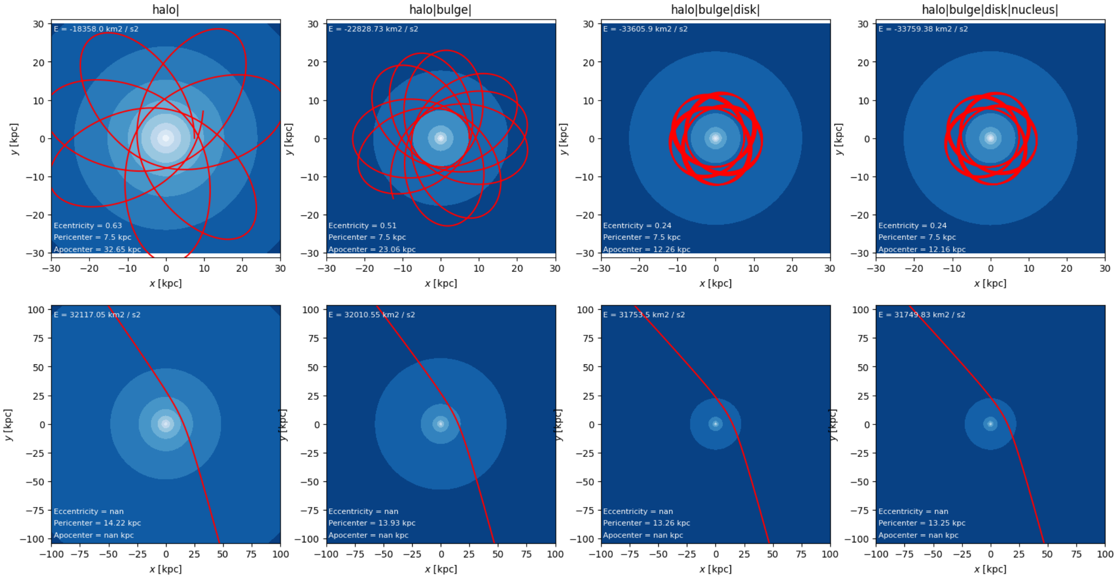
[6]:
```
orbit_integrate(oldgalpot)
```

```
/home/marcoritou/anaconda3/envs/galatopicos/lib/python3.12/site-
packages/numpy/core/fromnumeric.py:3504: RuntimeWarning: Mean of empty slice.
  return _methods._mean(a, axis=axis, dtype=dtype,
/home/marcoritou/anaconda3/envs/galatopicos/lib/python3.12/site-
packages/numpy/core/_methods.py:129: RuntimeWarning: invalid value encountered
```

```
in scalar divide
  ret = ret.dtype.type(ret / rcount)
--------------------------------------------------------------------------------
----
halo|
--------------------------------------------------------------------------------
----
Std deviation of Energy
5.282064624981633e-08 kpc2 / Myr2
 5.1652334433290194e-08 kpc2 / Myr2
Std deviation of Ang.Mom
4.0894219647285164e-15 kpc2 / Myr
 1.6883644340429877e-13 kpc2 / Myr
--------------------------------------------------------------------------------
----
halo|bulge|
--------------------------------------------------------------------------------
----
Std deviation of Energy
7.739724675770838e-08 kpc2 / Myr2
 6.368840922873448e-08 kpc2 / Myr2
Std deviation of Ang.Mom
6.6392235314686294e-15 kpc2 / Myr
 3.20919034251333e-13 kpc2 / Myr
--------------------------------------------------------------------------------
----
halo|bulge|disk|
--------------------------------------------------------------------------------
----
Std deviation of Energy
1.306619770051138e-07 kpc2 / Myr2
 9.990359975750819e-08 kpc2 / Myr2
Std deviation of Ang.Mom
1.914497966406166e-15 kpc2 / Myr
 2.5398320672928374e-13 kpc2 / Myr
--------------------------------------------------------------------------------
----
halo|bulge|disk|nucleus|
--------------------------------------------------------------------------------
----
Std deviation of Energy
1.3077955020815733e-07 kpc2 / Myr2
 1.0050217193964668e-07 kpc2 / Myr2
Std deviation of Ang.Mom
2.236970743950807e-15 kpc2 / Myr
 2.2504376157291334e-13 kpc2 / Myr
```

[6]:

```
(<Figure size 2000x1000 with 8 Axes>,
 array([[<Axes: title={'center': 'halo|'}, xlabel='$x$ [$\\mathrm{kpc}$]',
ylabel='$y$ [$\\mathrm{kpc}$]'>,
         <Axes: title={'center': 'halo|bulge|'}, xlabel='$x$ [$\\mathrm{kpc}$]',
ylabel='$y$ [$\\mathrm{kpc}$]'>,
         <Axes: title={'center': 'halo|bulge|disk|'}, xlabel='$x$
[$\\mathrm{kpc}$]', ylabel='$y$ [$\\mathrm{kpc}$]'>,
         <Axes: title={'center': 'halo|bulge|disk|nucleus|'}, xlabel='$x$
[$\\mathrm{kpc}$]', ylabel='$y$ [$\\mathrm{kpc}$]'>],
        [<Axes: xlabel='$x$ [$\\mathrm{kpc}$]', ylabel='$y$ [$\\mathrm{kpc}$]'>,
         <Axes: xlabel='$x$ [$\\mathrm{kpc}$]', ylabel='$y$ [$\\mathrm{kpc}$]'>,
         <Axes: xlabel='$x$ [$\\mathrm{kpc}$]', ylabel='$y$ [$\\mathrm{kpc}$]'>,
         <Axes: xlabel='$x$ [$\\mathrm{kpc}$]', ylabel='$y$
[$\\mathrm{kpc}$]'>]],
       dtype=object))
```



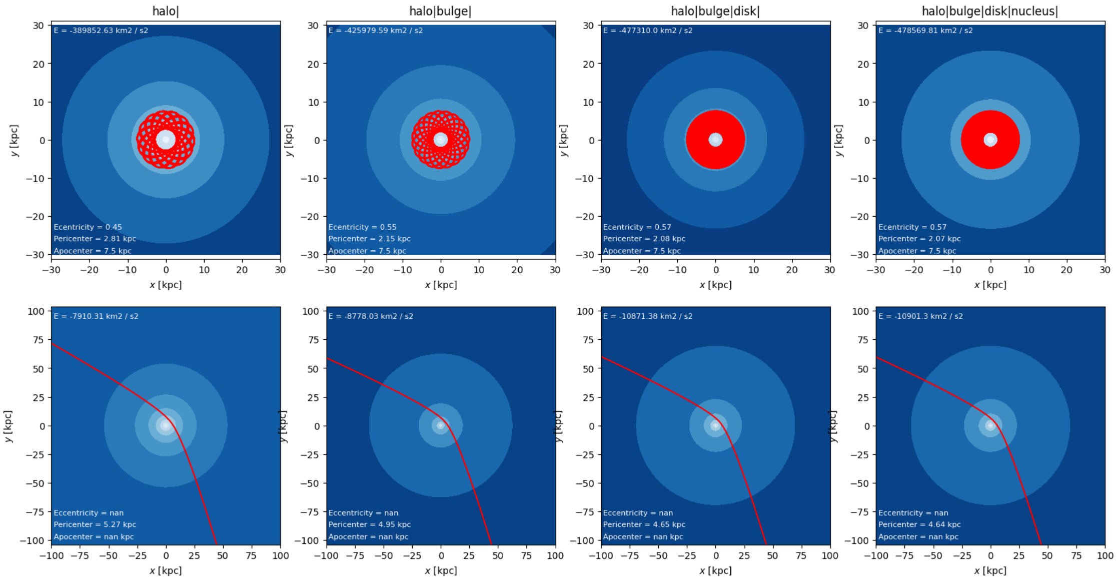
[7]:

```
orbit_integrate(newgalpot)
```

```
--------------------------------------------------------------------------------
----
halo|
--------------------------------------------------------------------------------
----
Std deviation of Energy
2.836599698070888e-05 kpc2 / Myr2
 1.0284121916748385e-05 kpc2 / Myr2
Std deviation of Ang.Mom
4.131331762910151e-15 kpc2 / Myr
```

```
 7.848084455925017e-14 kpc2 / Myr
--------------------------------------------------------------------------------
----
halo|bulge|
--------------------------------------------------------------------------------
----
Std deviation of Energy
0.00011468422063876896 kpc2 / Myr2
 1.6276716278089295e-05 kpc2 / Myr2
Std deviation of Ang.Mom
6.2872043623462105e-15 kpc2 / Myr
 1.605188472161369e-13 kpc2 / Myr
--------------------------------------------------------------------------------
----
halo|bulge|disk|
--------------------------------------------------------------------------------
----
Std deviation of Energy
0.00013196197532522818 kpc2 / Myr2
 2.090979815077077e-05 kpc2 / Myr2
Std deviation of Ang.Mom
4.4561205923234054e-15 kpc2 / Myr
 1.5448358318461416e-13 kpc2 / Myr
--------------------------------------------------------------------------------
----
halo|bulge|disk|nucleus|
--------------------------------------------------------------------------------
----
Std deviation of Energy
0.00013853432120844276 kpc2 / Myr2
 2.1225038406008355e-05 kpc2 / Myr2
Std deviation of Ang.Mom
3.034951910999407e-15 kpc2 / Myr
 1.4593351891812216e-13 kpc2 / Myr
```

```
[7]: (<Figure size 2000x1000 with 8 Axes>,
      array([[<Axes: title={'center': 'halo|'}, xlabel='$x$ [$\\mathrm{kpc}$]',
     ylabel='$y$ [$\\mathrm{kpc}$]'>,
               <Axes: title={'center': 'halo|bulge|'}, xlabel='$x$ [$\\mathrm{kpc}$]',
     ylabel='$y$ [$\\mathrm{kpc}$]'>,
               <Axes: title={'center': 'halo|bulge|disk|'}, xlabel='$x$
     [$\\mathrm{kpc}$]', ylabel='$y$ [$\\mathrm{kpc}$]'>,
               <Axes: title={'center': 'halo|bulge|disk|nucleus|'}, xlabel='$x$
     [$\\mathrm{kpc}$]', ylabel='$y$ [$\\mathrm{kpc}$]'>],
              [<Axes: xlabel='$x$ [$\\mathrm{kpc}$]', ylabel='$y$ [$\\mathrm{kpc}$]'>,
               <Axes: xlabel='$x$ [$\\mathrm{kpc}$]', ylabel='$y$ [$\\mathrm{kpc}$]'>,
               <Axes: xlabel='$x$ [$\\mathrm{kpc}$]', ylabel='$y$ [$\\mathrm{kpc}$]'>,
         <Axes: xlabel='$x$ [$\\mathrm{kpc}$]', ylabel='$y$
[$\\mathrm{kpc}$]'>]],
       dtype=object))
```



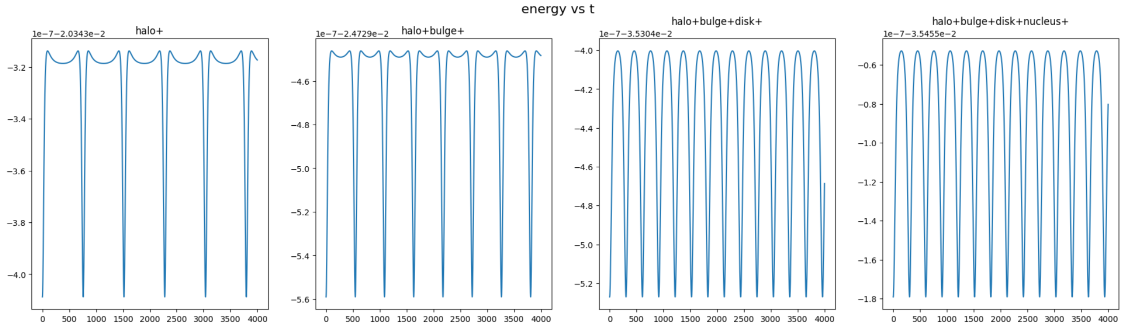
3 1) Evolucion temporal de parametros de las orbitas

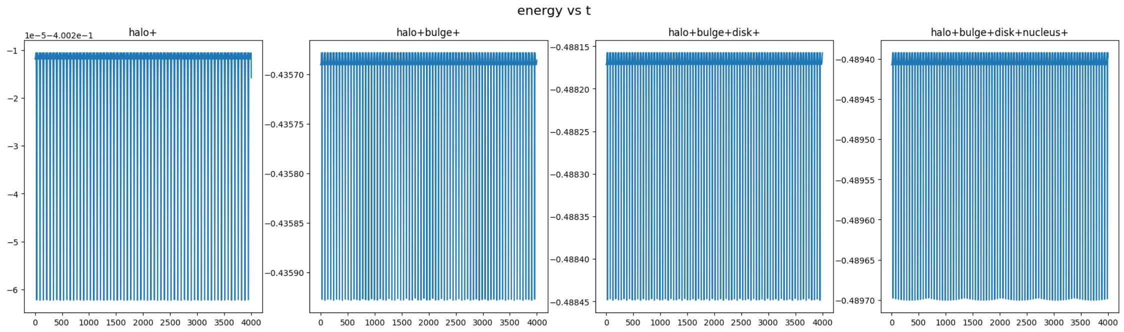
Aqui son mostrados los parametros con respecto al tiempo de las orbitas de manera secuencial en los potenciales mejorados y antiguos - Energia(E_T) vs t - Momento angular total(L_T) vs t - Componentes del momento angular(L_x,L_y,L_z) vs t - Eccentricidad(e) vs t

```
[8]: def parametersvstime(pot,parameter,ics_closed):
         fig, axes = plt.subplots(1,4,figsize=(24,6))
         sumpot = gp.CCompositePotential()
         i = 0
         grid_closed = np.linspace(-30,30,1000)
         grid_hypebolic = np.linspace(-150,150,1000)
         components_str = ""
         for key in pot.keys():
             sumpot[key] = pot[key]
             closed_orbit = gp.Hamiltonian(sumpot).integrate_orbit(ics_closed, dt=0.
      ↪4, n_steps=1e4)
             components_str += key + '+'
             axes[i].set_title(f'{components_str}')
             cparameters = {}
             cparameters["energy"] = closed_orbit.energy()
             cparameters["L_x"] = closed_orbit.angular_momentum()[0,:]
             cparameters["L_y"] = closed_orbit.angular_momentum()[1,:]
```

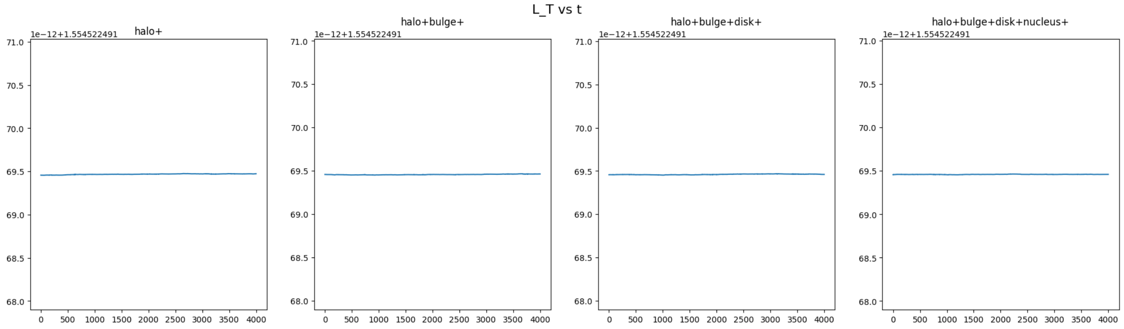
```
        cparameters["L_z"] = closed_orbit.angular_momentum()[2,:]
        cparameters["L_T"] = np.sqrt(cparameters["L_x"]**2 +␣
↪cparameters["L_y"]**2 + cparameters["L_z"]**2)
        if parameter in ["energy","L_T"]:
            x = closed_orbit.t
            y = cparameters[parameter]
            axes[i].plot(x,y)
        if parameter in ["e"]:
            apo = closed_orbit.apocenter(func=None,return_times=True)[0][:]
            apo_times = closed_orbit.apocenter(func=None,return_times=True)[1][:
↪]
            per = closed_orbit.pericenter(func=None,return_times=True)[0][:]
            per_times = closed_orbit.
↪pericenter(func=None,return_times=True)[1][:]
            try:
                cparameters["e"] = (apo-per)/(apo+per)
            except:
                cparameters["e"] = (apo-per[1:])/(apo+per[1:])
            x = apo_times
            y = cparameters[parameter]
            axes[i].plot(x,y)
        if parameter in ["L"]:
            x = closed_orbit.t
            for name in ["L_x","L_y","L_z"]:
                y = cparameters[name]
                axes[i].plot(x,y, label=f"{name}")
                axes[i].legend(fontsize=10)
        i += 1
    fig.suptitle(f"{parameter} vs t",size=16)
    return(fig,axes)
```

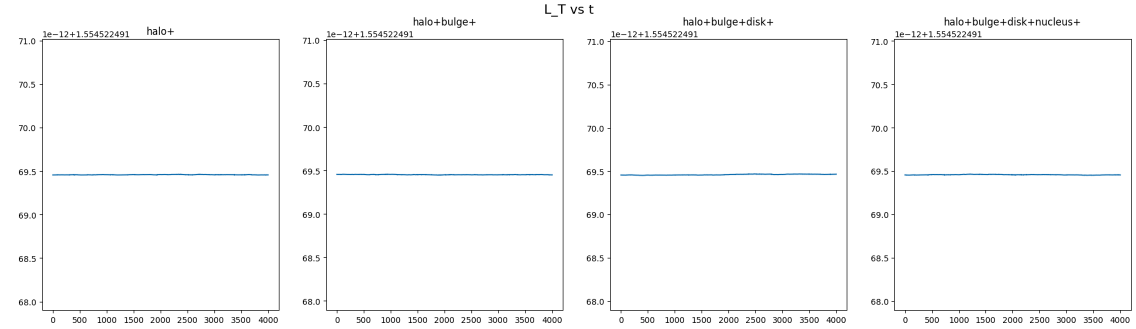
[9]:
```
# Orbitas usadas initial
r = [8,0,0] * u.kpc
v = [0, 190, 0] * u.km/u.s
ics_closed = gd.PhaseSpacePosition(pos=r,vel=v)

r = [100,-300,0] * u.kpc
v = [-70, 260, 0] * u.km/u.s
ics_hyperbolic = gd.PhaseSpacePosition(pos=r,vel=v)

fig,axes = parametersvstime(oldgalpot,"energy",ics_closed)
fig,axes = parametersvstime(newgalpot,"energy",ics_closed)
plt.show()
```



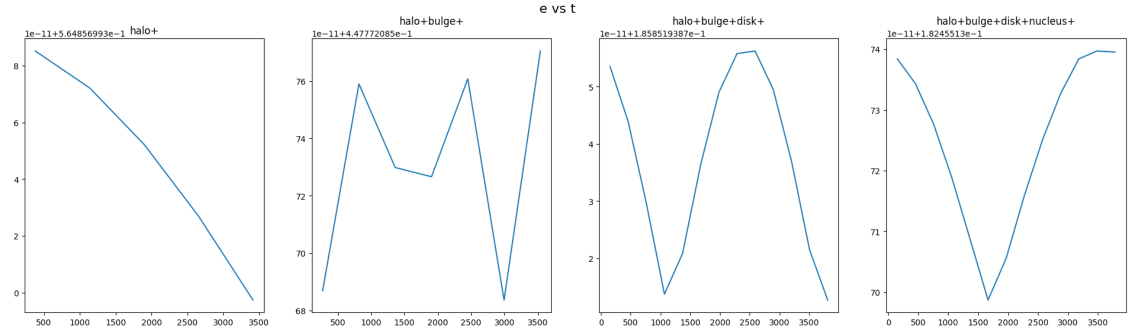


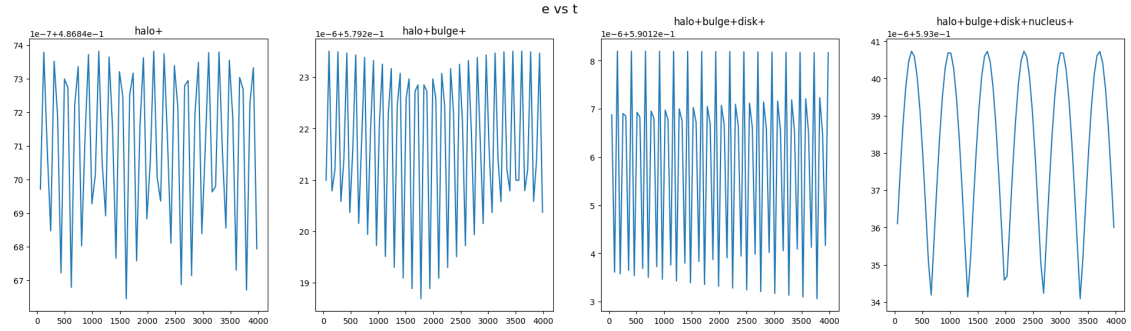
[10]:
```
fig,axes = parametersvstime(oldgalpot,"L_T",ics_closed)
fig,axes = parametersvstime(newgalpot,"L_T",ics_closed)
plt.show()
```



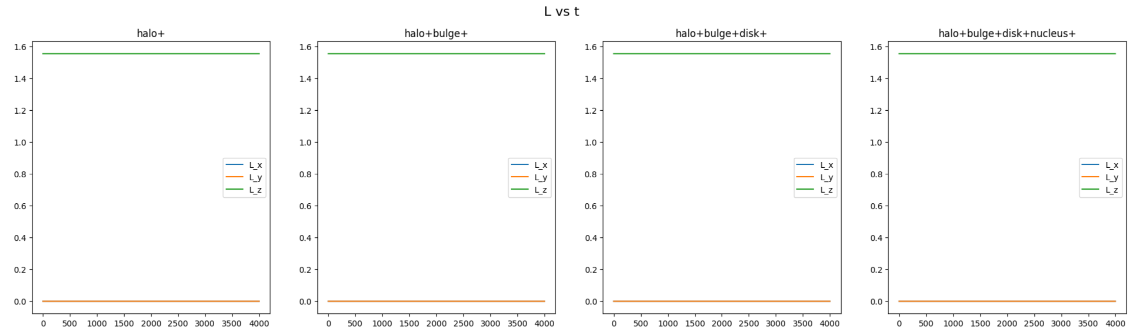


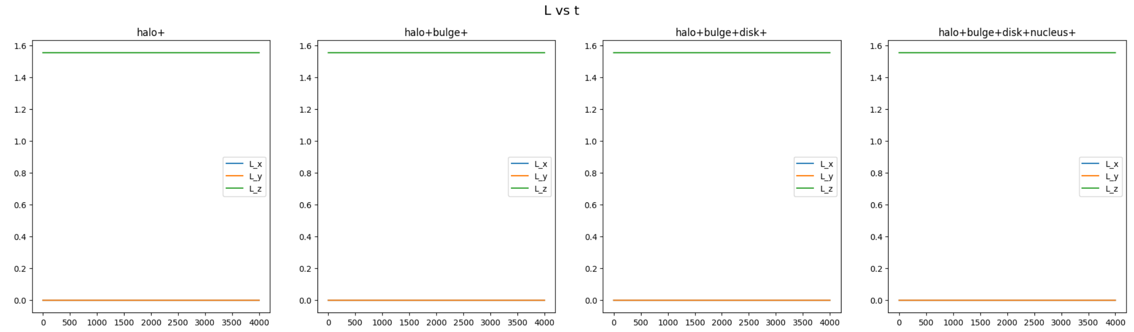
```
[11]: fig,axes = parametersvstime(oldgalpot,"e",ics_closed)
      fig,axes = parametersvstime(newgalpot,"e",ics_closed)
      plt.show()
```





```
[12]: fig,axes = parametersvstime(oldgalpot,"L",ics_closed)
      fig,axes = parametersvstime(newgalpot,"L",ics_closed)
      plt.show()
```





3.1 1.1) Discusion

EL observar estos valores de manera temporal permite saber que tan buena fue la integracion, ya que para valores demasiado grandes de “dt” la integracion es incorrecta y ocurren situaciones donde ni la energia ni el momento angular se conservan. Sin embargo esto sera solo cierto si el potencial que se esta considerando no cambia con respecto al tiempo, que en el caso particular presentado es asi, todos los potenciales son estaticos temporalmente.

Viendo los casos por orden: La energia vs el tiempo, si bien puede aparentar que esta cambiando, las variaciones no superan un valor de 0.0003, por ende es practicamente constante, aun asi si se desea se puede reducir dt, para mejorar aun mas la precision, sin embargo ya es suficientemente preciso.

El momentum angular total vs el tiempo, se conserva completamente como es esperado, y es practicamente constante en toda la integración.

La excentricidad vs el tiempo, es practicamente constante nuevamente, esto tiene sentido al considerar que la orbita que posee el cuerpo no es particularmente caotica, y se mantiene en forma, solo rotando la orbita en si como un todo.

Luego si vemos las componentes del momento angular tiene sentido que apunte directamente en z, ya que la orbita que dibuja el objeto es bidimensional

4 2) Superficies de poincare de las orbitas

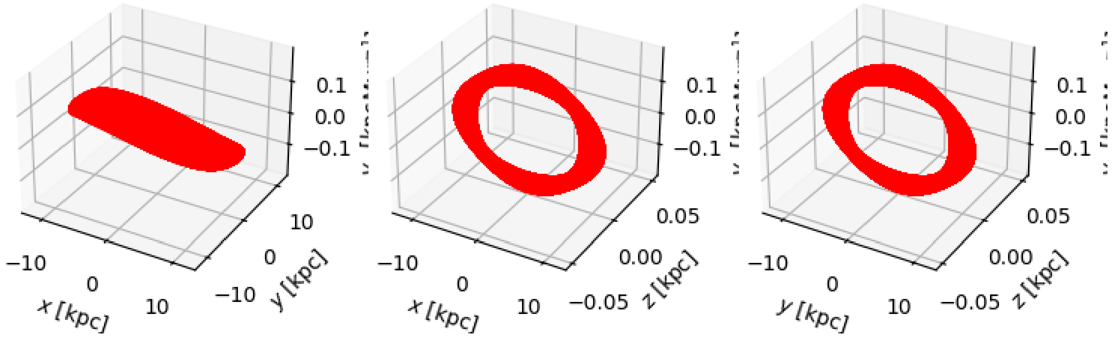
Se realizan los cortes tanto en las orbitas en los potenciales antiguos como nuevos

[13]:
```
def poincare_surface(pot, ics,
                     ax=None, xyz=["x","y","v_x"],
                     dt=0.1*u.Myr, t_final=1000*u.Myr
                    ):
    """
    Generates a 3d figure of the poincare surface, ax must have a 3d property
    """
    orbit = gp.Hamiltonian(pot).integrate_orbit(ics, dt=dt, n_steps=t_final/dt)
    orbit.plot_3d(components=xyz, color='red', ax=ax)
    return(orbit)

def multi_poincare(pot,ics,
                   ␣
 ↪xyz1=["x","y","v_x"],xyz2=["x","z","v_x"],xyz3=["y","z","v_y"],
                   t_final=4000*u.Myr
                  ):
    """
    Makes 3 poincare 3d surfaces, according to xyz1,xyz2 and xyz3
    """
    fig,axes = plt.subplots(1,3,figsize=(9,3), subplot_kw={'projection': "3d"})
    i = 0
    xyz=[xyz1,xyz2,xyz3]
    for ax in axes:
        poincare_surface(pot,ics,t_final=t_final,xyz=xyz[i], ax=ax)
        i+=1
    return(fig,axes)

def poincare_slice(pot,ics,
                   hor="x",ver="v_x", cut="y",
                   proj_plane=0,
                   dproj=1e-1, ax=None,
                   dt=0.1*u.Myr, t_final=1000*u.Myr
                  ):
    """
    Makes a poincare slice, by limiting the slice around a point according to a␣
 ↪dproj. that cuts the plane "cut"
    """
    orbit = gp.Hamiltonian(pot).integrate_orbit(ics, dt=dt, n_steps=t_final/dt)
    orbit_data = {}
    orbit_data["x"] = orbit.pos.x
    orbit_data["y"] = orbit.pos.y
    orbit_data["z"] = orbit.pos.z
    orbit_data["v_x"] = orbit.vel.d_x
    orbit_data["v_y"] = orbit.vel.d_y
    orbit_data["v_z"] = orbit.vel.d_z
    x,y = orbit_data[hor],orbit_data[ver]
    z = orbit_data[cut]
    filtre = np.where((z < (proj_plane + dproj) * z.unit) & (z > (proj_plane -␣
↪dproj) * z.unit))
    x,y = x[filtre],y[filtre]
    return(x,y)
```

4.0.1 Superficies de poincare en potencial completo

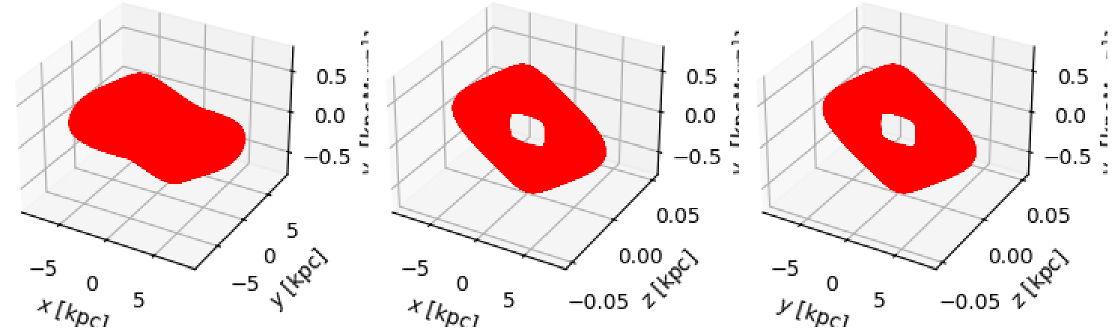
[14]:

```
fig,axes = multi_poincare(oldgalpot,ics_closed,t_final=1e5*u.Myr)
```



[15]:

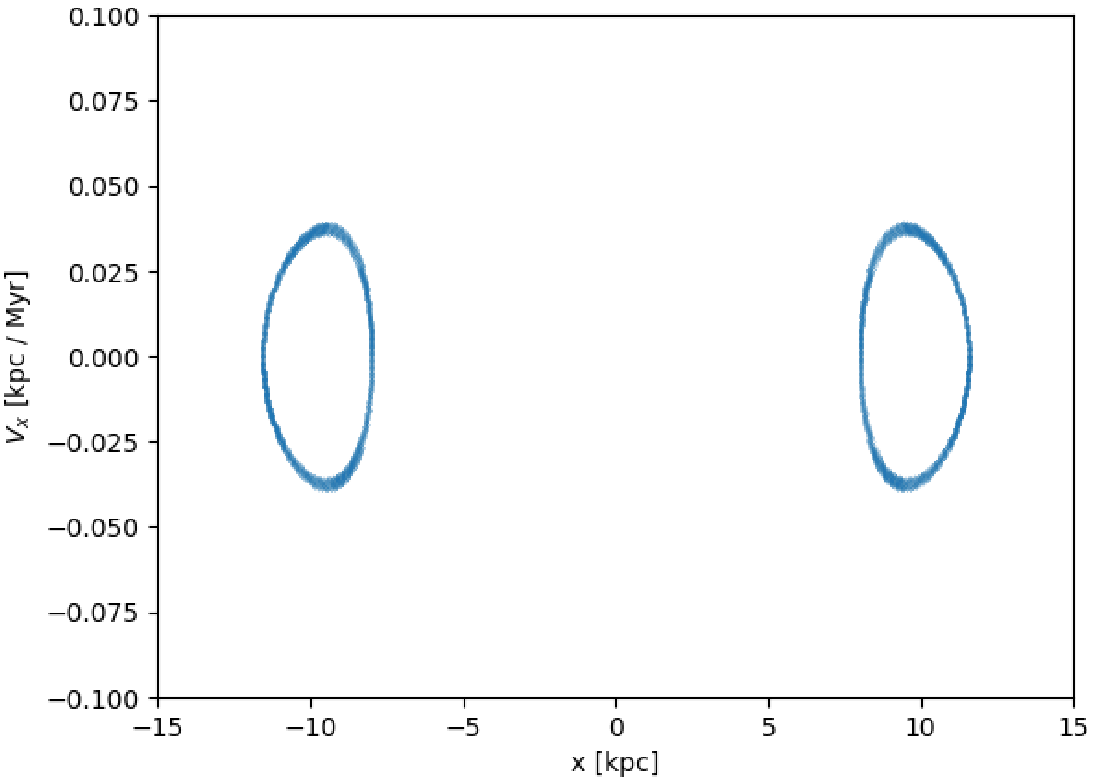
```
fig,axes = multi_poincare(newgalpot,ics_closed,t_final=1e4*u.Myr)
```



4.0.2 Poincare cortes para orbita en el potencial completo

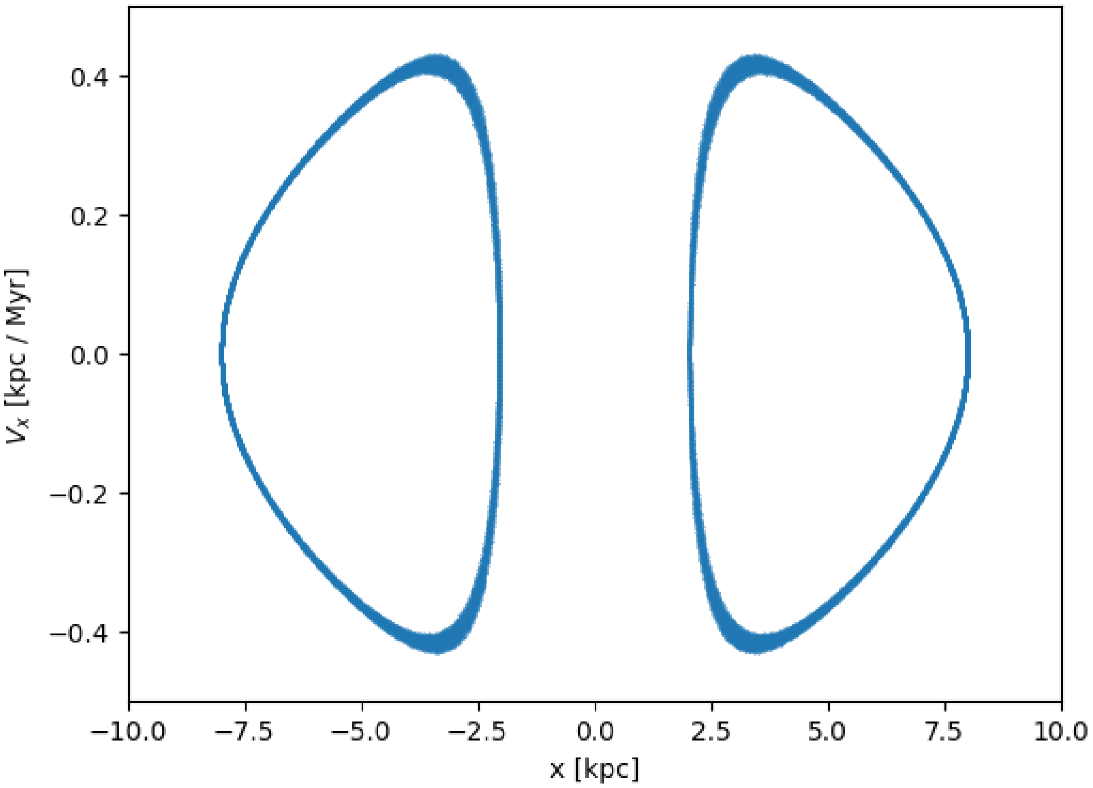
[16]:
```
fig,ax = plt.subplots(1,1)
x,y = poincare_slice(oldgalpot,ics_closed,t_final=1e5*u.Myr)
ax.scatter(x,y,s=1e-2)
ax.set_xlabel(f"x [{x.unit}]")
ax.set_ylabel(f"$V_x$ [{y.unit}]")
ax.set_xlim(-15,15)
ax.set_ylim(-0.1,0.1)
```

[16]:
```
(-0.1, 0.1)
```



[17]:
```
fig,ax = plt.subplots(1,1)
x,y = poincare_slice(newgalpot,ics_closed,t_final=1e5*u.Myr)
ax.scatter(x,y,s=.1)
ax.set_xlabel(f"x [{x.unit}]")
ax.set_ylabel(f"$V_x$ [{y.unit}]")
ax.set_xlim(-10,10)
ax.set_ylim(-0.5,0.5)
```

[17]:
```
(-0.5, 0.5)
```



4.0.3 Superficies de poincare en cada potencial progresivo

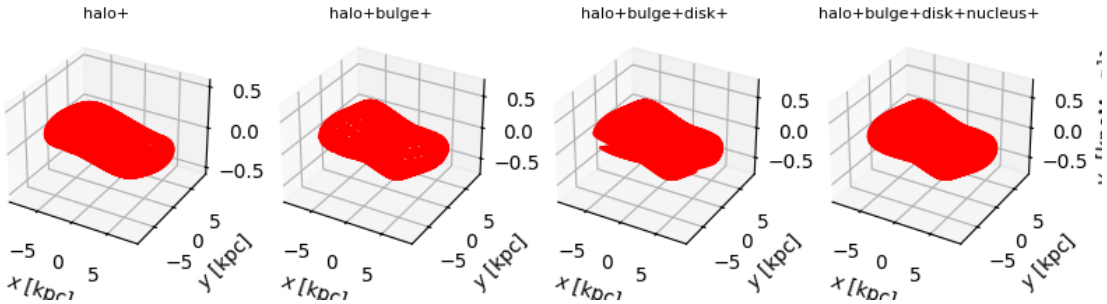
[18]:

```
def multi_poincare_pots(pot,ics,
                   xyz=["x","y","v_x"],
                   t_final=4000*u.Myr
                  ):
    """
    Makes 3 poincare 3d surfaces, according to xyz1,xyz2 and xyz3
    """
    N = len(pot.keys())
    fig,axes = plt.subplots(1,N,figsize=(2*N,2), subplot_kw={'projection':␣
 ↪"3d"})
    i = 0
    sumpot = gp.CCompositePotential()
    components_str = ''
    for key in pot.keys():
        sumpot[key] = pot[key]
        poincare_surface(sumpot,ics,t_final=t_final,xyz=xyz, ax=axes[i])
        components_str += key + '+'
        axes[i].set_title(f'{components_str}',fontsize=8)
        i+=1
    return(fig,axes)

def poincare_slice_pots(pot, ics,
                         hor="x",ver="v_x", cut="y",
                         proj_plane=0,
                         dproj=1e-1,
                         dt=0.1*u.Myr, t_final=1000*u.Myr
                        ):
    """
    Makes a poincare slice, by limiting the slice around a point according to a␣
 ↪dproj. that cuts the plane "cut"
    """
    N = len(pot.keys())
    fig,axes = plt.subplots(1,N,figsize=(2*N,2))
    sumpot = gp.CCompositePotential()
    i = 0
    components_str = ''
    for key in pot.keys():
        sumpot[key] = pot[key]
        x,y = poincare_slice(sumpot,ics,
                            ␣
 ↪hor=hor,ver=ver,cut=cut,proj_plane=proj_plane,dproj=dproj,ax=axes[i],dt=dt,t_final=t_final
                            )
        axes[i].scatter(x,y,s=1e-2)
        axes[i].set_xlabel(f"x [{x.unit}]")
        axes[i].set_ylabel(f"$V_x$ [{y.unit}]")
        components_str += key + '+'
        axes[i].set_title(f'{components_str}',fontsize=8)
        i+=1
    return(fig,axes)
```

desde aqui solo utilizo el potencial nuevo Se representan las superficies de las orbitas de manera progresiva, se considera solo el caso x vs y vs v_x añadido en el apendice se ven casos extras

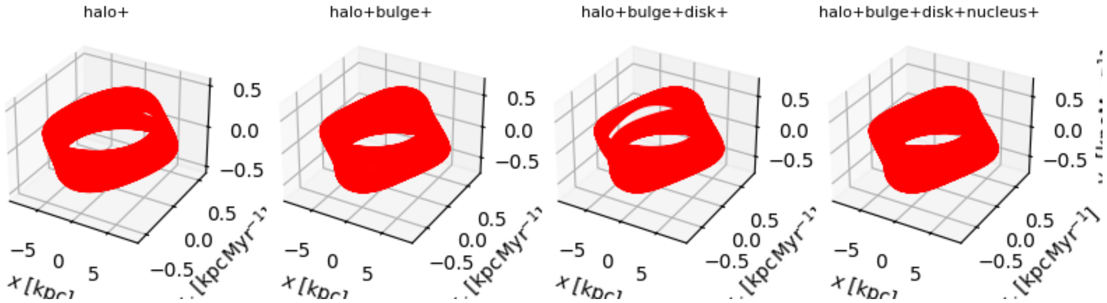
[19]:

```
r = [8,0,0] * u.kpc
v = [0, 190, 0] * u.km/u.s
ics_closed = gd.PhaseSpacePosition(pos=r,vel=v)

plt.ioff(); fig = plt.figure(); plt.ion()
# whatever plotting you want

fig, axes = multi_poincare_pots(newgalpot, ics_closed, xyz=["x","y","v_x"])
plt.tight_layout()
display(fig)
plt.close()
plt.show()
```

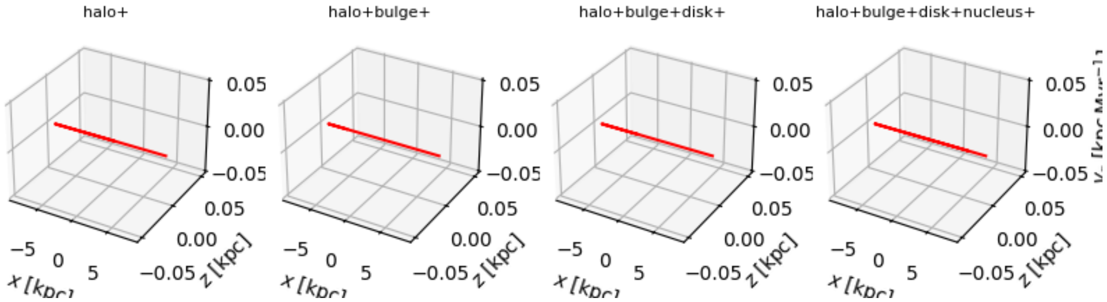


```
<Figure size 640x480 with 0 Axes>
```

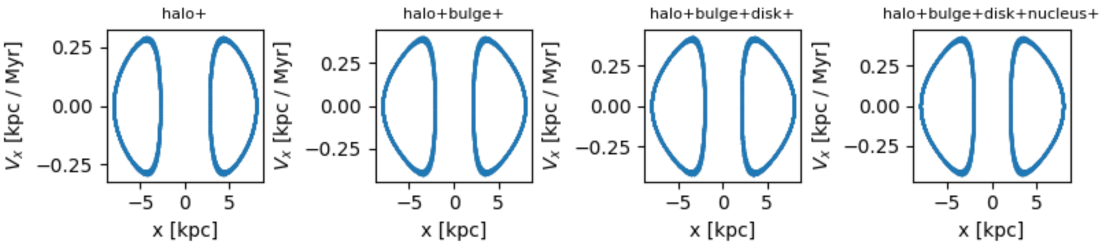
```
[20]: multi_poincare_pots(newgalpot, ics_closed, xyz=["x","v_y","v_x"])
      plt.tight_layout()
```



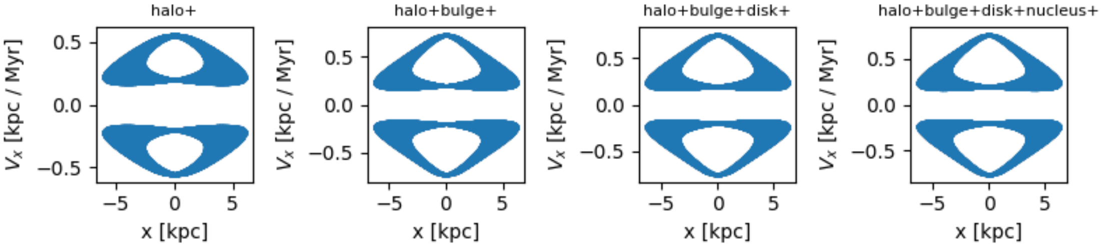
```
[21]: multi_poincare_pots(newgalpot, ics_closed, xyz=["x","z","v_z"])
      plt.tight_layout()
```



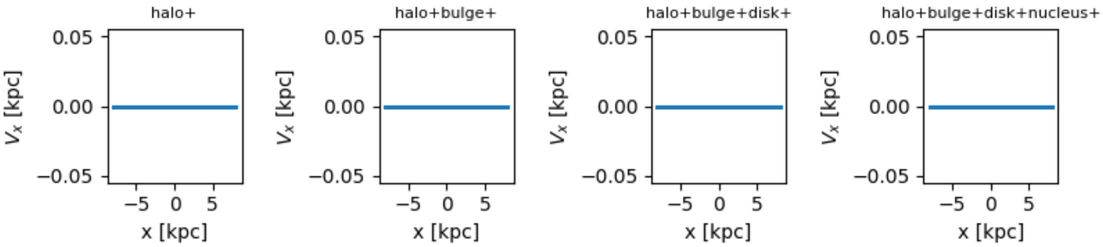
```
[22]: poincare_slice_pots(newgalpot, ics_closed, t_final=1e5*u.Myr,hor="x",ver="v_x",␣
       ↪cut='y')
      plt.tight_layout()
```



[23]:
```
poincare_slice_pots(newgalpot, ics_closed, t_final=1e5*u.Myr,hor="x",ver="v_x",␣
  ↪cut='v_y')
plt.tight_layout()
```



[24]:
```
poincare_slice_pots(newgalpot, ics_closed, t_final=1e5*u.Myr,hor="x",ver="z",␣
  ↪cut='v_z')
plt.tight_layout()
```



4.0.4 Cortes de las superficies de poincare en cada potencial progresivo

4.1 2.1) Discusion

Podemos ver claramente que estamos tratando con una orbita regular, ya que los cortes de las superficies de poincare estan limitados a un rmin y un rmax, al igual que al verlo en 3d se ven como torus limitados, en todos los casos.

Si fueran orbitas caoticas ocurriria que veriamos en alguno de los cortes de las superficies como la orbita no esta limitada

5 3) Analisis repeticion

Realizando evolucion de parametros temporalmente y superficies de poincare para: - Orbita circular en potencial DM_Halo y Miyamoto-Nagai - Orbita anterior levemente perturbada

5.1 Orbita circular

[25]:

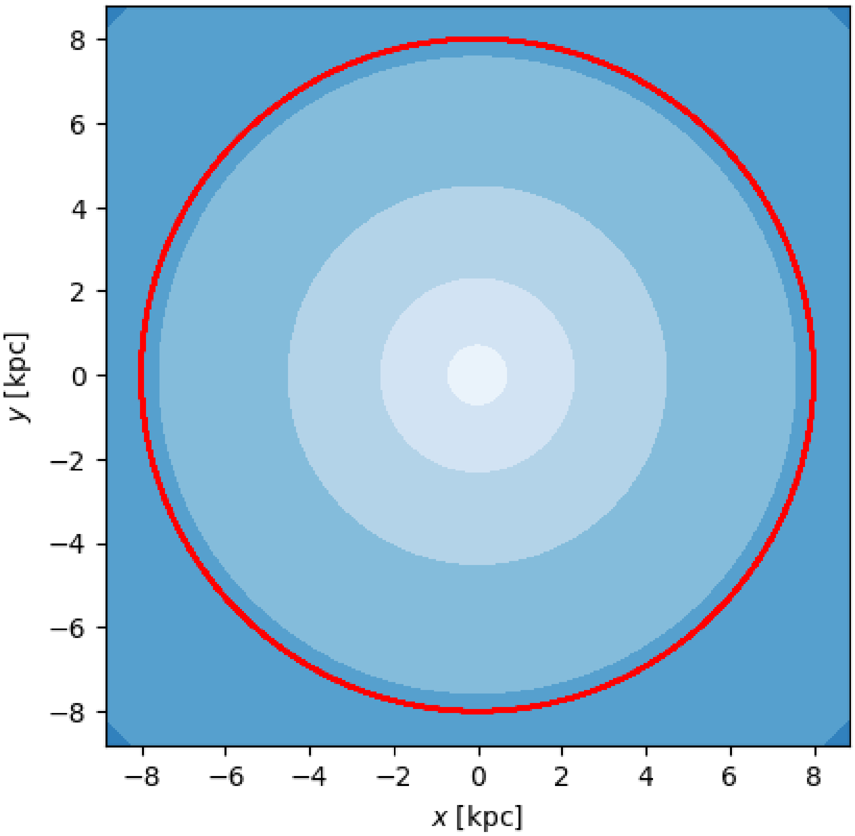
```
circpot = gp.CCompositePotential()
circpot["halo"] = newgalpot["halo"]
circpot["disk"] = newgalpot["disk"]

r = [8,0,0] * u.kpc

V_circ = circpot.circular_velocity(r)
V_circ = V_circ[0]
V_circ = V_circ.value

v = [0, V_circ, 0] * u.km/u.s
circular_ics = gd.PhaseSpacePosition(pos=r,vel=v)
```

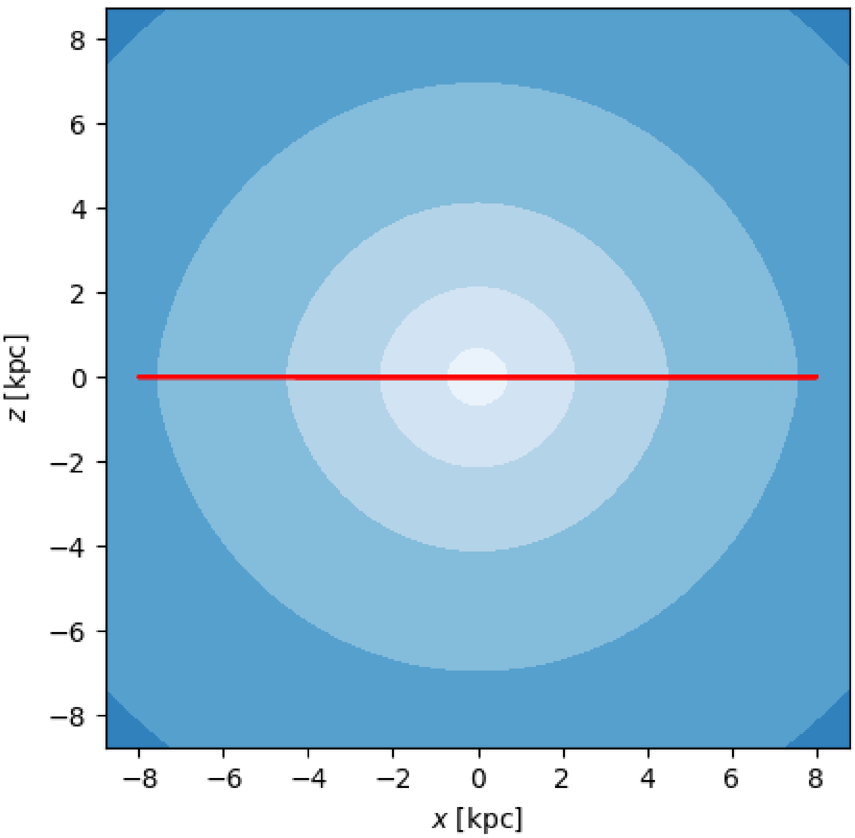
[26]:

```
orbit = gp.Hamiltonian(circpot).integrate_orbit(circular_ics, dt=0.4,␣
 ↪n_steps=1e4)
grid = np.linspace(-30,30,1000)

fig,ax = plt.subplots(1,1,figsize=(5,5))
orbit.plot(components=['x','y'], color='red', axes=ax)
circpot.plot_contours(grid=(grid,grid,0), ax=ax)
plt.show

fig,ax = plt.subplots(1,1,figsize=(5,5))
orbit.plot(components=['x','z'], color='red', axes=ax)
circpot.plot_contours(grid=(grid,0,grid), ax=ax)
plt.show
```

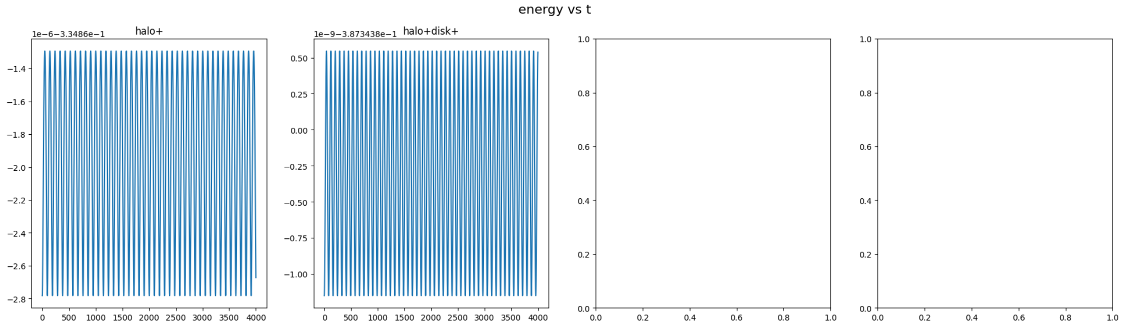
[26]:

```
<function matplotlib.pyplot.show(close=None, block=None)>
```

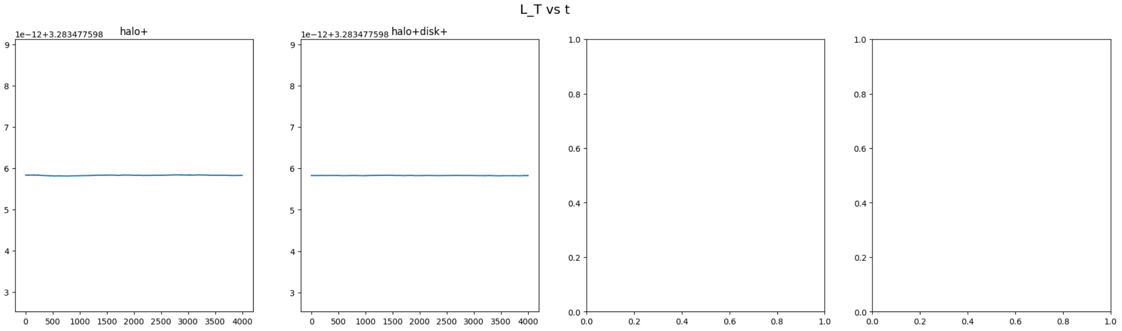

8
6
4
2
0
−2
−4
−6
−8
y [kpc]
−8
−6
−4
−2
0
2
4
6
8
x [kpc]



[27]:
```
fig,axes = parametersvstime(circpot,"energy",circular_ics)
plt.show()
```

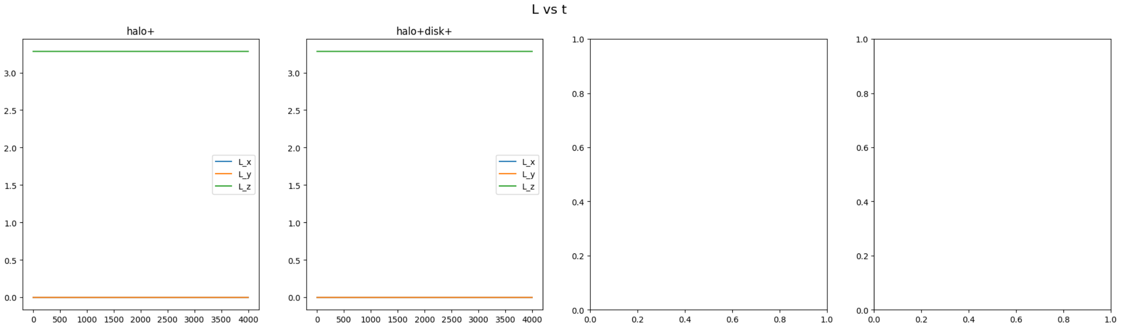


[28]:
```
fig,axes = parametersvstime(circpot,"L_T",circular_ics)
plt.show()
```



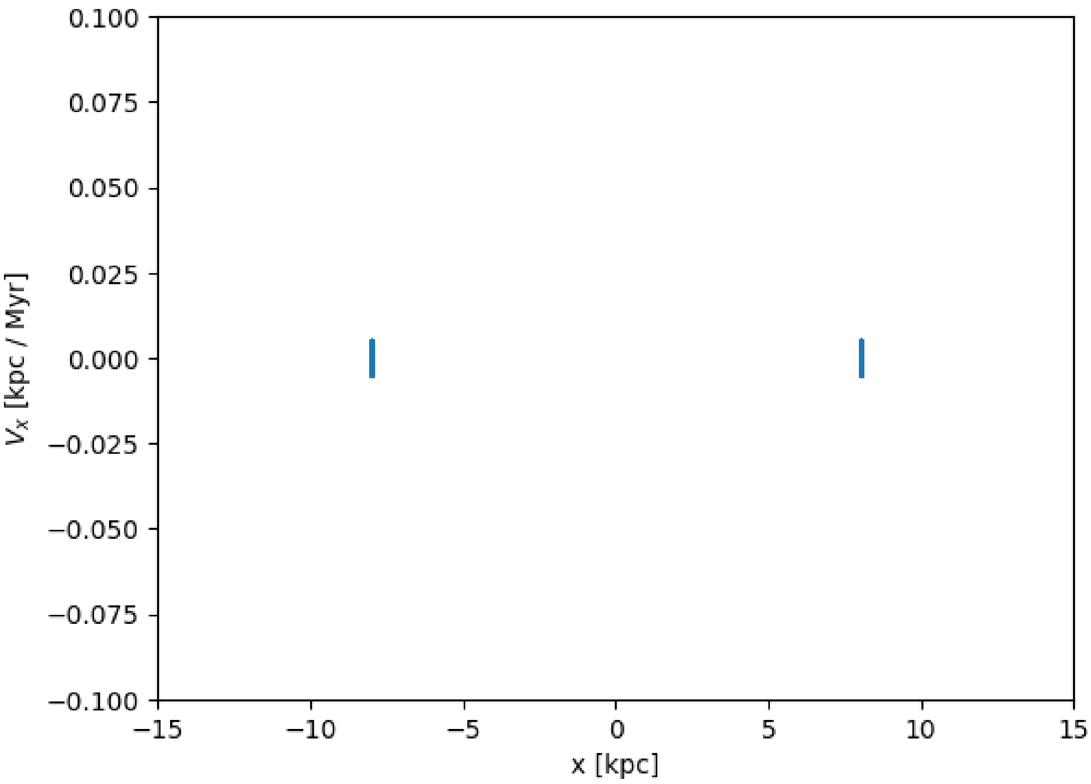
```
[30]: #fig,axes = parametersvstime(circpot,"e",circular_ics)
      plt.show()
```

```
[31]: fig,axes = parametersvstime(circpot,"L",circular_ics)
      plt.show()
```



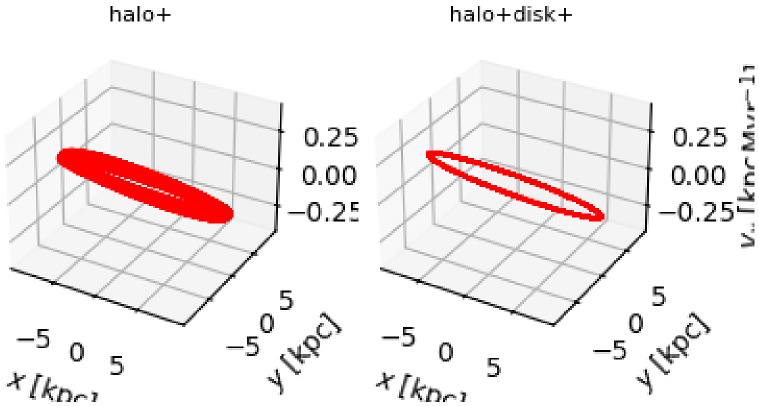
```
[32]: fig,ax = plt.subplots(1,1)
      x,y = poincare_slice(circpot,circular_ics,t_final=1e5*u.Myr)
      ax.scatter(x,y,s=1e-2)
      ax.set_xlabel(f"x [{x.unit}]")
      ax.set_ylabel(f"$V_x$ [{y.unit}]")
      ax.set_xlim(-15,15)
      ax.set_ylim(-0.1,0.1)
```

```
[32]: (-0.1, 0.1)
```



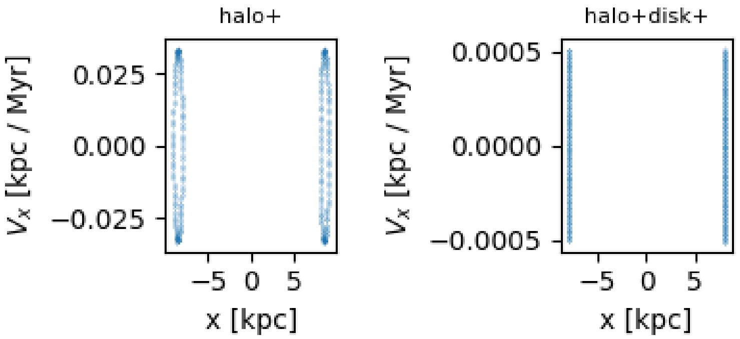
[33]:

```
multi_poincare_pots(circpot, circular_ics, xyz=["x","y","v_x"])
plt.tight_layout()
```



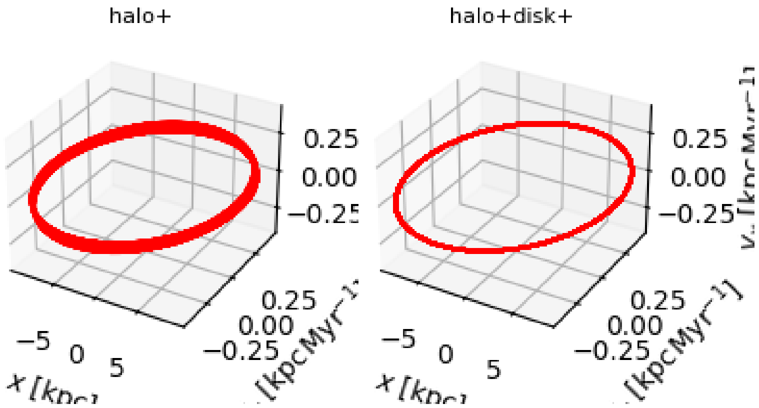
[34]:

```
poincare_slice_pots(circpot, circular_ics, t_final=1e5*u.Myr,hor="x",ver="v_x",␣
  ↪cut='y', dproj=1e-2)
plt.tight_layout()
```



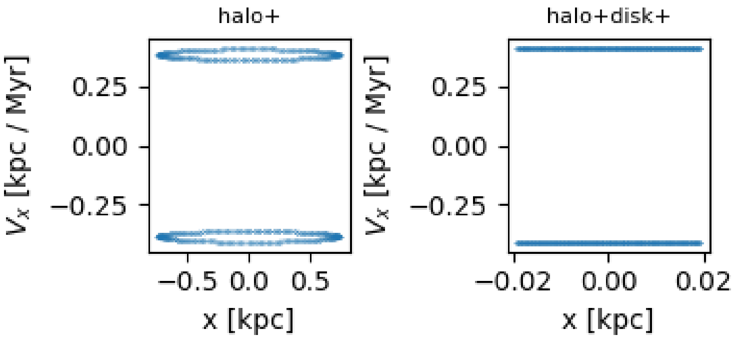
[35]:

```
multi_poincare_pots(circpot, circular_ics, xyz=["x","v_y","v_x"])
plt.tight_layout()
```



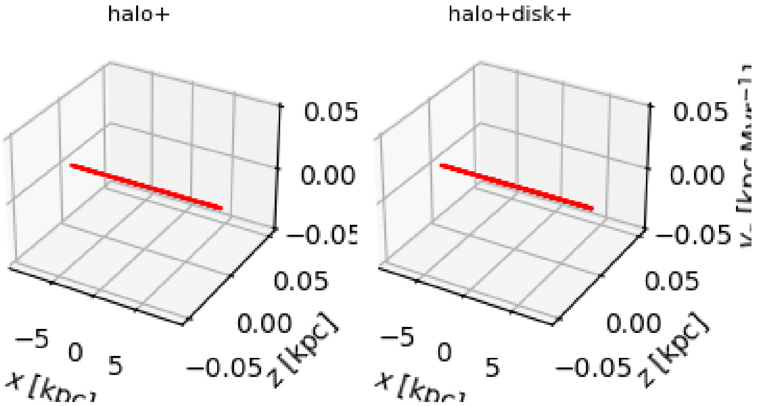
[36]:

```
poincare_slice_pots(circpot, circular_ics, t_final=1e5*u.Myr,hor="x",ver="v_x",␣
  ↪cut='v_y', dproj=1e-3)
plt.tight_layout()
```



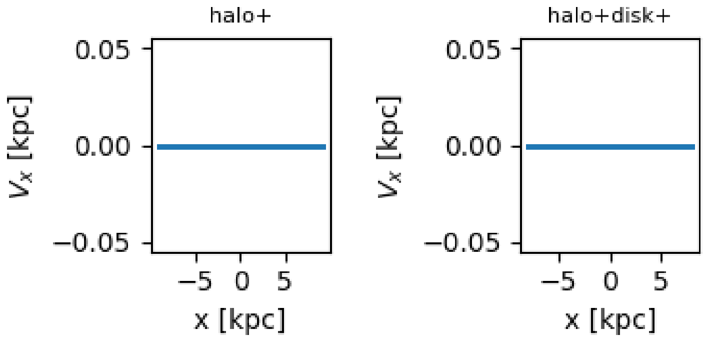
[37]:

```
multi_poincare_pots(circpot, circular_ics, xyz=["x","z","v_z"])
plt.tight_layout()
```



[38]:

```
poincare_slice_pots(circpot, circular_ics, t_final=1e5*u.Myr,hor="x",ver="z",␣
 ↪cut='v_z', dproj=1e-3)
plt.tight_layout()
```



5.2 Orbita perturbada levemente

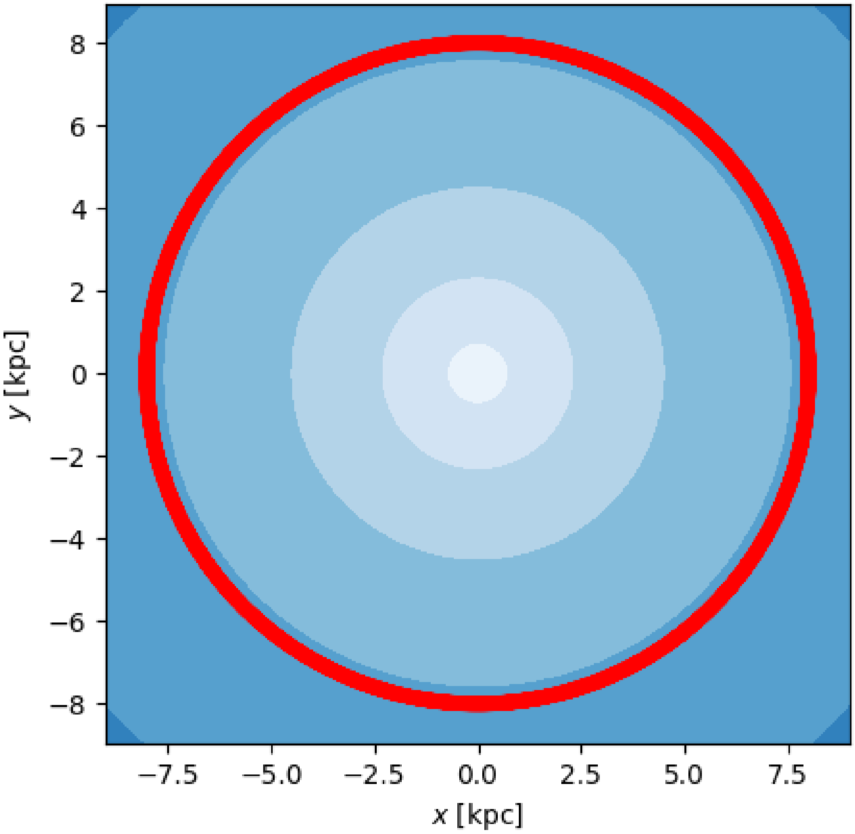
[39]:

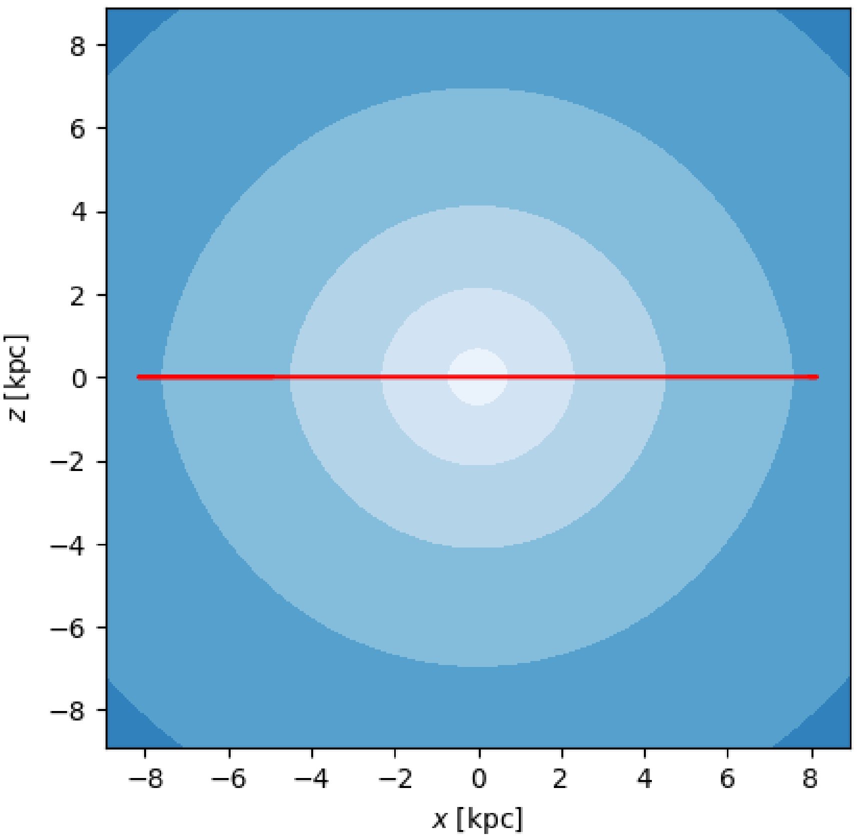
```
r = [8,0,0] * u.kpc

V_circ = circpot.circular_velocity(r)
print(V_circ)
V_circ = V_circ[0]
V_circ = V_circ.value

v = [10, V_circ, 0] * u.km/u.s
perturbed_ics = gd.PhaseSpacePosition(pos=r,vel=v)
```

```
perturbed_orbit = gp.Hamiltonian(circpot).integrate_orbit(perturbed_ics, dt=0.
 ↪4, n_steps=1e4)
grid = np.linspace(-30,30,1000)

fig,ax = plt.subplots(1,1,figsize=(5,5))
perturbed_orbit.plot(components=['x','y'], color='red', axes=ax)
circpot.plot_contours(grid=(grid,grid,0), ax=ax)
plt.show

fig,ax = plt.subplots(1,1,figsize=(5,5))
perturbed_orbit.plot(components=['x','z'], color='red', axes=ax)
circpot.plot_contours(grid=(grid,0,grid), ax=ax)
plt.show
```

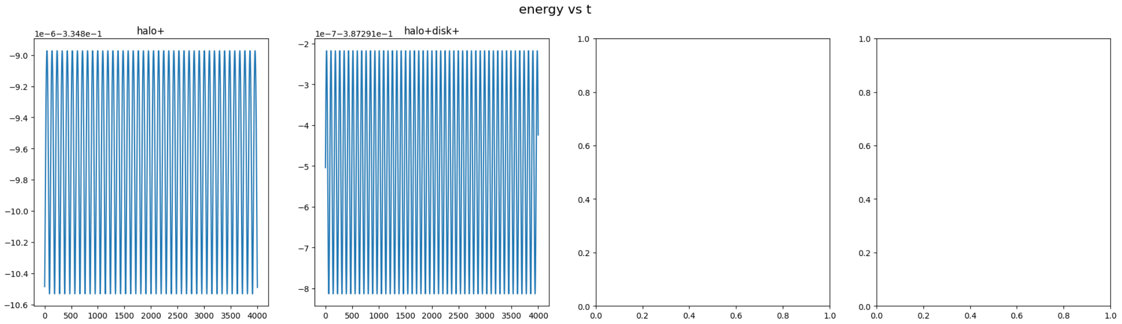
```
[401.31985689] km / s
```

```
[39]: <function matplotlib.pyplot.show(close=None, block=None)>
```

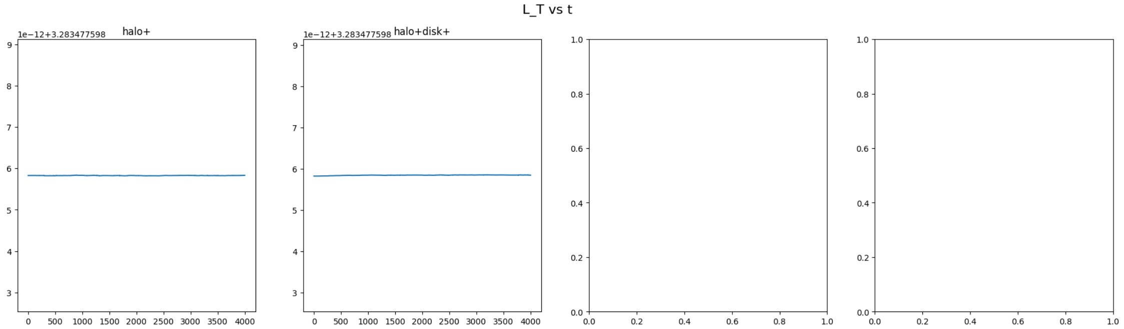




[47]:
```
fig,axes = parametersvstime(circpot,"energy",perturbed_ics)
plt.show()
```



[48]:
```
fig,axes = parametersvstime(circpot,"L_T",perturbed_ics)
plt.show()
```

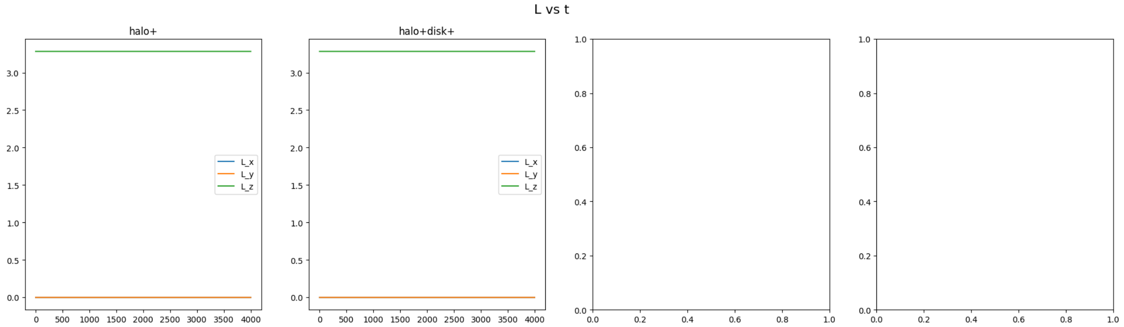


[49]:

```
#fig,axes = parametersvstime(circpot,"e",perturbed_ics)
plt.show()
```

[50]:

```
fig,axes = parametersvstime(circpot,"L",perturbed_ics)
plt.show()
```

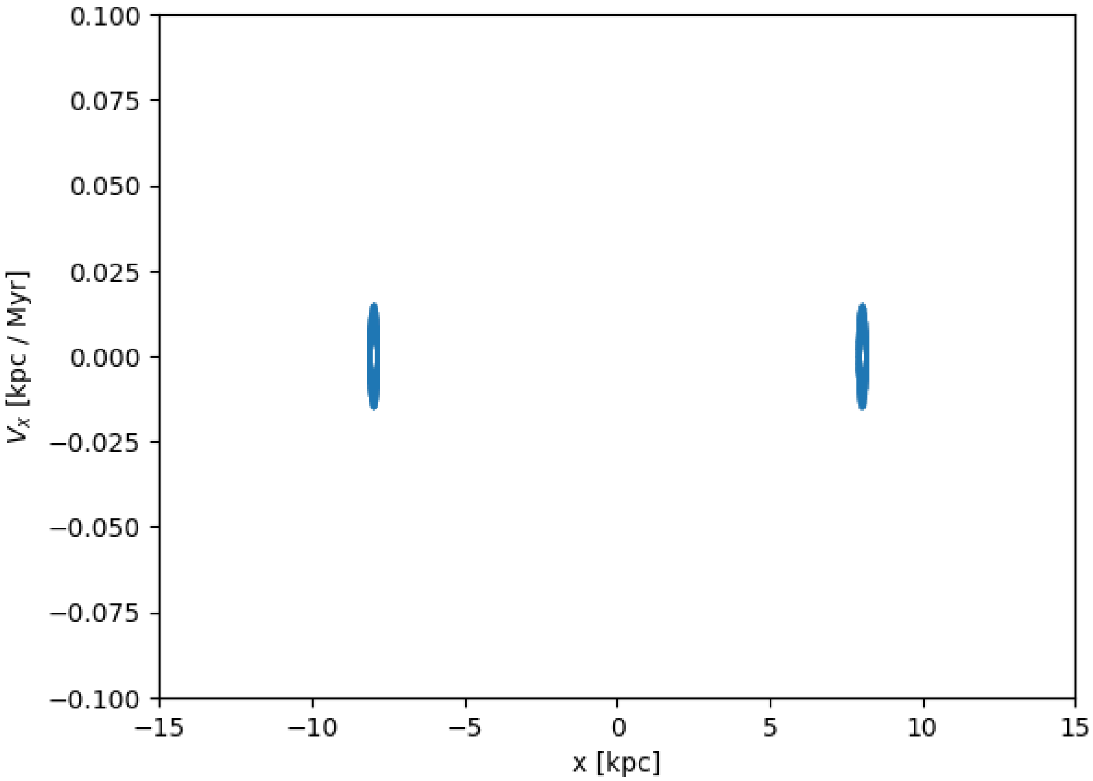


[40]:

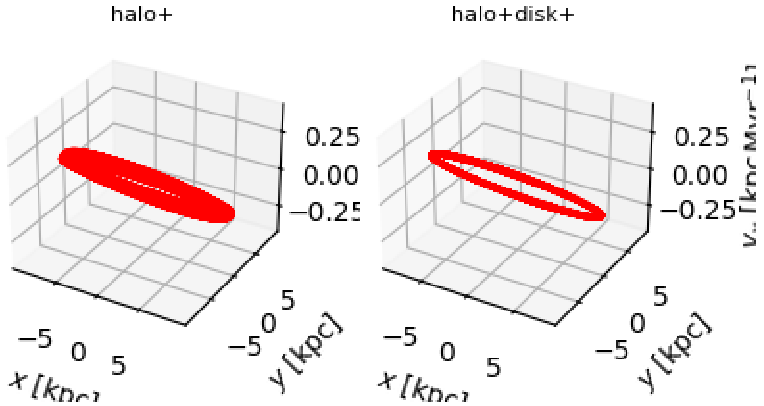
```
fig,ax = plt.subplots(1,1)
x,y = poincare_slice(circpot,perturbed_ics,t_final=1e5*u.Myr)
ax.scatter(x,y,s=1e-2)
ax.set_xlabel(f"x [{x.unit}]")
ax.set_ylabel(f"$V_x$ [{y.unit}]")
ax.set_xlim(-15,15)
ax.set_ylim(-0.1,0.1)
```

[40]:

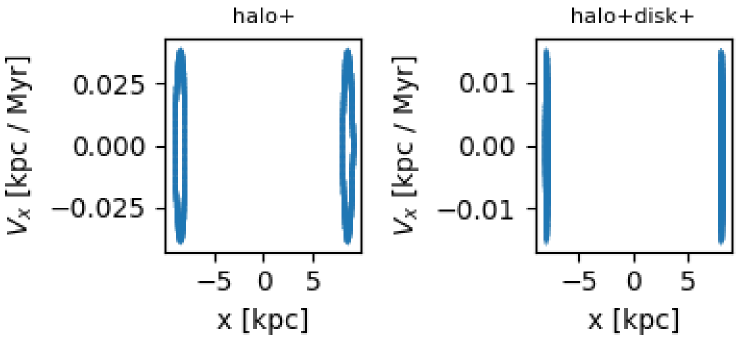
```
(-0.1, 0.1)
```



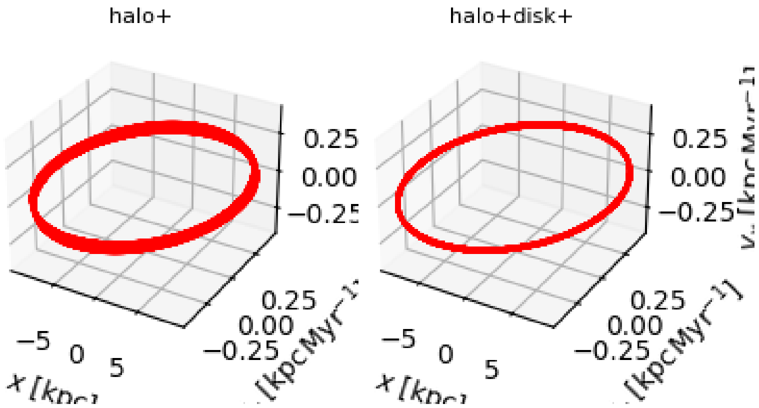
```
[41]: multi_poincare_pots(circpot, perturbed_ics, xyz=["x","y","v_x"])
      plt.tight_layout()
```



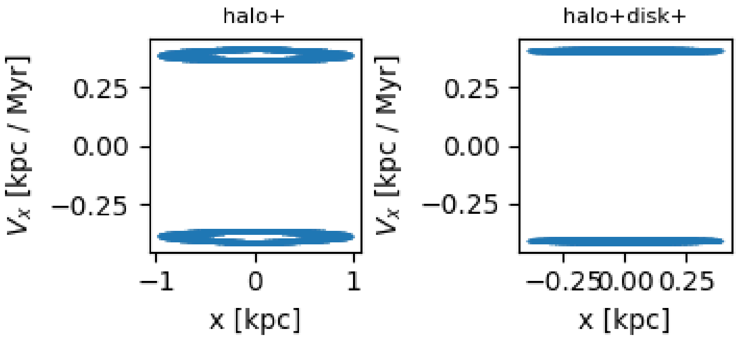
```
[42]: poincare_slice_pots(circpot, perturbed_ics, t_final=1e5*u.
        ↪Myr,hor="x",ver="v_x", cut='y', dproj=1e-1)
      plt.tight_layout()
```



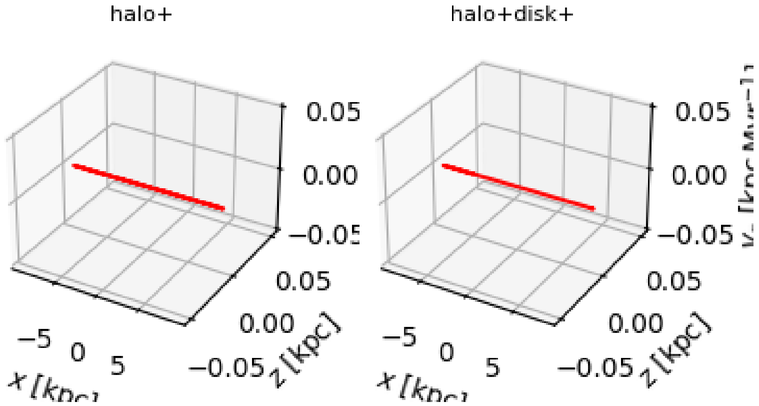
[43]:
```
multi_poincare_pots(circpot, perturbed_ics, xyz=["x","v_y","v_x"])
plt.tight_layout()
```



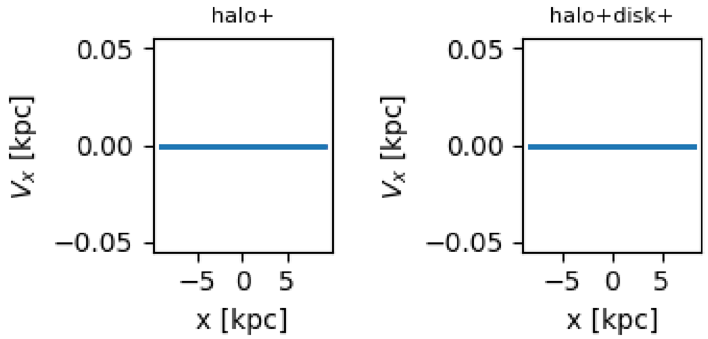
[44]:
```
poincare_slice_pots(circpot, perturbed_ics, t_final=1e5*u.
↪Myr,hor="x",ver="v_x", cut='v_y', dproj=1e-2)
plt.tight_layout()
```



[45]:
```
multi_poincare_pots(circpot, perturbed_ics, xyz=["x","z","v_z"])
plt.tight_layout()
```



[46]:
```
poincare_slice_pots(circpot, perturbed_ics, t_final=1e5*u.Myr,hor="x",ver="z",␣
  ↪cut='v_z', dproj=1e-2)
plt.tight_layout()
```



5.3 3.1 Discusion

Como podemos ver en las superficies, cuando se trata de perturbaciones tan leves, los cortes de las superficies no suelen cambiar demasiado, ya que seguimos estando en un punto estable energeticamente hablando.

Es posible realizar perturbaciones mayores las cuales si llegan a desembocar en cambios en los cortes de las superficies(zona bonus)

llegando a llenar densamente un corte en los casos donde las 2 integrales de movimiento restantes no son aislantes. LLegando a tener curvas en los cortes de superficie cuando la segunda integral de movimiento si es aislante Y el caso extremo es donde tenemos un numero finito de puntos cuando tenemos una tercera integral aislante

Claramente en todas estas orbitas y potenciales tenemos asegurada una integral aislante, la energia, debido a que nuestros potenciales simulados son constantes en el tiempo

5.4 (BONUS)Orbita locaaa

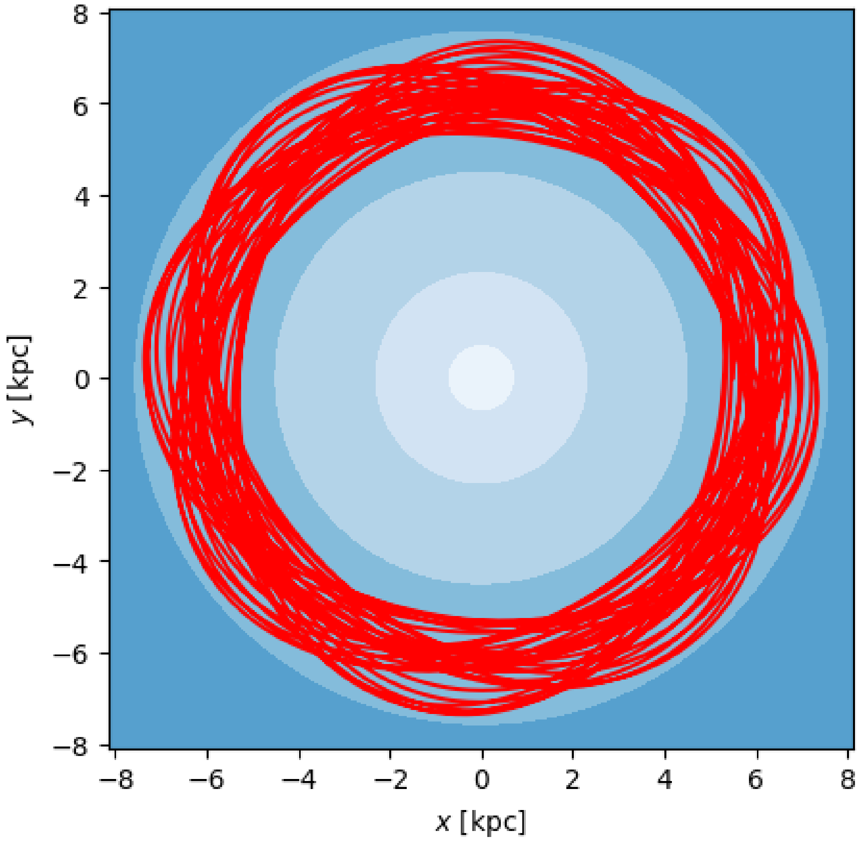
[51]:

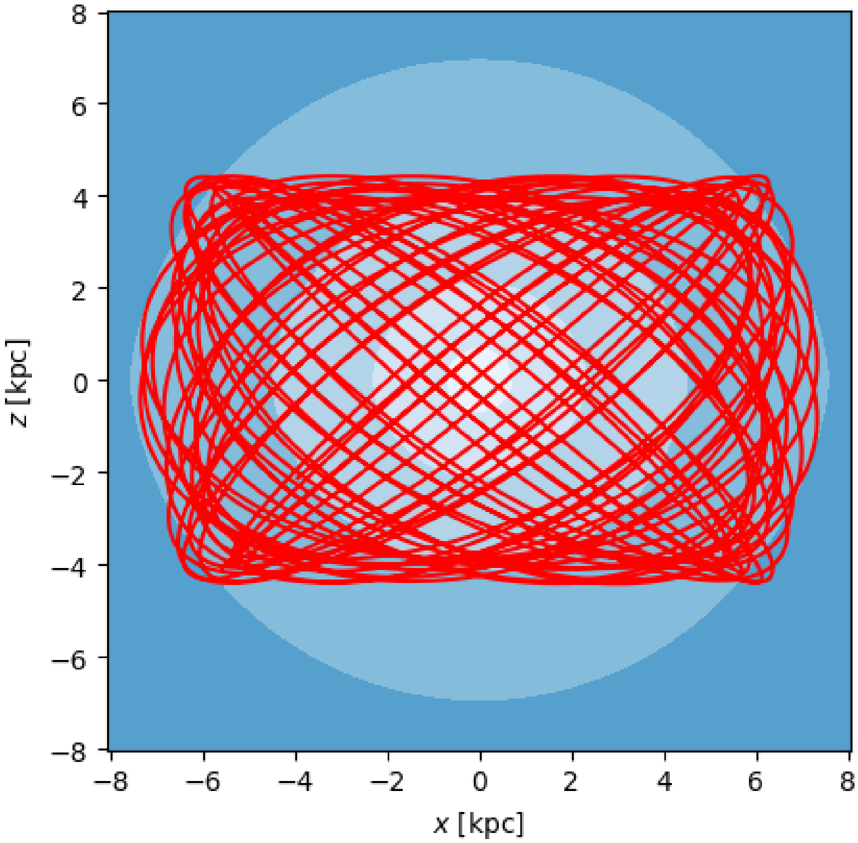
```python
r = [5.5,0,4] * u.kpc

V_circ = circpot.circular_velocity(r)
print(V_circ)
V_circ = V_circ[0]
V_circ = V_circ.value

v = [30, V_circ, 35] * u.km/u.s
perturbed_ics = gd.PhaseSpacePosition(pos=r,vel=v)

perturbed_orbit = gp.Hamiltonian(circpot).integrate_orbit(perturbed_ics, dt=0.4, n_steps=1e4)
grid = np.linspace(-30,30,1000)

fig,ax = plt.subplots(1,1,figsize=(5,5))
perturbed_orbit.plot(components=['x','y'], color='red', axes=ax)
circpot.plot_contours(grid=(grid,grid,0), ax=ax)
plt.show

fig,ax = plt.subplots(1,1,figsize=(5,5))
perturbed_orbit.plot(components=['x','z'], color='red', axes=ax)
circpot.plot_contours(grid=(grid,0,grid), ax=ax)
plt.show
```

```
[394.9016256] km / s
```

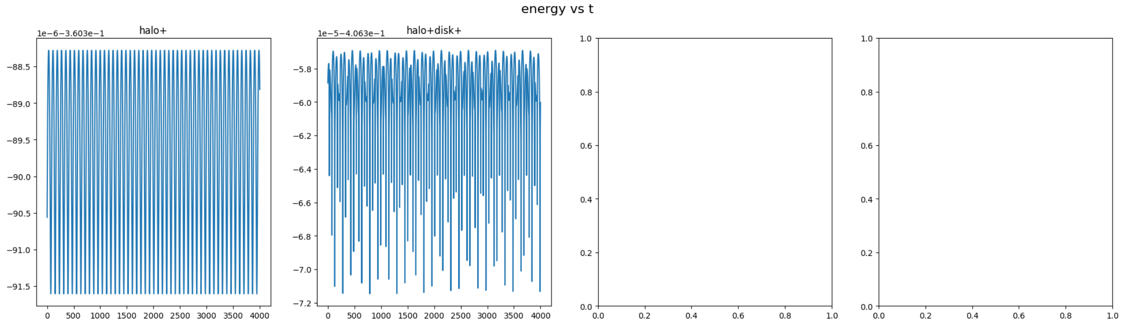
[51]:

```
<function matplotlib.pyplot.show(close=None, block=None)>
```

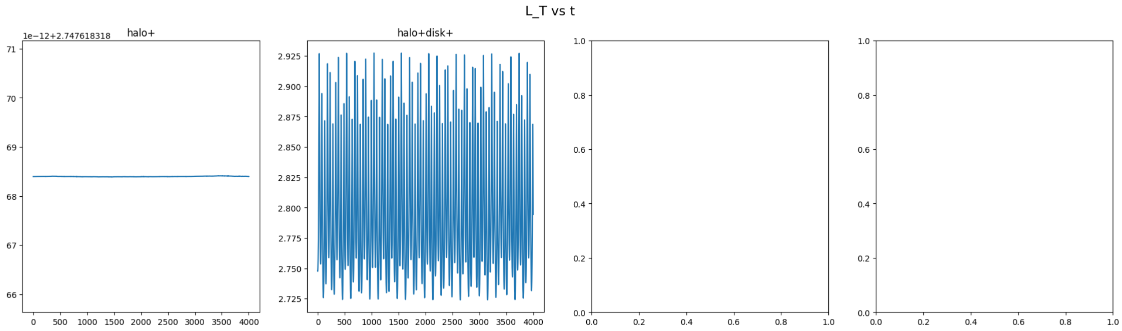

8
6
4
2
0
−2
−4
−6
−8
y [kpc]
−8
−6
−4
−2
0
2
4
6
8
x [kpc]



```
[52]: fig,axes = parametersvstime(circpot,"energy",perturbed_ics)
      plt.show()
```

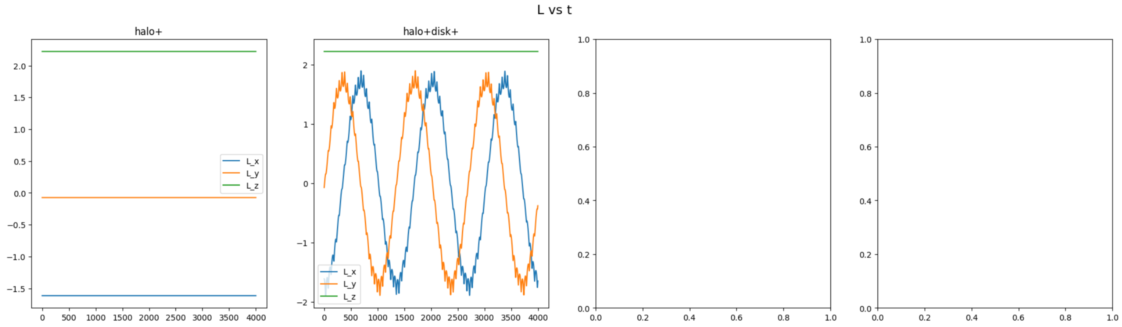


```
[53]: fig,axes = parametersvstime(circpot,"L_T",perturbed_ics)
      plt.show()
```

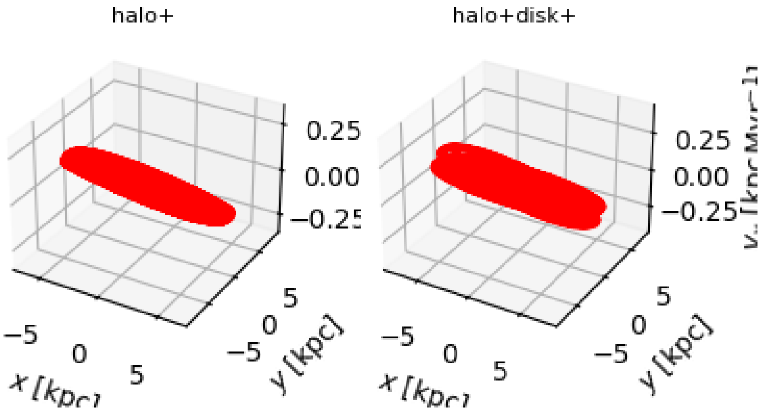


```
[54]: #fig,axes = parametersvstime(circpot,"e",perturbed_ics)
      plt.show()
```

```
[55]: fig,axes = parametersvstime(circpot,"L",perturbed_ics)
      plt.show()
```

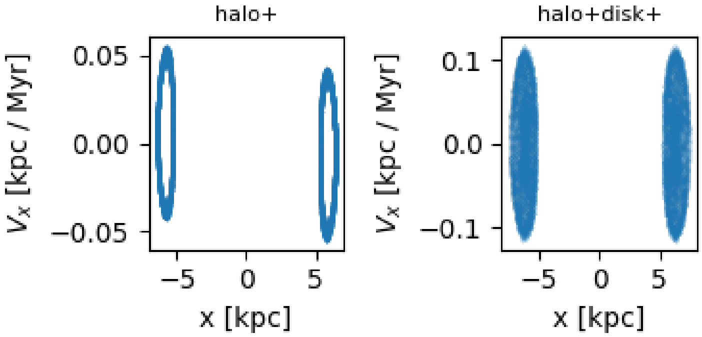


```
[56]: multi_poincare_pots(circpot, perturbed_ics, xyz=["x","y","v_x"])
      plt.tight_layout()
```



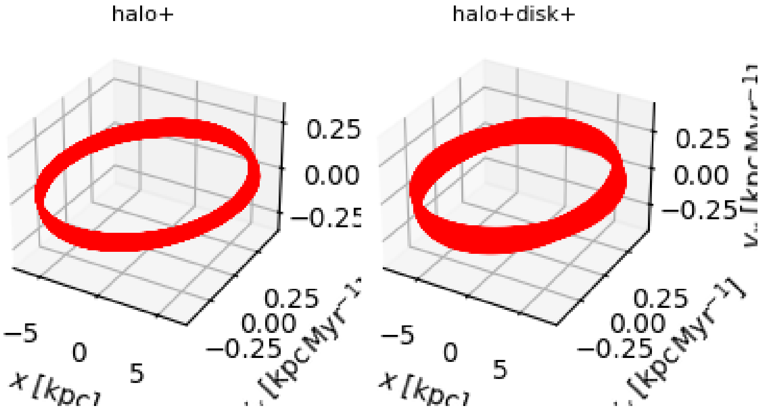
[57]:

```
poincare_slice_pots(circpot, perturbed_ics, t_final=1e5*u.
 ↪Myr,hor="x",ver="v_x", cut='y', dproj=1e-1)
plt.tight_layout()
```



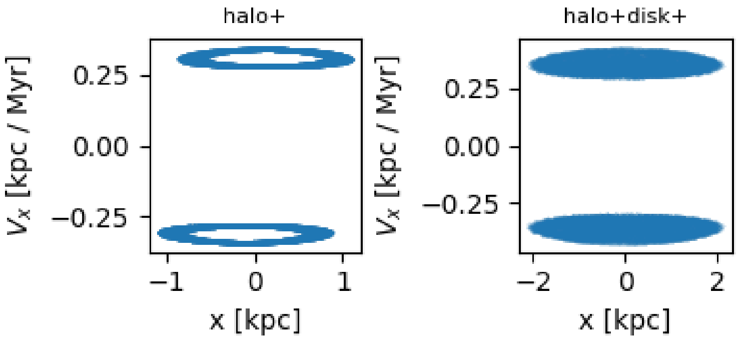
[58]:

```
multi_poincare_pots(circpot, perturbed_ics, xyz=["x","v_y","v_x"])
plt.tight_layout()
```

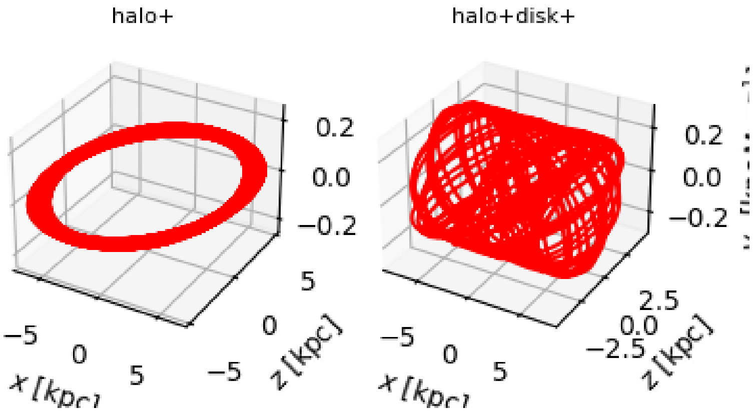


[59]:

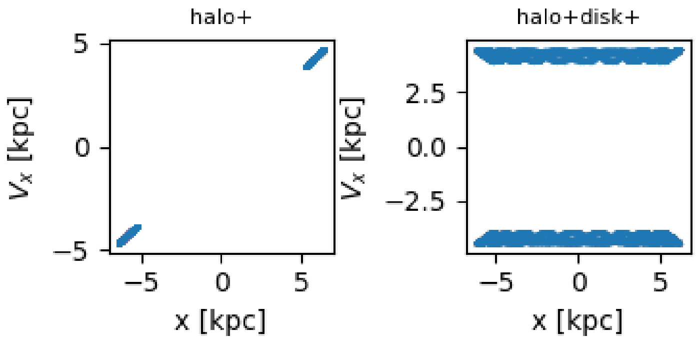
```
poincare_slice_pots(circpot, perturbed_ics, t_final=1e5*u.
 ↪Myr,hor="x",ver="v_x", cut='v_y', dproj=1e-2)
plt.tight_layout()
```



[60]:
```
multi_poincare_pots(circpot, perturbed_ics, xyz=["x","z","v_z"])
plt.tight_layout()
```



[61]:
```
poincare_slice_pots(circpot, perturbed_ics, t_final=1e5*u.Myr,hor="x",ver="z",␣
  ↪cut='v_z', dproj=1e-2)
plt.tight_layout()
```


halo+
halo+disk+
V_x [kpc]
x [kpc]
V_x [kpc]
x [kpc]