Simulating Planetary Orbits

Unless stated otherwise, length = AU and time = yr

Initial Setup

In [1]:
```
#!gcc -shared -O2 -fPIC ode.c -o libode.so
```

In [1]:
```
import csv
import ctypes
from ctypes import *
from numpy.ctypeslib import ndpointer
import numpy as np
import matplotlib.pyplot as plt
import numba
import math
import random
```

In [2]:
```
import importlib
import odesolver
importlib.reload(odesolver)
from odesolver import *
import helpers
importlib.reload(helpers)
from helpers import *
import interfunc
importlib.reload(interfunc)
from interfunc import *
```

func_2_body mercury testing

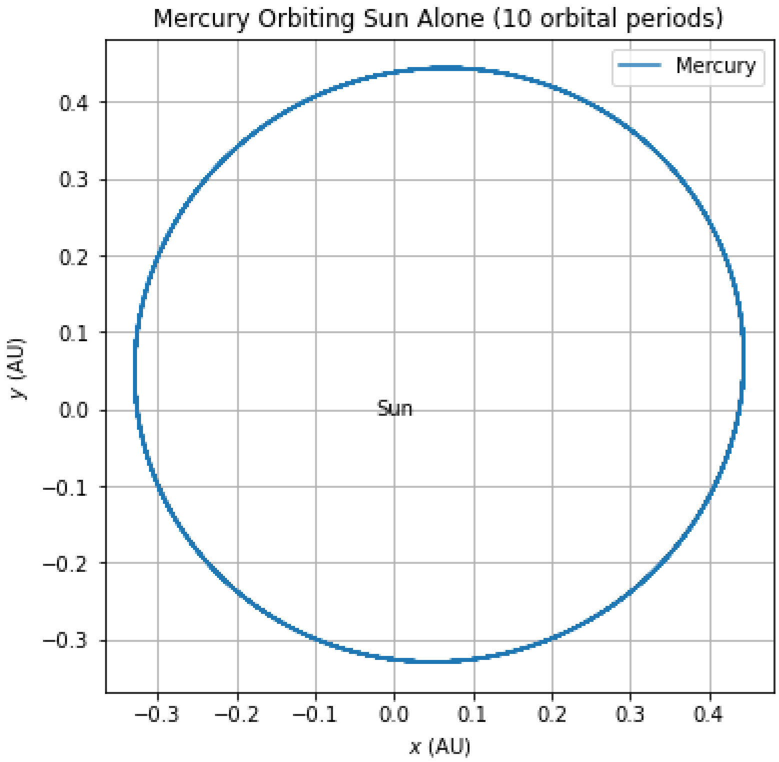
In [7]:
```
GM_S = 39.4229 #AU^3.yr^{-2} solar mass parameter

a_0 = 0.39
e_0 = 0.206
theta_E_0 = -3*np.pi/4
theta_0 = theta_E_0
x_0,v_x_0,y_0,v_y_0 = ellipse_to_xy(a_0, e_0, theta_0, theta_E_0)
initial_mercury = [x_0,v_x_0,y_0,v_y_0]
```

In [4]:
```
total_time = 10*orbital_period(a_0,GM_S)
step_size = orbital_period(a_0,GM_S)/400
n_steps = int(total_time/step_size)
t,sol = solve_ode(func_2_body,[0.,total_time], n_steps, initial_mercury, args=[GM_S], m
x,v_x,y,v_y = sol.T
```

In [5]:
```
plt.figure(figsize=(6,6))
plt.plot(x,y,label=r"Mercury")
plt.legend()
plt.grid()
plt.xlabel(r"$x$ (AU)")
plt.ylabel(r"$y$ (AU)")
```

```
plt.text(0,0,"Sun",ha="center",va="center")
plt.title(r"Mercury Orbiting Sun Alone (10 orbital periods)")
```

Out[5]: Text(0.5, 1.0, 'Mercury Orbiting Sun Alone (10 orbital periods)')



func_n_body solar system testing

In [4]:
```
GM_Sun = 39.4229 #AU^3.yr^{-2} solar mass parameter

# Earth's standard gravitational parameter
GM_Ear = 0.00011841685 #AU^3/yr^2

# https://nssdc.gsfc.nasa.gov/planetary/factsheet/planet_table_ratio.html
GM_Mer = GM_Ear*0.0553
GM_Ven = GM_Ear*0.815
GM_Mar = GM_Ear*0.107
GM_Jup = GM_Ear*317.8
GM_Sat = GM_Ear*95.2
GM_Ura = GM_Ear*14.5
GM_Nep = GM_Ear*17.1
```

In [7]:
```
# https://www.princeton.edu/~willman/planetary_systems/Sol/
init_Mer = np.array(ellipse_to_xy(0.3870993, 0.20564, 0., 0.))
init_Ven = np.array(ellipse_to_xy(0.723336, 0.00678, 0., 0.))
init_Ven[ind_v_y(0)] *= -1
init_Ear = np.array(ellipse_to_xy(1.000003, 0.01671, 0., 0.))
init_Mar = np.array(ellipse_to_xy(1.52371, 0.09339, 0., 0.))
init_Jup = np.array(ellipse_to_xy(5.2029, 0.0484, 0., 0.))
init_Sat = np.array(ellipse_to_xy(9.537, 0.0539, 0., 0.))
init_Ura = np.array(ellipse_to_xy(19.189, 0.04726, 0., 0.))
init_Nep = np.array(ellipse_to_xy(30.0699, 0.00859, 0., 0.))
```

In [8]:
```
n_planets = 8
```

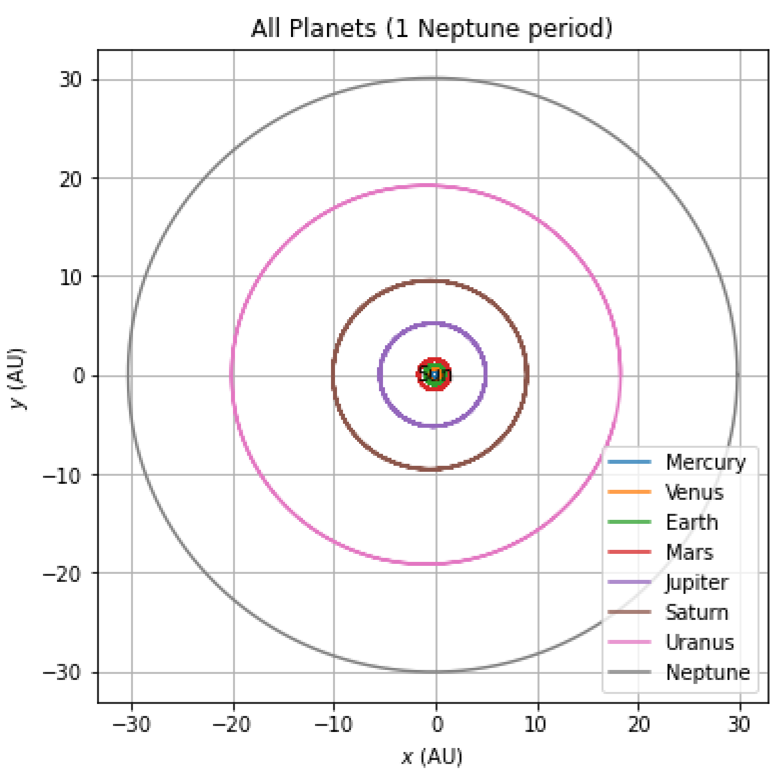
```
params = [GM_Sun, n_planets, GM_Mer, GM_Ven, GM_Ear, GM_Mar, GM_Jup, GM_Sat, GM_Ura, GM
init_solar_planets = np.concatenate((init_Mer,init_Ven,init_Ear,init_Mar,init_Jup,init_

a_Nep = 30.0699
total_time = orbital_period(a_Nep,GM_S) # 1 Neptune period
step_size = orbital_period(a_0,GM_S)/100 # 1/100 of Mercury period
n_steps = int(total_time/step_size)
t,sol_untransposed = solve_ode(func_n_body,[0.,total_time], n_steps, init_solar_planets
sol = sol_untransposed.T
```

In [9]:

```
plt.figure(figsize=(6,6))
plt.plot(sol[ind_x(0)],sol[ind_y(0)],label=r"Mercury")
plt.plot(sol[ind_x(1)],sol[ind_y(1)],label=r"Venus")
plt.plot(sol[ind_x(2)],sol[ind_y(2)],label=r"Earth")
plt.plot(sol[ind_x(3)],sol[ind_y(3)],label=r"Mars")
plt.plot(sol[ind_x(4)],sol[ind_y(4)],label=r"Jupiter")
plt.plot(sol[ind_x(5)],sol[ind_y(5)],label=r"Saturn")
plt.plot(sol[ind_x(6)],sol[ind_y(6)],label=r"Uranus")
plt.plot(sol[ind_x(7)],sol[ind_y(7)],label=r"Neptune")
plt.legend()
plt.grid()
plt.xlabel(r"$x$ (AU)")
plt.ylabel(r"$y$ (AU)")
plt.text(0,0,"Sun",ha="center",va="center")
plt.title(r"All Planets (1 Neptune period)")
```

Out[9]:

```
Text(0.5, 1.0, 'All Planets (1 Neptune period)')
```

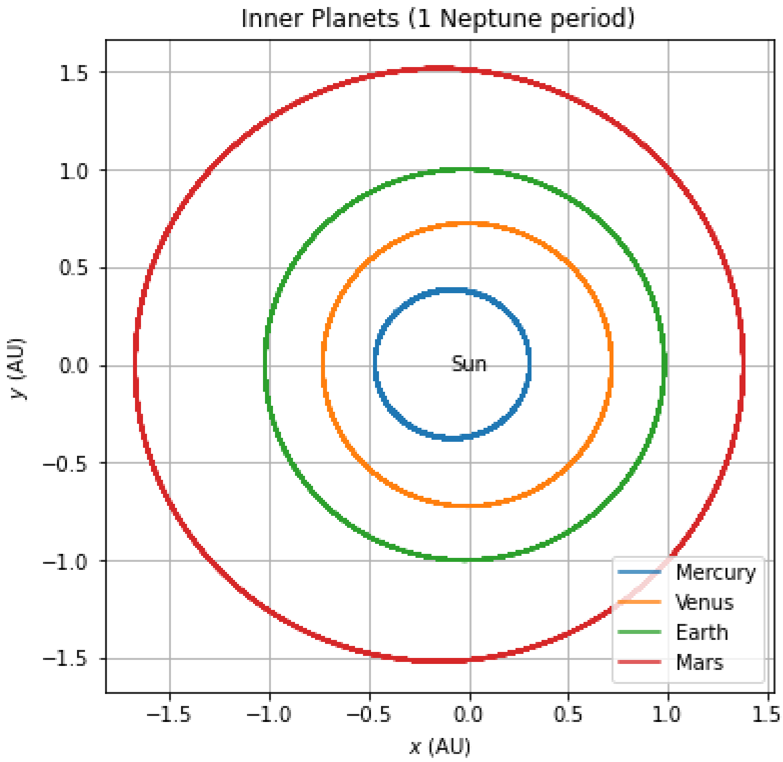


In [10]:

```
plt.figure(figsize=(6,6))
plt.plot(sol[ind_x(0)],sol[ind_y(0)],label=r"Mercury")
plt.plot(sol[ind_x(1)],sol[ind_y(1)],label=r"Venus")
plt.plot(sol[ind_x(2)],sol[ind_y(2)],label=r"Earth")
plt.plot(sol[ind_x(3)],sol[ind_y(3)],label=r"Mars")
plt.legend()
plt.grid()
```

```
plt.xlabel(r"$x$ (AU)")
plt.ylabel(r"$y$ (AU)")
plt.text(0,0,"Sun",ha="center",va="center")
plt.title(r"Inner Planets (1 Neptune period)")
```

Out[10]: Text(0.5, 1.0, 'Inner Planets (1 Neptune period)')



In [37]:
```
init_Mer = np.array(ellipse_to_xy(random.gauss(0.3870993, 1.), random.gauss(0.20564, 1.
init_Ven = np.array(ellipse_to_xy(random.gauss(0.723336, .0001), random.gauss(0.00678,
init_Ven[ind_v_y(0)] *= -1
init_Ear = np.array(ellipse_to_xy(random.gauss(1.000003, .0001), random.gauss(0.01671,
init_Mar = np.array(ellipse_to_xy(random.gauss(1.52371, .0001), random.gauss(0.09339, .
init_Jup = np.array(ellipse_to_xy(random.gauss(5.2029, .0001), random.gauss(0.0484, .00
init_Sat = np.array(ellipse_to_xy(random.gauss(9.537, .0001), random.gauss(0.0539, .000
init_Ura = np.array(ellipse_to_xy(random.gauss(19.189, .0001), random.gauss(0.04726, .0
init_Nep = np.array(ellipse_to_xy(random.gauss(30.0699, .0001), random.gauss(0.00859, .
```

In [38]:
```
# randomize simulation

n_planets = 8
params = [GM_Sun, n_planets, GM_Mer, GM_Ven, GM_Ear, GM_Mar, GM_Jup, GM_Sat, GM_Ura, GM
noisy_planets = np.concatenate((init_Mer,init_Ven,init_Ear,init_Mar,init_Jup,init_Sat,i

a_Nep = 30.0699
total_time = 1000 * orbital_period(a_Nep,GM_S) # 1 Neptune period
step_size = orbital_period(a_0,GM_S)/100 # 1/100 of Mercury period
n_steps = int(total_time/step_size)
t,sol_untransposed = solve_ode(func_n_body,[0.,total_time], n_steps, init_solar_planets
sol = sol_untransposed.T
```

In [39]:
```
print(init_solar_planets)
print(noisy_planets)
```

```
[ 3.07496200e-01  7.61815267e-16  0.00000000e+00  1.24413875e+01
  7.18431782e-01  4.55444274e-16  0.00000000e+00 -7.43796945e+00
```

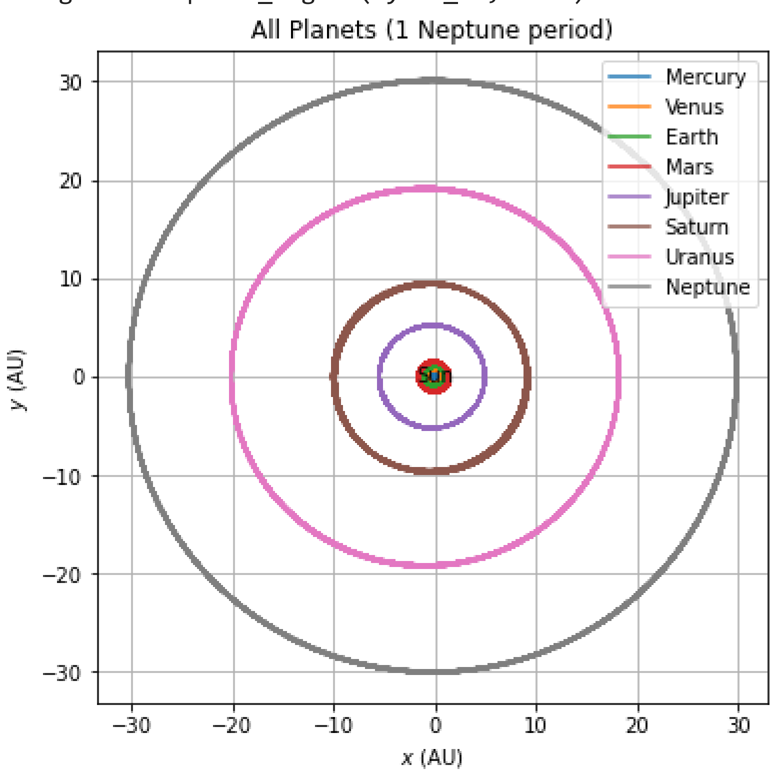
```
  9.83292950e-01  9.52044104e-08  0.00000000e+00  6.38905980e+00
  1.38141072e+00  3.42284207e-16  0.00000000e+00  5.58992532e+00
  4.95107964e+00  1.77041171e-16  0.00000000e+00  2.89130175e+00
  9.02295570e+00  1.31487968e-16  0.00000000e+00  2.14736148e+00
  1.82821279e+01  2.24085559e-08  0.00000000e+00  1.50381272e+00
  2.98115996e+01  7.07661248e-17  0.00000000e+00  1.15569852e+00]
[-9.33479655e-02  1.58773965e-15 -0.00000000e+00 -2.59297562e+01
  7.18471623e-01  4.55416750e-16  0.00000000e+00 -7.43751995e+00
  9.83349122e-01  3.91208025e-16  0.00000000e+00  6.38891189e+00
  1.38173640e+00  3.42217193e-16  0.00000000e+00  5.58883088e+00
  4.95143378e+00  1.77028722e-16  0.00000000e+00  2.89109844e+00
  9.02332401e+00  1.31481484e-16  0.00000000e+00  2.14725559e+00
  1.82816242e+01  9.20841614e-17  0.00000000e+00  1.50384848e+00
  2.98084977e+01  7.07732214e-17  0.00000000e+00  1.15581442e+00]
```

In [40]:

```python
plt.figure(figsize=(6,6))
plt.plot(sol[ind_x(0)],sol[ind_y(0)],label=r"Mercury")
plt.plot(sol[ind_x(1)],sol[ind_y(1)],label=r"Venus")
plt.plot(sol[ind_x(2)],sol[ind_y(2)],label=r"Earth")
plt.plot(sol[ind_x(3)],sol[ind_y(3)],label=r"Mars")
plt.plot(sol[ind_x(4)],sol[ind_y(4)],label=r"Jupiter")
plt.plot(sol[ind_x(5)],sol[ind_y(5)],label=r"Saturn")
plt.plot(sol[ind_x(6)],sol[ind_y(6)],label=r"Uranus")
plt.plot(sol[ind_x(7)],sol[ind_y(7)],label=r"Neptune")
plt.legend()
plt.grid()
plt.xlabel(r"$x$ (AU)")
plt.ylabel(r"$y$ (AU)")
plt.text(0,0,"Sun",ha="center",va="center")
plt.title(r"All Planets (1 Neptune period)")
```

Out[40]:

```
Text(0.5, 1.0, 'All Planets (1 Neptune period)')

/Users/maxpaik/opt/anaconda3/lib/python3.8/site-packages/IPython/core/pylabtools.py:132:
UserWarning: Creating legend with loc="best" can be slow with large amounts of data.
  fig.canvas.print_figure(bytes_io, **kw)
```



In [32]:
```
plt.figure(figsize=(6,6))
plt.plot(sol[ind_x(0)],sol[ind_y(0)],label=r"Mercury")
plt.plot(sol[ind_x(1)],sol[ind_y(1)],label=r"Venus")
plt.plot(sol[ind_x(2)],sol[ind_y(2)],label=r"Earth")
plt.plot(sol[ind_x(3)],sol[ind_y(3)],label=r"Mars")
plt.legend()
plt.grid()
plt.xlabel(r"$x$ (AU)")
plt.ylabel(r"$y$ (AU)")
plt.text(0,0,"Sun",ha="center",va="center")
plt.title(r"Inner Planets (1 Neptune period)")
```

Out[32]:
```
Text(0.5, 1.0, 'Inner Planets (1 Neptune period)')

/Users/maxpaik/opt/anaconda3/lib/python3.8/site-packages/IPython/core/pylabtools.py:132:
UserWarning: Creating legend with loc="best" can be slow with large amounts of data.
  fig.canvas.print_figure(bytes_io, **kw)

---------------------------------------------------------------------------
OverflowError                             Traceback (most recent call last)
~/opt/anaconda3/lib/python3.8/site-packages/matplotlib/backends/backend_agg.py in draw_p
ath(self, gc, path, transform, rgbFace)
    158         try:
--> 159             self._renderer.draw_path(gc, path, transform, rgbFace)
    160         except OverflowError as err:

OverflowError: In draw_path: Exceeded cell block limit

The above exception was the direct cause of the following exception:

OverflowError                             Traceback (most recent call last)
~/opt/anaconda3/lib/python3.8/site-packages/IPython/core/formatters.py in __call__(self,
obj)
    339                 pass
    340             else:
--> 341                 return printer(obj)
    342             # Finally look for special method names
    343             method = get_real_method(obj, self.print_method)

~/opt/anaconda3/lib/python3.8/site-packages/IPython/core/pylabtools.py in <lambda>(fig)
    246 
    247     if 'png' in formats:
--> 248         png_formatter.for_type(Figure, lambda fig: print_figure(fig, 'png', **k
wargs))
    249     if 'retina' in formats or 'png2x' in formats:
    250         png_formatter.for_type(Figure, lambda fig: retina_figure(fig, **kwargs)
)

~/opt/anaconda3/lib/python3.8/site-packages/IPython/core/pylabtools.py in print_figure(f
ig, fmt, bbox_inches, **kwargs)
    130         FigureCanvasBase(fig)
    131 
--> 132     fig.canvas.print_figure(bytes_io, **kw)
    133     data = bytes_io.getvalue()
    134     if fmt == 'svg':

~/opt/anaconda3/lib/python3.8/site-packages/matplotlib/backend_bases.py in print_figure
(self, filename, dpi, facecolor, edgecolor, orientation, format, bbox_inches, pad_inche
s, bbox_extra_artists, backend, **kwargs)
   2208 
   2209             try:
-> 2210                 result = print_method(
   2211                     filename,
   2212                     dpi=dpi,
```

```
~/opt/anaconda3/lib/python3.8/site-packages/matplotlib/backend_bases.py in wrapper(*arg
s, **kwargs)
   1637                 kwargs.pop(arg)
   1638
-> 1639             return func(*args, **kwargs)
   1640
   1641         return wrapper

~/opt/anaconda3/lib/python3.8/site-packages/matplotlib/backends/backend_agg.py in print_
png(self, filename_or_obj, metadata, pil_kwargs, *args)
    507                 *metadata*, including the default 'Software' key.
    508             """
--> 509             FigureCanvasAgg.draw(self)
    510             mpl.image.imsave(
    511                 filename_or_obj, self.buffer_rgba(), format="png", origin="upper",

~/opt/anaconda3/lib/python3.8/site-packages/matplotlib/backends/backend_agg.py in draw(s
elf)
    405                  (self.toolbar._wait_cursor_for_draw_cm() if self.toolbar
    406                   else nullcontext()):
--> 407                 self.figure.draw(self.renderer)
    408                 # A GUI class may be need to update a window using this draw, so
    409                 # don't forget to call the superclass.

~/opt/anaconda3/lib/python3.8/site-packages/matplotlib/artist.py in draw_wrapper(artist,
renderer, *args, **kwargs)
     39                     renderer.start_filter()
     40
---> 41                 return draw(artist, renderer, *args, **kwargs)
     42             finally:
     43                 if artist.get_agg_filter() is not None:

~/opt/anaconda3/lib/python3.8/site-packages/matplotlib/figure.py in draw(self, renderer)
   1861
   1862                 self.patch.draw(renderer)
-> 1863                 mimage._draw_list_compositing_images(
   1864                     renderer, self, artists, self.suppressComposite)
   1865

~/opt/anaconda3/lib/python3.8/site-packages/matplotlib/image.py in _draw_list_compositin
g_images(renderer, parent, artists, suppress_composite)
    129         if not_composite or not has_images:
    130             for a in artists:
--> 131                 a.draw(renderer)
    132         else:
    133             # Composite any adjacent images together

~/opt/anaconda3/lib/python3.8/site-packages/matplotlib/artist.py in draw_wrapper(artist,
renderer, *args, **kwargs)
     39                     renderer.start_filter()
     40
---> 41                 return draw(artist, renderer, *args, **kwargs)
     42             finally:
     43                 if artist.get_agg_filter() is not None:

~/opt/anaconda3/lib/python3.8/site-packages/matplotlib/cbook/deprecation.py in wrapper(*
inner_args, **inner_kwargs)
    409                         else deprecation_addendum,
    410                     **kwargs)
--> 411             return func(*inner_args, **inner_kwargs)
    412
    413         return wrapper

~/opt/anaconda3/lib/python3.8/site-packages/matplotlib/axes/_base.py in draw(self, rende
rer, inframe)
```

```
   2745             renderer.stop_rasterizing()
   2746 
-> 2747         mimage._draw_list_compositing_images(renderer, self, artists)
   2748 
   2749         renderer.close_group('axes')

~/opt/anaconda3/lib/python3.8/site-packages/matplotlib/image.py in _draw_list_compositin
g_images(renderer, parent, artists, suppress_composite)
    129     if not_composite or not has_images:
    130         for a in artists:
--> 131             a.draw(renderer)
    132     else:
    133         # Composite any adjacent images together

~/opt/anaconda3/lib/python3.8/site-packages/matplotlib/artist.py in draw_wrapper(artist,
renderer, *args, **kwargs)
     39                 renderer.start_filter()
     40 
---> 41             return draw(artist, renderer, *args, **kwargs)
     42         finally:
     43             if artist.get_agg_filter() is not None:

~/opt/anaconda3/lib/python3.8/site-packages/matplotlib/lines.py in draw(self, renderer)
    784 
    785                 gc.set_dashes(self._dashOffset, self._dashSeq)
--> 786                 renderer.draw_path(gc, tpath, affine.frozen())
    787                 gc.restore()
    788 

~/opt/anaconda3/lib/python3.8/site-packages/matplotlib/backends/backend_agg.py in draw_p
ath(self, gc, path, transform, rgbFace)
    159                 self._renderer.draw_path(gc, path, transform, rgbFace)
    160             except OverflowError as err:
--> 161                 raise OverflowError("Exceeded cell block limit (set "
    162                                     "'agg.path.chunksize' rcparam)") from err
    163 

OverflowError: Exceeded cell block limit (set 'agg.path.chunksize' rcparam)
<Figure size 432x432 with 1 Axes>
```

In [ ]:

```
for i in range(5000):
    init_Mer = np.array(ellipse_to_xy(random.gauss(0.3870993, .0001), random.gauss(0.20
    init_Ven = np.array(ellipse_to_xy(random.gauss(0.723336, .0001), random.gauss(0.006
    init_Ven[ind_v_y(0)] *= -1
    init_Ear = np.array(ellipse_to_xy(random.gauss(1.000003, .0001), random.gauss(0.016
    init_Mar = np.array(ellipse_to_xy(random.gauss(1.52371, .0001), random.gauss(0.0933
    init_Jup = np.array(ellipse_to_xy(random.gauss(5.2029, .0001), random.gauss(0.0484,
    init_Sat = np.array(ellipse_to_xy(random.gauss(9.537, .0001), random.gauss(0.0539,
    init_Ura = np.array(ellipse_to_xy(random.gauss(19.189, .0001), random.gauss(0.04726
    init_Nep = np.array(ellipse_to_xy(random.gauss(30.0699, .0001), random.gauss(0.0085
    n_planets = 8

    init_Mer = list(map(lambda x : x + random.gauss(0, .02), init_Mer))
    params = [GM_Sun, n_planets, GM_Mer, GM_Ven, GM_Ear, GM_Mar, GM_Jup, GM_Sat, GM_Ura
    noisy_planets = np.concatenate((init_Mer,init_Ven,init_Ear,init_Mar,init_Jup,init_S

    a_Nep = 30.0699
    total_time = 10000 * orbital_period(a_Nep,GM_Sun) # 1 Neptune period
    step_size = orbital_period(a_0,GM_S)/100 # 1/100 of Mercury period
    n_steps = int(total_time/step_size)
    t,sol_untransposed = solve_ode(func_n_body,[0.,total_time], n_steps, noisy_planets,
    sol = sol_untransposed.T
```

```
    ejected = 0
    print(np.amax(sol[ind_x(0)]))
    if np.amax(sol[ind_x(0)]) > 10:
        ejected = 1

    with open('training.csv', mode='a') as file:
        writer = csv.writer(file, delimiter=',', quotechar='"', quoting=csv.QUOTE_MINIM

        data = np.ndarray.tolist(noisy_planets)
        data.append(ejected)
        writer.writerow(data)
```

In [ ]:

other func_n_body test

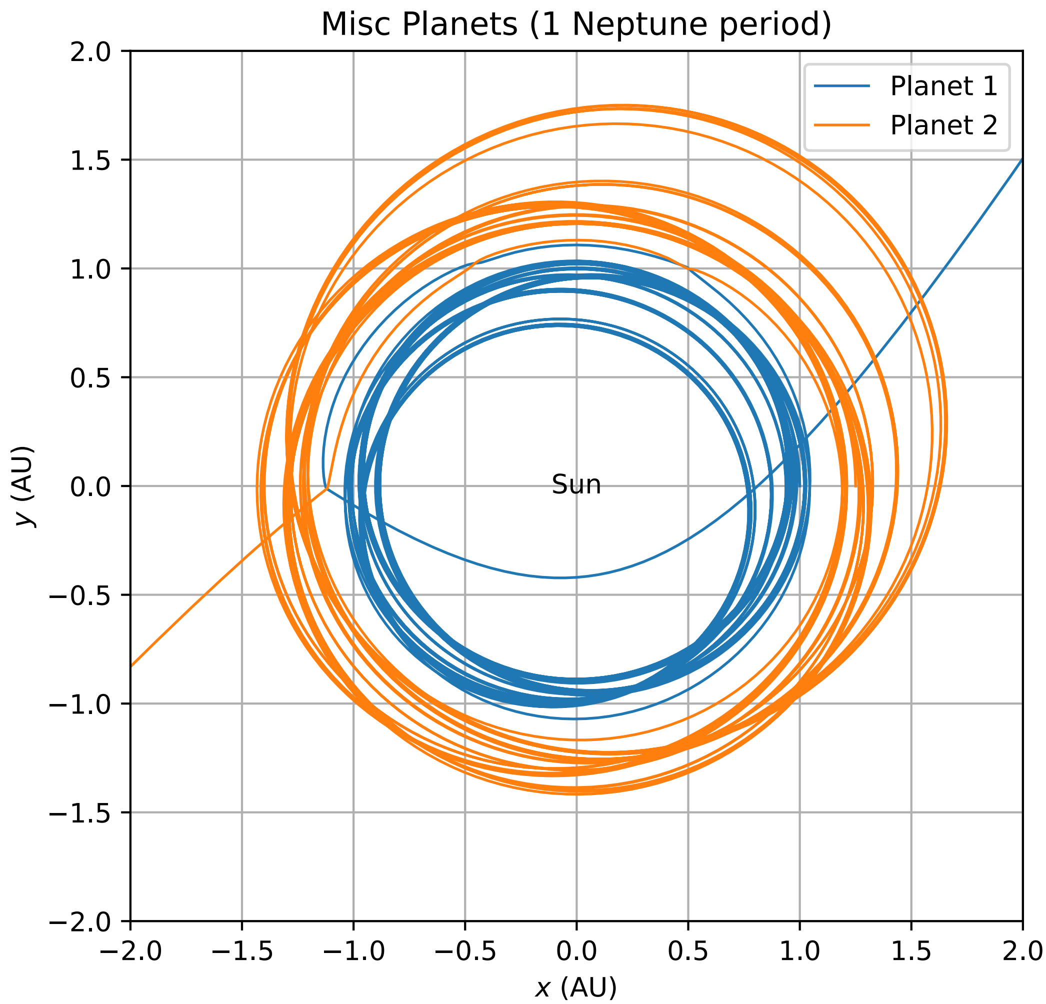
In [32]:

```
init_1 = np.array(old_ellipse_to_xy(1, 0., 0., 0., GM_Sun))
init_2 = np.array(old_ellipse_to_xy(1.25, 0., 0., 0., GM_Sun))

n_misc = 2
params_misc = [GM_Sun, n_misc, GM_Jup, GM_Jup]
init_misc = np.concatenate((init_1,init_2))
print(init_misc)

total_time = 0.25*orbital_period(a_Nep,GM_S) # 0.25 Neptune period
step_size = orbital_period(a_0,GM_S)/500 # 1/500 of Mercury period
n_steps = int(total_time/step_size)
t,sol_untransposed = solve_ode(func_n_body,[0.,total_time], n_steps, init_misc, args=pa
sol = sol_untransposed.T

plt.figure(figsize=(6,6))
plt.plot(sol[ind_x(0)],sol[ind_y(0)],label=r"Planet 1",linewidth=1)
plt.plot(sol[ind_x(1)],sol[ind_y(1)],label=r"Planet 2",linewidth=1)
plt.xlim(-2,2)
plt.ylim(-2,2)
plt.legend()
plt.grid()
plt.xlabel(r"$x$ (AU)")
plt.ylabel(r"$y$ (AU)")
plt.text(0,0,"Sun",ha="center",va="center")
plt.title(r"Misc Planets (1 Neptune period)")
```

```
[1.00000000e+00 3.84463522e-16 0.00000000e+00 6.27876580e+00
 1.25000000e+00 3.43874628e-16 0.00000000e+00 5.61589886e+00]
```

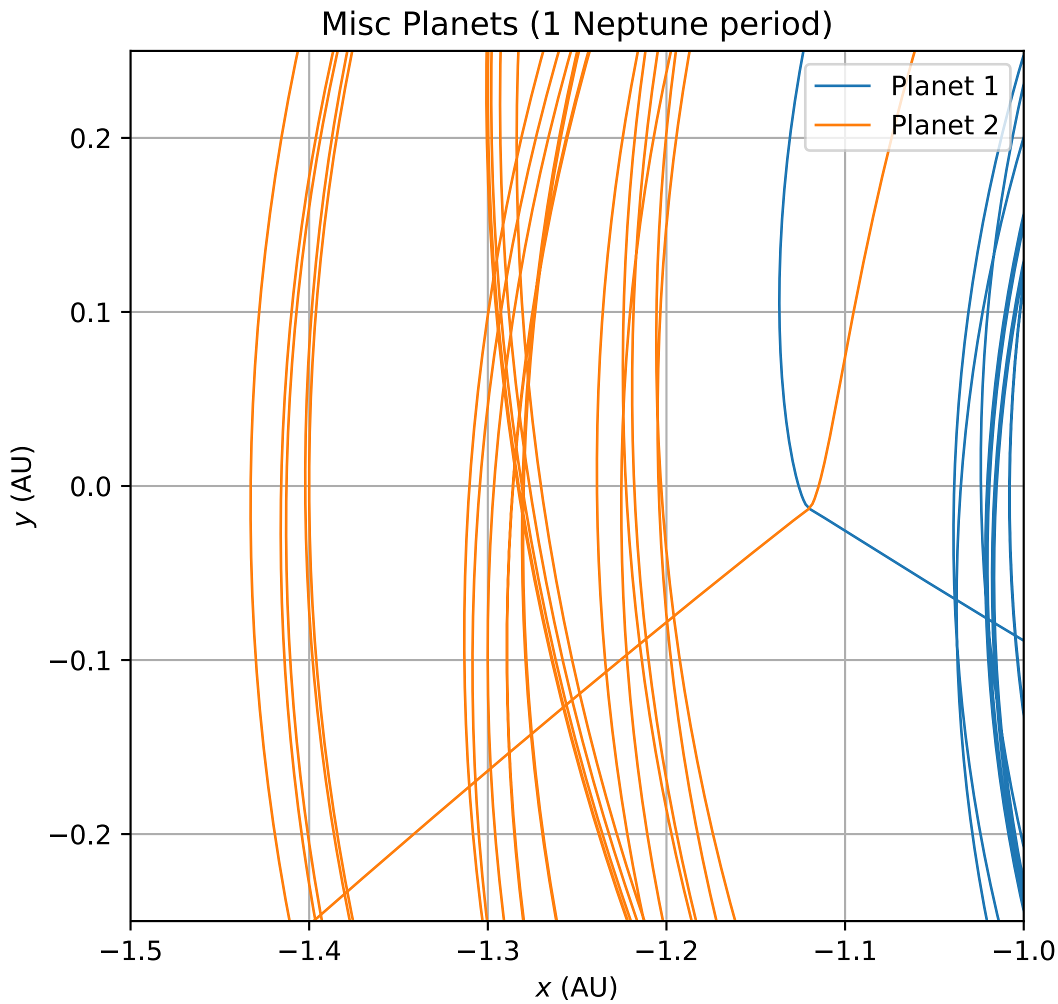
Out[32]:

```
Text(0.5, 1.0, 'Misc Planets (1 Neptune period)')
```



In [33]:
```
plt.figure(figsize=(6,6))
plt.plot(sol[ind_x(0)],sol[ind_y(0)],label=r"Planet 1",linewidth=1)
plt.plot(sol[ind_x(1)],sol[ind_y(1)],label=r"Planet 2",linewidth=1)
plt.xlim(-1.5,-1.0)
plt.ylim(-0.25,0.25)
plt.legend()
plt.grid()
plt.xlabel(r"$x$ (AU)")
plt.ylabel(r"$y$ (AU)")
plt.title(r"Misc Planets (1 Neptune period)")
```

Out[33]:
```
Text(0.5, 1.0, 'Misc Planets (1 Neptune period)')
```


Misc Planets (1 Neptune period)
Planet 1
Planet 2
0.2
0.1
0.0
−0.1
−0.2
y (AU)
−1.5
−1.4
−1.3
−1.2
−1.1
−1.0
x (AU)