In [1]:

```
import numpy as np
import matplotlib.pyplot as plt
%matplotlib inline
from scipy import integrate
from astropy import constants as const
from astropy import units as u
```

In [2]:

```
plt.rcParams.update({'font.size': 14, 'text.usetex': True})
```

In [3]:

```
#Define universal gravitation constant
G=6.67408e-11 #N-m2/kg2
#Reference quantities
m_nd=1.989e+30 #kg #mass of the sun
r_nd=5.326e+12 #m #distance between stars in Alpha Centauri
v_nd=30000 #m/s #relative velocity of earth around the sun
t_nd=79.91*365*24*3600*0.51 #s #orbital period of Alpha Centauri
#Net constants
K1=G*t_nd*m_nd/(r_nd**2*v_nd)
K2=v_nd*t_nd/r_nd
```

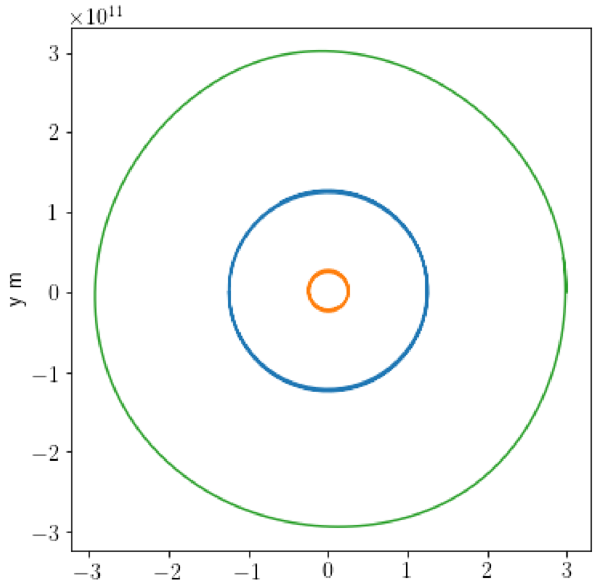
In [4]:

```
#vector input has initial conditions for 3 bodies

def threebodyfunc(vec, t):
    #assigning the initial conditions to vector elements
    x1, y1, z1 = vec[0], vec[1], vec[2]
    vx1, vy1, vz1 = vec[3], vec[4], vec[5]

    x2, y2, z2 = vec[6], vec[7], vec[8]
    vx2, vy2, vz2 = vec[9], vec[10], vec[11]

    x3, y3, z3 = vec[12], vec[13], vec[14]
    vx3, vy3, vz3 = vec[15], vec[16], vec[17]

    #separation vectors
    dx12, dy12, dz12 = x2-x1, y2-y1, z2-z1
    dx13, dy13, dz13 = x3-x1, y3-y1, z3-z1
    dx23, dy23, dz23 = x3-x2, y3-y2, z3-z2

    d12 = np.sqrt(dx12**2+dy12**2+dz12**2)
    d13 = np.sqrt(dx13**2+dy13**2+dz13**2)
    d23 = np.sqrt(dx23**2+dy23**2+dz23**2)

    #acceleration calculations
#     Gmr3_1 = G*m2/d12**3 + G*m3/d13**3       #acceleration on body 1 due to bodies 2 and 3
#     Gmr3_2 = G*m1/d12**3 + G*m3/d23**3       #acceleration on body 2 due to bodies 1 and 3
#     Gmr3_3 = G*m1/d13**3 + G*m2/d23**3       #acceleration on body 3 due to bodies 1 and 2
    ax1 = (G*m2/d12**3)*dx12 + (G*m3/d13**3)*dx13
    ay1 = (G*m2/d12**3)*dy12 + (G*m3/d13**3)*dy13
    az1 = (G*m2/d12**3)*dz12 + (G*m3/d13**3)*dz13
    ax2 = -(G*m1/d12**3)*dx12 + (G*m3/d23**3)*dx23
    ay2 = -(G*m1/d12**3)*dy12 + (G*m3/d23**3)*dy23
    az2 = -(G*m1/d12**3)*dz12 + (G*m3/d23**3)*dz23
    ax3 = -(G*m1/d13**3)*dx13 - (G*m2/d23**3)*dx23
    ay3 = -(G*m1/d13**3)*dy13 - (G*m2/d23**3)*dy23
    az3 = -(G*m1/d13**3)*dz13 - (G*m2/d23**3)*dz23

    #idk what to do for these

    #vector with derivatives of initial vector giving velocity and acceleration
    dvec = np.zeros(len(vec))
    dvec[0], dvec[1], dvec[2] = vx1, vy1, vz1
    dvec[3], dvec[4], dvec[5] = ax1, ay1, az1
```

```
    dvec[6], dvec[7], dvec[8] = vx2, vy2, vz2
    dvec[9], dvec[10], dvec[11] = ax2, ay2, az2

    dvec[12], dvec[13], dvec[14] = vx3, vy3, vz3
    dvec[15], dvec[16], dvec[17] = ax3, ay3, az3

    return dvec
```

In [5]:

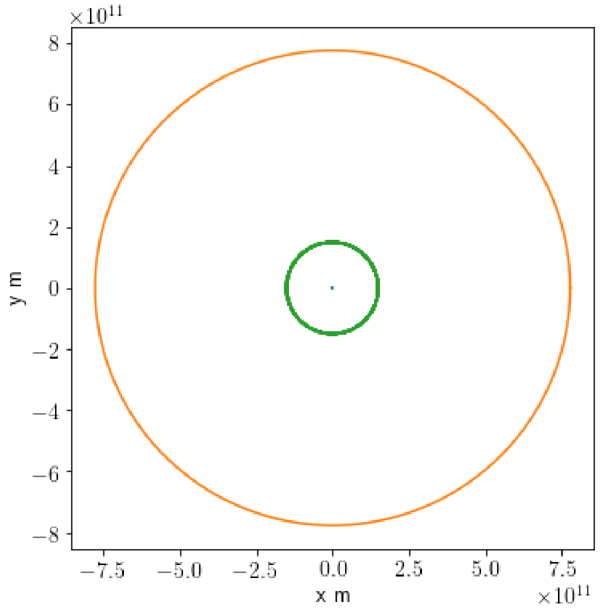
```
#initial conditions, starting with 2 sun types and planet
m1 = (1 * u.Msun).decompose().value
m2 = (5 * u.Msun).decompose().value
m3 = (10 * u.Mjup).decompose().value
mu = (m1*m2)/(m1+m2)
G = const.G.value
a = (1 * u.AU).decompose().value
a3 = (2 * u.AU).decompose().value

r1 = -a*(mu/m1)
r2 = a*(mu/m2)
r3 = a3

P = 2*np.pi*np.sqrt((a**3)/(G*(m1+m2)))
P3 = 2*np.pi*np.sqrt((r3**3)/(G*(m1+m2)))

v1 = 2*np.pi*r1/P
v2 = 2*np.pi*r2/P
v3 = 2*np.pi*r3/P3

vect = np.array([r1, 0, 0, 0, v1, 0, r2, 0, 0, 0, v2, 0, r3, 0, 0, 0, v3, 0])
tarr = np.linspace(0,P3,200)

ans = integrate.odeint(threebodyfunc, vect, tarr)

x1, y1, z1 = ans[:,0], ans[:,1], ans[:,2]
vx1, vy1, vz1 = ans[:,3], ans[:,4], ans[:,5]

x2, y2, z2 = ans[:,6], ans[:,7], ans[:,8]
vx2, vy2, vz2 = ans[:,9], ans[:,10], ans[:,11]

x3, y3, z3 = ans[:,12], ans[:,13], ans[:,14]
vx3, vy3, vz3 = ans[:,15], ans[:,16], ans[:,17]

plt.figure(figsize=(6,6))
plt.plot(x1,y1)
plt.plot(x2,y2)
plt.plot(x3,y3)
plt.xlabel('x m')
plt.ylabel('y m')
#plt.title('Circular Orbit')
plt.gca().set_aspect('equal')
plt.show()
```



x m ×10^11

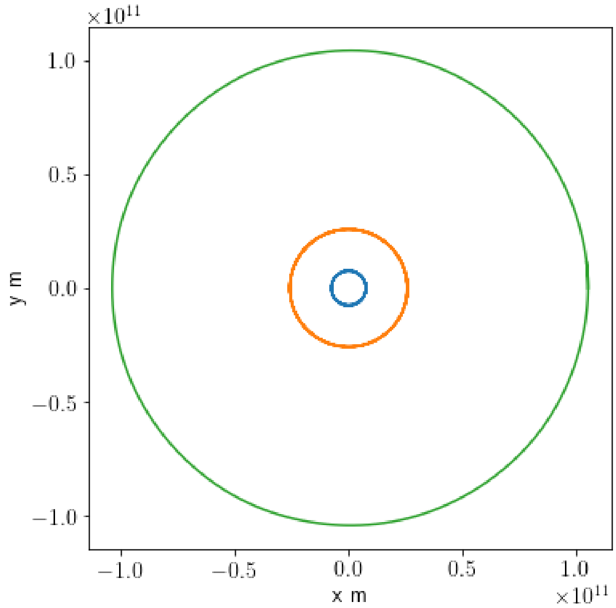
In [6]:

```
#initial conditions, sun jupiter earth
m1 = (1 * u.Msun).decompose().value
m2 = (1 * u.Mjup).decompose().value
m3 = (1 * u.Mearth).decompose().value
mu = (m1*m2)/(m1+m2)
G = const.G.value
a = (5.2 * u.AU).decompose().value
a3 = (1 * u.AU).decompose().value

r1 = -a*(mu/m1)
r2 = a*(mu/m2)
r3 = a3

P = 2*np.pi*np.sqrt((a**3)/(G*(m1+m2)))
P3 = 2*np.pi*np.sqrt((r3**3)/(G*(m1+m2)))

v1 = 2*np.pi*r1/P
v2 = 2*np.pi*r2/P
v3 = 2*np.pi*r3/P3

vect = np.array([r1, 0, 0, 0, v1, 0, r2, 0, 0, 0, v2, 0, r3, 0, 0, 0, v3, 0])
tarr = np.linspace(0,P,200)

ans = integrate.odeint(threebodyfunc, vect, tarr)

x1, y1, z1 = ans[:,0], ans[:,1], ans[:,2]
vx1, vy1, vz1 = ans[:,3], ans[:,4], ans[:,5]

x2, y2, z2 = ans[:,6], ans[:,7], ans[:,8]
vx2, vy2, vz2 = ans[:,9], ans[:,10], ans[:,11]

x3, y3, z3 = ans[:,12], ans[:,13], ans[:,14]
vx3, vy3, vz3 = ans[:,15], ans[:,16], ans[:,17]

plt.figure(figsize=(6,6))
plt.plot(x1,y1)
plt.plot(x2,y2)
plt.plot(x3,y3)
plt.xlabel('x m')
plt.ylabel('y m')
#plt.title('Circular Orbit')
plt.gca().set_aspect('equal')
plt.show()
```



In [7]:

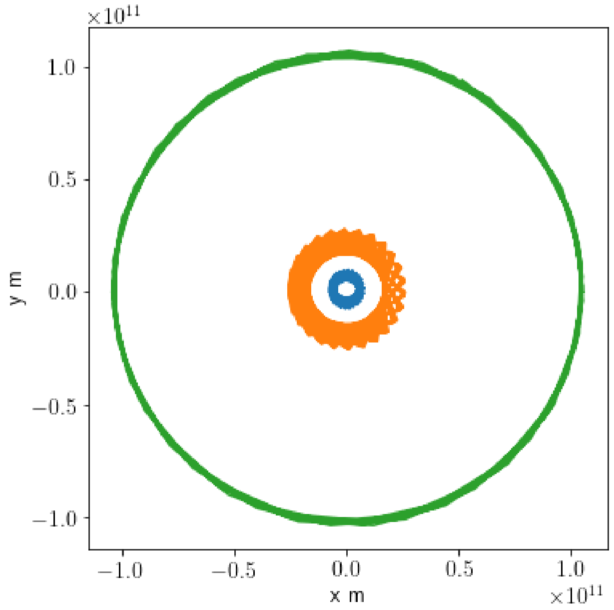
```
#using the known conditions of the Kepler-16 system to check

#initial conditions, Kepler-16 system
m1 = (0.6897 * u.Msun).decompose().value
m2 = (0.20255 * u.Msun).decompose().value
m3 = (0.333 * u.Mjup).decompose().value
mu = (m1*m2)/(m1+m2)
G = const.G.value
a = (0.22431 * u.AU).decompose().value
a3 = (0.7048 * u.AU).decompose().value

r1 = -a*(mu/m1)
r2 = a*(mu/m2)
r3 = a3

P = (41.079 * u.day).decompose().value
P3 = (228.776 * u.day).decompose().value

v1 = 2*np.pi*r1/P
v2 = 2*np.pi*r2/P
v3 = 2*np.pi*r3/P3

vect = np.array([r1, 0, 0, 0, v1, 0, r2, 0, 0, 0, v2, 0, r3, 0, 0, 0, v3, 0])
tarr = np.linspace(0,P3,200)

ans = integrate.odeint(threebodyfunc, vect, tarr)

x1, y1, z1 = ans[:,0], ans[:,1], ans[:,2]
vx1, vy1, vz1 = ans[:,3], ans[:,4], ans[:,5]

x2, y2, z2 = ans[:,6], ans[:,7], ans[:,8]
vx2, vy2, vz2 = ans[:,9], ans[:,10], ans[:,11]

x3, y3, z3 = ans[:,12], ans[:,13], ans[:,14]
vx3, vy3, vz3 = ans[:,15], ans[:,16], ans[:,17]

plt.figure(figsize=(6,6))
plt.plot(x1,y1)
plt.plot(x2,y2)
plt.plot(x3,y3)
plt.xlabel('x m')
plt.ylabel('y m')
#plt.title('Circular Orbit')
plt.gca().set_aspect('equal')
plt.show()
```



In [8]:

```
#same as above but with more time to see how the orbits behave after 10 planetary revolutions
#using the known conditions of the Kepler-16 system to check

#initial conditions, Kepler-16 system
```

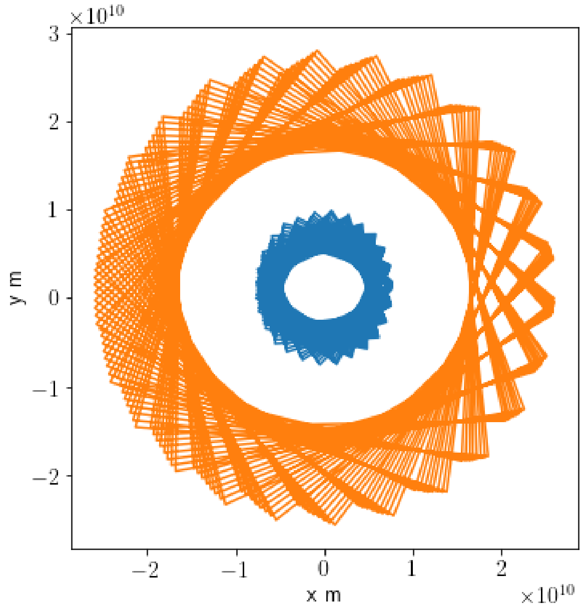
```
m1 = (0.6897 * u.Msun).decompose().value
m2 = (0.20255 * u.Msun).decompose().value
m3 = (0.333 * u.Mjup).decompose().value
mu = (m1*m2)/(m1+m2)
G = const.G.value
a = (0.22431 * u.AU).decompose().value
a3 = (0.7048 * u.AU).decompose().value

r1 = -a*(mu/m1)
r2 = a*(mu/m2)
r3 = a3

P = (41.079 * u.day).decompose().value
P3 = (228.776 * u.day).decompose().value

v1 = 2*np.pi*r1/P
v2 = 2*np.pi*r2/P
v3 = 2*np.pi*r3/P3

vect = np.array([r1, 0, 0, 0, v1, 0, r2, 0, 0, 0, v2, 0, r3, 0, 0, 0, v3, 0])
tarr = np.linspace(0,10*P3,200)

ans = integrate.odeint(threebodyfunc, vect, tarr)

x1, y1, z1 = ans[:,0], ans[:,1], ans[:,2]
vx1, vy1, vz1 = ans[:,3], ans[:,4], ans[:,5]

x2, y2, z2 = ans[:,6], ans[:,7], ans[:,8]
vx2, vy2, vz2 = ans[:,9], ans[:,10], ans[:,11]

x3, y3, z3 = ans[:,12], ans[:,13], ans[:,14]
vx3, vy3, vz3 = ans[:,15], ans[:,16], ans[:,17]

plt.figure(figsize=(6,6))
plt.plot(x1,y1)
plt.plot(x2,y2)
plt.plot(x3,y3)
plt.xlabel('x m')
plt.ylabel('y m')
#plt.title('Circular Orbit')
plt.gca().set_aspect('equal')
plt.show()
```



In [9]:

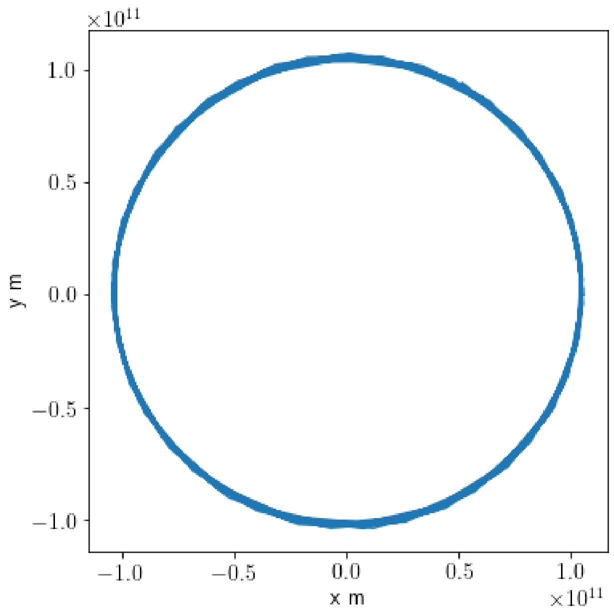
```
#close up of the binary stars after 10 planetary revolutions

plt.figure(figsize=(6,6))
plt.plot(x1,y1)
plt.plot(x2,y2)
plt.xlabel('x m')
```

```
plt.ylabel('y m')
#plt.title('Circular Orbit')
plt.gca().set_aspect('equal')
plt.show()
```



In [10]:

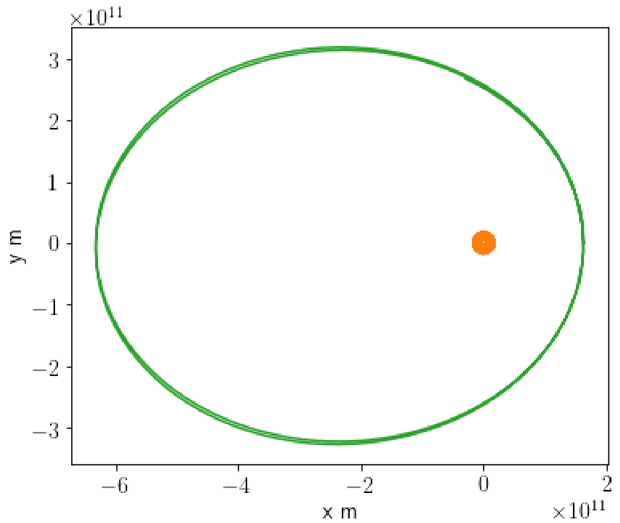
```
#just the planet orbit after 10 planetary revolutions

plt.figure(figsize=(6,6))
plt.plot(x3,y3)
plt.xlabel('x m')
plt.ylabel('y m')
#plt.title('Circular Orbit')
plt.gca().set_aspect('equal')
plt.show()
```



In [28]:

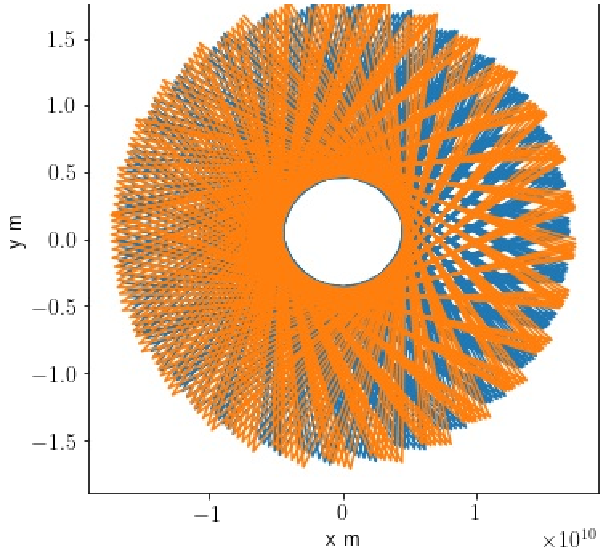
```
#using the known conditions of the Kepler-16 system to check

#initial conditions, Kepler-16 system
m1 = (1.0479 * u.Msun).decompose().value
m2 = (1.0208 * u.Msun).decompose().value
m3 = (0.220 * u.Mjup).decompose().value
mu = (m1*m2)/(m1+m2)
```

```
G = const.G.value
a = (0.22882 * u.AU).decompose().value
a3 = (1.0896 * u.AU).decompose().value

r1 = -a*(mu/m1)
r2 = a*(mu/m2)
r3 = a3

P = (27.7958103 * u.day).decompose().value
P3 = (228.822 * u.day).decompose().value

v1 = 2*np.pi*r1/P
v2 = 2*np.pi*r2/P
v3 = 2*np.pi*r3/P3

vect = np.array([r1, 0, 0, 0, v1, 0, r2, 0, 0, 0, v2, 0, r3, 0, 0, 0, v3, 0])
tarr = np.linspace(0,10*P3,200)

ans = integrate.odeint(threebodyfunc, vect, tarr)

x1, y1, z1 = ans[:,0], ans[:,1], ans[:,2]
vx1, vy1, vz1 = ans[:,3], ans[:,4], ans[:,5]

x2, y2, z2 = ans[:,6], ans[:,7], ans[:,8]
vx2, vy2, vz2 = ans[:,9], ans[:,10], ans[:,11]

x3, y3, z3 = ans[:,12], ans[:,13], ans[:,14]
vx3, vy3, vz3 = ans[:,15], ans[:,16], ans[:,17]

plt.figure(figsize=(6,6))
plt.plot(x1,y1)
plt.plot(x2,y2)
plt.plot(x3,y3)
plt.xlabel('x m')
plt.ylabel('y m')
#plt.title('Circular Orbit')
plt.gca().set_aspect('equal')
plt.show()
```



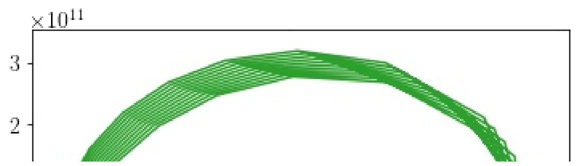
In [29]:

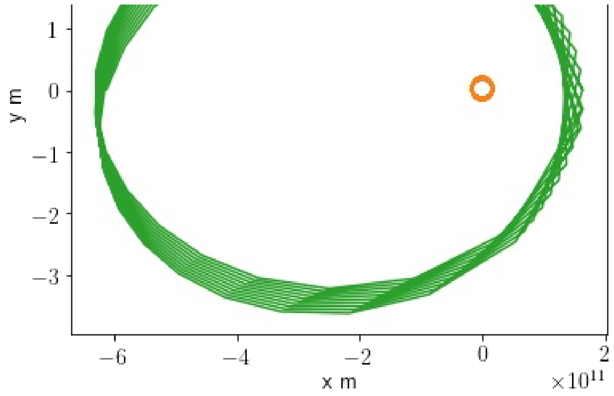
```
#close up of the binary stars after 10 planetary revolutions

plt.figure(figsize=(6,6))
plt.plot(x1,y1)
plt.plot(x2,y2)
plt.xlabel('x m')
plt.ylabel('y m')
#plt.title('Circular Orbit')
plt.gca().set_aspect('equal')
plt.show()
```



In [37]:

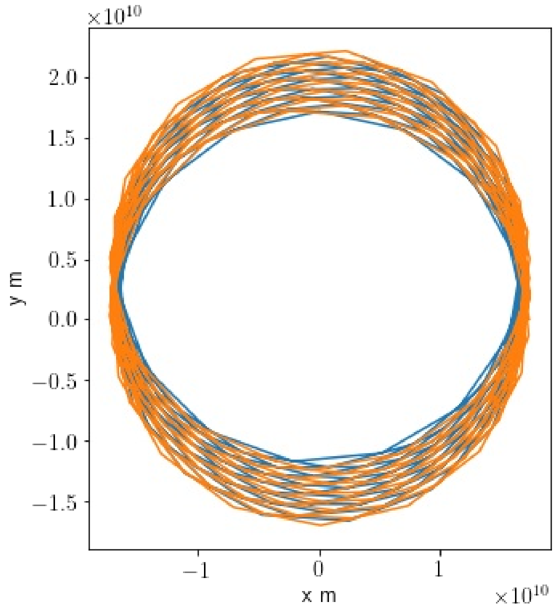
```
#using the known conditions of the Kepler-16 system to check

#initial conditions, Kepler-16 system
m1 = (1.0479 * u.Msun).decompose().value
m2 = (1.0208 * u.Msun).decompose().value
m3 = (0.220 * u.Mjup).decompose().value
mu = (m1*m2)/(m1+m2)
G = const.G.value
a = (0.22882 * u.AU).decompose().value
a3 = (1.0896 * u.AU).decompose().value

r1 = -a*(mu/m1)
r2 = a*(mu/m2)
r3 = a3

P = (27.7958103 * u.day).decompose().value
P3 = (228.822 * u.day).decompose().value

v1 = 2*np.pi*r1/P
v2 = 2*np.pi*r2/P
v3 = 2*np.pi*r3/P3

vect = np.array([r1, 0, 0, 0, v1, 0, r2, 0, 0, 0, v2, 0, r3, 0, 0, 0, v3, 0])
tarr = np.linspace(0,50*P3,200)

ans = integrate.odeint(threebodyfunc, vect, tarr)

x1, y1, z1 = ans[:,0], ans[:,1], ans[:,2]
vx1, vy1, vz1 = ans[:,3], ans[:,4], ans[:,5]

x2, y2, z2 = ans[:,6], ans[:,7], ans[:,8]
vx2, vy2, vz2 = ans[:,9], ans[:,10], ans[:,11]

x3, y3, z3 = ans[:,12], ans[:,13], ans[:,14]
vx3, vy3, vz3 = ans[:,15], ans[:,16], ans[:,17]

plt.figure(figsize=(6,6))
plt.plot(x1,y1)
plt.plot(x2,y2)
plt.plot(x3,y3)
plt.xlabel('x m')
plt.ylabel('y m')
#plt.title('Circular Orbit')
plt.gca().set_aspect('equal')
plt.show()
```





In [38]:

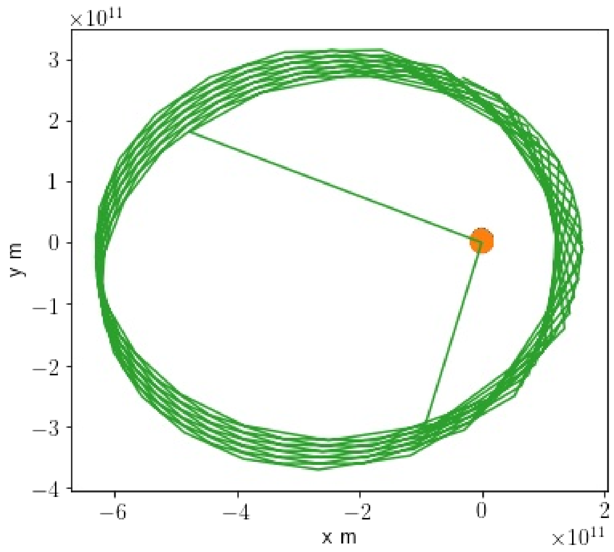
```
#close up of the binary stars after 10 planetary revolutions

plt.figure(figsize=(6,6))
plt.plot(x1,y1)
plt.plot(x2,y2)
plt.xlabel('x m')
plt.ylabel('y m')
#plt.title('Circular Orbit')
plt.gca().set_aspect('equal')
plt.show()
```



In [51]:

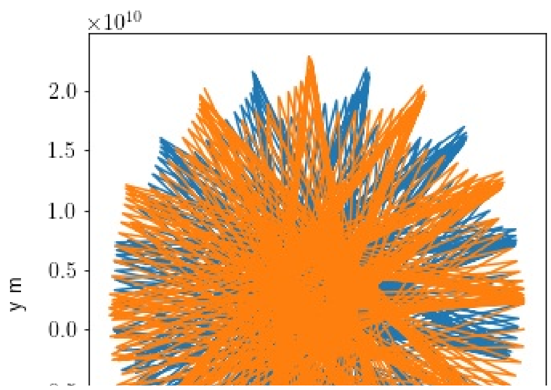
```
#using the known conditions of the Kepler-16 system to check

#initial conditions, Kepler-16 system
m1 = (1.0479 * u.Msun).decompose().value
m2 = (1.0208 * u.Msun).decompose().value
m3 = (0.220 * u.Mjup).decompose().value
mu = (m1*m2)/(m1+m2)
G = const.G.value
a = (0.22882 * u.AU).decompose().value
a3 = (1.0896 * u.AU).decompose().value

r1 = -a*(mu/m1)
r2 = a*(mu/m2)
r3 = a3

P = (27.7958103 * u.day).decompose().value
P3 = (228.822 * u.day).decompose().value

v1 = 2*np.pi*r1/P
v2 = 2*np.pi*r2/P
```

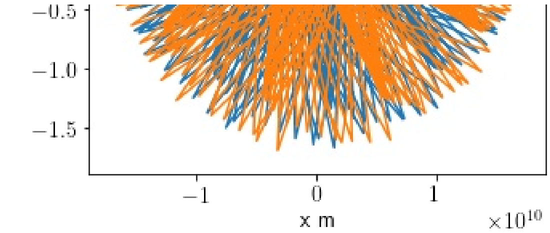
```
v3 = 2*np.pi*r3/P3

vect = np.array([r1, 0, 0, 0, v1, 0, r2, 0, 0, 0, v2, 0, r3, 0, 0, 0, v3, 0])
tarr = np.linspace(0,61.5*P3,200)

ans = integrate.odeint(threebodyfunc, vect, tarr)

x1, y1, z1 = ans[:,0], ans[:,1], ans[:,2]
vx1, vy1, vz1 = ans[:,3], ans[:,4], ans[:,5]

x2, y2, z2 = ans[:,6], ans[:,7], ans[:,8]
vx2, vy2, vz2 = ans[:,9], ans[:,10], ans[:,11]

x3, y3, z3 = ans[:,12], ans[:,13], ans[:,14]
vx3, vy3, vz3 = ans[:,15], ans[:,16], ans[:,17]

plt.figure(figsize=(6,6))
plt.plot(x1,y1)
plt.plot(x2,y2)
plt.plot(x3,y3)
plt.xlabel('x m')
plt.ylabel('y m')
#plt.title('Circular Orbit')
plt.gca().set_aspect('equal')
plt.show()
```



In [52]:

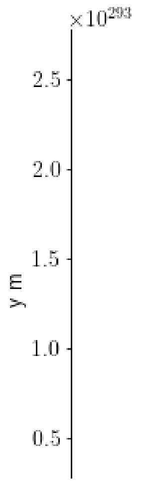
```
#close up of the binary stars after 10 planetary revolutions

plt.figure(figsize=(6,6))
plt.plot(x1,y1)
plt.plot(x2,y2)
plt.xlabel('x m')
plt.ylabel('y m')
#plt.title('Circular Orbit')
plt.gca().set_aspect('equal')
plt.show()
```

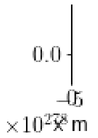




In [53]:

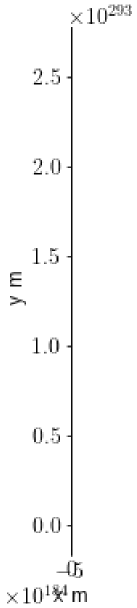
```
#using the known conditions of the Kepler-16 system to check

#initial conditions, Kepler-16 system
m1 = (1.0479 * u.Msun).decompose().value
m2 = (1.0208 * u.Msun).decompose().value
m3 = (0.220 * u.Mjup).decompose().value
mu = (m1*m2)/(m1+m2)
G = const.G.value
a = (0.22882 * u.AU).decompose().value
a3 = (1.0896 * u.AU).decompose().value

r1 = -a*(mu/m1)
r2 = a*(mu/m2)
r3 = a3

P = (27.7958103 * u.day).decompose().value
P3 = (228.822 * u.day).decompose().value

v1 = 2*np.pi*r1/P
v2 = 2*np.pi*r2/P
v3 = 2*np.pi*r3/P3

vect = np.array([r1, 0, 0, 0, v1, 0, r2, 0, 0, 0, v2, 0, r3, 0, 0, 0, v3, 0])
tarr = np.linspace(0,63*P3,200)

ans = integrate.odeint(threebodyfunc, vect, tarr)

x1, y1, z1 = ans[:,0], ans[:,1], ans[:,2]
vx1, vy1, vz1 = ans[:,3], ans[:,4], ans[:,5]

x2, y2, z2 = ans[:,6], ans[:,7], ans[:,8]
vx2, vy2, vz2 = ans[:,9], ans[:,10], ans[:,11]

x3, y3, z3 = ans[:,12], ans[:,13], ans[:,14]
vx3, vy3, vz3 = ans[:,15], ans[:,16], ans[:,17]

plt.figure(figsize=(6,6))
plt.plot(x1,y1)
plt.plot(x2,y2)
plt.plot(x3,y3)
plt.xlabel('x m')
plt.ylabel('y m')
#plt.title('Circular Orbit')
plt.gca().set_aspect('equal')
plt.show()
```





In [54]:

```
#close up of the binary stars after 10 planetary revolutions

plt.figure(figsize=(6,6))
plt.plot(x1,y1)
plt.plot(x2,y2)
plt.xlabel('x m')
plt.ylabel('y m')
#plt.title('Circular Orbit')
plt.gca().set_aspect('equal')
plt.show()
```



I analyzed the Kepler 34 system, which is unique in that Tatiana Demidova and Ivan Shevchenko say that this system is usually not possible, and the reason why it can happen here is that the system is close to a nearby debris disk in their article "Simulations of the dynamics of the debris disks in the systems Kepler-16, Kepler-34, and Kepler-35".

When adding more revolutions, we see that the orbit is not stable in the long term for similar conditions with what we know about the planetary system. Because there is a nearby debris field, it is possible that there is multiple rocks or gas planets that are not stable circumbinaries but instead instatnces of planets on an eccentric orbit that eventually leads them to leave the system.

cited:

@article{Demidova_2018, title={Simulations of the Dynamics of the Debris Disks in the Systems Kepler-16, Kepler-34, and Kepler-35}, volume={44}, ISSN={1562-6873}, url={http://dx.doi.org/10.1134/S1063773718010012}, DOI={10.1134/s1063773718010012}, number={2}, journal={Astronomy Letters}, publisher={Pleiades Publishing Ltd}, author={Demidova, T. V. and Shevchenko, I. I.}, year={2018}, month={Feb}, pages={119–125} }