Is the World Going to End in 2029?

No, but why do you ask?

Asteroid 2004 (MN 4) a.k.a. Apophis Apophis is a near-earth asteroid discovered in 2004. Preliminary orbital calculations indicated that in would slam into Earth on April 13, 2029. Since the asteroid is 270 meters across and masses about 27 trillion kilograms (about 30 million tons), this was a great concern. An impact of an asteroid this size would be the equivalent to the explosion of several hundred megatons of TNT. Which is enough to destroy a large city and its metropolitan area. After several months of observations of the asteroid, its orbital calculations were refined to show that it will be a near miss. But how close of a call is it?

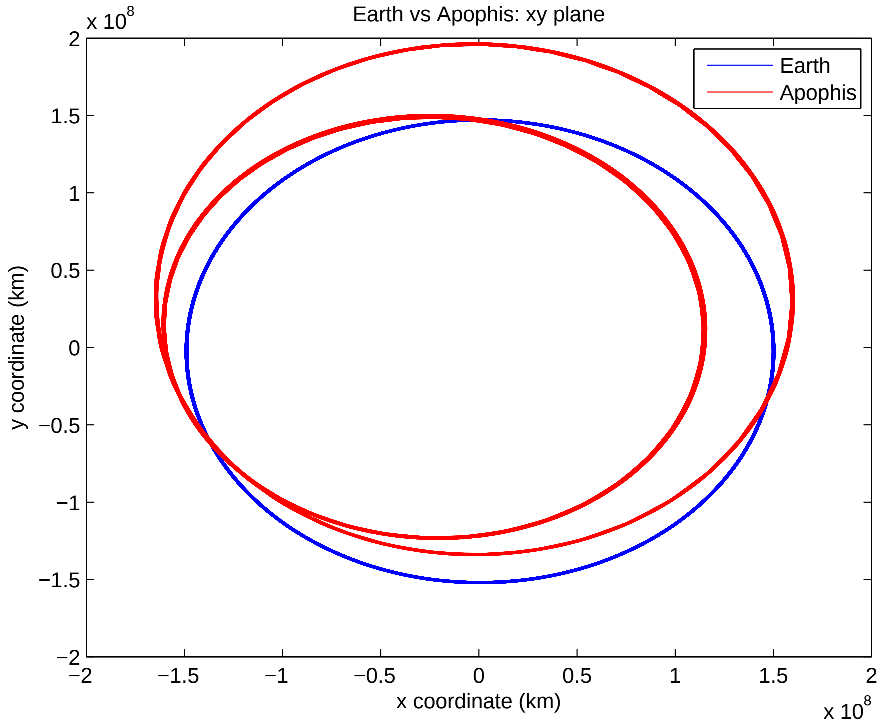
The orbit of Earth and Apophis The data for the positions of Earth and Apophis every day from the year 1900 to 2100 are in the files: `earth_daily.xyz` and `apophis_daily.xyz`. The can be loaded into Matlab using the commands:

```
load apophis_daily.xyz
load earth_daily.xyz
```

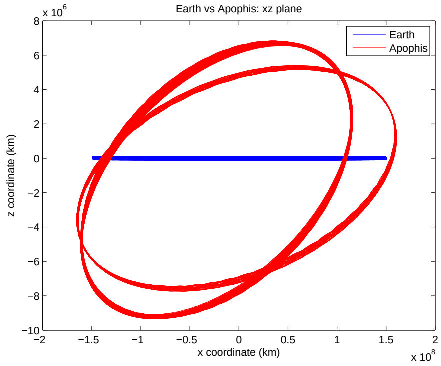
This creates a pair of matrices with 73,049 rows (one for each day) and 4 columns: time (in years after 1900) and the x, y, and z coordinates of each body (measured in kilometers with the Sun at the origin).

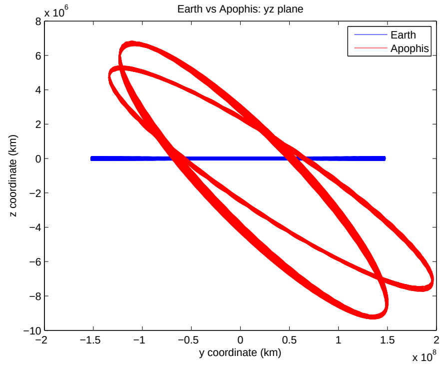
Below are the orbits of the Earth and Apophis. Notice that the orbits cross (or at least come very close.)

The orbit of Earth and Apophis is the xy-plane:



The orbits in the xz-plane and yz-plane:





Here is the Matlab code that produces the three plots.

```
plot(earth_daily(:,2), earth_daily(:,3), 'b', apophis_daily(:,2), apophis_daily(:,3), 'r')
title('Earth vs Apophis: xy plane')
xlabel('x coordinate (km)')
ylabel('y coordinate (km)')
legend('Earth','Apophis')

figure
plot(earth_daily(:,2), earth_daily(:,4), 'b', apophis_daily(:,2), apophis_daily(:,4), 'r')
title('Earth vs Apophis: xz plane')
xlabel('x coordinate (km)')
ylabel('z coordinate (km)')
legend('Earth','Apophis')

figure
plot(earth_daily(:,3), earth_daily(:,4), 'b', apophis_daily(:,3), apophis_daily(:,4), 'r')
title('Earth vs Apophis: yz plane')
xlabel('y coordinate (km)')
ylabel('z coordinate (km)')
legend('Earth','Apophis')
```

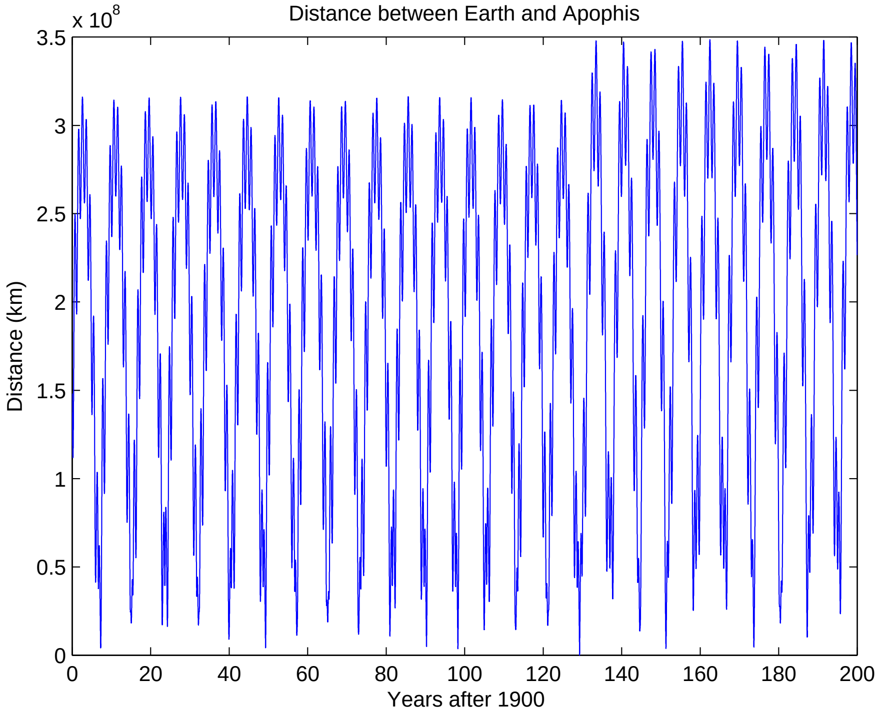
Measuring the distance We can create an array that is the distance between the two at each data points using:

```
dist_daily = sqrt( (earth_daily(:,2)-apophis_daily(:,2)).^2 + (earth_daily(:,3)-apophis_daily(:,
```

And then plot this data on a new graph, using:

```
figure
time_daily = earth_daily(:,1);
plot(time_daily, dist_daily)
title('Distance between Earth and Apophis')
xlabel('Years after 1900')
ylabel('Distance (km)')
```

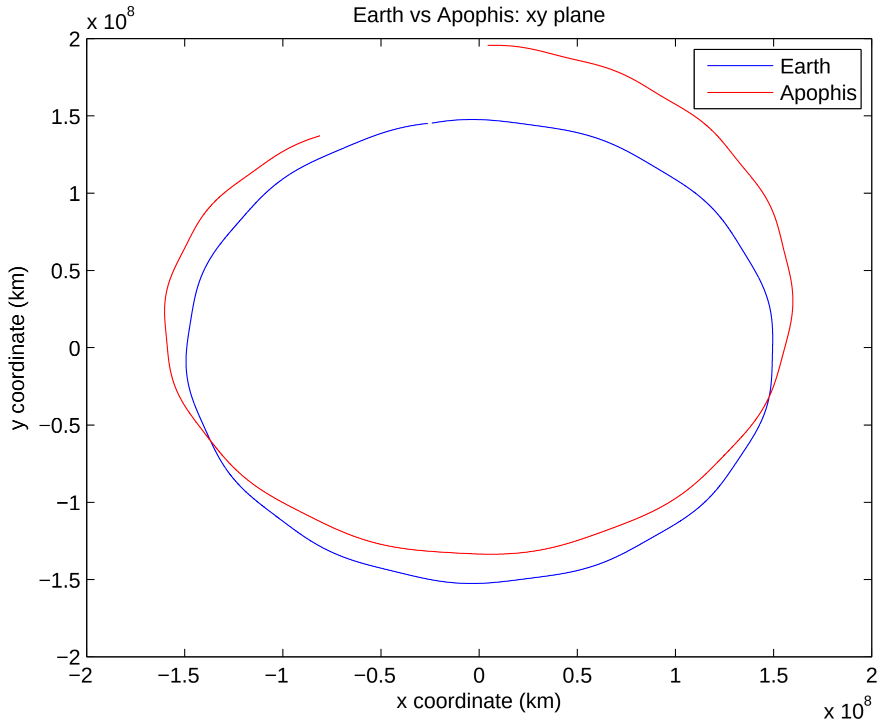
The graph below indicates that there is a point in time where they become relatively close in the year 2029 (129 years after 1900). At that point they are well within 5 million kilometers of each other. The distance between the Earth and the Moon is about 384,000 kilometers, so this might be close.

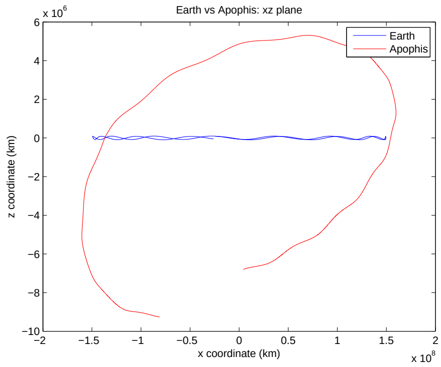


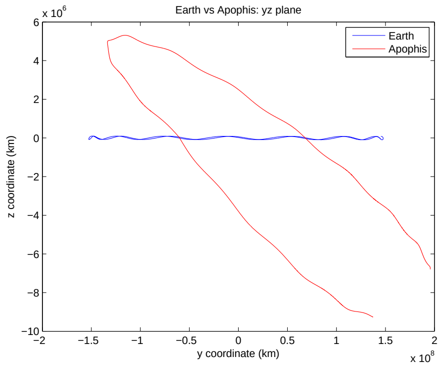
Zooming in We will examine the same information but just for the year 2029. The files `earth_hourly.xyz` and `apophis_hourly.xyz` have their position each hour of the year. We can download them and display the same graphs as above for this data using:

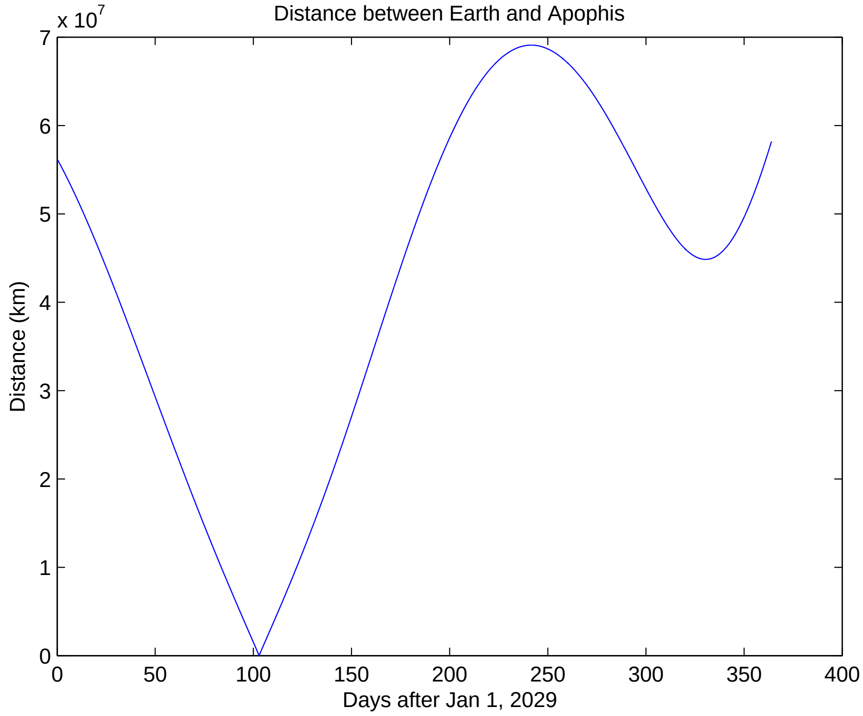
```
load apophis_hourly.xyz
load earth_hourly.xyz

time_hourly = earth_hourly(:,1);

figure(1)
plot(earth_hourly(:,2), earth_hourly(:,3), 'b', apophis_hourly(:,2), apophis_hourly(:,3), 'r')
title('Earth vs Apophis: xy plane')
xlabel('x coordinate (km)')
ylabel('y coordinate (km)')
legend('Earth','Apophis')

figure(2)
plot(earth_hourly(:,2), earth_hourly(:,4), 'b', apophis_hourly(:,2), apophis_hourly(:,4), 'r')
title('Earth vs Apophis: xz plane')
xlabel('x coordinate (km)')
ylabel('z coordinate (km)')
legend('Earth','Apophis')

figure(3)
plot(earth_hourly(:,3), earth_hourly(:,4), 'b', apophis_hourly(:,3), apophis_hourly(:,4), 'r')
title('Earth vs Apophis: yz plane')
xlabel('y coordinate (km)')
```

```
ylabel('z coordinate (km)')
legend('Earth','Apophis')

dist_hourly = sqrt( (earth_hourly(:,2)-apophis_hourly(:,2)).^2 + (earth_hourly(:,3)-apophis_hour

figure(4)
plot(time_hourly, dist_hourly)
title('Distance between Earth and Apophis')
xlabel('Days after Jan 1, 2029')
ylabel('Distance (km)')
```







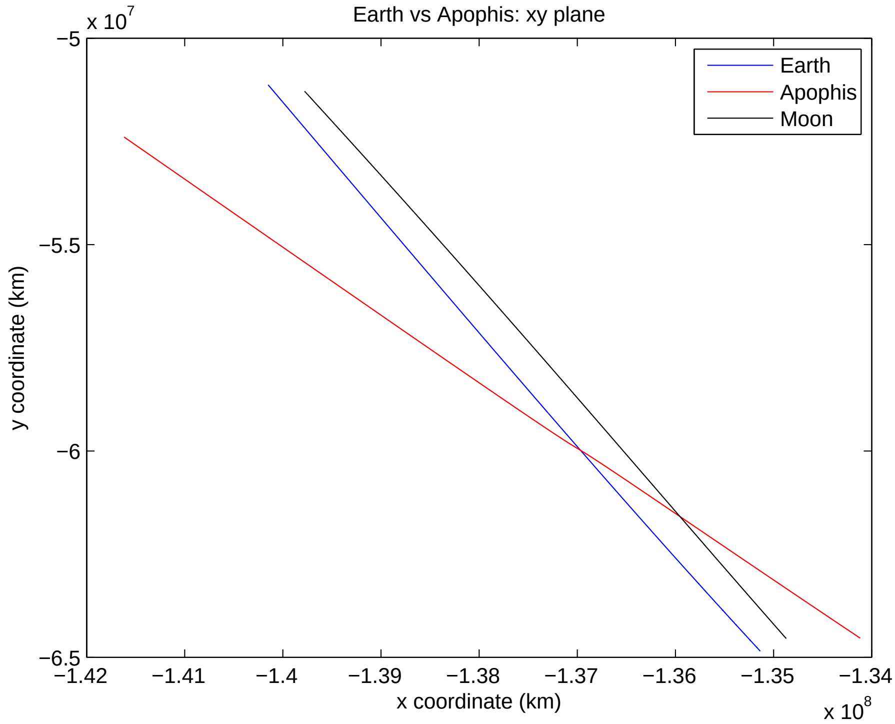


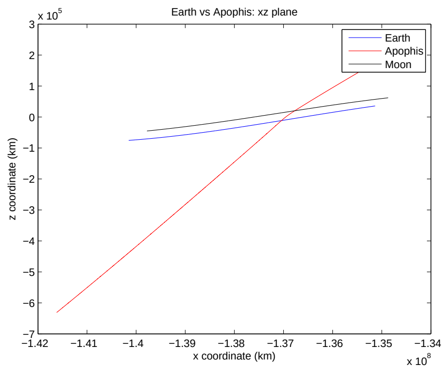
They still might cross and on the distance plot the distance appears to come close to zero! That minimum value is about 103 days into the year (April 13).

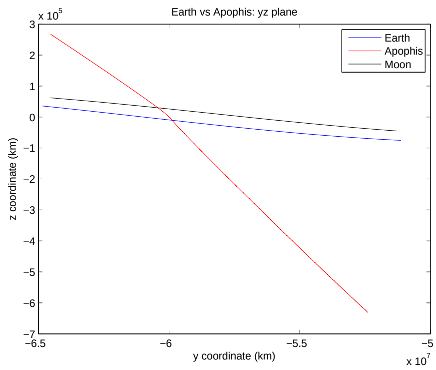
Zooming in again This time we will examine data every minute from April 10-16, 2029. And for a sense of scale we will also include the Moon in our figures. The data can be found in `earth_minutely.xyz`, `apophis_minutely.xyz` and `moon_minutely.xyz`. Here is the Matlab code to produce the same plots for this data:

```
load apophis_minutely.xyz
load earth_minutely.xyz
load moon_minutely.xyz

time_minutely = earth_minutely(:,1);

figure(1)
plot(earth_minutely(:,2), earth_minutely(:,3), 'b', apophis_minutely(:,2), apophis_minutely(:,3)
title('Earth vs Apophis: xy plane')
xlabel('x coordinate (km)')
ylabel('y coordinate (km)')
legend('Earth','Apophis')
legend('Earth','Apophis','Moon')

figure(2)
plot(earth_minutely(:,2), earth_minutely(:,4), 'b', apophis_minutely(:,2), apophis_minutely(:,4)
title('Earth vs Apophis: xz plane')
xlabel('x coordinate (km)')
ylabel('z coordinate (km)')
```

```
legend('Earth','Apophis','Moon')

figure(3)
plot(earth_minutely(:,3), earth_minutely(:,4), 'b', apophis_minutely(:,3), apophis_minutely(:,4)
title('Earth vs Apophis: yz plane')
xlabel('y coordinate (km)')
ylabel('z coordinate (km)')
legend('Earth','Apophis')
legend('Earth','Apophis','Moon')
```





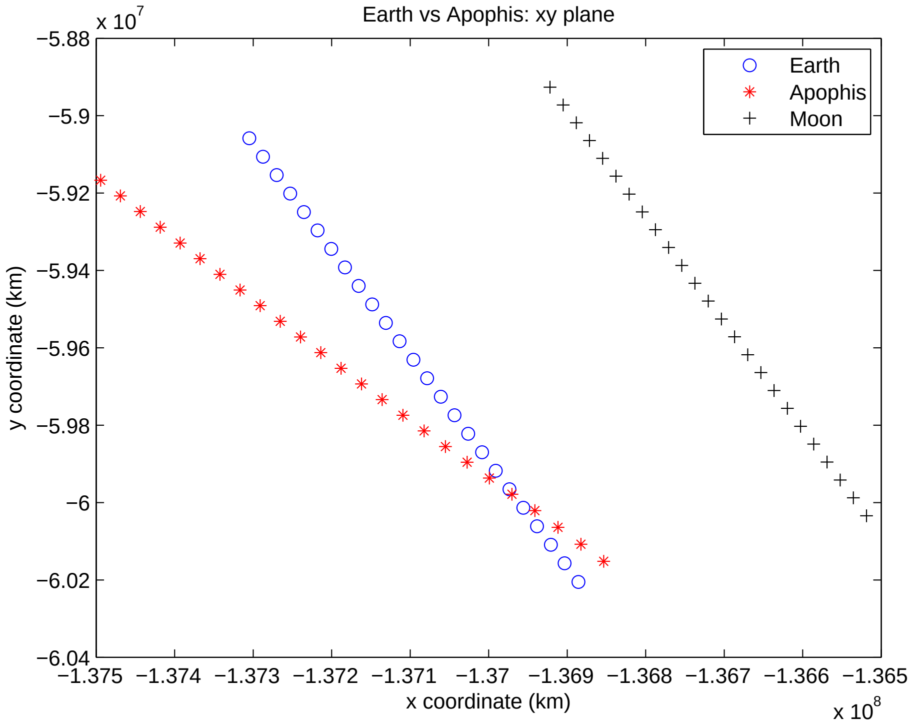


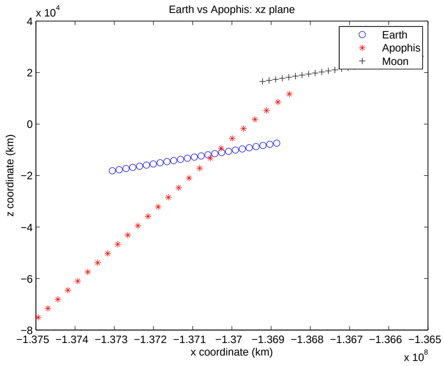
The orbits are definitely coming very close together.

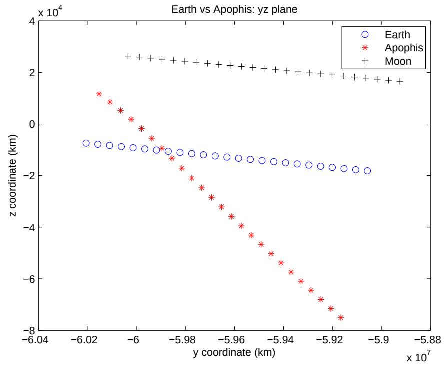
But where are Earth and Apophis at different times? We will examine the positions of the three bodies at 30 minute intervals during the second half of April 13, 2029. This time slice corresponds to rows

5040 to 5760 in the matrices. The plots will put marks at the positions every 30 minutes. Here is the Matlab code:

```
figure(1)
plot(earth_minutely(5040:30:5760,2), earth_minutely(5040:30:5760,3), 'ob', apophis_minutely(5040
title('Earth vs Apophis: xy plane')
xlabel('x coordinate (km)')
ylabel('y coordinate (km)')
legend('Earth','Apophis')
legend('Earth','Apophis','Moon')

figure(2)
plot(earth_minutely(5040:30:5760,2), earth_minutely(5040:30:5760,4), 'ob', apophis_minutely(5040
title('Earth vs Apophis: xz plane')
xlabel('x coordinate (km)')
ylabel('z coordinate (km)')
legend('Earth','Apophis','Moon')

figure(3)
plot(earth_minutely(5040:30:5760,3), earth_minutely(5040:30:5760,4), 'ob', apophis_minutely(5040
title('Earth vs Apophis: yz plane')
xlabel('y coordinate (km)')
ylabel('z coordinate (km)')
legend('Earth','Apophis')
legend('Earth','Apophis','Moon')
```



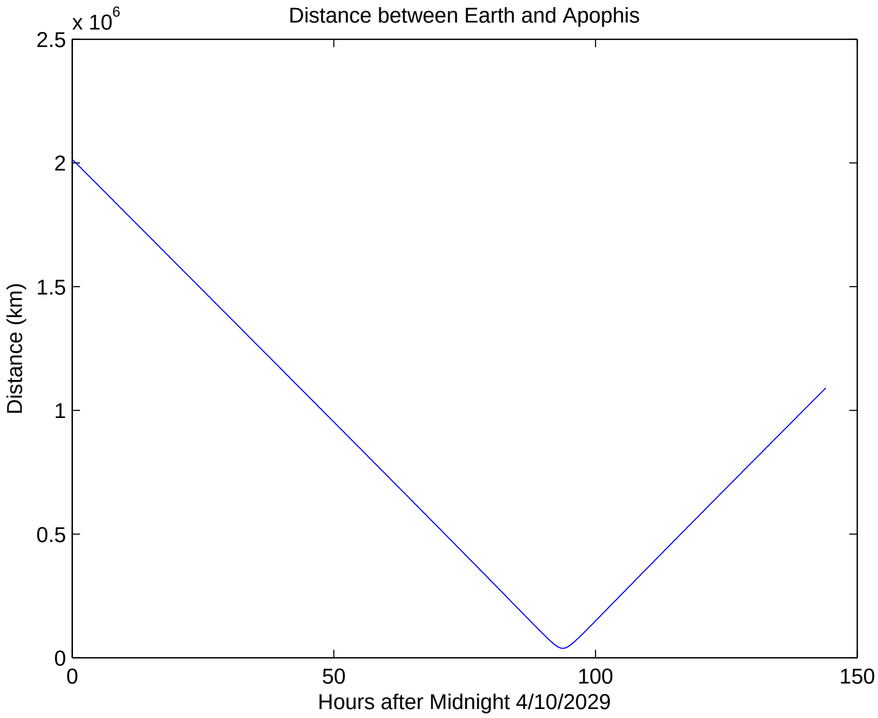




Notice that the orbits cross in each of the 3 projections but at different time! We're safe!

How close was it? We can redo the distance calculations for this 6 day time period.

```
dist_minutely = sqrt( (earth_minutely(:,2)-apophis_minutely(:,2)).^2 + (earth_minutely(:,3)-apop

figure(4)
plot(time_minutely, dist_minutely)
title('Distance between Earth and Apophis')
xlabel('Hours after Midnight 4/10/2029')
ylabel('Distance (km)')
```



The distance is definitely positive and the command `min(dist_minutely)` tells us that the minimum distance between the center of the Earth and Apophis is 38,160 kilometers. The radius of the earth is 6,357 kilometers, so this is about 32,000 kilometers above the surface of the Earth. Geosynchronous orbit (where many communication and weather satellites orbit) is 48,521 kilometers from Earth's center. So Apophis will pass inside this layer of satellites.

How fast would an impact be? We can estimate how fast any collision between Earth and Apophis would be by taking the average velocity from April 10 to April 12 using the following Matlab command:

```
vel = abs((dist_minutely(2*24*60)-dist_minutely(1)) / (time_minutely(2*24*60)-time_minutely(1)))
```

This is 21,244 kilometers per hour. Converting this to meters per second allows us to calculate the energy of an impact as $\frac{1}{2}mv^2$:

```
vel = abs((dist_minutely(2*24*60)-dist_minutely(1)) / (time_minutely(2*24*60)-time_minutely(1)))
m = 2.7e10
E = .5*m*vel^2
```

The speed in meters per second is 590 meters per second with kinetic energy 4.7^{17} Joules (kgm^2/s^2). To put in other terms, an explosion of megaton of TNT 4.184^{15} Joules. The kinetic energy released by a collision would be equivalent to approximately 112 megatons of TNT. This is over twice as large as the largest nuclear bomb.