Artificial Satellites
Earth & Sky

Name: ____

Introduction

In this lab, you will have the opportunity to find out when satellites may be visible from the RPI campus, and if any are visible during the activity, you will get a chance to see them. You'll also get to learn a bit about satellites and their orbits.

Pre-test

1. How far do you think satellites are from Earth?

2. How often do you think that satellites are visible from Troy?

A Brief History of Artificial Satellites

As you may already know, the first artificial satellite to be launched into Earth orbit was Sputnik, on October 5, 1957. Since then, over 32,000 man-made objects have orbited Earth at some point or other. Surprisingly, many of these objects are not actually what you might think of as satellites, but rather other debris that has accreted since the first space flight over 50 years ago.

Since 1957, nine national groups have successfully launched satellites into orbit, starting with the United States' launch of Explorer 1 on January 31, 1958. Other groups who have launched satellites into orbit include France, Japan, China, the United Kingdom, the European Union (via the European Space Agency), India, and Israel, and now over 250 satellites are launched into orbit every year worldwide.

Orbital Mechanics

The field of astrodynamics focuses on the motion of rockets and spacecraft, and is used by those who wish to place a satellite into orbit to understand its movement in the sky. The fundamental laws that are used in astrodynamics are Newton's laws of gravitation and motion, and thus, are relatively easily learned, but the need to sum up the gravitational forces of all objects in the sky makes predicting the movements of satellites and interplanetary probes much more difficult than it might seem at first.

The most important law for satellites, however, is the law of gravitation. For geocentric satellites (those that orbit the Earth), the period of revolution around the earth is equal to the following:

$$T = 2\pi\sqrt{(6378.1 + a)^3/3.986 \times 10^{14}}/3600 \tag{1}$$

In this equation, T is the number of hours it takes an object to orbit the Earth and a the altitude of the satellite from sea level in km. Notice that as the distance from the Earth's surface increases, the time for one revolution also increases, so that objects close to the Earth orbit faster than those far away.

1. How far from the Earth's surface must an object be to orbit the Earth in a sidereal day (23.9344 hours)? Satellites that orbit at this rate are said to be in geosynchronous orbit.

Satellite Orbits

Satellites may have one of any number of different orbits, depending on how it is to be used. For example, some satellites need to remain in one location in the sky to provide satellite television, and others may revolve around Earth in a predictable pattern to allow for the geolocation of locations on Earth, like with GPS.

Orbits may be classified by any number of methods, including center of the orbit, its distance from the object it orbits, its orientation relative to the Equator, its eccentricity (i.e. how circular is the orbit?), and its orbital time.

Almost all satellites that we can see from the ground orbit the Earth, and are in what are considered geocentric orbits. Some probes, like those that study the sun and other planets, orbit other objects and are not considered to be geocentric.

Of those satellites that orbit the Earth, their orbits generally fall into one of three different categories based on their altitude from the Earth's surface. Many satellites orbit in what is called Low Earth Orbit (LEO), which range up to about 2000 km from the Earth's surface, and are thus relatively close to the Earth. Above LEO is Medium Earth Orbit (MEO), in which GPS and other navigation satellite systems orbit. High Earth Orbit (HEO) is the highest orbit, being above the geosynchronous orbit altitude of 35786 km.

Many satellites do not orbit directly along the equator, but rather orbit diagonal to it in an inclined orbit. These satellites will appear to make a sinusoidal pattern across the Earth's surface, as they vary from their northernmost point to their southernmost point. Satellites that are not in geostationary orbit are usually in an inclined orbit. Some satellites are in a polar orbit that nearly passes nearly directly above the north and south poles.

Orbits are usually circular, staying a specific height above the earth, but some orbits are designed in such a way that they actually alter between being close and far from the Earth in an elliptical orbit. Several reasons exist for this, but they are often used to transition from a Low Earth Orbit to a geosynchronous orbit (called a geosynchronous transfer orbit).

Perhaps the most important type of orbit is the geostationary orbit. This orbit is positioned at an altitude and inclination such that it will always stay at a fixed position in the sky, thanks to the speed at which it orbits the Earth and its inclination of zero degrees. This orbit is especially important for many weather and communications satellites that need to cover a specific location on Earth. If you have ever had to aim a satellite dish to get satellite TV, you have been able to get a specific angle to aim at because satellite television is almost always provided by geostationary satellites.

2. Do you think objects in geostationary orbits orbit the Earth orbit the Earth once per sidereal day (the time it takes for a star to return to the same place in the sky) or once per solar day (the time it takes for the sun to return to the same place in the sky)? Why? Remember that as a day passes, the Earth continues to move along its orbit, so the Sun is not where the rest of the stars are located. A sidereal day is slightly shorter as a result.

3. Objects in elliptical orbits will not be the same distance from Earth at all points in the orbit, and will be farther at some times than others. What does this mean for the speed of the satellite when throughout its orbit?

4. There are two special types of orbits called Tundra and Molniya orbits. These orbits are highly elliptical, highly inclined (and are usually farthest from Earth and northernmost from the Equator when over 63.4deg N latitude), and orbit once or twice a day. Given everything you know about elliptical orbits, why do you think these orbits are special?

Satellite Spotting

Surprisingly enough, satellites can be regularly spotted by backyard astronomers as they pass overhead. The glares that make the satellites visible normally are not caused by lights on the satellites however, as many man-made lights are too dim to be seen from a satellite over a satellite's lifetime, due to their distance from Earth, and the lifetime of a satellite's power. Instead, most satellites are visible thanks to the the reflection of the sun off the satellite onto the Earth. These reflection events are called 'satellite flares,' and the most prevalent and brightest flares are caused by a set of communications satellites called the Iridium satellites. These satellites have such reflective antennae that some flares can be seen during the day!

It is relatively easy to determine when a satellite will be visible from your location, as many websites exist to list these times and anticipated brightnesses. One of these websites, Heavens Above (http://www.heavens-above.com/) will calculate these for both Iridium and other satellite sightings. Knowing your longitude and latitude, you can enter them and find out when you will be able to see a satellite in the near future, and how bright it will be.

5. Visit the Heavens Above site for the Hirsch Observatory by visiting the Hirsch Observatory Clear Sky Clock (http://cleardarksky.com/c/HrchObNYkey.html?1) and clicking on "Satellite Predictions." What are the next Iridium flares to be visible? How bright are they? If there are any flares or other events scheduled to be visible during this lab, try to view them!

6. Most satellites are above 200 km in altitude. Given that the apparent magnitude of a light source is determined as:

$$m = M + 5(\log_{10} d - 1) \tag{2}$$

Where m is the relative magnitude, M the absolute magnitude, and d the distance in parsecs. The brightest Iridium flares may be -8 magnitude. Given that Iridium satellites are 780 km (2.53×10^{-11} parsecs) from the Earth, how bright (in relative magnitude) would an Iridium flare be if it was 10 meters away (3.24×10^{-16} parsecs)? Is it brighter than the sun (app. mag. -26.73)?

Post-test

1. Do you think there are many reasons to place satellites farther out than geosynchronous orbit (5.6 Earth radii)?

2. Using Heavens Above, how many satellites are scheduled to be visible in the next day (above magnitude 4.5)? Don't forget to add Iridium flares, as they aren't listed in the daily satellite predictions. Does the number surprise you?