

Pale Blue Dot Training Manual

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What is Astrobiology?

Is there life on other planets?

This is a complex question and we simply do not know. Earth is the only planet known to harbor life. As such it is the only model we have for comparison. When we look for life we look for life as we know it and that means we look for water. Wherever life is found on Earth it depends on water. NASA's search for life in the universe comes down to the mantra "Follow the Water."

In our solar system follow the water begins with Mars. For over 100 years it has been known that Mars has water ice at the poles. Due to its low atmospheric pressure water as a liquid cannot currently exist on the surface. There is evidence that Mars had a warmer and wetter environment in the distant past. In 2004 the rover Opportunity discovered small spherules of hematite (Iron Oxide, rust) which can only accrete in standing water. In addition the Mars Science Laboratory (Curiosity) has shown evidence that lakes of liquid water existed. Due to the thin atmosphere water as a liquid cannot exist on Mars today so the evidence for past water on Mars is also evidence for a past Mars with a thicker atmosphere. The question about Mars is not so much "what happened to the water" as it is "what happened to the air?" Scientists have theories but not enough evidence to say for sure. There is a spacecraft orbiting Mars (MAVEN) seeking answers to this question.

There are two other places in the solar system known to have liquid water. Both are moons of gas giants. Jupiter's moon Europa shows evidence of a vast ocean of liquid water beneath a crust of ice. It is thought that the force of Jupiter's gravity pulling on the moon has warmed the interior so that water can exist as a liquid.

In a similar way Saturn's gravity warms its moon Enceladus. The Cassini spacecraft observed plumes from water geysers erupting from cracks in the southern hemisphere.

If there is, or was, life elsewhere in the solar system (this is a big IF) these are the most likely places. In any event it is extremely unlikely that any extraterrestrial life in our solar system evolved into anything more complicated than a microbe.

Scientists looking for life beyond Earth are called astrobiologists. In addition to looking in our Solar System astrobiologists are looking for “Earthlike” planets outside of our solar system. These planets are called exoplanets. In order to find a planet considered Earthlike they look for a planet of the right size, the right distance from the star. If a planet is too massive, say more than three times Earth’s mass, it is likely an Ice or Gas Giant like Neptune or Jupiter, not very Earthlike. Then there is distance from the star. Whether the star is a very hot star or a cooler star there is a point where a planet is so far from the star that water freezes. Likewise there is a point where a planet is so close to the star that any water would vaporize. There is also an area between these two points where water can exist as a liquid. This is called the habitable zone. In our solar system three planets are in the habitable zone. Mars is on the outside edge, Venus is on the inside edge and Earth is in the middle.

As of this writing (July 2015) almost 5,000 candidate exoplanets have been discovered and more than 1,700 have been confirmed. Of these confirmed exoplanets 1 is of the proper mass in the proper orbit to be considered Earthlike. This may seem like a discouraging figure to those interested in finding life beyond Earth. However we have only been looking for exoplanets since 1995 and our most advanced instrument, the Kepler space telescope, looked at one very small part of the sky for just over 3 years.

What is an exoplanet?

An exoplanet is simply a planet which orbits a star other than our Sun. While long theorized it wasn’t until the last decade of the 20th Century that evidence began to show that exoplanets did indeed exist. The first “planet-like” objects found orbiting a “star-like” object were discovered in 1994. These objects were quite different from anything anyone might consider to be Earthlike. The star they are orbiting is a pulsar, the rapidly spinning remnant of a star which exploded in a supernova at the end of its life. It wasn’t until the next year that planets were found around stars like our sun. The first exoplanet discovered was around the star 51 Pegasi. More planet discoveries came quickly, with dozens of planets being discovered by the year 2000. The discoveries continued with the current

count of confirmed planets reaching almost 2,000 with over 5,000 candidates yet to be confirmed.

How are exoplanets found?

Exoplanets are too far away from Earth and too dim to be directly detected. The presence of exoplanets is inferred by how their orbit affects the star. One would think a planet is far too small to affect a star but there are subtle effects which can be observed. While there are a number of methods of discovery we are going to focus on the two most common methods. They are the Radial Velocity method and the Planet Transit Method.

Radial Velocity Method

The method first used to detect exoplanets was the Radial Velocity method. This detects the wobble of the star caused by the orbit of the planet. Now, before we get to how this wobble is detected let's talk about why the star wobbles.

An educated person born in the last 400 years would state that the Earth and the planets all orbit the Sun and that the Moon orbits the Earth. These statements are not fully accurate. In fact the Sun and the Earth both orbit around a mutually shared center of gravity. This center of gravity is called the barycenter. The Earth and the Moon, likewise orbit around a mutually shared center of gravity. In the case of the Earth and the Moon this barycenter lies 1,000 miles below the surface of the Earth on the side of the Earth facing the Moon. (See fig. 1) The Earth is almost 4,000 miles in radius so the Earth wobbles around this barycenter.

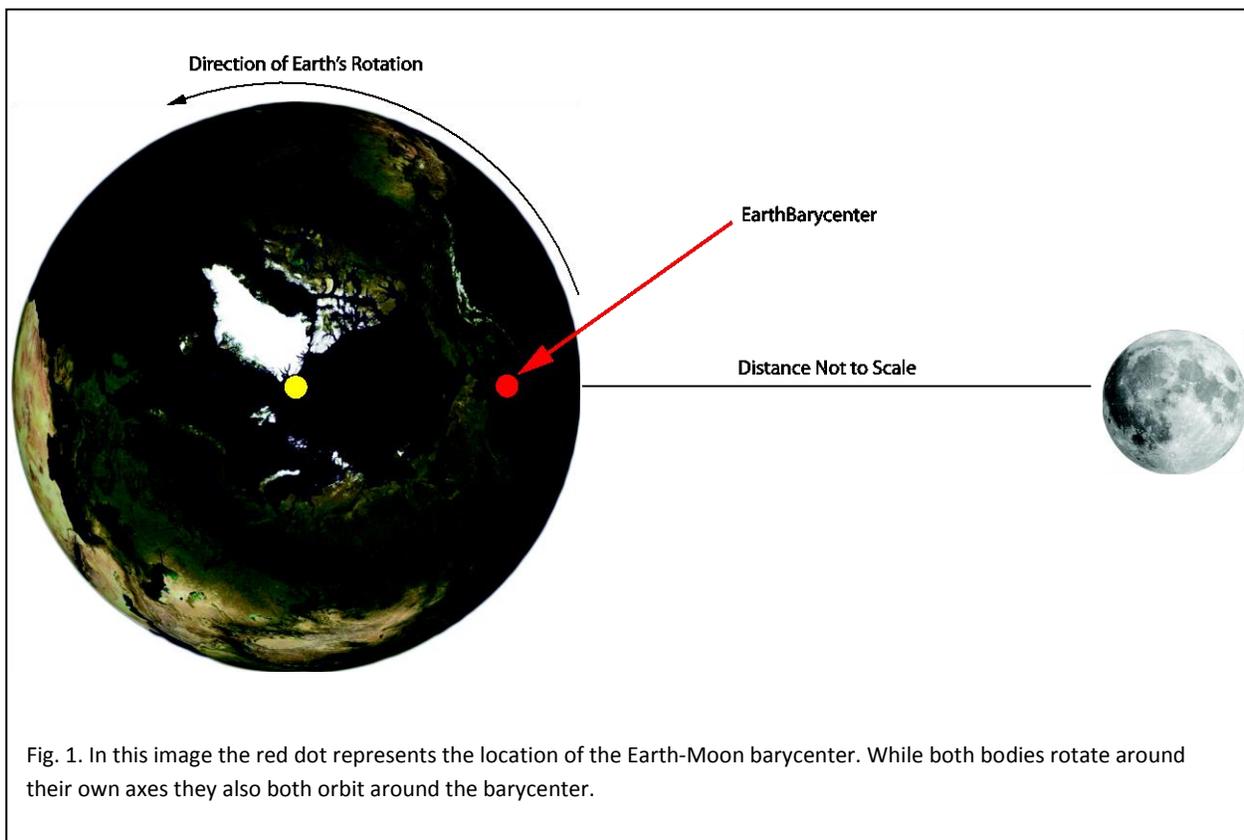


Fig. 1. In this image the red dot represents the location of the Earth-Moon barycenter. While both bodies rotate around their own axes they also both orbit around the barycenter.

The Sun and the planets in the Solar System likewise have a common barycenter. While the Earth-Sun barycenter is not a significant distance from the Sun's center the Jupiter-Sun barycenter is far enough off-center to cause the Sun to wobble. If someone were to observe the Sun from another star system it would be possible to deduce the existence of Jupiter by detecting the wobble of the Sun. They would do that by examining the light from the Sun and noticing how its color shifted from red to blue and back. This is how 51 Pegasi the very first exoplanet was discovered. This planet is not very Earth-like at all.

The Doppler Effect

Have you ever noticed the sound of a train increasing in pitch as it travels towards you and then getting lower in pitch as it moves away from you? This is caused by the Doppler Effect and it happens not only with sound waves but with light waves as well.

Imagine dropping a stone into still water. The waves will move out from the stone at the same speed in all directions. Fig. 2 shows a stationary light source with waves emanating from it in all directions. In Fig. 3 the light source is now in motion. To an observer located at position A, the light has to travel less distance as the object moves closer. The wavelengths would appear shorter. To an observer located at position B as the light moved away the waves would appear longer. Fig. 4 shows the electromagnetic spectrum of light from

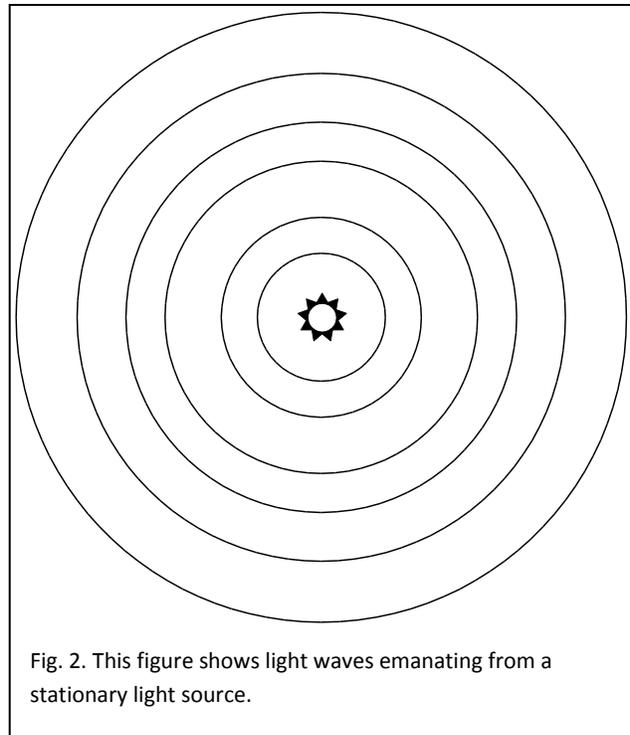


Fig. 2. This figure shows light waves emanating from a stationary light source.

short wavelength gamma rays through the visible to the longer wavelength radio waves. In the visible part of the spectrum blue and violet wavelengths are shorter than red wavelengths. Referring back to fig. 2, to an observer at position A the light from the star would be shifted towards the blue part of the spectrum while the light would be red-shifted to an observer at B.

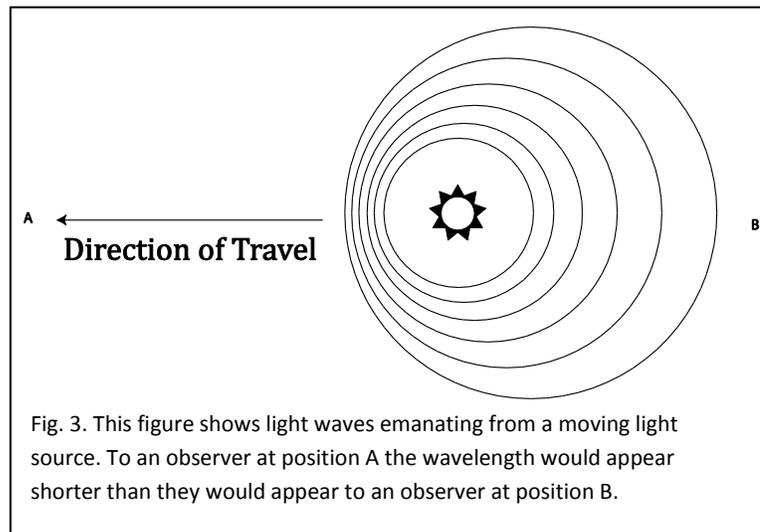


Fig. 3. This figure shows light waves emanating from a moving light source. To an observer at position A the wavelength would appear shorter than they would appear to an observer at position B.

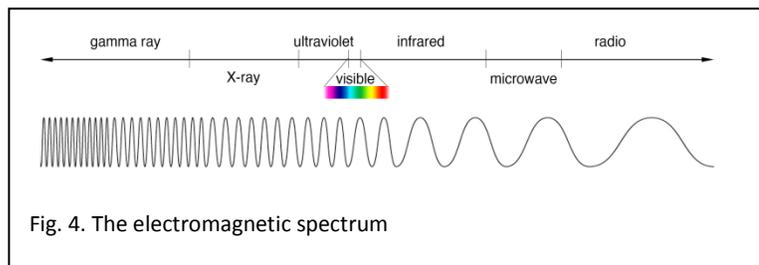


Fig. 4. The electromagnetic spectrum

So what does this have to do with discovering exoplanets?

Well if a star is orbited by a large enough planet the star will wobble. If we on Earth are situated in a position to be looking at that solar system edge on we would notice the star

blue shifting as it wobbled towards us and red shifting as it wobbled away from us. And that is exactly how the first exoplanet was discovered orbiting the star 51 Pegasi in 1995.

Planet Transit Method

Another method of detecting exoplanets is the planet transit method.

Simply put this method detects the minute dimming of light that occurs when a planet moves between an observer and the star. If you look at figure 6 the images shows a star with a planet moving across it.

As the planet moves across the face of the star the light from that star would dim. It is possible to detect that dimming.

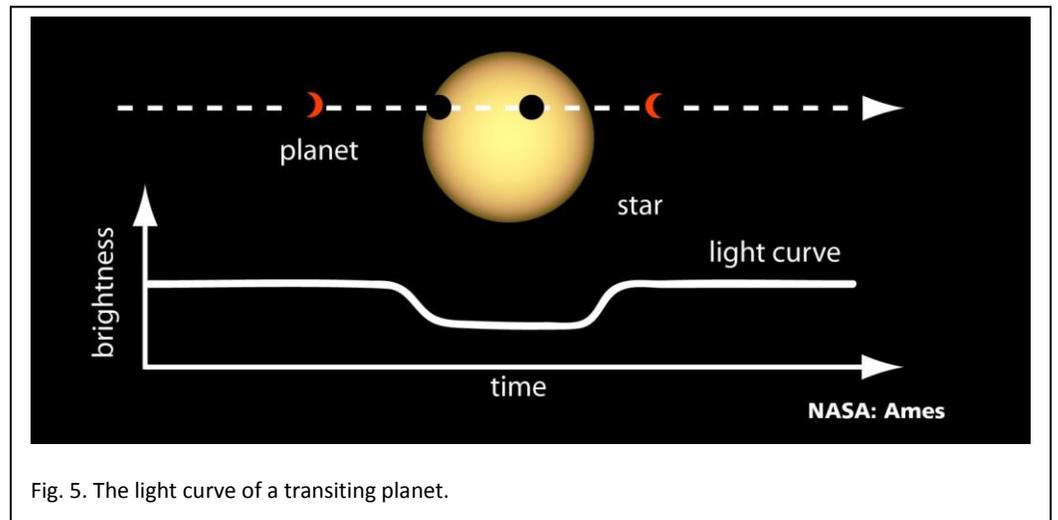


Fig. 5. The light curve of a transiting planet.

In order to be considered a candidate the light curve must be seen a minimum of three times. After witnessing the light curve the second time the curve is looked for again at the same interval of time. If it does occur at that interval of time you have a candidate. The candidate still needs to be confirmed through multiple observations with different instruments. For example, referring back to figure 5, if that light curve is seen regularly every 22 days you have a candidate planet with an orbital period (a year) of 22 days. For reasons explored in the section on Johannes Kepler we know that a planet with such a short year would be orbiting extremely close to it's star. Much too close to potentially harbor life. To find a planet orbiting a sun-like star at the same distance that the Earth orbits the Sun would require a minimum of three years to see the three light curves required to become a candidate.

The Kepler Telescope

In 2009 the Kepler spacecraft was launched on a mission to search for exoplanets using the Planet Transit method. The telescope orbits the Sun in what is called an Earth trailing orbit. In this orbit the spacecraft follows Earth at a distance of tens of millions of miles. At this distance the telescope can observe its targets free from the glare of light reflected off of the Earth.

The target area for Kepler is an area of sky in the constellation Cygnus, *fig. 6*. This area was chosen because it met the requirements of the mission.

“Since transits only last a fraction

of a day, Kepler must monitor all target stars continuously. Their brightnesses must be measured at least once every few hours. (We sum the light accumulated in this time to obtain a statistically significant measurement). The ability to continuously view the stars being monitored dictated that the field of view (FOV) must never be blocked at any time during the year. So, Kepler orbits the Sun (heliocentric orbit), not the Earth. Further, to avoid the Sun, the FOV must be out of the ecliptic plane.”

<http://kepler.nasa.gov/Science/about/targetFieldOfView/>

Simply put, this area has a large number of stars and Kepler’s view of it would not be obscured by the Earth or the Sun for the duration of the mission. Over the course of its mission Kepler has discovered 4,696 candidate systems with 1,040 confirmed exoplanets.

Johannes Kepler

The namesake for the Kepler spacecraft was a 17th Century German mathematician and astronomer named Johannes Kepler. Kepler was hired by Tycho Brahe to study Brahe’s observation data and prove that Brahe’s geocentric view of the Solar System was correct. In Brahe’s model of the Solar System, the Moon and the Sun orbited the Earth and the other

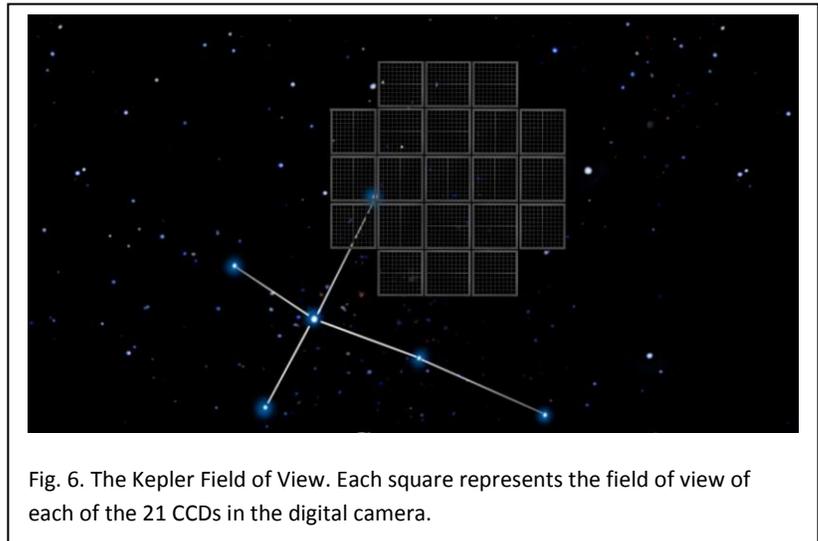
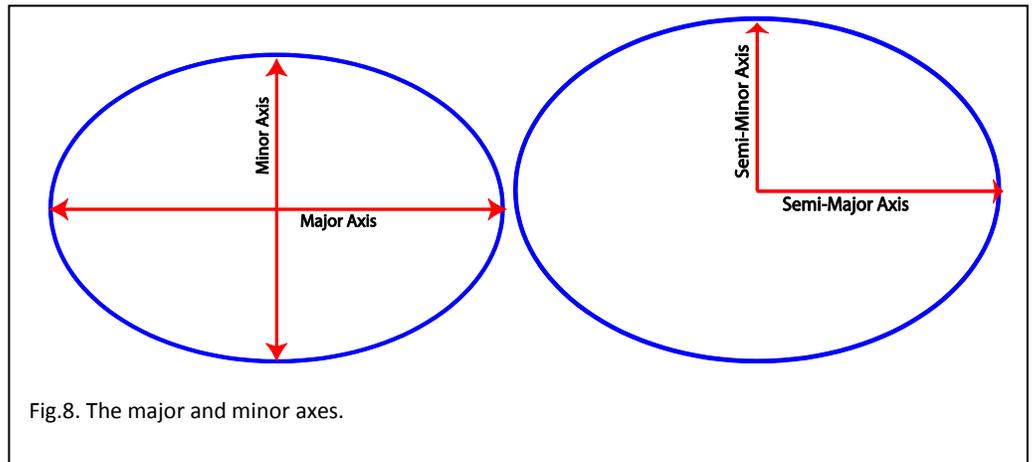
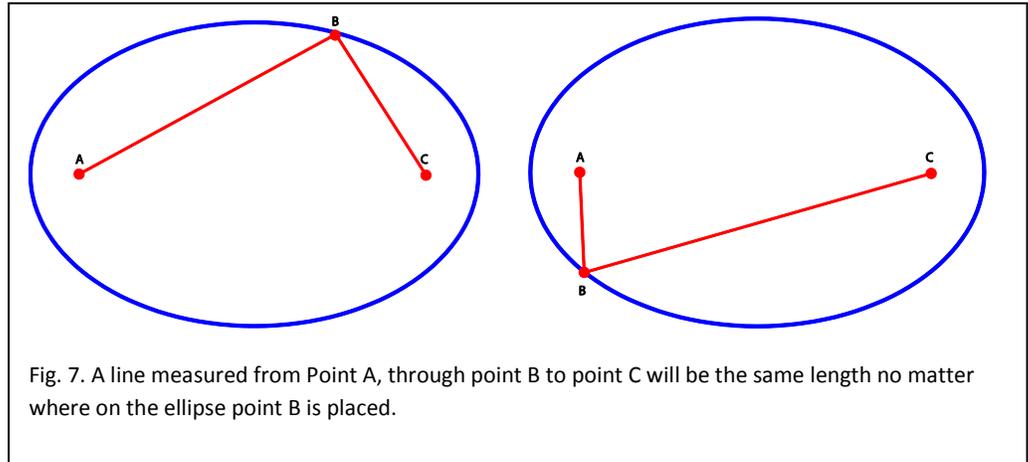


Fig. 6. The Kepler Field of View. Each square represents the field of view of each of the 21 CCDs in the digital camera.

planets orbited the Sun. Kepler found that the data did not support this model. In analyzing his own and Brahe's observational data Kepler discovered the fundamental aspects of orbital mechanics. These are Kepler's Three Laws of Planetary Motion. In order to understand these it is important to first understand some terminology for ellipses.

Meriam-Webster defines ellipse as: *a shape that resembles a flattened circle; a closed plane curve generated by a point moving in such a way that the sums of its distances from two fixed points is a constant.* Refer to figure 7. A line drawn from Point A, through Point B, to Point C will be the same length no

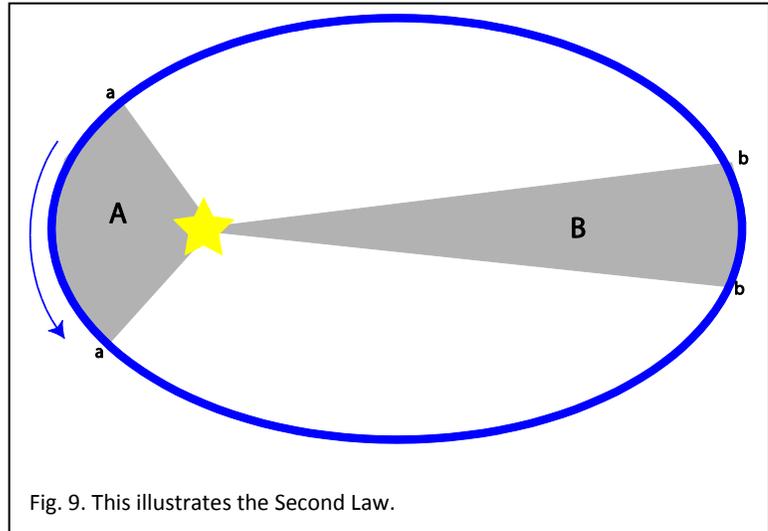


matter where on the ellipse Point B is placed. Points A and C are referred to as the foci. Using this definition a circle is a unique ellipse where the two foci overlap. Figure 8 shows some further definitions. The distance across the long side of the ellipse is called the Major Axis while the distance across the short side is the Minor Axis. Half of these distances are called the semi-major and semi-minor axes.

Kepler's Three Laws of Planetary Motion.

1) The orbit of every planet is an ellipse with the Sun at one of the two foci.

The orbits of the planets around the Sun are nearly circular so this places the Sun at the center of the Solar System. While the planets' orbits are nearly circular other Solar System objects such as comets have highly eccentric orbits.



2) A line joining a planet and the Sun sweeps out equal areas during equal intervals of time.

In figure 9 we see a highly eccentric orbit. If it takes 1 day for the planet to travel from a to a, and 1 day to travel from b to b, then the shaded cones labeled A and B are of the same area. What this illustrates is one of the fundamentals of orbital mechanics. The closer an object is to the Sun the faster it will be moving. A comet on a highly eccentric orbit like the one illustrated would be moving faster the closer it got to the Sun.

3) The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit.

While it sounds complicated (and it can be) this third rule demonstrates that the closer a planet is to the star (or a moon to the planet, or an artificial satellite to the Earth) the faster it will be moving. In the formula $P^2 \sim a^3$, P equals the time it takes the object to complete an orbit and a represents the semi-major axis.

The Datasets

More detailed descriptions of the datasets can be found at <http://sos.noaa.gov/Datasets/index.html>

The Blue Marble

This data set is called the Blue Marble and is a true color image of the planet Earth from orbit. It was generated from imagery taken over a four month period by NASA's Terra satellite. It took four months to get the entire Earth cloud-free. This mosaic was then stitched together and an average cloudy day super imposed over it.

<http://sos.noaa.gov/Datasets/dataset.php?id=82>

Pale Blue Dot

This image was taken by the Voyager I spacecraft at a distance of over six billion miles. From this distance taking a picture of the Earth required pointing the camera very close to the sun resulting in the streaks of light due to the glare. In the image the Earth appears as a tiny dot centered in one of those rays of light.

X-Ray Sun

This is an x-ray movie of the Sun taken from a geosynchronous weather satellite. In addition to monitoring weather on Earth these satellites are also equipped with instruments to monitor the space environment. This movie spans a period of 17 days in October and November of 2001.

<http://sos.noaa.gov/Datasets/dataset.php?id=265>

Earth as an Exoplanet

Created by the University of Washington's Virtual Planetary Laboratory, this datasets shows what Earth might look like if viewed from solar system distances. The image starts with the Earth as viewed from geostationary orbit and the image is pixelated to show the resolution change to only one pixel representing an average of the colors.

Venus

The Venus cloud tops imaged by the Magellan spacecraft.

<http://sos.noaa.gov/Datasets/dataset.php?id=216>

Clouds IR Weather

This is a looping movie of the Earth's weather over the past 30 days. It is continuously updated and it ends two hours prior to the current time. The time stamp on the globe is GMT. These weather images are in the Infrared frequencies. IR shows temperature. If an area has cloud cover the clouds will be colder than the surface. They will show up on the image as grey or white. The colder the cloud tops the brighter they will appear in the image. The altitude of the cloud tops can be inferred by their temperature with higher cloud tops being colder.

Land Surface Temperature Real Time

This dataset shows the surface temperature on Earth as imaged by Microwave sensors on orbiting weather satellites. This shows that temperature on a global scale can be sensed remotely.

<http://sos.noaa.gov/Datasets/dataset.php?id=128>

Earth With Glint

This dataset, developed by the Virtual Planetary Lab at the University of Washington simulates the "glint" from the Earth. Earth glint has been observed from the moon. It is the glare of sunlight off of the oceans. It changes with the crescent phase of the Earth relative to an observer. It might be possible if such glint is observed on an exoplanet to determine whether there are oceans on an exoplanet, although other factors, such as clouds, contribute to glint.

To learn more about glint: http://www.nasa.gov/mission_pages/epoxi/sun-glints.html

Earthlike Exoplanet

This is an artist conception of what an Earthlike exoplanet might look like. It has landmasses oceans and clouds, much like our own Earth.

<http://sos.noaa.gov/Datasets/dataset.php?id=416>