Space Physics: Measuring the Infinite Void…

Introduction

To measure things on Earth, we use small units of measure for short distances and larger ones for greater distances. By measuring in inches, feet, yards, rods, and miles, we do an excellent job of measuring our Earth and everything on it.

US Unit	Equivalent	Metric Unit	Equivalent
1 foot (ft)	12 inches (in.)	1 centimeter (cm)	10 millimeters (mm)
1 yard (yd)	3 feet (ft)	1 meter (m)	100 centimeters (cm)
1 rod (rd)	5.5 yards (yd)	1 kilometer (km)	1,000 meters (m)
1 mile (mi)	1, 760 yards (yd)		

But when we look into space, scientists have found that we need different methods and units of measure to describe our universe. The “space” between celestial objects in incredibly vast, and it is void of almost everything except minor amounts of space dust. Even the most knowledgeable scientists are challenged by quantifying the vast distances in space, and for most of us, the concept is difficult to grasp. In the last article, we shared the fact that in the United States space is considered to begin at 50 mi (80.4 km) above the ground surface. In this article, we’ll introduce a discussion related to exploring space, specifically, methods for measuring speed and distance in space.

Getting off the Earth

Escape velocity is the speed at which an object must travel to break free of a planet’s gravitational force and enter orbit. A spacecraft leaving the surface of Earth, for example, must travel approximately 7 miles (mi) (11 km) per second, or greater than 25,000 mi per hour (40,000 km per hour), to enter orbit.

Achieving escape velocity is one of the biggest challenges in accomplishing space travel. Rockets and other space vehicles require an enormous amount of fuel to break free from Earth's *gravitational pull* (check out Fun Fact below). All that fuel adds significant weight to a spacecraft and, as an object becomes heavier, the more thrust it takes to lift it. To create more thrust, you need more fuel! It's a cycle that scientists are hoping to resolve by creating lighter vehicles, more efficient fuels, and new methods of propulsion that don't require the same ingredients to attain great speeds.

To reach space, the Space Shuttle used a main engine and two solid rocket boosters with over a million pounds of rocket fuel for an 8–9-minute ride into space.

> Fun Fact:
> *Gravitational pull* is the attraction that one object has for another object due to the invisible force of gravity. The mass of an object affects its gravitational pull. The gravitational pull of the Sun keeps the planets in orbit around it.

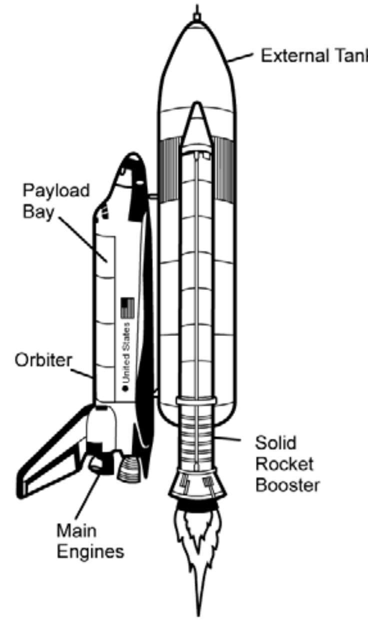
Space Shuttle (Photo: NASA.)

Shuttle solid rocket booster:

- Requires 454,000 kg (1 million pounds [lb]) of propellant
  - Provides 1,194,020 kg (1,315 tons) of thrust (calculation is for sea level)
  - Burn time = 2 minutes and 2 seconds.

Main engines:

- Each utilize 547,524 kg (603 tons) of liquid oxygen and 91,708 kg (101 tons) of liquid hydrogen in external tank
  - Provide 154,360 kg (170 tons) of thrust (sea level)
  - Burn time = 8 minutes.

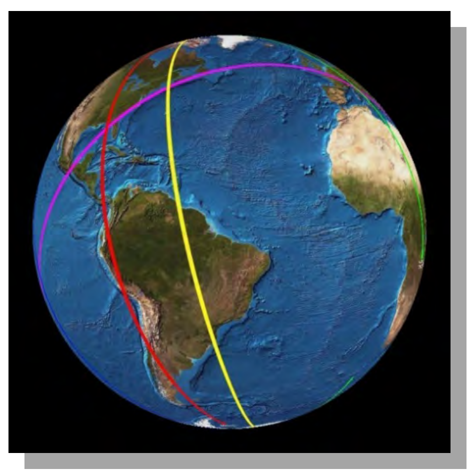


Satellites Are Hard at Work, High above Us

In the context of spaceflight, a satellite is an artificial object that has been intentionally placed into orbit. These objects are sometimes called artificial satellites to distinguish them from natural satellites, such as the Moon.

Most satellites are launched into space on rockets. A satellite orbits the Earth when its speed is perfectly balanced by the pull of Earth's gravity. If that balance were to be lost or never achieved, the satellite would fly off into space or fall to Earth. Satellites orbit Earth at different heights, different speeds, and along different paths. The two most common types of orbit are *geostationary* and *polar*.

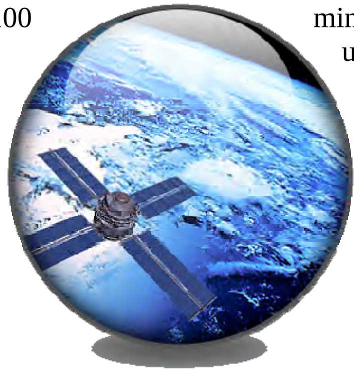
A geosynchronous satellite is a satellite in *geosynchronous* orbit, thus having an orbital period the same as the Earth's rotation period, 1 day. A type of geosynchronous satellite is a **geostationary** satellite, which travels from west to east over the Earth's equator. It moves in the same direction and at the same rate as Earth is spinning; thus, geostationary satellites stay over the same spot on Earth and appear motionless—as a fixed object—to observers on the ground below. Satellites launched into geostationary orbits begin their orbits at 22,236 mi, (35,786 km) or 117.5 million ft above the Earth. These satellites line up above the Earth's equator and, because they are geosynchronous, have an orbital period of 1 day.



Polar-orbiting satellites pass above, or nearly above, both poles of the body being orbited (usually a planet such as Earth, but possibly another body, like the Sun) on each revolution. The satellite, therefore, has an inclination (or angle) of approximately 90 degrees to the equator. A satellite in polar orbit passes over the Earth's equator at a different longitude on each of its orbits; thus eventually it can view much of the planet (see graphic at right).

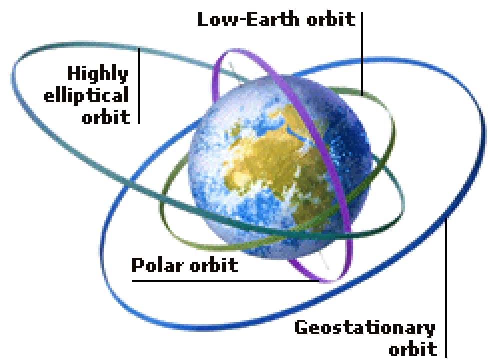
Travelling polar-orbiting satellites have a view of the entire Earth, but of just one section at a time (see image below, left), as they move north-south from pole to pole. Normally, a satellite in this orbit moves in a circle approximately 600 mi (1,000 km) above ground. At heights lower than that, air resistance (also called air friction or drag) is too great and the satellite's speed is adversely affected. Each orbit takes about 100 minutes. Polar-orbiting satellites are useful for Earth mapping and observation, as well as for some weather satellites.

What is Drag?
As an object moves through the air, the air behaves as a fluid, impeding the object's path. This is known as drag (also called air resistance, which is a type of friction). Drag is the force opposite the relative motion of an object moving through air.



Many satellites go into low Earth orbit (LEO) (see graphic below), with an altitude between 100 mi (160 km) and 1,240 mi (2,000 km). A low Earth orbit is simplest and most cost effective for a satellite placement. However, the lower the LEO, the more atmospheric drag is placed on the satellite, as the Earth's atmosphere is denser than space.

To get an idea of how high above the Earth some high-altitude satellites are travelling, we can begin by thinking of how many miles compose the measurement around the Earth at its middle point. The circumference of the Earth at the equator is 24,901.55 mi (40,075.16 km). Satellites in geosynchronous orbit are almost has high above the Earth as it is round. That distance, however, is very short compared to the distance to the Moon or even the nearest planets.



Representation of orbit types (Graphic: Fact Monster).

How Far Is It to the Moon?

Our closest neighbor in space is the Moon. The average distance to the Moon is 238,857 mi (384,403 km) or the equivalent of walking around the equator of the Earth over nine and a half times. Since the Moon takes an elliptical (or oval) path around the Earth, the Moon can get closer and further away. Therefore, the distance from Earth to the Moon can vary by 26,465, mi (42,592 km). This can make the Moon appear different in size depending on where it is in its orbit.

How long is the trip in modern spacecraft? The Apollo 11 astronauts were launched toward the Moon atop a huge Saturn V rocket on July 16, 1969. They reached lunar orbit after only 3 days in space, on July 19, 1969.

Fun Fact:
The fastest mission to fly by the Moon was NASA's 2006 New Horizons Probe mission on its way to fly past Pluto (expected in July 2015). At launch, the probe's rockets quickly powered it to over 36,373 mi per hour (58,536 km per hour). It took just 8 hours 35 minutes to cover the 238,857 mi (384,403 km) and fly by the Moon.

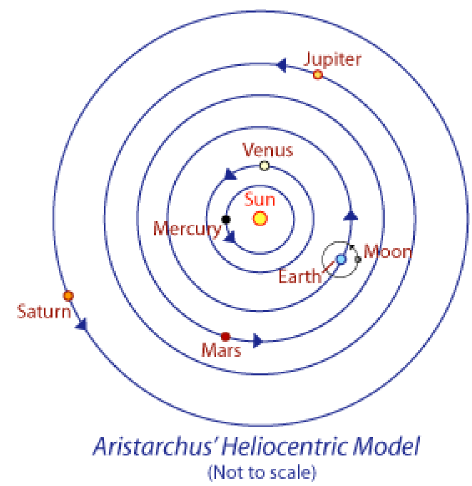
How Fast Have Space Craft Traveled?

Orbiting satellites typically move at more than 17,000 mi per hour (about 27,400 km per hour). The Voyager 1 space probe has reached solar escape velocity at approximately 38,600 mi per hour (62,120 km per hour).

Helios 1 and Helios 2 are a pair of space probes that were launched into *heliocentric orbit* (see text box, right) for the purpose of studying the Sun and its processes. With the aid of the Sun's immense gravity, the Helios 2 probe reached a speed exceeding 150,000 mi per hour (about 241,400 km per hour), one of the fastest spacecraft speeds recorded, as it orbited the Sun in April 1976. A joint venture of West Germany and NASA, the Helios probes (see prototype photo below) are no longer functional but still remain in their elliptical orbits around the Sun.

Heliocentric Orbit

Heliocentric orbit is an orbit around the barycenter (or center of mass) of the Solar System, which is usually located within or very near the surface of the Sun. All planets, comets, and asteroids in our Solar System are in such orbits, as are many artificial probes and pieces of debris.



Helios prototype (Photo: Wikipedia).

Light… You Can't Catch It!

Scientific theory suggests that nothing can travel faster than the speed of light. Light travels at a speed of 186,000 mi a second or 700 million mi an hour. If the distance from Earth to the Moon is approximately 239,000 mi, then light would travel from the Moon to Earth in 1.3 seconds.

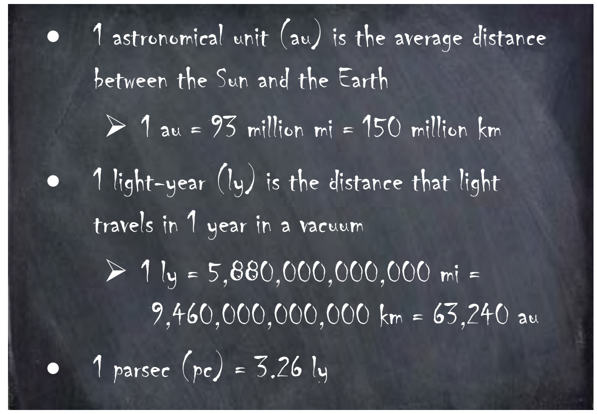
When looking at the vast distances of space, even light seems slow. If the Sun were to stop shinning, it would take 8.5 minutes for the Earth to be in the dark. Light from the Sun takes 5 hours 40 minutes to reach Pluto. Light from the nearest star, excluding the Sun, takes 4 1/2 years to reach the Earth, and from the farthest stars in distant galaxies, the light they emit doesn't arrive on Earth for billions of years.

Consider this: If something that travels 700 million mi per hour through space takes 4 1/2 years to reach Earth (from the nearest neighboring star), it is really no surprise that we require unique units of measurement. If we tried to use miles, we might not have enough room on our paper for all the zeros!

Fun Fact:
Radio transmissions sent by NASA astronauts on the Moon took over 1 second, travelling at the speed of light, to reach us here on Earth.

Measuring Space

The distance light can travel in a year is called a light year. In astronomy, the science that studies celestial objects (planets, moons, stars, black holes, and galaxies), the light year is one of the basic units of measure for distance. The most commonly used units of measure for distance are the light year, parsec, and astronomical unit.



Astronomical Unit (au)

An astronomical unit (au) is the average distance between the Earth and the Sun, which is approximately 93 million mi (150 million km). Astronomical units are generally used to measure distances within our solar system. For example, the planet Mercury is approximately 1/3 au from the Sun, while the farthest planet, Pluto, is approximately 40 au from the Sun (that's 40 times as far from the Sun as the Earth).

Light-Year (ly)

Most objects in space are so far away that using a relatively small unit of distance is not practical. A light-year (ly) is the distance that light can travel in 1 year in a vacuum (empty space). The speed of light is approximately 186,000 mi (300,000 km) per second. So, in 1 year light travels a distance of approximately 5,880,000,000,000 mi (9,460,000,000,000 km); which is 1 light-year. For example, the nearest star to Earth is about 4.3 ly away. Our galaxy, the Milky Way, is approximately 150,000 ly across, and the nearest large galaxy, Andromeda, is about 2.3 million ly away.

Parsec (pc)

Astronomers use another unit of distance called a parsec (pc), which is equal to 3.26 light-years (19.2 trillion mi or 30.9 trillion km). All known stars lie more than 1 pc away; most lie within 500 pc of the Sun. Use of parsecs is preferred in astronomy and astrophysics, though popular science texts commonly use light years.

The Milky Way as seen from Earth (Photo: "Universe Today," Kerry-Ann Hepburn, photographer).

Conclusion

Space can be defined as the vast distances between planetary objects. Because of this vastness, special methods for reaching those objects, studying them, and measuring their positions have been devised. The units of measure specific to astronomy and astrophysics apply uniquely relative identifiers, which enhance understanding and further our study of space.

Fun Fact:
Earth is located in the outer edge of our galaxy, the Milky Way. It is about 28,000 light years from the rotational center (known commonly as the galactic center) of the galaxy and is part of a solar system that includes seven other known planets. The Milky Way is one of billions of spiral galaxies in the universe.

Over its lifetime, NASA's Hubble Space Telescope (left [NASA image]) has captured many stunning images. Among the most memorable is an edge-on mosaic image of the Sombrero galaxy (lower right [National Geographic, Hubble images]).

"Telescopes are in some ways like time machines. They reveal galaxies so far away that their light has taken billions of years to reach us. We in astronomy have an advantage in studying the universe, in that we can actually see the past."

~ Sir Martin Rees, Astronomer Royal of Great Britain

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