U.S. Government Efforts to

Deal With Orbiting Space Junk

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About the Editor

Michael Erbschloe has worked for over 30 years performing analysis of the economics of information technology, public policy relating to technology, and utilizing technology in reengineering organization processes. He has authored several books on social and management issues of information technology that were published by McGraw Hill and other major publishers. He has also taught at several universities and developed technology-related curriculum. His career has focused on several interrelated areas:

- Technology strategy, analysis, and forecasting
- Teaching and curriculum development
- Writing books and articles
- Publishing and editing
- Public policy analysis and program evaluation

Books by Michael Erbschloe
Social Engineering: Hacking Systems, Nations, and Societies
Extremist Propaganda in Social Media: A Threat to Homeland Security (CRC Press)
Threat Level Red: Cybersecurity Research Programs of the U.S. Government (CRC Press)
Social Media Warfare: Equal Weapons for All (CRC Press)
Walling Out the Insiders: Controlling Access to Improve Organizational Security (CRC Press)
Physical Security for IT (Elsevier Science)
Trojans, Worms, and Spyware (Butterworth-Heinemann)
Implementing Homeland Security in Enterprise IT (Digital Press)
Guide to Disaster Recovery (Course Technology)
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The Executive's Guide to Privacy Management (McGraw Hill)
Net Privacy: A Guide to Developing & Implementing an e-business Privacy Plan (McGraw Hill)

Introduction

It is estimated that hundreds of millions of pieces of space trash are now floating through our region of the solar system. Some of them are as large as trucks while others are smaller than a flake of paint. There are a couple of relatively famous pieces of space trash. One is the glove that floated away from the Gemini 4 crew during the first spacewalk by U.S. astronauts. The other is the camera Michael Collins lost during the Gemini 10 mission. Rocket boosters, pieces that came loose from spacecraft, and fragments and particles created by space collisions or explosions are other examples of the types of trash whizzing around Earth at speeds of up to 36,000 km per hour.

Earth’s gravitational field pulls a lot of space trash into lower and lower orbits until it finally reaches Earth's atmosphere. Most of the trash burns up when it enters Earth's atmosphere. The higher the altitude at which it orbits the longer the space trash will remain in orbit. Space trash moving in orbits lower than 600 km normally falls back to Earth within a few years. Space trash orbiting at altitudes higher than 1,000 km can continue circling Earth for a century or more.

More than 500,000 pieces of debris, or “space junk,” are tracked as they orbit the Earth. They all travel at speeds up to 17,500 mph, fast enough for a relatively small piece of orbital debris to damage a satellite or a spacecraft. The rising population of space debris increases the potential danger to all space vehicles, but especially to the International Space Station, space shuttles and other spacecraft with humans aboard.

NASA takes the threat of collisions with space debris seriously and has a long-standing set of guidelines on how to deal with each potential collision threat. These guidelines, part of a larger body of decision-making aids known as flight rules, specify when the expected proximity of a piece of debris increases the probability of a collision enough that evasive action or other precautions to ensure the safety of the crew are needed.

Space debris encompasses both natural (meteoroid) and artificial (man-made) particles. Meteoroids are in orbit about the sun, while most artificial debris is in orbit about the Earth. Hence, the latter is more commonly referred to as orbital debris.

Orbital debris is any man-made object in orbit about the Earth which no longer serves a useful function. Such debris includes nonfunctional spacecraft, abandoned launch vehicle stages, mission-related debris and fragmentation debris.

There are more than 20,000 pieces of debris larger than a softball orbiting the Earth. They travel at speeds up to 17,500 mph, fast enough for a relatively small piece of orbital debris to damage a satellite or a spacecraft. There are 500,000 pieces of debris the size of a marble or larger. There are many millions of pieces of debris that are so small they can’t be tracked.

Even tiny paint flecks can damage a spacecraft when traveling at these velocities. In fact a number of space shuttle windows have been replaced because of damage caused by material that was analyzed and shown to be paint flecks. With so much orbital debris, there have been surprisingly few disastrous collisions.

In 1996, a French satellite was hit and damaged by debris from a French rocket that had exploded a decade earlier. On Feb. 10, 2009, a defunct Russian satellite collided with and destroyed a functioning U.S. Iridium commercial satellite. The collision added more than 2,000 pieces of trackable debris to the inventory of space junk. China's 2007 anti-satellite test, which used a missile to destroy an old weather satellite, added more than 3,000 pieces to the debris problem. The Department of Defense maintains a highly accurate satellite catalog on objects in Earth orbit that are larger than a softball.

NASA and the DoD cooperate and share responsibilities for characterizing the satellite (including orbital debris) environment. DoD’s Space Surveillance Network tracks discrete objects as small as 2 inches (5 centimeters) in diameter in low Earth orbit and about 1 yard (1 meter) in geosynchronous orbit. Currently, about 15,000 officially cataloged objects are still in orbit. The total number of tracked objects exceeds 21,000. Using special ground-based sensors and inspections of returned satellite surfaces, NASA statistically determines the extent of the population for objects less than 4 inches (10 centimeters) in diameter.

Collision risks are divided into three categories depending upon size of threat. For objects 4 inches (10 centimeters) and larger, conjunction assessments and collision avoidance maneuvers are effective in countering objects which can be tracked by the Space Surveillance Network. Objects smaller than this usually are too small to track and too large to shield against. Debris shields can be effective in withstanding impacts of particles smaller than half an inch (1 centimeter).

NASA has a set of long-standing guidelines that are used to assess whether the threat of such a close pass is sufficient to warrant evasive action or other precautions to ensure the safety of the crew. These guidelines essentially draw an imaginary box, known as the “pizza box" because of its flat, rectangular shape, around the space vehicle. This box is about a mile deep by 30 miles across by 30 miles long (1.5 x 50 x 50 kilometers), with the vehicle in the center. When predictions indicate that the debris will pass close enough for concern and the quality of the tracking data is deemed sufficiently accurate, Mission Control centers in Houston and Moscow work together to develop a prudent course of action.

Sometimes these encounters are known well in advance and there is time to move the station slightly, known as a “debris avoidance maneuver” to keep the debris outside of the box. Other times, the tracking data isn’t precise enough to warrant such a maneuver or the close pass isn’t identified in time to make the maneuver. In those cases, the control centers may agree that the best course of action is to move the crew into the Soyuz spacecraft that are used to transport humans to and from the station. This allows enough time to isolate those spaceships from the station by closing hatches in the event of a damaging collision. The crew would be able to leave the station if the collision caused a loss of pressure in the life-supporting module or damaged critical components. The Soyuz act as lifeboats for crew members in the event of an emergency.

Mission Control also has the option of taking additional precautions, such as closing hatches between some of the station's modules, if the likelihood of a collision is great enough.

NASA has a set of long-standing guidelines that are used to assess whether the threat of a close approach of orbital debris to a spacecraft is sufficient to warrant evasive action or precautions to ensure the safety of the crew.

Debris avoidance maneuvers are planned when the probability of collision from a conjunction reaches limits set in the space shuttle and space station flight rules. If the probability of collision is greater than 1 in 100,000, a maneuver will be conducted if it will not result in significant impact to mission objectives. If it is greater than 1 in 10,000, a maneuver will be conducted unless it will result in additional risk to the crew.

Debris avoidance maneuvers are usually small and occur from one to several hours before the time of the conjunction. Debris avoidance maneuvers with the shuttle can be planned and executed in a matter of hours. Such maneuvers with the space station require about 30 hours to plan and execute mainly due to the need to use the station's Russian thrusters, or the propulsion systems on one of the docked Russian or European spacecraft. Several collision avoidance maneuvers with the shuttle and the station have been conducted during the past 10 years.

NASA implemented the conjunction assessment and collision avoidance process for human spaceflight beginning with shuttle mission STS-26 in 1988. Before launch of the first element of the International Space Station in 1998, NASA and DoD jointly developed and implemented a more sophisticated and higher fidelity conjunction assessment process for human spaceflight missions.

In 2005, NASA implemented a similar process for selected robotic assets such as the Earth Observation System satellites in low Earth orbit and Tracking and Data Relay Satellite System in geosynchronous orbit. In 2007, NASA extended the conjunction assessment process to all NASA maneuverable satellites within low Earth orbit and within 124 miles (200 kilometers) of geosynchronous orbit.

DoD's Joint Space Operations Center (JSpOC) is responsible for performing conjunction assessments for all designated NASA space assets in accordance with an established schedule (every eight hours for human spaceflight vehicles and daily Monday through Friday for robotic vehicles). JSpOC notifies NASA (Johnson Space Center for human spaceflight and Goddard Space Flight Center for robotic missions) of conjunctions which meet established criteria.

JSpOC tasks the Space Surveillance Network to collect additional tracking data on a threat object to improve conjunction assessment accuracy. NASA computes the probability of collision, based upon miss distance and uncertainty provided by JSpOC. Based upon specific flight rules and detailed risk analysis, NASA decides if a collision avoidance maneuver is necessary.
If a maneuver is required, NASA provides planned post-maneuver orbital data to JSpOC for screening of near-term conjunctions. This process can be repeated if the planned new orbit puts the NASA vehicle at risk of future collision with the same or another space object.

One congresswoman summed up the issue succinctly during a House Science, Space and Technology Committee hearing May 9, 2014: space junk is a growing problem.

Lt. Gen. John W. "Jay" Raymond, the commander of the 14th Air Force, Air Force Space Command and U.S. Strategic Command's Joint Force Component Command for Space, testified at the hearing, along with technical and legal experts and officials from the Federal Aviation Administration and Federal Communications Commission.

Raymond noted his task force provides emergency warning of impending orbital collisions to all of the world's spacefaring governments and companies, though it collaborates closely in space primarily with Australia, Canada and the United Kingdom. JFCC Space, he explained, catalogs and tracks the trajectories of all known orbiting systems and debris.

"JFCC Space is the world's premier provider of space situational awareness, data and products," Raymond said. "Over the past few years, we have bolstered our commercial and international partnerships, we've implemented two-way sharing agreements and we've worked collaboratively to refine our sharing processes." The general noted the command also is on track to deliver a new command-and-control system, the Joint Space Operations Mission System and additional space situational-awareness sensors.

Each agency represented at the hearing, along with NASA and others, has a role to play in U.S. space operations. All of the witnesses stated that the United States must improve domestic space traffic management, and move quickly to foster international agreement on use of space.

Key orbits, mostly crowded with government-owned vehicles, are becoming obstacle courses, experts testified, as more countries launch more objects into space. But each of those objects could become a minefield if it collided with another at "hypervelocity" orbital speeds many times faster than a bullet, as one witness testified.

Such a disaster has happened spectacularly at least twice in the past decade.

In 2007, China destroyed one of its own old satellite systems in orbit during an anti-satellite weapon test, in what hearing attendees called the largest known creation of space debris in history. China's test blasted the nonworking mass into a "cloud" that diffused widely -- in some depictions, it now resembles a seeding dandelion head -- and is estimated by some at the hearing to include 150,000 objects centimeter-sized or larger.

The second orbital catastrophe occurred in 2009, when Russian satellite Kosmos-2251 and U.S. commercial satellite Iridium 33 collided, destroying both. Each vehicle disintegrated along its orbital path, scattering a roughly X-shaped debris field one witness said holds some 2,000 objects of at least a centimeter.

Each piece of space junk, as well as each functioning orbital object that eventually will become junk, has a projected duration in orbit that varies from months to centuries, witnesses noted -- mostly depending on the object's size, shape and orbital elevation.

Raymond said monitoring increasingly complex traffic and debris in the space domain is and will remain his command's mission as part of Defense Department, both to protect national security and because no other agency is equipped to do so.

While JFCC Space constantly tracks orbital objects and adjusts recorded trajectories, Raymond acknowledged the command has no authority to act against a potentially destructive satellite or other object in space.

Regulations governing even U.S. domestic spaceflight are complicated. As witnesses explained, the FAA has authority over U.S. commercial and government space vehicles -- but only on launch and re-entry, not during orbit. The DOD has responsibility to monitor, but cannot enforce, space movements. But testimony suggested the need to bring order to managing close encounters in space is pressing.

Raymond noted one witness had testified that NASA's International Space Station had changed position 16 times to avoid striking other objects in orbit.

"In fact, just last month we told them to move it twice," he added.

Witnesses and committee members agreed as the hearing closed that effectively managing space transportation, clearing debris from orbit and protecting the planet from strikes by near-Earth objects are all challenges that will require national and international effort.

Landsat 7 Maneuvers to Avoid Space Debris

Source: USGS Landsat website

More than half a million pieces of space junk are in orbit floating in and around operational missions. In coordination with NASA, the USGS keeps constant vigil to avoid space debris that might collide with the Landsat 5 and 7 satellites.

On April 17, 2012, Landsat 7 maneuvered out of the path of a piece of debris that was on a collision course with the spacecraft. This move will affect the location of the data imaged. As a result, the geographic coverage of collected imagery will drift to the west until the easternmost portion of the scene will be missing as compared to previous acquisitions. The most affected region will be the Tropics, which will begin seeing a small offset on or around April 25.

The westward movement will continue until the USGS Flight Operations Team can maneuver and reposition the satellite to its proper orbit. This process is expected to take approximately 2 months, and the USGS will continue to acquire data during this time. Details about returning to nominal orbit will be announced when they become available.

In 1957 after the beginning of the space race (started by the launch of Sputnik),the North American Aerospace Defense Command (NORAD) started compiling a database of all known debris. The Department of Defense maintains a highly accurate satellite catalog on objects in Earth orbit that are larger than a softball. NASA and the DoD cooperate and share responsibilities for characterizing the satellite (including orbital debris) environment.

Catalog of Earth Satellite Orbits

Credits to Holli Riebeek Design by Robert Simmon September 4, 2009

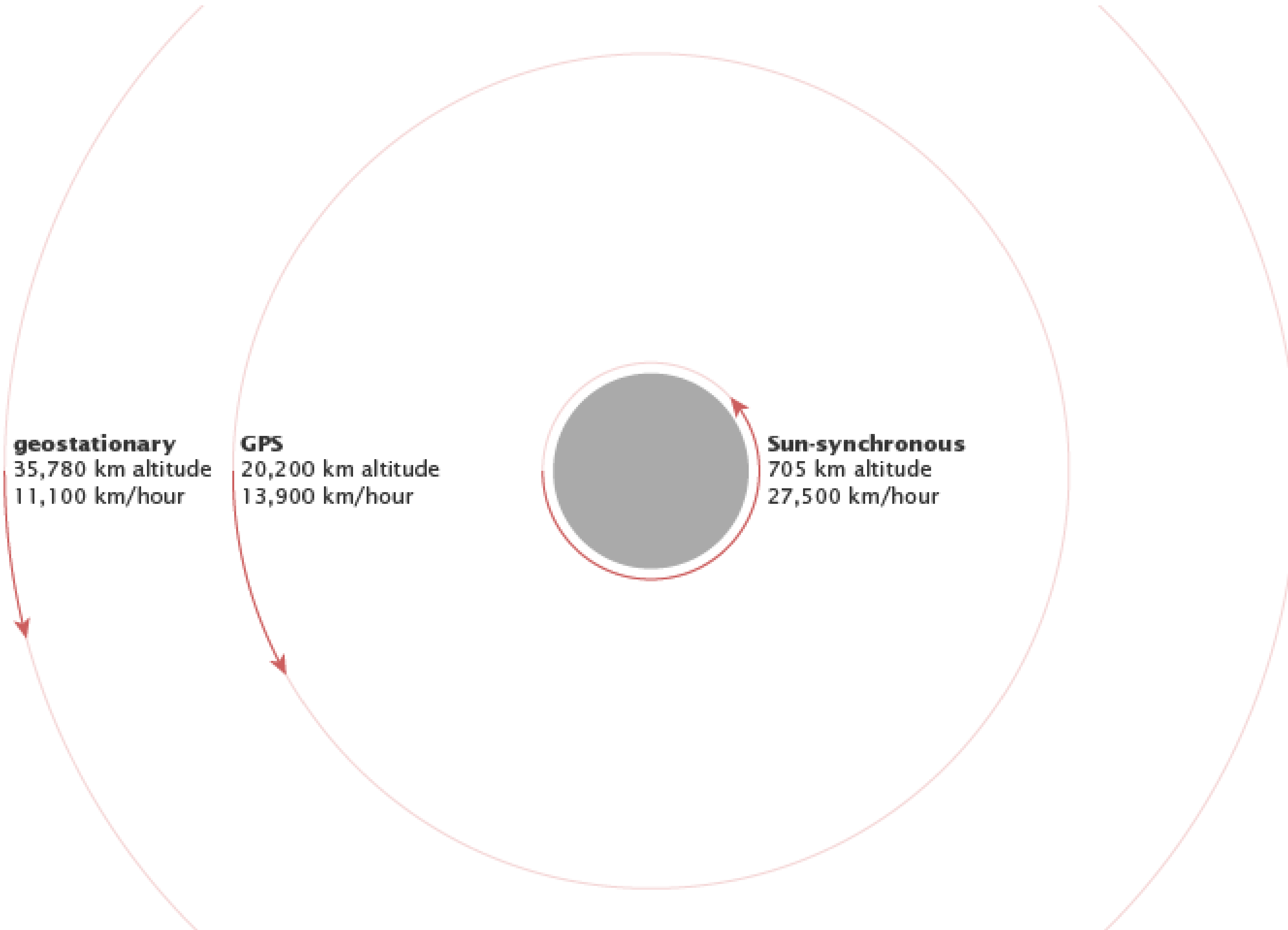
Just as different seats in a theater provide different perspectives on a performance, different Earth orbits give satellites varying perspectives, each valuable for different reasons. Some seem to hover over a single spot, providing a constant view of one face of the Earth, while others circle the planet, zipping over many different places in a day.

Flying hundreds of kilometers above the Earth, the International Space Station and other orbiting satellites provide a unique perspective on our planet. (NASA Photograph S126-E-014918.)

There are essentially three types of Earth orbits: high Earth orbit, medium Earth orbit, and low Earth orbit. Many weather and some communications satellites tend to have a high Earth orbit, farthest away from the surface. Satellites that orbit in a medium (mid) Earth orbit include navigation and specialty satellites, designed to monitor a particular region. Most scientific satellites, including NASA's Earth Observing System fleet, have a low Earth orbit.

One way of classifying orbits is by altitude. Low Earth orbit starts just above the top of the atmosphere, while high Earth orbit begins about one tenth of the way to the moon. (NASA illustration by Robert Simmon)

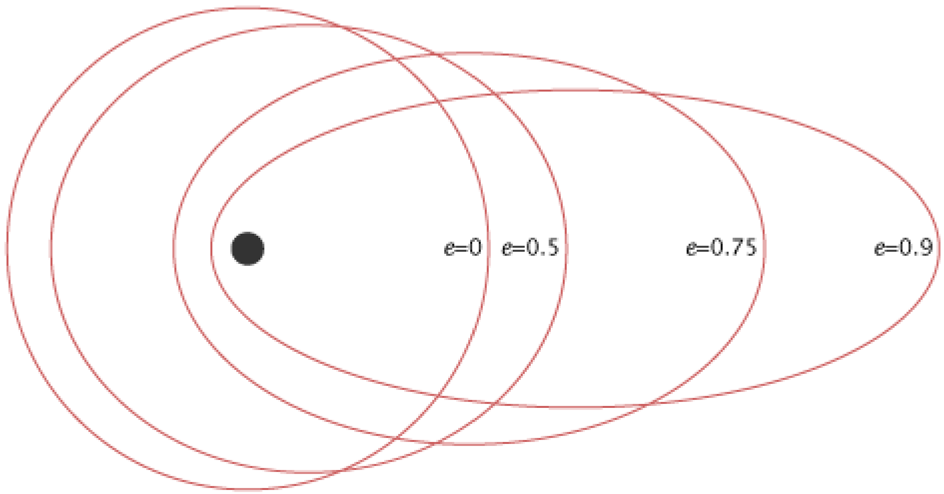
The height of the orbit, or distance between the satellite and Earth's surface, determines how quickly the satellite moves around the Earth. An Earth-orbiting satellite's motion is mostly controlled by Earth's gravity. As satellites get closer to Earth, the pull of gravity gets stronger, and the satellite moves more quickly. NASA's Aqua satellite, for example, requires about 99 minutes to orbit the Earth at about 705 kilometers up, while a weather satellite about 36,000 kilometers from Earth's surface takes 23 hours, 56 minutes, and 4 seconds to complete an orbit. At 384,403 kilometers from the center of the Earth, the Moon completes a single orbit in 28 days.



The higher a satellite's orbit, the slower it moves. Certain orbital altitudes have special properties, like a geosynchronous orbit, in which a satellite travels around the Earth exactly once each day. The length of each red arrow in this diagram represents the distance traveled by a satellite in an hour. View animation. (NASA illustration by Robert Simmon.)

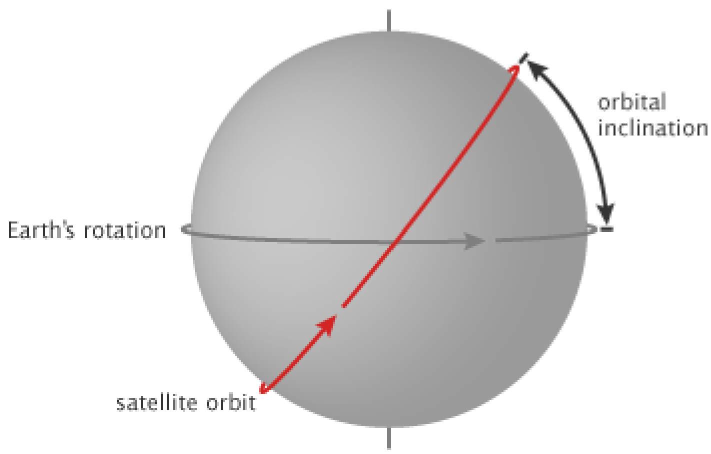
Changing a satellite's height will also change its orbital speed. This introduces a strange paradox. If a satellite operator wants to increase the satellite's orbital speed, he can't simply fire the thrusters to accelerate the satellite. Doing so would boost the orbit (increase the altitude), which would *slow* the orbital speed. Instead, he must fire the thrusters in a direction opposite to the satellite's forward motion, an action that on the ground would slow a moving vehicle. This change will push the satellite into a lower orbit, which will increase its forward velocity.

In addition to height, eccentricity and inclination also shape a satellite's orbit. Eccentricity refers to the shape of the orbit. A satellite with a low eccentricity orbit moves in a near circle around the Earth. An eccentric orbit is elliptical, with the satellite's distance from Earth changing depending on where it is in its orbit.



The eccentricity (e) of an orbit indicates the deviation of the orbit from a perfect circle. A circular orbit has an eccentricity of 0, while a highly eccentric orbit is closer to (but always less than) 1. A satellite in an eccentric orbit moves around one of the ellipse's focal points, not the center. (NASA illustration by Robert Simmon.)

Inclination is the angle of the orbit in relation to Earth's equator. A satellite that orbits directly above the equator has zero inclination. If a satellite orbits from the north pole (geographic, not magnetic) to the south pole, its inclination is 90 degrees.



Orbital inclination is the angle between the plane of an orbit and the equator. An orbital inclination of 0° is directly above the equator, 90° crosses right above the pole, and 180° orbits above the equator in the opposite direction of Earth's spin. (NASA illustration by Robert Simmon.)

Together, the satellite's height, eccentricity, and inclination determine the satellite's path and what view it will have of Earth.

Three Classes of Orbit

High Earth Orbit

When a satellite reaches exactly 42,164 kilometers from the center of the Earth (about 36,000 kilometers from Earth's surface), it enters a sort of "sweet spot" in which its orbit matches Earth's rotation. Because the satellite orbits at the same speed that the Earth is turning, the satellite seems to stay in place over a single longitude, though it may drift north to south. This special, high Earth orbit is called geosynchronous.

A satellite in a circular geosynchronous orbit directly over the equator (eccentricity and inclination at zero) will have a geostationary orbit that does not move at all relative to the ground. It is always directly over the same place on the Earth's surface.

A geostationary orbit is extremely valuable for weather monitoring because satellites in this orbit provide a constant view of the same surface area. When you log into your favorite weather web site and look at the satellite view of your hometown, the image you are seeing comes from a satellite in geostationary orbit. Every few minutes, geostationary satellites like the Geostationary Operational Environmental Satellite (GOES) satellites send information about clouds, water vapor, and wind, and this near-constant stream of information serves as the basis for most weather monitoring and forecasting.

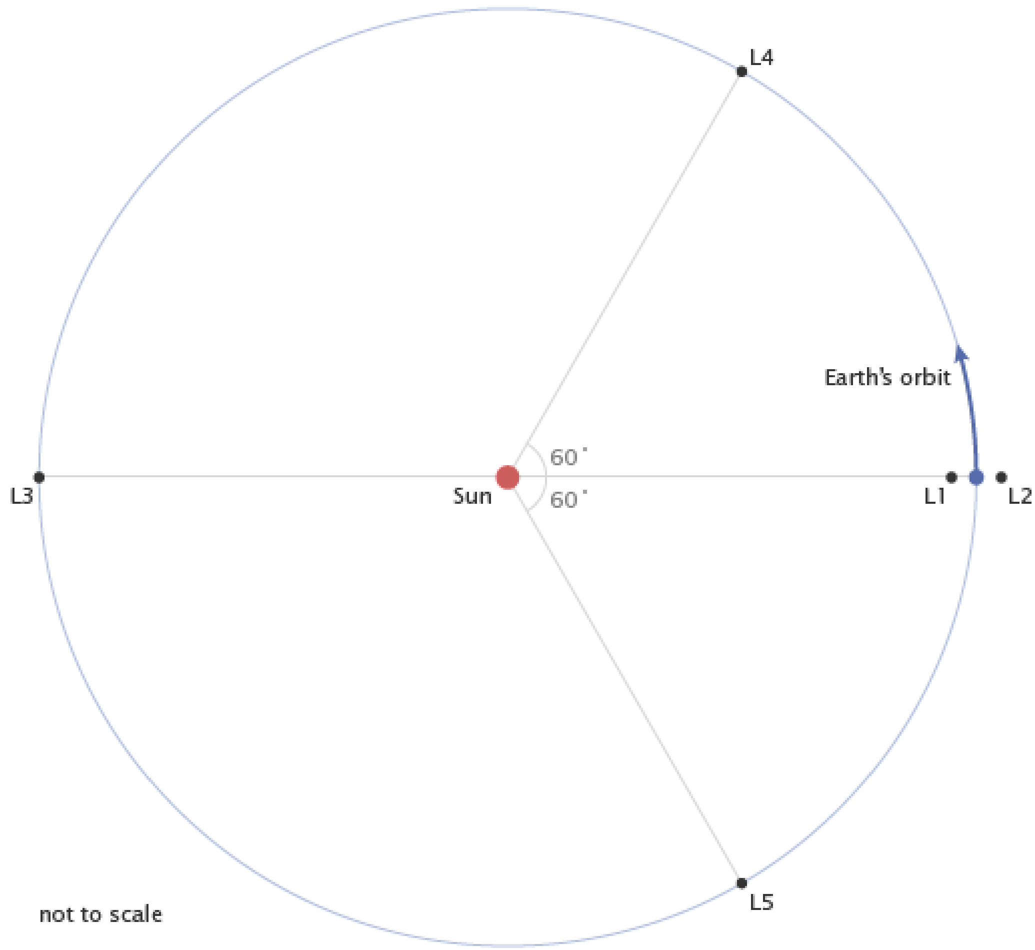
Satellites in geostationary orbit rotate with the Earth directly above the equator, continuously staying above the same spot. This position allows satellites to observe weather and other phenomena that vary on short timescales. (NASA images by Marit Jentoft-Nilsen and Robert Simmon.)

Because geostationary satellites are always over a single location, they can also be useful for communication (phones, television, radio). Built and launched by NASA and operated by the National Oceanic and Atmospheric Administration (NOAA), the GOES satellites provide a search and rescue beacon used to help locate ships and airplanes in distress.

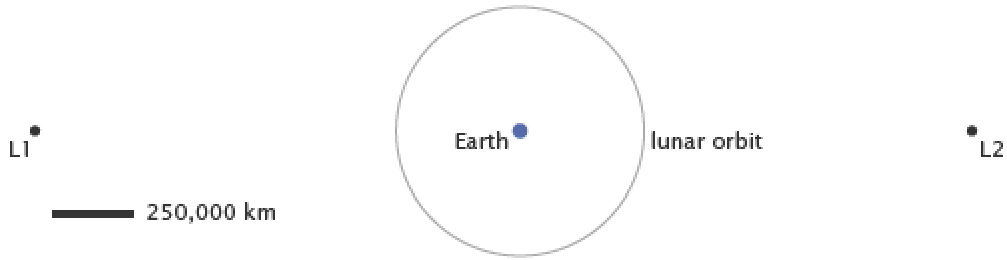
Finally, many high Earth orbiting satellites monitor solar activity. The GOES satellites carry a large contingent of "space weather" instruments that take images of the Sun and track magnetic and radiation levels in space around them.

Other orbital “sweet spots,” just beyond high Earth orbit, are the Lagrange points. At the Lagrange points, the pull of gravity from the Earth cancels out the pull of gravity from the Sun. Anything placed at these points will feel equally pulled toward the Earth and the Sun and will revolve with the Earth around the Sun.

Of the five Lagrange points in the Sun-Earth system, only the last two, called L4 and L5, are stable. A satellite at the other three points is like a ball balanced at the peak of a steep hill: any slight perturbation will push the satellite out of the Lagrange point like the ball rolling down the hill. Satellites at these three points need constant adjustments to stay balanced and in place. Satellites at the last two Lagrange points are more like a ball in a bowl: even if perturbed, they return to the Lagrange point.



Lagrange points are special locations where a satellite will stay stationary relative to the Earth as the satellite and the Earth revolve around the Sun. L1 and L2 are positioned above the day and night sides of the Earth, respectively. L3 is on the other side of the Sun, opposite the Earth. L4 and L5 are 60° ahead and behind the Earth in the same orbit. (NASA illustration by Robert Simmon.)

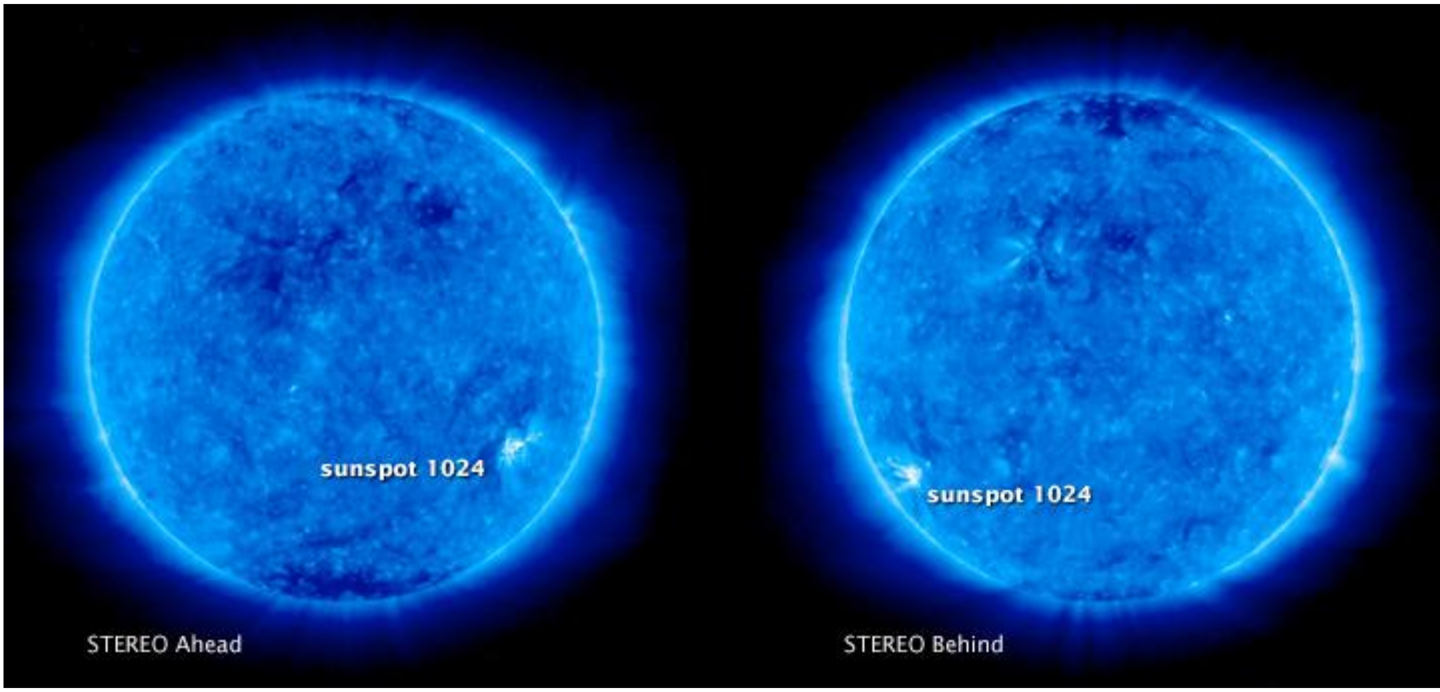


The Lagrange points nearest the Earth are about 5 times the distance from the Earth to the Moon. L1 is between the Sun and Earth, and always views the Earth's daylight side. L2 is opposite the sun, always on the night side. (NASA illustration by Robert Simmon.)

The first Lagrange point is located between the Earth and the Sun, giving satellites at this point a constant view of the Sun. The Solar and Heliospheric Observatory (SOHO), a NASA and European Space Agency satellite tasked to monitor the Sun, orbits the first Lagrange point, about 1.5 million kilometers away from Earth.

The second Lagrange point is about the same distance from the Earth, but is located behind the Earth. Earth is always between the second Lagrange point and the Sun. Since the Sun and Earth are in a single line, satellites at this location only need one heat shield to block heat and light from the Sun and Earth. It is a good location for space telescopes, including the future James Webb Space Telescope (Hubble's successor, scheduled to launch in 2014) and the current Wilkinson Microwave Anisotropy Probe (WMAP), used for studying the nature of the universe by mapping background microwave radiation.

The third Lagrange point is opposite the Earth on the other side of the Sun so that the Sun is always between it and Earth. A satellite in this position would not be able to communicate with Earth. The extremely stable fourth and fifth Lagrange points are in Earth's orbital path around the Sun, 60 degrees ahead of and behind Earth. The twin Solar Terrestrial Relations Observatory (STEREO) spacecraft will orbit at the fourth and fifth Lagrange points to provide a three-dimensional view of the Sun.



The twin Solar Terrestrial Relations Observatory (STEREO) spacecraft took these images of sunspot 1024 on July 5, 2009, while on their way to L4 and L5. The perspectives of the Sun from 60 degrees behind (left) and ahead (right) of Earth's orbit reveal portions of the Sun's surface that would otherwise be hidden from view. (NASA images courtesy STEREO Science Center.)

Medium Earth Orbit

Closer to the Earth, satellites in a medium Earth orbit move more quickly. Two medium Earth orbits are notable: the semi-synchronous orbit and the Molniya orbit.

The semi-synchronous orbit is a near-circular orbit (low eccentricity) 26,560 kilometers from the center of the Earth (about 20,200 kilometers above the surface). A satellite at this height takes 12 hours to complete an orbit. As the satellite moves, the Earth rotates underneath it. In 24-hours, the satellite crosses over the same two spots on the equator every day. This orbit is consistent and highly predictable. It is the orbit used by the Global Positioning System (GPS) satellites.

The second common medium Earth orbit is the Molniya orbit. Invented by the Russians, the Molniya orbit works well for observing high latitudes. A geostationary orbit is valuable for the constant view it provides, but satellites in a geostationary orbit are parked over the equator, so they don't work well for far northern or southern locations, which are always on the edge of view for a geostationary satellite. The Molniya orbit offers a useful alternative.