MOST of us have often wondered what is it that keeps satellites hanging in mid-space. Well, in our science class, we learn about three types of equilibrium states: neutral, meta-stable and stable. These equilibrium states can be physically described as akin to a ball on a plane, saddle point and at the bottom of the concave bowl respectively (See Figure 1).

These equilibrium points can result due to the balance of two forces in space as in the case of Lagrange points. Newton’s law of universal gravitation states that any two bodies in the universe exert force on each other dependent on their masses and the separation distance between them. A gravitational field thus surrounds every point mass with varying intensity. The motion of the bodies in the gravitational force can be explained by Kepler’s laws of orbital motion.

There are locations in space in a two-body system where the forces of gravity and orbital motion balance each other out, creating small regions of orbital stability. These points are named after an Italian-French mathematician Joseph-Louis Lagrange (1736-1813), who worked out their locations in 1772. They are also known as libration locations.

Joseph-Louis Lagrange published his results in his gravitational studies of the ‘General Three body problem’: how a third, small body would orbit around two orbiting large ones. In a two-body system such as Sun-Earth, there are five of these stability regions.

These locations have greatly contributed to space exploration and have become popular abode to the several space observatories in the last few decades. The points that are of most interest to us are the five Lagrangian points in the Sun-Earth system and five in the Earth-Moon system.

An object placed at a Lagrange point will be in a state of gravitational equilibrium, and will orbit the larger body with the same period as the bodies in the system. In other words, in the Earth-Moon system, an object in a Lagrange point will keep pace with the Moon in its orbit about Earth. The third particle can rotate at a constant relative speed with respect to the two bodies if placed at one of the Lagrangian points.

The first Lagrange point, usually abbreviated L1 (see Figure 2), is located directly between the primary body...
equilibrium. The forces of gravity and points are all in metastable or unstable stable viewpoint.

heat radiation, L2 provides a much more this restriction and far away from the temperature due to the variability in the changing its view and also the surface orbits of Earth, which would have kept at L2 would not have to make constant observe the larger Universe. A spacecraft at L2 would not have to make constant orbits of Earth, which would have kept changing its view and also the surface temperature due to the variability in the free from this restriction and far away from the heat radiation, L2 provides a much more stable viewpoint.

The L1, L2, and L3 Lagrange points are all in metastable or unstable equilibrium. The forces of gravity and orbital motion are precisely balanced at these points, but even a slight nudge will send any object at them drifting off as in the case of a saddle point. Because satellites, even in the vacuum of space, are not completely devoid of forces acting on them (such as due to solar wind, meteors and asteroids), anything placed at the first three Lagrange points will need periodic course corrections to keep them in place. For example, a satellite at one of these three regions will need occasional thrusters to keep them in the orbit.

Figure 3 shows the gravitational potential lines in white for the Sun-Earth system with the Lagrange points L1 to L5. The blue triangles are enhanced regions of repulsion and the right triangles show regions of enhanced attraction (towards the libration point).

The L4 Lagrange point lies 60 degrees trailing the satellite (Moon) in its orbit, and the L5 Lagrange point lies 60 degrees spin ward of the satellite (Moon) in its orbit, about 238,000 miles from both the Moon and Earth, forming an equilateral triangle with those bodies. These are also called the Trojan Points, after the asteroids Agamemnon, Achilles and Hector that orbit in the L4 and L5 points of the Jupiter-Sun system. There are several natural bodies including moons, minor planets, and asteroids in the solar system that orbit near Trojan points. There are several thousand known Trojan minor planets orbiting the Sun. Most of these minor planets orbit near Jupiter’s Lagrangian points.

In the last few decades, several space crafts equipped with instruments of different capabilities have been launched towards the Earth-Moon and Sun-Earth Lagrange points to perform the assigned observations. Several future space projects of NASA and European Space Agencies have been planned where these stability zones will either serve as a permanent home or an outpost. Some of the current and future space explorations are described next.

Since the position of L3 lies behind the Sun, any object that may be orbiting there cannot be seen from Earth. As of now, no satellite or observatory is planned to position at Sun-Earth L3.

In 1956, the Polish astronomer Kordylewski discovered large concentrations of dust at the Trojan points of the Earth-Moon system. For large space structure whose course corrections in other orbits would require large expenditures of fuel and energy, this is a very attractive option.

Fig 2. Sun-Earth Lagrangian Points System

Earth-Moon Lagrange Points in Space Exploration

L1: “Gateway” Station

For large-scale exploration and colonization of the Moon, NASA has long since envisioned a “staging base” station at the Earth-Moon L1 point. An L1 Gateway station would have a number of important functions. One, it is in a perfect location to monitor and coordinate communications among various expeditions and missions on the nearside of the Moon.
A vessel launched from L1 could reach anywhere on the Moon within a few hours, which would make it ideal for coordinating and initiating crisis management. Also, it would function very much as a way-station, especially once built up, and would probably be used to handle tourists and visitors to Moon.

The Gateway can also serve an important function as storage and repair center. It can help in repairing trans-lunar spacecraft. Eventually, the station can temporarily store raw materials collected from Moon until they are brought back to Earth.

**L2: Far-side Communication**

A far side halo satellite can be used on the L2 Lagrange point on the far side of the moon. It would be set up in a broad orbit perpendicular to the plane of the Moon’s orbit. This would give it the unusual property of always being visible from Earth at every point in its orbit, inscribing a circle in the sky slightly larger than that of the moon itself.

In other words, to an observer on Earth, the satellite’s rounded path in the sky would always circle the disk of the moon but never slip behind it. However, maintaining a halo orbit around a metastable Lagrange point will have to be constantly monitored for necessary course corrections.

**As an orbital infrastructure grows, numerous structures including colonies, stations, and automated satellites would likely be seen circling these Lagrange points in halo orbits.**

**Astronomical Observatories’ “out-post”**

The L2 point lies some 35,000 miles beyond the Moon, and thus provides an unprecedented stable venue for astronomical instruments away from Earth’s radiation and radio noise. Space-based radio telescopes are a proven technology, but one has never been placed so far out in space. Also, because L2 is metastable, periodic station-keeping would be required.

Recently, NASA has proposed to start building a small outpost in 2017, likely with parts left over from the $100 billion International Space Station, at Earth-
Lagrange published his results in his gravitational studies of the ‘General Three body problem’: how a third, small body would orbit around two orbiting large ones.

Moon’s L2. Since this is a gravitational well, minimal power will be required to keep it in place. This station can support a small astronaut crew and function as a staging area for future missions to the outer planets.

L4, L5: Clusters

Both the L4 and L5 points are functionally the same. The L4 and L5 points are often the sites of gigantic space colonies in science fiction, such as Hollowed Asteroids or Bernal Spheres or O’Neill Colonies. This is because they offer stability, and an object at or orbiting one of these points can stay in that position indefinitely.

In 1956, the Polish astronomer Kordylewski discovered large concentrations of dust at the Trojan points of the Earth-Moon system. For large space structure whose course corrections in other orbits would require large expenditures of fuel and energy, this is a very attractive option.

Solar power satellites can also be advantageously positioned at L4 or L5. As an orbital infrastructure grows, numerous structures including colonies, stations, and automated satellites would likely be seen circling these Lagrange points in halo orbits.

In other words, in the Earth-Moon system, an object in a Lagrange point will keep pace with the Moon in its orbit about Earth. The third particle can rotate at a constant relative speed with respect to the two bodies if placed at one of the Lagrangian points.

Sun-Earth Lagrange Points in Space Exploration

Similar to the Earth-Moon system, the Lagrange points of the Sun-Earth system also provide several incentives to aid space explorations.

L1 is a very good position for monitoring the Sun. The solar wind reaches it about one hour before reaching Earth. In 1978, the International Sun-Earth Explorer-3 (ISEE-3) was launched towards L1, where it conducted such observations for several years.

Now the ESA/NASA SOHO (Solar and Heliospheric Observatory spacecraft) solar watchdog is positioned there. Launched in 1995, SOHO was designed by NASA and the European Space Agency to study the Sun’s effects on the Earth. The SOHO follows a “halo” orbit around Earth’s L1, which is 1.53 x 106 km from Earth. From there it has an uninterrupted view of its target the Sun, and its orbital excursions ensure that ground stations are not always pointing right at the noisy Sun for communications.

The Wilkinson Microwave Anisotropy Probe (WMAP) spacecraft resides in a halo orbit near Earth’s L2 (about the same distance from Earth as L1), which is about 1.5 million km from the Earth. It enjoys an uninterrupted view into deep space from L2 location. Its six-month orbit about L2 prevents the Earth’s shadow from ever blocking the craft’s solar arrays.

By collecting microwave radiation from over 13 billion light years away, scientists have been able to precisely determine the age of the universe and its components, and produce substantial evidence supporting the Big Bang theory. The forces acting on WMAP at L2 tend to keep the spacecraft aligned on the Sun-Earth axis, but require course correction to keep from moving toward or away from the Earth.

ESA (European Space Agency) has a number of missions that will make use of this spot in the coming years. L2 will become home to ESA missions such as Herschel, Gaia and the James Webb Space Telescope (JWST). JWST is scheduled to take off in 2018 to look at the first galaxies that formed in the early Universe, connecting the Big Bang to our own Milky Way Galaxy.

Planck, launched in 2009, is the first European mission to study the birth of the Universe. It currently orbits in a Lissajous curve about the second Lagrange point of the Earth-Sun system (L2), with average amplitude of about 400,000 km.

Since the position of L3 lies behind the Sun, any object that may be orbiting there cannot be seen from Earth. As of now, no satellite or observatory is planned to position at Sun-Earth L3.

In 2010, NASA’s Wide-field Infrared Survey Explorer (WISE) telescope finally confirmed the first Trojan asteroid, called 2010 TK7, around Earth’s leading L4. The asteroid is roughly 1,000 feet (300 meters) in diameter. The Sun’s pull causes any object in the L4 and L5 locations to ‘orbit’ the Lagrange point in an 89-day cycle.

STEREO (Solar TERrestrial RElations Observatory), launched in 2006 by NASA, consists of two space-based observatories – one ahead of Earth in its orbit (L4), the other trailing behind (L5). With this new pair of viewpoints, scientists will be able to see the structure and evolution of solar storms as they blast from the Sun and move out through space.

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