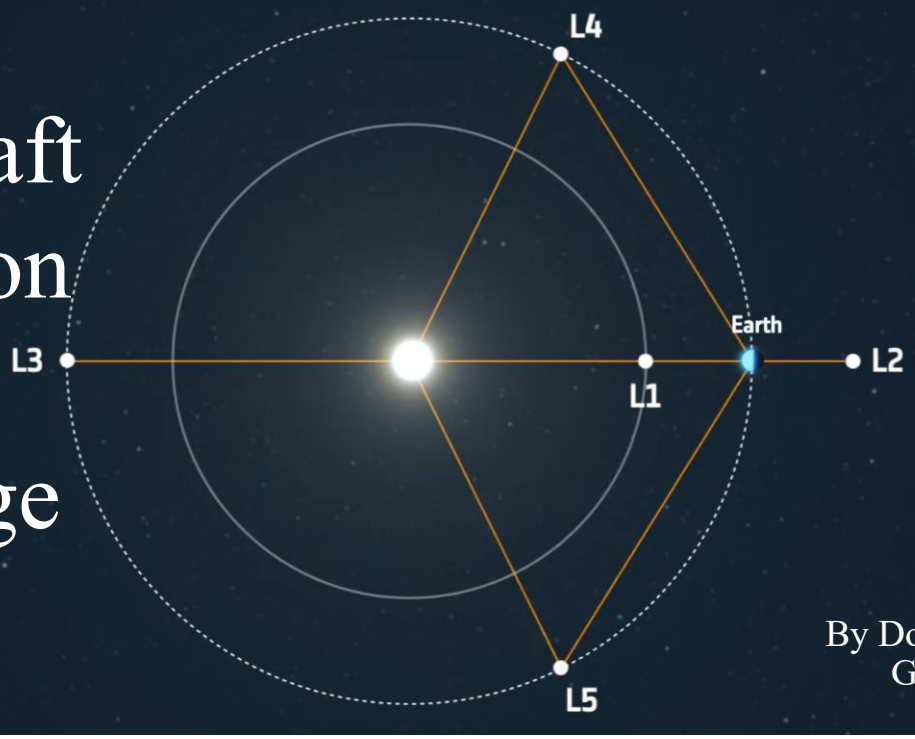
Spacecraft utilisation of Lagrange points

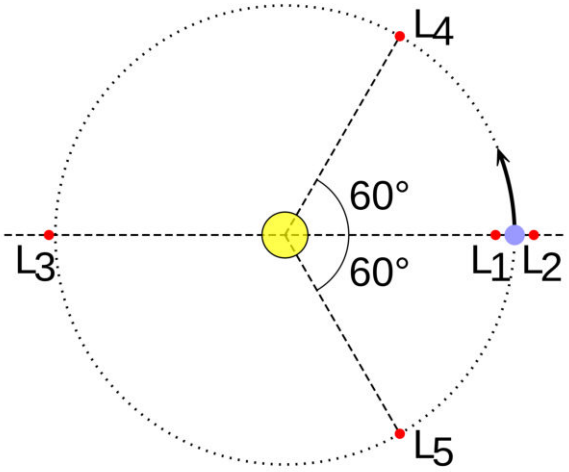


By Don Hillger and Garry Toth

Introduction

The use of Lagrange points or Lagrange orbits is common for certain types of spacecraft missions. After a brief explanation of Lagrange points for the Sun and Earth, there will be discussion of some of the spacecraft that orbit these Lagrange points yet remain basically stationary with respect to both the Sun and the Earth.

The following diagram shows the five Lagrange points for the Sun and Earth. The same type of diagram applies to the Sun and other planets, as well as to Earth and the Moon. The three points in a straight line (L1, L2, and L3) are referred to as the co-linear Lagrange points. L1 and L2 are on each side of Earth in line with the Sun, whereas L3 is on the opposite side of the Sun from Earth. The other two triangular Lagrange points (L4 and L5) form the third vertex of an equilateral triangle with the main two masses of the system. These points are equal distances ahead and behind Earth as it orbits around the Sun. Note the arrow on Earth's orbit, indicating the orbit direction, with L4 and L5 leading and trailing the Earth by 60 degrees, respectively. While L4 and L5 are stable equilibrium points, L1 thru L3 are intrinsically unstable equilibrium points, about which spacecraft can orbit to maintain stability.



In the context of a three-body problem, it is easier to consider the two more massive bodies to be fixed, and then calculate the location in orbit of the third body with respect to the other two. In 1760, Leonard Euler noted the existence of stationary points L1, L2, and L3. Then, in 1772, Joseph Louis Lagrange predicted the points L4 and L5. Neither Euler nor Lagrange provided a diagram of any of these points. Subsequently, these points were named to give credit to Lagrange, but Euler also contributed to the concept. Postage stamps from East Germany and France are provided depicting Euler and Lagrange, respectively. The authors also have online information about both of these men, in their website noted at the end of this article.

Germany (East) *Scott* 353 *Michel* 575 (1957) depicting Euler; France *Scott* 869 *Michel* 1182 (1958) with Lagrange.

These Lagrange points are important positions for certain types of observations, mostly astronomical or solar-observing, by spacecraft positioned at these points. Concerning actual distances, L1 and L2 are located about 1.5 million km from Earth, L3 is about 300 million km (about 2 au) from Earth, and L4 and L5 are about 30 million km from Earth.

Spacecraft at the Sun-Earth L2 point

A recent and famous spacecraft found at a Lagrange point is the **James Webb Space Telescope (JWST)** launched in late 2021. It arrived at L2 30 days later. For that reason, we start our discussion with the L2 point, on the side of Earth away from the Sun. The L2 point provides significant distance and therefore isolation from Earth's heat. JWST is an infrared-observing telescope, with wavelengths out to 28,500 nm (nanometers). A tremendous amount of effort was put into the JWST design to keep the instruments as cold as possible. To stay sufficiently cool, it needs to be far away from heat sources such as Earth, whose radiation peaks at about 10 μm or 10,000 nm, well within the wavelength range of the instrument. (In contrast, the Hubble Space Telescope orbits at less than 600 km above Earth. HST cameras employ near-infrared wavelengths out to 1700 nm, which are not as vulnerable to Earth's heat). USA's JWST postage stamp from 2022 is one of the many postal items depicting this spacecraft.

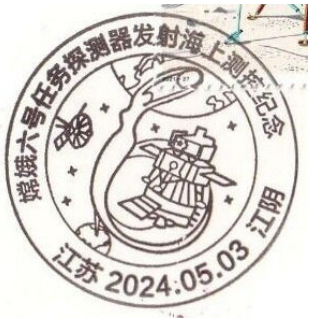
United States *Scott* 5720 *Michel* 5971 (2022).

Since L2 is an intrinsically unstable equilibrium point, JWST orbits about it in what is known as a "halo orbit", which is maintained using minimal spacecraft thrust. (Halo orbits can be used by spacecraft to maintain position at the L1, L2, or L3 points. For more detailed information on them, see https://en.wikipedia.org/wiki/Halo_orbit.) The JWST thrusters have a lifetime of at least 10 years, and the JWST active cryo-cooler (heat pump) is not subject to running out of expendable coolant, so the telescope should be operational for many years to come.

Other currently operational spacecraft at the L2 location are two ESA astronomical spacecraft, the **Global Astrometric Interferometer for Astrophysics (GAIA, or Gaia)**, launched in 2013, and **Euclid**, launched in 2023. The GAIA mission is to construct the largest and most precise catalog of space objects ever built: stars, planets, comets, asteroids, quasars, etc. The Euclid mission is designed to measure the accelerating expansion of the universe. Postage stamps are provided depicting each of these spacecraft.

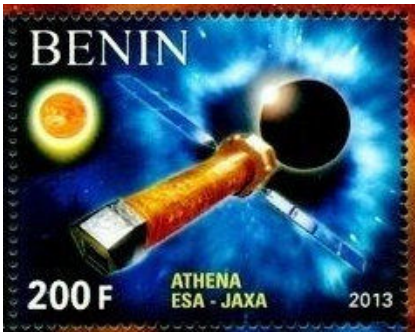
(left) Jersey (Great Britain) *Scott* 1959 *Michel* 2033 (2016) depicting GAIA;
(right) Mali, no *Scott* or *Michel* numbers [known illegal issue] (2018) with Euclid.

The joint Russian-German high-energy astrophysics observatory **Spektr-RG**, launched in 2019, also orbits the L2 point. It was designed to conduct an X-ray survey of the universe and to map and detect new clusters of galaxies and active galactic nuclei. The Chinese **Chang'e-6** lunar orbiter launched in 2024 was re-assigned to L2 after delivering a re-entry module to Earth with lunar samples. A postage stamp and a pictorial cancel are provided depicting these two spacecraft, respectively.



(left) Russia *Scott* 8170b *Michel* 2876 (2020) depicting Spektr-RG;
(right) China (PR) pictorial cancel (2024) with Chang'e-6 orbiter and lander.

A spacecraft that will be launched in 2027 to the L2 point is the **Wide-Field InfraRed Survey Telescope (WFIRST)**. In 2022 it was renamed the **Nancy Grace Roman Space Telescope (NGRST)**. It has been designed to address cutting-edge questions in cosmology and exoplanet research. Also proposed for L2, in 2035, is ESA's **Advanced Telescope for High-ENergy Astrophysics (ATHENA)** spacecraft. Its mission will be to map and determine the physical properties of hot gas structures and supermassive black holes. Postage stamps are provided depicting each of these spacecraft.



(left) Mali, no *Scott* or *Michel* numbers (2020), depicting WFIRST;
(right) Benin, no *Scott* or *Michel* numbers (2013), with ATHENA.

A few other spacecraft have occupied the L2 point for part of their lifetime but are no longer positioned there. Afterwards, they were moved to other orbits to avoid being hazards and endangering future missions. They included **WMAP/Explorer-80, Wind, HSO/Herschel, Planck**, and **Chang'e-2**. These missions will not be discussed here but are mentioned for readers who are interested in a more complete list.

Spacecraft at the Sun-Earth L1 point

The Sun-Earth L1 point is the same distance from Earth as L2 but is on the side of the Earth towards the Sun. This is a preferred location for solar-observing spacecraft.

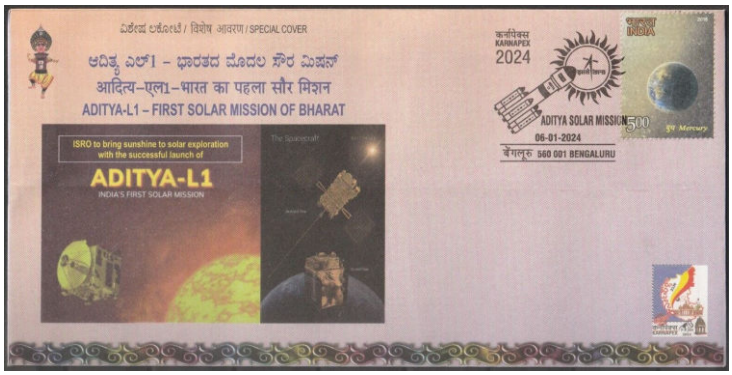
ESA's **SOlar and Heliospheric Observatory (SOHO)**, launched to L1 in 1995, is still observing the solar wind and the outer layers of the Sun. Similarly, NASA's **Advanced Composition Explorer (ACE)/ Explorer-71** has been observing the Sun from orbit around L1 since 1997. Postage stamps are provided depicting each of these spacecraft.

(left) Mali, no *Scott* or *Michel* numbers [known illegal issue] (2015) depicting SOHO;
(right) Guinea Republic *Michel* 4544A (2006) with ACE/Explorer-71.

The American **Deep Space Climate ObserVatoRy (DSCOVR)**, launched in 2015, orbits at Sun-Earth L1. It was unofficially known as "GoreSat" when proposed by Vice President Albert Gore in 1998. First named **Triana**, it was to be launched on the STS-107 mission in 2003 but was placed in storage for many years until being given a new mission, part of which was to image Earth at 10 different wavelengths from the L1 location. DSCOVR continuously monitors Earth but is not a geostationary satellite. It "sees" Earth rotating and so does not make the type of time-sequence loops that geostationary satellites provide for meteorological purposes. A DSCOVR mission patch from a launch cover is provided.

DSCOVR mission patch (from a DSCOVR launch cover, 2015).

Aditya-L1 was launched in 2023 and reached L1 orbit in 2024. It is an Indian/ ISRO solar-observing spacecraft designed to study the solar atmosphere, solar magnetic storms, and their environmental impact on Earth. A postal cover is provided depicting Aditya-L1 in both the pictorial cancel and the printed cachet.



Indian cover with printed cachet for Aditya-L1 and pictorial cancel with the date of the arrival at Sun-Earth L1 on 6 Jan 2024.

A proposed spacecraft destined for the Sun-Earth L1 point will be one of the Chinese (PR) Kuafu Project (https://en.wikipedia.org/wiki/Kuafu_project) series, the first of which was launched in 2022 as **ASO-S (Advanced Space-based Solar Observatory)/Kuafu-1** into a sun-synchronous orbit. The launch date for the future Kuafu to be placed into L1 orbit has not yet been determined. A China/PR postage stamp showing ASO-S/Kuafu-1 is provided.

China (PR) *Scott* 5009 *Michel* 5538 (2023) depicting ASO-S/ Kuafu-1.

Other spacecraft that have utilised the L1 point in the past are **ISEE-3/ICE, Genesis, LISA-Pathfinder**, and **Chang'e-5** on an extended mission after orbiting the Moon. Those spacecraft will not be discussed further here but are mentioned to provide a more complete list for the interested reader.

Spacecraft at Sun-Earth L4 and L5 points

No spacecraft are known to orbit at Sun-Earth L3, on the opposite side of the Sun from Earth. Direct communications with Earth would be impossible because of blockage by the Sun. Nor have any celestial objects gathered at this point over time.

The two remaining Lagrange points, L4 and L5, have hosted some interesting spacecraft. USA's two **Solar-TErrestrial RElations Observatory (STEREO-A and STEREO-B)** spacecraft, launched in 2005, orbit the Sun slightly faster and slightly slower than the Earth, respectively. Although the two spacecraft are not currently at the L4 and L5 points, they have passed through those points in their lifetimes. **STEREO-A and B** take images of the Sun from solar orbit, but at view angles significantly different from that from Earth, to monitor solar flares and coronal mass ejections all around the Sun.

The Spitzer Space Telescope (SST), launched in 2003 but deactivated in 2020, also orbits the Sun in an Earth-trailing heliocentric orbit. (SST is one of four NASA "Great Observatories", which was the topic of our article in the Spring 2022 issue of *Astrofax* at https://rammb.cira.colostate.edu/dev/hillger/pdf/NASA's_Great_Observatories.pdf.) The infrared space telescope on SST, like JWST, needs to stay away from Earth's heat. During its lifetime, Spitzer's Earth-trailing orbit passed L5 and the spacecraft continues to drift away from the Sun. Postage stamps are provided depicting these spacecraft.

(left) Guinea Republic *Michel* 4539A (2006) depicting STEREO-A and B;
(right) Sierra Leone *Scott* 2931a *Michel* 5122 (2009) with Spitzer/SST.

Spacecraft at the Earth-Moon L2 point

Like the Sun and Earth, Earth and the Moon have Lagrange points that function similarly. The Earth-Moon L2 point was occupied by the five **THEMIS- P1/P5 (Time History of Events and Macroscale Interactions during Sub-storms)** spacecraft. Two of them were renamed **ARTEMIS (Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun)** for extended operations in 2011, during which time they were the first spacecraft to achieve orbit around the Earth-Moon L2 point. The two spacecraft were later moved into lunar orbit. A postage stamp is provided depicting two of the THEMIS spacecraft, not necessarily the two that were renamed ARTEMIS.

Gabon, no *Scott* or *Michel* numbers [known illegal issue] (2016) depicting two THEMIS spacecraft.

The **Chang'e-5-T1** spacecraft, after deploying its test return capsule back to Earth, was moved to the Earth-Moon L2 point in 2015 for exploring that orbit for future use, and **Queqiao-1**, a communications relay satellite for Chinese lunar missions, was sent to the Earth-Moon L2 point on the far side of the Moon in 2018. It is thus able to relay communications to Earth from the far side of the Moon. Postage stamps are provided depicting each of these spacecraft.

(left) One label from China (PR) *Scott* 3846A_ms5 *Michel* A4181_ms5 (2014) depicting Chang'e-5-T1 orbiter;
(right) Guinea-Bissau *Michel* 11612 (2020) with Queqiao-1 providing communications for the Chang'e-4 lander.

Spacecraft at the Earth-Moon L4 and L5 points

The only spacecraft known to have utilized the Earth-Moon L4 and L5 points was **Muses-A/Hiten**. It followed a low energy trajectory to achieve lunar orbit by passing through those Lagrange points. Hiten was the first lunar probe launched by a country other than the Soviet Union or the USA. A postage stamp is provided depicting Hiten, incorrectly depicted in association with an astronaut.

Lower-center margin from St. Thomas *Scott* 2138 *Michel* 4135-4138 (2009) depicting Muses-A/Hiten, as well as a bogus astronaut.

Other Lagrange points

The **Lucy** spacecraft, launched in 2021, is tasked with exploring seven of the Trojan asteroids, some of which lead Jupiter by 60 degrees at the Sun-Jupiter L4 point (the "Trojan camp") and others which trail Jupiter by 60 degrees at the L5 point (the "Greek camp"). After visiting the Greek camp Trojans at L5, Lucy will actually head back to Earth in 2030 to receive a gravitational slingshot toward the leading Trojans at Jupiter's L4 point. It will arrive there in 2033. A postage stamp is provided depicting Lucy.

Sierra Leone, no *Scott* or *Michel* numbers (2023), depicting the Lucy spacecraft.

Summary

The following table summarises the spacecraft in the order that they were discussed in this article. They are arranged by their Lagrange points. Among the spacecraft utilising the Lagrange points, most are either astronomical or for solar observing. Only a few are for other types of scientific missions. One postal item was provided to illustrate each spacecraft that was featured in some detail. The table notes other spacecraft besides the ones that are discussed in this article. They are included for a more complete list and for readers interested in doing further research.

Lagrange point	Spacecraft
Sun-Earth L2	JWST, GAIA/Gaia, Euclid, Spektr-RG, Chang'e-6 (extended mission), WFIRST/NGRST, ATHENA/Athena
	(the following were **not** discussed here) WMAP/ Explorer-80, Wind, HSO/Herschel, Planck, and Chang'e-2 (extended mission)
Sun-Earth L1	SOHO, ACE/Explorer-71, DSCOVR/"GoreSat"/Triana, Aditya-L1, (future) ASO-S/Kuafu-1
	(the following were **not** discussed here) ISEE-3/ICE, Genesis, LISA-Pathfinder, Chang'e-5 (extended mission)
Sun-Earth L4 and L5	STEREO-A, STEREO-B, Spitzer/SST
Earth-Moon L2	THEMIS-P1/P5 / Explorer-85/89 / ARTEMIS-P1/P2 (only two of THEMIS), Chang'e-5-T1 (extended mission), Queqiao-1
	(the following was **not** discussed here) EQUULEUS (nanosat)
Earth-Moon L4 and L5	Muses-A/Hiten
Sun-Jupiter L4 and L5	Lucy (to study Jupiter's Trojan asteroids)

Biographical notes

The authors have researched and written extensively on the subjects of weather, climate, and un-manned spacecraft on stamps and covers, as well as other topics. Their Un-manned Spacecraft Philately website can be found at http://rammb.cira.colostate.edu/dev/hillger/satellites.htm. Links to our collections for Euler and Lagrange can be found at https://rammb.cira.colostate.edu/dev/hillger/meteorologist.htm. Email correspondence with the authors is welcome, using the addresses below.

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