SAMPLE

Worlds Beyond Earth: Trojan Asteroids

Hidden Worlds in Lagrange's Shadow

Aira Astralis

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Conclusion

This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

In astronomy, a trojan is a small celestial body (mostly asteroids) that shares the orbit of a larger body, remaining in a stable orbit approximately 60 degrees ahead of or behind the main body near one of its Lagrangian points L4 and L5. Trojans can share the orbits of planets or of large moons. Trojans are one type of co-orbital object.

In this arrangement, a star and a planet orbit about their common barycenter, which is close to the center of the star because it is usually much more massive than the orbiting planet. In turn, a much smaller mass than both the star and the planet, located at one of the Lagrangian points of the star-planet system, is subject to a combined gravitational force that acts through this barycenter.

Hence the smallest object orbits around the barycenter with the same orbital period as the planet, and the arrangement can remain stable over time. In the Solar System, most known trojans share the orbit of Jupiter. They are divided into the Greek camp at L4 (ahead of Jupiter) and the Trojan camp at L5 (trailing Jupiter). More than a million Jupiter trojans larger than one kilometer are thought to exist, of which more than 7,000 are currently catalogued.

In other planetary orbits only nine Mars trojans, 31 Neptune trojans, two Uranus trojans, two Earth trojans, and one Saturn trojan have been found to date. Venus, too, has hosted a short-lived camp member, while simulations argue that Saturn's own points, destabilized by its massive neighbors, can keep nothing for long. The same arrangement can appear when the primary object is a planet and the secondary is one of its moons, whereby much smaller trojan moons can share its orbit.

A temporary Venus trojan is also known.

All known trojan moons are part of the Saturn system. Telesto and Calypso are trojans of Tethys, and Helene and Polydeuces of Dione. In 1772, the Italian-French mathematician and astronomer Joseph-Louis Lagrange obtained two constant-pattern solutions (collinear and equilateral) of the general three-body problem. In the restricted three-body problem, with one mass negligible (which Lagrange did not consider), the five possible positions of that mass are now termed Lagrange points.

On February 12th, 1906, Max Wolf discovered the trojan asteroid 588 Achilles; His contemporary Carl Charlier noticed that the asteroid was caught in the L4 point of Jupiter, and thus 588 Achilles was the first discovered instance of Lagrange's theoretical calculations applying in practice. The term "trojan"

originally referred to the "trojan asteroids" (Jovian trojans) that orbit close to the Lagrangian points of Jupiter. These have long been named for figures from the Trojan War of Greek mythology.

By convention, the asteroids orbiting near the L4 point of Jupiter are named for the characters from the Greek side of the war, whereas those orbiting near the L5 of Jupiter are from the Trojan side. There are two exceptions, named before the convention was adopted: 624 Hektor in the L4 group, and 617 Patroclus in the L5 group. Astronomers estimate that the Jovian trojans are about as numerous as the asteroids of the asteroid belt.

Later on, objects were found orbiting near the Lagrangian points of Neptune, Mars, Earth, Uranus, and Venus. Minor planets at the Lagrangian points of planets other than Jupiter may be called Lagrangian minor planets.

Four Martian trojans are known: 5261 Eureka, (101429) 1998 VF31, (311999) 2007 NS2, and (121514) 1999 UJ7 - the only trojan body in the leading "cloud" at L4, There seem to be, also, (385250) 2001 DH47, (816688) 2011 SC191, and 2011 UN63, but these have not yet been accepted by the Minor Planet Center. There are 28 known Neptunian trojans, but the large Neptunian trojans are expected to outnumber the large Jovian trojans by an order of magnitude.

The road through this book follows that arc. The opening chapters set out the mechanics: what a Lagrange point is, why the geometry of three bodies makes some orbits permanent, and how the first camp members were told apart from ordinary asteroids. Later chapters walk the camps planet by planet, from the teeming swarms at Jupiter to the lonely singletons that ride with Saturn, and from the famous 2010 TK7 at Earth's side to the candidates still being argued over.

The measurement story follows, because trojans are dark and slow to give up their sizes, compositions, and histories; every confident number in these pages rests on a clever workaround. The exploration story follows that: Lucy, the first mission sent to fly past trojan worlds, and the surveys that will keep the census growing long after its tour ends. The closing chapters take stock of the riddles the camps still guard.

One idea threads through all of it. Stability in the sky is not a quiet default but a narrow achievement; the trojans sit where disturbance has tried and failed for four billion years. Watching them is the closest thing to watching the Solar System keep a promise.

Chapter 01: The Discovery of Trojan Asteroids

The search began with a prediction. Joseph-Louis Lagrange showed in 1772 that a small body could share a planet's orbit, riding at one of two gravitationally quiet points 60 degrees ahead of or behind it, and in 1906 the German astronomer Max Wolf finally caught one: 588 Achilles, holding position at Jupiter's leading point. (706765) 2010 TK7 was confirmed in 2011 as the first known trojan of our own planet, a faint companion riding ahead of Earth in its travels.

A second candidate, (636872) 2014 YX49, was announced in 2017, and small temporary companions of Venus, of Mars' neighbors, and even of the dwarfs Ceres and Vesta have been suspected as well. 2013 ND15 is a temporary Venusian trojan, the first one to be identified. The large asteroids Ceres and Vesta have temporary trojans. Saturn has 1 known trojan in the L4 Lagrangian point, 2019 UO14.

Whether or not a system of star, planet, and trojan is stable depends on how large the perturbations are to which it is subject. If, for example, the planet is the mass of Earth, and there is also a Jupiter-mass object orbiting that star, the trojan's orbit would be much less stable than if the second planet had the mass of Pluto.

As a rule of thumb, the system is likely to be long-lived if m1 > 100m2 > 10,000m3 (in which m1, m2, and m3 are the masses of the star, planet, and trojan). More formally, in a three-body system with circular orbits, the stability condition is 27(m1m2 + m2m3 + m3m1) < (m1 + m2 + m3)2. So the trojan being a mote of dust, m3 to 0, imposes a lower bound on m1/m2 of 25+sqrt621/2 ~ 24.9599.

And if the star were hyper-massive, m1 to +infinity, then under Newtonian gravity, the system is stable whatever the planet and trojan masses. And if m1/m2 = m2/m3, then both must exceed 13+sqrt168 ~ 25.9615. However, this all assumes a three-body system; once other bodies are introduced, even if distant and small, stability of the system requires even larger ratios.

Caught bodies do not sit pinned at their points; they wander around them. Seen from Jupiter, a trojan traces a stretched loop, now edging ahead, now falling back, coiling around the stable point the way a pendulum swings about its rest position. Astronomers borrowed a name for the shape: the tadpole orbit, because plotted against the planet the loops genuinely resemble fat-headed tadpoles nudging each other along the road. A wider dance, the horseshoe orbit, swings a body clear across both points in one long arc, and at least one small neighbor of Earth is known to travel that way around us. The

Jupiter trojans themselves form two great swarms, one riding sixty degrees ahead of the planet and one trailing by the same amount, each swarm a curved, elongated province of its own.

Jupiter trojans are distributed in two elongated, curved regions around these Lagrangian points with an average semi-major axis of about 5.2 AU. The first Jupiter trojan discovered, 588 Achilles, was spotted in 1906 by German astronomer Max Wolf. More than 15,300 Jupiter trojans have been found as of October 2025. By convention, they are each named from Greek mythology after a figure of the Trojan War, hence the name "trojan".

The total number of Jupiter trojans larger than 1 km in diameter is believed to be about 1 million, approximately equal to the number of asteroids larger than 1 km in the asteroid belt. Like main-belt asteroids, Jupiter trojans form families. As of 2004, many Jupiter trojans showed to observational instruments as dark bodies with reddish, featureless spectra.

The term "Trojan asteroid" specifically refers to the asteroids co-orbital with Jupiter, but the general term "trojan" is sometimes more generally applied to other small Solar System bodies with similar relationships to larger bodies: Mars trojans, Neptune trojans, Uranus trojans and Earth trojans are known to exist. Temporary Venus trojans and Saturn trojans exist, as well as for 1 Ceres and 4 Vesta.

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ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.