Jupiter trojan

The Jupiter trojans , commonly called Trojan asteroids or just Trojans , are a large group of asteroids that share the orbit of the planet Jupiter around the Sun . Relative to Jupiter , each trojan librates around one of Jupiter 's two stable Lagrangian points , L4 , lying 60 ° ahead of the planet in its orbit , and L5 , 60 ° behind . 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 . A total of 6 @,@ 178 Jupiter trojans have been found as of January 2015 . By convention they are each named after a mythological figure from 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 .
Jupiter trojans are dark bodies with reddish , featureless spectra . No firm evidence of the presence of water , or any other specific compound on their surface has been obtained , but it is thought that they are coated in tholins , organic polymers formed by the Sun 's radiation . The Jupiter trojans ' densities (as measured by studying binaries or rotational lightcurves) vary from 0 @.@ 8 to 2 @.@ 5 g · cm ? 3 . Jupiter trojans are thought to have been captured into their orbits during the early stages of the Solar System 's formation or slightly later , during the migration of giant planets .
The term " trojan " has come to be used more generally to refer to other small Solar System bodies with similar relationships to larger bodies : for example , there are both Mars trojans and Neptune trojans , and Saturn has trojan moons . NASA has announced the discovery of an Earth trojan . The term " Trojan asteroid " is normally understood to specifically mean the Jupiter trojans because the first Trojans were discovered near Jupiter 's orbit and Jupiter currently has by far the most known Trojans .

Observational history

In 1772 , Italian @-@ born mathematician Joseph @-@ Louis Lagrange , in studying the restricted three @-@ body problem , predicted that a small body sharing an orbit with a planet but lying 60 ° ahead or behind it will be trapped near these points . The trapped body will librate slowly around the point of equilibrium in a tadpole or horseshoe orbit . These leading and trailing points are called the L4 and L5 Lagrange points . However , no asteroids trapped in Lagrange points were observed until more than a century after Lagrange 's hypothesis . Those associated with Jupiter were the first to be discovered .
E. E. Barnard made the first recorded observation of a trojan , (12126) 1999 RM11 (identified as A904 RD at the time) , in 1904 , but neither he nor others appreciated its significance at the time . Barnard believed he saw the recently discovered Saturnian satellite Phoebe , which was only two arc @-@ minutes away in the sky at the time , or possibly an asteroid . The object 's identity was not realized until its orbit was calculated in 1999 .
The first recognized discovery of a trojan occurred in February 1906 , when astronomer Max Wolf of Heidelberg @-@ Königstuhl State Observatory discovered an asteroid at the L4 Lagrangian point of the Sun ? Jupiter system , later named 588 Achilles . In 1906 ? 1907 two more Jupiter trojans were found by fellow German astronomer August Kopff (624 Hektor and 617 Patroclus) . Hektor , like Achilles , belonged to the L4 swarm (" ahead " of the planet in its orbit) , whereas Patroclus was the first asteroid known to reside at the L5 Lagrangian point (" behind " the planet) . By 1938 , 11 Jupiter trojans had been detected . This number increased to 14 only in 1961 . As instruments improved , the rate of discovery grew rapidly : by January 2000 , a total of 257 had been discovered ; by May 2003 , the number had grown to 1 @,@ 600 . As of February 2014 there are 3 @,@ 898 known Jupiter trojans at L4 and 2 @,@ 049 at L5,

Nomenclature

The custom of naming all asteroids in Jupiter 's L4 and L5 points after famous heroes of the Trojan War was suggested by Johann Palisa of Vienna , who was the first to accurately calculate their orbits . Asteroids in the L4 group are named after Greek heroes (the " Greek node or camp " or " Achilles group ") , and those at the L5 point are named after the heroes of Troy (the " Trojan node or camp ") . Confusingly , 617 Patroclus was named before the Greece / Troy rule was devised , and a Greek name thus appears in the Trojan node . The Greek node also has one " misplaced " asteroid , 624 Hektor , named after a Trojan hero .

= = Numbers and mass = =

Estimates of the total number of Jupiter trojans are based on deep surveys of limited areas of the sky . The L4 swarm is believed to hold between 160 ? 240 @,@ 000 asteroids with diameters larger than 2 km and about 600 @,@ 000 with diameters larger than 1 km . If the L5 swarm contains a comparable number of objects , there are more than 1 million Jupiter trojans 1 km in size or larger . For the objects brighter than absolute magnitude 9 @.@ 0 the population is probably complete . These numbers are similar to that of comparable asteroids in the asteroid belt . The total mass of the Jupiter trojans is estimated at 0 @.@ 0001 of the mass of Earth or one @-@ fifth of the mass of the asteroid belt .

Two more recent studies indicate , however , that the above numbers may overestimate the number of Jupiter trojans by several @-@ fold . This overestimate is caused by (1) the assumption that all Jupiter trojans have a low albedo of about 0 @.@ 04 , whereas small bodies may actually have an average albedo as high as 0 @.@ 12 ; (2) an incorrect assumption about the distribution of Jupiter trojans in the sky . According to the new estimates , the total number of Jupiter trojans with a diameter larger than 2 km is 6 @.@ 3 ± 1 @.@ 0 × 104 and 3 @.@ 4 ± 0 @.@ 5 × 104 in the L4 and L5 swarms , respectively . These numbers would be reduced by a factor of 2 if small Jupiter trojans are more reflective than large ones .

The number of Jupiter trojans observed in the L4 swarm is slightly larger than that observed in L5 . However , because the brightest Jupiter trojans show little variation in numbers between the two populations , this disparity is probably due to observational bias . However , some models indicate that the L4 swarm may be slightly more stable than the L5 swarm .

The largest Jupiter trojan is 624 Hektor , which has an average diameter of 203 ± 3 @.@ 6 km . There are few large Jupiter trojans in comparison to the overall population . With decreasing size , the number of Jupiter trojans grows very quickly down to 84 km , much more so than in the asteroid belt . A diameter of 84 km corresponds to an absolute magnitude of 9 @.@ 5 , assuming an albedo of 0 @.@ 04 . Within the 4 @.@ 4 ? 40 km range the Jupiter trojans ' size distribution resembles that of the main @-@ belt asteroids . An absence of data means that nothing is known about the masses of the smaller Jupiter trojans . The size distribution suggests that the smaller Trojans are the products of collisions by larger Jupiter trojans .

= = Orbits = =

Jupiter Trojans have orbits with radii between 5 @.@ 05 and 5 @.@ 35 AU (the mean semi @-@ major axis is 5 @.@ 2 ± 0 @.@ 15 AU) , and are distributed throughout elongated , curved regions around the two Lagrangian points ; each swarm stretches for about 26 ° along the orbit of Jupiter , amounting to a total distance of about 2 @.@ 5 AU . The width of the swarms approximately equals two Hill 's radii , which in the case of Jupiter amounts to about 0 @.@ 6 AU . Many of Jupiter trojans have large orbital inclinations relative to Jupiter 's orbital plane ? up to 40 ° .

Jupiter trojans do not maintain a fixed separation from Jupiter . They slowly librate around their respective equilibrium points , periodically moving closer to Jupiter or farther from it . Jupiter trojans generally follow paths called tadpole orbits around the Lagrangian points ; the average period of their libration is about 150 years . The amplitude of the libration (along the Jovian orbit) varies from 0 @.@ 6 ° to 88 ° , with the average being about 33 ° . Simulations show that Jupiter trojans can follow even more complicated trajectories when moving from one Lagrangian point to another ?

these are called horseshoe orbits (currently no Jupiter Trojan with such an orbit is known) .

= = = Dynamical families and binaries = = =

Discerning dynamical families within the Jupiter Trojan population is more difficult than it is in the asteroid belt , because the Jupiter trojans are locked within a far narrower range of possible positions . This means that clusters tend to overlap and merge with the overall swarm . However , by 2003 roughly a dozen dynamical families were identified . Jupiter @-@ trojan families are much smaller in size than families in the asteroid belt ; the largest identified family , the Menelaus group , consists of only eight members .

In 2001 , 617 Patroclus was the first Jupiter Trojan to be identified as a binary asteroid . The binary 's orbit is extremely close , at 650 km , compared to 35 @,@ 000 km for the primary 's Hill sphere . The largest Jupiter Trojan ? 624 Hektor ? likely is a contact binary with a moonlet .

= = Physical properties = =

Jupiter trojans are dark bodies of irregular shape . Their geometric albedos generally vary between 3 and 10 % . The average value is 0 @.@ 056 ± 0 @.@ 003 for the objects larger than 57 km , and 0 @.@ 121 ± 0 @.@ 003 (R @-@ band) for those smaller than 25 km . The asteroid 4709 Ennomos has the highest albedo (0 @.@ 18) of all known Jupiter trojans . Little is known about the masses , chemical composition , rotation or other physical properties of the Jupiter trojans .

= = = Rotation = = =

The rotational properties of Jupiter trojans are not well known . Analysis of the rotational light curves of 72 Jupiter trojans gave an average rotational period of about 11 @.@ 2 hours , whereas the average period of the control sample of asteroids in the asteroid belt was 10 @.@ 6 hours . The distribution of the rotational periods of Jupiter trojans appeared to be well approximated by a Maxwellian function , whereas the distribution for main @-@ belt asteroids was found to be non @-@ Maxwellian , with a deficit of periods in the range 8 ? 10 hours . The Maxwellian distribution of the rotational periods of Jupiter trojans may indicate that they have undergone a stronger collisional evolution compared to the asteroid belt .

However , in 2008 a team from Calvin College analyzed the light curves of a debiased sample of ten Jupiter trojans , and found a median spin period of 18 @.@ 9 hours . This value was significantly higher than that for main @-@ belt asteroids of similar size (11 @.@ 5 hours) . The difference could mean that the Jupiter trojans possess a lower average density , which may imply that they formed in the Kuiper belt (see below) .

= = = Composition = = =

Spectroscopically , the Jupiter trojans mostly are D @-@ type asteroids , which predominate in the outer regions of the asteroid belt . A small number are classified as P or C @-@ type asteroids . Their spectra are red (meaning that they reflect more light at longer wavelengths) or neutral and featureless . No firm evidence of water , organics or other chemical compounds has been obtained as of 2007 . However , 4709 Ennomos has an albedo slightly higher than the Jupiter @-@ trojan average , which may indicate the presence of water ice . In addition , a number of other Jupiter Trojans , such as 911 Agamemnon and 617 Patroclus , have shown very weak absorptions at 1 @.@ 7 and 2 @.@ 3 ?m , which might indicate the presence of organics . The Jupiter trojans ' spectra are similar to those of the irregular moons of Jupiter and , to certain extent , comet nuclei , though Jupiter trojans are spectrally very different from the redder Kuiper belt objects . A Jupiter trojan 's spectrum can be matched to a mixture of water ice , a large amount of carbon @-@ rich material (charcoal) , and possibly magnesium @-@ rich silicates . The composition of the Jupiter trojan population appears to be markedly uniform , with little or no differentiation between the two

swarms .
A team from the Keck Observatory in Hawaii announced in 2006 that it had measured the density of the binary Jupiter trojan 617 Patroclus as being less than that of water ice (0 @.@ 8 g / cm3) , suggesting that the pair , and possibly many other Trojan objects , more closely resemble comets or Kuiper belt objects in composition ? water ice with a layer of dust ? than they do the main @-@ belt asteroids . Countering this argument , the density of Hektor as determined from its rotational lightcurve (2 @.@ 480 g / cm3) is significantly higher than that of 617 Patroclus . Such a difference in densities is puzzling and indicates that density may not be a good indicator of asteroid origin .

= = Origin and evolution = =

Two main theories have emerged to explain the formation and evolution of the Jupiter trojans . The first suggests that the Jupiter trojans formed in the same part of the Solar System as Jupiter and entered their orbits while it was forming . The last stage of Jupiter 's formation involved runaway growth of its mass through the accretion of large amounts of hydrogen and helium from the protoplanetary disk ; during this growth , which lasted for only about 10 @,@ 000 years , the mass of Jupiter increased by a factor of ten . The planetesimals that had approximately the same orbits as Jupiter were caught by the increased gravity of the planet . The capture mechanism was very efficient ? about 50 % of all remaining planetesimals were trapped . This hypothesis has two major problems : the number of trapped bodies exceeds the observed population of Jupiter trojans by four orders of magnitude , and the present Jupiter trojan asteroids have larger orbital inclinations than are predicted by the capture model . However , simulations of this scenario show that such a mode of formation also would inhibit the creation of similar trojans for Saturn , and this has been borne out by observation : to date no trojans have been found near Saturn .
The second theory , part of the Nice model , proposes that the Jupiter trojans were captured during planetary migration , which happened about 500 ? 600 million years after the Solar System 's formation . The migration was triggered by the passage of Jupiter and Saturn through the 1 : 2 mean @-@ motion resonance . During this period Uranus , Neptune and to some extent Saturn moved outward , whereas Jupiter moved slightly inward . Migrating giant planets destabilized the primordial Kuiper belt , throwing millions of objects into the inner Solar System . In addition , their combined gravitational influence would have quickly disturbed any pre @-@ existing Jupiter trojans . In this theory , the present Jupiter trojan population eventually accumulated from runaway Kuiper belt objects as Jupiter and Saturn moved away from the resonance .
The long @-@ term future of the Jupiter trojans is open to question , because multiple weak resonances with Jupiter and Saturn cause them to behave chaotically over time . In addition , collisional shattering slowly depletes the Jupiter trojan population as fragments are ejected . Ejected Jupiter trojans could become temporary satellites of Jupiter or Jupiter @-@ family comets . Simulations show that the orbits of up to 17 % of Jupiter trojans are unstable over the age of the Solar System . Levison et al. believe that roughly 200 ejected Jupiter trojans greater than 1 km in diameter might be traveling the Solar System , with a few possibly on Earth @-@ crossing orbits . Some of the escaped Jupiter trojans may become Jupiter @-@ family comets as they approach the Sun and their surface ice begins evaporating .