General Information (Wiki)

# Basics

The Jupiter trojans, commonly called Trojan asteroids or simply Trojans, are a large group of asteroids that share the planet Jupiter's orbit around the Sun. Relative to Jupiter, each Trojan librates around one of Jupiter's two stable Lagrange 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.[1]

The first Jupiter trojan discovered, 588 Achilles, was spotted in 1906 by German astronomer Max Wolf.[2] A total of 7,040 Jupiter trojans have been found as of October 2018.[3] 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.[1] Like main-belt asteroids, Jupiter trojans form families.[4]

# 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.[2] The trapped body will librate slowly around the point of equilibrium in a tadpole or horseshoe orbit.[9] These leading and trailing points are called the L4 and L5 Lagrange points.[10][Note 1] The first asteroids trapped in Lagrange points were observed more than a century after Lagrange's hypothesis. Those associated with Jupiter were the first to be discovered.[2]

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.[11] Barnard believed he had seen 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 understood until its orbit was calculated in 1999.[11]

The first accepted 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.[2] In 1906–1907 two more Jupiter trojans were found by fellow German astronomer August Kopff (624 Hektor and 617 Patroclus).[2] 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).[12] By 1938, 11 Jupiter trojans had been detected.[13] This number increased to 14 only in 1961.[2] As instruments improved, the rate of discovery grew rapidly: by January 2000, a total of 257 had been discovered;[10] by May 2003, the number had grown to 1,600.[14] As of October 2018 there are 4,601 known Jupiter trojans at L4 and 2,439 at L5.[15]

# 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.[2]

Asteroids in the leading (L4) orbit are named after Greek heroes (the "Greek node or camp" or "Achilles group"), and those at the trailing (L5) orbit are named after the heroes of Troy (the "Trojan node or camp").[2] The asteroids 617 Patroclus and 624 Hektor were named before the Greece/Troy rule was devised, resulting in a Greek spy in the Trojan node and a Trojan spy in the Greek node.[13][16]

# Size

The largest Jupiter trojan is 624 Hektor, which has an mean diameter of 203 ± 3.6 km.[14] There are few large Jupiter trojans in comparison to the overall population. This allows us to consider the mass of these asteroids as negligible in gravitational modelling.

# 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;[1] each swarm stretches for about 26° along the orbit of Jupiter, amounting to a total distance of about 2.5 AU.[10] The width of the swarms approximately equals two Hill's radii, which in the case of Jupiter amounts to about 0.6 AU.[9] Many of Jupiter trojans have large orbital inclinations relative to Jupiter's orbital plane—up to 40°.[10]

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.[9] Jupiter trojans generally follow paths called tadpole orbits around the Lagrangian points; the average period of their libration is about 150 years.[10] The amplitude of the libration (along the Jovian orbit) varies from 0.6° to 88°, with the average being about 33°.[9] 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).[9]

#Dynamic orbit stability may be worth further investigation!!

Literature Review

## Origin and Evolution of Trojan Asteroids

<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.681.6034&rep=rep1&type=pdf>

Very useful review of literature, and cites original Lagrange paper.

The regions around the L4 and L5 Lagrangian points of Jupiter are populated by two large swarms of asteroids called the Trojans. They may be as numerous as the main-belt asteroids and their dynamics is peculiar, involving a 1:1 resonance with Jupiter

## On the stability of Trojan Asteroids

<http://articles.adsabs.harvard.edu.ezp.lib.cam.ac.uk/cgi-bin/nph-iarticle_query?1997A%26A...317..254G&defaultprint=YES&filetype=.pdf>

<http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.702.7323> *– bibtex citation*

We reconsider the problem of stability of the triangular Lagrangian equilibria of the restricted problem of three bodies. We consider in particular the Sun–Jupiter model and the Trojan asteroids in the neighbourhood of the point L4. In the spirit of Nekhoroshev’s theory on stability\* over exponentially large times, we are able to prove that stability over the age of the universe is guaranteed on a region big enough to include a few known asteroids. This significantly improves previous works on the same subject.

Previous work has showed stability over the age of the universe is proved in a neighbourhood the size of which is of order 104 Km for the L4 point, however the true stable region is 300-3000 times the size of this.

\*quantises long-time stability of solutions of integrable systems under a small perturbation of the Hamiltonian. doi:10.1007/BF01086753.

## Trojan asteroids: populations, dynamical structure and origin of the L4 and L5 swarms

<https://ui-adsabs-harvard-edu.ezp.lib.cam.ac.uk/abs/1989aste.conf..487S/abstract>

<https://www.researchgate.net/publication/234208547_Trojan_asteroids_-_Populations_dynamical_structure_and_origin_of_the_L4_and_L5_swarms>

Difficult to find full text- here is abstract:

A total of 157 Trojans had been discovered as of mid-1988, 52 of which were numbered. Two-thirds of the known Trojans are in the L4 swarm, where discovery is estimated to be complete to B(1, 0) = 9.75. The L4 population to B(1, 0) = 14 is estimated to be 1000±200. Bright Trojans are about as numerous in the L5 swarm as in L4, but faint L5 Trojans appear to be only 50% as numerous. The total population of Trojans >15 km diameter is roughly half that estimated for main-belt asteroids. Similarity of characteristic orbital parameters among certain Trojans with accurately determined orbits suggests the presence of 5 and possibly as many as 8 collisional groups in the L4 swarm. Further, the magnitude distribution of L4 Trojans probably is a result of strong collisional evolution. The authors suggest that the present Trojans are chiefly fragments of Jupiter planetesimals that were captured during an episode of heavy flux near Jupiter during dispersal of the planetesimal swarm.

Publication:

IN: Asteroids II; Proceedings of the Conference, Tucson, AZ, Mar. 8-11, 1988 (A90-27001 10-91). Tucson, AZ, University of Arizona Press, 1989, p. 487-523.

## Theory of Trojan Asteroids - Part 1

<http://adsabs.harvard.edu.ezp.lib.cam.ac.uk/full/1977AJ.....82..368G>

<http://articles.adsabs.harvard.edu.ezp.lib.cam.ac.uk/cgi-bin/nph-iarticle_query?1977AJ.....82..368G&defaultprint=YES&filetype=.pdf>

More complex mathematical paper regarding the stability of different dynamic orbits – may be useful references for this work, although unlikely to be essential for my report. Possibly useful to reference on more complex dynamic orbits.

This article constructs an analytical long-periodic solution for the case of 1:1 resonance in the restricted problem of three bodies. The solution is of the first order in the mass parameter m, assumed sufficiently small. The solution embraces the families of the tadpole-shaped and the horseshoe-shaped orbits, and is valid except in the neighbourhood of D =0 and \=0. The paper refutes and refines the Brown conjecture (1911) regarding the Lagrangian point L 3.

## Dynamic evolution of Jupiter’s Trojan Asteroids

<https://www-nature-com.ezp.lib.cam.ac.uk/articles/385042a0.pdf?platform=oscar&draft=collection>

TROJAN asteroids, which may outnumber the asteroids in the asteriod belt, are objects that orbit the Sun with the same mean semi-major axis as Jupiter, but lead or trail the position of Jupiter in its orbit by ~ 60°. One very interesting aspect of the Trojan swarms is that a significant number of asteroids are on orbits that analytic theory suggests should be unstable.

Here we present the results of long-term dynamical integrations of the Trojan asteroids, that enable us to investigate the stability of the swarm population. We find that the orbits of the swarm asteroids are not stable indefinitely-the gravitational effects of the giant planets have reduced the swarms' outer boundaries over time. We estimate that there are over 200 escaped Trojan asteroids with diameters > 1 km currently roaming the Solar System, a few of which may be on Earth-crossing orbits.

## The resonant structure of Jupiter's Trojan asteroids – I. Long-term stability and diffusion

<https://academic-oup-com.ezp.lib.cam.ac.uk/mnras/article/372/4/1463/1184958>

We study the global dynamics of the jovian Trojan asteroids by means of the frequency map analysis. We find and classify the main resonant structures that serve as skeleton of the phase space near the Lagrangian points. These resonances organize and control the long-term dynamics of the Trojans. Besides the secondary and secular resonances, that have already been found in other asteroid sets in mean motion resonance (e.g. main belt, Kuiper belt), we identify a new type of resonance that involves secular frequencies and the frequency of the great inequality, but not the libration frequency. Moreover, this new family of resonances plays an important role in the slow transport mechanism that drives Trojans from the inner stable region to eventual ejections. Finally, we relate this global view of the dynamics with the observed Trojans, identify the asteroids that are close to these resonances and study their long-term behaviour.

## Stability of Lagrange Points L4 and L5

<http://pi.math.cornell.edu/~templier/junior/final_paper/Thomas_Greenspan-Stability_of_Lagrange_points.pdf>

Junior research paper, not worth citing but useful maths.

A proof of the stability of the non collinear Lagrange Points, L4 and L5. We will start by covering the basics of stability, stating a theorem (without proof) with a few corollaries, and then turn to the Lagrange points, proving first the stability of all Lagrange points in the z-direction and then restricting our attention to the the points, L4 and L5.

The Complex History of Trojan Asteroids

<https://arxiv.org/ftp/arxiv/papers/1506/1506.01658.pdf>

Provides information on size and composition distributions as well as a summary on evolution.

## Population and Size Distribution of Small Jovian Trojan Asteroids

<https://iopscience-iop-org.ezp.lib.cam.ac.uk/article/10.1086/301453/meta> - for size dist. references

Astronomical data based on 93 Jovian Trojans detected, with radii 2 km ≤ r ≤ 20 km (assumed visual albedo 0.04). Their differential magnitude distribution has a slope of 0.40 ± 0.05, corresponding to a power-law size distribution index 3.0 ± 0.3 (1 σ). The total number of L4 Trojans with radii ≥1 km is of order 1.6 × 105, and their combined mass (dominated by the largest objects) is ~10-4 MEarth. The bias-corrected mean inclination is 13fdg7 ± 0fdg5. We also discuss the size and spatial distribution of the L4 swarm.

## The composition of the Trojan asteroids

<https://doi-org.ezp.lib.cam.ac.uk/10.1038/283840a0> -for composition/albedo references

Physical studies have shown that most asteroids are covered with material of low visual albedo (pv∼0.04) having flat, nearly featureless reflection spectra between 0.4 and 1.1 µm (ref. 1). This large class of objects, the C asteroids, accounts for a progressively larger fraction of minor planets as one goes from the inner to the outer regions of the asteroid belt, a trend which has been interpreted as evidence of a decrease in effective condensation temperature in the original solar nebula with increasing distance from the proto-Sun2. We suggest here that the very low albedos and red spectra of some Trojan asteroids can be explained by the presence of kerogen-like organic compounds. Materials containing these types of carbonaceous substances, rather than those found in the more familiar carbonaceous chondrite matrix, may have been the primary rocky condensate in the outer Solar System and may therefore be typical of the rocky component of comet nuclei.

## Chaotic capture of Jupiter's Trojan asteroids in the early Solar System

<https://doi-org.ezp.lib.cam.ac.uk/10.1038/nature03540> - – for formation references

Formation of Trojan asteroid belt is not particularly well understood, particularly how such a wide angular distribution (circa 40 degrees) was formed. This paper suggests a formation mechanism in the early universe, where the Trojans could have formed in more distant regions and been subsequently captured into co-orbital motion with Jupiter during the time when the giant planets migrated by removing neighbouring planetesimals. The capture was possible during a short period of time, just after Jupiter and Saturn crossed their mutual 1:2 resonance, when the dynamics of the Trojan region were completely chaotic. Our simulations of this process satisfactorily reproduce the orbital distribution of the Trojans and their total mass.