THE EXPANSE

System

December 10, 2020

Contents

List of notable Solar System bodies and distances between them for communication and travel. This is a living document: positions of bodies change over the time. Effective date can be seen in the image and table titles.

1 Inner System

The inner system map shows positions of notable objects inside Jupiter's orbit. Future orbit positions are displayed for some bodies at one month intervals.

Tycho Station The Belt headquarters of Tycho Manufacturing and Engineering Concern is the largest mobile construction platform in the Sol System. Fifteen thousand workers and their families live within Tycho, building megastructures or massive ships far beyond the reach of a planet.

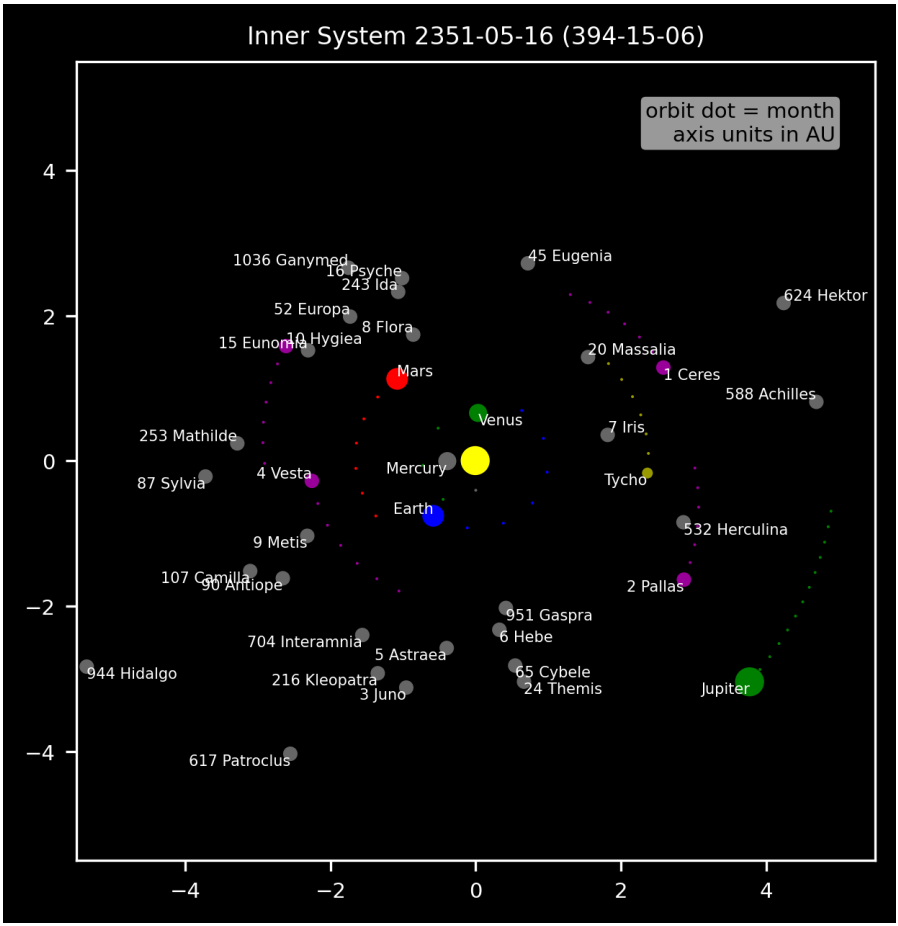
1.1 Colonized Asteroids

1 Ceres The only dwarf planet in the inner solar system, and the first asteroid discovered by humanity. Only object in the asteroid belt rounded by its own gravity. Tycho corporation spun up the asteroid in a dramatic feat of engineering, granting it a gravity of 0.3g. Now the most important port of call in the Belt with population of approximately six million permanent residents

2 Pallas The third largest asteroid in the Asteroid Belt, and the second asteroid discovered by humanity. It hosts one of the oldest stations, Pallas Station, in the outer planets, but is also known for a revolt at its colony. The station itself has a long history of a refinement station for the mining operations of the Belt. Due to this legacy, it continues to have its infrastructure maintained and upgraded, making use of its older equipment as overflow capacity.

4 Vesta The second-most-massive asteroid in the Asteroid Belt after Ceres and the only known remaining rocky protoplanet of the kind that formed the terrestrial planets. It hosts one of the largest settlements in the outer planets. At some time during the UN-MCR Cold War, Vesta was the site of the Vesta Blockade, a confrontation between the UN and MCR that would delay the Martian terraforming efforts for over a century.

10 Hygiea The fourth largest asteroid in the Asteroid Belt and somewhat oblong. It hosts Hygeia Station. Like many places in the Belt, its population suffered from high UN taxes that made survival expensive and kept the population routinely destitute.



1.2 Other Notable asteroids

3 Juno One of the two largest stony asteroids, along with 15 Eunomia. It contains about 1% of the total mass of the Asteroid Belt. Its orbit has an extreme eccentricity which brings Juno closer to the Sun at perihelion than Vesta and further out at aphelion than Ceres.

5 Astraea The fifth asteroid discovered. Physically unremarkable but notable because after its discovery, thousands of other asteroids would follow. The discovery of Astraea proved to be the starting point for the eventual demotion of the four original asteroids (which were regarded as planets at the time) to their current status.

6 Hebe Large main-belt asteroid, containing around 0.5% of the mass of the Belt. This high bulk density means an extremely solid body that has not been impacted by collisions, which is not typical of asteroids of its size. In brightness, Hebe is the fifth-brightest object in the Asteroid Belt.

7 Iris Large main-belt asteroid orbiting the Sun between Mars and Jupiter. It is the fourth-brightest object in the asteroid belt. It is classified as an S-type asteroid, meaning that it has a stony composition.

8 Flora Large, bright main-belt asteroid. It is the innermost large asteroid: no asteroid closer to the Sun has a diameter above 25 kilometres or two-elevenths that of Flora itself, and not until the tiny 149 Medusa was discovered was a single asteroid orbiting at a closer mean distance known.

9 Metis One of the larger main-belt asteroids. It is composed of silicates and metallic nickel-iron, and may be the core remnant of a large asteroid that was destroyed by an ancient collision. Metis is estimated to contain just under half a percent of the total mass of the Asteroid Belt.

15 Eunomia The largest of the stony asteroids. Eunomian family is the most prominent family in the intermediate asteroid belt and the 6th-largest family with nearly six thousand known members, or approximately 1.4% of all asteroids in the Asteroid Belt.

16 Psyche One of the most massive asteroids in the asteroid belt. This object is over 200 km in diameter and contains about 1% of the mass of the entire asteroid belt. It is thought to be the exposed iron core of a protoplanet, and is the most massive metallic M-type asteroid.

20 Massalia Stony asteroid and the parent body of the Massalia family located in the inner region of the asteroid belt, approximately 145 kilometers in diameter. The family is fairly young, estimated to have been created by an impact 150 to 200 million years ago.

24 Themis The largest member of the Themistian family with surface completely covered in ice. There is also organic compounds in the form of tholins, high-molecular weight organics found in the outer solar system, distinguished by a brown or reddish color in optical spectra.

45 Eugenia Famed as one of the first asteroids to be found to have a moon orbiting it, and the first one to been discovered by an Earth-based telescope. Eugenia I Petit-Prince is the larger (diameter of 13 km), outer moon. A second, smaller (diameter of 6 km) satellite orbits closer to Eugenia.

52 Europa The 6th-largest asteroid in the asteroid belt, having an average diameter of around 315 km. It is not round but is shaped like an ellipsoid

of approximately 380×330×250 km. Europa is a very dark carbonaceous C-type, and is the second largest of this group.

65 Cybele One of the largest asteroids in the Solar System and is located in the outer asteroid belt. It gives its name to the Cybele group of asteroids that orbit outward from the Sun from the 2:1 orbital resonance with Jupiter. The last outpost of an extended asteroid belt.

87 Sylvia The 8th-largest asteroid in the asteroid belt. It is the parent body of the Sylvia family and member of Cybele group located beyond the core of the belt. Sylvia was the first asteroid known to possess more than one moon. They have been named (87) Sylvia I Romulus and (87) Sylvia II Remus.

90 Antiope A double asteroid in the outer asteroid belt. It was found to consist of two almost-equally-sized bodies orbiting each other. At average diameters of about 88 km and 84 km, both components are among the 500 largest asteroids.

107 Camilla One of the largest asteroids from the outermost edge of the asteroid belt, approximately 220 kilometers. It is a member of the Sylvia family and located within the Cybele group. The X-type asteroid is a rare trinary asteroid with two minor-planet moons.

216 Kleopatra A metallic, ham-bone-shaped asteroid and trinary system orbiting in the central region of the asteroid belt, approximately 138 kilometers in diameter. It is believed that Kleopatra's shape, rotation, and moons are due to an oblique impact perhaps 100 million years ago.

243 Ida An asteroid in the Koronis family of the asteroid belt. It was the second asteroid visited by a spacecraft and the first found to have a natural satellite. Ida's moon Dactyl is only 1.4 kilometres in diameter, about 1/20 the size of Ida.

253 Mathilde An asteroid with a relatively elliptical orbit that requires more than four years to circle the Sun. Nonetheless, the orbit lies entirely between the orbits of Mars and Jupiter; it does not cross the planetary orbits. This tumbling asteroid has an unusually slow rate of rotation, requiring 17.4 days to complete a 360° revolution about its axis. It is a primitive C-type asteroid, which means the surface has a high proportion of carbon; giving it a dark surface that reflects only 4% of the light that falls on it.

532 Herculina One of the larger members of the main asteroid belt with size of 260×220×215 km. It is not spherical, but a blocky shape not unlike a battered cuboid - or, as the original analysis described it, it "resembles a toaster". It has multiple largish craters, but no major variation in albedo.

588 Achilles Large Jupiter trojan from the Greek camp. Archillies was the first Jupiter trojan to be discovered. The dark D-type asteroid measures 133 kilometers in diameter which makes it one of the 10 largest Jupiter trojans.

617 Patroclus A binary Jupiter trojan approximately 140 kilometers in diameter. It was the second trojan to be discovered and the only member of the Trojan camp named after a Greek character. The dark D-type asteroid is also slow rotator and one of the largest Jupiter trojans.

624 Hektor The largest Jupiter trojan and the namesake of the Hektor family, with a highly elongated shape equivalent in volume to a sphere of approximately 225 to 250 kilometers diameter. It has one small 12-kilometer sized satellite, Skamandrios.

704 Interamnia Large F-type asteroid with an estimated diameter of 350 kilometres. It is the fifth-most-massive asteroid with a mass estimated to be 1.2% of the mass of the Asteroid Belt. Interamnia may represent a transitional body between small solar system bodies and dwarf planets.

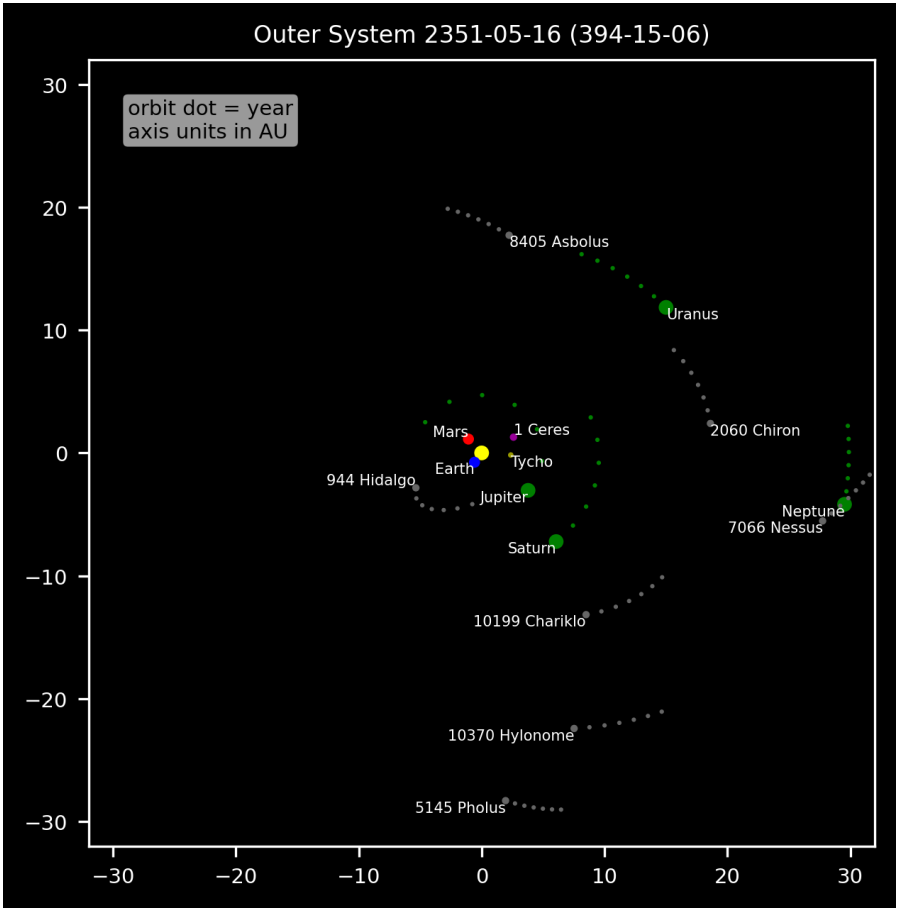
944 Hidalgo A centaur and unusual object on an eccentric, cometary-like orbit between the asteroid belt and the outer Solar System, approximately 52 kilometers in diameter. It is the first member of the dynamical class of centaurs ever to be discovered.

951 Gaspra An S-type asteroid that orbits very close to the inner edge of the asteroid belt. Gaspra was the first asteroid ever to be closely approached when it was visited by the Galileo spacecraft, which flew by on its way to Jupiter on October 1990.

1036 Ganymed A stony asteroid on a highly eccentric orbit, classified as a near-Earth object of the Amor group. With a diameter of 35 kilometers, Ganymed is the largest of all near-Earth objects. Amor asteroids is a subgroup of the near-Earth asteroids that approach the orbit of Earth from beyond, but do not cross.

2 Outer System

The outer system map shows positions of giant planets within the orbit of Neptune. Earth, Mars and some asteroid colonies are included for reference. Future orbit positions are displayed for some objects at one year intervals.



2.1 Centaurs

Centaurs are small Solar System bodies with either a perihelion or a semi-major axis between those of the outer planets. They generally have unstable orbits because they cross or have crossed the orbits of one or more of the giant planets; almost all their orbits have dynamic lifetimes of only a few million years. Centaurs typically behave with characteristics of both asteroids and comets.

944 Hidalgo The first member of the dynamical class of centaurs ever to be discovered. The dark D-type object has a rotation period of 10.1 hours and an elongated shape. Its orbit takes it to the inner edge of the Asteroid Belt and as far out as to the orbit of Saturn.

2060 Chiron Although Chiron was initially called an asteroid and classified only as a minor planet with the designation "2060 Chiron", it was later found to exhibit behavior typical of a comet. Today it is classified as both a minor planet and a comet.

5145 Pholus An eccentric centaur in the outer Solar System, approximately 180 kilometers in diameter, that crosses the orbit of both Saturn and Neptune. The very reddish object has an elongated shape and a rotation period of 9.98 hours. It was the second centaur to be discovered.

7066 Nessus A centaur on an eccentric orbit, located beyond Saturn in the outer Solar System. The dark and reddish minor planet is elongated and measures approximately 60 kilometers in diameter. It has a relatively long orbital half-life of about 4.9 million years.

8405 Asbolus A centaur orbiting in the outer Solar System between the orbits of Jupiter and Neptune. It measures approximately 80 kilometers in diameter and has a fresh impact crater on its surface, less than 10 million years old.

10199 Chariklo The largest centaur with a diameter of 232 km. It orbits the Sun between Saturn and Uranus, grazing the orbit of Uranus. Chariklo has two ice rings (named Oiapoque and Chuí) with radii 396 and 405 km and widths of about 7 km and 3.5 km respectively.

10370 Hylonome A minor planet orbiting in the outer Solar System. The dark and icy body belongs to the class of centaurs and measures approximately 75 kilometers in diameter. It is a Neptune-crosser, and an outer-grazer of the orbit of Uranus, which it hence does not cross.

3 Communication Delay

One of the few true constants in the universe remains the speed of light. Whether communications are sent as radio waves or on the laser of a tightbeam, they travel 300,000 kilometers per second. Often a message can be slowed while the receiver waits for redundant copies of lost packets of data to arrive, or for a message to work its way to the top of the queue at a tightbeam relay station and get passed along on the next stage of its journey. Worse, a distance of 15 light minutes between Earth and Ceres doesn't mean it takes 15 minutes to establish a connection: it means it takes 15 minutes for the first part of the message to travel the distance ("How are you?"), then another 15 minutes for the reply to return ("I'm fine, thanks."). Conversations of alternating messages can take hours or days to complete. Because of this, most transmitted conversations are sent as recorded messages rather than attempting a live conversation, unless the light-speed delay is only a few seconds.

System Communication Delay in Minutes 2351-05-16 (394-15-06)

	Venus	Earth	Mars	Tycho	Ceres	Pallas	Vesta	Hygiea	Jupiter	Saturn
Venus	0	14	10	21	22	30	21	23	46	88
Earth	14	0	18	25	32	30	15	27	42	81
Mars	10	18	0	31	31	40	16	13	56	97
Tycho	21	25	31	0	12	13	38	44	30	72
Ceres	22	32	31	12	0	24	42	43	39	81
Pallas	30	30	40	13	24	0	44	53	19	60
Vesta	21	15	16	38	42	44	0	16	57	94
Hygiea	23	27	13	44	43	53	16	0	67	107
Jupiter	46	42	56	30	39	19	57	67	0	42
Saturn	88	81	97	72	81	60	94	107	42	0

Delay between Earth and Moon is about 1.3 seconds. Likewise, in Saturn's inner system, delays are always within 2 seconds. Delay between outmost Iapetus and inner Saturn system is less than 15 seconds.

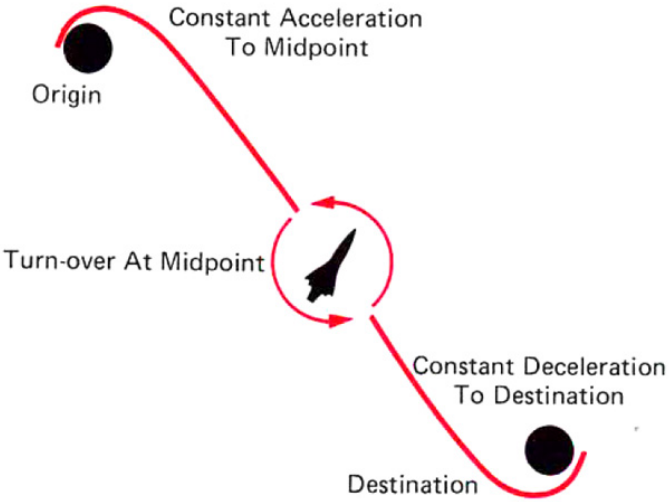
Jovian system outer satellites are farther away and communication delays between them are significant.

Jovian Communication Delay in Seconds 2351-05-16 (394-15-06)

	Ganymede	Callisto	Leda	Himalia	Elara	Lysithea	Ananke	Pasiphae	Carme	Sinope
Ganymede	0	9	29	35	32	38	65	100	82	89
Callisto	9	0	36	43	36	35	70	92	76	87
Leda	29	36	0	30	48	49	69	122	108	82
Himalia	35	43	30	0	33	57	64	129	113	105
Elara	32	36	48	33	0	64	46	120	87	120
Lysithea	38	35	49	57	64	0	103	79	98	65
Ananke	65	70	69	64	46	103	0	154	96	146
Pasiphae	100	92	122	129	120	79	154	0	89	104
Carme	82	76	108	113	87	98	96	89	0	136
Sinope	89	87	82	105	120	65	146	104	136	0

4 Travel Times

Because the Epstein Drive removed Δv limitations to space travel, ships no longer needed to execute Hohmann transfers to maneuver between bodies. To transfer, ships can simply burn prograde at a constant rate, then flip around and decelerate by burning retrograde. This maneuver is called a Brachistochrone trajectory, from the Greek meaning "shortest time." A course using this maneuver tends to be curved as it uses the sun's gravity to increase the ship's acceleration.



The time it takes to execute a flight path along a Brachistochrone trajectory depends on two factors: the distance between the two points, and the acceleration of the ship. The greater the acceleration, the less time it takes to travel, but the multiple g-forces created by these "hard burns" are extremely stressful on the human body. Crash couches and pharmaceutical cocktails like "the juice" alleviate some, but not all, of the damage inflicted by the hardest burns.

The following tables show the time to travel the average distance between the two locations at an average acceleration of 0.3g, 0.5g and 1.0g, presented as total required travel time under acceleration without any of the necessary breaks taken into consideration. The first acceleration is belter standard, the second one is tolerable for belters and the third is suitable for earthers.

The last table starts and ends the journey with an acceleration boost. The central part of the journey uses normal 0.5g acceleration and flip at the middle.

System Travel Time in Days (0.3g) 2351-05-16 (394-15-06)

	Venus	Earth	Mars	Tycho	Ceres	Pallas	Vesta	Hygiea	Jupiter	Saturn
Venus	0	6.7	5.8	8.2	8.5	10.0	8.2	8.8	12.3	16.9
Earth	6.7	0	7.6	9.1	10.2	9.9	7.0	9.4	11.7	16.3
Mars	5.8	7.6	0	10.0	10.0	11.5	7.1	6.6	13.5	17.8
Tycho	8.2	9.1	10.0	0	6.3	6.5	11.2	12.0	9.8	15.3
Ceres	8.5	10.2	10.0	6.3	0	8.9	11.8	11.9	11.3	16.3
Pallas	10.0	9.9	11.5	6.5	8.9	0	12.0	13.2	7.8	14.1
Vesta	8.2	7.0	7.1	11.2	11.8	12.0	0	7.2	13.6	17.6
Hygiea	8.8	9.4	6.6	12.0	11.9	13.2	7.2	0	14.9	18.8
Jupiter	12.3	11.7	13.5	9.8	11.3	7.8	13.6	14.9	0	11.8
Saturn	16.9	16.3	17.8	15.3	16.3	14.1	17.6	18.8	11.8	0

System Travel Time in Days (0.5g) 2351-05-16 (394-15-06)

	Venus	Earth	Mars	Tycho	Ceres	Pallas	Vesta	Hygiea	Jupiter	Saturn
Venus	0	5.2	4.5	6.4	6.6	7.7	6.4	6.8	9.5	13.1
Earth	5.2	0	5.9	7.1	7.9	7.7	5.4	7.2	9.1	12.6
Mars	4.5	5.9	0	7.8	7.8	8.9	5.5	5.1	10.5	13.8
Tycho	6.4	7.1	7.8	0	4.9	5.0	8.7	9.3	7.6	11.9
Ceres	6.6	7.9	7.8	4.9	0	6.9	9.1	9.2	8.8	12.6
Pallas	7.7	7.7	8.9	5.0	6.9	0	9.3	10.2	6.1	10.9
Vesta	6.4	5.4	5.5	8.7	9.1	9.3	0	5.6	10.6	13.6
Hygiea	6.8	7.2	5.1	9.3	9.2	10.2	5.6	0	11.5	14.5
Jupiter	9.5	9.1	10.5	7.6	8.8	6.1	10.6	11.5	0	9.1
Saturn	13.1	12.6	13.8	11.9	12.6	10.9	13.6	14.5	9.1	0

System Travel Time in Days (1.0g) 2351-05-16 (394-15-06)

	Venus	Earth	Mars	Tycho	Ceres	Pallas	Vesta	Hygiea	Jupiter	Saturn
Venus	0	3.7	3.2	4.5	4.6	5.5	4.5	4.8	6.7	9.3
Earth	3.7	0	4.2	5.0	5.6	5.4	3.8	5.1	6.4	8.9
Mars	3.2	4.2	0	5.5	5.5	6.3	3.9	3.6	7.4	9.7
Tycho	4.5	5.0	5.5	0	3.5	3.6	6.1	6.6	5.4	8.4
Ceres	4.6	5.6	5.5	3.5	0	4.9	6.4	6.5	6.2	8.9
Pallas	5.5	5.4	6.3	3.6	4.9	0	6.6	7.2	4.3	7.7
Vesta	4.5	3.8	3.9	6.1	6.4	6.6	0	4.0	7.5	9.6
Hygiea	4.8	5.1	3.6	6.6	6.5	7.2	4.0	0	8.1	10.3
Jupiter	6.7	6.4	7.4	5.4	6.2	4.3	7.5	8.1	0	6.5
Saturn	9.3	8.9	9.7	8.4	8.9	7.7	9.6	10.3	6.5	0

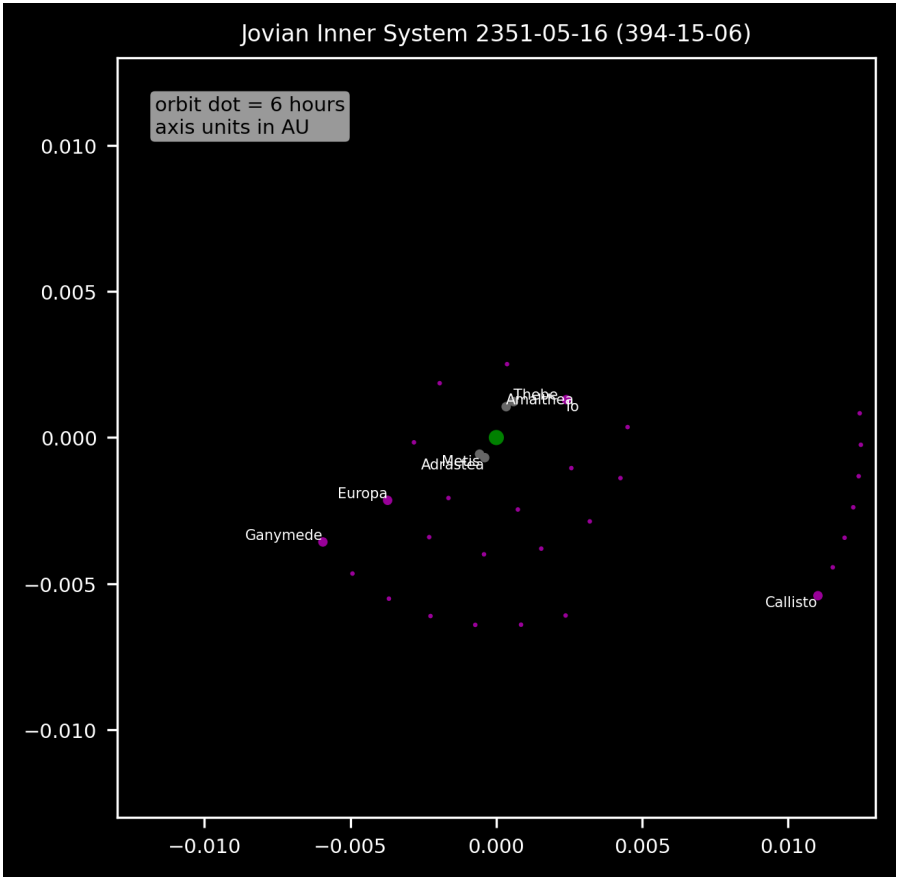
System Travel Time in Days (0.5g + 6g x 4h) 2351-05-16 (394-15-06)

	Venus	Earth	Mars	Tycho	Ceres	Pallas	Vesta	Hygiea	Jupiter	Saturn
Venus	0	2.8	2.2	3.8	3.9	5.0	3.8	4.1	6.6	10.0
Earth	2.8	0	3.4	4.4	5.1	4.9	3.0	4.5	6.2	9.5
Mars	2.2	3.4	0	5.0	5.0	6.0	3.1	2.7	7.5	10.6
Tycho	3.8	4.4	5.0	0	2.6	2.7	5.8	6.4	4.9	8.8
Ceres	3.9	5.1	5.0	2.6	0	4.2	6.2	6.3	5.9	9.5
Pallas	5.0	4.9	6.0	2.7	4.2	0	6.4	7.2	3.5	7.9
Vesta	3.8	3.0	3.1	5.8	6.2	6.4	0	3.1	7.6	10.5
Hygiea	4.1	4.5	2.7	6.4	6.3	7.2	3.1	0	8.5	11.4
Jupiter	6.6	6.2	7.5	4.9	5.9	3.5	7.6	8.5	0	6.2
Saturn	10.0	9.5	10.6	8.8	9.5	7.9	10.5	11.4	6.2	0

5 Jovian system

Named for the gas giant it surrounds, the Jovian System has drawn the largest population in the Outer Planets to Jupiter's moons. The planet itself is — of course — uninhabitable, but there are dozens of settlements and orbiting space stations around it and its moons. It is a kind of miniature solar system.

The Jovian System is responsible for growing and distributing most of the food in the Outers and the Belt. Most extrasolar astronomy was done in the Jovian System before the Uranian System was colonized. It is a vital piece of humanity's survival in the furthest reaches of the solar system, and of the Belt's economy.

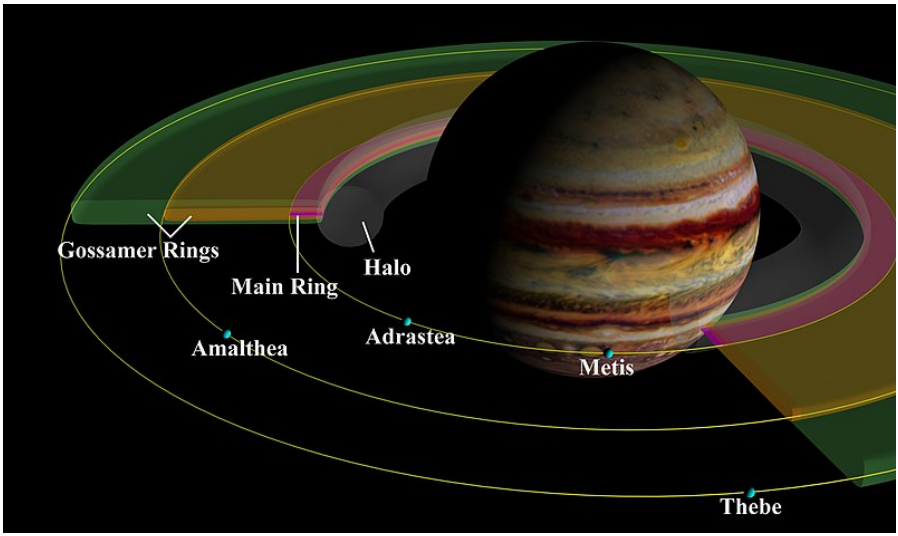


Jupiter is primarily composed of hydrogen with a quarter of its mass being helium, though helium comprises only about a tenth of the number of molecules.

5.1 Ring System

The planet Jupiter has a system of rings known as the rings of Jupiter or the Jovian ring system. It was the third ring system to be discovered in the Solar System, after those of Saturn and Uranus.

The Jovian ring system is faint and consists mainly of dust. It has four main components: a thick inner torus of particles known as the "halo ring"; a relatively bright, exceptionally thin "main ring"; and two wide, thick and faint outer "gossamer rings", named for the moons of whose material they are composed: Amalthea and Thebe.



The main and halo rings consist of dust ejected from the moons Metis, Adrastea, and other unobserved parent bodies as the result of high-velocity impacts. In visible and near-infrared light, the rings have a reddish color, except the halo ring, which is neutral or blue in color.

5.2 Inner Moons

Inner moons are unpopulated primarily due to their proximity to Jupiter and location in its harsh radiation belt — even aboveground structures on moons further from the planet require heavy shielding.

Metis Metis is the innermost moon of Jupiter. It is tidally locked to Jupiter, and its shape is strongly asymmetrical, with one of the diameters being almost twice as large as the smallest one. It is one of the two moons known to orbit

Jupiter in less than the length of Jupiter's day, the other being Adrastea. It orbits within the main ring of Jupiter, and is a major contributor of material to the rings. The surface of Metis is heavily cratered, dark, and appears to be reddish in color.

Adrastea Adrastea is the second by distance, and the smallest of the four inner moons of Jupiter. It also orbits Jupiter in less than the length of planet's day. It orbits at the edge of Jupiter's Main Ring and, like Metis, is the main contributor of material to the rings. Adrastea has an irregular shape.

Amalthea Amalthea has the third closest orbit around Jupiter among known moons. It is in a close orbit around Jupiter and is within the outer edge of the Amalthea Gossamer Ring which is formed from dust ejected from its surface. Jupiter would appear 46.5 degrees in diameter from its surface. Amalthea is the largest of the inner satellites of Jupiter and is irregularly shaped and reddish in color. Its surface features include large craters and ridges.

Thebe Thebe is the fourth of Jupiter's moons by distance from the planet. The second largest of the inner satellites of Jupiter, Thebe orbits within the outer edge of the Thebe gossamer ring that is formed from dust ejected from its surface. It is irregularly shaped and reddish in colour Its surface features include large craters and high mountains — some of them are comparable to the size of the moon itself.

5.3 Galilean Moons

The Galilean moons are the four largest moons of Jupiter. They were first seen by Galileo Galilei in 1609 and were the first objects found to orbit a planet other than the Earth.

Io One of Jupiter's larger moons, Io is an extremely hostile and unforgiving environment for colonists. Its atmosphere of sulfur dixoide and hot spots of volcanic and tectonic activity make Io a very dangerous environment for humanity. Io's volcanos produce vents of heat in excess of 2,000° K, and the moon itself creates an intense electrical field when its nickel and iron core passes through Jupiter's magnetic field, producing in excess of 1 trillion watts. Power stations dotted around the surface converting heat transfer and atmospheric electrical charge into usable energy have made Io one of the primary storable energy production facilities in the Outers.

Europa One of the most populated of Jupiter's moons, Europa has some similarities to Ganymede — they both have stable tectonics and aboveground dome greenhouses, and were amongst the first moons to be colonized. Earthers,

Belters, and Martians all store eggs and sperm on Europa and Ganymede, as well as Luna and Earth. However, while Ganymede has significantly increased its investment in agricultural and medical technology over the decades, Europa has fallen behind. Now, the moon's primary advantage is its thick surface layer of ice, which allows its settlements to supply themselves with water and oxygen without outside help.

Ganymede Ganymede Station is the bread basket and the main birthing center for the Outers and the Belt, and a center of civilization in the far reaches of the solar system. It is the safest station in the Jovian system, where people come to give birth, avoiding the defects that can come with carrying to term in low or zero g. As the only moon with any magnetosphere, it's the only place where dome-grown crops stand a chance in Jupiter's harsh radiation belt, even with heavy shielding on the domes and habitats. Ganymede is also unique in its intricate system of orbital mirror stations that shine concentrated sunlight down onto the dome greenhouses that produce vegetables, fruits, and even some meat. The moon's ice, on the surface and reaching into the depths of the moon, provides all the water necessary for life.

Callisto Callisto is the second-largest moon of Jupiter and the third-largest in the Sol system. Its orbit requires it to be tidally locked – one side constantly faces Jupiter. This large moon's tectonic stability and significant deposits of rare minerals made it an ideal location for Mars' shipyards, the largest in the Outers. Most of the MCRN's fleet has been built orbiting Callisto, where the shipyards are capable of building hulls up to 700 meters in length. Callisto is one of the only moons of Jupiter where radioactive minerals are close enough to the surface for easy extraction, however it hasn't created a strong economy. Mining and shipbuilding are the only sources of revenue, and revenue that comes only from Mars.

5.4 Outer Moons

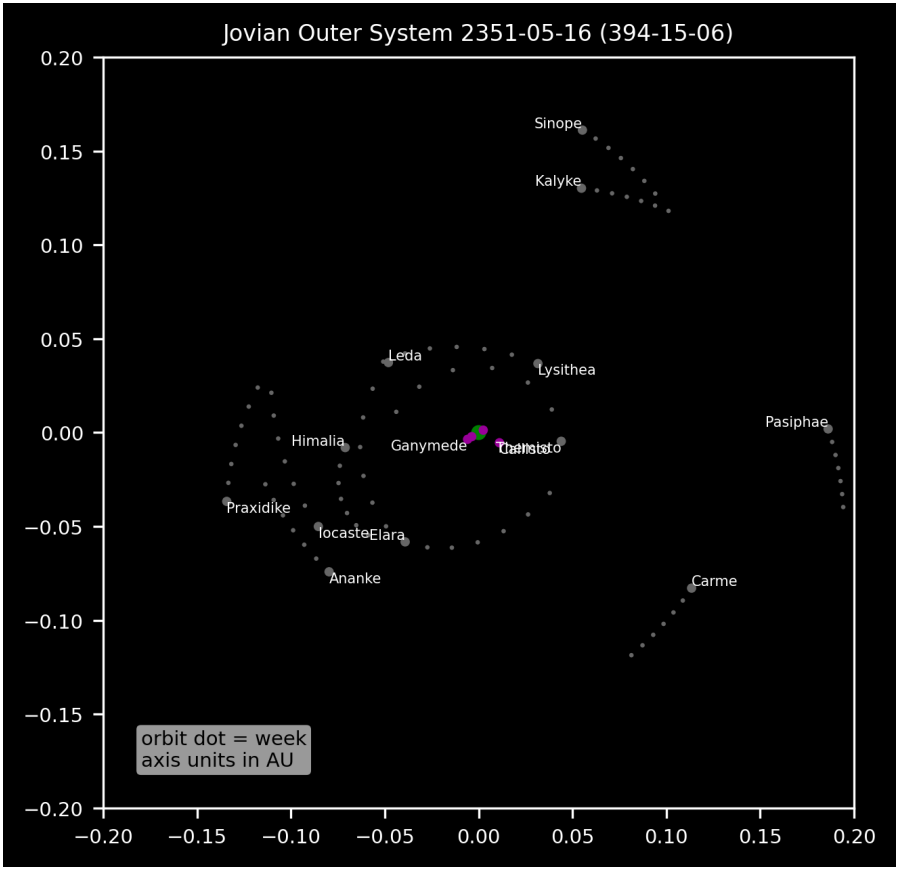
These outer moons are all too small to support a colony, but they are, or have been, used as scientific and mining outposts.

Themisto Themisto's orbit is unusual: unlike most of Jupiter's moons, which orbit in distinct groups, Themisto orbits alone. The moon is located midway between the Galilean moons and the first group of prograde irregular moons, called the Himalia group. It is about 8 kilometers in diameter.

Leda Leda is a prograde irregular satellite of Jupiter. It belongs to the Himalia group, five moons orbiting between 11 and 13 Gm from Jupiter at an

inclination of about 28°. Its orbit is continuously changing due to solar and planetary perturbations.

Himalia Himalia is the largest irregular satellite of Jupiter, with a diameter of 140 km. It is the fifth largest Jovian satellite, after the four Galilean moons. Himalia's rotational period is 7 h 47 m, and appears neutral in color (grey), like the other members of its group.



Elara Elara is a prograde irregular satellite of Jupiter. It is the eighth-largest moon of Jupiter. It has a mean radius of just 43 kilometres, thus it is 2% of the size of Europa. However, it is half the size of Himalia, so it is the second-biggest moon in the Himalia group. It reflects very little light.

Lysithea Lysithea is a prograde irregular satellite of Jupiter. It belongs to the Himalia group, five moons orbiting between 11 and 13 Gm from Jupiter at

an inclination of about 28°. Its orbit is continuously changing due to solar and planetary perturbations.

Iocaste Iocaste is a retrograde irregular satellite of Jupiter. It orbits Jupiter at an average distance of 20.723 million kilometers in 609.427 days, at an inclination of 147° to the ecliptic with an eccentricity of 0.2874. Iocaste belongs to the Ananke group, believed to be the remnants of a break-up of a captured heliocentric asteroid. The satellite is about 5 kilometres in diameter and appears grey.

Praxidike Praxidike is a retrograde irregular satellite of Jupiter. It orbits Jupiter at an average distance of 20,824,000 km in 613.904 days, at an inclination of 144° to the ecliptic, in a retrograde direction and with an eccentricity of 0.1840. Praxidike belongs to the Ananke group, believed to be the remnants of a break-up of a captured heliocentric asteroid. With a diameter of 7 km, Praxidike is the second largest member of the group after Ananke itself.

Ananke Ananke is a retrograde irregular moon of Jupiter. It gives its name to the Ananke group, retrograde irregular moons which orbit Jupiter between 19.3 and 22.7 Gm, at inclinations of roughly 150°. Ananke orbits Jupiter on a high-eccentricity and high-inclination retrograde orbit.

Kalyke Kalyke is a retrograde irregular satellite of Jupiter. Kalyke's albedo is measured at 2.9%, corresponding to a diameter of 6.9 kilometres. It belongs to the Carme group, made up of irregular retrograde moons orbiting Jupiter at a distance ranging between 23 and 24 Gm and at an inclination of about 165°.

Pasiphae Pasiphae is a retrograde irregular satellite of Jupiter. Pasiphae orbits Jupiter on a high eccentricity and high inclination retrograde orbit. It gives its name to the Pasiphae group, irregular retrograde moons orbiting Jupiter at distances ranging between 22.8 and 24.1 million km, and with inclinations ranging between 144.5° and 158.3°. Pasiphae is also known to be in a secular resonance with Jupiter. With diameter of 60 km Pasiphae is the largest retrograde and third largest irregular satellite after Himalia and Elara.

Carme Carme is a retrograde irregular satellite of Jupiter. It gives its name to the Carme group, made up of irregular retrograde moons orbiting Jupiter at a distance ranging between 23 and 24 Gm and at an inclination of about 165°. Its orbital elements are continuously changing due to solar and planetary perturbations. It has diameter of 47 km.

Sinope Sinope is a retrograde irregular satellite of Jupiter. Sinope orbits Jupiter on a high-eccentricity and high-inclination retrograde orbit. Its orbit is continuously changing due to solar and planetary perturbations. Sinope

belongs to the Pasiphae group of retrograde irregular moons. It is also known to be in a secular resonance with Jupiter, similar to Pasiphae.

Distances within Jovian system are vast, and while travel times aren't as long as in interplanetary journeys, they are still quite significant.

Jovian Travel Time in Hours (0.3g) 2351-05-16 (394-15-06)

	Ganymede	Callisto	Leda	Himalia	Elara	Lysithea	Ananke	Pasiphae	Carme	Sinope
Ganymede	0	16	30	33	32	34	45	56	51	53
Callisto	16	0	34	37	34	33	47	54	49	52
Leda	30	34	0	31	39	39	47	62	58	51
Himalia	33	37	31	0	32	42	45	64	60	58
Elara	32	34	39	32	0	45	38	61	52	61
Lysithea	34	33	39	42	45	0	57	50	56	45
Ananke	45	47	47	45	38	57	0	70	55	68
Pasiphae	56	54	62	64	61	50	70	0	53	57
Carme	51	49	58	60	52	56	55	53	0	65
Sinope	53	52	51	58	61	45	68	57	65	0

Jovian Travel Time in Hours (0.5g) 2351-05-16 (394-15-06)

	Ganymede	Callisto	Leda	Himalia	Elara	Lysithea	Ananke	Pasiphae	Carme	Sinope
Ganymede	0	13	24	26	25	27	35	43	39	41
Callisto	13	0	26	29	26	26	36	42	38	41
Leda	24	26	0	24	30	30	36	48	45	39
Himalia	26	29	24	0	25	33	35	49	46	45
Elara	25	26	30	25	0	35	30	48	41	48
Lysithea	27	26	30	33	35	0	44	39	43	35
Ananke	35	36	36	35	30	44	0	54	43	52
Pasiphae	43	42	48	49	48	39	54	0	41	44
Carme	39	38	45	46	41	43	43	41	0	51
Sinope	41	41	39	45	48	35	52	44	51	0

Jovian Travel Time in Hours (1.0g) 2351-05-16 (394-15-06)

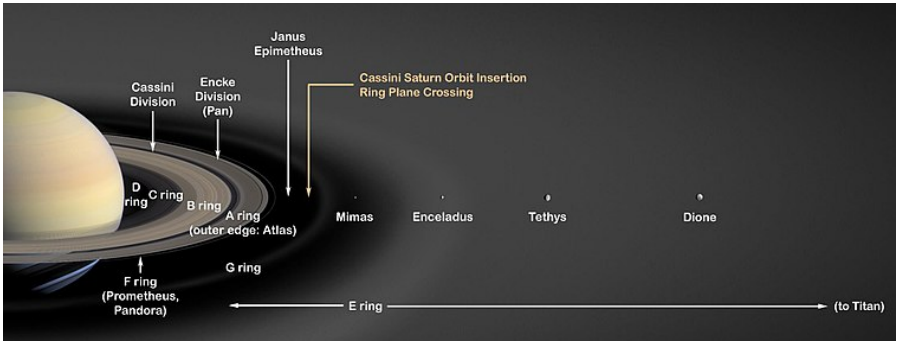
	Ganymede	Callisto	Leda	Himalia	Elara	Lysithea	Ananke	Pasiphae	Carme	Sinope
Ganymede	0	9	17	18	17	19	25	31	28	29
Callisto	9	0	19	20	19	18	26	29	27	29
Leda	17	19	0	17	21	21	26	34	32	28
Himalia	18	20	17	0	18	23	25	35	33	32
Elara	17	19	21	18	0	25	21	34	29	34
Lysithea	19	18	21	23	25	0	31	27	30	25
Ananke	25	26	26	25	21	31	0	38	30	37
Pasiphae	31	29	34	35	34	27	38	0	29	31
Carme	28	27	32	33	29	30	30	29	0	36
Sinope	29	29	28	32	34	25	37	31	36	0

6 Cronian System

Surrounding the second largest gas giant in the solar system, the Saturnian System has — or had — one large orbiting station functioning as a way point for exploration and resource harvesting inside Saturn's rings, and a few settled moons. Pan, Atlas, Prometheus, Pandora, Epimetheus, Janus, Mimas, Enceladus, Tethys, Telesto, Calypso, Dione, and Helene all exist within the rings of Saturn and are too small to support any long-term habitat. Hyperion has not yet been developed.

6.1 Ring System

The rings of Saturn are the most extensive ring system of any planet in the Solar System. They consist of countless small particles, ranging in size from micrometers to meters, that orbit about Saturn. The ring particles are made almost entirely of water ice, with a trace component of rocky material.



The rings have numerous gaps where particle density drops sharply: two opened by known moons embedded within them, and many others at locations of known destabilizing orbital resonances with the moons of Saturn.

D Ring Very faint innermost ring.

C Ring Wide but faint ring located inward of the B Ring.

B Ring The largest, brightest, and most massive of the rings.

A ring The outermost of the large, bright rings.

F Ring Very thin ring near the outer edge of the A ring.

E Ring Wide ring composed of microscopic particles.

6.2 Inner Moons

Shepherd satellites are small moons that orbit within, or just beyond, a planet's ring system. They have the effect of sculpting the rings: giving them sharp edges, and creating gaps between them. Saturn's shepherd moons are Pan, Daphnis, Atlas, Prometheus and Pandora. These moons together with co-orbitals (see below) probably formed as a result of accretion of the friable ring material on preexisting denser cores. The cores with sizes from one-third to one-half the present-day moons may be themselves collisional shards formed when a parental satellite of the rings disintegrated.

Janus and Epimetheus are called co-orbital moons. They are of roughly equal size, with Janus being slightly larger than Epimetheus. Janus and Epimetheus have orbits with only a few kilometers difference in semi-major axis, close enough that they would collide if they attempted to pass each other. Instead of colliding, however, their gravitational interaction causes them to swap orbits every four years.

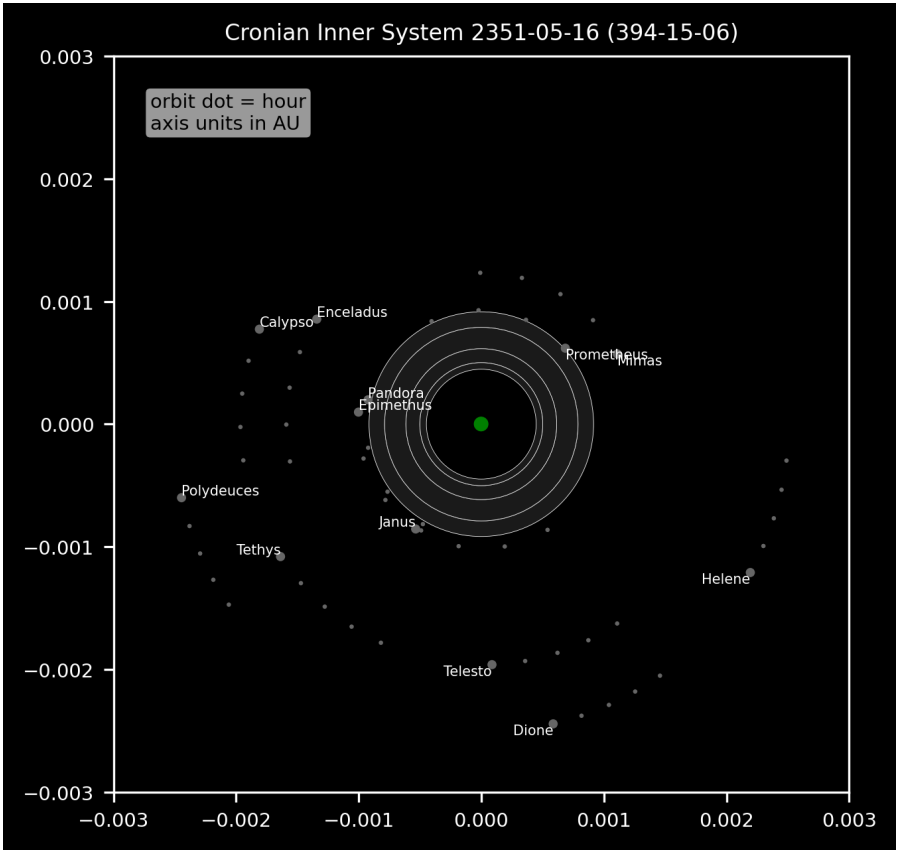
Trojan moons are a unique feature only known from the Saturnian system. A trojan body orbits at either the leading L4 or trailing L5 Lagrange point of a much larger object, such as a large moon or planet. Tethys has two trojan moons, Telesto and Calypso, and Dione also has two, Helene and Polydeuces. Helene is by far the largest trojan moon, while Polydeuces is the smallest and has the most chaotic orbit. These moons are coated with dusty material that has smoothed out their surfaces.

Prometheus Prometheus is extremely elongated, measuring approximately 136 km $\times$ 79 km $\times$ 59 km. It has several ridges and valleys and a number of impact craters of about 20 km diameter are visible, but it is less cratered than nearby Pandora, Epimetheus, and Janus.

Pandora Pandora is more heavily cratered than nearby Prometheus, and has at least two large craters 30 kilometres in diameter. The majority of craters on Pandora are shallow as a result of being filled with debris. Ridges and grooves are also present on moon's surface. The orbit of Pandora appears to be chaotic, as a consequence of a series of four 118:121 mean-motion resonances with Prometheus.

Epimethus Epimetheus occupies essentially the same orbit as the moon Janus. There are several Epimethean craters larger than 30 km in diameter, as well as both large and small ridges and grooves. The extensive cratering indicates that Epimetheus must be quite old. Janus and Epimetheus may have formed from a disruption of a single parent to form co-orbital satellites, but if this is the case the disruption must have happened early in the history of the satellite system.

Janus Janus's orbit is co-orbital with that of Epimetheus. Janus is extensively cratered with several craters larger than 30 km, but has few linear features. Janus's surface appears to be older than Prometheus's but younger than Pandora's.



Mimas With a diameter of 396 kilometres, Mimas is the smallest astronomical body that is known to still be rounded in shape because of self-gravitation. The low density indicates that it is composed mostly of water ice with only a small amount of rock. Due to the tidal forces acting on it, Mimas is noticeably prolate; its longest axis is about 10% longer than the shortest. Mimas's most distinctive feature is a giant impact crater 130 km across, named Herschel after the discoverer of Mimas. Herschel's diameter is almost a third of Mimas's own diameter. The Mimantean surface is saturated

with smaller impact craters, but no others are anywhere near the size of Herschel.

Enceladus Enceladus is about 500 kilometers in diameter. It is mostly covered by fresh, clean ice, making it one of the most reflective bodies of the Solar System. Geyser observations, along with the finding of escaping internal heat and very few impact craters in the south polar region, show that Enceladus is currently geologically active. Its resonance with Dione excites its orbital eccentricity, which is damped by tidal forces, tidally heating its interior and driving the geological activity. Plumes from Enceladus, which are similar in composition to comets, have been shown to be the source of the material in Saturn's E ring.

Tethys Tethys is a mid-sized moon of Saturn about 1,060 km across. It has the lowest of all the major moons in the Solar System, indicating that it is made of water ice with just a small fraction of rock. The surface of Tethys is very bright, being the second-brightest of the moons of Saturn after Enceladus, and neutral in color. Tethys is heavily cratered and cut by a number of large faults/graben. The largest impact crater, Odysseus, is about 400 km in diameter, whereas the largest graben, Ithaca Chasma, is more than 2000 km long. Tethys has two co-orbital moons, Telesto and Calypso orbiting near Tethys's trojan points L4 and L5 respectively.

Dione At 1122 km in diameter, Dione is the 15th largest moon in the Solar System. About two thirds of Dione's mass is water ice, and the remaining is a dense core. Dione orbits Saturn with a semimajor axis about 2% less than that of the Moon. However, reflecting Saturn's greater mass, Dione's orbital period is one tenth that of the Moon. Dione is currently in a 1:2 mean-motion orbital resonance with moon Enceladus, completing one orbit of Saturn for every two orbits completed by Enceladus. Dione has two co-orbital, or trojan, moons, Helene and Polydeuces. They are located within Dione's Lagrangian points L4 and L5 respectively.

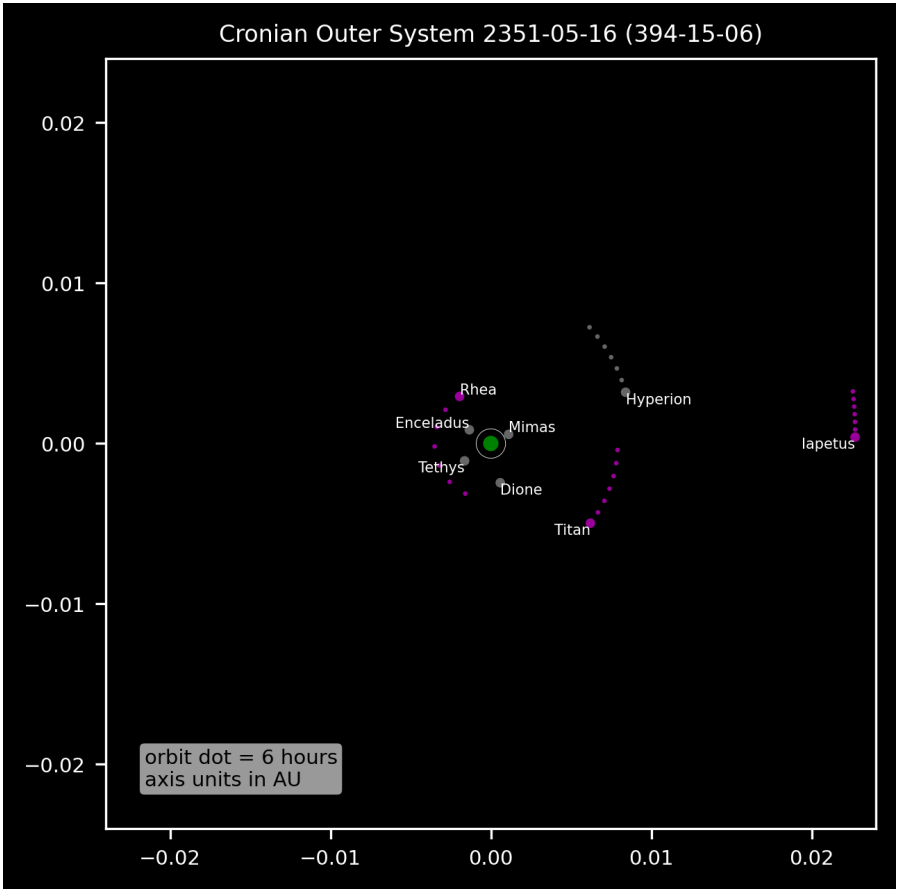
6.3 Outer Moons

These moons all orbit beyond the E Ring.

Rhea One of the frontiers of human civilization, Rhea is only just large enough for a colony, and primarily composed of water, ice, and rock. The only thing the moon has to offer the rest of the system is Helium-3 deposits, and some small mineral mining operations. Rhea's several small underground habitats provide all the living space required for its population, mostly comprised of miners and workers in the Helium-3 refineries. Most of their food must be

imported from Titan, increasing costs, and mineral and Helium-3 exports do not bring much money into the local economy.

Titan The most populous moon in the system has a thick cloud cover that generates strange and beautiful solar wind displays as the moon moves in and out of Saturn's powerful magnetic field. Titan is also the most chemically active body in the solar system, aside from Earth. Both the atmosphere and icy surface of the moon are filled with organic compounds not found anywhere else. Easy access to ice suitable for oxygen and water production and a lack of available sunlight have put Titan on the forefront of sunlight-free food production.



Hyperion Hyperion is Titan's nearest neighbor in the Saturn system. The two moons are locked in a 4:3 mean-motion resonance with each other, meaning

that while Titan makes four revolutions around Saturn, Hyperion makes exactly three. With an average diameter of about 270 km, Hyperion is smaller and lighter than Mimas. It has an extremely irregular shape, and a very odd, tan-colored icy surface resembling a sponge.

Iapetus The moon is primarily known for its leading and trailing hemispheres being radically different. The albedo of most of the leading hemisphere is as dark as lampblack, while the trailing hemisphere's albedo is as bright as Europa. The 'dark' side of Iapetus is covered in minerals ready for harvesting right there on the surface. The colonists have built special mechs that make regular runs to sweep the surface for these materials for export and sale off-moon.

Travel times within Cronian system are quite short, usually just few hours.

Cronian Travel Time in Hours. (0.3g) 2351-05-16 (394-15-06)

	Prometheus	Janus	Mimas	Enceladus	Tethys	Dione	Rhea	Titan	Hyperion	Iapetus
Prometheus	0	5.5	2.6	5.7	6.7	6.9	7.4	11.1	11.3	18.8
Janus	5.5	0	5.9	5.4	4.2	5.5	8.0	11.1	12.4	19.3
Mimas	2.6	5.9	0	6.2	7.1	6.9	7.8	10.9	11.1	18.6
Enceladus	5.7	5.4	6.2	0	5.5	7.7	5.8	12.2	12.6	19.6
Tethys	6.7	4.2	7.1	5.5	0	6.4	8.0	11.7	13.1	19.7
Dione	6.9	5.5	6.9	7.7	6.4	0	9.7	9.8	12.3	18.9
Rhea	7.4	8.0	7.8	5.8	8.0	9.7	0	13.4	12.8	19.9
Titan	11.1	11.1	10.9	12.2	11.7	9.8	13.4	0	11.5	16.7
Hyperion	11.3	12.4	11.1	12.6	13.1	12.3	12.8	11.5	0	15.3
Iapetus	18.8	19.3	18.6	19.6	19.7	18.9	19.9	16.7	15.3	0

Cronian Travel Time in Hours. (0.5g) 2351-05-16 (394-15-06)

	Prometheus	Janus	Mimas	Enceladus	Tethys	Dione	Rhea	Titan	Hyperion	Iapetus
Prometheus	0	4.3	2.0	4.4	5.2	5.4	5.7	8.6	8.8	14.5
Janus	4.3	0	4.5	4.2	3.3	4.3	6.2	8.6	9.6	14.9
Mimas	2.0	4.5	0	4.8	5.5	5.4	6.0	8.4	8.6	14.4
Enceladus	4.4	4.2	4.8	0	4.3	6.0	4.5	9.5	9.7	15.2
Tethys	5.2	3.3	5.5	4.3	0	5.0	6.2	9.1	10.2	15.3
Dione	5.4	4.3	5.4	6.0	5.0	0	7.5	7.6	9.6	14.6
Rhea	5.7	6.2	6.0	4.5	6.2	7.5	0	10.3	9.9	15.4
Titan	8.6	8.6	8.4	9.5	9.1	7.6	10.3	0	8.9	13.0
Hyperion	8.8	9.6	8.6	9.7	10.2	9.6	9.9	8.9	0	11.9
Iapetus	14.5	14.9	14.4	15.2	15.3	14.6	15.4	13.0	11.9	0