OpenSpace

Datasets for Asteroids and Comets

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Contents

About this guide

This document outlines the datasets available within the OpenSpace astrovisualization software (version 0.15.2). These datasets were compiled from the Jet Propulsion Laboratory's (JPL) Small-Body Database (SBDB) and NASA's Planetary Data Service (PDS). These datasets provide insights into the characteristics, classifications, and abundance of small-bodies in the solar system, as well as their relationships to more prominent bodies.

Part 1: Visualization Settings

To load the Asteroids scene in OpenSpace, load the OpenSpace Launcher and select "asteroids" from the drop-down menu for "Scene." Then launch OpenSpace normally.

The Asteroids package is a big dataset, so it can take a few hours to load the first time even on very powerful machines and good internet connections. After a couple of times opening the program with this scene, it should take less time. If you are having trouble loading the scene, check the OpenSpace Wiki or the OpenSpace Support Slack for information and assistance.

When OpenSpace launches, the focus is Earth and none of the asteroids and comets are initially visible. To load these groups, open *Scene > solar system > Comets* or *Scene > solar system > Small Bodies.* Select the datasets you wish to view, and they will load in the visualization. All of the trajectories cover at least the inner solar system, with several encompassing the entire solar system, so make sure you are zoomed out enough to see all of the objects and their trails. The datasets only show orbital trajectories; users cannot view particular objects or focus on individual objects within datasets.

There are several tools that are useful in visualizing these datasets. To access these, click on a dataset to work with. A menu will drop down with settings for the dataset. Below is a list of settings that can be manipulated to benefit your project:

- **Renderable > Appearance**
  - **> Color** sets the RGB main color for the lines and points.
  - **> Line Fade** is a slider from 0-30 that determines the length of the lines representing the orbital trails. Smaller values make the lines shorter, larger values make the lines longer.
  - **> Line Width** is a slider that determines the width of the lines. Increasing the value makes lines easier to see, but can make it difficult to distinguish between lines.
  - **> Point Size** is a slider that changes the size of the points being visualized.
  - **> Rendering Mode** determines how the trail should be rendered to the screen. If 'Lines' is selected, only the line part is visible, if 'Points' is selected, only the corresponding points and subpoints are shown. 'Lines+Points' shows both parts.
- **Renderable > Segment Quality** is a slider from 0-10 that allows the user to define the number of line segments in the rendering of the orbital trail. This often has the visual effect of making the lines appear more are less dense, particularly with larger sets like the Amor or Apollo asteroids. It is useful to manipulate this value to achieve a visual that appropriately reflects the size and density of the datasets, and that clearly distinguishes between the orbital trajectories of each object.

- **Renderable > Transparency** is a slider from 0-1 that allows the user to establish the transparency of the orbital trails, with 0 being completely transparent and 1 being completely opaque. This setting is useful for viewing the relationship between the objects in a dataset and the other objects loading on the screen, especially the planets. Especially with the larger datasets, it is hard to see other objects in the solar system for reference, and changing the transparency makes it easier.
- **Renderable > Starting Index of Render** is a slider that chooses the index within the dataset at which the program will begin rendering objects. The value defaults to 0, meaning it automatically starts at the beginning of the dataset. Moving the slider will stop rendering all objects indexed before that value.
- **Renderable > Size of Render Block** is a slider that determines the number of objects loaded from the dataset starting at the *Starting Index of Render*. This value defaults to the number of objects in the set if the user is loading a contiguous set of objects.
- **Renderable > Upper Limit** is a slider that determines the number of objects rendered from whatever block of data you are loading. For example, the main asteroid belt contains almost a million asteroids. Setting *Upper Limit* to 10,000 will make OpenSpace render every 100th object in the main belt file, providing an even sampling (rendering only the first 10,000 objects could skew the visualization because some data files are sorted).
- **Renderable > Scale** determines the scale of the dataset the user is working with. For single objects, this will make them bigger or smaller, with 1 being normal size. However, with these datasets, changing scale proportionally expands or collapses the entire dataset, rather than making any objects larger. Increasing the scale value increases the distances between objects, such that orbital characteristics themselves are changed rather than anything about the objects.
- **Renderable > Rotation** and **Renderable > Translation** simply rotate or shift the dataset relative to its original orientation and position.

For more information about rendering the datasets appropriately and adding more data to the scene from the Small-Body Database, visit the Asteroids Building Content and Small Solarsystem Body Database pages on the OpenSpace Wiki.

Part 2: Near-Earth Asteroids

Near-Earth Asteroids (NEAs) are defined as those with perihelion distance less than 1.3 AU (within Mars's orbital path). These objects are rocky bodies made up of debris left over from the formation of the terrestrial inner planets 4.6 billion years ago. NEAs have short dynamical lifetimes because they are likely to collide with or have their orbits perturbed by the inner planets and the Sun. Therefore, astronomers believe this group is being replenished by the asteroid belt; if it weren't, all or most of the NEAs would have disappeared by this point in our solar system's development.

Most of them likely formed between Mars and Jupiter and have been gravitationally drawn in closer to the inner planets. They are of scientific interest and importance because they offer a glimpse into the chemical composition of the early solar system. They also pose a significant threat to life on Earth should they collide with the planet; a collision with an NEA with a diameter of just 1 km could kick up enough dust to block sunlight for years. The roughly 14,600 known NEAs are classified into four major groups based on their orbital characteristics with respect to the Sun, as well as two others classified by their relationship to Earth and Mars.

Amor Asteroids

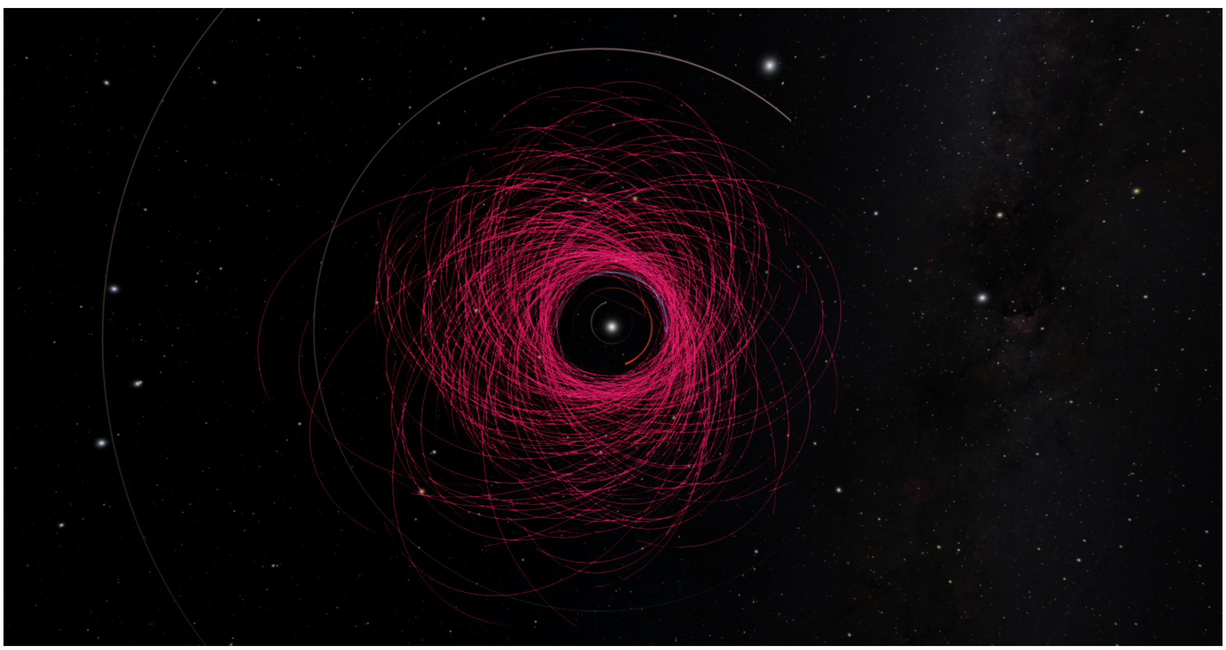

Figure 1: A view of the solar system from above with the Sun at its center, with the Amor asteroids dataset in pink.

Background: The Amor asteroids are those with orbits entirely exterior to Earth's but with perihelion distances less than 1.3 AU. Most of these objects cross the orbit of Mars, and some extreme cases have aphelion beyond Jupiter. They are named after 1221 Amor, discovered by Eugène Delporte in 1932.

They are the second largest group of NEAs with 8,728 discovered members in the JPL SBDB, typically 1-5 kilometers in diameter. The largest NEA, 1036 Ganymed, is classified as an Amor asteroid with a diameter of 37.675 km.

The lifetimes of these objects are limited by their proximity to Mars; they are likely to eventually collide with the planet. It is possible Mars' moons, Deimos and Phobos, are Amor asteroids captured by Mars' gravity. Over long periods of time, they will become Apollo asteroids as they are drawn closer to the Sun by gravity.

OpenSpace: The Amor asteroids are available as a dataset in OpenSpace. OpenSpace renders trails representing the orbital paths of the many asteroids in this dataset. The individual asteroids are not renderable. Users can examine and modify the visualization of the Amors in the *Scene* settings outlined in Part 1: Visualization Settings. There are 8,628 asteroids rendered in this dataset, making it the second largest of the classifications of the NEAs. In the image above, it is apparent that the orbital trails of the Amors (pink trails) are concentrated outside of Earth's orbit (blue trail), the defining characteristic of the Amor asteroids.

Resources:

- JPL Small-Body Database
- Basics of Near-Earth Objects
- OpenSpace Wiki (Asteroids and Comets)
- COSMOS - the SAO Encyclopedia of Astronomy

Apollo Asteroids

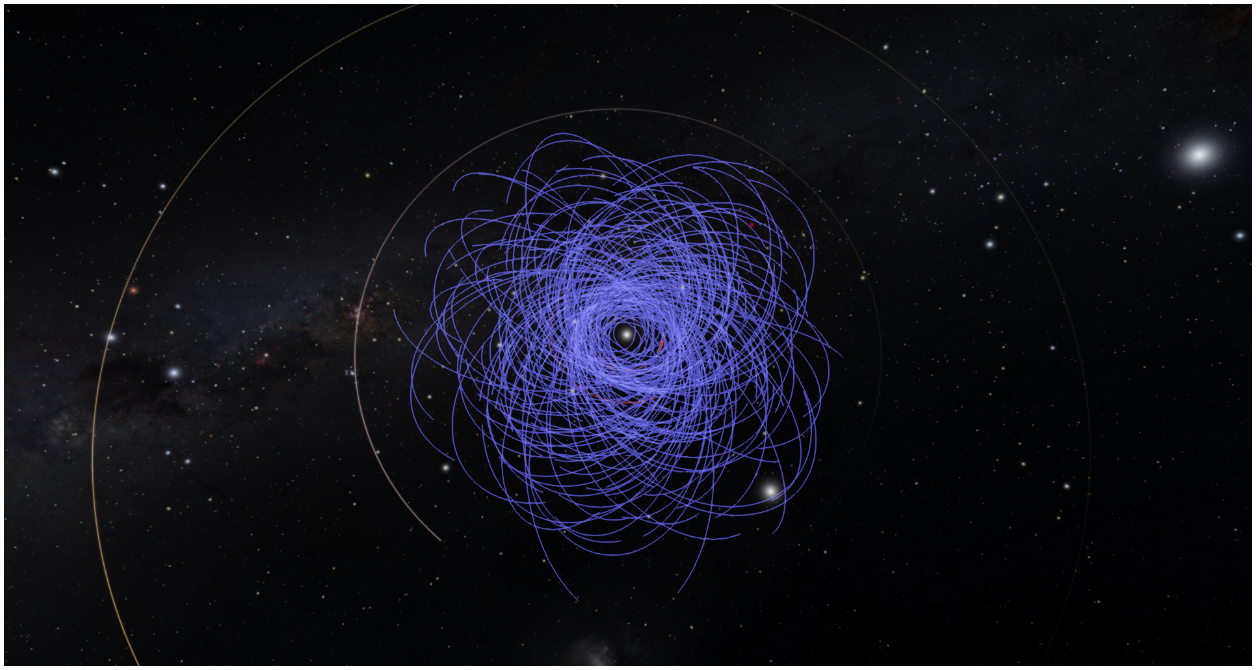

Figure 2: A view from above the solar system with the Sun at the center, showing the Apollo asteroids dataset in blue.

Background: The Apollo asteroids are Earth-crossing asteroids with semi-major axes larger than Earth's. Named after 1862 Apollo, the majority of NEAs and Potential Hazardous Asteroids (PHAs) are classified as Apollos, with more than 13,000 in this category so far. Their lifetimes are relatively short because of their proximity to and high chance to collide with the inner planets.

Many of these probably originated in the main asteroid belt, but were ejected due to gravitational interactions with Jupiter and the inner planets. The largest of these objects is 1866 Sisyphus with a diameter of 8.48 km. The meteor that broke up in the atmosphere over Russia in 2013 was also a member of the Apollo family.

***OpenSpace*:** The Apollo asteroids are available as a dataset in OpenSpace, and can be rendered and modified using the settings outlined in Part 1: Visualization Settings. Objects in this dataset cannot be individually rendered, only the orbital trajectories of the objects. In the image above, all of the asteroids cross Earth's path, but the majority spend most of their time outside of Earth's orbit, which is their defining characteristic. There are 12,317 objects users can load in this scene.

Resources:

- COSMOS - the SAO Encyclopedia of Astronomy
- JPL Small-Body Database
- Wolfram Research: Apollo Asteroids
- Basics of Near-Earth Objects

Aten Asteroids

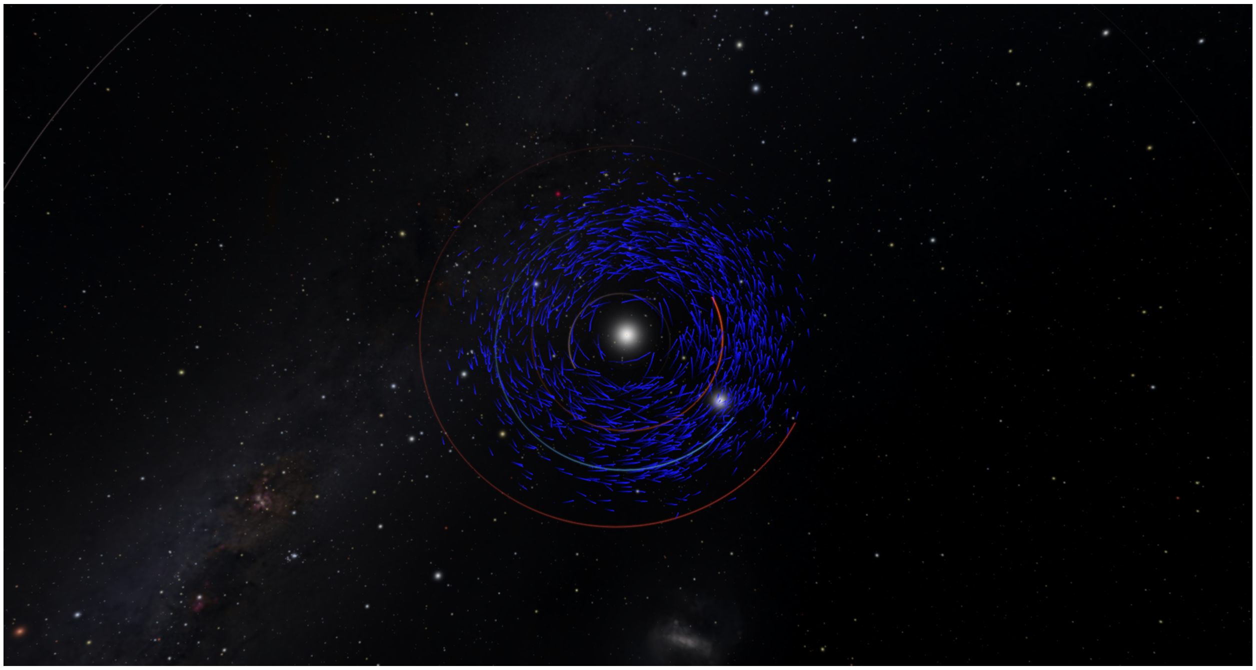

Figure 3: A view from above the solar system with the Sun at the center, showing the Aten asteroids dataset in blue.

Background: The Aten asteroids are Earth-crossing NEAs with semi-major axes smaller than Earth's. These are a smaller group than the Apollos or the Amors, with 1,790 in the JPL SBDS. They are named after 2062 Aten, a 1.1 km diameter asteroid discovered in 1976.

As with the other groups of NEAs, these have short lifetimes and likely originated in the main asteroid belt. Some of these are also classified as PHAs, given that they are Earth-crossing. The largest known of these objects is 3554 Amun at 3.341 km in diameter.

OpenSpace: The Aten asteroids is a smaller dataset to render than the Amors and the Apollos, and they are easier to visualize on less sophisticated machines. It is possible to observe the orbiting patterns of the asteroids collectively, but it is difficult to look at individual asteroids because there are so many of them. The defining characteristic of the Atens is they cross Earth's path but spend the majority of their time inside Earth's orbit, which is apparent when the objects are rendered. There are 1,685 objects to render in this dataset.

Resources:

- JPL Small-Body Database
- COSMOS - the SAO Encyclopedia of Astronomy
- Basics of Near-Earth Objects

Atira Asteroids

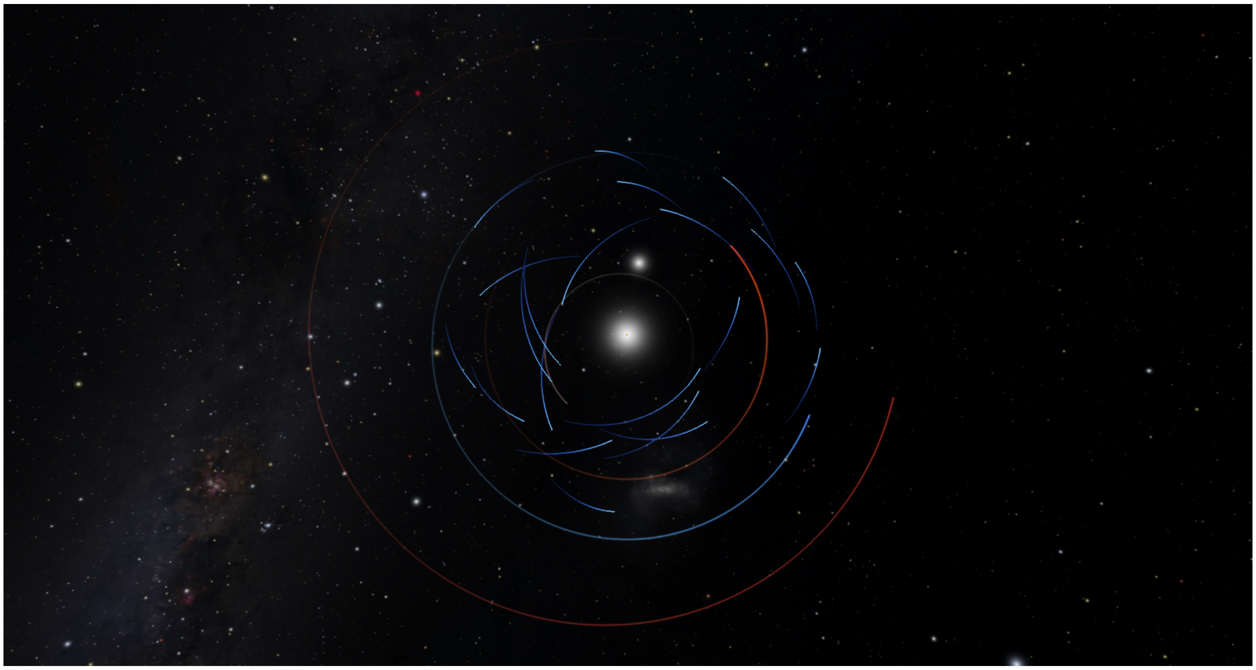

Figure 4: A view from above the solar system with the Sun at the center, showing the Atira asteroids dataset in light blue.

Background: The Atira asteroids are NEAs whose orbits are contained entirely within the orbit of the Earth. This is by far the smallest group of NEAs, with just 23 members in the group. They are often considered a subset of the Aten set because there are so few of them. They are named for 163693 Atira, the first of these objects discovered in 2003.

Atira asteroids are not of particular concern to us because they will never cross Earth's path, but they provide insights to the formation of the solar system nonetheless. It was confirmed in the summer of 2020 that 2020 AV_2 was the first known asteroid to orbit entirely within Venus's orbit.

OpenSpace: There are 21 Atira asteroids to visualize in this dataset. All are contained entirely within Earth's orbit. Because they are a smaller group, it is easier to examine the relationships between each object and the inner planets and observe the orbits of each asteroid by changing the time settings in the menu at the bottom of the screen.

Resources:

- JPL Small-Body Database
- Basics of Near-Earth Objects
- Physical characterization of 2020 AV_2, the first known asteroid orbiting inside Venus orbit

Potentially Hazardous Asteroids (PHAs)

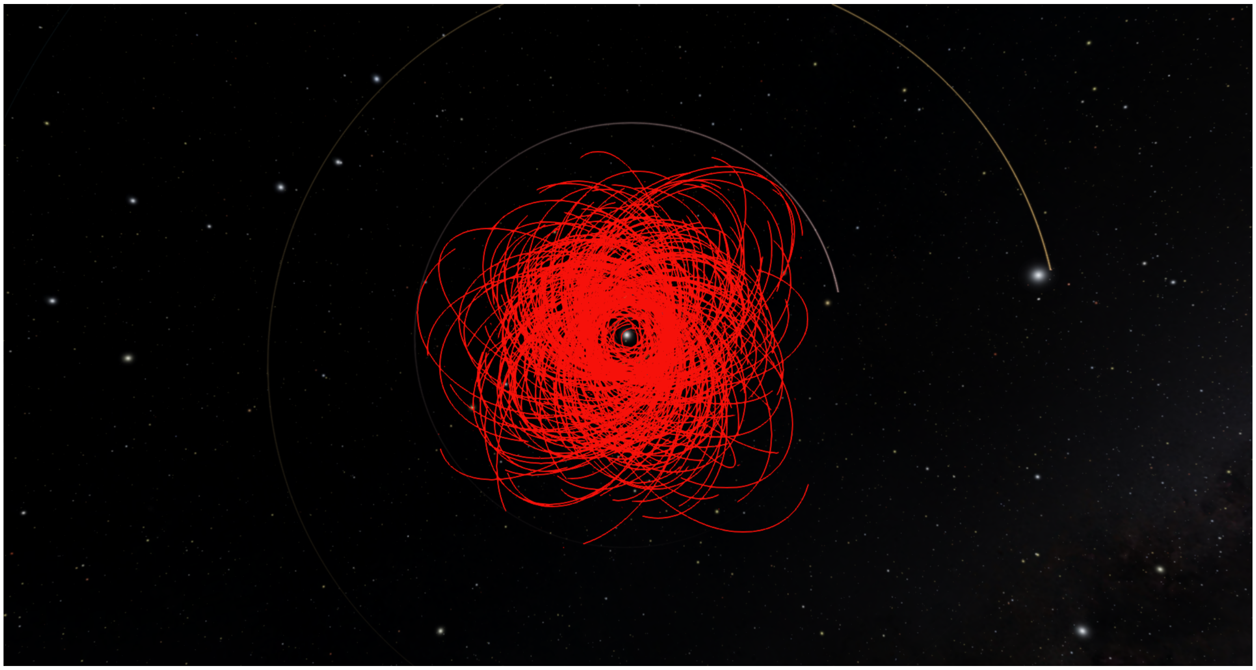

Figure 5: A view of the solar system from above with the Sun at the center, showing the Potentially Hazardous Asteroids dataset in red.

Background: Potentially Hazardous Asteroids (PHAs) are defined as NEAs whose Minimum Orbit Intersection Distance (MOID) with Earth is 0.05 au or less, and whose absolute magnitude is 22.0 or brighter. In other words, any asteroid (regardless of classification) that comes within 5% of Earth's average distance from the Sun of Earth and with H ≤ 22.0 is considered a PHA.

There are over 2,000 asteroids in this group, coming mostly from the Apollo group of NEAs. According to the [JPL SBDB], 6 PHAs are Atira asteroids, 176 are Atens, 1,798 are Apollos, and 120 are Amors. Of these 2,100 objects, [more than 150] of them are larger than 1 km in diameter.

If an object of that size were to collide with Earth, it would kick up enough debris to block out sunlight for several years, which would be absolutely catastrophic for agriculture and human life as a whole. That is why it is so important to study and classify asteroids, and PHAs in particular.

OpenSpace: There are 2,011 PHAs in the OpenSpace dataset. The dataset is so large that it is difficult to observe the paths of any individual objects, but it does reflect the sheer number of objects that are potentially hazardous to Earth, and how they come in many different forms. Users should use small line widths and small line fades to more clearly observe this dataset.

Resources:
- Basics of Near-Earth Objects
- Minimum Orbital Intersection Distance

- [List of Potentially Hazardous Objects - Minor Planet Center]
- [Report of the Task Force on Potentially Hazardous Near-Earth Objects (2000)]
- [JPL Small-Body Database]

Mars-crossing Asteroids

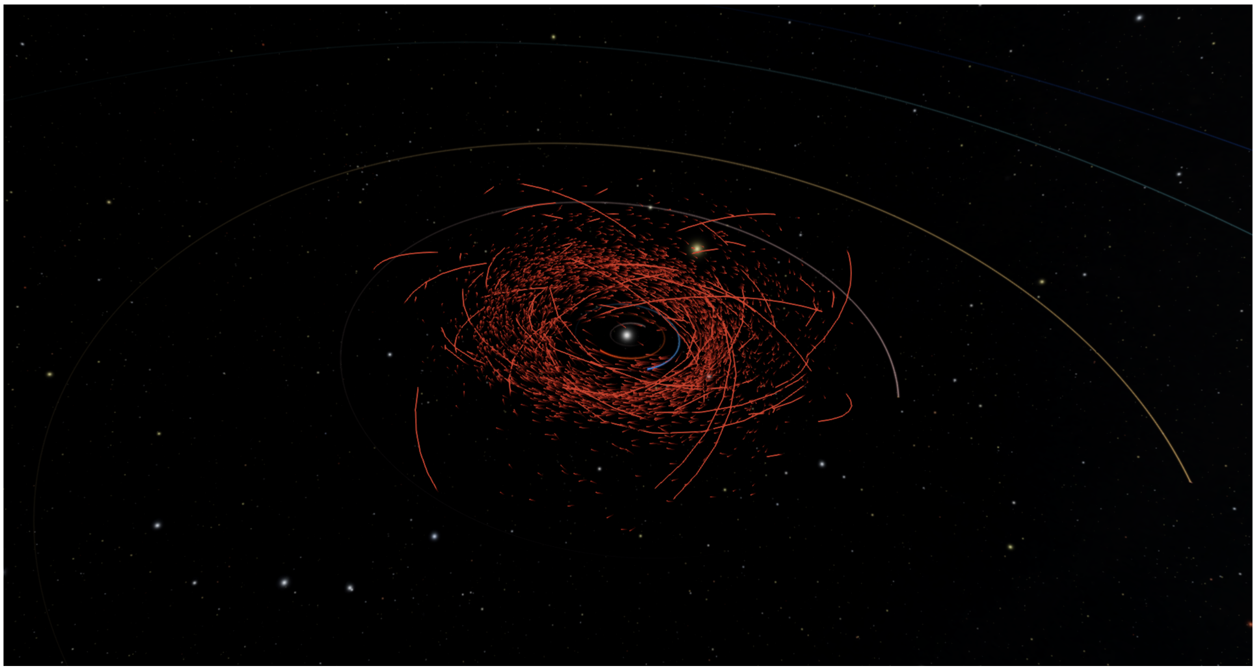

Figure 6: A view of the solar system with the Sun at the center, showing the Mars-crossing asteroids dataset in red.

Background: Mars-crossing asteroids are those that cross the orbit of Mars, with a semi-major axis of less than 3.2 au, and a perihelion distance of between 1.3 and 1.666 au. These are objects that on average orbit beyond Mars, but cross within Mars' orbit. This is the classification of asteroids between the Amor asteroids and the Inner-main Asteroid Belt. There are 19,219 objects listed in the JPL SMDB with this classification.

OpenSpace: This dataset is interesting to observe in OpenSpace because it shows that the distinctions between classifications of asteroids aren't always clean cut. From looking at the image, it isn't obvious that all of these objects are Mars-crossing, and given any of these objects in comparison to other asteroid groups, the distinction falls apart a little bit. It only becomes clear that they are Mars-crossing asteroids when the user increases the simulation speed and observes the full orbits. It is particularly interesting to look at these in comparison to the asteroid belt datasets because most of these objects spend a good amount of time in the region of the asteroid belt, they just happen to cross Mars, which is why they are in a separate category. OpenSpace has 18,675 renderable mars-crossing asteroids.

Resources:
- JPL Small-Body Database

Part 3: Main-Belt Asteroids

The asteroid belt is the largest collection of asteroids anywhere in the solar system. It is located between the orbits of Mars and Jupiter, and it contains over a million asteroids, as well as the dwarf planet Ceres. Ceres is the largest and was the first object discovered in the asteroid belt at about a quarter the size of Earth's moon, but objects in this region can range from the size of boulders to tens of kilometers across. There more than 200 known main-belt asteroids larger than 100 km in diameter.

The asteroid belt likely formed out of material that was never able to coalesce as a planet following the formation of the solar system, held in its current position by Jupiter's gravity. Some theorize that the asteroid belt was once a planet that somehow disintegrated, but there is so little mass collectively in the asteroid belt that this theory presently seems unlikely. It is often divided into the inner belt (asteroids nearer to Mars) and the outer belt (asteroids nearer to Jupiter). In terms of population density, there are peaks in the inner belt and outer belt because these locations are gravitationally optimal for minor bodies in relation to Mars and Jupiter.

Inner Main Asteroid Belt

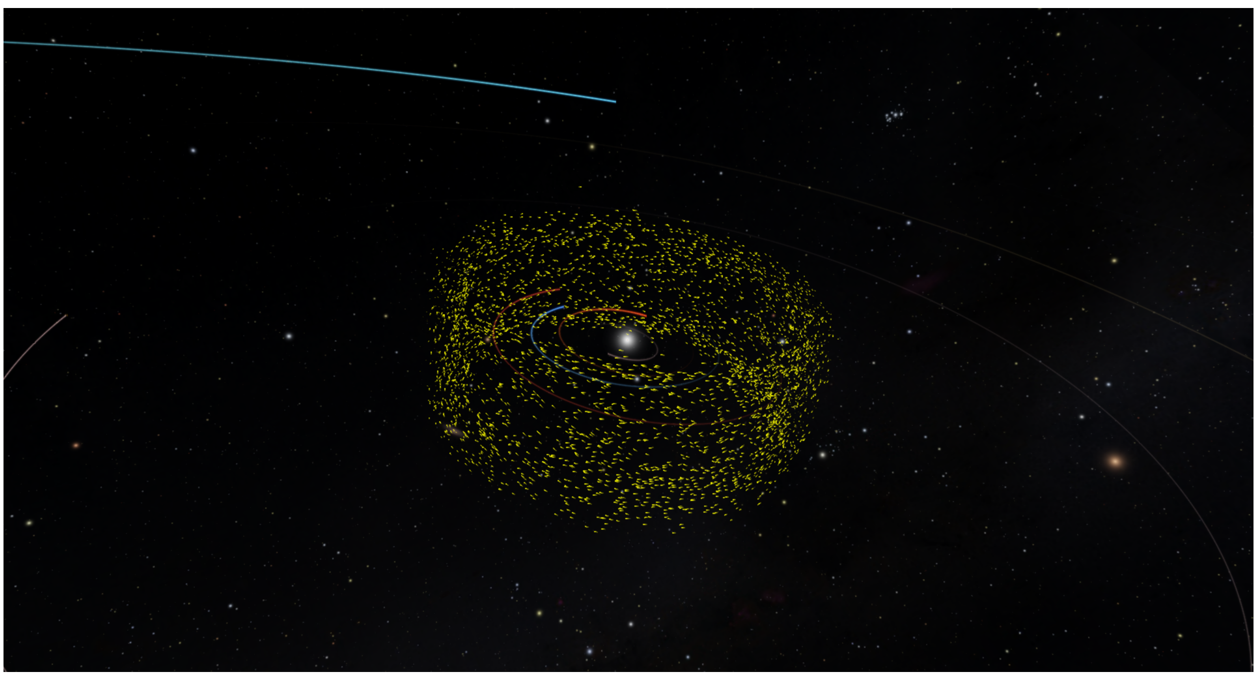

Figure 7: A view of the solar system with the Sun at the center with the inner main asteroid belt dataset in yellow.

Background: The Inner Main-belt asteroids are those with a semi-major axis less than 2.0 au and a perihelion distance greater than 1.666 au. These are objects that orbit beyond the orbit of Mars, but within the boundary of the Main-belt. There are 21,030 objects in this set, according to the JPL SMBD.

OpenSpace: The inner main-belt asteroids are easy and interesting to visualize in OpenSpace because despite it being a large dataset, the user can easily distinguish between each object. Individual objects are not viewable, but users can collectively observe 20,294 objects in this set. The movement of these objects over time is also observable given the distinction between objects.

Resources:

- JPL: Small-Body Database

Main Asteroid Belt

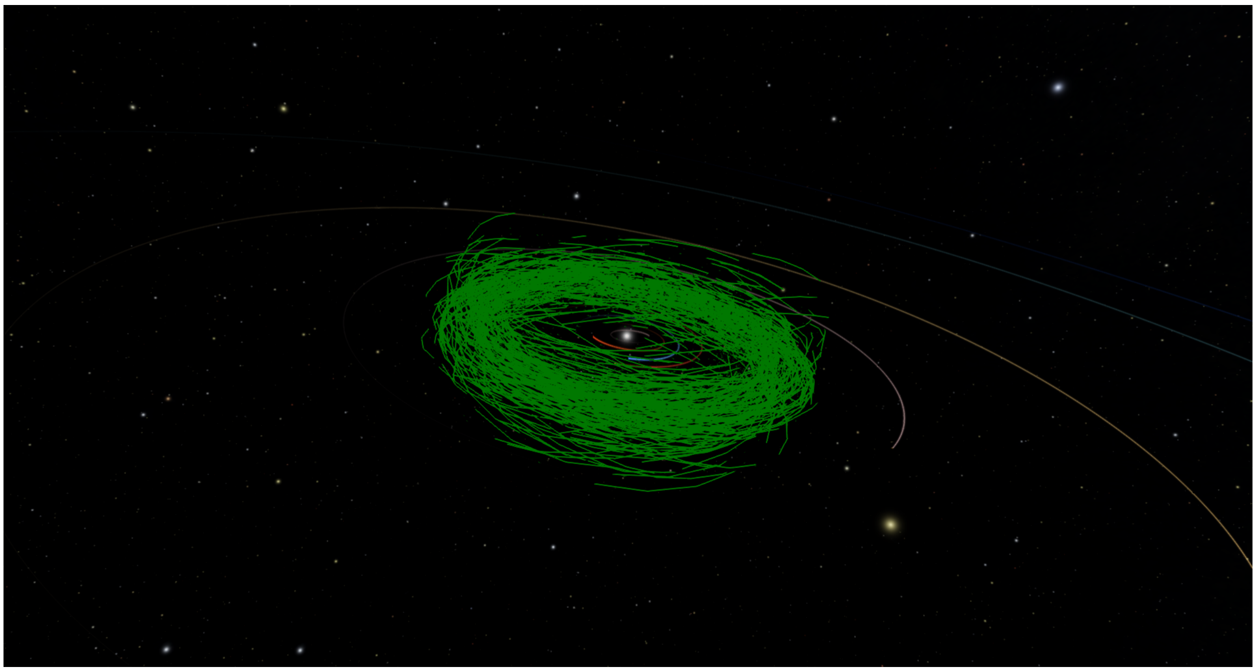

Figure 8: A view of the solar system with the Sun at the center, with the main asteroid belt dataset in green.

Background: The Main Asteroid Belt contains asteroids with a semi-major axis of between 2.0 and 3.2 au, and a perihelion distance greater than 1.666 au, is by far the majority of all asteroids in the solar system. There are probably millions of asteroids in this region, with 888,738 objects in the JPL SMDB.

The asteroids here are characteristic of other asteroids in the solar system, likely composed of the same or similar materials as the inner terrestrial planets. They vary in shape and size, with the largest being Ceres, which orbits at an average distance of 2.77 au. Ceres was visited by the Dawn spacecraft in 2015, and is known to be composed in part of water.

OpenSpace: This is easily the largest dataset available to load in OpenSpace. There are 834,041 objects available to render, and rendering all of them at once can reduce the frame rate on smaller machines to 1-3 FPS. Therefore, it is recommended that when using this dataset for visualizations, the upper limit be reduced such to get an appropriate representation of the dataset but not incapacitate the computer. However, this is an interesting set to observe in the context of the other groups because there are so many objects.

Resources:

- Asteroid Belt: Facts and Formation
- NASA Overview: Ceres
- JPL: Small-Body Database

Outer Main Asteroid Belt

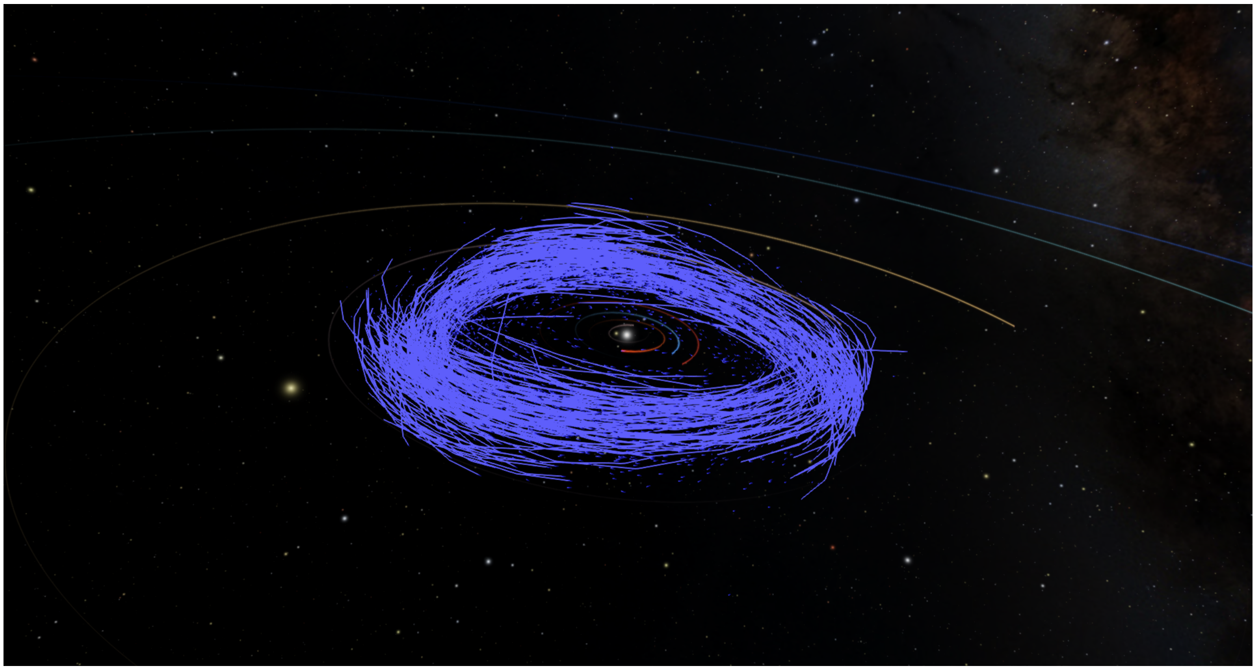

Figure 9: A view of the solar system with the Sun at the center showing the outer main asteroid belt dataset in purple.

Background: The Outer Main-belt asteroids are those with a semi-major axis of between 3.2 and 4.6 au. These objects orbit outside the boundaries of the main-belt, but within the orbit of Jupiter. There are 29,646 objects in this set, according to the JPL SMBD.

OpenSpace: The Outer Main-belt asteroids are a little bit larger of a dataset than the inner main-belt asteroids with 28,288 objects. When loaded at the same time as the inner main-belt group, the separation between them and their relationship to Mars and Jupiter is apparent. Notice the three bulges about 120° apart around the band of these asteroids. These bulges occur due to gravitational influences from Jupiter, similar in terms of physics to the Jupiter-Trojan asteroids discussed in the next section.

Resources:

- JPL: Small-Body Database

Part 4: Centaurs, Trojans, and Trans-Neptunian Objects

Outer and trans-neptunian objects (TNOs) are those beyond the asteroid belt. While there are likely millions of these objects, particularly TNOs, they are difficult to observe because they are small and dark. Some are observed by Earth-based telescopes, while others are seen by Hubble Space Telescope or missions designed specifically to observe them. Astronomers classify these asteroids into three groups: those that orbit largely between Jupiter and Neptune, those that orbit primarily beyond Neptune, and those that orbit in the Lagrange points of the giant planets.

Centaur Objects

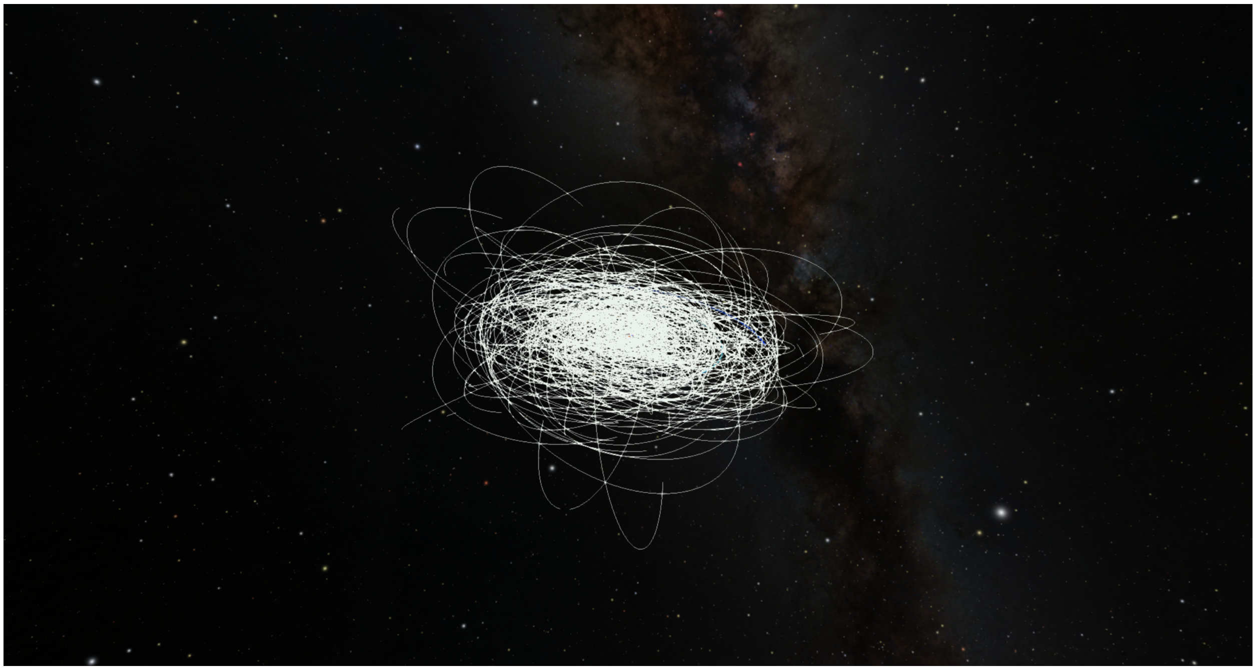

Figure 10: View of the solar system with the centaur objects dataset in white.

Background: Centaurs are defined as any small solar system bodies with orbits between Jupiter and Neptune. These objects typically have highly unstable orbits because their trajectories are so perturbed by the giant planets. Often due to this instability, the centaurs are classified different ways by different institutions. JPL (where OpenSpace acquires data) defines them as having a semi-major axis between those of Jupiter and Neptune (5.5 au < a < 30.1 au). Using this definition, JPL lists 525 objects as centaurs, but this number varies depending on the source. Centaurs are generally rich in ice and other volatile compounds because they are beyond the frost line, and many are probably objects that originated in the scattered disk through gravitational interactions with Neptune and the other giants.

OpenSpace: OpenSpace has 508 renderable Centaurs. These objects are long orbital trails in OpenSpace, even with small Line fade values, which makes them somewhat difficult to observe fully. However, the data is useful for seeing the variety in the orbits on these objects. As evident in the image above, these objects are not coplanar by any means; many have orbits nearly perpendicular to the plane of the rest of the solar system. The Centaurs in OpenSpace do extend beyond Neptune and within Jupiter, but they spend the majority of their time between the two.

Resources:

- JPL Small-Body Database: List of Centaurs

Jupiter Trojan Asteroids

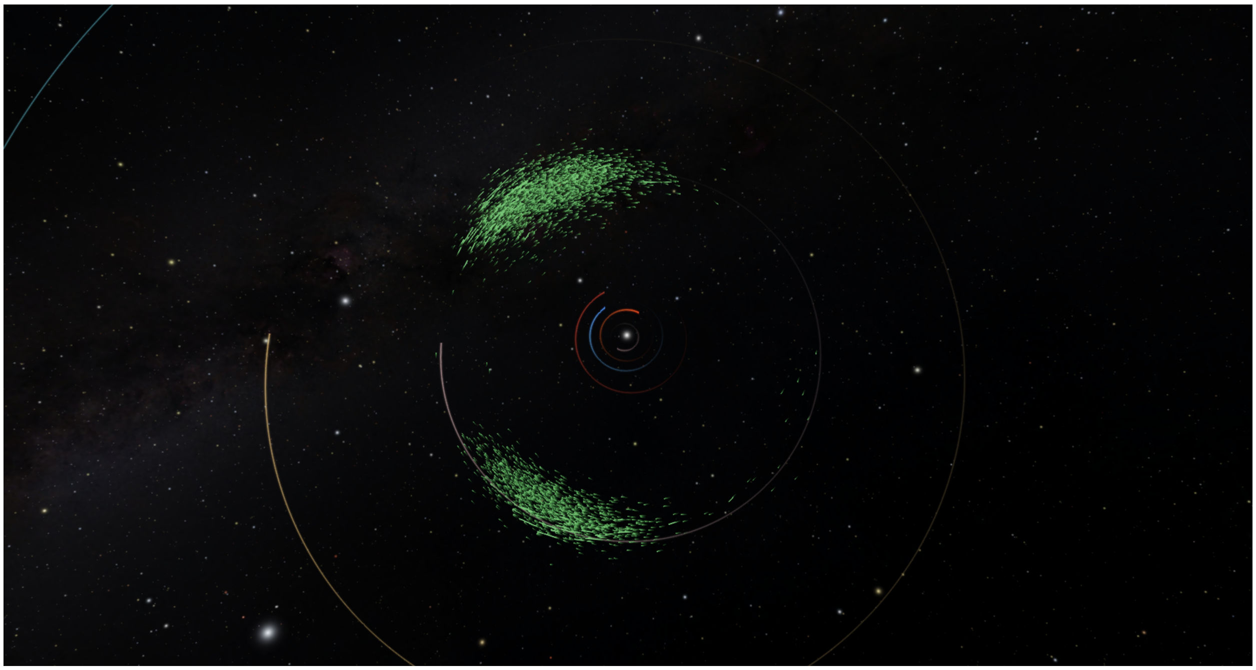

Figure 11: View of the solar system with the Sun at the center and the Jupiter Trojans dataset in green.

Background: Jupiter Trojan asteroids are those trapped in Jupiter's L4/L5 Lagrange points (semimajor axis of between 4.6 and 5.5 au), with an eccentricity of less than 0.3. Lagrange points are locations where the gravitational forces from the Sun and an object balance such that objects can orbit the Sun at that location in a stable configuration. Essentially, they orbit along Jupiter's path, but do not themselves orbit Jupiter.

The first Trojan (588 Achilles) was discovered in 1906, and they are named by convention after a figure from the Trojan War in Greek mythology. Trojans in general refer to objects that orbit in the Lagrange points of the planets, but Jupiter-trojans are the largest group. Trojans have also been identified in the orbits of Mars, Neptune, and Earth, but there are much fewer of them and they are not available as datasets in the JPL SMBD (and therefore OpenSpace). There are 8,710 Jupiter-trojans listed by JPL.

OpenSpace: The Jupiter Trojans are fascinating to observe in OpenSpace. Because they are concentrated at Jupiter's Lagrange points, they are easy to observe as an entire group, and they make it easy to identify Jupiter's Lagrange points. Users can also observe how the objects orbit with Jupiter, but not around it by increasing the simulation speed or the line fade. This makes OpenSpace a useful tool for explaining what Lagrange points are and how scientists define Trojan asteroids. There are 8,188 Jupiter Trojans renderable in OpenSpace.

Resources:

- JPL: Small-Body Database
- List of Jupiter Trojans
- 588 Achilles

Trans-Neptunian Objects

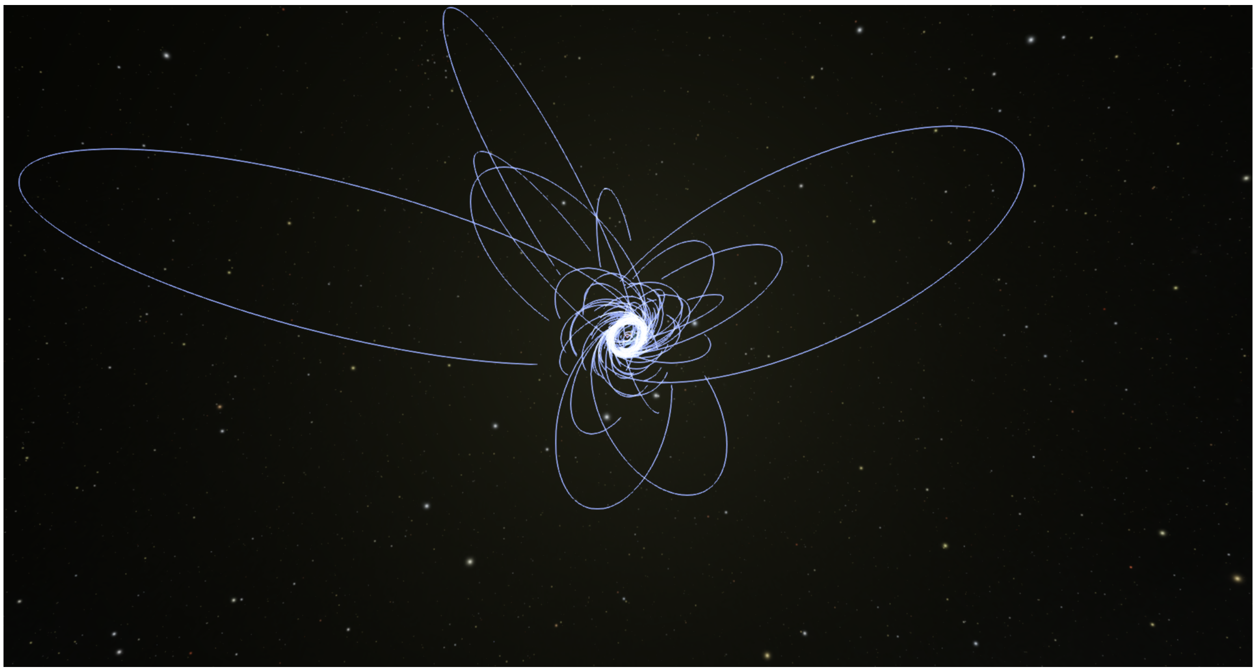

Figure 12: View of the solar system with the Trans-Neptunian Objects dataset in white.

Background: Trans-Neptunian Objects (TNOs) are any small bodies that orbit the Sun at a greater average distance than Neptune, with a semi-major axis of 30.1 au. Of all the asteroid groups, the TNOs are probably the least understood because they are so far away and difficult to observe. JPL SMBD lists 3,537 TNOs, but scientists believe this is by far the largest group of small bodies in the solar system. There are likely millions of asteroids, comets, and dwarf planets in this classification that we haven't discovered yet.

The region beyond Neptune that contains these objects is often divided into the Kuiper Belt, the scattered disk, and the Oort Cloud, with increasing distance from the Sun. The Kuiper Belt (~30-50 AU) is thought to contain more than 100,000 objects larger than 50 km in radius, and it is dominated by objects composed of astrophysical ices rather than rock. The scattered disk (up to 100 AU) is made up of objects likely composed of icy remnants from the formation of the solar system. The Oort Cloud (~2,000-50,000 AU) is a hypothesized region where most longer period comets originate.

The first of these objects to be discovered was Pluto in 1930, with three other dwarf planets (Eris, Makemake, and Haumea) being classified as TNOs.

OpenSpace: Pluto is the only dwarf planet and the only object in this scene in OpenSpace to be observable as its own object. Pluto is rendered in all scenes of OpenSpace using data from the New Horizons spacecraft that flew by Pluto in 2015. The rest of the TNOs set is only viewable like the other sets, with the orbital trails being visible. To view the entire set at once, users must zoom out very far because the objects in this dataset extend far beyond Neptune.

Resources:
- JPL SMBD: List of TNOs
- Kuiper Belt
- Trans-Neptunian Objects

Part 5: Comets

Comets are objects composed of rock and ice that orbit that Sun, and as they get close to it, the ice melts or sublimates in a process called outgassing that leaves a trail of materials millions of miles long behind it.

Often what we see from Earth is the trail of outgassed material following the comet rather than the object itself. Comets actually have two tails: one of gas that points directly away from the Sun (influenced significantly by the Solar wind) and one of dust that follows the comet's path.

Comets can range in size from a few kilometers to many tens of kilometers in size. They have particularly elongated orbits, which sets them apart from most asteroids, in addition to the devolatilization of icy materials on the surface. Their elongated orbits are why they are sometimes difficult to observe and why outgassing is possible in the first place; if the objects were consistently close to or far away from the Sun, icy materials would either not be present (NEAs) or would not sublimate (centaurs, Jupiter-trojans, and some TNOs).

NASA has sent numerous missions to observe comets, including Deep Space I, which observed the nucleus of comet Borrelly in 2001, and Stardust, which collected cometary particles and interstellar dust from Comet Wild 2 in 2004. The European Space Agency's Rosetta mission observed 67P/Churyumov-Gerasimenko from 2014-2016, with a lander attempting to make contact with an observe the surface. The lander ultimately made it to the surface, but is no longer communicating data. So far, NASA has identified 3,676 comets.

Like the asteroids, all of the data in OpenSpace regards orbital trajectories rather than composition and imaging of the comets themselves. The data on the comets also comes from the JPL Small-Body Database, and as such, are classified into various types in the same way JPL classifies the objects. These distinctions are largely based on Tisserand's Parameter with respect to Jupiter, a quantity useful for understanding the pre- and post-encounter dynamics of comets as they orbit.

Chiron-type Comets

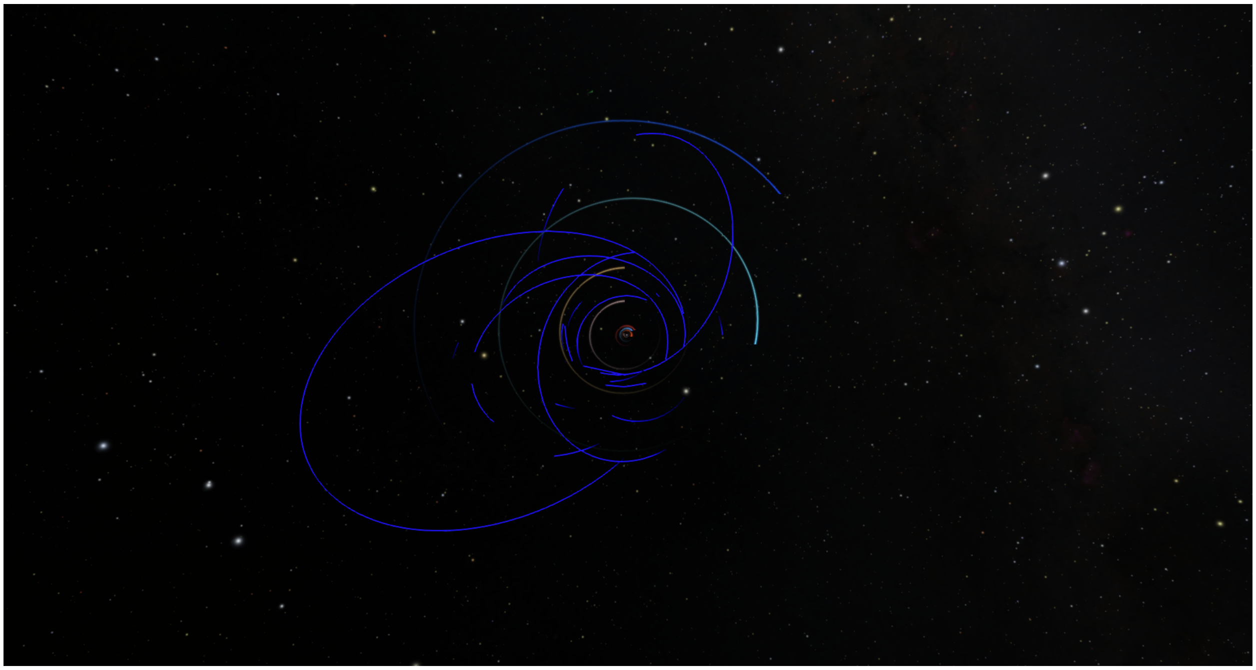

Figure 13: View of the solar system with the Chiron-type comets dataset in dark blue.

Background: Chiron-type comets are those with a Tisserand's parameter with respect to Jupiter of greater than 3 and a semi-major axis greater than that of Jupiter. They are named for Chiron 2060, the largest and most prominent of this group's members. Chiron 2060 is also classified in the Centaur group. There are 15 total Chiron-type comets according to the JPL Small-Body Database.

OpenSpace: All 15 Chiron-type comets are renderable in OpenSpace. Because there are only a few of them, it is easy to observe each of their orbits individually while increasing the simulation speed or line fade. Users can also observe how close the objects get to Earth and the other major bodies in the solar system, and that the orbits are not strictly in the orbital plane of the major planets.

Resources:

- NASA PDS: Small Body Nodes
- JPL: Small Body Database

Encke-type Comets

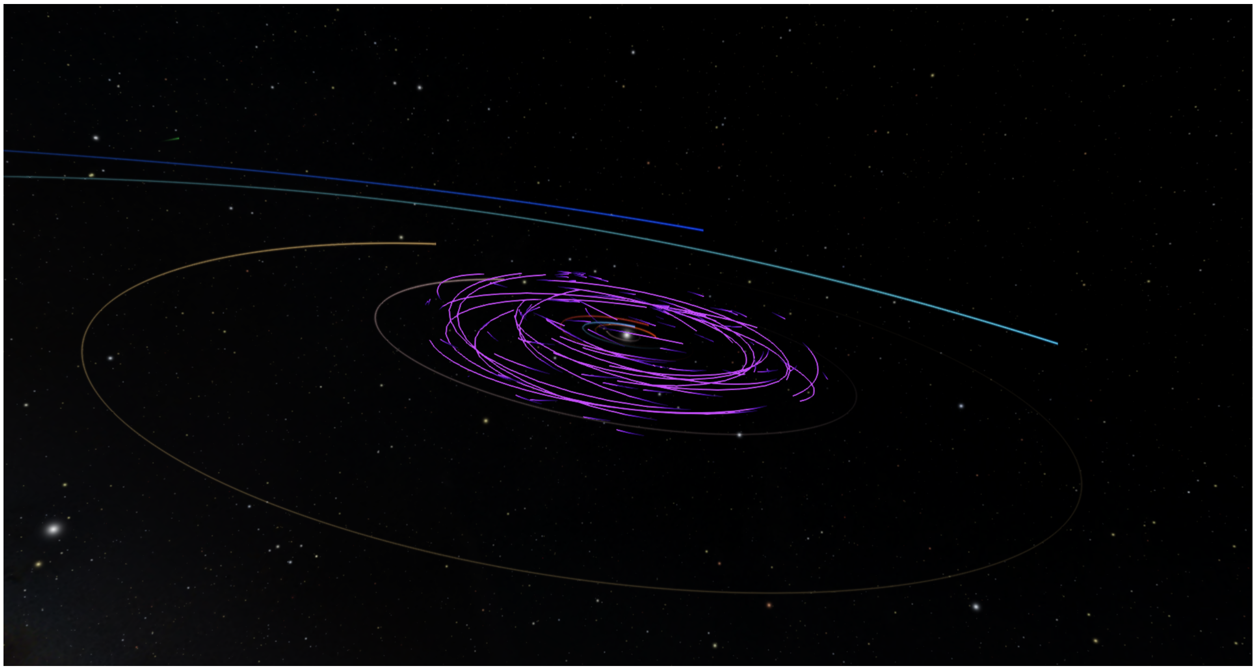

Figure 14: View of the solar system with the Encke-type comets database in purple.

Background: Encke-type comets are those with a Tisserand's parameter with respect to Jupiter of greater than 3 and a semi-major axis less than that of Jupiter. These are named for 2P/Encke, the most prominent of this classification that is also considered a near-Earth asteroid because of its near-passes to Earth. There are 61 Encke-type comets.

OpenSpace: There are 58 Encke-type comets to be observed in OpenSpace. The objects are fairly evenly spaced and the orbits are not as eccentric as some of the other datasets, which makes them easily observable. Most of their orbits are relatively coplanar, with the trajectories tilting about 30 degrees at most from the plane of the major planets. Line fade and simulation speed are useful for observing the orbits of these objects.

Resources:

- 2P/Encke: Space Reference
- NASA PDS: Small Body Nodes
- JPL: Small Body Database

Halley-type Comets

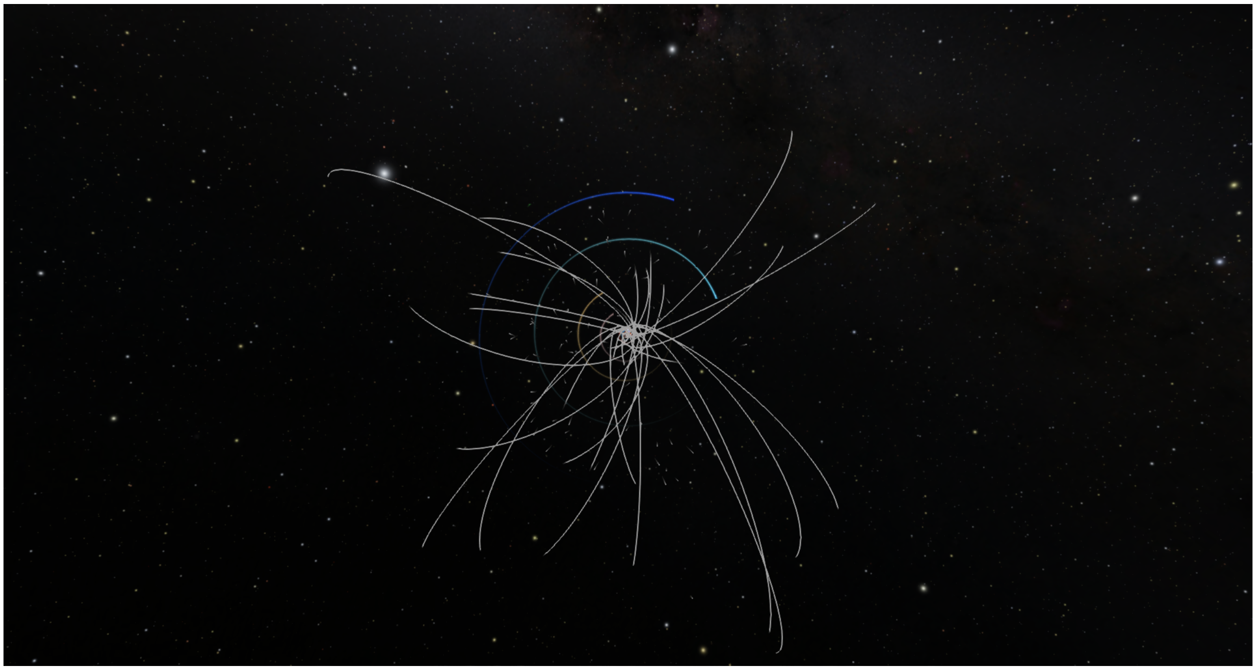

Figure 15: View of the solar system with the Halley-type comets dataset in white.

Background: Halley-type comets are periodic comets with an orbital period between 20 and 200 years by the classical definition, and by some definitions, with a Tisserand's Parameter of less than 2. They are named for Halley's Comet, the "most famous" periodic. Halley's Comet orbits the Sun every 76 years, with the most recent appearance in our sky coming in 1986. Halley-type comets most likely originated in the Oort Cloud, the region of trans-Neptunian objects beyond the Kuiper Belt and the scattered disk.

Those that began in the Oort Cloud were probably pulled by Neptune's gravity and shot towards the Sun, ultimately stabilizing in a periodic orbit with the help of Jupiter. Because the classical definition is broad, there is overlap between this classification and others. For example, 2P/Encke, the comet and NEA for which the Encke-type comets are named, is also a Halley-type comet according to the JPL: Small Body Database. There are 153 Halley-type comets in the database.

OpenSpace: Halley-type comets are interesting to observe because their orbits are extremely eccentric and they are not in the orbital place of the major planets. There are 89 Halley-type comets in OpenSpace. Some have long trails, others have very short trails, given the wide range of orbital periods between 20 and 200 years. To get the best sense for the orbital characteristics of this dataset is to maximize line fade to see the full orbital paths of all of the objects.

Resources:

- Halley's Comet

- NASA PDS: Small Body Nodes
- JPL: Small Body Database
- COSMOS: The SAO Encyclopedia of Astronomy

Jupiter-family Comets

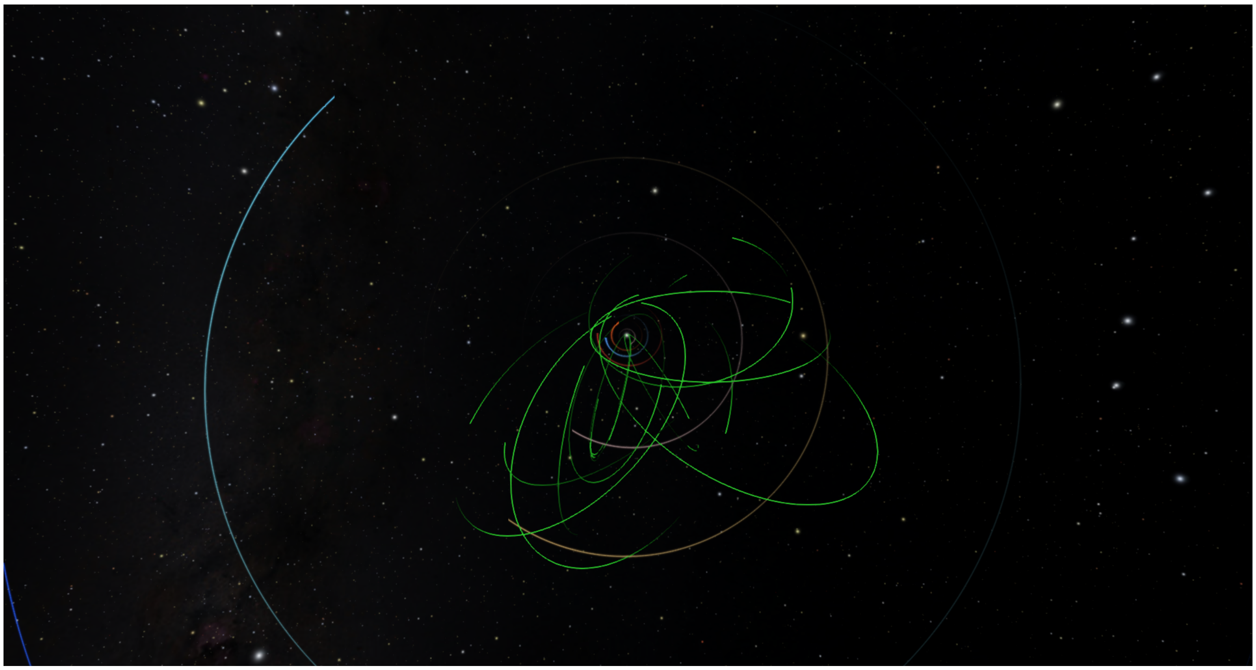

Figure 16: View of the solar system with the Jupiter-family comets dataset in green.

Background: Jupiter-family comets are those with a Tisserand's parameter with respect to Jupiter of between 2 and 3. They are classically defined as comets with periodic orbits of less than 20 years, specifically shorter than Halley-type comets. Their name comes from their orbits, which are significantly influenced by Jupiter's gravity; Jupiter's attraction pulls them into much more elliptical orbits, shortening their orbital period. Jupiter-family comets likely originated as pieces of broken up Kuiper Belt objects that were drawn in by Neptune and later perturbed by Jupiter. There are 51 Jupiter-family comets in the JPL: Small Body Database.

OpenSpace: Like the Halley-type comets, Jupiter-family comets have extremely eccentric orbits and are not coplanar with the major planets. However, the orbits are a little bit easier to observe because the orbital periods are more consistent within the dataset. They also stay relatively close to Jupiter and Saturn at the outer regions of their orbits because they are so influenced by Jupiter's gravity. There are 15 Jupiter-family comets in OpenSpace, making it easy to observe individual orbital trajectories.

Resources:

- List of Jupiter-family and Halley Type Comets
- NASA PDS: Small Body Nodes

- JPL: Small Body Database
- COSMOS: The SAO Encyclopedia of Astronomy

C 2019 Y4 ATLAS

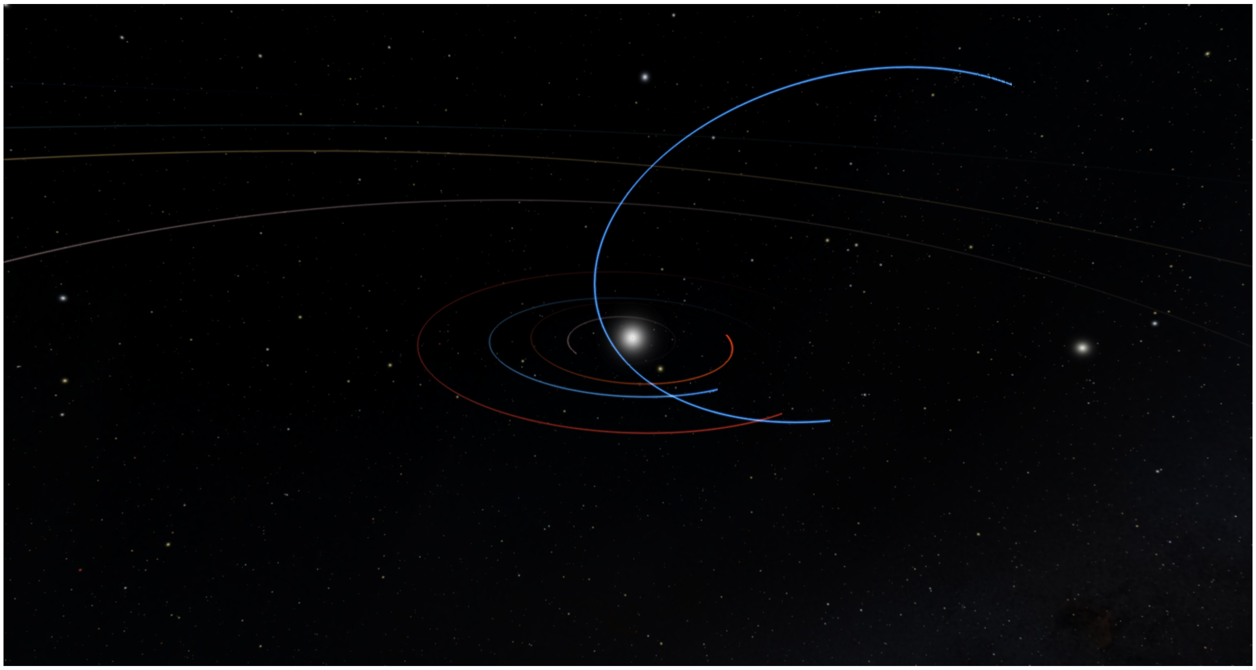

Figure 17: View of the solar system with C 2019 Y4 ATLAS trajectory in blue.

Background: C 2019 Y4 ATLAS was discovered in December 2019 by the Asteroid Terrestrial-impact Last Alert System (ATLAS), and astronomers anticipated that it would be a visible-naked eye comet in the May 2020 sky. It was brighter than most comets and would come into close proximity to Earth and the Sun, actually passing within Mercury's orbit. Its brightness temporarily skyrocketed in early 2020, but has since been deteriorating. In fact, the comet was observed to have broken into pieces by Hubble in April 2020. This is a rare event that scientists get to witness, as most comets are too dim at the point of breaking apart to be observed. The object was last observed in May, and it is now in the Monoceros constellation but no longer visible.

OpenSpace: C 2019 Y4 is observable as its own dataset in OpenSpace. Aside from observing the enormous eccentricity of its orbit, OpenSpace is useful for observing the comet pass by the inner planets. This dataset will likely never be updated in future versions of OpenSpace because the comet is no longer visible.

Resources:
- C/2019 Y4 (Atlas)
- Comet Y4 Atlas in Outburst: First Good Comet for 2020?
- Hubble Watches Comet ATLAS Disintegrate Into More Than Two Dozen Pieces

For more about OpenSpace, visit: https://www.openspaceproject.com/

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