Far Comet Ion Tail Crossings

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Abstract

A comet ion tail extend behind the comet to really long distance. Some unexpected crossing of spacecrafts with ion tails in the past opened new opportunities of studying the physics of these structures. All the conditions that must be fulfilled to have the comet and spacecraft at the right time and position to have an encounter were analysed in previous works and some predictions were obtained. Following their steps, this project has consisted in developing a new Python program to find possible encounters that happened or will happen in the future. We have updated the previous works providing lists of possible future encounters for Solar Orbiter, Parker Solar Probe, JUICE, Earth and Mars. These predictions enables operations planning for the instruments of the spacecrafts to get as much data as possible and study better the ions tails. We also present overview plots of key parameters for some of the possible encounters in the past, though deeper analysis would be needed to find if there indeed are comet ion tail signatures in these events.

Contents

1 Introduction

When thinking about comets, one consider them among the most spectacular objects in the sky. From the Ancient Greece where they were thought to be exhalations of the planets catching fire high in the atmosphere until nowadays, comets have been fascinating objects which have woken up the curiosity of the astronomers. Kepler and Newton defined the comets' orbits and, by use of Newton's methods, astronomer Edmond Halley determined the orbits for 24 observed comets, which he published in 1705. He also noted that there were several comets that had remarkably similar orbits and had appeared at approximately 76-year intervals. His suggestion that it was really one comet was confirmed when it was seen again at the predicted time he said, and was named in his honour comet Halley, being the first recognised periodic comet. As the time went by, the study of the comets benefited greatly from the improvement in the quality and size of telescopes and the technology for observing them. In 1858, artist William Usherwood took the first photograph of a comet, Comet Donati (C/1858 L1) [1].

The 20th century saw continued progress in cometary science. Spectroscopy revealed many of the molecules and ions in the coma and tails of the comets. An understanding began to develop about the nature of cometary tails, with the ion tails resulting from the interaction of ionized molecules with some form of "corpuscular radiation," possibly electrons and protons from the Sun, and the dust tails coming from solar radiation pressure on the fine dust particles emitted from the comet. In fact, in 1951 astronomer Ludwig Biermann used comet tails to conclude the existence of solar wind, which was directly detected 8 years later [1].

Another big question was the origin of the comets, which had mainly three possible answers: comets were captured from interstellar space, or erupted out of the giant planets, or they were primeval matter that had not been incorporated into the planets. Theories about the nature of the comets have succeeded each other through time. Oort's paper, published in 1950 [2], and two months later a paper on the nature of the cometary nucleus by Fred Whipple [3], suggested that the cometary nucleus was a solid body made up of volatile ices and meteoritic material, popularly known as the "dirty snowball" [1].

During the later half of the 20^{th} century, a massive leap forward in the understanding of the solar system took place as a result of spacecraft visits to the planets and their satellites. Comets were not less important and the return of Halley's Comet in 1986, provided substantial motivation to begin using spacecrafts to study comets. The first comet mission was the International Cometary Explorer (ICE) spacecraft's encounter with Comet 21P/Giacobini-Zinner in 1985. A bit later, in 1986, five spacecrafts were sent to encounter Halley's Comet. The next comet mission was not until 1998, when NASA launched Deep Space 1, a spacecraft designed to test a variety of new technologies. The NASA Stardust mission was launched in 1999 with the goal of collecting samples of dust from the coma of Comet 81P/Wild 2. In 2005 NASA launched another comet mission, called Deep Impact. The spacecraft flew by Comet 9P/Tempel 1 and released an impactor that would be deliberately crashed into the comet nucleus. The impactor produced the highest-resolution pictures of a nucleus surface ever for that time. In 2004, ESA launched Rosetta on a trajectory to Comet 67P/Churyumov-Gerasimenko. Rosetta carried a spacecraft called Philae that landed on the nucleus surface on November 12, 2014. It was the first mission to orbit and land on a cometary nucleus. Its two years of detaliled studies of the nucleus and the coma provided a huge data set still being analyzed [1].

Even though there are specific missions for comets research, some unexpected crossing of other spacecrafts with comets tails provided some farther opportunity to study such structures. One of the most highlighted ones was the unexpected encounter Ulysses spacecraft had with Comet C/1996 B2 Hyakutake, in 1996 [4], [5]. It was reported that the density of protons seen at Ulysses data dropped dramatically for several hours on May 1, 1996, while the O^+ density drastically increased, a good signature of an ion tail. Convinced the were in front of an ion tail and, therefore, looking for the source of it, they saw that no comets were close to the spacecraft at that time. They realized that comet Hyakutake had crossed the Sun-Ulysses line around April 23, 1996. Checking the radial position and the expected size of the tail by the amount of gas that was given off by the comet so days before, they confirmed it was its tail. The most remarkable result of this event is that the tail's length was at least 3.8 AU, being the longest that has been measured, and the most productive comet ever to have been encountered by a spacecraft. This event provided unique information about the conditions within cometary ion tails when very far downstream of the nucleus.

Finding and identifying encounters has interested in the past, and two other previous student's projects have worked on it and found promising results [6], [7]. Rosetta, Ulysses, Cassini and Earth Satelite have been the spacecrafts studied in the reports. They have provided guidelines and have been of great help when developing these project.

In order to update these works, and because it is one of the latest ESA missions sent into space, Solar Orbiter has been the principle target to find encounters with in this project. In addition, Solar Orbiter has the advantage of the close distance it has to the Sun during its trajectory and, as it will be explain later, ion tails are more intense for comets close to the Sun. These aspect and the compilation of the relevant instruments it carries, makes Solar Orbiter to be worth finding encounters with. Once these work was done, other spacecrafts, Parker Solar Probe and JUICE, and then Earth and Mars, have also been studied in these project.

This report starts with an introduction to the comets in Section 2: their components, orbits and orbital elements. In Section 3, an explanation of the physics of the solar wind and the interaction of it with the comets its described. Following this, a brief summary of the Solar Orbiter mission is provided in Section 4. One of the main things done in this project is the creation of a Python script to find encounters between comets and spacecrafts so, an extended description of the necessary conditions to have this situation and of the different sections of the script follows in Section 5. Once the script its done, the results of the possible encounters that already happened and the predictions of futures ones are obtained and showed in Section 6. Finally, it was possible to do a brief analysis of some of the data for some encounters and it is described at the end in Section 7. The complete script and information and representations of the encounters appears in the appendices.

2 Comets

2.1 Components of the Comets

Comets are believed to be one of the most accessible remains left from the formation of the Solar System. They are small bodies travelling through space captured by the Sun gravitation, making them orbit it. A comet consists of three main parts: the nucleus, the coma and the tails.

The comet nucleus is made mostly of ice, rock and dust, seen as a cosmic snowball. As the comet gets closer to the Sun, it starts to heat up and the ice particles of its surface turn to gas (by sublimation) and leave the nucleus. This gas detached from the nucleus expands outward, carrying dust grains with it. Its expansion forms a giant gas envelope around the nucleus, known as the coma. This can be larger than a planet and it is the origin of the tails [8].

The tails are formed due to solar radiation pressure and the solar wind, and one can distinguish two most common types, pointing in different directions. The dragged dust follows a long curved path behind the comet. This is mainly the comet's trajectory, even though it is affected by the solar radiation pressure. Part of the gas released from the nucleus becomes ionized, by solar ultraviolet radiation and energetic particles. These cometary ions are then accelerated to solar wind speed by electromagnetic fields, resulting in an ion tail pointing almost radially away from the Sun [1].

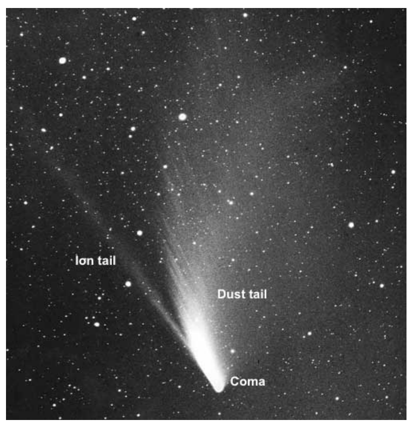


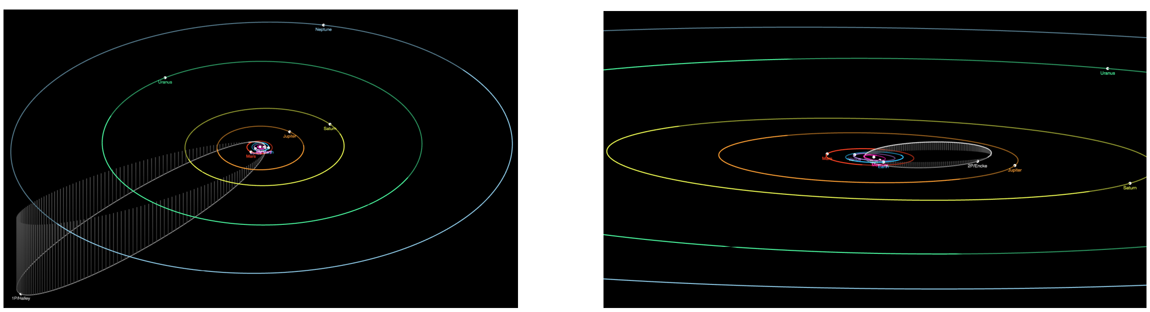
Figure 1: Picture of Comet Mrkos on August 13, 1957, showing the coma and two tails. *Image source: Photographed by Alan McClure at the north of Los Angeles, California in 1957. https://www.rocketstem.org/2020/08/08/ice-and-stone-comet-of-week-33/*

2.2 Comet Orbits and Types

The principles of orbit determination of the comets were mainly discovered by Kepler and Newton. The comets travel through the Solar System in orbits around the Sun. However, these bodies not only feel the gravitational interaction of the Sun, but also of other planets, leading to modifications of their orbits. Considering the two-body problem, the comets orbit in elliptic orbit with well-defined periods. In this work, we are going to focus in this scenario, but one has to be aware that this can change and orbits can become parabolic and hyperbolic if another mass (as one of a planet) enters the problem. Orbits can be very elongated and comets can spend hundreds and thousands of years out in the depths of the Solar System before they return to the inner parts of the Solar System at their perihelion [9].

The most famous short-period comet is the comet Halley, which travels in a very inclined orbit from the ecliptic with a period of 76.2 years. After it, there is defined the Halley-type comet prototype. These comets have orbital periods between 20 and 200 years, and orbits which can be highly inclined from the ecliptic. These bodies are thought to originate further out in the Solar System, specifically in the spherical shell known as the Oort Cloud. The icy bodies that make up the Oort Cloud may be perturbed by a passing star or a giant molecular cloud, setting them on highly elliptical paths possible taking them through the inner Solar System. If they are influenced by the gravitational field of, for example, Neptune or Uranus during their journey, their orbit may be altered so that their aphelion distance, and hence, orbital period, is shortened. If their orbit around the Sun is not significantly influenced by the gravity of the giant planets, these objects will remain long-period comets, and will not be considered Halley-type comets [10].

The other important class of short-period comets is the Jupiter-family type. With orbital periods of less than 20 years and inclinations no more than 18º from the ecliptic, they travel not much farther out than from the Jupiter orbit. However, these comets are thought to be originate from the Kuiper Belt, a circumstellar disc in the outer Solar System, extending from the orbit of Neptune at 30 AU to approximately 50 AU from the Sun, which are launched towards the Sun by the gravity of Neptune and further perturbed by the gravity of Jupiter. After the first disturbance by Neptune, they acquire highly elliptical orbits but later, they become tighter and with short periods as they approach Jupiter. These two type of comets are the ones we have been used in our project, because they are the ones possible to predict when they appear due to their relationdy short periods [11].



(a) (b)

Figure 2: NASA Ilustration of the orbit of Comet 1P/Halley, an example of a Halley-type comet (a), and of the orbit of Comet 2P/Encke, an example of a Jupiter-family comet (b). *Images source: https://ssd.jpl.nasa.gov/sbdb.cgi?*

2.3 Comet Orbital Elements

In order to describe the motion of a comet, several parameters known as orbital elements are needed. These orbital elements describe the plane in which the comet is moving in reference to the plane of the ecliptic [7]. The two elements that describe the shape and size of the ellipse are:

- Eccentricity e: describes the shape of the ellipse, describing how much it is elongated compared to a circle.
- Semimajor axis a: the sum of the periapsis and apoapsis distances divided by two.

The two elements that describe the orientation of the orbital plane are:

- Inclination i: vertical tilt of the ellipse with respect to the reference plane, in this case, the ecliptic plane.
- Longitude of the ascending node : the angle between the ascending node (direction where the orbit passes upward through the reference plane) and the reference frame's vernal point.

The last elements are:

- Argument of periapsis : the angle measured from the ascending node to the periapsis (the closest point the satellite object comes to the primary object around which it orbits). It defines the orientation of the ellipse in the orbital plane.
- True anomaly f: the angle that defines the position of the body in its orbit at a specific time, between periapsis and the position of the comet.

In this report, the distance between the Sun and the periapsis is called QR.

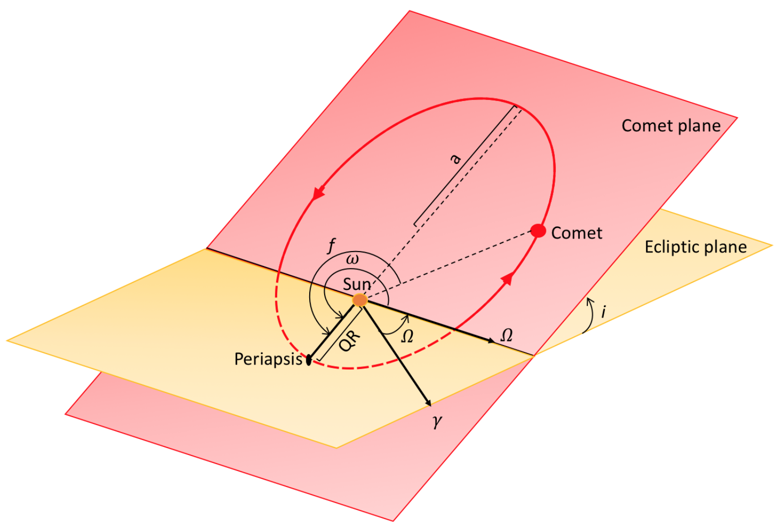


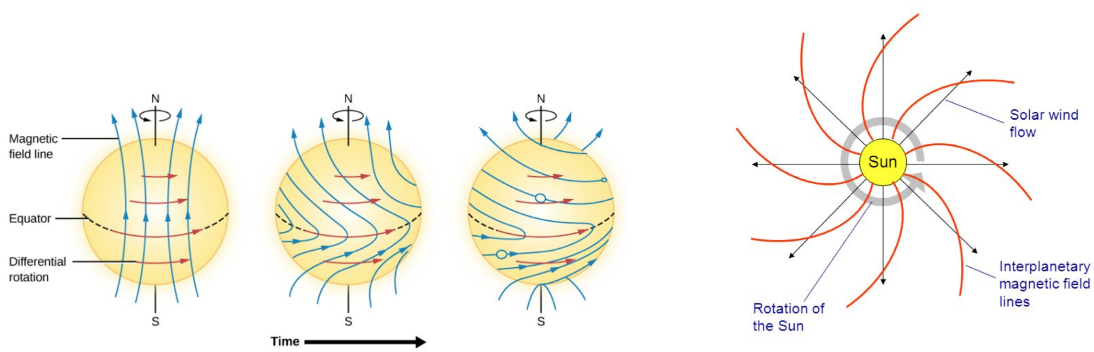
Figure 3: Drawing of the intersection of the comet's plane with the ecliptic plane. *Image source: Drawn by the author.*

3 Generation and Physics of the Ion Tails

3.1 Solar Wind

The solar wind is an outflowing plasma, a state of matter governed by its own set of physical laws just as solids, liquids, and gases are, released from the Sun's corona, its upper atmosphere. It consists of charged particles, mainly electrons, protons and alpha particles, but it also includes a small fraction of heavy ions. This stream of outflowing particles, however, is far from uniform or constant: it comes mainly in two varieties, "fast" (about 750 km/s) and "slow" (350 to 400 km/s), which depends on the source region in the solar atmosphere. The fast wind emanates mainly from coronal holes, regions often found near the poles caused when the magnetic field lines coming out from the Sun do not fall back, allowing the solar wind to escape along the magnetic field lines. On the other hand, the slow and denser wind usually comes from near the equator. During high activity, the particles can escape the Sun's gravity as a supersonic wind due to the high energy resulting from the extremely high temperature of the corona. It travels approximately radially outwards from the Sun [12].

The solar wind carries into space the Interplanetary Magnetic Field (IMF), which is said to be *frozen-in* it. The Sun is not a solid, but a giant ball of gas, and different parts of it rotate at different rates. The equatorial region spins faster than the poles. Because of the solar rotation, the magnetic field rotates as well, forming a spiral known as the Parker spiral. Over time, the Sun's differential rotation rates cause its magnetic field to become twisted and tangled. In this process, very strong concentrations of magnetic field are formed, known as sunspots. These produce solar flares and coronal mass ejections, which are the peaks of action in the 11-years cycle. Once it is finished, the polarity of the magnetic field changes and the cycle starts again [13].



(a) (b)

Figure 4: Drawing of (a) the behaviour of the magnetic field due to the Sun's rotation.*Image source: https://courses.lumenlearning.com/astronomy/chapter/the-solar-cycle/* and (b) the Parker spiral that magnetic field lines form.*Image source:*

3.2 Solar Wind Interaction With the Comet

The absence of an intrinsic magnetic field, the small size of the nucleus, and its extremely low gravity combined with its highly elliptical orbit result in the continuous escape of the plasma of the coma from the comet, dragged away by the magnetised stream of solar particles. These properties result in one of the largest obstacles to the solar wind in the solar system. Magnetic field lines are unable to penetrate the sphere of ions that envelopes a comet nucleus, and so they pile up in front of it and drape around it. As a result, the ion tail appears on the comet's side facing away from the Sun. The ions flow away from the Sun along the oppositely directed magnetic field lines in the tail.

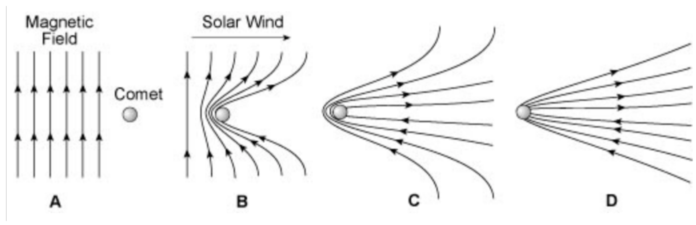


Figure 5: Drawing of draping of the magnetic field lines around the comet. *Image source:* $https : //ase.tufts.edu/cosmos/view_picture.asp?id = 734$

Once the neutral particles are released from the nucleus by sublimation, the ions are produced by photo-ionisation. These particles known as the cometary plasma, are an obstacle for the solar wind. The ions are trapped by the magnetic field lines, by a phenomena call *mass loading*. Comparing the speeds of both the ions and the solar wind, one can consider newborn ions are almost stationary (having the neutral outflow speed of about 1 km/s), causing the slow down of the solar wind when it faces the ions. The decrease of the solar wind speed leads to a creation of a magnetic barrier in front of the comet, including a bow shock. In this region, the flow is mass-loaded with the cometary ions. From the point of view of a new-born cometary ion, the solar wind is a conductor moving in a magnetic field, so it experiences and induced electric field. That is why, cometary ions are accelerated anti-sunward, forming the famous ion tail. As we have mentioned before, the ions are trapped in the magnetic field lines, and they are accelerated to the solar wind speed by the transfer of momentum from the solar wind via the magnetic field. The draping of the magnetic field lines results in two tail lobes, each of it with opposite magnetic field direction. Inevitably, there is the neutral sheet, a current sheet between them. Also, the pile-up can, at a sufficiently active comet, create a cavity around the nucleus of the comet known as the diamagnetic cavity [14].

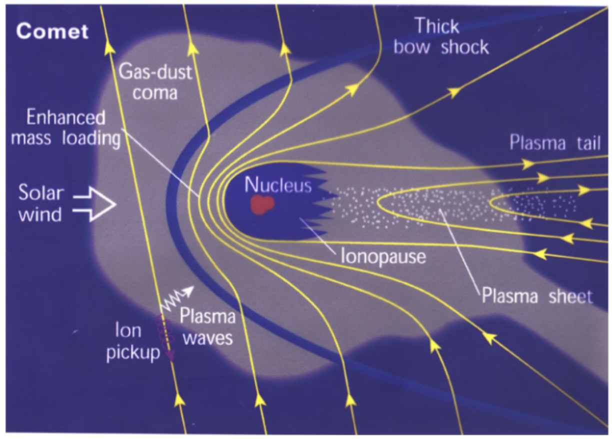


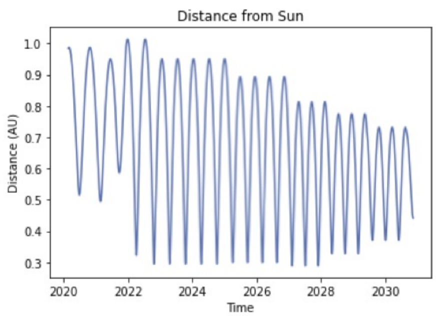
Figure 6: Illustration of the magnetic field and plasma configuration in the neighborhood of a comet. *Image source: J. A. Van Allen, 1999. Planetary magnetospheres and the interplanetary medium, in "The New Solar System".*

4 Solar Orbiter

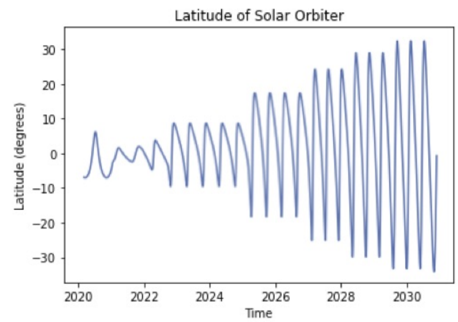
Solar Orbiter is one of the most complex and especial missions ever sent to investigate the Sun, as it will be taking images of the Sun from closer than any other spacecraft before and, at the same time, investigate the plasma and electromagnetic field in the solar wind at the spacecraft location. In addition, it will look at the, so far unexplored, polar regions of it. It is a cooperative ESA and NASA mission that is aiming to resolve some questions about how the Sun creates and controls the constantly changing space environment throughout the Solar System, as how the solar wind is produced, what heats up the the corona or what drives the 11 years cycle. To do so, it carries 10 different instruments that complement each other to create a picture of our star and measure the magnetic field, waves and plasma emanating from it, among others. One of the goals is to analyse these different aspects of the solar wind close to its origin, minimizing the possible changes it can suffer travelling the long journey throughout the space.

The spacecraft was launched in February 2020 and it is expected to operate around the Sun for more than ten years, reaching the closest point from the Sun at 42 million km from it (0,28 AU). Completing 22 orbits around the Sun and using gravity from Venus and Earth, it is gradually lifting itself out of the ecliptic plane, getting its maximum inclination (see Section 2.3) at 33º from the Sun's equator [17], [18].

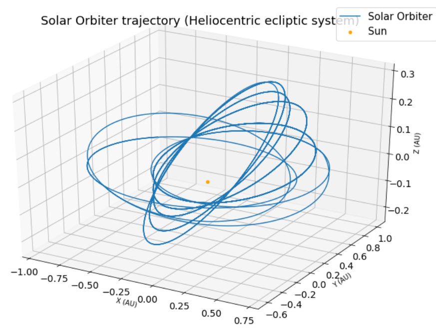
As the Sun is the core of the mission, the spacecraft is always travelling within the space between Sun and Earth, which covers a radial distance of 1 AU. There is an exception around 2021 and 2022, when Solar Orbiter goes far to 1.02 AU, but this small increase is irrelevant to our study, and we will still focus it on comets that will approach the Sun as close as 1 AU or less.

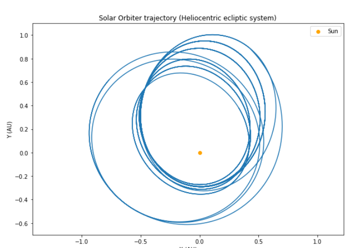


(a) Distance in AU from Sun of Solar Orbiter since its launch until 2030

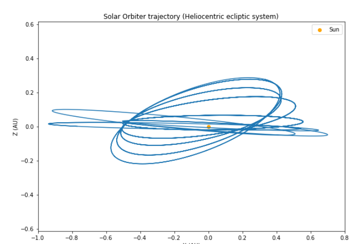


(b) Ecliptic latitude of Solar Orbiter since its launch until 2030





(a)



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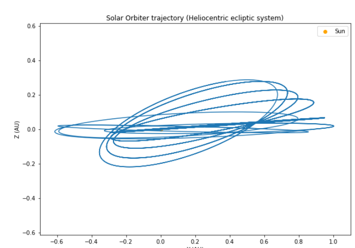


(c)

Figure 8: Solar Orbiter's trajectory in the heliocentric ecliptic coordinate system, since its launch until 2030. View in 3D (upper graphic) and 2D for every set of two coordinates: (a): Y vs X, (b): Z vs X and (c): Z vs Y. The Sun is represented by the orange dot. *Images source: Python program by the author.*

Thanks to the different instruments Solar Orbiter carries, it could be possible to identify comets' tails by measuring the conditions around the spacecraft. For the ion tail, the MAG instrument, the Solar Orbiter Magnetometer, might detect the variation of the interplanetary magnetic field because of its interaction with the ions of the tail (pointing toward or away from the sun, then at best also changing direction 180º if we cross the center of the tail), while the Solar Wind Analyser

SWA could directly capture some of the tail particles. Comets mostly emit H20, so higher than usual flares of H20+, H30+, 0H+ or 0+ is a good sign of a tail [18].

5 Method to Search For Possible Ion Tail Encounters

5.1 Necessary Conditions

In order to find a good time when there would be a good change of an ion tail encounter, some conditions need to happen.

The plasma in the ion tails of the comets move in the anti-sunward direction, following the radial direction of the solar wind. Therefore, the spacecraft must be farther from the Sun than the comet was some time before, and has to be placed in the same direction of the line connecting the Sun and the comet. Following this, we know all the possible encounters will happen at a distance (from the Sun) equal or smaller to the longest distance from the Sun the spacecraft has. To fulfill this condition, we consider the fact that the perihelion of an orbit is the closest position to the Sun one body reaches. So, we must only study those comets whose perihelia are smaller or equal to this spacecraft's distance (different depending on the spacecraft). However, this does not assure the spacecraft is crossing the tail, because it could be in a higher or lower position compared to it at the time of an actual crossing. It must be in the same plane of the orbit of the comet, or very close to it.

Finally, an encounter is defined by the spacecraft crossing (or being sufficiently close to it) the comet orbital plane at the right time, meaning that the time that has passed since the comet passed between the encounter point and the Sun is just right for the solar wind to travel the distance to the encounter point. As will be discussed in Section 5.2.2, this can be formulated as a criterion on solar wind speed. Figure 9 will be explained in detail in that section.

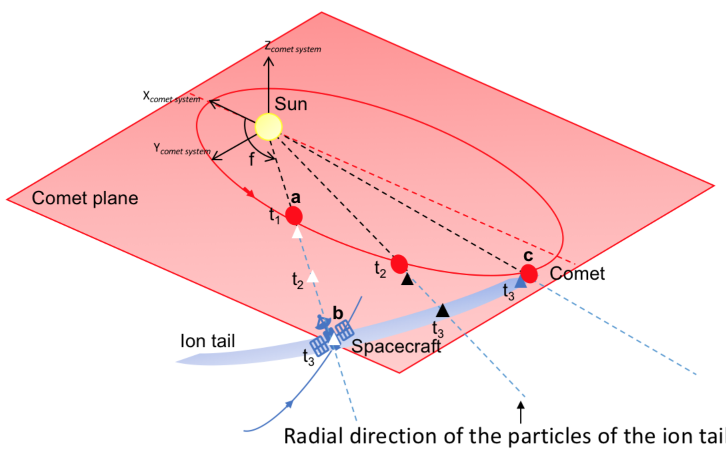


Figure 9: Drawing of the disposition of the spacecraft and the comet, showing the ion tail, at an encounter. *Image source: Drawn by the author.*

Then, the necessary conditions for encounters to happen, and hence, used to select relevant comets are:

- Spacecraft's orbit (at the encounter position) bigger than comet's orbit (at the ion tail production position).

- Perihelion of the comet ≤ longest distance from the Sun of the spacecraft.

The necessary conditions that must be calculated are:

- Spacecraft crosses the orbital comet plane (or is close to it).
- Spacecraft and the comet on the same side of the Sun.
- Same radial direction between comet and spacecraft (not at the same time)
- Ion tail production date before the spacecraft's encounter position date
- Reasonable soar wind speed of the ions to reach the spacecraft's position from their production's position.

5.2 Python Script Description

In order to get the possible encounters, we have created a Python script with all the steps to follow. The code has been validating by obtaining some already predicted encounters in previous works. For Solar Orbiter there was a prediction of an encounter last year on 31^{st} May 2020 [5], and is the first encounter we study in this project. Also, checking the first encounters with Rosetta predicted in one of the previous student's project [**?**], we see that we get them as well with our program. Also, that previous student project has been a big help when developing the Python script.

In addition to this main script, another parallel one to obtain the list of the wished comets kernels for each spacecraft has been developed. The script reads all the locally available comets kernels and, by checking the perihelion distance each one has in the comment section, it adds to a new metakernel the comets files that satisfied the perihelion distance the user has chosen. For example, if we are looking for comets with a perihelion distance smaller or equal to 1 AU, the script will ask us what maximum distance we want. We introduce 1, and the metakernel with these comets will be created.

Going back to the main script, the algorithm of the main function is:

1. **load_comet_SolarOrbiter**: The metakernel with the comets files and the Solar Orbiter metakernel are opened.
2. **read_handle**: Get the handles (the identifier of each comet file).
3. **read_comet_SolarOrbiter**: We choose the time and we obtain the positions of Solar Orbiter and every comet in the ecliptic coordinate system.
4. The spice kernels have been cleaned at the end of step 3, so we load again the **read_handle** function to get the handles again.
5. We start a loop and we get the first comet handle and positions.
6. **orbital_elements**: The orbital elements necessary for the coordinate transformation are taken from the comet file.
7. **coord_transf**: Transformation of the Solar Orbiter coordinates into the comet orbital coordinate system (which we define as a heliocentric coordinate system with the X and Y axis along the major and minor axis, respectively, of the comet trajectory). We use the Euler's angles rotation.

8. **encounter**: Finds the possibles encounters.

9. The loop continues with the handle and positions of the next comet and the program starts again from step 5. It continues until all the comets are evaluated.

Now we describe in detail some of the functions created.

5.2.1 Function coord_transf

As we have said, our goal is to have Solar Orbiter in the comet orbital system, so that we conveniently can find the points where they both are in the same plane, or close to it.

To do so, we use the Euler's angles rotation [15]. The Euler's rotation theorem states that any rotation may be described using three angles. In terms of matrix, the rotation can be written as the multiplication of the three angles rotation matrix:

$$A = BCD = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \tag{1}$$

In our case, the angles are: OM: longitude of ascending node, W: argument of periapsis and IN: inclination. The first rotation is by the angle OM about the z-axis using B, the second one is by IN about the x-axis using C and finally, the third rotation is by the angle W about the z-axis.

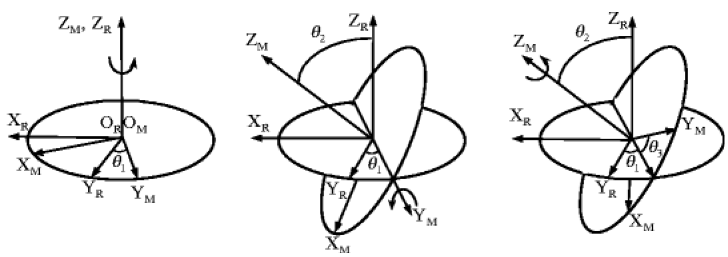


Figure 10: Representation of the three rotations of the Euler's rotation theorem. Image from: $https : //link.springer.com/chapter/10.1007/978 - 94 - 007 - 5006 - 7_3$

The rotation matrices are:

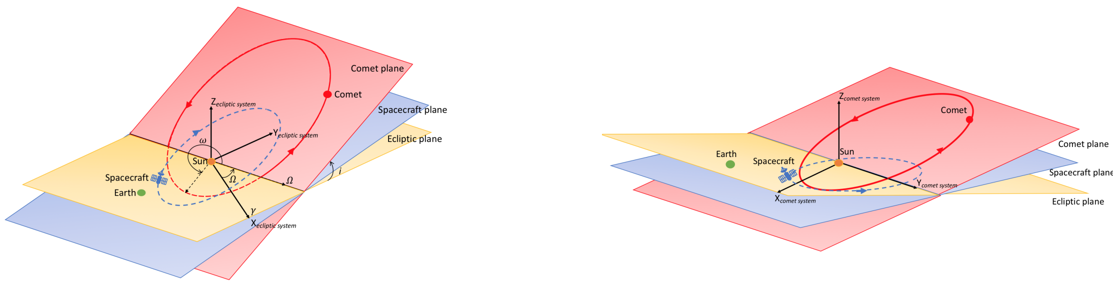
$$D = \begin{pmatrix} \cos OM & \sin OM & 0 \\ -\sin OM & \cos OM & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{2}$$

$$C = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos IN & \sin IN \\ 0 & -\sin IN & \cos IN \end{pmatrix} \tag{3}$$

$$B = \begin{pmatrix} \cos W & \sin W & 0 \\ -\sin W & \cos W & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{4}$$

Then, the transformation from the ecliptic coordinate system to the plane-of-orbit system is:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{plane-orbit} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \cdot \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{ecliptic} \tag{5}$$



(a) (b)

Figure 11: Drawings of the interaction between the comet plane, the spacecraft plane and the ecliptic plane. (a) represents the interaction before the transformation (point of view from the ecliptic), and (b) after the transformation (point of view from the comet orbital system). *Images source: Drawn by the author.*

The python function calculates the three angles in radians and uses a SPICE function to get the rotation matrix A. Both the spacecraft and the comet coordinates are transformed, as it is necessary for both objects to be in the same coordinate system. By the definition of the comet orbital plane system, the comet should have always been at z=0. However, as we use the same transformation for all the orbit, which can cover many years, there can be perturbations to the orbital plane due to third body interactions. This can be seen in several of the orbits plots we produce, and introduces a small error we have not corrected for.

5.2.2 Function encounter

Once we have both the comets and Solar Orbiter in the same coordinate system, it is time to find those points where they are in the same plane, or close to it. To do so, we take only those positions of Solar Orbiter with the z coordinate between -0.15 AU and 0.15 AU, selecting this value as one relatively close to the plane. We obtain then, its radial distance from the Sun for each point.

For each point on the spacecraft trajectory, this radial line crosses the comet's orbit at one point. That points corresponds to the position of the comet at the production of the ion tail that later arrives to the Solar Orbiter location. The radial line creates an angle with the direction of the periapsis of the orbit, known as true anomaly, f. It is calculated inside a function called **true_anomaly** and it is defined by:

$$f = \arctan \frac{y_{SO}}{x_{SO}} \tag{6}$$

At the same time, knowing the eccentricity, EC, and the perihelion distance of the comet, QR,

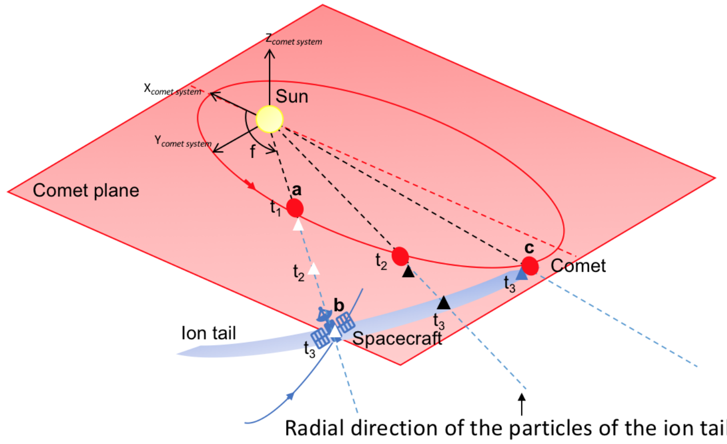


Figure 12: Drawing of the disposition of the spacecraft and the comet, showing the ion tail, at an encounter. Note that, for reasons of figure clarity, the comet has been drawn as moving at almost as high speed as the solar wind. A more realistic relation between the speeds will give an almost radial tail, but the principle is the same. *Image source: Drawn by the author.*

we can calculate the semi-major axis of the orbit, a:

$$a = \frac{QR}{1 - EC} \tag{7}$$

These values allow us to get the radial distance from the Sun of the comet, r_comet, and finally obtain the desired x-y positions of the comet:

$$r\_comet = \frac{a \cdot (1 - EC^2)}{1 + EC \cdot \cos f} \tag{8}$$

$$x = r \cdot \cos f \tag{9}$$

$$y = r \cdot \sin f \tag{10}$$

The next step is to fulfill the condition of Solar Orbiter being outside the orbit of the comet, so we get the radial distance between both of them, d, and we reduce the possible encounters by taking only those comet's positions where it is bigger than zero.

By an interpolation of the time for each comet position known by the comet files, we obtain the instant when the comet is in the production ion tail's position. The difference in time between the Solar Orbiter's position when crossing the plane, or close to it, T, and the time of the production ion tail, t, is the time the ions need to take to travel to Solar Orbiter's location if a tail crossing shall occur:

$$t_{delay} = T - t \tag{11}$$

Finally, the necessary solar wind velocity can be calculated by this time delay and the radial distance between the comet and the spacecraft:

$$v = \frac{d}{t} \tag{12}$$

If the velocity has a reasonable value of the range of the solar wind speed, we have found a possible encounter between Solar Orbiter and the comet. All these points are saved for their later analysis of the measurements.

Finally, there is the function **crossing**, that gets the date and solar wind speed at the points where the spacecraft crosses the plane of the orbit of the comet. Also, the function **iontail** calculates the positions of the ion tail.

5.2.3 Function crossing

Another class of interesting events are the exact crossings of the spacecraft with the plane of the orbit of the comet. To find these, we read the z coordinate vector of the spacecraft and stop when the sign between two consecutive values is different. By interpolation, the time when Solar Orbiter is at z=0 is calculated. The x and y coordinates are obtained by interpolation as well, and the radial distance of Solar Orbiter to the Sun and the true anomaly at that position are calculated. The next step is to find the comet's time at the position with the same true anomaly as the spacecraft. As we did with the encounters, we interpolate the comet's true anomaly values. In this case, we have done it looking backwards in time. In other words, we look for the moments before the spacecraft's crossing date when the comet has had the same true anomaly as Solar Orbiter. As we did with the encounters, knowing the time delay between these two dates and the distance between both objects, we obtain the respective solar wind speed.

5.2.4 Function ion tail

Once the possible encounters are obtained, it is very useful to get a plot illustrating the positions of the comet, spacecraft and ion tail, and see how the ion tail looks in those situations. To represent this, the time range we have chosen goes from the date when Solar Orbiter crosses the ion tail until 3 years before (running the time array backwards).

The ion tails travels radially outwards from the Sun, pushed by the solar wind. However, the comet is moving through the space at the same time, so, when observing it, the ion tail curves itself due to the movement.

To calculate the ion tail's position for each time, we first get the position the comet had when it produced these ion tail particles the spacecraft is crossing. For this position, we can calculate the longitude and latitude. As we know, any position is defined by the three spherical coordinates. As the ion tail is connected radially with the comet, the latitude and longitude of the tail are the same as for the comet in this position. Finally, the radial component is called d and we have defined it as the distance between the comet and this ion tail position. This distance is:

$$d = v_{SW} \cdot t_{delay} = v_{SW} \cdot (t_{start} - t_{comet}) \tag{13}$$

Being t_{start} the time Solar Orbiter finds the ion tail,t_{comet} the time of this ion tail production and $t_{start} \geq t_{comet}$. With all this set, the final step is to add to this position, the one of the comet, as the origin of the coordinate system is the Sun, and not the comet.

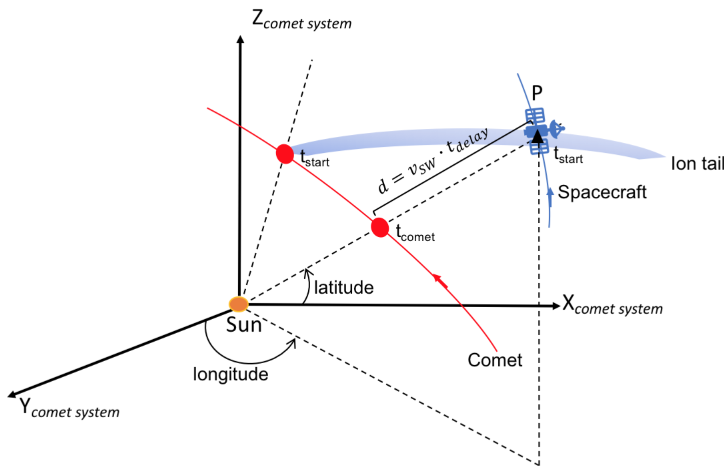


Figure 13: Drawing of the position of a point of the ion tail at a specific time. *Image source: Drawn by the author.*

The comets and each spacecraft files are SPICE data which can be downloaded from [16]. We have used a local copy maintened at a server at IRFU Uppsala.

6 Possible Found Encounters

As we have seen by the necessary conditions that must happen at the same time, the probability of finding an encounter between a spacecraft and a comet is low, but we have found some possible candidates to analyse. Even though they satisfy the conditions, not all of them can be considered as good ones. The distance between the comet and the spacecraft is one of the main values that establish if the probability of having an actual encounter is high, but at the same time, there is no established range of it. As it has been mentioned before, in general, the ion tail has an observed length of 0.6 AU, but some longer ion tails have been detected in the past. For example, the Hyakutake tail encounter by Ulysses at 3.8 AU distance [4]. In this work, we have considered good encounters the ones with a distance up to 0.6 or 0.7 AU, having in mind that some others with bigger values could result equally good. The other important value is the *flare angle* (abbreviated in results tables to *angle*), define as the angle between the spacecraft, at the encounter time, and the comet, at the ion tail production time. Even though the ion tail travels in the comet's plane, it expands itself in the space below and above this plane, as well as in the plane, due to thermal motion of ions, solar wind turbulence and other processes. However, the extension is not very big, and we have consider a limit of 8º or 10º up (or down) the plane. Mixing these two conditions, the best possible encounters have been selected and written down in bold font in the tables to follow below.

In the tables we can see **Date** : the date when the spacecraft crosses the ion tail, **Date Comet**: the date when the comet produced the ion tail, **t delay**; the time delay between these two dates, **SW Speed**: the speed the ion tail particles have, $d_{Spacecraft-C}$: distance between the spacecraft and the comet in these two positions. The spacecrafts are denominated as: *SO*: Solar Orbiter, *PSP*: Parker Solar Probe, *J*: JUICE, *E*: Earth and *M*: Mars. Continuing with the table we have $d_{Spacecraft-T}$: the distance between the spacecraft and the tail. These is the same as the z coordinate of the spacecraft, the vertical distance between the spacecraft and the comet orbital plane, **Angle**: angle between the spacecraft at the encounter position and the comet at the ion tail production position, $d_{Spacecraft-S}$: distance from the Sun to the spacecraft in the crossing point, and d_{C-S}: distance from the Sun to the Comet in the ion tail production point.

6.1 Solar Orbiter Encounters

Knowing that Solar Orbiter will almost never be outside the Earth's orbit, another necessary condition for our particular study is that the encounters must happen at a distance smaller or equal to 1 AU (distance between Sun and Earth).

We have mentioned before that the comets considered for encounters with Solar Orbiter must necessary be the ones with a perihelion distance smaller or equal to 1 AU.

The encounters found for these comets are shown in table 1. All the dates are at 00:00 am. The full interval in which the encounter criteria are satisfied is given in Appendix A.2, with 24 hours time resolution. From this, we have chosen the best value for each comet which is know presented in Table 1 (and in the later tables for each spacecraft).

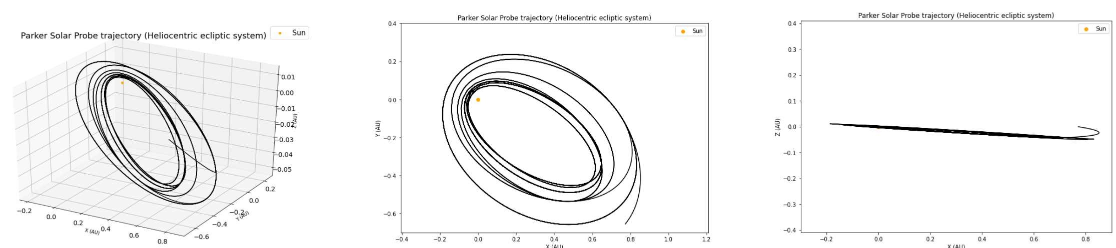
Comet	Date SO	t delay (days)	SW Speed (km/s)	d_{SO-C} (AU)	d_{SO-T} (AU)	Angle (deg)	d_{SO-S} (AU)	d_{C-S} (AU)
C_2019_Y4-C	2020 MAY 31	1.048	495	0.299	0.119	23.548	0.554	0.255
323P	**2021 JAN 20**	**2.771**	**327**	**0.523**	**0.015**	**1.686**	**0.569**	**0.047**
342P	**2021 OCT 21**	**3.297**	**349**	**0.662**	**0.019**	**1.619**	**0.753**	**0.091**
322P	2023 AUG 25	3.021	387	0.674	0.097	8.245	0.760	0.086
321P	2023 OCT 29	2.180	377	0.473	0.087	10.598	0.524	0.051
P_2008_Y12	**2025 MAR 09**	**2.343**	**325**	**0.438**	**0.065**	**8.471**	**0.526**	**0.087**
P_2002_S7	2025 NOV 08	3.540	370	0.754	0.129	9.869	0.808	0.055

Table 1: Comets' encounters with Solar Orbiter.

6.2 Other Spacecrafts Encounters

6.2.1 Parker Solar Probe Encounters

Parker Solar Probe is a NASA mission that will travel the closer to the Sun than any other spacecraft before, up to 0.04 AU close to the Sun, well within the orbit of Mercury. The spacecraft was launched on August 12t̂h 2018 and since then, it is using Venus' gravity during seven flybys over nearly seven years to gradually bring its orbit closer to the Sun, staying near the ecliptic plane [19].



(a) (b) (c)

Figure 14: Parker Solar Probe's trajectory in the heliocentric ecliptic coordinate system. View in 3D (a) and Z vs X (b).The Sun is represented by the orange dot. *Images source: Python program by the author.*

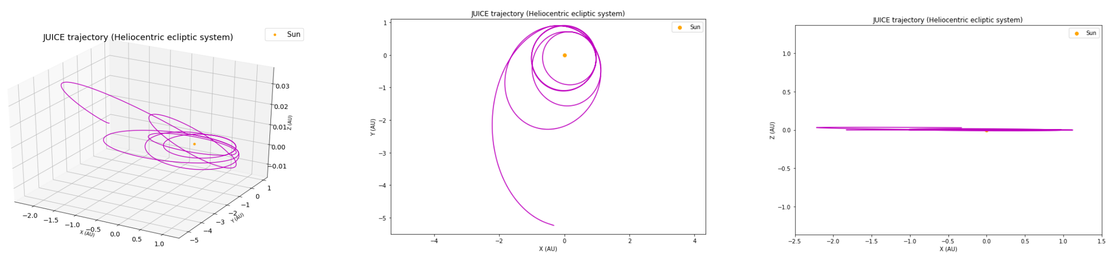
Due to its trajectory, the comets analysed do not have a perihelion distance bigger than 1 AU. The time range used goes from August 12t̂h 2018 until August 31t̂h 2025.

Comet	Date PSP	t delay (days)	SW Speed (km/s)	d_{PSP-C} (AU)	d_{PSP-T} (AU)	Angle (deg)	d_{PSP-S} (AU)	d_{C-S} (AU)
C_2002_R5	2019 DEC 15	2.939	449	0.760	0.048	3.599	0.834	0.073
321P	2020 JAN 19	1.208	438	0.305	0.078	14.713	0.364	0.059
P_2002_S7	**2020 JAN 25**	**0.539**	**511**	**0.159**	**0.018**	**6.425**	**0.212**	**0.053**
P_2003_T12	2020 APR 18	0.944	299	0.163	0.087	32.344	0.844	0.681
342P	2021 OCT 16	2.104	374	0.453	0.117	15.013	0.731	0.278
322P	**2023 AUG 23**	**2.864**	**386**	**0.637**	**0.028**	**2.485**	**0.721**	**0.085**
249P	2025 FEB 08	0.642	572	0.212	0.146	43.741	0.731	0.519
323P	**2025 MAR 16**	**1.383**	**338**	**0.269**	**0.035**	**7.492**	**0.314**	**0.045**
P_2008_Y12	2025 MAR 02	1.629	336	0.315	0.138	25.981	0.590	0.275

Table 2: Comets' encounters with Parker Solar Probe.

6.2.2 JUICE Encounters

One interesting spacecraft to look for encounters with is JUICE. This ESA's mission is planned for launch in September 2022 and arrive at Jupiter in October 2029. After that, it will spend at least three years making detailed observations of the giant gaseous planet and three of its largest moons, Ganymede, Callisto and Europa. It will travel through the Solar System so, finding possible encounters, will allow to see how comets behave far from the Sun [20].



(a) (b) (c)

Figure 15: JUICE's trajectory in the heliocentric ecliptic coordinate system. View in 3D (a), Y vs X (b) and Z vs X (c).The Sun is represented by the orange dot. *Images source: Python program by the author.*

The comets observed for these encounters have a maximum perihelion distance of 5.2 AU (the distance from Jupiter to Sun). Our observations go from September 4^{th} 2022 to July 16^{th} 2031.

Comet	Date JUICE	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
364P	**2023 APR 30**	**0.862**	**500**	**0.248**	**0.040**	**9.197**	**1.082**	**0.834**
322P	2023 AUG 24	3.898	418	0.938	0.110	6.764	1.026	0.088
323P	2025 MAR 17	3.288	443	0.840	0.068	4.645	0.888	0.048
P_2002_S7	2025 NOV 10	3.996	388	0.894	0.149	9.599	0.989	0.095
320P	**2026 JUL 12**	**1.794**	**408**	**0.421**	**0.039**	**5.344**	**1.423**	**1.002**
169P	**2026 SEP 03**	**1.844**	**418**	**0.444**	**0.051**	**6.531**	**1.164**	**0.720**
2P	2027 FEB 15	4.346	421	1.053	0.049	2.644	1.389	0.336
197P	2027 NOV 14	5.410	429	1.336	0.101	4.346	2.409	1.073
73P	2027 DEC 15	5.644	432	1.403	0.024	0.983	2.406	1.003
9P	2028 MAR 11	2.968	414	0.708	0.109	8.875	2.270	1.563
81P	2029 JUL 15	3.533	403	0.820	0.113	7.894	2.513	1.693
P_2014_C1	2030 FEB 06	7.825	442	1.994	0.135	3.891	3.851	1.857
117P	2030 MAY 22	4.442	448	1.146	0.105	5.268	4.328	3.182
94P	2030 NOV 30	6.677	475	1.826	0.081	2.545	4.925	3.099
80P	2031 FEB 14	12.743	466	3.421	0.028	0.469	5.075	1.654
414P	2031 MAR 26	6.482	452	1.688	0.112	3.810	5.136	3.447

Table 3: Comets' encounters with JUICE.

6.2.3 Earth Encounters

As several spacecrafts orbit the Earth, we have look for comets encounters with our planet. As we know, the Earth is orbiting the Sun at 1 AU, so the candidates comets have a perihelion distance smaller or equal to 1 AU. The time range chosen in this case is from July 16^{th} 2000 to July 1^{th} 2025.

(As it happens with Solar Orbiter and Parker Solar Probe, the advantage in these encounters is that comets are closer to the Sun, so the ion tail is more intense.)

23 are the possible encounters that have been found.

Comet	Date Earth	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
322P	2003 SEP 12	3.930	413	0.936	0.041	2.504	1.007	0.071
P_2003_T12	2003 OCT 13	1.937	371	0.414	0.077	10.678	0.998	0.584
289P	2003 DEC 14	0.050	872	0.025	0.022	61.625	0.984	0.959
300P	**2005 JUL 10**	**0.735**	**334**	**0.141**	**0.021**	**8.489**	**1.017**	**0.875**
169P	2005 AUG 20	0.923	355	0.189	0.097	30.857	1.012	0.823
P_2005_T4	2005 OCT 02	1.655	334	0.319	0.098	17.833	1.001	0.682
342P	2005 NOV 27	3.899	413	0.928	0.083	5.104	0.987	0.059
249P	2006 SEP 12	1.658	444	0.424	0.138	19.010	1.006	0.582
322P	2007 SEP 13	3.437	473	0.936	0.034	2.057	1.006	0.070
P_2007_T2	**2007 SEP 15**	**1.297**	**409**	**0.305**	**0.034**	**6.389**	**1.006**	**0.700**
323P	2008 JUN 03	3.983	419	0.960	0.090	5.351	1.015	0.054
321P	2008 SEP 21	3.821	434	0.955	0.082	4.914	1.004	0.048
210P	**2008 DEC 25**	**1.647**	**465**	**0.441**	**0.002**	**0.234**	**0.983**	**0.543**
222P	2009 AUG 17	0.948	354	0.193	0.061	18.371	1.012	0.819
322P	2011 SEP 09	3.691	440	0.935	0.048	2.966	1.007	0.072
323P	2012 AUG 23	3.520	479	0.971	0.011	0.664	1.011	0.040
P_2002_S7	2014 APR 20	3.242	462	0.863	0.079	5.253	1.005	0.142
322P	2015 SEP 06	3.784	428	0.933	0.059	3.645	1.008	0.075
321P	2016 MAR 31	2.825	283	0.460	0.149	18.885	0.999	0.539
323P	2016 NOV 28	3.776	400	0.870	0.090	5.942	0.986	0.116
2P	**2017 MAR 14**	**3.027**	**375**	**0.655**	**0.069**	**6.029**	**0.994**	**0.340**
322P	2019 SEP 02	3.333	485	0.931	0.074	4.537	1.009	0.078
249P	**2020 JUN 21**	**2.047**	**399**	**0.471**	**0.076**	**9.283**	**1.016**	**0.546**
342P	2021 OCT 21	4.051	391	0.913	0.059	3.685	0.995	0.082
322P	2023 AUG 23	3.901	411	0.923	0.108	6.698	1.011	0.088

Table 4: Comets' encounters with Earth.

6.2.4 Mars Encounters

Mars is one of the main goals for NASA and ESA missions. The red planet is 1.5 AU far from the Sun, so the comets it might cross can not have a bigger perihelion distance than this one. The time range is the same as for the Earth. The possible encounters found are 36.

Comet	Date Mars	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
P_2003_T12	2003 OCT 07	2.972	450	0.770	0.018	1.305	1.391	0.622
323P	2004 MAR 25	5.451	414	1.301	0.077	3.388	1.581	0.280
398P	2004 MAY 24	1.078	367	0.228	0.077	19.754	1.638	1.410
P_2009_WX51	2004 SEP 26	3.305	427	0.812	0.113	8.019	1.654	0.842
300P	2005 AUG 26	2.120	383	0.468	0.104	12.858	1.392	0.924
169P	2005 SEP 13	3.252	415	0.777	0.049	3.595	1.404	0.627
P_2005_T4	**2005 SEP 28**	**3.035**	**397**	**0.694**	**0.055**	**4.545**	**1.417**	**0.723**
342P	2005 NOV 29	5.977	414	1.426	0.074	2.986	1.488	0.062
294P	2008 APR 12	0.923	394	0.210	0.130	38.406	1.661	1.452
C_2002_R5	2008 JUN 17	5.592	468	1.506	0.103	3.938	1.660	0.154
364P	2008 AUG 10	2.297	455	0.602	0.144	13.824	1.627	1.025
398P	2009 DEC 22	1.188	375	0.256	0.126	29.382	1.620	1.364
27P	2011 JUL 23	2.507	485	0.701	0.150	12.351	1.491	0.790
414P	2011 SEP 11	4.438	393	1.006	0.095	5.444	1.556	0.550
C_2011_S2	**2011 OCT 06**	**1.546**	**475**	**0.423**	**0.060**	**8.197**	**1.585**	**1.162**
45P	2011 OCT 16	3.622	469	0.978	0.015	0.888	1.596	0.618
49P	**2011 DEC 04**	**0.700**	**315**	**0.127**	**0.001**	**0.530**	**1.640**	**1.513**
323P	2012 AUG 24	5.609	450	1.452	0.125	4.952	1.512	0.060
P_2007_T2	**2013 FEB 27**	**2.704**	**445**	**0.693**	**0.010**	**0.786**	**1.390**	**0.697**
46P	**2013 JUL 06**	**2.444**	**333**	**0.469**	**0.071**	**8.703**	**1.526**	**1.057**
C_2002_R5	2014 MAR 24	5.139	456	1.350	0.022	0.951	1.634	0.284
P_2002_S7	2014 APR 22	5.523	466	1.483	0.138	5.348	1.609	0.126
15P	2014 DEC 05	1.585	385	0.352	0.066	10.775	1.382	1.030
19P	2015 JUN 17	0.973	318	0.179	0.102	34.913	1.557	1.378
323P	2016 NOV 28	5.127	455	1.344	0.103	4.413	1.388	0.044
45P	2016 DEC 18	3.130	430	0.776	0.072	5.360	1.399	0.623
P_2002_S7	2020 FEB 02	5.105	444	1.307	0.001	0.059	1.551	0.244
C_2019_Y4-C	2020 JUN 04	4.753	421	1.154	0.061	3.030	1.406	0.252
141P	**2021 JAN 07**	**2.953**	**384**	**0.654**	**0.064**	**5.644**	**1.518**	**0.865**
414P	2021 JAN 18	3.777	443	0.964	0.009	0.509	1.533	0.569
323P	2021 JAN 24	5.084	472	1.383	0.108	4.476	1.540	0.157
P_2020_T3	**2021 FEB 13**	**0.415**	**437**	**0.104**	**0.017**	**9.643**	**1.565**	**1.461**
342P	2021 OCT 26	6.282	409	1.481	0.104	4.022	1.613	0.131
169P	2022 JUN 16	2.834	371	0.605	0.148	14.123	1.381	0.776
339P	**2023 AUG 23**	**0.950**	**555**	**0.304**	**0.028**	**5.318**	**1.631**	**1.327**
79P	2023 OCT 19	2.020	367	0.427	0.083	11.133	1.574	1.146
222P	**2024 MAY 02**	**2.192**	**460**	**0.581**	**0.027**	**2.645**	**1.382**	**0.801**
P_2003_T12	2024 JUN 26	2.975	464	0.796	0.023	1.655	1.399	0.603
P_2019_Y3	2025 MAR 02	2.931	440	0.743	0.083	6.452	1.656	0.913
P_2008_Y12	2025 MAR 11	5.755	478	1.586	0.139	5.041	1.660	0.074

Table 5: Comets' encounters with Mars.

Mars Express was Europe's first mission to this planet. It launched on June 2^{nd} 2003 and it entered orbit around Mars on December 25^{th} 2003 [21]. Mars Atmosphere and Volatile EvolutioN (MAVEN) is a spacecraft developed by NASA to investigate the upper atmosphere and ionosphere of Mars and how the solar wind strips volatile compounds from this atmosphere. It was launched the 18^{th} November of 2013. As we have mentioned before, the importance for the spacecraft of not passing through the magnetosphere of the planet is crucial as, if this happens, it is not possible to distinguish possible changes in the data that will confirm the comet's existence.

7 Data overview

7.1 Signatures of Ion tails

Following what it has been mentioned in Section 3, the different aspects that should be reflected in the data when crossing and ion tail are:

- **Particles composition**:

Comets are mainly ice and they emit mostly H_20. After the photo-ionization and charge exchange processes happen, flares of H20+, H30+, 0H+ or 0+ appear. Water and oxygen (another big component of the cometary plasma) have masses of 18 and 16 times the mass of the hydrogen, so, the ions originated will be heavy ions.

- **Density**:
  - Proton: The solar wind proton density (and alpha particles) should show a decrease due to the charge exchanges happening in the coma during the creation of the new ions. However, because of the mass loading and consecutive, slow down of the solar wind, the proton density can also show a small increase to compensate this phenomena.
  - Ions: Ions are created in the process so, there should be an increase of their density.
- **Speed**: The solar wind faces the mass loading and, as a consequence, its speed decreases. The solar wind should be lower than the surrounding solar wind speed. On the other hand, the newborn ions are trapped by the magnetic field lines and, later, pushed and accelerated by the solar wind. That is why, ions speed could show and increase from a very low value to the solar wind speed. Nevertheless, some slow down could be expected even at large distance
- **Temperature**: It should increase as a result of wave activity, but it is not that clear.
- **Magnetic Field**
  - Direction: The magnetic field in the solar wind has a complex nature and can be very hard to predict. Others solar wind disturbances can be happening at the same time as the crossing, so the data may not show clear signatures of the ion tail. Moreover, the magnetic field changes depending on where the encounter is happening: center of the tail or in the lobes. One thing one may assume is that, as the magnetic field lines are draped around the comet, they become more radial than usual, pointing towards or away from the Sun. This can be represented by an increase in the magnetic field component X in the GSE Coordinate System. Another aspect of the magnetic field is that it changes directions in the ion tail, existing a current sheet at the center of the tail between the two regions of the magnetic field. If the current sheet is passed, the magnetic field components should change senses.
  - Magnitude: Due to the draping of the magnetic field lines, the magnitude of the field should be increased compare to the surrounding magnetic field. Also, the value in the lobes comparing it with the value in the center of the tail (current sheet) should be higher.

We will now present some overview data from the indentifed encounter candidates for which data are available at **CDAWeb (Coordinate Data Analysis Web)** from NASA [22].

7.2 Solar Orbiter data

From among the comet's encounters with Solar Orbiter, only two of them have happened already. Unfortunately, there is data available to the public only for the encounter with comet C_2019_Y4-C at 2020 MAY 31.

- **C_2019_Y4-C at 2020 MAY 31**

The only data available and suitable from analysing an encounter with the comet is the magnetic field data. It has been taken from the file $SOLO\_L2\_MAG-RTN-NORMAL-1-MINUTE$ and is represented in the RTN coordinates. Magnetic field data from the 2020 MAY 31 was not available to the public, so that is why we took the day after. However, it is to be noted that, if an encounter would happen so late, the table in Appendix A.2.1, on page **??**2019_Y4-C/ SolO.,ws that the solar wind would either need to be very slow (which we can see in figure 16 that it was not) or very much non-radial in direction. Any encounter signature in this time range is therefore very unlikely.

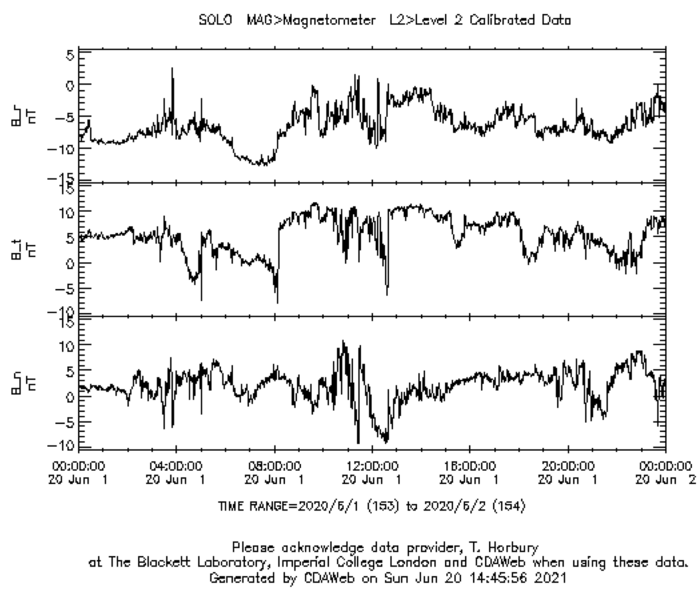


Figure 16: Magnetic field coordinates measured by Solar Orbiter in 2020 JUN 01.

Around 12:00:00 on 2020 JUN 01 we can see in Figure 16 on page 31 a reverse in the senses of magnetic field components B_t and B_n. However, it is know that magnetic field has a very complex nature and the changes of its values could be because of other events rather than because of an encounter with a comet tail. Also, with just one parameter as we have here is not possible to confirmed any crossing.

7.3 Parker Solar Probe data

During the time we had for the analysis of the data, it was not able to find suitable data of Parker Solar Probe. Data of some interesting parameters was available but the resolution was 1 hour.

Considering that some previous works have seen crossing lasting a few hours, this resolution is consider too big and no signatures of ion tails are probably going to be successfully identified.

7.4 JUICE data

JUICE has not been launched yet, so there is no data available to look at. These encounters will have to be analyse in the future.

7.5 Earth data

There are several spacecrafts orbiting the Earth from which we can get data from. OMNI is an hourly resolution multi-source data set of near-Earth solar wind's magnetic field and plasma parameters spanning the period from November 1963 to today. OMNI provides the IMF (magnitude and vector), flow velocity (magnitude and vector), flow pressure, proton density, alpha particle to proton density ratio, and several additional parameters. Spacecraft data used for compiling the OMNI solar wind reference include IMP-8, ACE, Wind, ISEE-3, and Geotail. ACE and Wind are orbiting at the L1 Lagrange point. For the best possible encounters, this is the data we have found. The magnetic field coordinates, temperature, solar wind speed and proton density data have been obtained from the file *OMNI_HRO_1MIN*. The data of the ions composition is crucial in the analysis of the crossings, as it is very characteristic. Unfortunately, is not available.

- **300P at 2005 JUL 10**

The encounter with 300P is shown in Appendix A.2.1 on page **??**. The data shown in Figure 17 on page 33 covers two days. We can observe some changes in the region between 02:00:00 and 11:30:00 of JUL 10. At 02:00:00 there is an increase of the magnetic field magnitude, which is something that would happen if there is a draping of the magnetic field lines (consequence of a comet). Also, there is proton density and an increment in the temperature. However, we can observe a significant increase in the solar wind speed, being totally contrary of what is expected when encountering a comet. These changes can make us think we are in front of a solar wind disturbance, and not an encounter.

- **P_2007_T2 at 2007 SEP 15**

As the previous one, it is shown in detail in Appendix A.2.1 on page **??**. The data for this encounter is not clear either. During the two days, SEP 14 and SEP 15, we can see in Figure 18 on page 34 two moments where some significant changes take place. Around 17:00:00 on SEP 14 there are some good indicators of an ion tail: increase of the magnetic field magnitude, reverse sense of components x, and y of it. The increment of proton density could be a consequence of the solar wind slow down. The suppose increment of the temperature is not as clear, but it is a slightly increase, and there is no a clear solar wind speed decrease either. The ions composition data could clarify if there is an encounter, but again, it is not available. Later, around 00:00:00 on SEP 15, there are some particular changes worth to analyse. There is a peak in the magnetic field where it becomes very radial, and the reverse on the senses of components x and z. A significant increase of the temperature and a decrease of proton density. However, again the flow speed increases, contrary to what it is suppose to happen, probably showing a solar wind disturbance. In the future would be interesting to find ions data and see if at 17:00:00 on SEP 14, the data is showing an ion tail crossing.

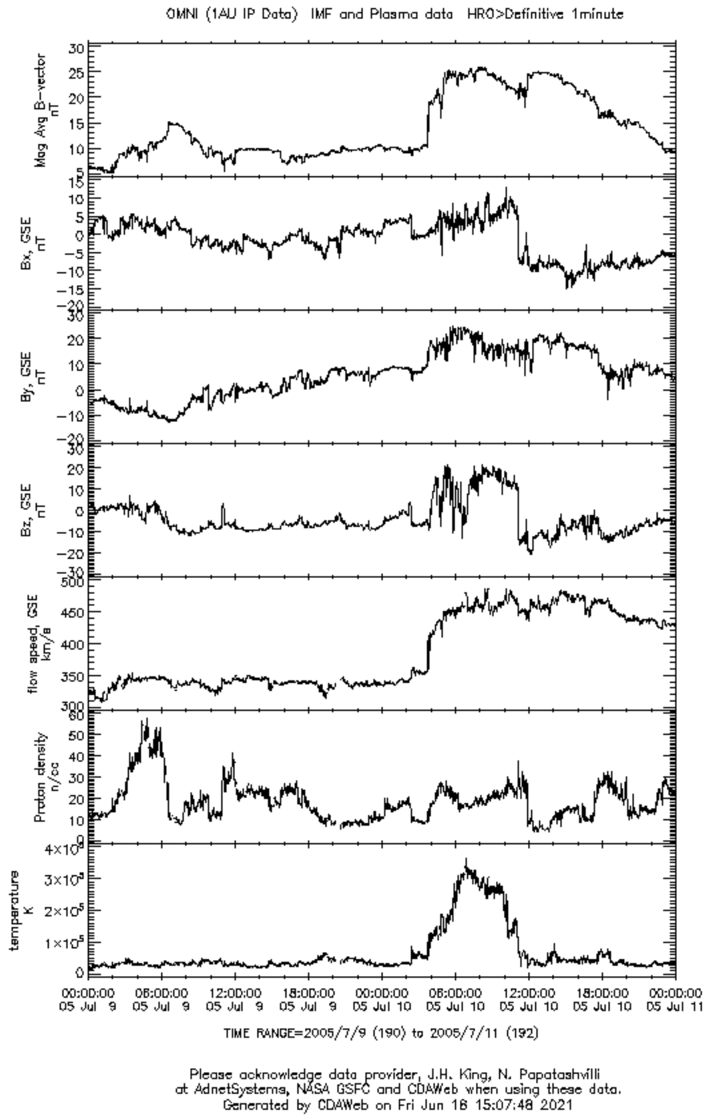


Figure 17: Magnetic field magnitude, magnetic field coordinates, solar wind speed, proton density and temperature from OMNI for date 2005 JUL 10.

- **210P at 2008 DEC 25**

For these encounter, presented on page **??** in Appendix A.2.1, at first the data was loaded during an interval of 4 days, and checking the results predicted with the Python program, the crossing should be sometime between DEC 24 and DEC 25. Analysing the data of DEC 24 in Figure 19 on page 35, we see it is very changeable and no big conclusions can be made. At 11:00:00 we can see some ion tail signatures, as the reverse of the sense of the three components of the magnetic

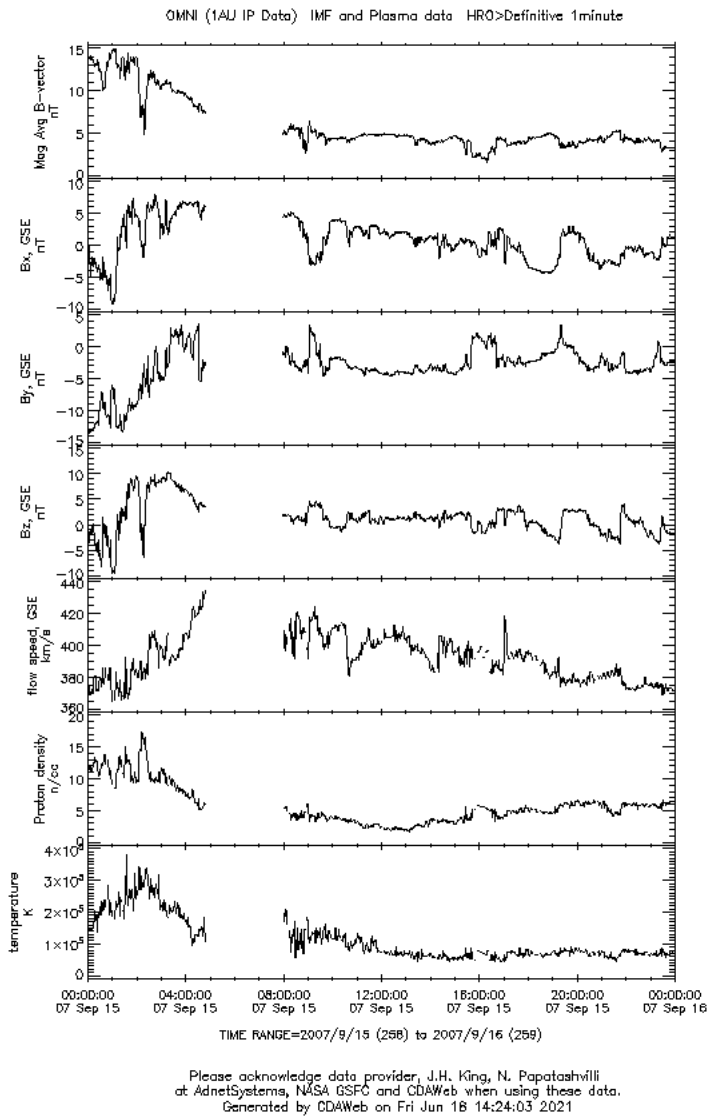


Figure 18: Magnetic field magnitude, magnetic field coordinates, solar wind speed, proton density and temperature from OMNI for date 2007 SEP 15.

field, and the decrease in the flow speed and proton density. However, there is no clear change and then come back to normal situation and, with more reason no having the ions data, nothing can be confirm.

- **2P at 2017 MAR 14**

The data shows an interval of three days, MAR 13, MAR 14 and MAR 15, chosen as the best dates with reasonable solar wind speed described in detail on page **??** in Appendix A.2.1. At MAR

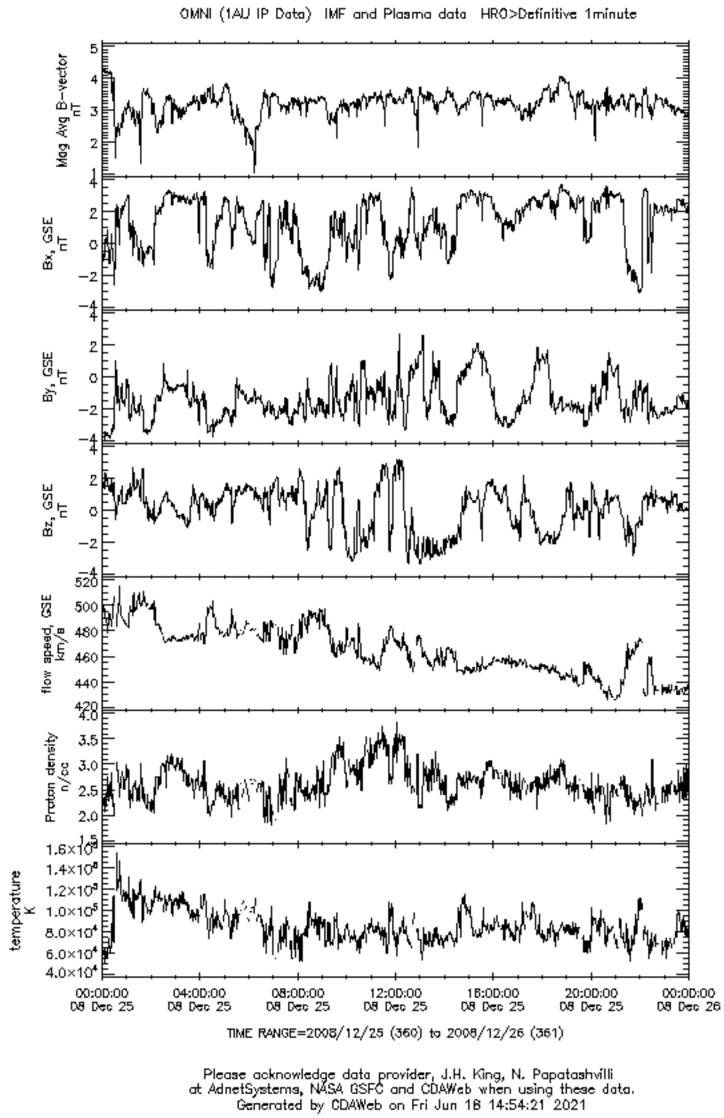


Figure 19: Magnetic field magnitude, magnetic field coordinates, solar wind speed, proton density and temperature from OMNI for date 2008 DEC 25.

13 13:00:00 in Figure 20 on page 36, we found what could be a sign of an ion tail, identifying all the changes one should expect. The magnetic field is very radial and its components y and z reverse their senses. Also there is a little decrease of the solar wind speed, and an increment of both the proton density and the temperature. Also, we see that the data changes and goes back , more or less, its previous values. Hopefully, if it is able to have ions data, these could help or even confirmed if we are in front of an ion tail.

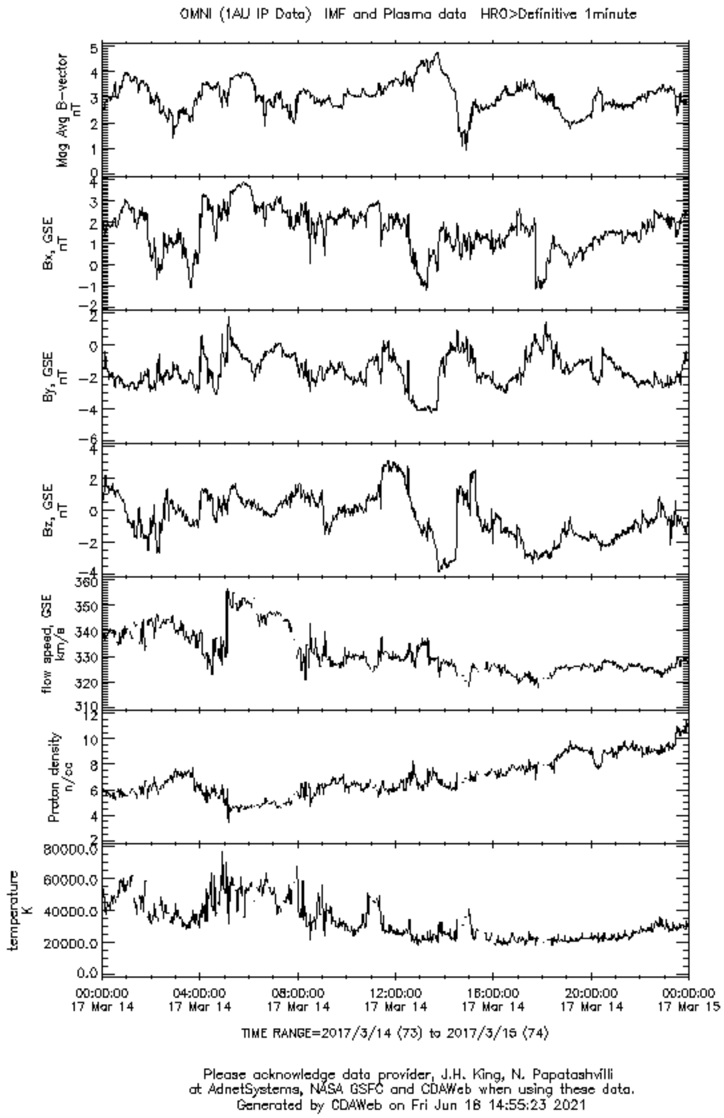


Figure 20: Magnetic field magnitude, magnetic field coordinates, solar wind speed, proton density and temperature from OMNI for date 2017 MAR 14.

- **249P at 2020 JUN 21**

In Figure 21 on page 37 for the encounter shown in page **??** in Appendix 2.2.1 we see the data for the day 2020 JUN 21. We can highlight a drastic drop of proton density at 12:00:00. Also, there is an increment of the magnitude of the magnetic field and we see how the components y and z of this field reverse their sense, even though the magnetic field does not seem to be radial. There is also a little increment of the flow speed and temperature. With this, we can see there are

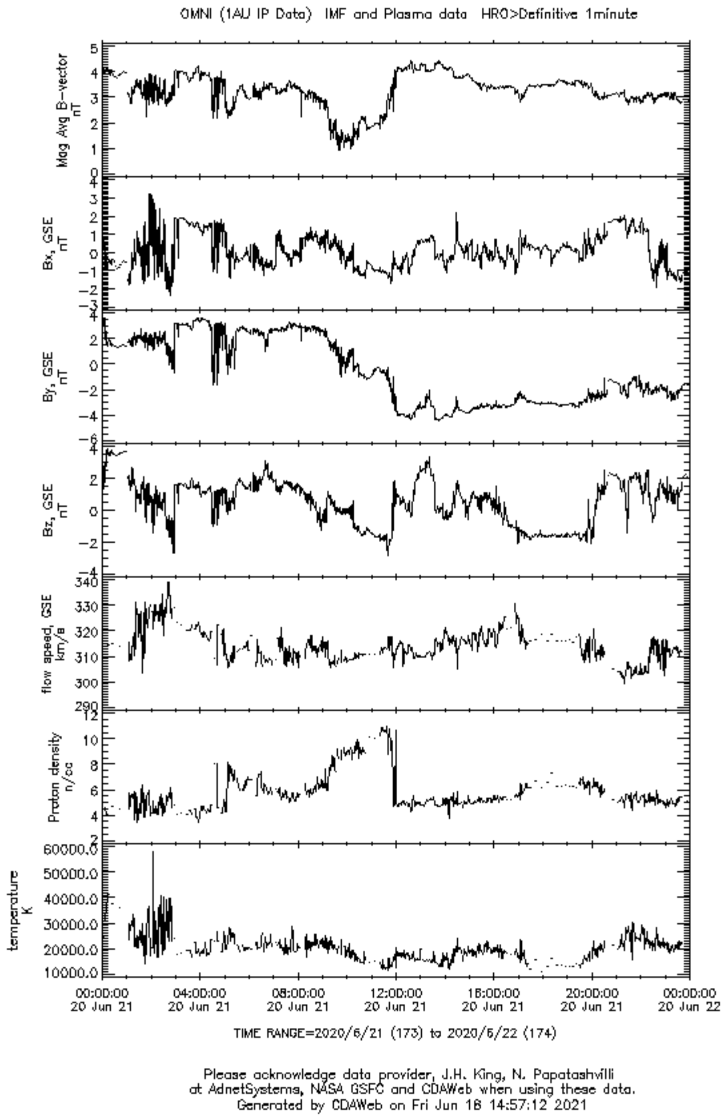


Figure 21: Magnetic field magnitude, magnetic field coordinates, solar wind speed, proton density and temperature from OMNI for date 2020 JUN 21.

almost every signature we expect to find in a crossing, but, as we have mentioned before, these is not necessary to confirmed the presence of an ion tail.

7.6 Mars data

Mars Express: no data available to the public.

8 Discussion and Conclusions

The aim of this work was to calculate possible ion tail encounters with spacecrafts in order to discover more by analysing the data for the ones that already have happened; and plan the instruments to get data when the future predicted encounters will happen. To this aim, a Python code using orbital data for spacecrafts and comets from the NASA SPICE system was written.

From the date of its launch, 10^{th} February 2020 until 20^{th} November 2032, 7 encounters with Solar Orbiter have been found, which 2 of them have already happened. For these two, only magnetic field data is available to the public for the encounter with comet C_2019_Y4-C in 31^{st} May 2020, and unfortunately only for the end of the encounter. No confirmations of an actual encounter have been able to be recognized on it and also, it is not enough data to conclude we are in front of an encounter. A promising encounter has been predicted on 21^{st} October 2021, when Solar Orbiter will be at 0.66 AU from the comet, creating an angle of 1.6º, and the comet at a distance of 0.09 AU from the Sun. This last value makes the ion tail be very intense because of the close the comet is to the Sun. The prediction of the event gives the opportunity to tune in at this date and hopefully get data. Seeing the predictions were done for Solar Orbiter, we thought it was useful to apply the Python program also to other spacecrafts.

For Parker Solar Probe we have found 6 encounters, which 3 of them are of special interest, during the nearly 7 years it is expected to travel. This comets are P_2002_S7, 322P and 323P.

For JUICE, there are predicted 16 encounters during the expected almost ten years the spacecraft will be traveling. The amount of comets one can encounter with JUICE is bigger than with most of the spacecrafts out in the space, but there is the disadvantage of the distance to the Sun these comets will have during these events. Under this condition, one can expect the signatures in the data might be harder to see. We expect comets outside 3-5 AU to have insignificant tails, and all the predicted encounters are inside this limit so, hopefully will be some, not that intense, traces of comets tails in the data.

With Earth, 23 encounters have been found from July 2000 until July 2025, and we have highlighted 4 as the most promising ones. Data of OMNI has been analysed for them. As it has been explained in detail in section 7, some indicators of ion tails have been recognized but, the missing ions data available makes impossible to confirmed we are actually seen the effect of the ion tail in the data. Also, some data have showed solar wind disturbance rather than the encounters, confirming once more that the probability of actually identifying the tails is low.

Mars was the last one to look for encounters with, which were 37, 10 of them more likely to happened. The time range was the same as for Earth. A problem here is that the two suitable spacecrafts, Mars Express and MAVEN, both spend only a small part of their time in the solar wind, so the change of a good encounter is small despite the large number of candidates.

After the little analysis of the data that has been done, it has been confirmed the difficulty in finding and identifying the encounters on it. Trying to change these, the importance of having the predictions of these events, will make us 'be prepared' to get as much data as possible, turning on the corresponded instruments of the spacecrafts for the wanted dates. However, determining ion tails in the data is a very rough task and not only one, but several parameters must be analysed to see if all the signatures appear at the same time. An ion tail provokes changes in these parameters during some few hours, and then the data must show a similar behaviour as the one it had before the event. Mayor and permanent changes are probably not due to a one event of this kind. The ions composition is the most important parameter in these cases, and the first one one should look at. When crossing an ion tail, very characteristic heavy ions as H2O$^+$, C^+ or 0^+ should appear. Once we recognize this, then its time to look for the rest of the data, as magnetic field data. These are as needed as the ions composition, but can suffer of more changes with an origin different than an encounter with an ion tail. As an example, magnetic field suffers from a lot of solar wind disturbances that could cover the signatures of the ion tail or confuse when arriving into conclusions.

Hopefully in the future it will be able to get some data and identify the predicted encounters, and continue using the method to find encounters with as much future spacecrafts with the right instruments as possible to discover and continue advancing in the path of studying these particular and spectacular objects.

9 Acknowledgements

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On the other hand, I thank David Andrews for the help given at the beginning of the project with Python knowledge. Also, thanks to Thomas Nilsson, who got the amiability of downloading the comets kernels into the IRFU server according to what it was needed for my project, and help me with my questions and issues with these files; and to Konrad Steinvall for providing me with some MMS data at the end of my project.

Finally, I would like to thank the Complutense University of Madrid for the financial support through this Erasmus internship.

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A Appendix

A.1 Python Program

A.1.1 comets_metakernel

```
import os
import math
from math import pi
import spiceypy as spice


spice.kclear()

def comets_metakernel():

    #get the metakernel with the comets files wanted to find encounters with

    #choose the maximum perihelion distance these comets must have
    z = input('maximum perohelion distance:')

    #get all the comet files from the directory (previously downloaded from the server)
    y = os.listdir("/Users/CristinaMadurgaFavieres/IRFU/CometsKernels/")

    #create a metakernel with all the comets files
    h = open('comets_all.txt','w+')
    h.write("\begindata\n")
    h.write("PATH_VALUES=( '/Users/CristinaMadurgaFavieres/IRFU/CometsKernels' )\n")
    h.write("PATH_SYMBOLS=( 'KERNELS' )\n")
    h.write("KERNELS_TO_LOAD=(\n")

    for i in range(2,len(y)):
        #spice.furnsh('/Users/CristinaMadurgaFavieres/IRFU/CometsKernels/'+y[i])
        h.write("'$KERNELS/"+y[i]+"'\n")
    h.write("  )\n")
    h.write("\begintext")
    h.close()


    #create a metakernel with only the comets files wanted
    f = open('comets_wanted.txt','w+')
    f.write("\begindata\n")
    f.write("PATH_VALUES=( '/Users/CristinaMadurgaFavieres/IRFU/CometsKernels' )\n")
    f.write("PATH_SYMBOLS=( 'KERNELS' )\n")
    f.write("KERNELS_TO_LOAD=(\n")

    #load the metakernel with all the comets files
    spice.furnsh('/Users/CristinaMadurgaFavieres/IRFU/PYTHON/comets_all.txt')
    count = spice.ktotal('SPK') #count of SPK files


    for i in range(0, count):
        [file,type,source,handle] = spice.kdata(i, 'SPK') #get file, type, source and handle from the SPK files

        #get the comments of the comment area of the file
        #returns [number of comment lines, comment lines, True or false if everything has been extracted]
        elements = spice.dafec(handle,80)
        orbital_elements=[1]
```

```
        for i in range(len(elements[1])):
            y = elements[1][i]
            orbital_elements.append(elements[1][i]) #get the comment section of the file
            x = orbital_elements[1].split() #convert string into a list
            orbital_elements=[1]
            if x==[]:
                x=[1]
            elif x[0]=='EC=':
                #get the values and convert them to float type
                EC = float(x[1]) #eccentricity
                QR = float(x[3]) #perihelion distance(AU)
                if EC>=1:
                    continue
                else:
                    a = QR/(1-EC)*1.496e+11 #semi-major axis(m)
                    P = math.sqrt((4*pi*pi*a*a*a)/(6.67e-11*1.98e+30))*3.17098e-8 #orbital period(years)

                    #get only those files which have smaller perihelion distance than the maximum establish, and with
                    #an orbital period smaller than 200 years (Only taken the Halley-type and Jupiter-family comets)
                    if QR <= float(z) and P<= 200:
                        f.write("'$KERNELS/"+file+ "'\n")
    f.write("  )\n")
    f.write("\begintext")
    f.close()
```

A.1.2 main

```
import os
import numpy as np
import math
from math import cos, sin, pi, atan, asin
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D
import spiceypy as spice
from scipy.interpolate import interp1d
from datetime import date
import tabulate
import latextable
from texttable import Texttable

spice.kclear()


def main():

    #choose the metakernel with the comets files
    metakernelname = 'mymetakernel_Jupiter-FamilyComets(1.5AU)Mars copia.txt'


    #get the handles (identifiers assigned to an open file) of the comets
    function_handle = read_handle(metakernelname)
    handle_comets = function_handle[0]
    j = function_handle[1]
    ID_comets = function_handle[2]
```

```
    #get time and positions of Solar Orbiter and comets
    function_read = read_comet_SolarOrbiter(j, ID_comets)
    times = function_read[0]
    positions_SO_AU = function_read[1]
    positions_Comet_AU_all = function_read[2]


    #the kernels have been cleaned and now the handles are loaded again
    function_handle = read_handle(metakernelname)
    handle_comets = function_handle[0]
    ID_comets = function_handle[2]
    name_comets = function_handle[3]


    for i in range(len(handle_comets)):
        name_comet = name_comets[i]
        print(name_comet)
        ID_comet = ID_comets[i]
        handle = handle_comets[i]
        positions_Comet_AU = positions_Comet_AU_all[i]

        #get the orbital elements necessary for the coordinate transformation
        function_orbital_elements = orbital_elements(handle)
        EC = function_orbital_elements[0] #eccentricity
        QR = function_orbital_elements[1] #perihelion distance
        OM = function_orbital_elements[2] #longitude of ascending mode
        W = function_orbital_elements[3] #argument of periapsis
        IN = function_orbital_elements[4] #inclination of the orbit


        #tranformation from the Ecliptic Coordinate System to the Heliocentric Comet Orbital Coordinate System
        #(comet plane-of-orbit system)
        function_coordinate_transformation = coord_transf(OM,W,IN,name_comet,positions_SO_AU,positions_Comet_AU)

        #Solar Orbiter coordinates
        x_SO_c = function_coordinate_transformation[0]
        y_SO_c = function_coordinate_transformation[1]
        z_SO_c = function_coordinate_transformation[2]

        #Comet coordinates
        x_comet_c = function_coordinate_transformation[3]
        y_comet_c = function_coordinate_transformation[4]
        z_comet_c = function_coordinate_transformation[5]

        #get the possible comet encounters with Solar Orbiter
        find_encounter = encounter(x_SO_c,y_SO_c,z_SO_c,times,EC,QR,x_comet_c,y_comet_c,z_comet_c,name_comet,ID_comet, \
            ,OM,W,IN)


        #plot the trajectory of Solar Orbiter and the comet
        plot = plot_comet_SolarOrbiter(name_comet,times,positions_SO_AU,positions_Comet_AU)
```

A.1.3 load_comet_SolarOrbiter

```
def load_comet_SolarOrbiter(metakernelname):

    #load the metakernel needed to get the positions of Solar Orbiter and the comets (using SPICE interface).
```

```
    spice.furnsh('/Users/CristinaMadurgaFavieres/IRFU/SolarOrbiterKernels/mk/solo_ANC_soc-flown-mk.tm')
    spice.furnsh('/Users/CristinaMadurgaFavieres/IRFU/CometsKernels/'+metakernelname)

    #metakernels for the rest of the spacecrafts
    #spice.furnsh('/Users/CristinaMadurgaFavieres/IRFU/RosettaKernels/mk/ROS_OPS_V330_20200731_001.TM') #Rosetta
    #spice.furnsh('/Users/CristinaMadurgaFavieres/IRFU/ParkerSolarProbeKernels/mk/spp_test.tm') #Parker Solar Probe
    #spice.furnsh('/Users/CristinaMadurgaFavieres/IRFU/JUICEKernels/mk/juice_crema_4_2b22_1_cruise.tm') #JUICE
    #spice.furnsh('/Users/CristinaMadurgaFavieres/IRFU/EarthKernels/naif0012.tls') #Earth,Mars
    #spice.furnsh('/Users/CristinaMadurgaFavieres/IRFU/EarthKernels/pck00010.tpc') #Earth,Mars
    #spice.furnsh('/Users/CristinaMadurgaFavieres/IRFU/EarthKernels/de435.bsp') #Earth
    #spice.furnsh('/Users/CristinaMadurgaFavieres/IRFU/SolarOrbiterKernels/spk/de421.bsp') #Mars
```

A.1.4 read_handle

```
def read_handle(metakernelname):

    #get the handles (identifier assigned to an open file), names and number of the comets

    #load Solar Orbiter and comets files
    function_load = load_comet_SolarOrbiter(metakernelname)

    count = spice.ktotal('SPK') #count of SPK files

    files=[]
    handle_comets=[]
    j=0
    for i in range(0, count):
        [file,type,source,handle] = spice.kdata(i, 'SPK') #get file, type, source and handle from the SPK files
        #create and array only with comets files
        if source == '/Users/CristinaMadurgaFavieres/IRFU/CometsKernels/'+metakernelname:
            files.append(file)
            handle_comets.append(handle) #get the handle of the file
            j=j+1 #number of comets

    #transform string (files names) into array and create an array with the comets ID and another one with the
    #comets names
    ID_comets=[]
    name_comets=[]
    for i in range(j):
        x = files[i].split('___')
        ID_comets.append(x[1])
        y =x[0].split('/')
        name_comets.append(y[5])

    return(handle_comets, j, ID_comets, name_comets)
```

A.1.5 read_comet_SolarOrbiter

```
def read_comet_SolarOrbiter(j, ID_comets):

    #get time and positions of Solar Orbiter and comets

    #get times bewteen two chosen dates
    utc = ['Feb 11, 2020','Nov 20, 2030'] #Solar Orbiter

    #time for the other spacecrafts
    #utc = ['Aug 12, 2018','Aug 16, 2025'] #Parker Solar Probe
```

```
    #utc = ['Sep 04, 2022','Jul 16, 2031'] #JUICE
    #utc = ['Jul 16, 2000','Jul 1, 2025'] #Earth, Mars

    #convert string date into et (seconds past the J2000 epoch) time
    etOne = spice.str2et(utc[0])
    etTwo = spice.str2et(utc[1])

    dateOne = date(2020,2,11)
    dateTwo = date(2030,11,20)
    days = (dateTwo-dateOne).days #number of days between the start and end date

    times = [x*86400 + etOne for x in range(days)] #array with every day
    times_date = spice.et2utc(times,'C',0) #final array with the dates
    print(times_date)


    #get Solar Orbiter positions (Heliocentric Ecliptic Coordinate System)
    positions_SO, lightTimes = spice.spkpos('Solo', times, 'ECLIPJ2000', 'NONE', 'SUN')

    #positions for the other spacecrafts
    #positions_SO, lightTimes = spice.spkpos('Rosetta', times, 'ECLIPJ2000', 'NONE', 'SUN')
    #positions_SO, lightTimes = spice.spkpos('SPP', times, 'ECLIPJ2000', 'NONE', 'SUN')
    #positions_SO, lightTimes = spice.spkpos('JUICE', times, 'ECLIPJ2000', 'NONE', 'SUN')
    #positions_SO, lightTimes = spice.spkpos('Earth', times, 'ECLIPJ2000', 'NONE', 'SUN')
    #positions_SO, lightTimes = spice.spkpos('Mars', times, 'ECLIPJ2000', 'NONE', 'SUN')

    positions_SO = positions_SO.T #transpose positions from (,3) into (3,) for easier indexing
    positions_SO_AU = positions_SO*6.68459e-9 #convert positions to AU units


    #get Comet positions (Heliocentric Ecliptic Coordinate System)
    positions_Comet_AU_all=[]
    for k in range(j):
        positions_Comet, lightTimes = spice.spkpos(ID_comets[k], times, 'ECLIPJ2000', 'NONE', 'SUN')
        positions_Comet = positions_Comet.T
        positions_Comet_AU = positions_Comet*6.68459e-9
        positions_Comet_AU_all.append(positions_Comet_AU) #generate an array with each comet positions array

    spice.kclear()
    return(times, positions_SO_AU, positions_Comet_AU_all)
```

A.1.6 orbital_elements

```
def orbital_elements(handle):

    #get the orbital elements necessary for the coordinate transformation

    #get the comments of the comment area of the file
    #returns [number of comment lines, comment lines, True or false
    #if everything has been extracted]
    elements = spice.dafec(handle,80)
    orbital_elements=[1]

    for i in range(len(elements[1])):
        y = elements[1][i]
        orbital_elements.append(elements[1][i]) #get the comment section of the file
        x = orbital_elements[1].split() #convert string into a list
        orbital_elements=[1]
```

```
        if x==[]:
            x=[1]
        elif x[0]=='EC=':
            #get the values and convert them to float type
            EC = float(x[1]) #eccentricity
            QR = float(x[3]) #perihelion distance
        elif x[0]=='OM=':
            #get the values and convert them to float type
            OM = float(x[1]) #longitude of ascending mode
            W = float(x[3]) #argument of periapsis
            IN = float(x[5]) #inclination of the orbit

    return(EC,QR,OM,W,IN)
```

A.1.7 coord_transf

```
def coord_transf(OM,W,IN,name_comet,positions_SO_AU,positions_Comet_AU):

    #tranformation from the Ecliptic Coordinate System to the Heliocentric Comet Orbital Coordinate System
    #(comet plane-of-orbit system)

    #convert the orbital values needed from degrees to radians units
    OM_rad = OM*pi/180
    W_rad = W*pi/180
    IN_rad = IN*pi/180

    #get the rotation matrix of the transformation
    matrix_transf = spice.eul2m(W_rad,IN_rad,OM_rad,3,1,3)

    #Solar Orbiter
    #product of matrix
    positions_SO_AU_c = np.dot(matrix_transf,positions_SO_AU)

    #new coordinates of Solar Orbiter in the plane-of-orbit system
    x_SO_c = positions_SO_AU_c[0]
    y_SO_c = positions_SO_AU_c[1]
    z_SO_c = positions_SO_AU_c[2]

    #Comet
    #product of matrix
    positions_comet_AU_c = np.dot(matrix_transf,positions_Comet_AU)
    #new coordinates of the comet in the plane-of-orbit system
    x_comet_c = positions_comet_AU_c[0]
    y_comet_c = positions_comet_AU_c[1]
    z_comet_c = positions_comet_AU_c[2]


    #plot13 = plt.figure(figsize=(11,8))
    #ax = plt.axes(projection='3d')
    #ax.plot(positions_SO_AU_c[0], positions_SO_AU_c[1], positions_SO_AU_c[2],'blue',label='SolO')
    #ax.plot(positions_comet_AU_c[0], positions_comet_AU_c[1], positions_comet_AU_c[2],'red',label='Comet')
    #ax.scatter3D(0,0,0, color='orange',label='Sun')
    #ax.set_xlabel('X (AU)')
    #ax.set_ylabel('Y (AU)')
    #ax.set_zlabel('Z (AU)')
    #plt.tick_params(axis='both',labelsize=14)
    #plt.title('Comet '+name_comet+' and Parker Solar Probe trajectory',fontsize=15)
    #plt.suptitle('(Heliocentric Comet Orbital Coordinate System)',fontsize=15)
```

```
    #ax.legend(fontsize=15)

    #plot14 = plt.figure(figsize=(11,8))
    #plt.plot(positions_SO_AU_c[0], positions_SO_AU_c[1],'blue',label='Solar Orbiter')
    #plt.plot(positions_comet_AU_c[0], positions_comet_AU_c[1],'red',label='Comet')
    #plt.scatter(0,0, color='orange',label='Sun')
    #plt.xlabel('X (AU)')
    #plt.ylabel('Y (AU)')
    #plt.tick_params(axis='both',labelsize=14)
    #plt.title('Comet '+name_comet+' and Solar Orbiter trajectory',fontsize=15)
    #plt.suptitle('(Heliocentrc Comet Coordinate System)',fontsize=15)
    #plt.legend(fontsize=15)

    #plot15 = plt.figure(figsize=(11,8))
    #plt.plot(positions_SO_AU_c[0], positions_SO_AU_c[2],'blue',label='Solar Orbiter')
    #plt.plot(positions_comet_AU_c[0], positions_comet_AU_c[2],'red',label='Comet')
    #plt.scatter(0,0, color='orange',label='Sun')
    #plt.xlabel('X (AU)')
    #plt.ylabel('Z (AU)')
    #plt.tick_params(axis='both',labelsize=14)
    #plt.title('Comet '+name_comet+' and Solar Orbiter trajectory',fontsize=15)
    #plt.suptitle('(Heliocentrc Comet Coordinate System)',fontsize=15)
    #plt.legend(fontsize=15)

    #plot16 = plt.figure(figsize=(11,8))
    #plt.plot(positions_SO_AU_c[1], positions_SO_AU_c[2],'blue',label='Solar Orbiter')
    #plt.plot(positions_comet_AU_c[1], positions_comet_AU_c[2],'red',label='Comet')
    #plt.scatter(0,0, color='orange',label='Sun')
    #plt.xlabel('Y (AU)')
    #plt.ylabel('Z (AU)')
    #plt.tick_params(axis='both',labelsize=14)
    #plt.title('Comet '+name_comet+' and  Solar Orbiter trajectory',fontsize=15)
    #plt.suptitle('(Heliocentrc Comet Coordinate System)',fontsize=15)
    #plt.legend(fontsize=15)

    #spice.kclear()
    return(x_SO_c, y_SO_c, z_SO_c, x_comet_c, y_comet_c, z_comet_c)
```

A.1.8 encounter

```
def encounter(x_SO_c,y_SO_c,z_SO_c,times,EC,QR,x_comet_c,y_comet_c,z_comet_c,name_comet,ID_comet,OM,W,IN):

    #get the possible comet encounters with Solar Orbiter

    #take the points with z coordinate between -0.15 AU and 0.15 AU from the plane-of-orbit of the comet
    z_SO_c_near=[]
    index_z_near=[]
    for i in range(len(z_SO_c)):
        if -0.15<=z_SO_c[i]<=0.15:
            z_SO_c_near.append(z_SO_c[i])
            index_z_near.append(i)

    #get x and y values of Solar Orbiter for each point with -0.15z0.15 AU
    x_SO_c_near=[]
    y_SO_c_near=[]
    t_SO_near=[]
    r_SO_c_near=[]
    for i in range(len(index_z_near)):
```

```
    x_SO_c_near.append(x_SO_c[index_z_near[i]])
    y_SO_c_near.append(y_SO_c[index_z_near[i]])

    #get the time of Solar Orbiter for each point of possible encounter
    t_SO_near.append(times[index_z_near[i]])

    #get the radial distance of Solar Orbiter from the Sun
    r_SO_c_near.append(math.sqrt(x_SO_c_near[i]*x_SO_c_near[i]+y_SO_c_near[i]*y_SO_c_near[i]+ \
        z_SO_c_near[i]*z_SO_c_near[i]))


#from these positions of Solar Orbiter, get the desired positions of the comet in the same radial direction
#from Sun of Solar Orbiter

#to do so, get the true anomaly f for the position of Solar Orbiter.
#In order to have Solar Orbiter and the comet in the same radial direction, the comet must be placed in the
#point of its orbit where the true anomaly f has the same value as the obtained one from Solar Orbiter.
f=[]
for i in range(len(x_SO_c_near)):
    f.append(true_anomaly(x_SO_c_near[i],y_SO_c_near[i]))

#to get the radial distance between the Sun and the comet: semi-major axis
a = QR/(1-EC)

#get x and y values for the Comet
r_comet_c_near=[]
x_comet_c_near=[]
y_comet_c_near=[]
d=[] #radial distance between the comet and Solar Orbiter

#values when d>0
x_comet_c_near_encounter=[]
r_comet_c_near_encounter=[]

d_encounter_c=[]
f_encounter=[]

t_SO_near_encounter=[]
x_SO_c_near_encounter=[]
y_SO_c_near_encounter=[]
z_SO_c_near_encounter=[]
r_SO_c_near_encounter=[]
for i in range(len(x_SO_c_near)):
    #radial distance of the comet from the Sun
    r_comet_c_near.append((a*(1-EC*EC))/(1+EC*cos(f[i])))

    x_comet_c_near.append(cos(f[i])*r_comet_c_near[i])
    y_comet_c_near.append(sin(f[i])*r_comet_c_near[i])

    #radial distance d between the comet and Solar Orbiter
    d.append(r_SO_c_near[i]-r_comet_c_near[i])
    #the radial distance must be positive (Solar Orbiter has to be behind the comet)
    if d[i]>0:
        x_comet_c_near_encounter.append(cos(f[i])*r_comet_c_near[i])
        r_comet_c_near_encounter.append(r_comet_c_near[i])

        d_encounter_c.append(d[i])
        f_encounter.append(f[i])
```

```
        t_SO_near_encounter.append(t_SO_near[i])
        x_SO_c_near_encounter.append(x_SO_c_near[i])
        y_SO_c_near_encounter.append(y_SO_c_near[i])
        z_SO_c_near_encounter.append(z_SO_c_near[i])
        r_SO_c_near_encounter.append(r_SO_c_near[i])

#the desired positions of the comet must be within the range of the orbit in the time we are loading the
#comet files (to do the interpolation). We can get one position of the comet that it will have later than
#the 21 years we are analysing.
x_comet_c_near_encounter_orbit=[]
r_comet_c_near_encounter_orbit=[]

d_encounter_c_orbit=[]
f_encounter_orbit=[]

t_SO_near_encounter_orbit=[]
x_SO_c_near_encounter_orbit=[]
y_SO_c_near_encounter_orbit=[]
z_SO_c_near_encounter_orbit=[]
r_SO_c_near_encounter_orbit=[]

for i in range(len(x_comet_c_near_encounter)):
    if min(x_comet_c)<=x_comet_c_near_encounter[i]<=max(x_comet_c):

        x_comet_c_near_encounter_orbit.append(x_comet_c_near_encounter[i])
        r_comet_c_near_encounter_orbit.append(r_comet_c_near_encounter[i])

        d_encounter_c_orbit.append(d_encounter_c[i])
        f_encounter_orbit.append(f_encounter[i])

        t_SO_near_encounter_orbit.append(t_SO_near_encounter[i])
        x_SO_c_near_encounter_orbit.append(x_SO_c_near_encounter[i])
        y_SO_c_near_encounter_orbit.append(y_SO_c_near_encounter[i])
        z_SO_c_near_encounter_orbit.append(z_SO_c_near_encounter[i])
        r_SO_c_near_encounter_orbit.append(r_SO_c_near_encounter[i])



#interpolation of the comet x positions of the file to get the time of each x_comet_near point.

#only continue with the next steps if the previous conditions have been satisfied
if len(x_comet_c_near_encounter_orbit)>=1:

    f_comet=[]
    for i in range(len(x_comet_c)):
        f_comet.append(true_anomaly(x_comet_c[i],y_comet_c[i]))

    w = interp1d(f_comet,times)

    #get the time for each x_comet_near point, using the true anomaly.
    t_comet_encounter_orbit=[]
    #time delay between the position of Solar Orbiter and the position of the comet in the desired
    #production point.
    t_delay=[]
    #get the velocity of solar wind for each point
    v_solar_wind=[]
```

```
#final values when the solar wind velocity has reasonable values
v_solar_wind_encounter=[]

r_comet_c_near_encounter_orbit_final=[]
t_comet_encounter_orbit_final=[]

d_encounter_c_orbit_final=[]
t_delay_final=[]

t_SO_encounter_final=[]
x_SO_c_near_encounter_orbit_final=[]
y_SO_c_near_encounter_orbit_final=[]
z_SO_c_near_encounter_orbit_final=[]
r_SO_c_near_encounter_orbit_final=[]
d_SO_to_plane=[]

angle=[] #angle between comet and spacecraft at the encounter

for i in range(len(x_comet_c_near_encounter_orbit)):
    #reverse both time and true anomaly arrays to find encounters running the time backforwards.
    #The comet must have passed the desired position before the spacecraft, as the ion tails takes
    #time to travel through the space.
    for j in range(len(times)):
        if times[j]==t_SO_near_encounter_orbit[i]:
            break
    t = times[0:j+1]
    t = list(reversed(t))
    f = f_comet[0:j+1]
    f = list(reversed(f))

    #interpolate again the true anomaly to get the time at each comet position.
    #run the comet's reversed true anomaly array and find the two values within Solar Orbiter true
    #anomaly is
    for k in range(1,len(f)):
        if f[k-1]<=f_encounter_orbit[i]<=f[k]:
            #as true anomaly goes from -pi to pi, the jump between these two values must be avoid.
            #The comet goes from -pi to pi, or reverse, directely, so it is not correct to do the
            #interpolation between these values.
            if pi-0.001<=f[k-1]<=pi+0.001 and -pi-0.001<=f[k]<=-pi+0.001:
                continue
            elif -pi-0.001<=f[k-1]<=-pi+0.001 and pi-0.001<=f[k]<=pi+0.001:
                continue
            else:
                w1 = interp1d([f[k-1],f[k]],[t[k-1],t[k]])

                #time at each x_comet_near_encounter_orbit point
                t_comet_encounter_orbit = w1(f_encounter_orbit[i])
                t_comet_encounter_orbit = float(t_comet_encounter_orbit)

                #time delay between the position of Solar Orbiter and the position of the comet in the
                #desired production point.
                t_delay = t_SO_near_encounter_orbit[i]-t_comet_encounter_orbit

                #velocity
                v_solar_wind = d_encounter_c_orbit[i]*1.5e8/t_delay

                #only consider possible encounters the ones with a reasonable solar wind velocity
                if 200<=v_solar_wind<=1200:
```

```
                    v_solar_wind_encounter.append(v_solar_wind)

                    r_comet_c_near_encounter_orbit_final.append(r_comet_c_near_encounter_orbit[i])
                    t_comet_encounter_orbit_final.append(t_comet_encounter_orbit)

                    d_encounter_c_orbit_final.append(d_encounter_c_orbit[i])
                    t_delay_final.append(t_delay/86400) #in days

                    t_SO_encounter_final.append(t_SO_near_encounter_orbit[i])
                    x_SO_c_near_encounter_orbit_final.append(x_SO_c_near_encounter_orbit[i])
                    y_SO_c_near_encounter_orbit_final.append(y_SO_c_near_encounter_orbit[i])
                    z_SO_c_near_encounter_orbit_final.append(z_SO_c_near_encounter_orbit[i])
                    r_SO_c_near_encounter_orbit_final.append(r_SO_c_near_encounter_orbit[i])
                    d_SO_to_plane.append(z_SO_c_near_encounter_orbit[i])

        elif f[k-1]>=f_encounter_orbit[i]>=f[k]:
            if pi-0.001<=f[k-1]<=pi+0.001 and -pi-0.001<=f[k]<=-pi+0.001:
                continue
            elif -pi-0.001<=f[k-1]<=-pi+0.001 and pi-0.001<=f[k]<=pi+0.001:
                continue
            else:
                w1 = interp1d([f[k-1],f[k]],[t[k-1],t[k]])

                t_comet_encounter_orbit = w1(f_encounter_orbit[i])
                t_comet_encounter_orbit = float(t_comet_encounter_orbit)

                t_delay = t_SO_near_encounter_orbit[i]-t_comet_encounter_orbit

                v_solar_wind = d_encounter_c_orbit[i]*1.5e8/t_delay

                if 200<=v_solar_wind<=1200:
                    v_solar_wind_encounter.append(v_solar_wind)

                    r_comet_c_near_encounter_orbit_final.append(r_comet_c_near_encounter_orbit[i])
                    t_comet_encounter_orbit_final.append(t_comet_encounter_orbit)

                    d_encounter_c_orbit_final.append(d_encounter_c_orbit[i])
                    t_delay_final.append(t_delay/86400)

                    t_SO_encounter_final.append(t_SO_near_encounter_orbit[i])
                    x_SO_c_near_encounter_orbit_final.append(x_SO_c_near_encounter_orbit[i])
                    y_SO_c_near_encounter_orbit_final.append(y_SO_c_near_encounter_orbit[i])
                    z_SO_c_near_encounter_orbit_final.append(z_SO_c_near_encounter_orbit[i])
                    r_SO_c_near_encounter_orbit_final.append(r_SO_c_near_encounter_orbit[i])
                    d_SO_to_plane.append(z_SO_c_near_encounter_orbit[i])

#get the times in date format
t_SO_encounter_final_date=[]
t_comet_encounter_orbit_final_date=[]
for i in range(len(t_SO_encounter_final)):
    t_SO_encounter_final_date.append(spice.et2utc(t_SO_encounter_final[i],'C',0))
    t_comet_encounter_orbit_final_date.append(spice.et2utc(t_comet_encounter_orbit_final[i],'C',0))
    angle.append(asin(d_SO_to_plane[i]/d_encounter_c_orbit_final[i])*180/pi)

    t_SO = t_SO_encounter_final[i]
    t_comet = t_comet_encounter_orbit_final[i]

    #get and plot the comets ion tails
```

```
        iontail3D(ID_comet,t_SO,t_comet,name_comet)
        iontailxy(ID_comet,t_SO,t_comet,name_comet)
        iontailyz(ID_comet,t_SO,t_comet,name_comet)
        iontailxz(ID_comet,t_SO,t_comet,name_comet)

        iontail_cometsystem3D(ID_comet,t_SO,t_comet,times,name_comet,OM,W,IN)
        iontail_cometsystemxy(ID_comet,t_SO,t_comet,times,name_comet,OM,W,IN)
        iontail_cometsystemxz(ID_comet,t_SO,t_comet,times,name_comet,OM,W,IN)
        iontail_cometsystemyz(ID_comet,t_SO,t_comet,times,name_comet,OM,W,IN)


    if v_solar_wind_encounter==[]:
        print('    No possible encounter')

    else:

        #get the values in a latex table
        table = Texttable()
        table.set_cols_align(["c"]*9)
        table.set_cols_valign(["m"]*9)
        table.set_deco(Texttable.BORDER | Texttable.HEADER | Texttable.VLINES)
        table.header(['Date', 'Date Comet','Solar wind Speed (km/s)','Time delay (days)', \
            'Distance Solar Orbiter-Comet (AU)','Distance Solar Orbiter-Ion tail (AU)', \
                'Angle (deg)','Distance Solar Orbiter-Sun (AU)','Distance Comet-Sun (AU)'])
        for i in range(len(t_SO_encounter_final_date)):
            table.add_row([t_SO_encounter_final_date[i],t_comet_encounter_orbit_final_date[i], \
                round(v_solar_wind_encounter[i]),t_delay_final[i],d_encounter_c_orbit_final[i], \
                    abs(d_SO_to_plane[i]),angle[i],r_SO_c_near_encounter_orbit_final[i], \
                        r_comet_c_near_encounter_orbit_final[i]])
        print(table.draw() + "\n")
        print(latextable.draw_latex(table, caption="Possible encounters.") + "\n")


        function_crossing = crossing(x_SO_c,y_SO_c,z_SO_c,times,a,EC,f_comet)

else:
    print('    No possible encounter')
```

A.1.9 true_anomaly

```
def true_anomaly(x,y): #-pi to pi

    #get the true anomaly of a position

    f = atan(abs(y/x))

    if np.sign(x)==1 and np.sign(y)==1:
        f = f

    elif np.sign(x)==-1 and np.sign(y)==1:
        f = pi-f

    elif np.sign(x)==-1 and np.sign(y)==-1:
        f = -pi+f

    elif np.sign(x)==1 and np.sign(y)==-1:
```

```
        f = -f
    return(f)
```

A.1.10 crossing

```
def crossing(x_SO_c,y_SO_c,z_SO_c,times,a,EC,f_comet):

    #get the values when the spacecraft is actually crossing the comets plane

    time_SO_z0 =[]
    v_crossing=[]
    k=0
    time_SO_z0_cometorbit=[]
    time_comet_crossing_array=[]
    times_array=[]
    f_comet_array=[]
    for i in range(1,len(z_SO_c)):
        if np.sign(z_SO_c[i-1])==np.sign(z_SO_c[i]):
            continue
        else:
            #get the time when Solar Orbiter is at z=0 by interpolation
            h = interp1d([z_SO_c[i-1],z_SO_c[i]],[times[i-1],times[i]])
            time_SO_z0.append(h(0))
            k=k+1

            #get x and y coordinate of Solar Orbiter at z=0, and the radial distance to the Sun
            x_interpolation = interp1d([times[i-1],times[i]],[x_SO_c[i-1],x_SO_c[i]])
            x_SO_c_crossing = x_interpolation(time_SO_z0[k-1])

            y_interpolation = interp1d([times[i-1],times[i]],[y_SO_c[i-1],y_SO_c[i]])
            y_SO_c_crossing = y_interpolation(time_SO_z0[k-1])

            #radial distance of Solar Orbiter to the Sun
            r_SO_c_crossing = (math.sqrt(x_SO_c_crossing*x_SO_c_crossing+y_SO_c_crossing*y_SO_c_crossing))

            #get the true anomaly at z0 by interpolation
            f_before_crossing = true_anomaly(x_SO_c[i-1],y_SO_c[i-1])
            f_after_crossing = true_anomaly(x_SO_c[i],y_SO_c[i])

            f_interpolation = interp1d([times[i-1],times[i]],[f_before_crossing,f_after_crossing])
            f_crossing = f_interpolation(time_SO_z0[k-1])

            #radial distance of the comet to the Sun at the position with the true anomaly f_crossing
            r_comet_c_crossing = (a*(1-EC*EC))/(1+EC*cos(f_crossing))

            #radial distance between the comet and the spacecraft
            d_crossing = r_SO_c_crossing-r_comet_c_crossing

            #reverse the time array that goes from the beggining to the time just after the crossing
            times_array = times[0:i]
            times_reversed = list(reversed(times_array))

            #do the same with the true anomaly values of the comet's orbit
            for l in range(len(times_array)):
                f_comet_array.append(f_comet[l])
            f_comet_reversed = list(reversed(f_comet_array))
```

```
        #run the comet's reversed true anomaly array and find the two values within Solar Orbiter true
        #anomaly is
        for j in range(1,len(f_comet_reversed)):

            if f_comet_reversed[j-1]<=f_crossing<=f_comet_reversed[j] and d_crossing>0:
                #as true anomaly goes from -pi to pi, the jump between these two values must be avoid.
                #The comet goes from -pi to pi, or reverse, directely, so it is not correct to do the
                #interpolation between these values.
                if pi-0.001<=f_comet_reversed[j-1]<=pi+0.001 and -pi-0.001<=f_comet_reversed[j]<=-pi+0.001:
                    continue
                elif -pi-0.001<=f_comet_reversed[j-1]<=-pi+0.001 and pi-0.001<=f_comet_reversed[j]<=pi+0.001:
                    continue
                else:
                    g = interp1d([f_comet_reversed[j-1],f_comet_reversed[j]],[times_reversed[j-1],times_reversed[j]])
                    #get the time of the comet at that position by interpolation
                    time_comet_crossing = g(f_crossing)
                    time_comet_crossing_array.append(time_comet_crossing)

                    #time delay between Solar Orbiter and the comet
                    t_delay_crossing = time_SO_z0[k-1]-time_comet_crossing
                    #solar wind velocity
                    v_crossing.append(d_crossing*1.5e8/t_delay_crossing)
                    time_SO_z0_cometorbit.append(time_SO_z0[k-1])
                    f_comet_array=[]
                    break

            elif f_comet_reversed[j-1]>=f_crossing>=f_comet_reversed[j] and d_crossing>0:
                if pi-0.001<=f_comet_reversed[j-1]<=pi+0.001 and -pi-0.001<=f_comet_reversed[j]<=-pi+0.001:
                    continue
                elif -pi-0.001<=f_comet_reversed[j-1]<=-pi+0.001 and pi-0.001<=f_comet_reversed[j]<=pi+0.001:
                    continue
                else:
                    g = interp1d([f_comet_reversed[j-1],f_comet_reversed[j]],[times_reversed[j-1],times_reversed[j]])
                    time_comet_crossing = g(f_crossing)
                    time_comet_crossing_array.append(time_comet_crossing)

                    t_delay_crossing = time_SO_z0[k-1]-time_comet_crossing
                    v_crossing.append(d_crossing*1.5e8/t_delay_crossing)
                    time_SO_z0_cometorbit.append(time_SO_z0[k-1])
                    f_comet_array=[]
                    break
            else:
                f_comet_array=[]


#ge the times in date format
date_z0 = spice.et2utc(time_SO_z0_cometorbit,'C',0)
time_comet_crossing_array_date = spice.et2utc(time_comet_crossing_array,'C',0)
#print('Crossings:', date_z0)
#print('veocity:', v_crossing)

table = Texttable()
table.set_cols_align(["c"]*3)
table.set_cols_valign(["m"]*3)
table.set_deco(Texttable.BORDER | Texttable.HEADER | Texttable.VLINES)
table.header(['Date Crossing', 'Date comet','Solar wind Speed (km/s)'])
for i in range(len(date_z0)):
```

```
        table.add_row([date_z0[i],time_comet_crossing_array_date[i],v_crossing[i]])
    print(table.draw() + "\n")
    print(latextable.draw_latex(table, caption="Crossings.") + "\n")
```

A.1.11 iontail

```
def iontail3D(ID_comet,t_SO,t_comet,name_comet):


    v = [200,400,600,800,1000,1200] #km/s

    #production time of the ion tail
    t_start = t_SO
    t_start_date = spice.et2utc(t_start,'C',0)

    plot1 = plt.figure(figsize=(11,8))
    ax = plt.axes(projection='3d')

    for i in range(len(v)):
        #final date: three years before the time the comet passes the ion tail production position
        t_end = t_comet - 3*3.15e7
        hours = int((t_start-t_end)/3600) #hours between the start and end date.
        time = [t_start - x*3600 for x in range(hours)] #time array going backwards
        time_date = spice.et2utc(time,'C',0)

        #Comet's positions (Heliocentric Ecliptic Coordinate System)
        coord_comet,lightTimes = spice.spkpos(ID_comet, time, 'ECLIPJ2000', 'NONE', 'SUN')
        coord_comet = coord_comet.T
        coord_comet_AU = coord_comet*6.68459e-9
        x_comet = coord_comet_AU[0]
        y_comet = coord_comet_AU[1]
        z_comet = coord_comet_AU[2]

        #Comet's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
        coord_comet_encounter,lightTimes = spice.spkpos(ID_comet, t_comet, 'ECLIPJ2000', 'NONE', 'SUN')
        coord_comet_encounter = coord_comet_encounter.T
        coord_comet_encounter_AU = coord_comet_encounter*6.68459e-9

        #Solar Orbiter's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
        coord_SO,lightTimes = spice.spkpos('Solo', t_start, 'ECLIPJ2000', 'NONE', 'SUN')

        #get the positions of the other spacecrafts
        #coord_SO,lightTimes = spice.spkpos('SPP', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Parker Solar Probe
        #coord_SO,lightTimes = spice.spkpos('JUICE', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #JUICE
        #coord_SO,lightTimes = spice.spkpos('Earth', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Earth
        #coord_SO,lightTimes = spice.spkpos('Mars', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Mars

        coord_SO = coord_SO.T
        coord_SO_AU = coord_SO*6.68459e-9
        x_SO_encounter = coord_SO_AU[0]
        y_SO_encounter = coord_SO_AU[1]
        z_SO_encounter = coord_SO_AU[2]

        x_iontail=np.zeros(len(time))
        y_iontail=np.zeros(len(time))
        z_iontail=np.zeros(len(time))
```

```
        for j in range(len(time)):
            pos_comet = [x_comet[j],y_comet[j],z_comet[j]]
            #Transformation from cartesians to spherical coordinates (for the comet)
            (distance_comet,colat_comet,longitude_comet) = spice.recsph(pos_comet)
            phi_comet = pi/2-colat_comet #latitude

            #Ion tail's positions for the time range
            x_iontail[j]=x_comet[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*cos(longitude_comet)
            y_iontail[j]=y_comet[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*sin(longitude_comet)
            z_iontail[j]=z_comet[j]+(v[i]*1000*j*3600/1.5e11)*sin(phi_comet)


        tail, = ax.plot(x_iontail, y_iontail, z_iontail,color='green')
        comet, = ax.plot(x_comet, y_comet, z_comet,color='red')
        SO = ax.scatter(x_SO_encounter, y_SO_encounter, z_SO_encounter,color='blue')
        Sun = ax.scatter3D(0,0,0, color='orange')
        comet_encounter = ax.scatter3D(coord_comet_encounter_AU[0],coord_comet_encounter_AU[1], \
            coord_comet_encounter_AU[2],marker='x',color='red')
        ax.set_xlabel('X (AU)')
        ax.set_ylabel('Y (AU)')
        ax.set_zlabel('Z (AU)')
        ax.set_xlim([-1.5, 1.5])
        ax.set_ylim([-1.5, 1.5])
        ax.set_zlim([-1.5, 1.5])
        plt.tick_params(axis='both',labelsize=14)
        plt.suptitle('(Ecliptic coordinate system) Encounter Comet'+' '+name_comet+'    '+t_start_date,fontsize=15)
        plt.legend([tail,comet,SO,Sun,comet_encounter],['Ion tail with different speeds','Comet','Solar Orbiter', \
            'Sun','Comet at tail production time'])
        plt.savefig(name_comet+' Encounter SolO Ecl 3D, '+t_start_date+'.png')

def iontailxy(ID_comet,t_SO,t_comet,name_comet):


    v = [200,400,600,800,1000,1200] #km/s

    #production time of the ion tail
    t_start = t_SO
    t_start_date = spice.et2utc(t_start,'C',0)

    plot2 = plt.figure(figsize=(11,8))

    for i in range(len(v)):
        #final date: three years before the time the comet passes the ion tail production position
        t_end = t_comet - 3*3.15e7
        hours = int((t_start-t_end)/3600) #hours between the start and end date.
        time = [t_start - x*3600 for x in range(hours)] #time array going backwards
        time_date = spice.et2utc(time,'C',0)

        #Comet's positions (Heliocentric Ecliptic Coordinate System)
        coord_comet,lightTimes = spice.spkpos(ID_comet, time, 'ECLIPJ2000', 'NONE', 'SUN')
        coord_comet = coord_comet.T
        coord_comet_AU = coord_comet*6.68459e-9
        x_comet = coord_comet_AU[0]
        y_comet = coord_comet_AU[1]
        z_comet = coord_comet_AU[2]

        #Comet's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
        coord_comet_encounter,lightTimes = spice.spkpos(ID_comet, t_comet, 'ECLIPJ2000', 'NONE', 'SUN')
```

```
        coord_comet_encounter = coord_comet_encounter.T
        coord_comet_encounter_AU = coord_comet_encounter*6.68459e-9

        #Solar Orbiter's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
        coord_SO,lightTimes = spice.spkpos('Solo', t_start, 'ECLIPJ2000', 'NONE', 'SUN')

        #get the position for the other spacecrafts
        #coord_SO,lightTimes = spice.spkpos('SPP', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Parker Solar Probe
        #coord_SO,lightTimes = spice.spkpos('JUICE', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #JUICE
        #coord_SO,lightTimes = spice.spkpos('Earth', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Earth
        #coord_SO,lightTimes = spice.spkpos('Mars', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Mars

        coord_SO = coord_SO.T
        coord_SO_AU = coord_SO*6.68459e-9
        x_SO_encounter = coord_SO_AU[0]
        y_SO_encounter = coord_SO_AU[1]
        z_SO_encounter = coord_SO_AU[2]

        x_iontail=np.zeros(len(time))
        y_iontail=np.zeros(len(time))
        z_iontail=np.zeros(len(time))


        for j in range(len(time)):

            pos_comet = [x_comet[j],y_comet[j],z_comet[j]]
            #Transformation from cartesians to spherical coordinates (for the comet)
            (distance_comet,colat_comet,longitude_comet) = spice.recsph(pos_comet)
            phi_comet = pi/2-colat_comet #latitude

            #Ion tail's positions for the time range
            x_iontail[j]=x_comet[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*cos(longitude_comet)
            y_iontail[j]=y_comet[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*sin(longitude_comet)
            z_iontail[j]=z_comet[j]+(v[i]*1000*j*3600/1.5e11)*sin(phi_comet)


        tail, = plt.plot(x_iontail, y_iontail, color='green')
        comet, = plt.plot(x_comet, y_comet, color='red')
        SO = plt.scatter(x_SO_encounter, y_SO_encounter, color='blue')
        Sun = plt.scatter(0,0,color='orange')
        comet_encounter = plt.scatter(coord_comet_encounter_AU[0],coord_comet_encounter_AU[1],marker='x',color='red')
        plt.xlabel('X (AU)')
        plt.ylabel('Y (AU)')
        plt.axis('equal')
        plt.xlim([-1.5, 1.5])
        plt.ylim([-1.5, 1.5])
        plt.tick_params(axis='both',labelsize=16)
        plt.title('Encounter Comet'+' '+name_comet+'    '+t_start_date,fontsize=15)
        plt.suptitle('(Ecliptic coordinate system)',fontsize=15)
        plt.legend([tail,comet,SO,Sun,comet_encounter],['Ion tail with different speeds','Comet','Solar Orbiter', \
            'Sun','Comet at tail production time'])
        plt.savefig(name_comet+' Encounter SoLO Ecl Y vs X, '+t_start_date+'.png')



def iontailyz(ID_comet,t_SO,t_comet,name_comet):
```

```
v = [200,400,600,800,1000,1200] #km/s

#production time of the ion tail
t_start = t_SO
t_start_date = spice.et2utc(t_start,'C',0)

plot4 = plt.figure(figsize=(11,8))

for i in range(len(v)):
    #final date: three years before the time the comet passes the ion tail production position
    t_end = t_comet - 3*3.15e7
    hours = int((t_start-t_end)/3600) #hours between the start and end date.
    time = [t_start - x*3600 for x in range(hours)] #time array going backwards
    time_date = spice.et2utc(time,'C',0)

    #Comet's positions (Heliocentric Ecliptic Coordinate System)
    coord_comet,lightTimes = spice.spkpos(ID_comet, time, 'ECLIPJ2000', 'NONE', 'SUN')
    coord_comet = coord_comet.T
    coord_comet_AU = coord_comet*6.68459e-9
    x_comet = coord_comet_AU[0]
    y_comet = coord_comet_AU[1]
    z_comet = coord_comet_AU[2]

    #Comet's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
    coord_comet_encounter,lightTimes = spice.spkpos(ID_comet, t_comet, 'ECLIPJ2000', 'NONE', 'SUN')
    coord_comet_encounter = coord_comet_encounter.T
    coord_comet_encounter_AU = coord_comet_encounter*6.68459e-9

    #Solar Orbiter's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
    coord_SO,lightTimes = spice.spkpos('Solo', t_start, 'ECLIPJ2000', 'NONE', 'SUN')

    #get the position for the other spacecrafts
    #coord_SO,lightTimes = spice.spkpos('SPP', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Parker Solar Probe
    #coord_SO,lightTimes = spice.spkpos('JUICE', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #JUICE
    #coord_SO,lightTimes = spice.spkpos('Earth', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Earth
    #coord_SO,lightTimes = spice.spkpos('Mars', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Mars

    coord_SO = coord_SO.T
    coord_SO_AU = coord_SO*6.68459e-9
    x_SO_encounter = coord_SO_AU[0]
    y_SO_encounter = coord_SO_AU[1]
    z_SO_encounter = coord_SO_AU[2]

    x_iontail=np.zeros(len(time))
    y_iontail=np.zeros(len(time))
    z_iontail=np.zeros(len(time))


    for j in range(len(time)):

        pos_comet = [x_comet[j],y_comet[j],z_comet[j]]
        #Transformation from cartesians to spherical coordinates (for the comet)
        (distance_comet,colat_comet,longitude_comet) = spice.recsph(pos_comet)
        phi_comet = pi/2-colat_comet #latitude

        #Ion tail's positions for the time range
        x_iontail[j]=x_comet[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*cos(longitude_comet)
        y_iontail[j]=y_comet[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*sin(longitude_comet)
```

```
            z_iontail[j]=z_comet[j]+(v[i]*1000*j*3600/1.5e11)*sin(phi_comet)


        tail, = plt.plot(y_iontail, z_iontail, color='green')
        comet, = plt.plot(y_comet, z_comet, color='red')
        SO = plt.scatter(y_SO_encounter, z_SO_encounter, color='blue')
        Sun = plt.scatter(0,0,color='orange')
        comet_encounter = plt.scatter(coord_comet_encounter_AU[1],coord_comet_encounter_AU[2],marker='x',color='red')
        plt.xlabel('Y (AU)')
        plt.ylabel('Z (AU)')
        plt.axis('equal')
        plt.xlim([-1.5, 1.5])
        plt.ylim([-1.5, 1.5])
        plt.tick_params(axis='both',labelsize=16)
        plt.title('Encounter Comet'+' '+name_comet+'    '+t_start_date,fontsize=15)
        plt.suptitle('(Ecliptic coordinate system)',fontsize=15)
        plt.legend([tail,comet,SO,Sun,comet_encounter],['Ion tail with different speeds','Comet','Solar Orbiter','Sun', \
            'Comet at tail production time'])
        plt.savefig(name_comet+' Encounter SolO Ecl Z vs Y, '+t_start_date+'.png')


def iontailxz(ID_comet,t_SO,t_comet,name_comet):


    v = [200,400,600,800,1000,1200] #km/s

    #production time of the ion tail
    t_start = t_SO
    t_start_date = spice.et2utc(t_start,'C',0)

    plot3 = plt.figure(figsize=(11,8))

    for i in range(len(v)):
        #final date: three years before the time the comet passes the ion tail production position
        t_end = t_comet - 3*3.15e7
        hours = int((t_start-t_end)/3600) #hours between the start and end date.
        time = [t_start - x*3600 for x in range(hours)] #time array going backwards
        time_date = spice.et2utc(time,'C',0)

        #Comet's positions (Heliocentric Ecliptic Coordinate System)
        coord_comet,lightTimes = spice.spkpos(ID_comet, time, 'ECLIPJ2000', 'NONE', 'SUN')
        coord_comet = coord_comet.T
        coord_comet_AU = coord_comet*6.68459e-9
        x_comet = coord_comet_AU[0]
        y_comet = coord_comet_AU[1]
        z_comet = coord_comet_AU[2]

        #Comet's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
        coord_comet_encounter,lightTimes = spice.spkpos(ID_comet, t_comet, 'ECLIPJ2000', 'NONE', 'SUN')
        coord_comet_encounter = coord_comet_encounter.T
        coord_comet_encounter_AU = coord_comet_encounter*6.68459e-9

        #Solar Orbiter's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
        coord_SO,lightTimes = spice.spkpos('Solo', t_start, 'ECLIPJ2000', 'NONE', 'SUN')

        #get the position for the other spacecrafts
        #coord_SO,lightTimes = spice.spkpos('SPP', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Parker Solar Probe
        #coord_SO,lightTimes = spice.spkpos('JUICE', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #JUICE
```

```
    #coord_SO,lightTimes = spice.spkpos('Earth', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Earth
    #coord_SO,lightTimes = spice.spkpos('Mars', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Mars

    coord_SO = coord_SO.T
    coord_SO_AU = coord_SO*6.68459e-9
    x_SO_encounter = coord_SO_AU[0]
    y_SO_encounter = coord_SO_AU[1]
    z_SO_encounter = coord_SO_AU[2]


    x_iontail=np.zeros(len(time))
    y_iontail=np.zeros(len(time))
    z_iontail=np.zeros(len(time))


    for j in range(len(time)):
        pos_comet = [x_comet[j],y_comet[j],z_comet[j]]
        #Transformation from cartesians to spherical coordinates (for the comet)
        (distance_comet,colat_comet,longitude_comet) = spice.recsph(pos_comet)
        phi_comet = pi/2-colat_comet #latitude

        #Ion tail's positions for the time range
        x_iontail[j]=x_comet[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*cos(longitude_comet)
        y_iontail[j]=y_comet[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*sin(longitude_comet)
        z_iontail[j]=z_comet[j]+(v[i]*1000*j*3600/1.5e11)*sin(phi_comet)


    tail, = plt.plot(x_iontail, z_iontail, color='green')
    comet, = plt.plot(x_comet, z_comet, color='red')
    SO = plt.scatter(x_SO_encounter, z_SO_encounter, color='blue')
    Sun = plt.scatter(0,0,color='orange')
    comet_encounter = plt.scatter(coord_comet_encounter_AU[0],coord_comet_encounter_AU[2],marker='x',color='red')
    plt.xlabel('X (AU)')
    plt.ylabel('Z (AU)')
    plt.axis('equal')
    plt.xlim([-1.5, 1.5])
    plt.ylim([-1.5, 1.5])
    plt.tick_params(axis='both',labelsize=16)
    plt.title('Encounter Comet'+' '+name_comet+'    '+t_start_date,fontsize=15)
    plt.suptitle('(Ecliptic coordinate system)',fontsize=15)
    plt.legend([tail,comet,SO,Sun,comet_encounter],['Ion tail','Comet','Solar Orbiter','Sun', \
        'Comet at tail production time'])
    plt.savefig(name_comet+' Encounter SolO Ecl Z vs X, '+t_start_date+'.png')


def iontail_cometsystemxy(ID_comet,t_SO,t_comet,times,name_comet,OM,W,IN):


    v = [200,400,600,800,1000,1200] #km/s

    #production time of the ion tail
    t_start = t_SO
    t_start_date = spice.et2utc(t_start,'C',0)

    #final date: tone year before the time the comet passes the ion tail production position
    t_end = t_comet - 1*3.15e7
    hours = int((t_start-t_end)/3600) #hours between the start and end date.
    time = [t_start - x*3600 for x in range(hours)] #time array going backwards
```

```
time_date = spice.et2utc(time,'C',0)

#Comet's positions (Heliocentric Ecliptic Coordinate System)
coord_comet,lightTimes = spice.spkpos(ID_comet, time, 'ECLIPJ2000', 'NONE', 'SUN')
coord_comet = coord_comet.T
coord_comet_AU = coord_comet*6.68459e-9

#Solar Orbiter's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
coord_SO,lightTimes = spice.spkpos('Solo', t_start, 'ECLIPJ2000', 'NONE', 'SUN')

#get the position for the other spacecrafts (Heliocentric Ecliptic Coordinate System)
#coord_SO,lightTimes = spice.spkpos('SPP', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Parker Solar Probe
#coord_SO,lightTimes = spice.spkpos('JUICE', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #JUICE
#coord_SO,lightTimes = spice.spkpos('Earth', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Earth
#coord_SO,lightTimes = spice.spkpos('Mars', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Mars

coord_SO = coord_SO.T
coord_SO_AU = coord_SO*6.68459e-9

#Transformation to the Heliocentric Comet Orbital Coordinate System
(x_SO_c,y_SO_c,z_SO_c,x_comet_c,y_comet_c,z_comet_c) = coord_transf(OM,W,IN,name_comet,coord_SO_AU,coord_comet_AU)

#Comet's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
coord_comet_encounter,lightTimes = spice.spkpos(ID_comet, t_comet, 'ECLIPJ2000', 'NONE', 'SUN')
coord_comet_encounter = coord_comet_encounter.T
coord_comet_encounter_AU = coord_comet_encounter*6.68459e-9

#Transformation to the Heliocentric Comet Orbital Coordinate System
(x_SO_c_encounter,y_SO_c_encounter,z_SO_c_encounter,x_comet_c_encounter,y_comet_c_encounter,z_comet_c_encounter) = \
    coord_transf(OM,W,IN,name_comet,coord_SO_AU,coord_comet_encounter_AU)

plot5 = plt.figure(figsize=(11,8))
comet, = plt.plot(x_comet_c, y_comet_c, color='red')

for i in range(len(v)):
    x_iontail=np.zeros(len(time))
    y_iontail=np.zeros(len(time))
    z_iontail=np.zeros(len(time))

    for j in range(len(time)):
        pos_comet = [x_comet_c[j],y_comet_c[j],z_comet_c[j]]
        #Transformation from cartesians to spherical coordinates (for the comet)
        (distance_comet,colat_comet,longitude_comet) = spice.recsph(pos_comet)
        phi_comet = pi/2-colat_comet #latitude

        #Ion tail's positions for the time range
        x_iontail[j]=x_comet_c[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*cos(longitude_comet)
        y_iontail[j]=y_comet_c[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*sin(longitude_comet)
        z_iontail[j]=z_comet_c[j]+(v[i]*1000*j*3600/1.5e11)*sin(phi_comet)


    tail, = plt.plot(x_iontail, y_iontail, color='green')
    SO = plt.scatter(x_SO_c, y_SO_c, color='blue')
    Sun = plt.scatter(0,0,color='orange')
    comet_encounter = plt.scatter(x_comet_c_encounter,y_comet_c_encounter,marker='x',color='red')
    plt.xlabel('X (AU)')
    plt.ylabel('Y (AU)')
    plt.axis('equal')
```

```
    plt.xlim([-1.5, 1.5])
    plt.ylim([-1.5, 1.5])
    plt.tick_params(axis='both',labelsize=16)
    plt.title('Encounter Comet'+' '+name_comet+'    '+t_start_date,fontsize=15)
    plt.suptitle('(Heliocentric Comet Orbital coordinate system)',fontsize=15)
    plt.legend([tail,comet,SO,Sun,comet_encounter],['Ion tail','Comet','Solar Orbiter','Sun', \
        'Comet at tail production time'])
    plt.savefig(name_comet+' Encounter SoLO Com Y vs X, '+t_start_date+'.png')


def iontail_cometsystemxz(ID_comet,t_SO,t_comet,times,name_comet,OM,W,IN):


    v = [200,400,600,800,1000,1200] #km/s

    #production time of the ion tail
    t_start = t_SO
    t_start_date = spice.et2utc(t_start,'C',0)

    #final date: tone year before the time the comet passes the ion tail production position
    t_end = t_comet - 1*3.15e7
    hours = int((t_start-t_end)/3600) #hours between the start and end date.
    time = [t_start - x*3600 for x in range(hours)] #time array going backwards
    time_date = spice.et2utc(time,'C',0)

    #Comet's positions (Heliocentric Ecliptic Coordinate System)
    coord_comet,lightTimes = spice.spkpos(ID_comet, time, 'ECLIPJ2000', 'NONE', 'SUN')
    coord_comet = coord_comet.T
    coord_comet_AU = coord_comet*6.68459e-9

    #Solar Orbiter's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
    coord_SO,lightTimes = spice.spkpos('Solo', t_start, 'ECLIPJ2000', 'NONE', 'SUN')

    #get the positions for the other spacecrafts
    #coord_SO,lightTimes = spice.spkpos('SPP', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Parker Solar Probe
    #coord_SO,lightTimes = spice.spkpos('JUICE', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #JUICE
    #coord_SO,lightTimes = spice.spkpos('Earth', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Earth
    #coord_SO,lightTimes = spice.spkpos('Mars', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Mars

    coord_SO = coord_SO.T
    coord_SO_AU = coord_SO*6.68459e-9

    #Transformation to the Heliocentric Comet Orbital Coordinate System
    (x_SO_c,y_SO_c,z_SO_c,x_comet_c,y_comet_c,z_comet_c) = coord_transf(OM,W,IN,name_comet,coord_SO_AU,coord_comet_AU)

    #Comet's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
    coord_comet_encounter,lightTimes = spice.spkpos(ID_comet, t_comet, 'ECLIPJ2000', 'NONE', 'SUN')
    coord_comet_encounter = coord_comet_encounter.T
    coord_comet_encounter_AU = coord_comet_encounter*6.68459e-9

    #Transformation to the Heliocentric Comet Orbital Coordinate System
    (x_SO_c_encounter,y_SO_c_encounter,z_SO_c_encounter,x_comet_c_encounter,y_comet_c_encounter,z_comet_c_encounter) = \
        coord_transf(OM,W,IN,name_comet,coord_SO_AU,coord_comet_encounter_AU)

    plot6 = plt.figure(figsize=(11,8))
    comet, = plt.plot(x_comet_c, z_comet_c, color='red')

    for i in range(len(v)):
```

```
        x_iontail=np.zeros(len(time))
        y_iontail=np.zeros(len(time))
        z_iontail=np.zeros(len(time))

        for j in range(len(time)):
            pos_comet = [x_comet_c[j],y_comet_c[j],z_comet_c[j]]
            #Transformation from cartesians to spherical coordinates (for the comet)
            (distance_comet,colat_comet,longitude_comet) = spice.recsph(pos_comet)
            phi_comet = pi/2-colat_comet #latitude

            #Ion tail's positions for the time range
            x_iontail[j]=x_comet_c[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*cos(longitude_comet)
            y_iontail[j]=y_comet_c[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*sin(longitude_comet)
            z_iontail[j]=z_comet_c[j]+(v[i]*1000*j*3600/1.5e11)*sin(phi_comet)


        tail, = plt.plot(x_iontail, z_iontail, color='green')
        SO = plt.scatter(x_SO_c, z_SO_c, color='blue')
        Sun = plt.scatter(0,0,color='orange')
        comet_encounter = plt.scatter(x_comet_c_encounter,z_comet_c_encounter,marker='x',color='red')
        plt.xlabel('X (AU)')
        plt.ylabel('Z (AU)')
        plt.axis('equal')
        plt.xlim([-1.5, 1.5])
        plt.ylim([-1.5, 1.5])
        plt.tick_params(axis='both',labelsize=16)
        plt.title('Encounter Comet'+' '+name_comet+'    '+t_start_date,fontsize=15)
        plt.suptitle('(Heliocentric Comet Orbital coordinate system)',fontsize=15)
        plt.legend([tail,comet,SO,Sun,comet_encounter],['Ion tail','Comet','Solar Orbiter','Sun', \
            'Comet at tail production time'])
        plt.savefig(name_comet+' Encounter SolO Com Z vs X, '+t_start_date+'.png')


def iontail_cometsystemyz(ID_comet,t_SO,t_comet,times,name_comet,OM,W,IN):


    v = [200,400,600,800,1000,1200] #km/s

    #production time of the ion tail
    t_start = t_SO
    t_start_date = spice.et2utc(t_start,'C',0)

    #final date: tone year before the time the comet passes the ion tail production position
    t_end = t_comet - 1*3.15e7
    hours = int((t_start-t_end)/3600) #hours between the start and end date.
    time = [t_start - x*3600 for x in range(hours)] #time array going backwards
    time_date = spice.et2utc(time,'C',0)

    #Comet's positions (Heliocentric Ecliptic Coordinate System)
    coord_comet,lightTimes = spice.spkpos(ID_comet, time, 'ECLIPJ2000', 'NONE', 'SUN')
    coord_comet = coord_comet.T
    coord_comet_AU = coord_comet*6.68459e-9

    #Solar Orbiter's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
    coord_SO,lightTimes = spice.spkpos('Solo', t_start, 'ECLIPJ2000', 'NONE', 'SUN')

    #get the positions for the other spacecrafts
    #coord_SO,lightTimes = spice.spkpos('SPP', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Parker Solar Probe
```

```
#coord_SO,lightTimes = spice.spkpos('JUICE', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #JUICE
#coord_SO,lightTimes = spice.spkpos('Earth', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Earth
#coord_SO,lightTimes = spice.spkpos('Mars', t_start, 'ECLIPJ2000', 'NONE', 'SUN') #Mars

coord_SO = coord_SO.T
coord_SO_AU = coord_SO*6.68459e-9

#Transformation to the Heliocentric Comet Orbital Coordinate System
(x_SO_c,y_SO_c,z_SO_c,x_comet_c,y_comet_c,z_comet_c) = coord_transf(OM,W,IN,name_comet,coord_SO_AU,coord_comet_AU)

#Comet's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
coord_comet_encounter,lightTimes = spice.spkpos(ID_comet, t_comet, 'ECLIPJ2000', 'NONE', 'SUN')
coord_comet_encounter = coord_comet_encounter.T
coord_comet_encounter_AU = coord_comet_encounter*6.68459e-9

#Transformation to the Heliocentric Comet Orbital Coordinate System
(x_SO_c_encounter,y_SO_c_encounter,z_SO_c_encounter,x_comet_c_encounter,y_comet_c_encounter,z_comet_c_encounter) = \
     coord_transf(OM,W,IN,name_comet,coord_SO_AU,coord_comet_encounter_AU)

plot7 = plt.figure(figsize=(11,8))
comet, = plt.plot(y_comet_c, z_comet_c, color='red')

for i in range(len(v)):
    x_iontail=np.zeros(len(time))
    y_iontail=np.zeros(len(time))
    z_iontail=np.zeros(len(time))

    for j in range(len(time)):

        pos_comet = [x_comet_c[j],y_comet_c[j],z_comet_c[j]]
        #Transformation from cartesians to spherical coordinates (for the comet)
        (distance_comet,colat_comet,longitude_comet) = spice.recsph(pos_comet)
        phi_comet = pi/2-colat_comet #latitude

        #Ion tail's positions for the time range
        x_iontail[j]=x_comet_c[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*cos(longitude_comet)
        y_iontail[j]=y_comet_c[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*sin(longitude_comet)
        z_iontail[j]=z_comet_c[j]+(v[i]*1000*j*3600/1.5e11)*sin(phi_comet)


    tail, = plt.plot(y_iontail, z_iontail, color='green')
    SO = plt.scatter(y_SO_c, z_SO_c, color='blue')
    Sun = plt.scatter(0,0,color='orange')
    comet_encounter = plt.scatter(y_comet_c_encounter,z_comet_c_encounter,marker='x',color='red')
    plt.xlabel('Y (AU)')
    plt.ylabel('Z (AU)')
    plt.axis('equal')
    plt.xlim([-1.5, 1.5])
    plt.ylim([-1.5, 1.5])
    plt.tick_params(axis='both',labelsize=16)
    plt.title('Encounter Comet'+' '+name_comet+'    '+t_start_date,fontsize=15)
    plt.suptitle('(Heliocentric Comet Orbital coordinate system)',fontsize=15)
    plt.legend([tail,comet,SO,Sun,comet_encounter],['Ion tail','Comet','Solar Orbiter','Sun', \
        'Comet at tail production time'])
    plt.savefig(name_comet+' Encounter SolO Com Z vs Y, '+t_start_date+'.png')
```

```
def iontail_cometsystem3D(ID_comet,t_SO,t_comet,times,name_comet,OM,W,IN):


    v = [200,400,600,800,1000,1200] #km/s

    #production time of the ion tail
    t_start = t_SO
    t_start_date = spice.et2utc(t_start,'C',0)

    #final date: tone year before the time the comet passes the ion tail production position
    t_end = t_comet - 1*3.15e7
    hours = int((t_start-t_end)/3600) #hours between the start and end date.
    time = [t_start - x*3600 for x in range(hours)] #time array going backwards
    time_date = spice.et2utc(time,'C',0)

    #Comet's positions (Heliocentric Ecliptic Coordinate System)
    coord_comet,lightTimes = spice.spkpos(ID_comet, time, 'ECLIPJ2000', 'NONE', 'SUN')
    coord_comet = coord_comet.T
    coord_comet_AU = coord_comet*6.68459e-9

    #Solar Orbiter's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
    coord_SO,lightTimes = spice.spkpos('Solo', t_start, 'ECLIPJ2000', 'NONE', 'SUN')
    coord_SO = coord_SO.T
    coord_SO_AU = coord_SO*6.68459e-9

    #Transformation to the Heliocentric Comet Orbital Coordinate System
    (x_SO_c,y_SO_c,z_SO_c,x_comet_c,y_comet_c,z_comet_c) = coord_transf(OM,W,IN,name_comet,coord_SO_AU,coord_comet_AU)

    #Comet's position at the ion tail production time (Heliocentric Ecliptic Coordinate System)
    coord_comet_encounter,lightTimes = spice.spkpos(ID_comet, t_comet, 'ECLIPJ2000', 'NONE', 'SUN')
    coord_comet_encounter = coord_comet_encounter.T
    coord_comet_encounter_AU = coord_comet_encounter*6.68459e-9

    #Transformation to the Heliocentric Comet Orbital Coordinate System
    (x_SO_c_encounter,y_SO_c_encounter,z_SO_c_encounter,x_comet_c_encounter,y_comet_c_encounter,z_comet_c_encounter) = \
         coord_transf(OM,W,IN,name_comet,coord_SO_AU,coord_comet_encounter_AU)


    plot8 = plt.figure(figsize=(11,8))
    ax = plt.axes(projection='3d')
    comet, = ax.plot(x_comet_c, y_comet_c, z_comet_c,color='red')

    for i in range(len(v)):
        x_iontail=np.zeros(len(time))
        y_iontail=np.zeros(len(time))
        z_iontail=np.zeros(len(time))

        for j in range(len(time)):

            pos_comet = [x_comet_c[j],y_comet_c[j],z_comet_c[j]]
            #Transformation from cartesians to spherical coordinates (for the comet)
            (distance_comet,colat_comet,longitude_comet) = spice.recsph(pos_comet)
            phi_comet = pi/2-colat_comet #latitude

            #Ion tail's positions for the time range
            x_iontail[j]=x_comet_c[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*cos(longitude_comet)
            y_iontail[j]=y_comet_c[j]+(v[i]*1000*j*3600/1.5e11)*cos(phi_comet)*sin(longitude_comet)
            z_iontail[j]=z_comet_c[j]+(v[i]*1000*j*3600/1.5e11)*sin(phi_comet)
```

```
        tail, = ax.plot(x_iontail, y_iontail, z_iontail,color='green')
        SO = ax.scatter(x_SO_c, y_SO_c, z_SO_c,color='blue')
        Sun = ax.scatter3D(0,0,0, color='orange')
        comet_encounter = ax.scatter3D(x_comet_c_encounter,y_comet_c_encounter,marker='x',color='red')
        ax.set_xlabel('X (AU)')
        ax.set_ylabel('Y (AU)')
        ax.set_zlabel('Z (AU)')
        ax.set_xlim([-1.5, 1.25])
        ax.set_ylim([-1.5, 1.25])
        ax.set_zlim([-1.5, 1.25])
        plt.tick_params(axis='both',labelsize=14)
        plt.suptitle('(Heliocentric Comet Orbital coordinate system) Encounter Comet'+' '+name_comet+'    '+t_start_date, \
            fontsize=15)
        plt.legend([tail,comet,SO,Sun,comet_encounter],['Ion tail with different speeds','Comet','Solar Orbiter','Sun', \
            'Comet at tail production time'])
        plt.savefig(name_comet+' Encounter SolO Com 3D, '+t_start_date+'.png')
```

A.1.12 plot_comet_SolarOrbiter

```
def plot_comet_SolarOrbiter(name_comet,times,positions_SO_AU,positions_Comet_AU):

    #plot of Solar Orbiter, Comet and Sun (Ecliptic Coordinate System)
    plot9 = plt.figure(figsize=(11,8))
    ax = plt.axes(projection='3d')
    ax.plot(positions_SO_AU[0], positions_SO_AU[1], positions_SO_AU[2],'blue',label='SolO')
    ax.plot(positions_Comet_AU[0], positions_Comet_AU[1], positions_Comet_AU[2],'red',label='Comet')
    ax.scatter3D(0,0,0, color='orange',label='Sun')
    ax.set_xlabel('X (AU)')
    ax.set_ylabel('Y (AU)')
    ax.set_zlabel('Z (AU)')
    plt.tick_params(axis='both',labelsize=14)
    plt.title('Comet '+name_comet+' and Solar Orbiter trajectory',fontsize=15)
    plt.suptitle('(Ecliptic coordinate system)',fontsize=15)
    ax.legend(fontsize=15)

    plot10 = plt.figure(figsize=(11,8))
    plt.plot(positions_SO_AU[0], positions_SO_AU[1],'blue',label='Solar Orbiter')
    plt.plot(positions_Comet_AU[0], positions_Comet_AU[1],'red',label='Comet')
    plt.scatter(0,0,color='orange',label='Sun')
    plt.xlabel('X (AU)')
    plt.ylabel('Y (AU)')
    plt.tick_params(axis='both',labelsize=14)
    plt.title('Comet '+name_comet+' and Solar Orbiter trajectory',fontsize=15)
    plt.suptitle('(Ecliptic coordinate system)',fontsize=15)
    plt.legend(fontsize=15)

    plot11 = plt.figure(figsize=(11,8))
    plt.plot(positions_SO_AU[0], positions_SO_AU[2],'blue',label='Solar Orbiter')
    plt.plot(positions_Comet_AU[0], positions_Comet_AU[2],'red',label='Comet')
    plt.scatter(0,0,color='orange',label='Sun')
    plt.xlabel('X (AU)')
    plt.ylabel('Z (AU)')
    plt.tick_params(axis='both',labelsize=14)
```

```
plt.title('Comet '+name_comet+' and Solar Orbiter trajectory',fontsize=15)
plt.suptitle('(Ecliptic coordinate system)',fontsize=15)
plt.legend(fontsize=15)

plot12 = plt.figure(figsize=(11,8))
plt.plot(positions_SO_AU[1], positions_SO_AU[2],'blue',label='Solar Orbiter')
plt.plot(positions_Comet_AU[1], positions_Comet_AU[2],'red',label='Comet')
plt.scatter(0,0,color='orange',label='Sun')
plt.xlabel('Y (AU)')
plt.ylabel('Z (AU)')
plt.tick_params(axis='both',labelsize=14)
plt.title('Comet '+name_comet+' and Solar Orbiter trajectory',fontsize=15)
plt.suptitle('(Ecliptic coordinate system)',fontsize=15)
plt.legend(fontsize=15)

#spice.kclear()
```

A.2 Results

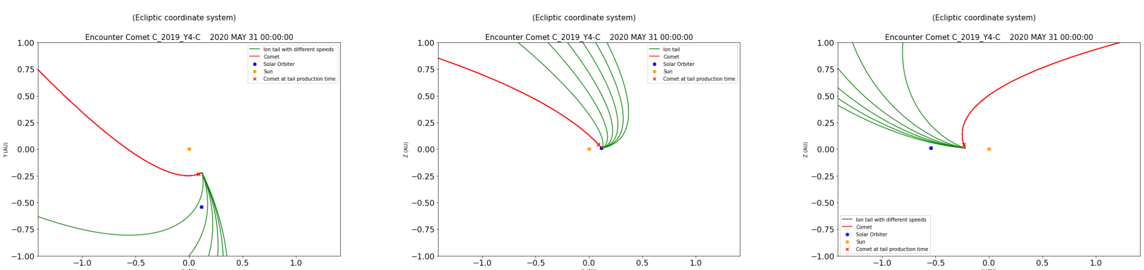
Here there are all the possible encounters we have found, with their corresponding tables with the most important values and their representations.

The representations are made in both the Heliocentric Ecliptic Coordinate System, and the Comet Orbital Coordinate System. The representations are made with a pair of components: Y vs X, Z vs X and Z vs Y. The red line is the comets trajectory, the red cross is the position of the comet when the particles the spacecraft is crossing were produced, then there is the Sun (yellow dot), the spacecraft (colored dot) and finally the green lines, which are the ion tail represented with different speeds its particles could have.

A.2.1 Solar Orbiter Encounters

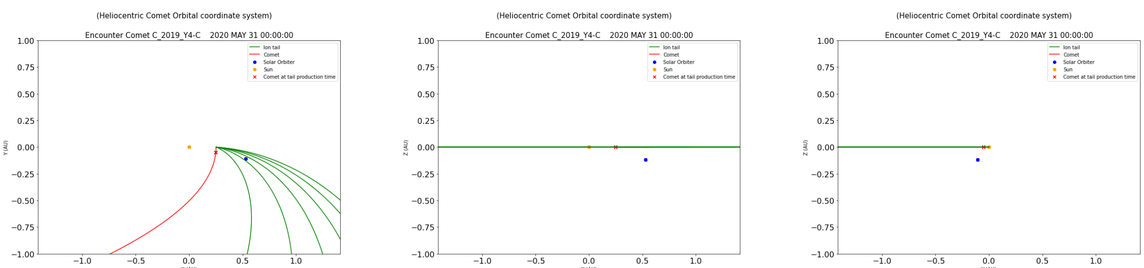
- Comet: **C_2019_Y4-C/ATLAS**

Date SO	Date Comet	t delay (days)	SW Speed (km/s)	d_{SO-C} (AU)	d_{SO-T} (AU)	Angle (deg)	d_{SO-S} (AU)	d_{C-S} (AU)
2020 MAY 31	2020 MAY 29 22:50	1.048	495	0.299	0.119	-23.548	0.554	0.255
2020 JUN 01	2020 MAY 30 03:16	1.863	275	0.295	0.102	-20.106	0.549	0.254
Crossing								
2020 JUN 06 12:36	2020 MAY 31 04:01		75.539					



(a) (b) (c)

Figure 22: Encounter with C_2019_Y4-C at 2021 OCT 21 in the Ecliptic Coordinate System.

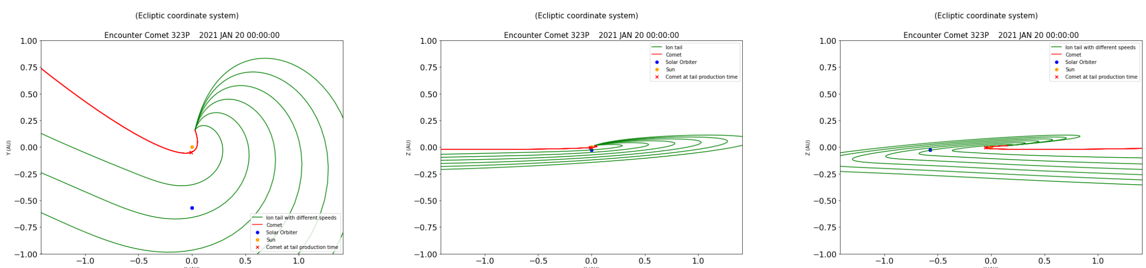


(a) (b) (c)

Figure 23: Encounter with C_2019_Y4-C at 2021 OCT 21 in the Comet Orbital Coordinate System.

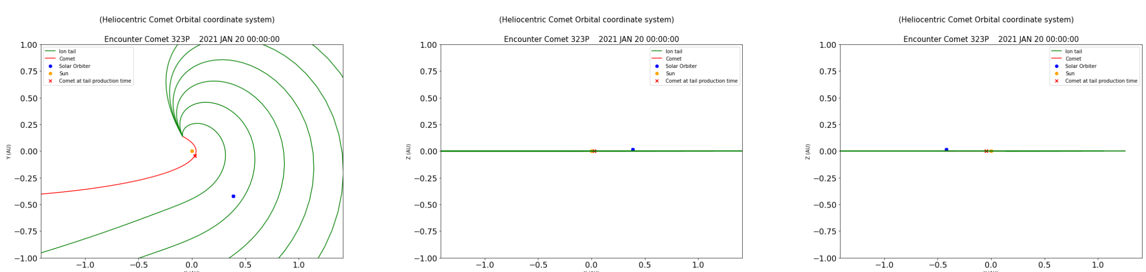
- Comet: **323P/SOHO**

Date SO	Date Comet	t delay (days)	SW Speed (km/s)	d_{SO-C} (AU)	d_{SO-T} (AU)	Angle (deg)	d_{SO-S} (AU)	d_{C-S} (AU)
2021 JAN 18	2021 JAN 17 04:38	0.807	1147	0.533	0.023	2.452	0.582	0.049
2021 JAN 19	2021 JAN 17 05:03	1.789	512	0.528	0.019	2.075	0.575	0.048
2021 JAN 20	2021 JAN 17 05:29	2.771	327	0.523	0.015	1.686	0.569	0.047
2021 JAN 21	2021 JAN 17 05:55	3.753	239	0.518	0.012	1.287	0.563	0.046
Crossing								
2021 JAN 24 01:44	2021 JAN 17 07:20		128.912					



(a) (b) (c)

Figure 24: Encounter with 323P at 2021 JAN 20 in the Ecliptic Coordinate System.

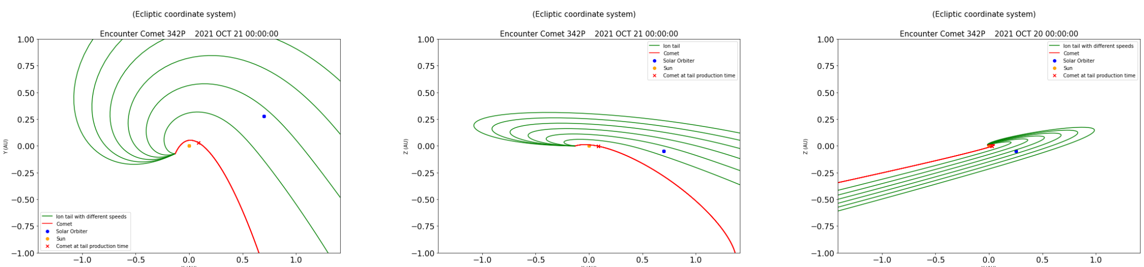


(a) (b) (c)

Figure 25: Encounter with 323P at 2021 JAN 20 in the Comet Orbital Coordinate System.

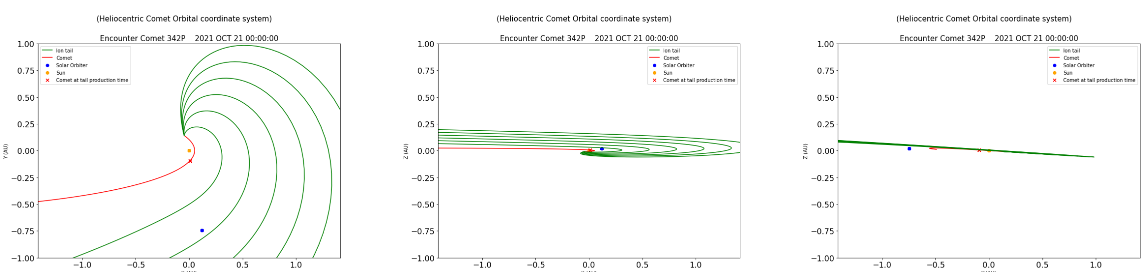
- Comet: **342P/SOHO**

Date SO	Date Comet	t delay (days)	SW Speed (km/s)	d_{SO-C} (AU)	d_{SO-T} (AU)	Angle (deg)	d_{SO-S} (AU)	d_{C-S} (AU)
2021 OCT 19	2021 OCT 17 14:26	1.398	800	0.645	0.024	2.167	0.740	0.095
2021 OCT 20	2021 OCT 17 15:39	2.347	483	0.653	0.022	1.889	0.746	0.093
2021 OCT 21	2021 OCT 17 16:51	3.297	349	0.662	0.019	1.619	0.753	0.091
2021 OCT 22	2021 OCT 17 18:02	4.248	274	0.671	0.016	1.354	0.760	0.089
2021 OCT 23	2021 OCT 17 19:11	5.200	227	0.679	0.013	1.095	0.766	0.087
Crossing								
2021 OCT 27 12:09	2021 OCT 18 00:03		130					



(a) (b) (c)

Figure 26: Encounter with 342P at 2021 OCT 21 in the Ecliptic Coordinate System.

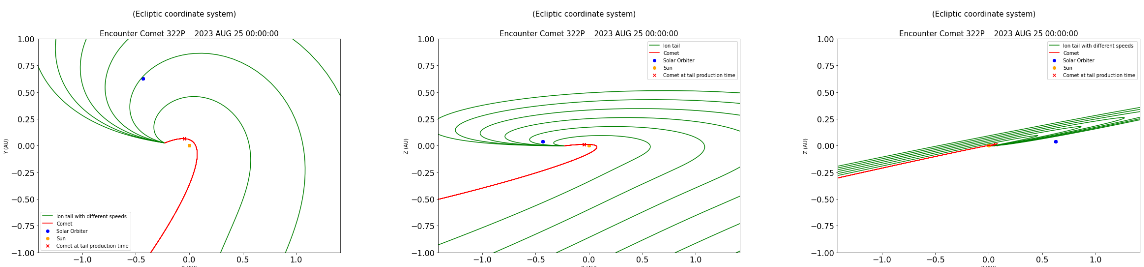


(a) (b) (c)

Figure 27: Encounter with 342P at 2021 OCT 21 in the Comet Orbital Coordinate System.

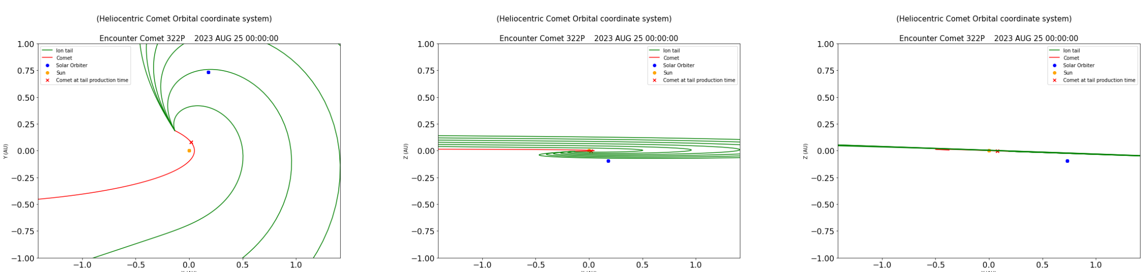
- Comet: **322P/SOHO**

Date SO	Date Comet	t delay (days)	SW Speed (km/s)	d_{SO-C} (AU)	d_{SO-T} (AU)	Angle (deg)	d_{SO-S} (AU)	d_{C-S} (AU)
2023 AUG 23	2023 AUG 21 22:53	1.046	1151	0.693	0.101	-8.392	0.777	0.084
2023 AUG 24	2023 AUG 21 23:11	2.033	584	0.684	0.099	-8.321	0.769	0.085
2023 AUG 25	2023 AUG 21 23:30	3.021	387	0.674	0.097	-8.245	0.760	0.086
2023 AUG 26	2023 AUG 21 23:49	4.008	288	0.664	0.094	-8.166	0.751	0.087
2023 AUG 27	2023 AUG 22 00:27	4.981	228	0.653	0.092	-8.082	0.742	0.089
Crossing								
2023 SEP 23 03:21	2023 AUG 26 19:23		6.224					



(a) (b) (c)

Figure 28: Encounter with 322P at 2023 AUG 25 in the Ecliptic Coordinate System.

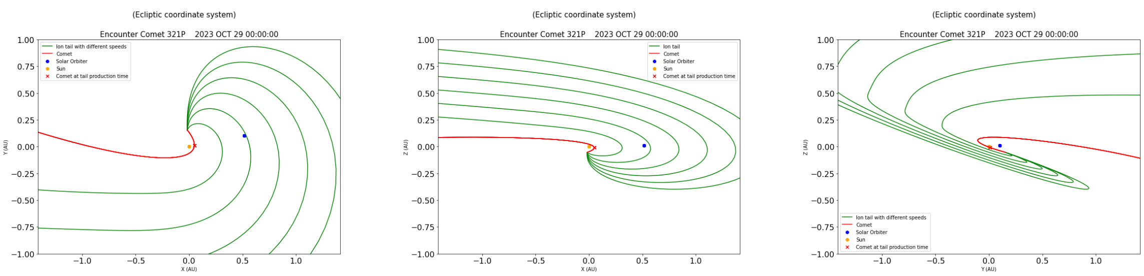


(a) (b) (c)

Figure 29: Encounter with 322P at 2023 AUG 25 in the Comet Orbital Coordinate System.

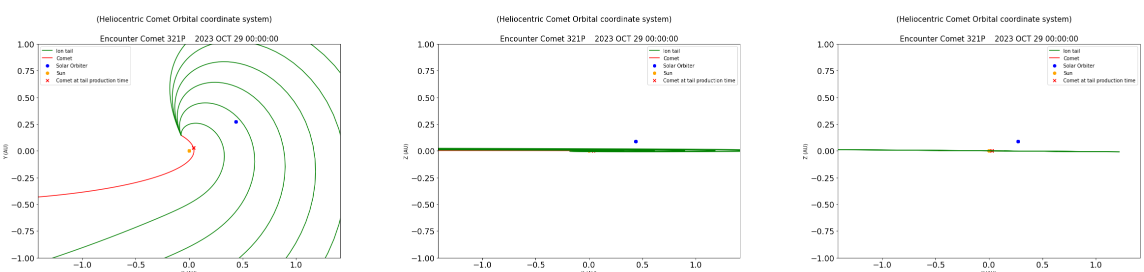
- Comet: **321P/SOHO**

Date SO	Date Comet	t delay (days)	SW Speed (km/s)	d_{SO-C} (AU)	d_{SO-T} (AU)	Angle (deg)	d_{SO-S} (AU)	d_{C-S} (AU)
2023 OCT 28	2023 OCT 26 19:11	1.200	666	0.461	0.077	9.593	0.511	0.050
2023 OCT 29	2023 OCT 26 19:40	2.180	377	0.473	0.087	10.598	0.524	0.051
2023 OCT 30	2023 OCT 26 20:07	3.161	267	0.486	0.097	11.536	0.537	0.051
2023 OCT 31	2023 OCT 26 20:33	4.143	209	0.498	0.107	12.413	0.550	0.052
Crossing								
2024 APR 17 16:30	2023 OCT 26 14:59		3.664					



(a) (b) (c)

Figure 30: Encounter with 321P at 2023 OCT 29 in the Ecliptic Coordinate System.

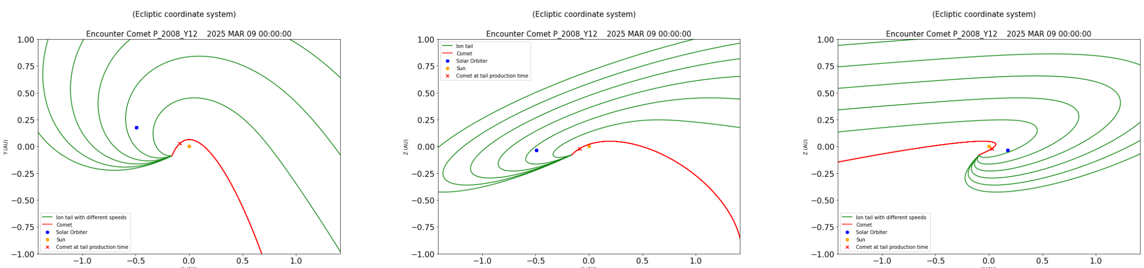


(a) (b) (c)

Figure 31: Encounter with 321P at 2023 OCT 29 in the Comet Orbital Coordinate System.

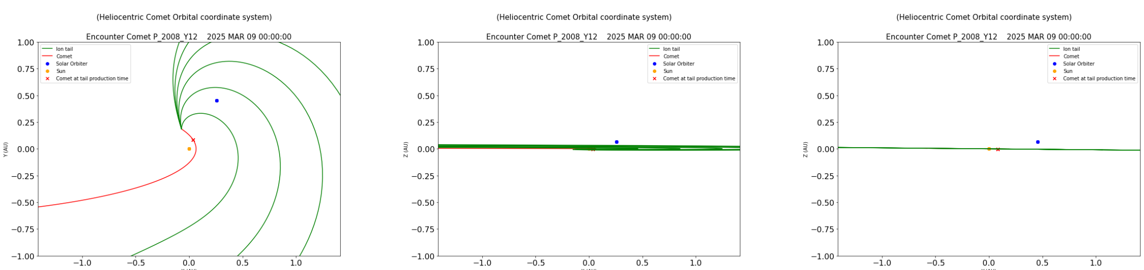
- Comet: **P_2008_Y12/SOHO**

Date SO	Date Comet	t delay (days)	SW Speed (km/s)	d_{SO-C} (AU)	d_{SO-T} (AU)	Angle (deg)	d_{SO-S} (AU)	d_{C-S} (AU)
2025 MAR 08	2025 MAR 06 14:40	1.389	566	0.453	0.063	7.961	0.538	0.085
2025 MAR 09	2025 MAR 06 15:46	2.343	325	0.438	0.065	8.471	0.526	0.087
2025 MAR 10	2025 MAR 06 16:56	3.294	223	0.424	0.066	9.008	0.513	0.090
Crossing								
2025 JUL 30 20:20	2025 MAR 05 22:18		8.300					



(a) (b) (c)

Figure 32: Encounter with P_2008_Y12 at 2025 MAR 09 in the Ecliptic Coordinate System.

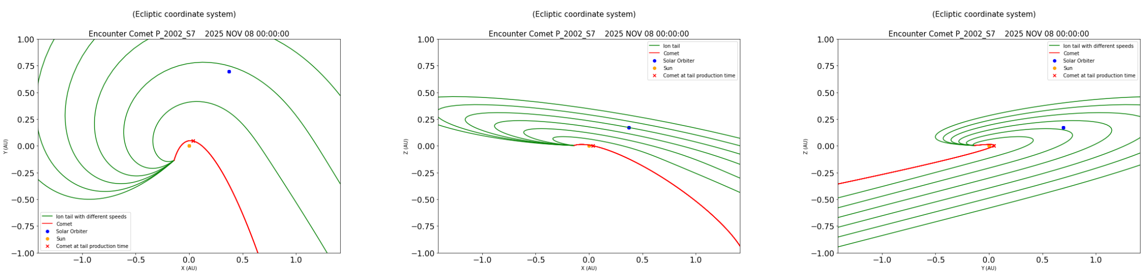


(a) (b) (c)

Figure 33: Encounter with P_2008_Y12 at 2025 MAR 09 in the Comet Orbital Coordinate System.

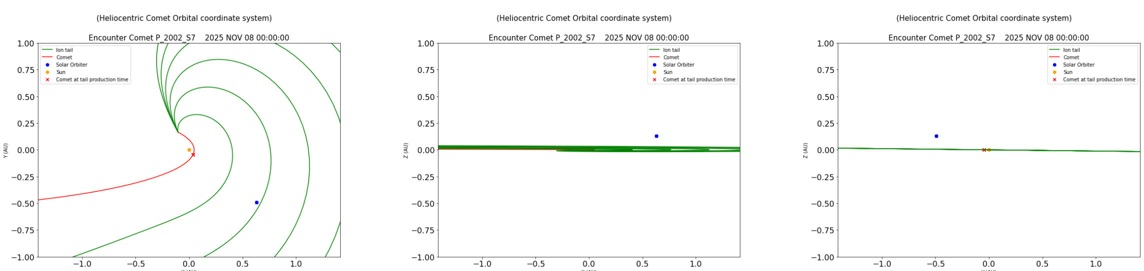
- Comet: **P_2002_S7/SOHO**

Date SO	Date Comet	t delay (days)	SW Speed (km/s)	d_{SO-C} (AU)	d_{SO-T} (AU)	Angle (deg)	d_{SO-S} (AU)	d_{C-S} (AU)
2025 NOV 06	2025 NOV 04 10:31	1.561	824	0.741	0.135	10.467	0.796	0.055
2025 NOV 07	2025 NOV 04 10:47	2.550	509	0.747	0.132	10.167	0.802	0.055
2025 NOV 08	2025 NOV 04 11:02	3.540	370	0.754	0.129	9.869	0.808	0.055
2025 NOV 09	2025 NOV 04 11:17	4.529	291	0.760	0.126	9.574	0.814	0.054
2025 NOV 10	2025 NOV 04 11:32	5.519	241	0.766	0.124	9.281	0.820	0.054
2025 NOV 11	2025 NOV 04 11:47	6.509	206	0.772	0.121	8.991	0.826	0.054
Crossing								
2025 DEC 14 10:03	2025 NOV 04 18:47		37.206					



(a) (b) (c)

Figure 34: Encounter with P_2002_S7 at 2025 NOV 08 in the Ecliptic Coordinate System.



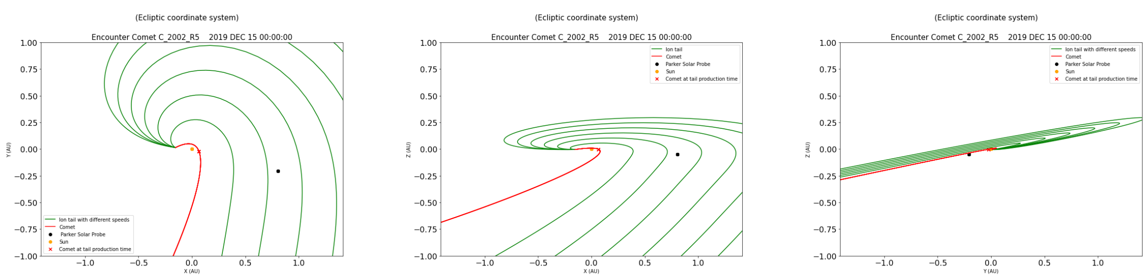
(a) (b) (c)

Figure 35: Encounter with P_2002_S7 at 2025 NOV 08 in the Comet Orbital Coordinate System.

A.2.2 Parker Solar Probe Encounters

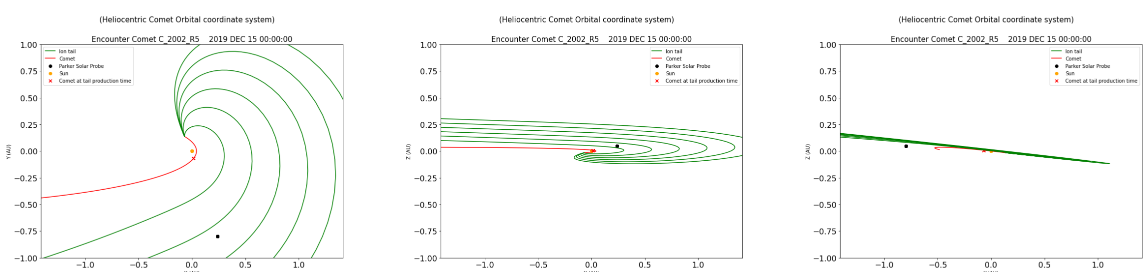
- Comet: **C_2002_R5/SOHO**

Date PSP	Date Comet	t delay (days)	SW Speed (km/s)	d_{PSP-C} (AU)	d_{PSP-T} (AU)	Angle (deg)	d_{PSP-S} (AU)	d_{C-S} (AU)
2019 DEC 14	2019 DEC 12 01:18	1.945	684	0.767	0.051	3.789	0.841	0.074
2019 DEC 15	2019 DEC 12 01:27	2.939	449	0.760	0.048	3.599	0.834	0.073
2019 DEC 16	2019 DEC 12 01:37	3.932	333	0.754	0.045	3.407	0.826	0.073
2019 DEC 17	2019 DEC 12 01:46	4.926	263	0.747	0.042	3.210	0.818	0.072
2019 DEC 18	2019 DEC 12 01:56	5.919	217	0.739	0.039	3.008	0.810	0.071
Crossing								
2019 DEC 31 02:38	2019 DEC 12 04:23		56.603					



(a) (b) (c)

Figure 36: Encounter with C_2002_R5 at 2019 DEC 15 in the Ecliptic Coordinate System.

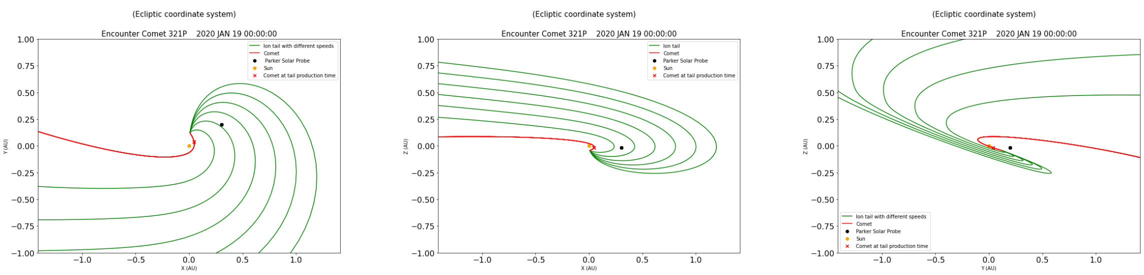


(a) (b) (c)

Figure 37: Encounter with C_2002_R5 at 2019 DEC 15 in the Comet Orbital Coordinate System.

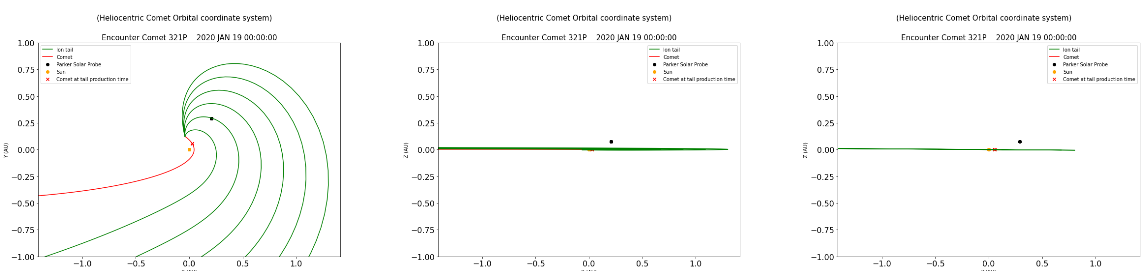
- Comet: **321P/SOHO**

Date PSP	Date Comet	t delay (days)	SW Speed (km/s)	d_{PSP-C} (AU)	d_{PSP-T} (AU)	Angle (deg)	d_{PSP-S} (AU)	d_{C-S} (AU)
2020 JAN 19	2020 JAN 17 18:59	1.208	438	0.305	0.078	14.713	0.364	0.059
2020 JAN 20	2020 JAN 17 19:49	2.174	223	0.280	0.078	16.267	0.341	0.061
Crossing								
2020 MAY 03 09:51	2020 JAN 17 10:46		11					



(a) (b) (c)

Figure 38: Encounter with 321P at 2020 JAN 19 in the Ecliptic Coordinate System.

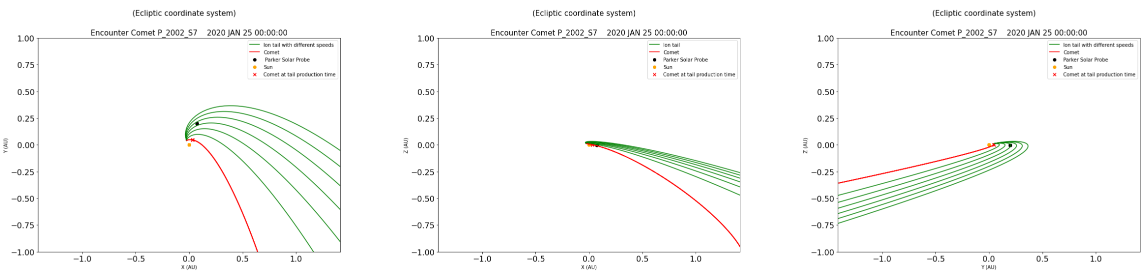


(a) (b) (c)

Figure 39: Encounter with 321P at 2020 JAN 19 in the Comet Orbital Coordinate System.

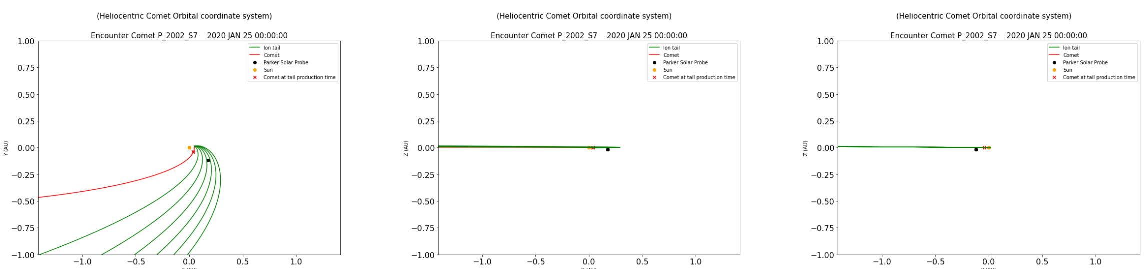
- Comet: **P_2002_S7/SOHO**

Date PSP	Date Comet	t delay (days)	SW Speed (km/s)	d_{PSP-C} (AU)	d_{PSP-T} (AU)	Angle (deg)	d_{PSP-S} (AU)	d_{C-S} (AU)
2020 JAN 25	2020 JAN 24 11:03	0.539	511	0.159	0.018	-6.425	0.212	0.053
Crossing								
2020 MAY 30 02:42	2020 JAN 24 04:30		3.381					



(a) (b) (c)

Figure 40: Encounter with P_2002_S7 at 2020 JAN 25 in the Ecliptic Coordinate System.

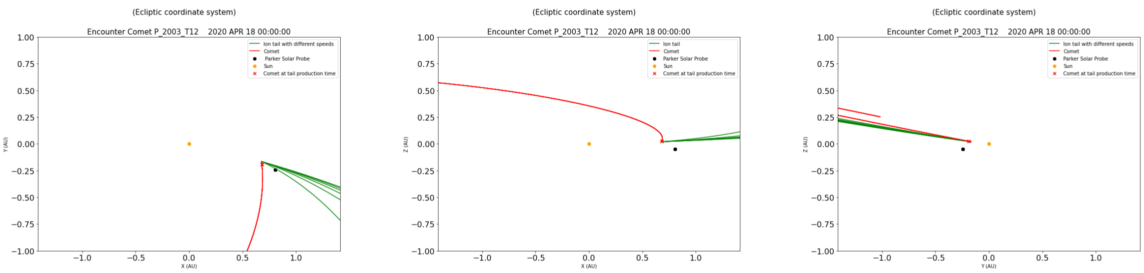


(a) (b) (c)

Figure 41: Encounter with P_2002_S7 at 2020 JAN 25 in the Comet Orbital Coordinate System.

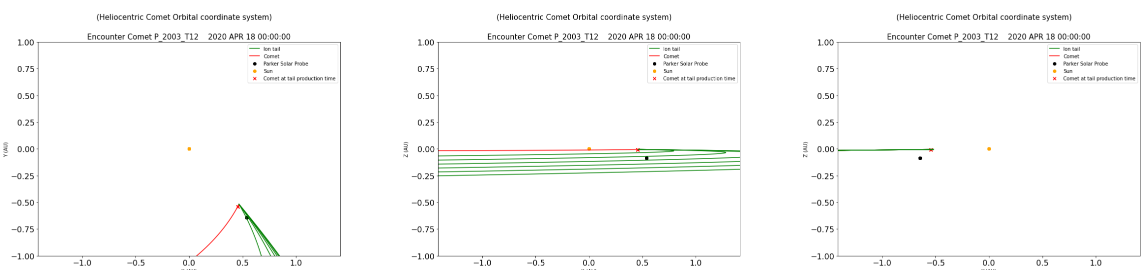
- Comet: **P_2003_T12/SOHO**

Date PSP	Date Comet	t delay (days)	SW Speed (km/s)	d_{PSP-C} (AU)	d_{PSP-T} (AU)	Angle (deg)	d_{PSP-S} (AU)	d_{C-S} (AU)
2020 APR 17	2020 APR 16 17:36	0.266	1069	0.164	0.089	-33.050	0.848	0.684
2020 APR 18	2020 APR 17 01:20	0.944	299	0.163	0.087	-32.344	0.844	0.681



(a) (b) (c)

Figure 42: Encounter with P_2003_T12 at 2020 APR 18 in the Ecliptic Coordinate System.

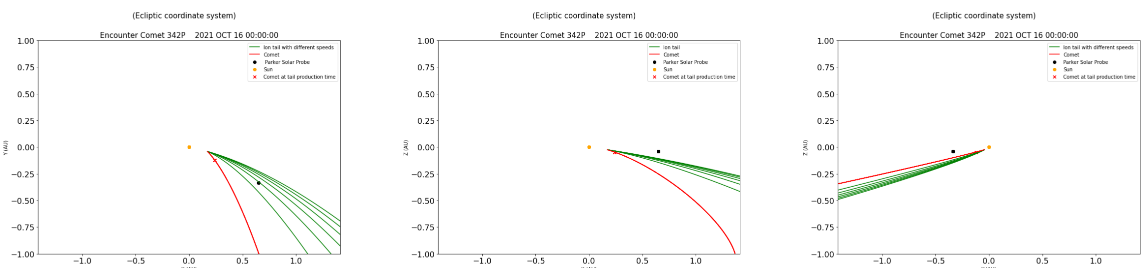


(a) (b) (c)

Figure 43: Encounter with P_2003_T12 at 2020 APR 18 in the Comet Orbital Coordinate System.

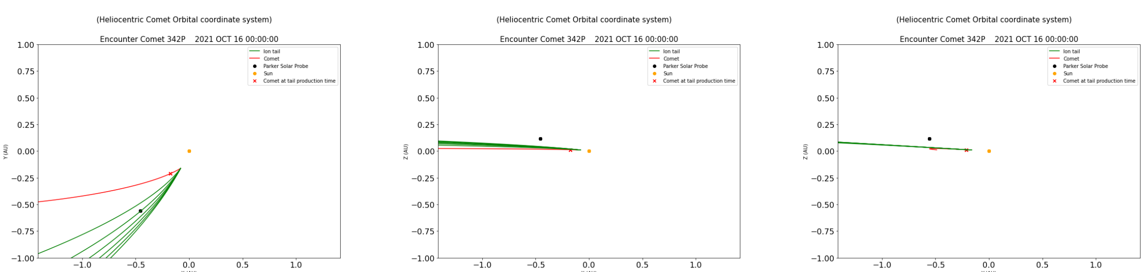
- Comet: **342P/SOHO**

Date PSP	Date Comet	t delay (days)	SW Speed (km/s)	d_{PSP-C} (AU)	d_{PSP-T} (AU)	Angle (deg)	d_{PSP-S} (AU)	d_{C-S} (AU)
2021 OCT 15	2021 OCT 13 17:13	1.282	613	0.452	0.119	15.261	0.737	0.284
2021 OCT 16	2021 OCT 13 21:29	2.104	374	0.453	0.117	15.013	0.731	0.278
2021 OCT 17	2021 OCT 14 01:10	2.951	267	0.453	0.116	14.782	0.724	0.271
2021 OCT 18	2021 OCT 14 04:08	3.828	205	0.453	0.114	14.561	0.718	0.265
Crossing								
2021 NOV 18 10:17	2021 OCT 18 00:57		4.966					



(a) (b) (c)

Figure 44: Encounter with 342P at 2021 OCT 16 in the Ecliptic Coordinate System.

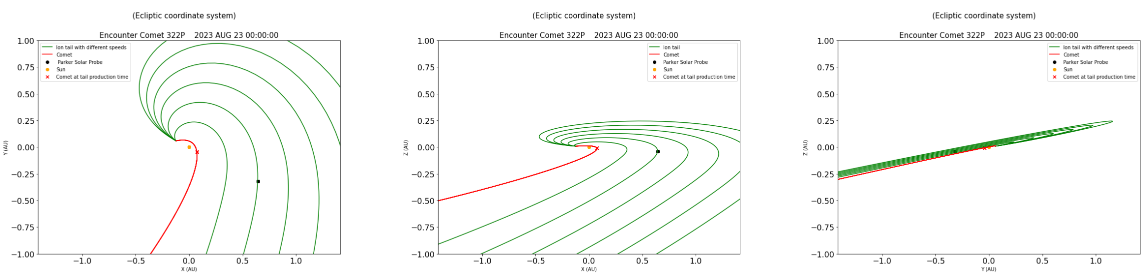


(a) (b) (c)

Figure 45: Encounter with 342P at 2021 OCT 16 in the Comet Orbital Coordinate System.

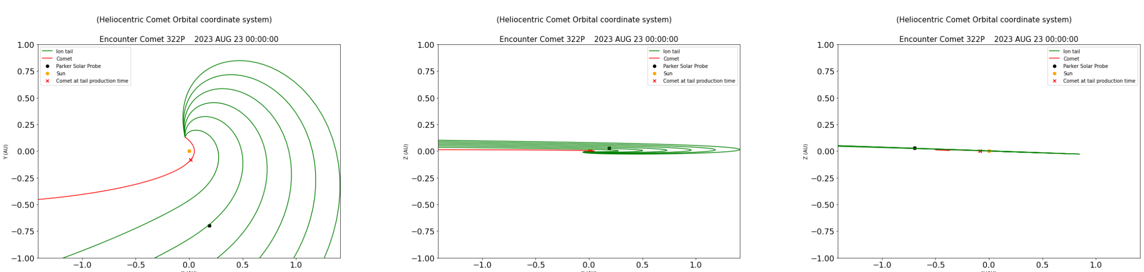
- Comet: **322P/SOHO**

Date PSP	Date Comet	t delay (days)	SW Speed (km/s)	d_{PSP-C} (AU)	d_{PSP-T} (AU)	Angle (deg)	d_{PSP-S} (AU)	d_{C-S} (AU)
2023 AUG 22	2023 AUG 20 03:04	1.872	594	0.640	0.029	2.626	0.726	0.085
2023 AUG 23	2023 AUG 20 03:15	2.864	386	0.637	0.028	2.485	0.721	0.085
2023 AUG 24	2023 AUG 20 03:26	3.856	285	0.632	0.026	2.342	0.716	0.084
2023 AUG 25	2023 AUG 20 03:38	4.848	225	0.627	0.024	2.197	0.711	0.083
Crossing								
2023 SEP 06 17:31	2023 AUG 20 06:31		52					



(a) (b) (c)

Figure 46: Encounter with 322P at 2023 AUG 23 in the Ecliptic Coordinate System.

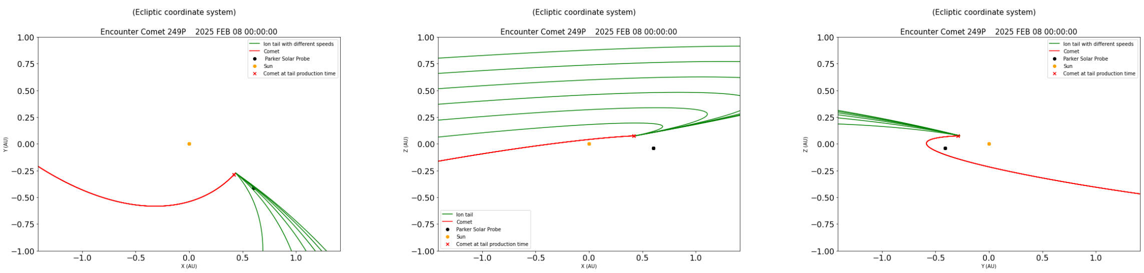


(a) (b) (c)

Figure 47: Encounter with 322P at 2023 AUG 23 in the Comet Orbital Coordinate System.

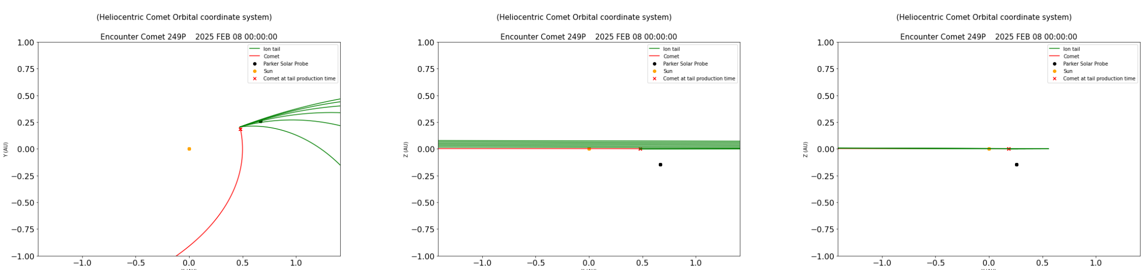
- Comet: **249P/SOHO**

Date PSP	Date Comet	t delay (days)	SW Speed (km/s)	d_{PSP-C} (AU)	d_{PSP-T} (AU)	Angle (deg)	d_{PSP-S} (AU)	d_{C-S} (AU)
2025 FEB 08	2025 FEB 07 08:34	0.642	572	0.212	0.146	-43.741	0.731	0.519
2025 FEB 09	2025 FEB 07 12:20	1.486	245	0.210	0.146	-44.208	0.730	0.520



(a) (b) (c)

Figure 48: Encounter with 249P at 2025 FEB 08 in the Ecliptic Coordinate System.

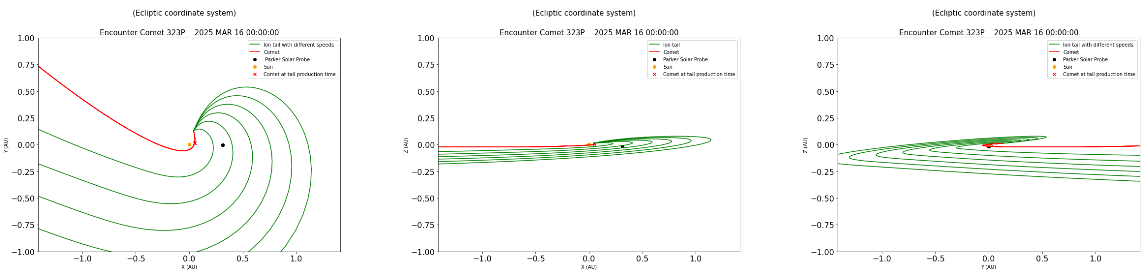


(a) (b) (c)

Figure 49: Encounter with 249P at 2025 FEB 08 in the Comet Orbital Coordinate System.

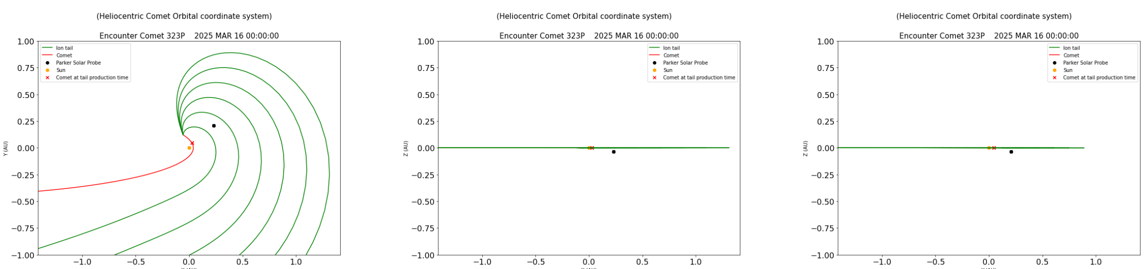
- Comet: **323P/SOHO**

Date PSP	Date Comet	t delay (days)	SW Speed (km/s)	d_{PSP-C} (AU)	d_{PSP-T} (AU)	Angle (deg)	d_{PSP-S} (AU)	d_{C-S} (AU)
2025 MAR 16	2025 MAR 14 14:48	1.383	338	0.269	0.035	-7.492	0.314	0.045
Crossing								
2025 APR 02 19:02	2025 MAR 14 02:35		33					



(a) (b) (c)

Figure 50: Encounter with 323P at 2025 MAR 16 in the Ecliptic Coordinate System.

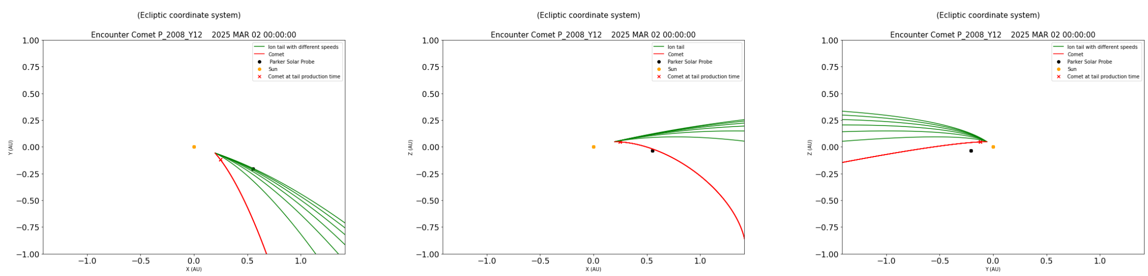


(a) (b) (c)

Figure 51: Encounter with 323P at 2025 MAR 16 in the Comet Orbital Coordinate System.

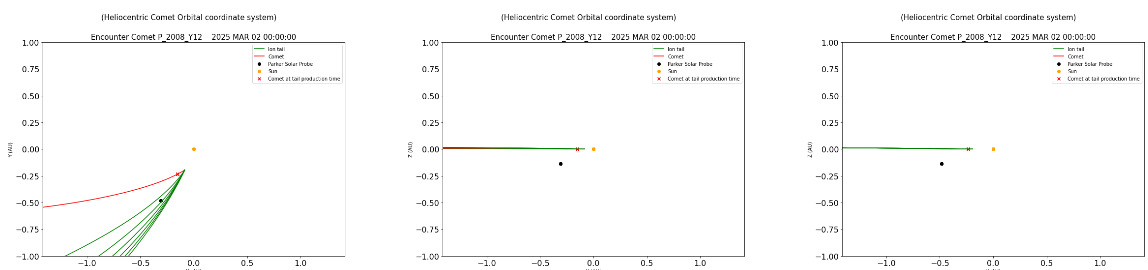
- Comet: **P_2008_Y12/SOHO**

Date PSP	Date Comet	t delay (days)	SW Speed (km/s)	d_{PSP-C} (AU)	d_{PSP-T} (AU)	Angle (deg)	d_{PSP-S} (AU)	d_{C-S} (AU)
2025 MAR 01	2025 FEB 28 04:59	0.792	704	0.321	0.138	-25.436	0.603	0.281
2025 MAR 02	2025 FEB 28 08:53	1.629	336	0.315	0.138	-25.981	0.590	0.275
2025 MAR 03	2025 FEB 28 12:59	2.459	218	0.309	0.138	-26.571	0.577	0.268



(a) (b) (c)

Figure 52: Encounter with P_2008_Y12 at 2025 MAR 02 in the Ecliptic Coordinate System.



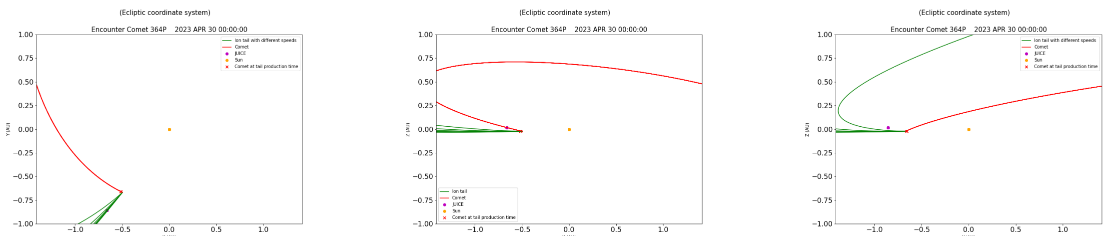
(a) (b) (c)

Figure 53: Encounter with P_2008_Y12 at 2025 MAR 02 in the Comet Orbital Coordinate System.

A.2.3 JUICE Encounters

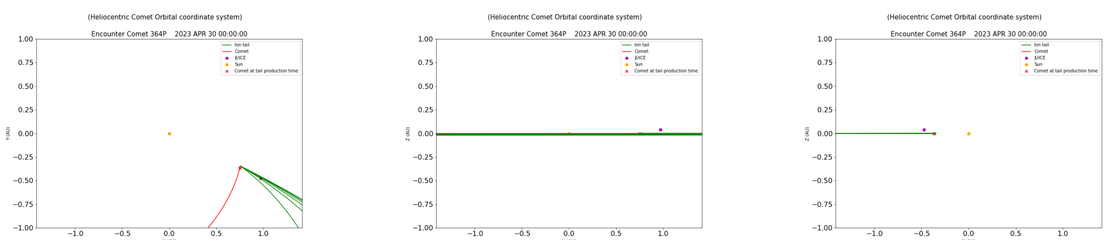
- Comet: **364P/PANSTARRS**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2023 APR 29	2023 APR 28 15:21	0.360	1181	0.245	0.036	8.508	1.081	0.836
2023 APR 30	2023 APR 29 03:19	0.862	500	0.248	0.040	9.197	1.082	0.834
2023 MAY 01	2023 APR 29 15:10	1.368	319	0.251	0.043	9.871	1.082	0.831
2023 MAY 02	2023 APR 30 02:58	1.876	235	0.254	0.046	10.533	1.083	0.829
Crossing								
2024 APR 18 19:37	2023 APR 25 06:18		1					



(a) (b) (c)

Figure 54: Encounter with 364P/PANSTARRS at 2023 APR 30 in the Ecliptic Coordinate System.

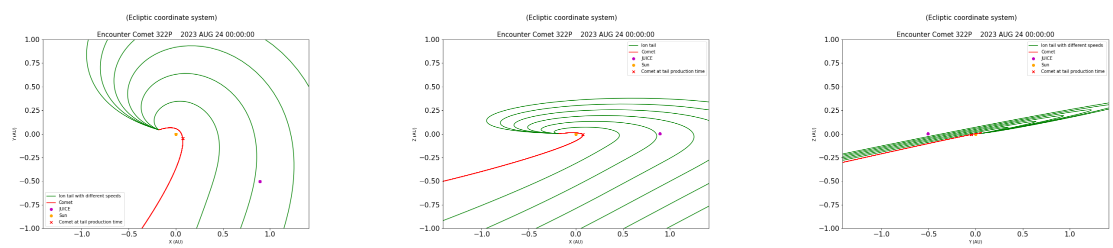


(a) (b) (c)

Figure 55: Encounter with 364P/PANSTARRS at 2023 APR 30 in the Comet Orbital Coordinate System.

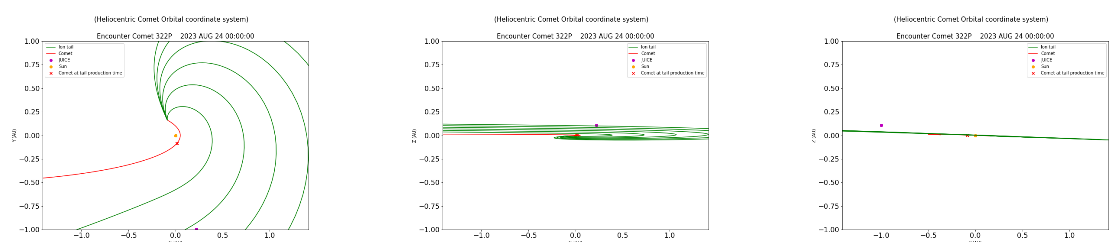
- Comet: **322P/SOHO**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2023 AUG 22	2023 AUG 20 01:51	1.923	848	0.939	0.118	7.195	1.029	0.090
2023 AUG 23	2023 AUG 20 02:08	2.910	560	0.938	0.114	6.980	1.027	0.089
2023 AUG 24	2023 AUG 20 02:26	3.898	418	0.938	0.110	6.764	1.026	0.088
2023 AUG 25	2023 AUG 20 02:44	4.886	333	0.937	0.107	6.545	1.024	0.086
2023 AUG 26	2023 AUG 20 03:02	5.874	277	0.937	0.103	6.325	1.022	0.085
2023 AUG 27	2023 AUG 20 03:19	6.861	237	0.936	0.100	6.103	1.021	0.084
2023 AUG 28	2023 AUG 20 03:37	7.849	207	0.936	0.096	5.880	1.019	0.083
2023 SEP 22 05:47	2023 AUG 20 11:31		48					



(a) (b) (c)

Figure 56: Encounter with 322P/SOHO at 2023 AUG 24 in the Ecliptic Coordinate System.

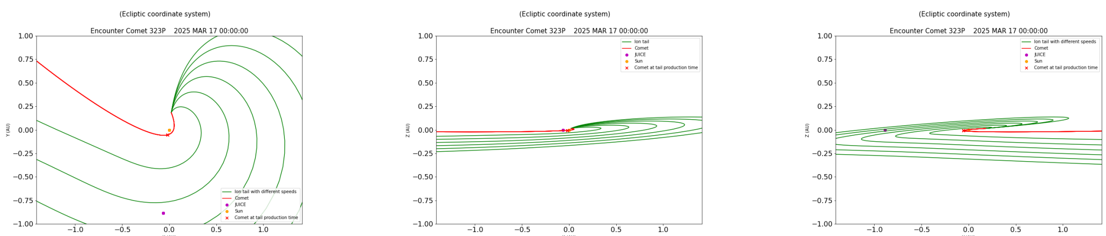


(a) (b) (c)

Figure 57: Encounter with 322P/SOHO at 2023 AUG 24 in the Comet Orbital Coordinate System.

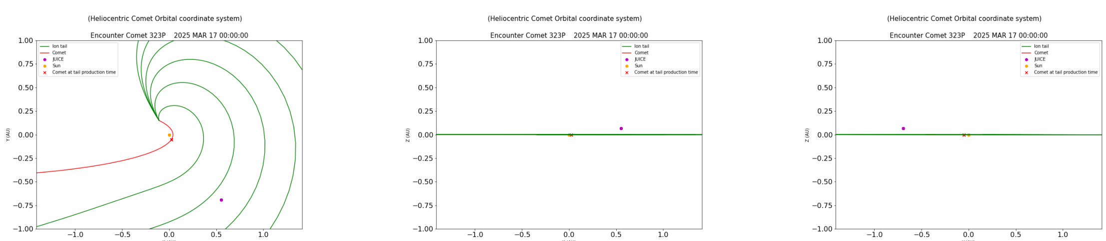
- Comet: **323P/SOHO**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2025 MAR 15	2025 MAR 13 16:18	1.320	1093	0.831	0.069	4.762	0.880	0.049
2025 MAR 16	2025 MAR 13 16:41	2.304	630	0.836	0.069	4.704	0.884	0.049
2025 MAR 17	2025 MAR 13 17:04	3.288	443	0.840	0.068	4.645	0.888	0.048
2025 MAR 18	2025 MAR 13 17:27	4.273	343	0.844	0.067	4.586	0.892	0.048
2025 MAR 19	2025 MAR 13 17:50	5.257	280	0.848	0.067	4.525	0.895	0.047
2025 MAR 20	2025 MAR 13 18:12	6.241	237	0.852	0.066	4.463	0.899	0.047
2025 MAR 21	2025 MAR 13 18:34	7.226	206	0.856	0.066	4.400	0.902	0.047
Crossing								
2025 MAY 18 05:59	2025 MAR 14 07:39		26					



(a) (b) (c)

Figure 58: Encounter with 323P/SOHO at 2025 MAR 17 in the Ecliptic Coordinate System.

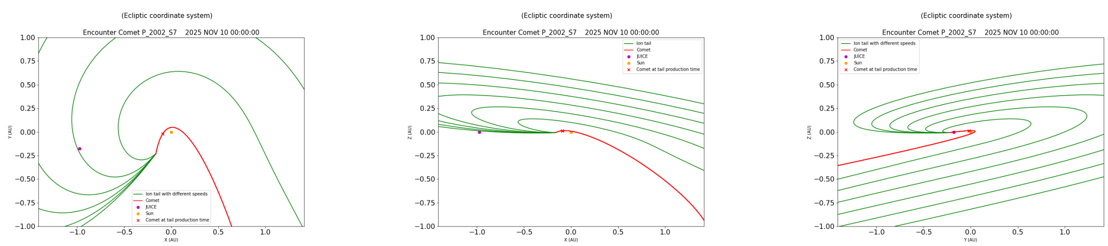


(a) (b) (c)

Figure 59: Encounter with 323P/SOHO at 2025 MAR 17 in the Comet Orbital Coordinate System.

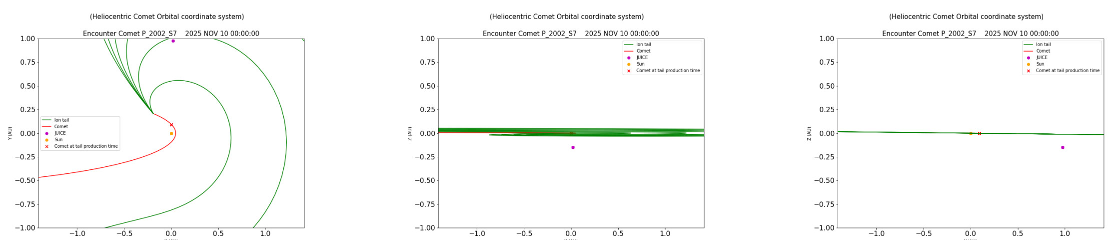
- Comet: **P_2002_S7/**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2025 NOV 10	2025 NOV 06 00:06	3.996	388	0.894	0.149	-9.599	0.989	0.095
2025 NOV 11	2025 NOV 06 01:09	4.952	315	0.899	0.147	-9.411	0.996	0.096
2025 NOV 12	2025 NOV 06 02:11	5.909	266	0.904	0.145	-9.223	1.002	0.098
2025 NOV 13	2025 NOV 06 03:12	6.866	230	0.909	0.143	-9.035	1.009	0.100
2025 NOV 14	2025 NOV 06 04:13	7.824	203	0.914	0.141	-8.846	1.015	0.101
Crossing								
2026 JAN 03 12:00	2025 NOV 09 00:54		33					



(a) (b) (c)

Figure 60: Encounter with P_2002_S7/ at 2025 NOV 10 in the Ecliptic Coordinate System.

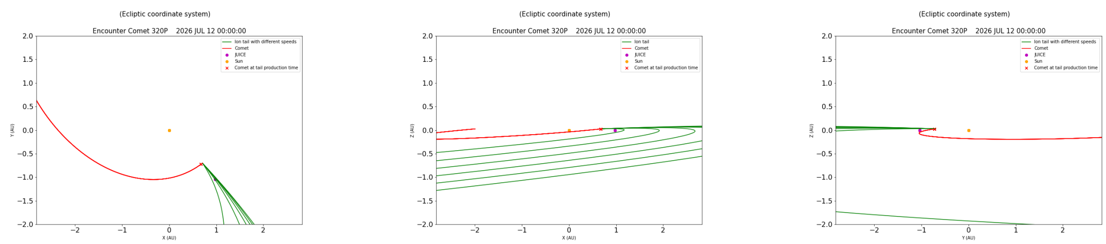


(a) (b) (c)

Figure 61: Encounter with P_2002_S7/ at 2025 NOV 10 in the Comet Orbital Coordinate System.

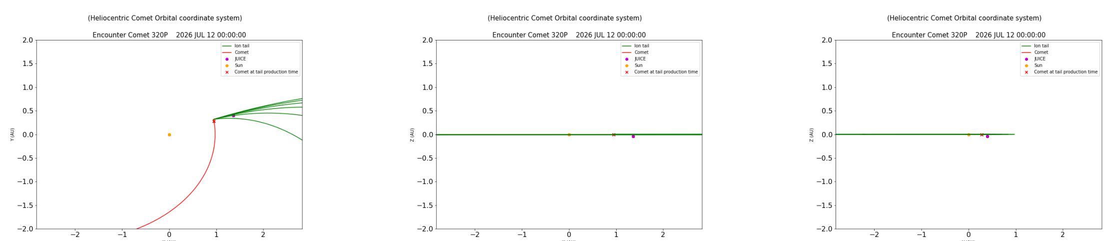
- Comet: **320P/McNaught**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2026 JUL 11	2026 JUL 09 20:00	1.166	634	0.426	0.038	-5.171	1.427	1.001
2026 JUL 12	2026 JUL 10 04:56	1.794	408	0.421	0.039	-5.344	1.423	1.002
2026 JUL 13	2026 JUL 10 13:56	2.419	299	0.417	0.040	-5.522	1.419	1.003
2026 JUL 14	2026 JUL 10 22:59	3.042	235	0.412	0.041	-5.705	1.416	1.004
Crossing								
2028 JUL 08 10:57	2026 JUN 27 07:00		2					



(a) (b) (c)

Figure 62: Encounter with 320P/McNaught at 2026 JUL 12 in the Ecliptic Coordinate System.

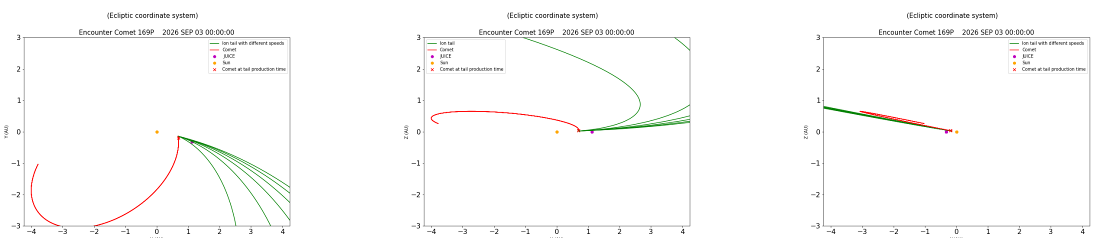


(a) (b) (c)

Figure 63: Encounter with 320P/McNaught at 2026 JUL 12 in the Comet Orbital Coordinate System.

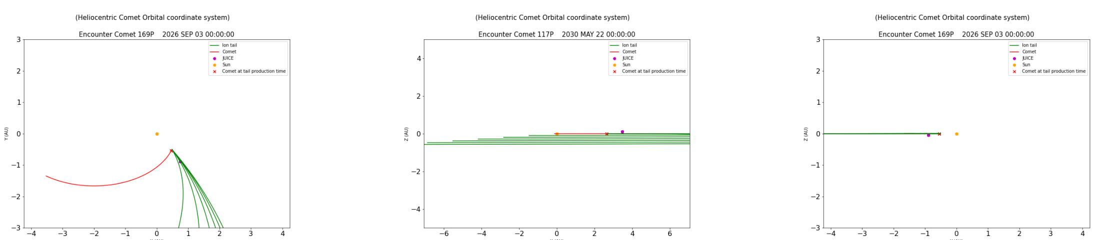
- Comet: **169P/NEAT**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2026 SEP 02	2026 AUG 31 19:11	1.200	646	0.447	0.054	-6.894	1.170	0.723
2026 SEP 03	2026 SEP 01 03:44	1.844	418	0.444	0.051	-6.531	1.164	0.720
2026 SEP 04	2026 SEP 01 12:14	2.490	308	0.442	0.047	-6.163	1.158	0.716
2026 SEP 05	2026 SEP 01 20:49	3.133	243	0.439	0.044	-5.791	1.152	0.713
2026 SEP 06	2026 SEP 02 05:20	3.777	201	0.437	0.041	-5.415	1.146	0.709
Crossing								
2026 SEP 19 00:40	2026 SEP 06 21:59		57					



(a) (b) (c)

Figure 64: Encounter with 169P/NEAT at 2026 SEP 03 in the Ecliptic Coordinate System.

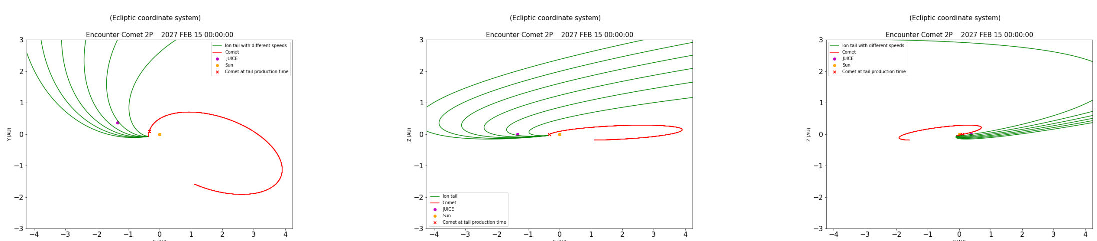


(a) (b) (c)

Figure 65: Encounter with 169P/NEAT at 2026 SEP 03 in the Comet Orbital Coordinate System.

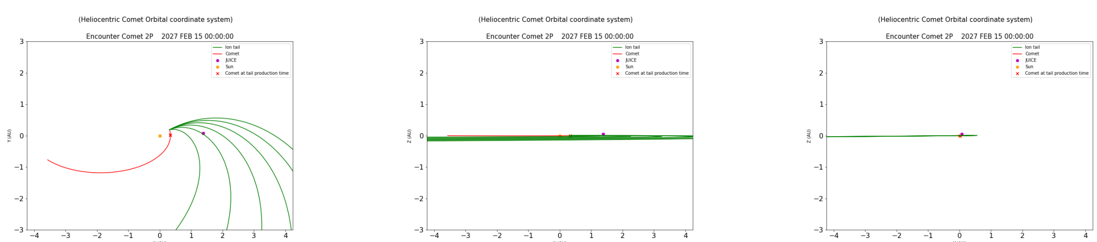
- Comet: **2P/Encke**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2027 FEB 12	2027 FEB 10 09:39	1.598	1121	1.032	0.039	2.190	1.368	0.336
2027 FEB 13	2027 FEB 10 11:41	2.513	718	1.039	0.042	2.343	1.375	0.336
2027 FEB 14	2027 FEB 10 13:42	3.429	530	1.046	0.046	2.494	1.382	0.336
2027 FEB 15	2027 FEB 10 15:41	4.346	421	1.053	0.049	2.644	1.389	0.336
2027 FEB 16	2027 FEB 10 17:40	5.264	350	1.060	0.052	2.790	1.397	0.336
2027 FEB 17	2027 FEB 10 19:37	6.182	300	1.067	0.055	2.935	1.404	0.336
2027 FEB 18	2027 FEB 10 21:33	7.102	263	1.075	0.058	3.078	1.411	0.336
2027 FEB 19	2027 FEB 10 23:27	8.022	234	1.082	0.061	3.218	1.418	0.337
2027 FEB 20	2027 FEB 11 01:22	8.943	211	1.089	0.064	3.357	1.425	0.337
Crossing								
2027 JAN 30 04:48	2023 OCT 21 12:40		1					



(a) (b) (c)

Figure 66: Encounter with 2P/Encke at 2027 FEB 15 in the Ecliptic Coordinate System.

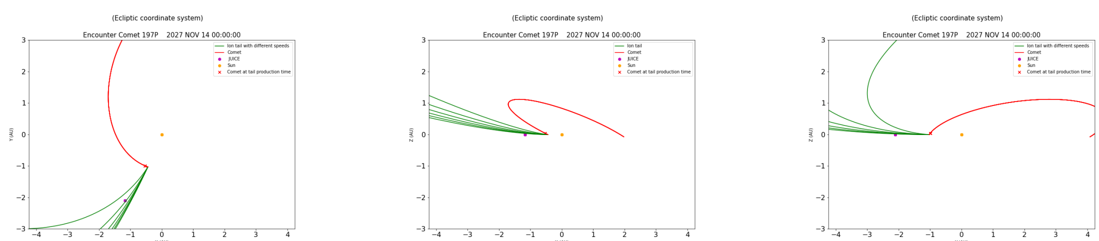


(a) (b) (c)

Figure 67: Encounter with 2P/Encke at 2027 FEB 15 in the Comet Orbital Coordinate System.

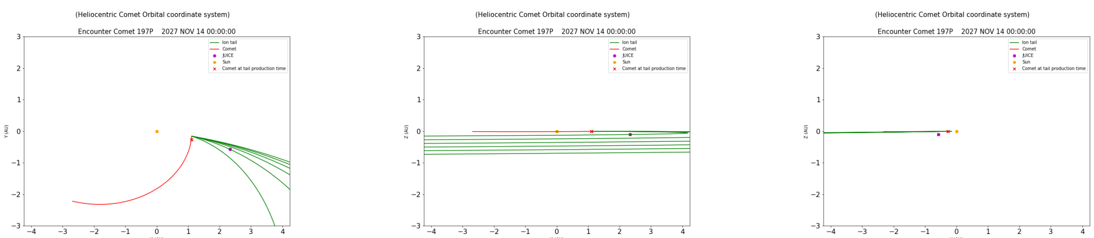
- Comet: **197P/LINEAR**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2027 NOV 10	2027 NOV 07 22:07	2.078	1114	1.334	0.115	-4.944	2.408	1.074
2027 NOV 11	2027 NOV 08 02:08	2.911	796	1.334	0.112	-4.794	2.408	1.074
2027 NOV 12	2027 NOV 08 06:09	3.744	619	1.335	0.108	-4.645	2.409	1.074
2027 NOV 13	2027 NOV 08 10:09	4.577	507	1.335	0.105	-4.495	2.409	1.073
2027 NOV 14	2027 NOV 08 14:09	5.410	429	1.336	0.101	-4.346	2.409	1.073
2027 NOV 15	2027 NOV 08 18:09	6.243	372	1.337	0.098	-4.197	2.409	1.073
2027 NOV 16	2027 NOV 08 22:09	7.076	328	1.337	0.094	-4.048	2.410	1.073
2027 NOV 17	2027 NOV 09 02:09	7.910	294	1.338	0.091	-3.899	2.410	1.072
2027 NOV 18	2027 NOV 09 06:08	8.744	266	1.338	0.088	-3.750	2.410	1.072
2027 NOV 19	2027 NOV 09 10:07	9.578	243	1.339	0.084	-3.602	2.410	1.072
2027 NOV 20	2027 NOV 09 14:06	10.412	223	1.339	0.081	-3.453	2.410	1.071
2027 NOV 21	2027 NOV 09 18:05	11.246	207	1.339	0.077	-3.305	2.410	1.071
Crossing								
2027 DEC 13 09:04	2027 NOV 13 10:38		78					



(a) (b) (c)

Figure 68: Encounter with 197P/LINEAR at 2027 NOV 14 in the Ecliptic Coordinate System.

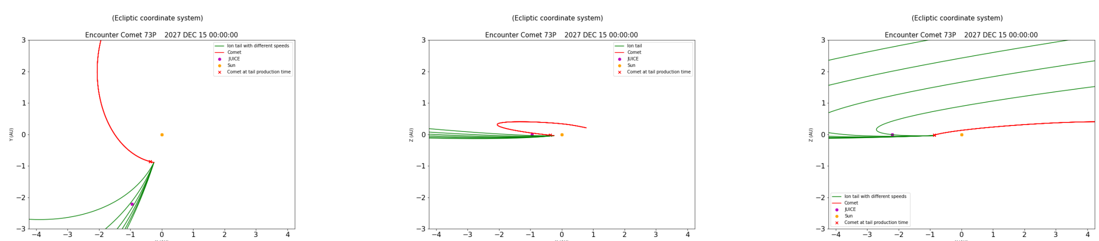


(a) (b) (c)

Figure 69: Encounter with 197P/LINEAR at 2027 NOV 14 in the Comet Orbital Coordinate System.

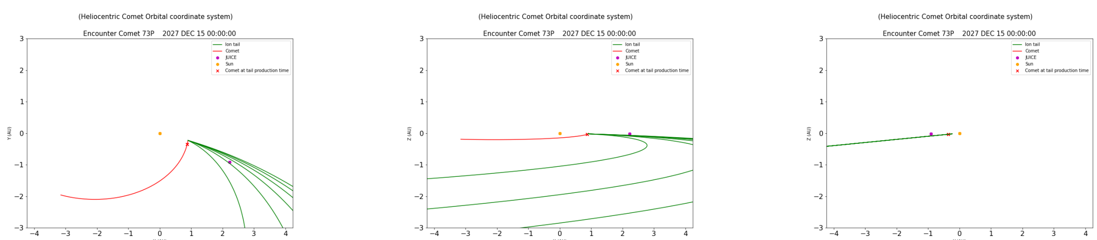
- Comet: **73P/Schwassmann-Wachmann 3-BT**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2027 DEC 11	2027 DEC 08 19:30	2.187	1113	1.403	0.030	-1.239	2.408	1.005
2027 DEC 12	2027 DEC 08 22:46	3.051	798	1.403	0.029	-1.175	2.407	1.004
2027 DEC 13	2027 DEC 09 02:02	3.915	622	1.403	0.027	-1.111	2.407	1.004
2027 DEC 14	2027 DEC 09 05:17	4.780	510	1.403	0.026	-1.047	2.406	1.003
2027 DEC 15	2027 DEC 09 08:32	5.644	432	1.403	0.024	-0.983	2.406	1.003
2027 DEC 16	2027 DEC 09 11:47	6.509	374	1.403	0.023	-0.919	2.405	1.002
2027 DEC 17	2027 DEC 09 15:02	7.373	330	1.403	0.021	-0.856	2.405	1.002
2027 DEC 18	2027 DEC 09 18:18	8.237	296	1.403	0.019	-0.792	2.404	1.001
2027 DEC 19	2027 DEC 09 21:33	9.102	268	1.403	0.018	-0.728	2.404	1.001
2027 DEC 20	2027 DEC 10 00:48	9.966	244	1.403	0.016	-0.664	2.403	1.000
2027 DEC 21	2027 DEC 10 04:03	10.831	225	1.403	0.015	-0.600	2.403	1.000
2027 DEC 22	2027 DEC 10 07:17	11.696	208	1.403	0.013	-0.536	2.402	0.999
Crossing								
2027 DEC 30 08:44	2027 DEC 11 10:24		128					



(a) (b) (c)

Figure 70: Encounter with 73P/Schwassmann-Wachmann 3-BT at 2027 DEC 15 in the Ecliptic Coordinate System.

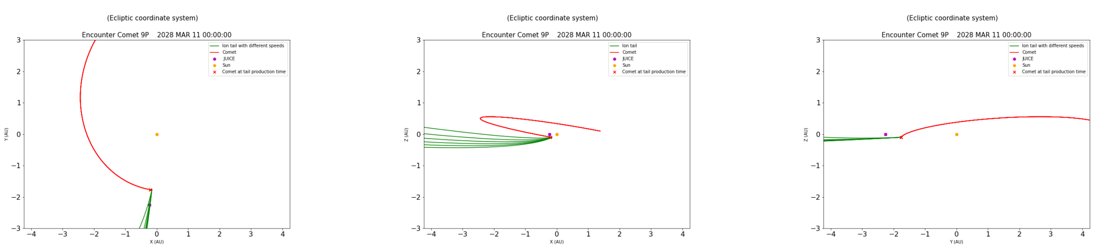


(a) (b) (c)

Figure 71: Encounter with 73P/Schwassmann-Wachmann 3-BT at 2027 DEC 15 in the Comet Orbital Coordinate System.

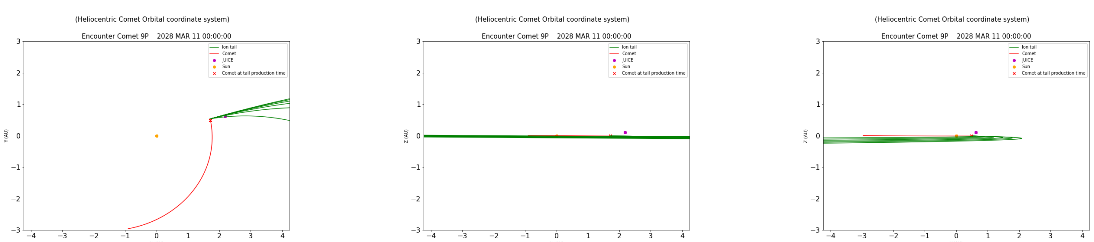
- Comet: **9P/Tempel 1**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2028 MAR 08	2028 MAR 06 18:21	1.235	1008	0.717	0.105	8.426	2.278	1.561
2028 MAR 09	2028 MAR 07 04:27	1.814	683	0.714	0.106	8.574	2.275	1.562
2028 MAR 10	2028 MAR 07 14:36	2.392	516	0.711	0.108	8.724	2.273	1.562
2028 MAR 11	2028 MAR 08 00:45	2.968	414	0.708	0.109	8.875	2.270	1.563
2028 MAR 12	2028 MAR 08 10:57	3.543	345	0.704	0.111	9.028	2.268	1.563
2028 MAR 13	2028 MAR 08 21:10	4.117	296	0.701	0.112	9.182	2.265	1.564
2028 MAR 14	2028 MAR 09 07:26	4.690	258	0.698	0.113	9.339	2.262	1.564
2028 MAR 15	2028 MAR 09 17:43	5.262	229	0.695	0.115	9.497	2.259	1.565
2028 MAR 16	2028 MAR 10 04:02	5.832	206	0.691	0.116	9.656	2.257	1.565
Crossing								
2030 JUN 09 07:17	2028 FEB 02 05:42		6					



(a) (b) (c)

Figure 72: Encounter with 9P/Tempel 1 at 2028 MAR 11 in the Ecliptic Coordinate System.

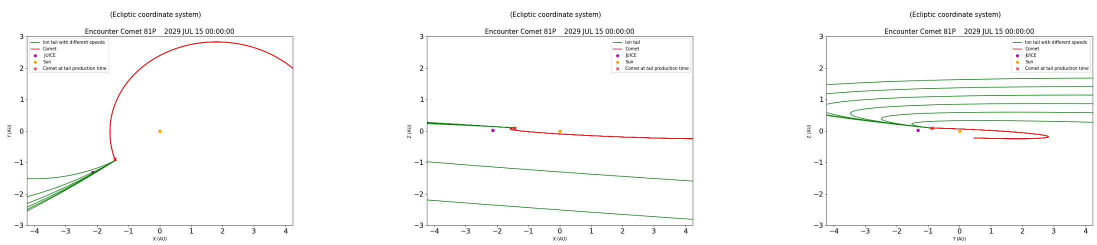


(a) (b) (c)

Figure 73: Encounter with 9P/Tempel 1 at 2028 MAR 11 in the Comet Orbital Coordinate System.

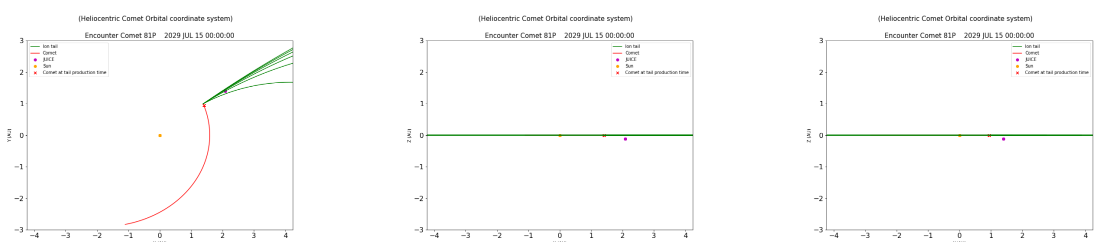
- Comet: **81P/Wild 2**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2029 JUL 12	2029 JUL 10 08:39	1.639	847	0.799	0.111	-7.993	2.488	1.689
2029 JUL 13	2029 JUL 10 17:33	2.269	617	0.806	0.112	-7.959	2.496	1.690
2029 JUL 14	2029 JUL 11 02:23	2.900	487	0.813	0.112	-7.926	2.504	1.691
2029 JUL 15	2029 JUL 11 11:12	3.533	403	0.820	0.113	-7.894	2.513	1.693
2029 JUL 16	2029 JUL 11 19:57	4.169	344	0.827	0.113	-7.862	2.521	1.694
2029 JUL 17	2029 JUL 12 04:40	4.806	301	0.834	0.114	-7.831	2.529	1.695
2029 JUL 18	2029 JUL 12 13:20	5.444	268	0.840	0.114	-7.801	2.537	1.696
2029 JUL 19	2029 JUL 12 21:57	6.085	242	0.847	0.115	-7.770	2.545	1.697
2029 JUL 20	2029 JUL 13 06:33	6.727	220	0.854	0.115	-7.741	2.553	1.699
2029 JUL 21	2029 JUL 13 15:06	7.371	203	0.861	0.116	-7.712	2.561	1.700



(a) (b) (c)

Figure 74: Encounter with 81P/Wild 2 at 2029 JUL 15 in the Ecliptic Coordinate System.

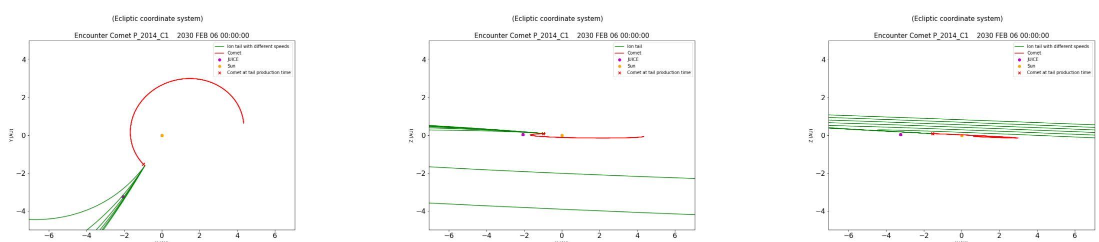


(a) (b) (c)

Figure 75: Encounter with 81P/Wild 2 at 2029 JUL 15 in the Comet Orbital Coordinate System.

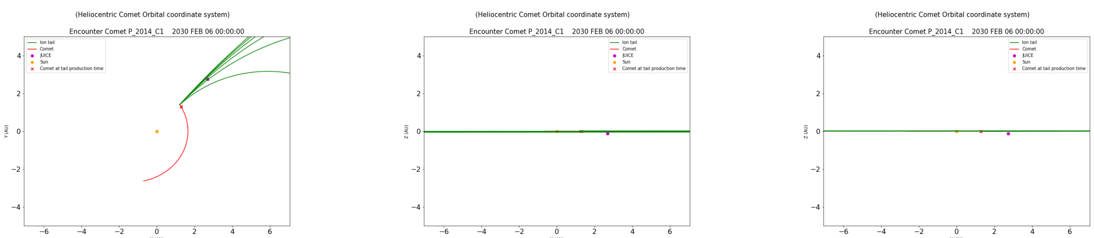
- Comet: **P_2014_C1/TOTAS**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2030 JAN 31	2030 JAN 28 01:45	2.926	1167	1.967	0.134	-3.891	3.820	1.853
2030 FEB 01	2030 JAN 28 06:11	3.742	915	1.972	0.134	-3.891	3.825	1.854
2030 FEB 02	2030 JAN 28 10:37	4.557	753	1.976	0.134	-3.891	3.831	1.854
2030 FEB 03	2030 JAN 28 15:01	5.374	640	1.981	0.134	-3.891	3.836	1.855
2030 FEB 04	2030 JAN 28 19:25	6.190	557	1.985	0.135	-3.891	3.841	1.856
2030 FEB 05	2030 JAN 28 23:49	7.008	493	1.990	0.135	-3.891	3.846	1.856
2030 FEB 06	2030 JAN 29 04:12	7.825	442	1.994	0.135	-3.891	3.851	1.857
2030 FEB 07	2030 JAN 29 08:35	8.642	402	1.999	0.136	-3.890	3.856	1.858
2030 FEB 08	2030 JAN 29 12:57	9.460	368	2.003	0.136	-3.890	3.861	1.858
2030 FEB 09	2030 JAN 29 17:18	10.279	339	2.008	0.136	-3.890	3.867	1.859
2030 FEB 10	2030 JAN 29 21:39	11.097	315	2.012	0.137	-3.890	3.872	1.860
2030 FEB 11	2030 JAN 30 02:00	11.917	294	2.016	0.137	-3.890	3.877	1.860
2030 FEB 12	2030 JAN 30 06:20	12.736	275	2.021	0.137	-3.890	3.882	1.861
2030 FEB 13	2030 JAN 30 10:40	13.555	259	2.025	0.137	-3.890	3.887	1.861
2030 FEB 14	2030 JAN 30 14:59	14.375	245	2.030	0.138	-3.890	3.892	1.862
2030 FEB 15	2030 JAN 30 19:17	15.196	232	2.034	0.138	-3.890	3.897	1.863
2030 FEB 16	2030 JAN 30 23:35	16.017	221	2.038	0.138	-3.890	3.902	1.863
2030 FEB 17	2030 JAN 31 03:53	16.838	211	2.043	0.139	-3.890	3.907	1.864
2030 FEB 18	2030 JAN 31 08:10	17.659	201	2.047	0.139	-3.890	3.912	1.865



(a) (b) (c)

Figure 76: Encounter with P_2014_C1/TOTAS at 2030 FEB 06 in the Ecliptic Coordinate System.

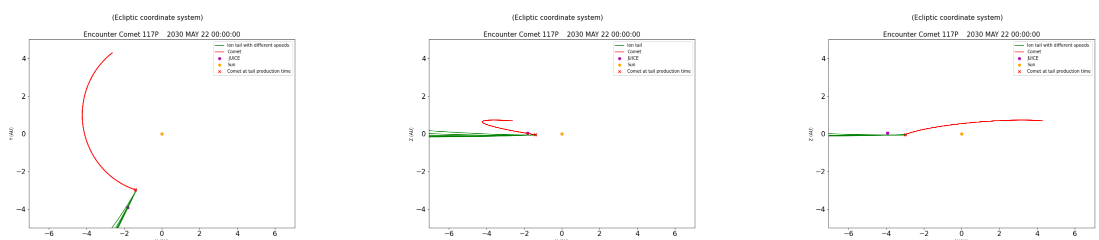


(a) (b) (c)

Figure 77: Encounter with P_2014_C1/TOTAS at 2030 FEB 06 in the Comet Orbital Coordinate System.

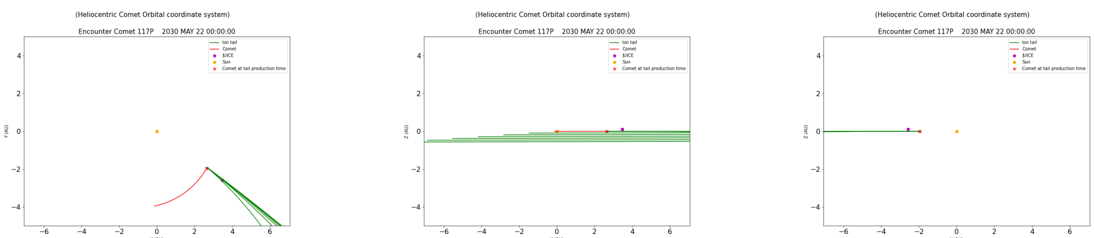
- Comet: **117P/Helin-Roman-Alu 1**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2030 MAY 18	2030 MAY 16 02:16	1.905	1028	1.128	0.102	5.184	4.312	3.184
2030 MAY 19	2030 MAY 16 11:04	2.538	775	1.133	0.103	5.205	4.316	3.183
2030 MAY 20	2030 MAY 16 19:51	3.172	622	1.137	0.104	5.226	4.320	3.183
2030 MAY 21	2030 MAY 17 04:38	3.807	521	1.142	0.104	5.247	4.324	3.183
2030 MAY 22	2030 MAY 17 13:23	4.442	448	1.146	0.105	5.268	4.328	3.182
2030 MAY 23	2030 MAY 17 22:07	5.078	393	1.151	0.106	5.288	4.332	3.182
2030 MAY 24	2030 MAY 18 06:50	5.715	351	1.155	0.107	5.309	4.336	3.181
2030 MAY 25	2030 MAY 18 15:31	6.353	317	1.159	0.108	5.329	4.340	3.181
2030 MAY 26	2030 MAY 19 00:12	6.991	289	1.164	0.109	5.349	4.344	3.180
2030 MAY 27	2030 MAY 19 08:52	7.631	266	1.168	0.109	5.370	4.348	3.180
2030 MAY 28	2030 MAY 19 17:30	8.270	246	1.173	0.110	5.390	4.352	3.179
2030 MAY 29	2030 MAY 20 02:07	8.911	229	1.177	0.111	5.409	4.356	3.179
2030 MAY 30	2030 MAY 20 10:44	9.553	215	1.181	0.112	5.429	4.360	3.178
2030 MAY 31	2030 MAY 20 19:19	10.195	202	1.186	0.113	5.449	4.364	3.178



(a) (b) (c)

Figure 78: Encounter with 117P/Helin-Roman-Alu 1 at 2030 MAY 22 in the Ecliptic Coordinate System.

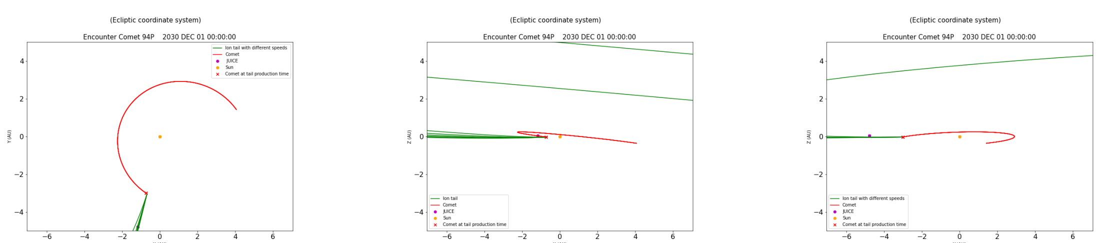


(a) (b) (c)

Figure 79: Encounter with 117P/Helin-Roman-Alu 1 at 2030 MAY 22 in the Comet Orbital Coordinate System.

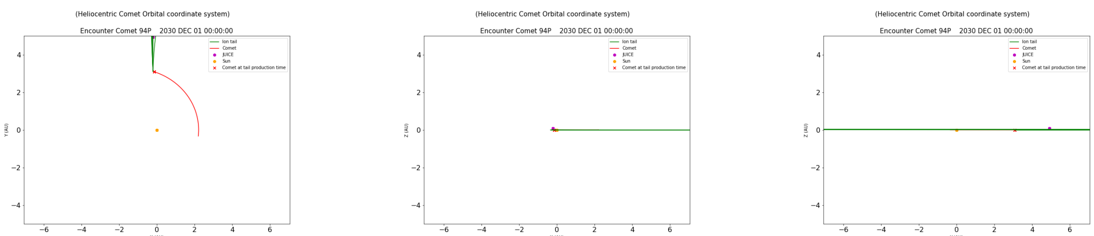
- Comet: **94P/Russell 4**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2030 NOV 25	2030 NOV 21 22:03	3.081	1025	1.819	0.079	2.479	4.913	3.094
2030 NOV 26	2030 NOV 22 04:47	3.800	832	1.820	0.079	2.492	4.916	3.095
2030 NOV 27	2030 NOV 22 11:32	4.519	700	1.822	0.080	2.505	4.918	3.096
2030 NOV 28	2030 NOV 22 18:16	5.239	604	1.823	0.080	2.519	4.920	3.097
2030 NOV 29	2030 NOV 23 01:00	5.958	532	1.824	0.081	2.532	4.923	3.098
2030 NOV 30	2030 NOV 23 07:44	6.677	475	1.826	0.081	2.545	4.925	3.099
2030 DEC 01	2030 NOV 23 14:28	7.397	429	1.827	0.082	2.558	4.927	3.100
2030 DEC 02	2030 NOV 23 21:11	8.117	391	1.828	0.082	2.571	4.930	3.101
2030 DEC 03	2030 NOV 24 03:55	8.837	359	1.829	0.082	2.584	4.932	3.102
2030 DEC 04	2030 NOV 24 10:38	9.556	333	1.831	0.083	2.597	4.934	3.103
2030 DEC 05	2030 NOV 24 17:22	10.276	309	1.832	0.083	2.610	4.936	3.104
2030 DEC 06	2030 NOV 25 00:04	10.997	289	1.833	0.084	2.624	4.938	3.105
2030 DEC 07	2030 NOV 25 06:48	11.717	272	1.834	0.084	2.637	4.941	3.106
2030 DEC 08	2030 NOV 25 13:31	12.437	256	1.835	0.085	2.650	4.943	3.107
2030 DEC 09	2030 NOV 25 20:13	13.157	242	1.837	0.085	2.663	4.945	3.108
2030 DEC 10	2030 NOV 26 02:56	13.878	230	1.838	0.086	2.676	4.947	3.109
2030 DEC 11	2030 NOV 26 09:38	14.598	219	1.839	0.086	2.689	4.950	3.110
2030 DEC 12	2030 NOV 26 16:21	15.319	209	1.840	0.087	2.702	4.952	3.111



(a) (b) (c)

Figure 80: Encounter with 94P/Russell 4 at 2030 DEC 01 in the Ecliptic Coordinate System.

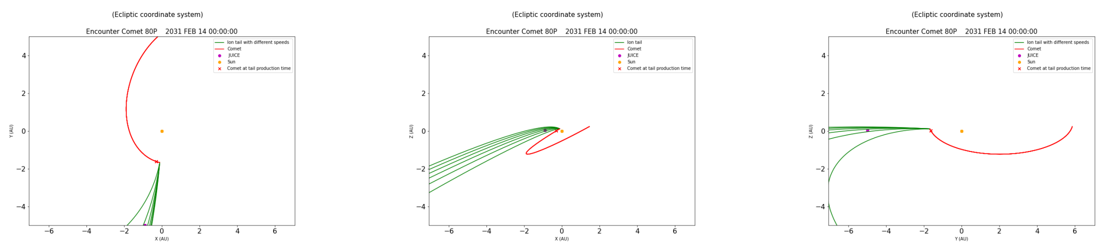


(a) (b) (c)

Figure 81: Encounter with 94P/Russell 4 at 2030 DEC 01 in the Comet Orbital Coordinate System.

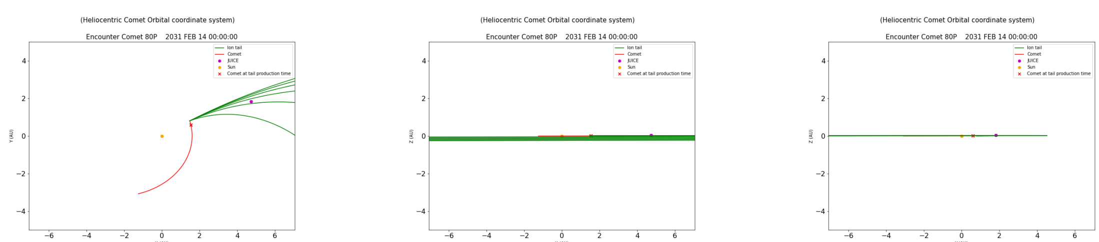
- Comet: **80P/Peters-Hartley**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2031 FEB 06	2031 JAN 31 16:36	5.308	1115	3.408	0.045	0.754	5.061	1.653
2031 FEB 07	2031 JAN 31 18:18	6.237	949	3.410	0.043	0.718	5.063	1.653
2031 FEB 08	2031 JAN 31 20:00	7.166	827	3.412	0.041	0.683	5.065	1.653
2031 FEB 09	2031 JAN 31 21:42	8.096	732	3.413	0.039	0.647	5.066	1.653
2031 FEB 10	2031 JAN 31 23:23	9.025	657	3.415	0.036	0.611	5.068	1.653
2031 FEB 11	2031 FEB 01 01:05	9.954	596	3.416	0.034	0.575	5.070	1.654
2031 FEB 12	2031 FEB 01 02:47	10.884	545	3.418	0.032	0.540	5.071	1.654
2031 FEB 13	2031 FEB 01 04:28	11.813	503	3.419	0.030	0.504	5.073	1.654
2031 FEB 14	2031 FEB 01 06:10	12.743	466	3.421	0.028	0.469	5.075	1.654
2031 FEB 15	2031 FEB 01 07:51	13.672	435	3.422	0.026	0.433	5.076	1.654
2031 FEB 16	2031 FEB 01 09:33	14.602	407	3.424	0.024	0.398	5.078	1.654
2031 FEB 17	2031 FEB 01 11:14	15.531	383	3.425	0.022	0.362	5.080	1.654
2031 FEB 18	2031 FEB 01 12:55	16.461	361	3.427	0.020	0.327	5.081	1.655
2031 FEB 19	2031 FEB 01 14:37	17.391	342	3.428	0.017	0.292	5.083	1.655
2031 FEB 20	2031 FEB 01 16:18	18.321	325	3.430	0.015	0.256	5.085	1.655
2031 FEB 21	2031 FEB 01 17:59	19.251	309	3.431	0.013	0.221	5.086	1.655
2031 FEB 22	2031 FEB 01 19:39	20.181	295	3.433	0.011	0.186	5.088	1.655
2031 FEB 23	2031 FEB 01 21:20	21.111	282	3.434	0.009	0.150	5.090	1.655
2031 FEB 24	2031 FEB 01 23:01	22.041	271	3.436	0.007	0.115	5.091	1.656
2031 FEB 25	2031 FEB 02 00:42	22.971	260	3.437	0.005	0.080	5.093	1.656
2031 FEB 26	2031 FEB 02 02:23	23.901	250	3.438	0.003	0.045	5.094	1.656
2031 FEB 27	2031 FEB 02 04:03	24.831	241	3.440	0.001	0.010	5.096	1.656
2031 FEB 28	2031 FEB 02 05:44	25.761	232	3.441	0.002	-0.025	5.097	1.656
2031 MAR 01	2031 FEB 02 07:25	26.691	224	3.443	0.004	-0.060	5.099	1.656
2031 MAR 02	2031 FEB 02 09:05	27.621	216	3.444	0.006	-0.095	5.101	1.657
2031 MAR 03	2031 FEB 02 10:45	28.551	209	3.445	0.008	-0.130	5.102	1.657
2031 MAR 04	2031 FEB 02 12:26	29.482	203	3.447	0.010	-0.165	5.104	1.657
Crossing								
2031 FEB 27 06:50	2031 FEB 02 04:32		238					



(a) (b) (c)

Figure 82: Encounter with 80P/Peters-Hartley at 2031 FEB 14 in the Ecliptic Coordinate System.

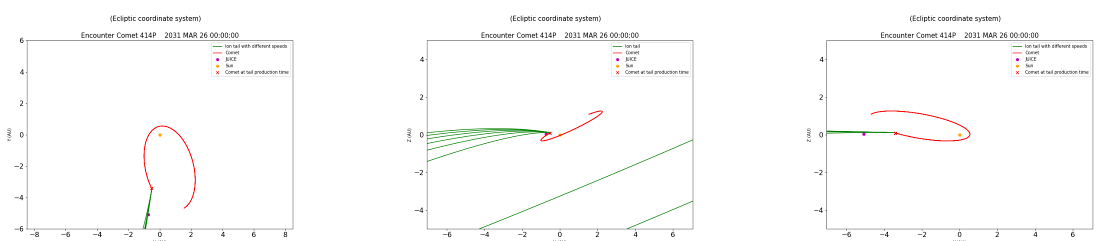


(a) (b) (c)

Figure 83: Encounter with 80P/Peters-Hartley at 2031 FEB 14 in the Comet Orbital Coordinate System.

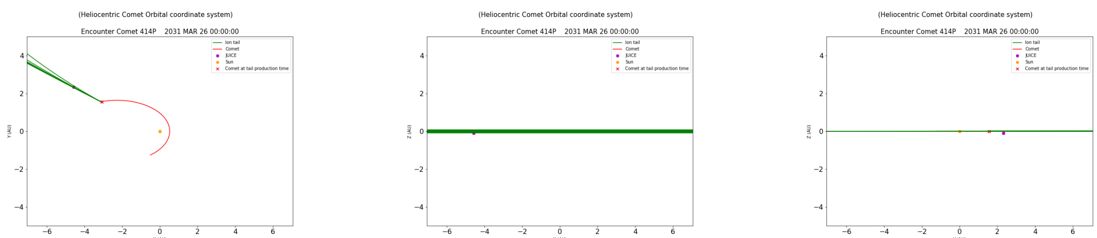
- Comet: **414P/STEREO**

Date JUICE	Date Comet	t delay (days)	SW Speed (km/s)	d_{J-C} (AU)	d_{J-T} (AU)	Angle (deg)	d_{J-S} (AU)	d_{C-S} (AU)
2031 MAR 18	2031 MAR 15 09:27	2.606	1135	1.704	0.099	-3.321	5.124	3.420
2031 MAR 19	2031 MAR 15 21:46	3.093	955	1.702	0.100	-3.382	5.126	3.424
2031 MAR 20	2031 MAR 16 10:06	3.579	825	1.700	0.102	-3.443	5.127	3.427
2031 MAR 21	2031 MAR 16 22:27	4.064	725	1.698	0.104	-3.504	5.129	3.430
2031 MAR 22	2031 MAR 17 10:49	4.549	647	1.696	0.105	-3.565	5.130	3.434
2031 MAR 23	2031 MAR 17 23:12	5.033	584	1.694	0.107	-3.626	5.131	3.437
2031 MAR 24	2031 MAR 18 11:36	5.516	533	1.692	0.109	-3.687	5.133	3.440
2031 MAR 25	2031 MAR 19 00:00	6.000	489	1.690	0.111	-3.749	5.134	3.444
2031 MAR 26	2031 MAR 19 12:26	6.482	452	1.688	0.112	-3.810	5.136	3.447
2031 MAR 27	2031 MAR 20 00:51	6.964	420	1.686	0.114	-3.872	5.137	3.451
2031 MAR 28	2031 MAR 20 13:19	7.445	393	1.684	0.116	-3.934	5.138	3.454
2031 MAR 29	2031 MAR 21 01:46	7.926	369	1.682	0.117	-3.996	5.140	3.457
2031 MAR 30	2031 MAR 21 14:15	8.406	347	1.680	0.119	-4.058	5.141	3.461
2031 MAR 31	2031 MAR 22 02:44	8.885	328	1.678	0.121	-4.121	5.142	3.464
2031 APR 01	2031 MAR 22 15:15	9.364	311	1.676	0.122	-4.183	5.144	3.467
2031 APR 02	2031 MAR 23 03:46	9.843	295	1.674	0.124	-4.246	5.145	3.471
2031 APR 03	2031 MAR 23 16:18	10.320	281	1.672	0.126	-4.309	5.146	3.474
2031 APR 04	2031 MAR 24 04:51	10.798	269	1.670	0.127	-4.371	5.148	3.477
2031 APR 05	2031 MAR 24 17:24	11.274	257	1.668	0.129	-4.434	5.149	3.481
2031 APR 06	2031 MAR 25 05:59	11.751	246	1.666	0.131	-4.498	5.150	3.484
2031 APR 07	2031 MAR 25 18:34	12.226	236	1.664	0.132	-4.561	5.151	3.487
2031 APR 08	2031 MAR 26 07:10	12.701	227	1.662	0.134	-4.624	5.153	3.491
2031 APR 09	2031 MAR 26 19:47	13.176	219	1.660	0.136	-4.688	5.154	3.494
2031 APR 10	2031 MAR 27 08:24	13.649	211	1.658	0.137	-4.752	5.155	3.497
2031 APR 11	2031 MAR 27 21:02	14.123	204	1.656	0.139	-4.816	5.157	3.501



(a) (b) (c)

Figure 84: Encounter with 414P/STEREO at 2031 MAR 26 in the Ecliptic Coordinate System.



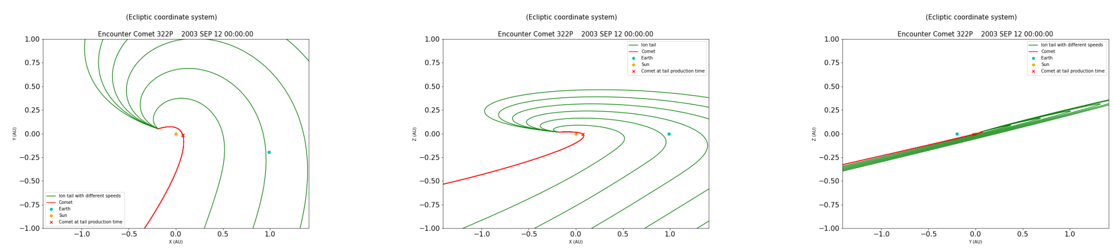
(a) (b) (c)

Figure 85: Encounter with 414P/STEREO at 2031 MAR 26 in the Comet Orbital Coordinate System.

A.2.4 Earth Encounters

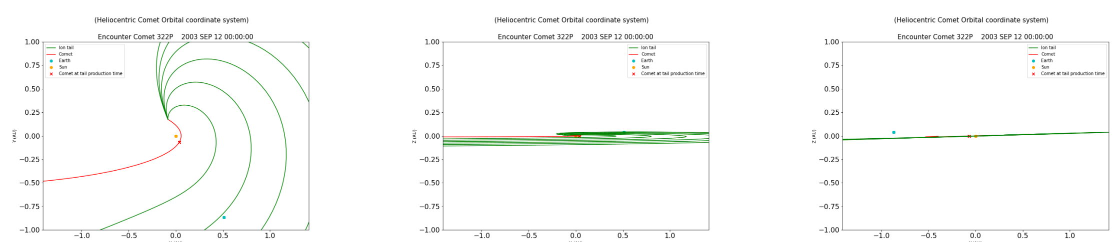
- Comet: **322P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2003 SEP 10	2003 SEP 08 01:07	1.953	831	0.935	0.048	2.955	1.007	0.072
2003 SEP 11	2003 SEP 08 01:23	2.942	552	0.935	0.045	2.730	1.007	0.072
2003 SEP 12	2003 SEP 08 01:40	3.930	413	0.936	0.041	2.504	1.007	0.071
2003 SEP 13	2003 SEP 08 01:56	4.919	330	0.936	0.037	2.278	1.006	0.070
2003 SEP 14	2003 SEP 08 02:12	5.908	275	0.936	0.034	2.051	1.006	0.070
2003 SEP 15	2003 SEP 08 02:29	6.896	236	0.937	0.030	1.824	1.006	0.069
2003 SEP 16	2003 SEP 08 02:45	7.885	206	0.937	0.026	1.597	1.006	0.068
Crossing								
2003 SEP 23 00:08	2003 SEP 08 04:40		110					



(a) (b) (c)

Figure 86: Encounter with 322P at 2003 SEP 12 in the Ecliptic Coordinate System.

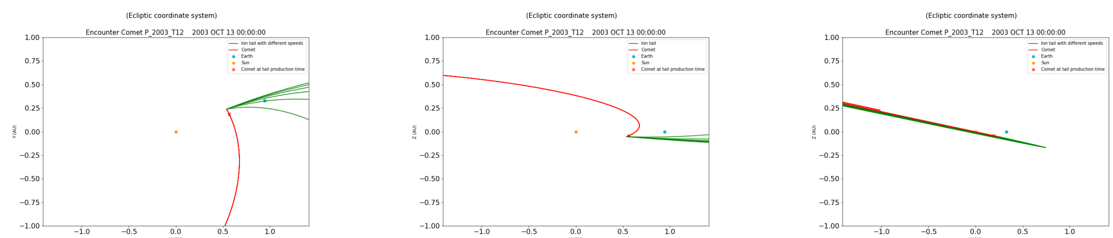


(a) (b) (c)

Figure 87: Encounter with 322P at 2003 SEP 12 in the Comet Orbital Coordinate System.

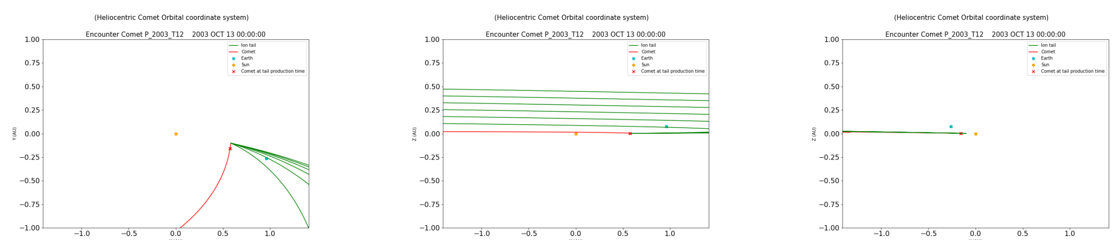
- Comet: **P_2003_T12/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2003 OCT 11	2003 OCT 10 08:49	0.632	1131	0.412	0.070	9.835	0.998	0.586
2003 OCT 12	2003 OCT 10 17:10	1.285	558	0.413	0.074	10.258	0.998	0.585
2003 OCT 13	2003 OCT 11 01:30	1.937	371	0.414	0.077	10.678	0.998	0.584
2003 OCT 14	2003 OCT 11 09:46	2.592	278	0.415	0.080	11.096	0.998	0.583
2003 OCT 15	2003 OCT 11 18:03	3.247	222	0.416	0.083	11.511	0.997	0.582
Crossing								
2004 SEP 19 03:09	2003 OCT 02 13:56		2					



(a) (b) (c)

Figure 88: Encounter with P_2003_T12 at 2003 OCT 13 in the Ecliptic Coordinate System.

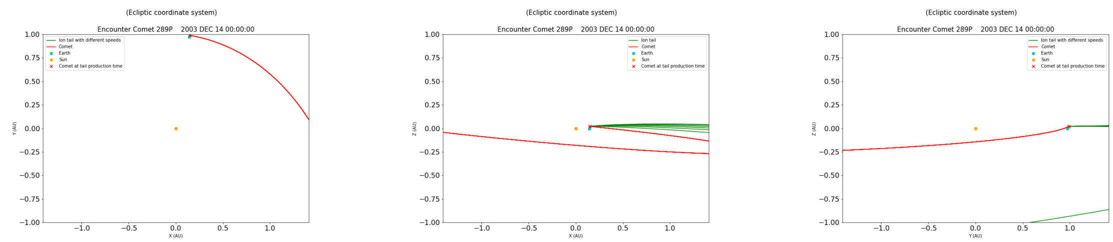


(a) (b) (c)

Figure 89: Encounter with P_2003_T12 at 2003 OCT 13 in the Comet Orbital Coordinate System.

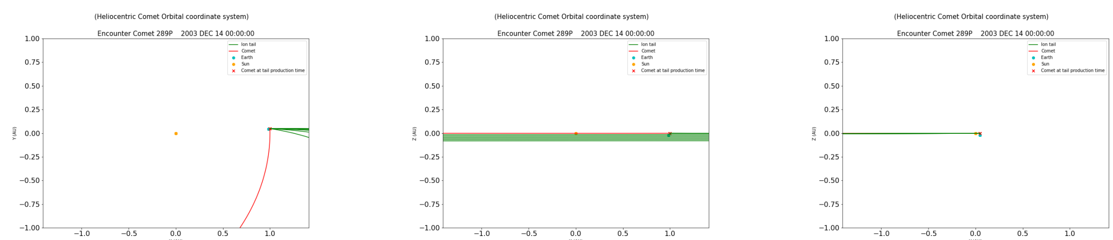
- Comet: **289P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2003 DEC 14	2003 DEC 13 22:48	0.050	872	0.025	0.022	-61.625	0.984	0.959
Crossing								
2004 NOV 30 20:19	2003 DEC 04 02:23		0.102					



(a) (b) (c)

Figure 90: Encounter with 289P/ at 2003 DEC 14 in the Ecliptic Coordinate System.

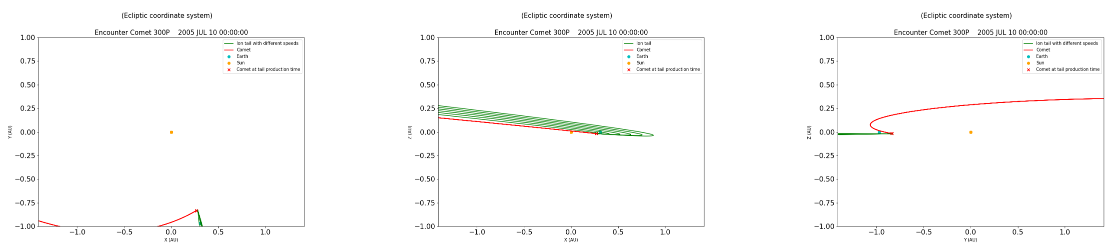


(a) (b) (c)

Figure 91: Encounter with 289P/ at 2003 DEC 14 in the Comet Orbital Coordinate System.

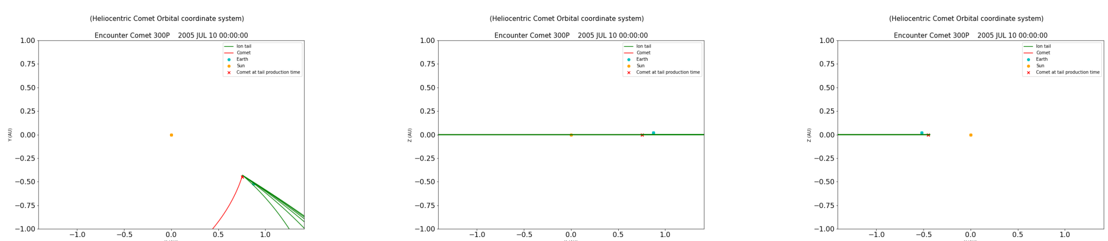
- Comet: **300P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2005 JUL 09	2005 JUL 08 15:17	0.363	660	0.138	0.019	8.001	1.017	0.879
2005 JUL 10	2005 JUL 09 06:22	0.735	334	0.141	0.021	8.489	1.017	0.875
2005 JUL 11	2005 JUL 09 21:20	1.111	226	0.144	0.022	8.961	1.017	0.872
Crossing								
2006 JUN 27 17:44	2005 JUL 01 00:30		0.439					



(a) (b) (c)

Figure 92: Encounter with 300P/ at 2005 JUL 10 in the Ecliptic Coordinate System.

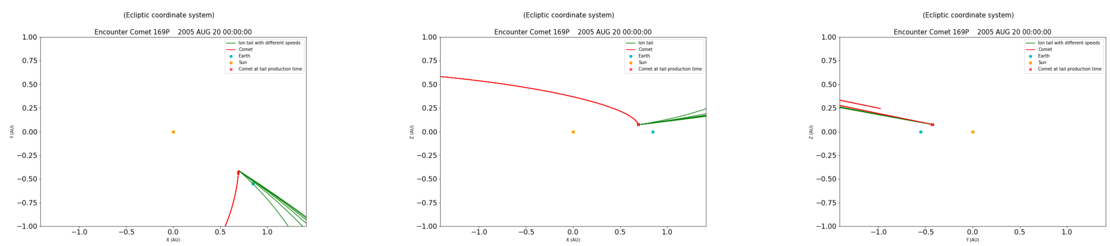


(a) (b) (c)

Figure 93: Encounter with 300P/ at 2005 JUL 10 in the Comet Orbital Coordinate System.

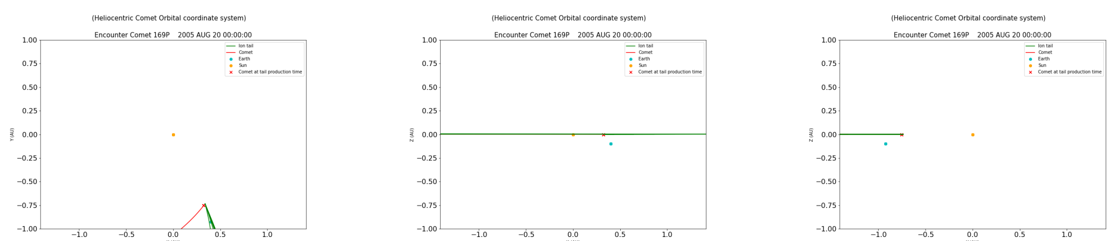
- Comet: **169P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2005 AUG 19	2005 AUG 18 10:33	0.560	562	0.181	0.100	-33.337	1.012	0.831
2005 AUG 20	2005 AUG 19 01:51	0.923	355	0.189	0.097	-30.857	1.012	0.823
2005 AUG 21	2005 AUG 19 16:46	1.301	261	0.196	0.094	-28.638	1.012	0.816
2005 AUG 22	2005 AUG 20 07:27	1.689	208	0.203	0.091	-26.634	1.011	0.809
Crossing								
2005 SEP 19 03:10	2005 SEP 03 06:52		37					



(a) (b) (c)

Figure 94: Encounter with 169P/ at 2005 AUG 20 in the Ecliptic Coordinate System.

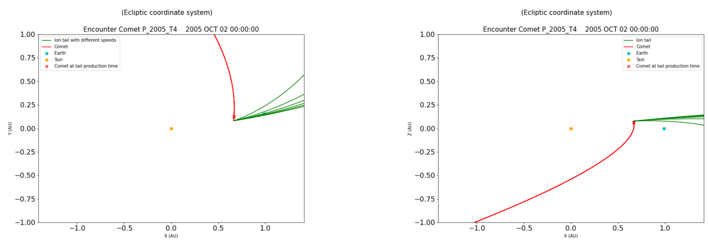


(a) (b) (c)

Figure 95: Encounter with 169P/ at 2005 AUG 20 in the Comet Orbital Coordinate System.

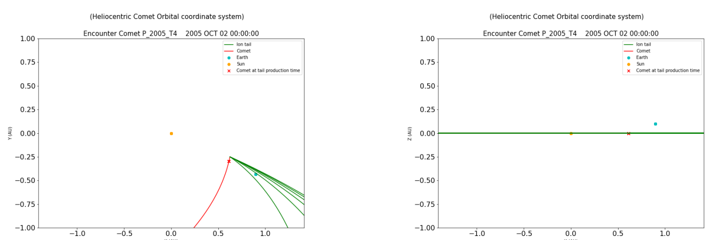
- Comet: **P_2005_T4/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2005 OCT 02	2005 SEP 30 08:17	1.655	334	0.319	0.098	17.833	1.001	0.682
Crossing								
2005 OCT 18 19:00	2005 SEP 23 05:42		17					



(a) (b) (c)

Figure 96: Encounter with P_2005_T4/ at 2005 OCT 02 in the Ecliptic Coordinate System.

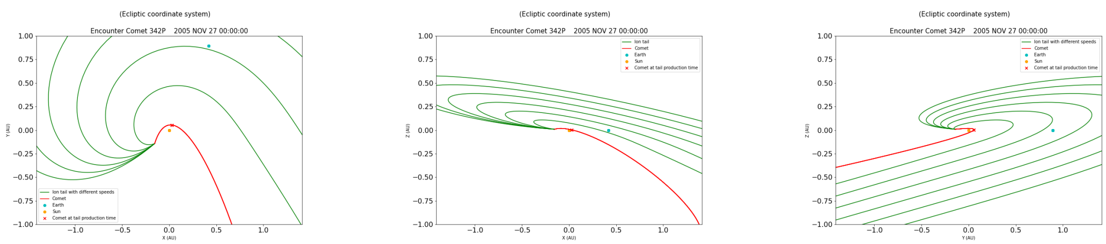


(a) (b) (c)

Figure 97: Encounter with P_2005_T4/ at 2005 OCT 02 in the Comet Orbital Coordinate System.

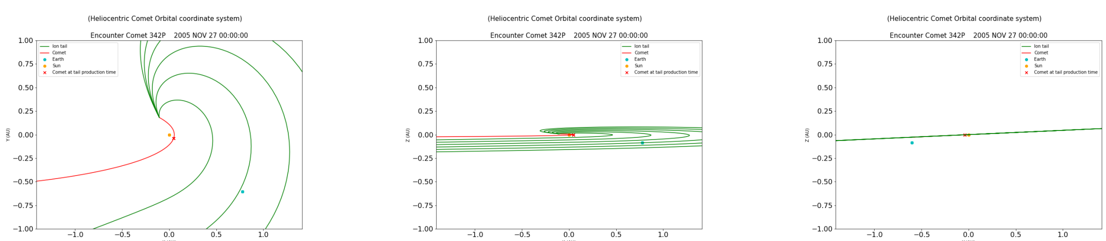
- Comet: **342P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2005 NOV 25	2005 NOV 23 01:55	1.920	839	0.927	0.075	-4.643	0.987	0.060
2005 NOV 26	2005 NOV 23 02:10	2.910	553	0.927	0.079	-4.874	0.987	0.059
2005 NOV 27	2005 NOV 23 02:24	3.899	413	0.928	0.083	-5.104	0.987	0.059
2005 NOV 28	2005 NOV 23 02:39	4.889	329	0.928	0.086	-5.333	0.987	0.059
2005 NOV 29	2005 NOV 23 02:54	5.879	274	0.928	0.090	-5.560	0.986	0.058
2005 NOV 30	2005 NOV 23 03:09	6.869	235	0.928	0.094	-5.785	0.986	0.058
2005 DEC 01	2005 NOV 23 03:24	7.858	205	0.928	0.097	-6.009	0.986	0.058
Crossing								
2006 MAY 04 01:53	2005 NOV 27		9					



(a) (b) (c)

Figure 98: Encounter with 342P/ at 2005 NOV 27 in the Ecliptic Coordinate System.

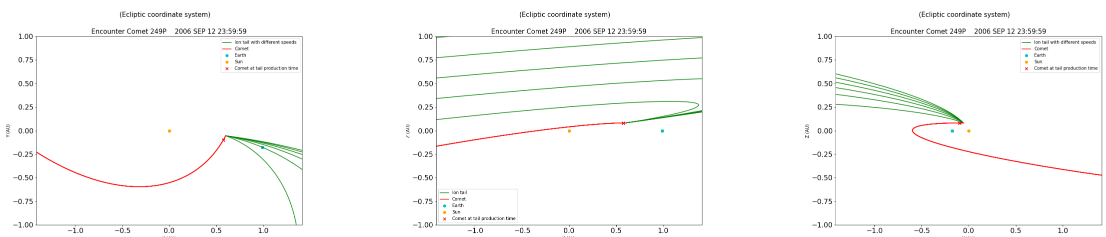


(a) (b) (c)

Figure 99: Encounter with 342P/ at 2005 NOV 27 in the Comet Orbital Coordinate System.

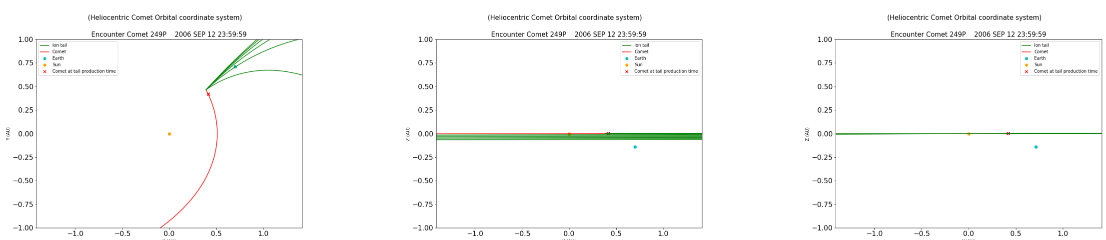
- Comet: **249P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2006 SEP 11	2006 SEP 10 23:32	1.019	730	0.428	0.139	-18.953	1.007	0.578
2006 SEP 12	2006 SEP 11 08:12	1.658	444	0.424	0.138	-19.010	1.006	0.582
2006 SEP 13	2006 SEP 11 16:53	2.296	318	0.420	0.137	-19.068	1.006	0.586
2006 SEP 14	2006 SEP 12 01:38	2.932	246	0.416	0.136	-19.126	1.006	0.590
2006 SEP 15	2006 SEP 12 10:38	3.556	201	0.412	0.135	-19.186	1.005	0.594
Crossing								
2007 MAY 21 13:11	2006 AUG 06 14:10		2					



(a) (b) (c)

Figure 100: Encounter with 249P/ at 2006 SEP 12 in the Ecliptic Coordinate System.

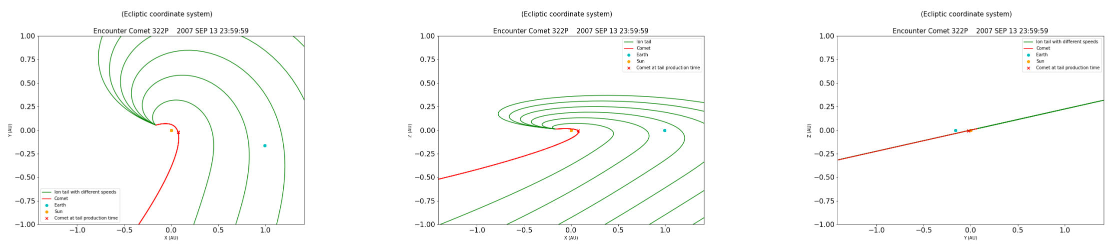


(a) (b) (c)

Figure 101: Encounter with 249P/ at 2006 SEP 12 in the Comet Orbital Coordinate System.

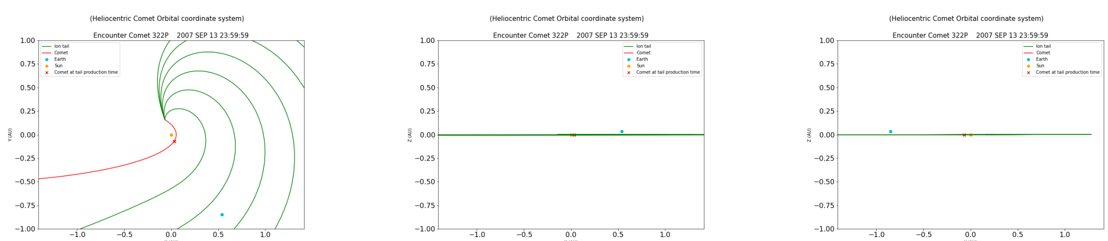
- Comet: **322P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2007 SEP 11	2007 SEP 10 12:40	1.472	1104	0.936	0.041	2.509	1.007	0.071
2007 SEP 12	2007 SEP 10 13:05	2.454	662	0.936	0.037	2.283	1.006	0.070
2007 SEP 13	2007 SEP 10 13:30	3.437	473	0.936	0.034	2.057	1.006	0.070
2007 SEP 14	2007 SEP 10 13:55	4.420	368	0.937	0.030	1.830	1.006	0.069
2007 SEP 15	2007 SEP 10 14:19	5.403	301	0.937	0.026	1.602	1.006	0.068
2007 SEP 16	2007 SEP 10 14:44	6.386	255	0.937	0.022	1.375	1.005	0.068
2007 SEP 17	2007 SEP 10 15:09	7.368	221	0.938	0.019	1.147	1.005	0.067
Crossing								
2007 SEP 23 00:44	2007 SEP 10 17:14		132					



(a) (b) (c)

Figure 102: Encounter with 322P at 2007 SEP 13 in the Ecliptic Coordinate System.

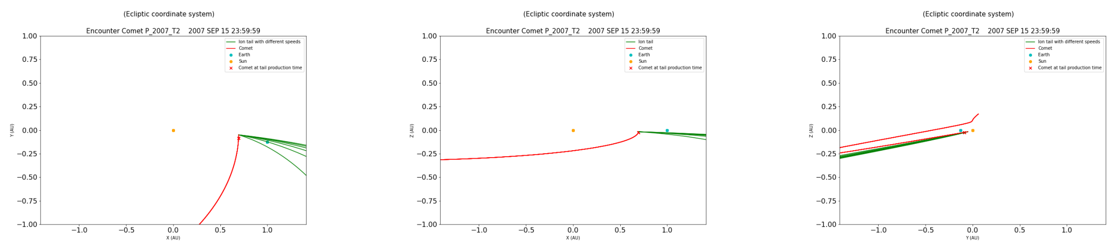


(a) (b) (c)

Figure 103: Encounter with 322P at 2007 SEP 13 in the Comet Orbital Coordinate System.

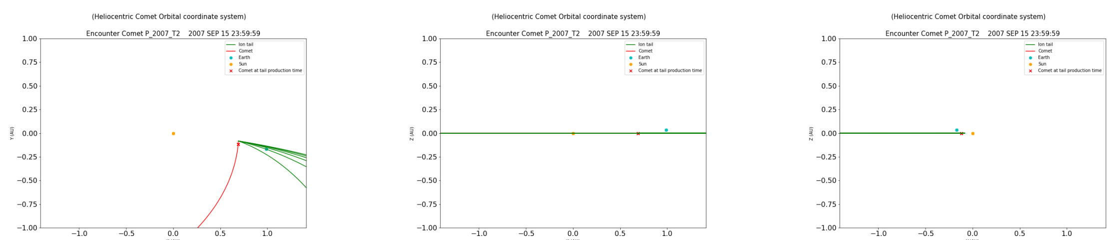
- Comet: **P_2007_T12/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2007 SEP 14	2007 SEP 14 06:31	0.728	727	0.305	0.037	6.949	1.006	0.701
2007 SEP 15	2007 SEP 14 16:51	1.297	409	0.305	0.034	6.389	1.006	0.700
2007 SEP 16	2007 SEP 15 03:11	1.867	284	0.306	0.031	5.832	1.005	0.699
2007 SEP 17	2007 SEP 15 13:28	2.438	218	0.306	0.028	5.277	1.005	0.699
Crossing								
2007 SEP 27 14:20	2007 SEP 19 15:50		67					



(a) (b) (c)

Figure 104: Encounter with P_2007_T2 at 2007 SEP 15 in the Ecliptic Coordinate System.

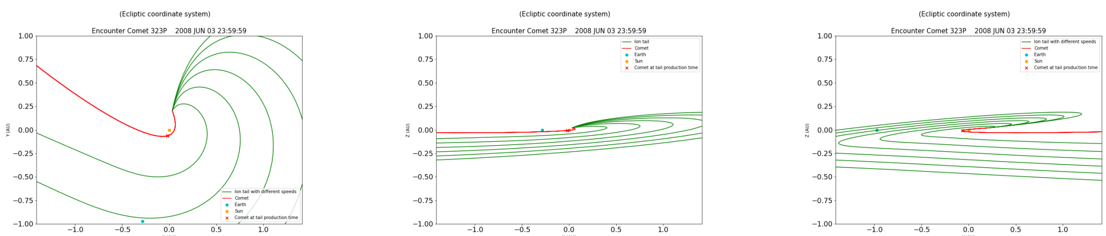


(a) (b) (c)

Figure 105: Encounter with P_2007_T2 at 2007 SEP 15 in the Comet Orbital Coordinate System.

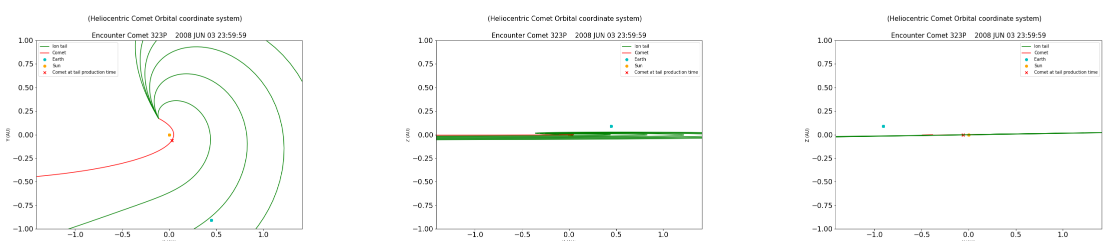
- Comet: **323P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2008 JUN 01	2008 MAY 30 23:56	2.002	832	0.959	0.091	5.418	1.014	0.055
2008 JUN 02	2008 MAY 31 00:11	2.992	557	0.960	0.090	5.385	1.014	0.055
2008 JUN 03	2008 MAY 31 00:24	3.983	419	0.960	0.090	5.351	1.015	0.054
2008 JUN 04	2008 MAY 31 00:36	4.974	335	0.961	0.089	5.316	1.015	0.054
2008 JUN 05	2008 MAY 31 00:49	5.966	280	0.962	0.088	5.279	1.015	0.053
2008 JUN 06	2008 MAY 31 01:02	6.957	240	0.962	0.088	5.241	1.015	0.053
2008 JUN 07	2008 MAY 31 01:14	7.948	210	0.963	0.087	5.202	1.015	0.052
Crossing								
2008 AUG 16 21:11	2008 MAY 31 15:54		22					



(a) (b) (c)

Figure 106: Encounter with 323P/ at 2008 JUN 03 in the Ecliptic Coordinate System.

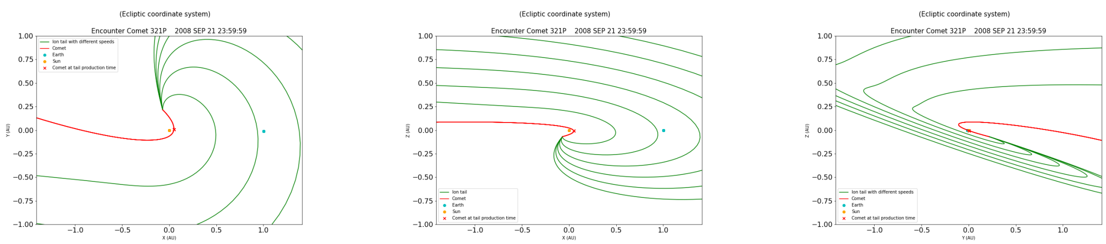


(a) (b) (c)

Figure 107: Encounter with 323P/ at 2008 JUN 03 in the Comet Orbital Coordinate System.

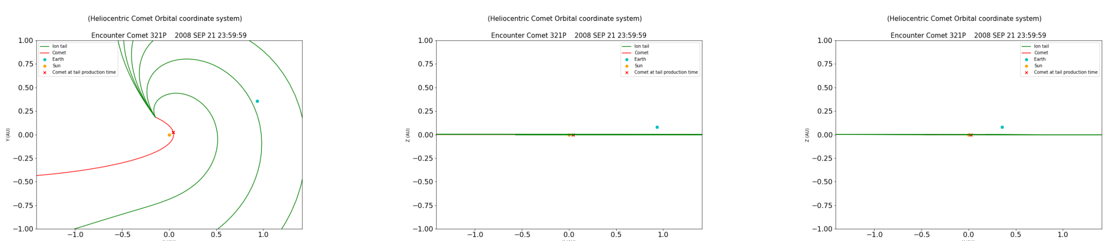
- Comet: **321P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2008 SEP 19	2008 SEP 18 03:45	1.844	900	0.956	0.071	4.234	1.004	0.048
2008 SEP 20	2008 SEP 18 04:01	2.832	586	0.956	0.076	4.574	1.004	0.048
2008 SEP 21	2008 SEP 18 04:17	3.821	434	0.955	0.082	4.914	1.004	0.048
2008 SEP 22	2008 SEP 18 04:34	4.810	345	0.955	0.087	5.252	1.003	0.049
2008 SEP 23	2008 SEP 18 04:50	5.798	286	0.954	0.093	5.590	1.003	0.049
2008 SEP 24	2008 SEP 18 05:06	6.787	244	0.954	0.098	5.926	1.003	0.049
2008 SEP 25	2008 SEP 18 05:23	7.775	213	0.953	0.104	6.261	1.003	0.049
Crossing								
2009 SEP 07 21:55	2008 SEP 18 00:25		5					



(a) (b) (c)

Figure 108: Encounter with 321P/ at 2008 SEP 21 in the Ecliptic Coordinate System.

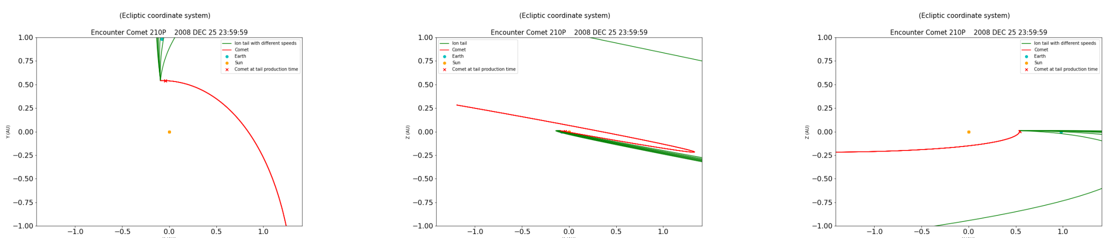


(a) (b) (c)

Figure 109: Encounter with 321P/ at 2008 SEP 21 in the Comet Orbital Coordinate System.

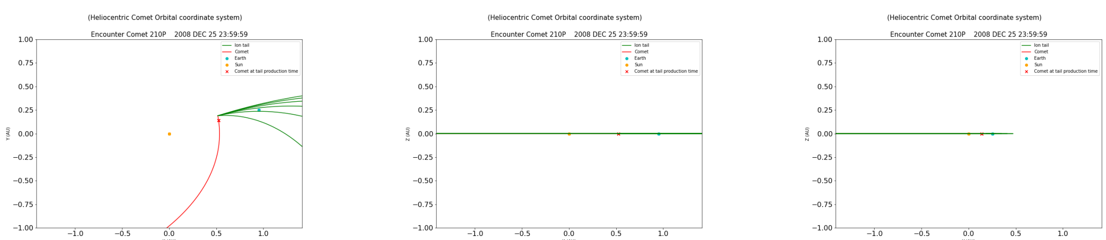
- Comet: **210P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2008 DEC 24	2008 DEC 24 01:11	0.951	807	0.442	0.001	0.169	0.984	0.542
2008 DEC 25	2008 DEC 24 08:28	1.647	465	0.441	0.002	-0.234	0.983	0.543
2008 DEC 26	2008 DEC 24 15:46	2.343	326	0.440	0.005	-0.639	0.983	0.544
2008 DEC 27	2008 DEC 24 23:03	3.039	250	0.438	0.008	-1.047	0.983	0.545
2008 DEC 28	2008 DEC 25 06:27	3.731	203	0.437	0.011	-1.456	0.983	0.546
Crossing								
2008 DEC 25 10:03	2008 DEC 24 04:14		617					



(a) (b) (c)

Figure 110: Encounter with 210P/ at 2008 DEC 25 in the Ecliptic Coordinate System.

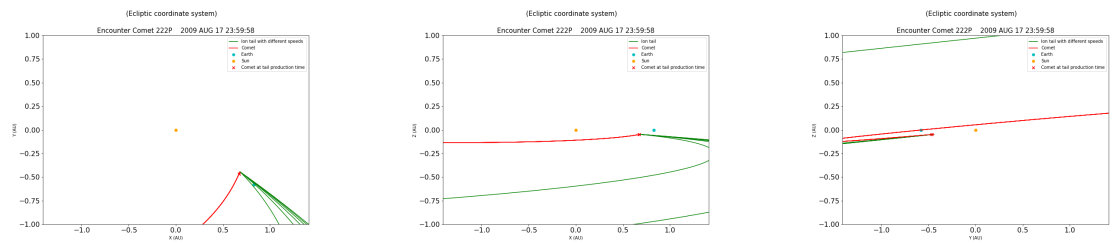


(a) (b) (c)

Figure 111: Encounter with 210P/ at 2008 DEC 25 in the Comet Orbital Coordinate System.

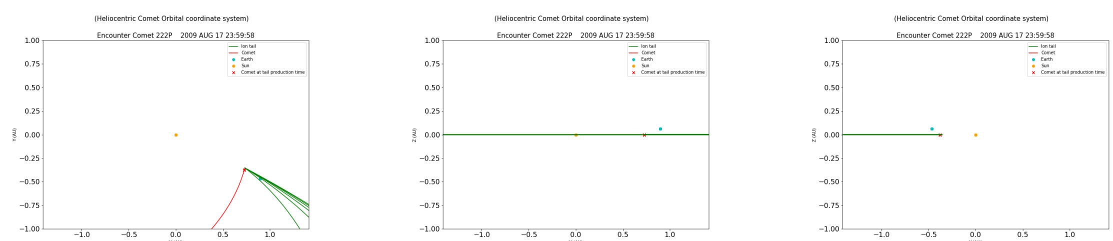
- Comet: **222P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2009 AUG 16	2009 AUG 16 11:39	0.514	643	0.190	0.062	18.998	1.012	0.822
2009 AUG 17	2009 AUG 17 01:15	0.948	354	0.193	0.061	18.371	1.012	0.819
2009 AUG 18	2009 AUG 17 14:42	1.387	245	0.196	0.060	17.769	1.012	0.816
Crossing								
2009 SEP 30 07:03	2009 SEP 08 22:10		17					



(a) (b) (c)

Figure 112: Encounter with 222P/ at 2009 AUG 17 in the Ecliptic Coordinate System.

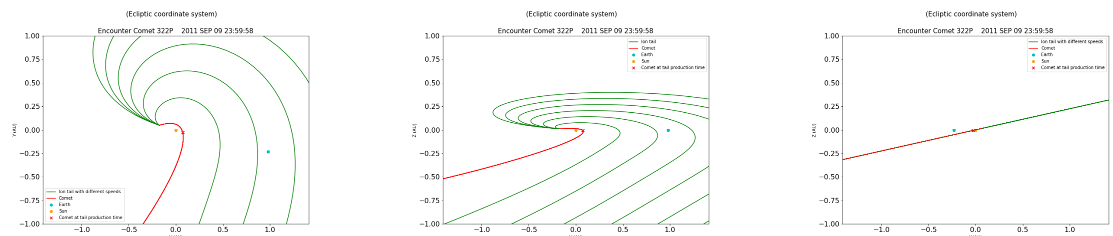


(a) (b) (c)

Figure 113: Encounter with 222P/ at 2009 AUG 17 in the Comet Orbital Coordinate System.

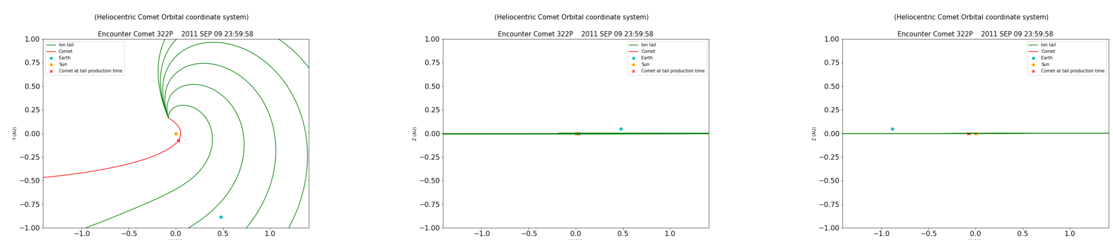
- Comet: **322P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2011 SEP 07	2011 SEP 06 06:45	1.718	944	0.934	0.056	3.415	1.008	0.074
2011 SEP 08	2011 SEP 06 07:05	2.705	600	0.934	0.052	3.191	1.007	0.073
2011 SEP 09	2011 SEP 06 07:25	3.691	440	0.935	0.048	2.966	1.007	0.072
2011 SEP 10	2011 SEP 06 07:44	4.677	347	0.935	0.045	2.741	1.007	0.072
2011 SEP 11	2011 SEP 06 08:04	5.663	287	0.936	0.041	2.515	1.007	0.071
2011 SEP 12	2011 SEP 06 08:24	6.650	244	0.936	0.037	2.289	1.006	0.070
2011 SEP 13	2011 SEP 06 08:44	7.636	213	0.936	0.034	2.062	1.006	0.070
Crossing								
2011 SEP 23 01:24	2011 SEP 06 11:43		98					



(a) (b) (c)

Figure 114: Encounter with 322P at 2011 SEP 09 in the Ecliptic Coordinate System.

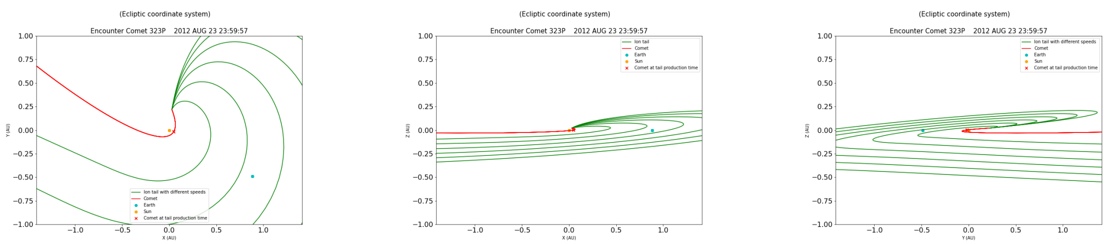


(a) (b) (c)

Figure 115: Encounter with 322P at 2011 SEP 09 in the Comet Orbital Coordinate System.

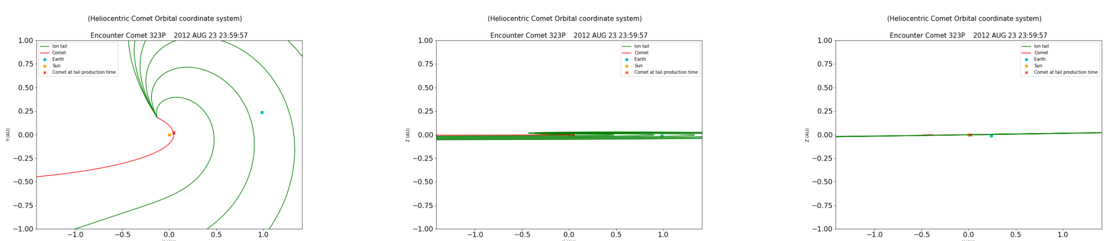
- Comet: **323P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2012 AUG 21	2012 AUG 20 11:04	1.538	1097	0.972	0.008	-0.477	1.011	0.040
2012 AUG 22	2012 AUG 20 11:17	2.529	667	0.972	0.010	-0.570	1.011	0.040
2012 AUG 23	2012 AUG 20 11:30	3.520	479	0.971	0.011	-0.664	1.011	0.040
2012 AUG 24	2012 AUG 20 11:43	4.511	374	0.971	0.013	-0.757	1.011	0.040
2012 AUG 25	2012 AUG 20 11:56	5.502	306	0.971	0.014	-0.850	1.011	0.040
2012 AUG 26	2012 AUG 20 12:10	6.493	259	0.970	0.016	-0.943	1.010	0.040
2012 AUG 27	2012 AUG 20 12:23	7.484	225	0.970	0.018	-1.036	1.010	0.040
Crossing								
2012 AUG 16 21:55	2008 MAY 31 15:54		1					



(a) (b) (c)

Figure 116: Encounter with 323P/ at 2012 AUG 23 in the Ecliptic Coordinate System.

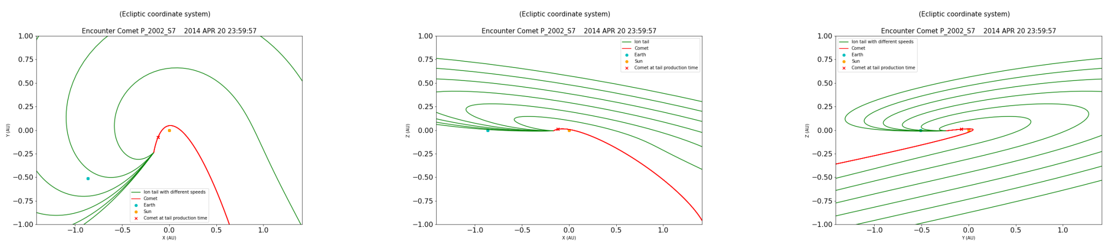


(a) (b) (c)

Figure 117: Encounter with 323P/ at 2012 AUG 23 in the Comet Orbital Coordinate System.

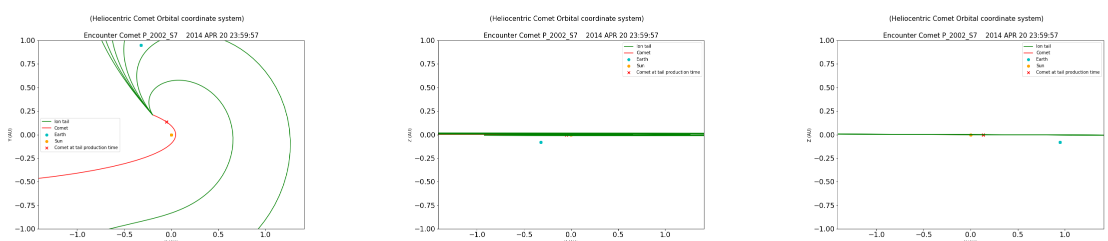
- Comet: **P_2002_S7/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2014 APR 18	2014 APR 17 15:47	1.342	1124	0.869	0.086	-5.714	1.004	0.136
2014 APR 19	2014 APR 17 16:59	2.292	656	0.866	0.083	-5.484	1.005	0.139
2014 APR 20	2014 APR 17 18:11	3.242	462	0.863	0.079	-5.253	1.005	0.142
2014 APR 21	2014 APR 17 19:23	4.192	356	0.860	0.075	-5.019	1.005	0.145
2014 APR 22	2014 APR 17 20:35	5.142	289	0.857	0.071	-4.782	1.005	0.149
2014 APR 23	2014 APR 17 21:46	6.092	243	0.854	0.068	-4.543	1.006	0.152
2014 APR 24	2014 APR 17 22:58	7.043	210	0.850	0.064	-4.302	1.006	0.156
Crossing								
2014 MAY 11 03:36	2014 APR 19 19:23		62					



(a) (b) (c)

Figure 118: Encounter with P_2002_S7/ at 2014 APR 20 in the Ecliptic Coordinate System.

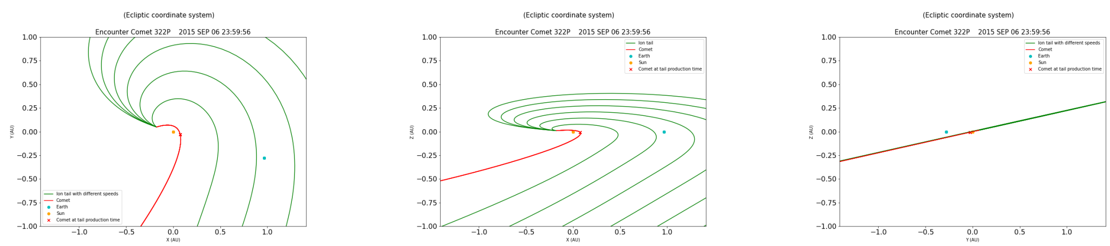


(a) (b) (c)

Figure 119: Encounter with P_2002_S7/ at 2014 APR 20 in the Comet Orbital Coordinate System.

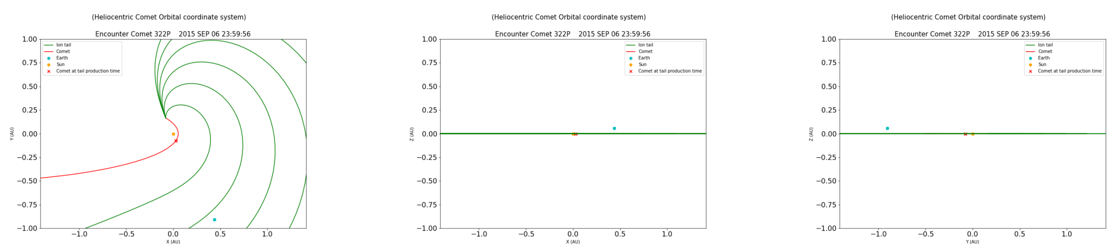
- Comet: **322P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2015 SEP 04	2015 SEP 03 04:33	1.810	894	0.932	0.066	4.090	1.008	0.076
2015 SEP 05	2015 SEP 03 04:52	2.797	579	0.933	0.063	3.868	1.008	0.075
2015 SEP 06	2015 SEP 03 05:11	3.784	428	0.933	0.059	3.645	1.008	0.075
2015 SEP 07	2015 SEP 03 05:29	4.771	340	0.934	0.056	3.421	1.008	0.074
2015 SEP 08	2015 SEP 03 05:48	5.758	282	0.934	0.052	3.197	1.007	0.073
2015 SEP 09	2015 SEP 03 06:07	6.745	241	0.935	0.048	2.972	1.007	0.072
2015 SEP 10	2015 SEP 03 06:25	7.732	210	0.935	0.045	2.747	1.007	0.072



(a) (b) (c)

Figure 120: Encounter with 322P at 2015 SEP 06 in the Ecliptic Coordinate System.

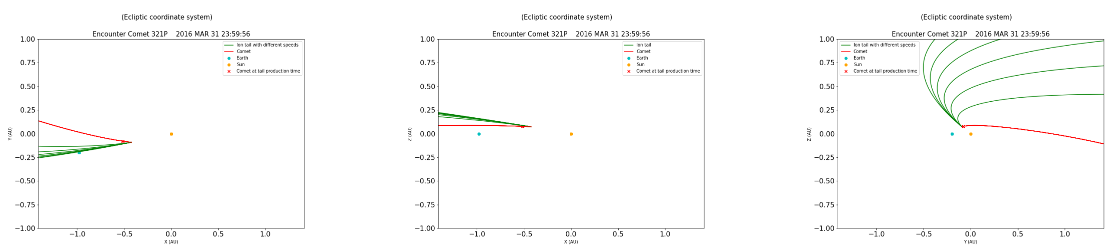


(a) (b) (c)

Figure 121: Encounter with 322P at 2015 SEP 06 in the Comet Orbital Coordinate System.

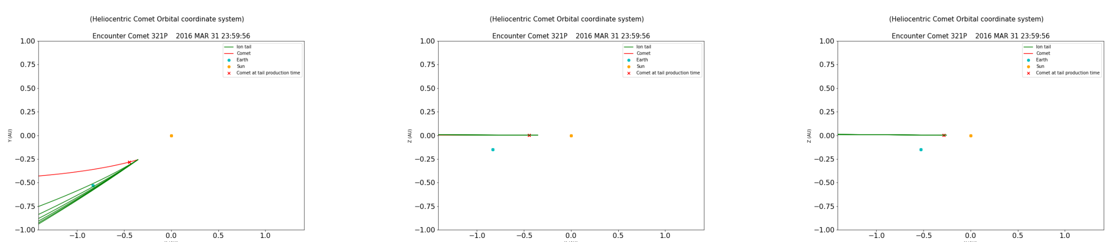
- Comet: **321P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2016 MAR 28	2016 MAR 26 01:16	2.947	217	0.368	0.133	-21.214	0.998	0.631
2016 MAR 29	2016 MAR 27 04:49	2.799	249	0.401	0.138	-20.194	0.999	0.598
2016 MAR 30	2016 MAR 28 05:41	2.763	271	0.432	0.144	-19.444	0.999	0.567
2016 MAR 31	2016 MAR 29 04:12	2.825	283	0.460	0.149	-18.885	0.999	0.539
Crossing								
2016 SEP 07 17:05	2016 APR 10 11:29		11					



(a) (b) (c)

Figure 122: Encounter with 321P/ at 2016 MAR 31 in the Ecliptic Coordinate System.

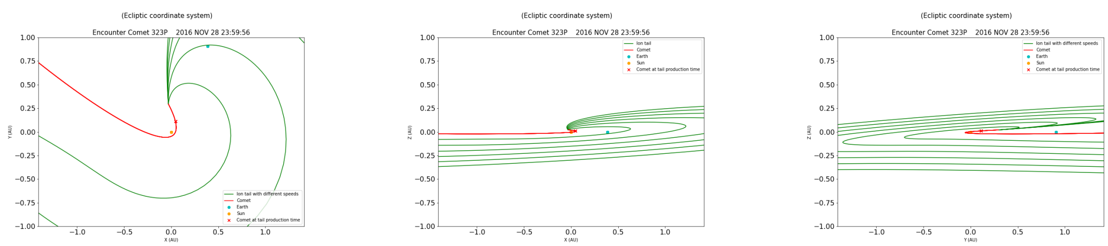


(a) (b) (c)

Figure 123: Encounter with 321P/ at 2016 MAR 311 in the Comet Orbital Coordinate System.

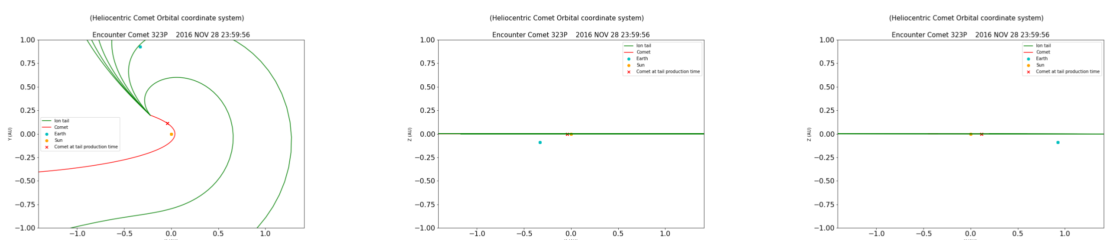
- Comet: **323P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2016 NOV 26	2016 NOV 25 02:13	1.907	797	0.876	0.091	-5.948	0.987	0.111
2016 NOV 27	2016 NOV 25 03:48	2.842	533	0.873	0.090	-5.946	0.987	0.113
2016 NOV 28	2016 NOV 25 05:22	3.776	400	0.870	0.090	-5.942	0.986	0.116
2016 NOV 29	2016 NOV 25 06:57	4.710	320	0.867	0.090	-5.938	0.986	0.119
2016 NOV 30	2016 NOV 25 08:31	5.645	266	0.864	0.089	-5.932	0.986	0.122
2016 DEC 01	2016 NOV 25 10:06	6.579	227	0.860	0.089	-5.925	0.986	0.125
Crossing								
2017 AUG 17 04:47	2016 NOV 23 15:19		6					



(a) (b) (c)

Figure 124: Encounter with 323P/ at 2016 NOV 28 in the Ecliptic Coordinate System.

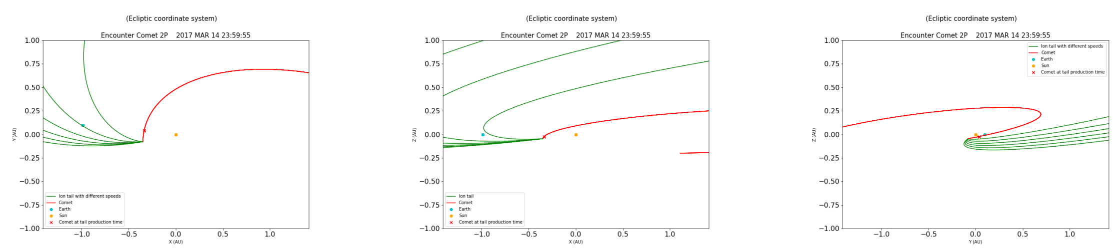


(a) (b) (c)

Figure 125: Encounter with 323P/ at 2016 NOV 28 in the Comet Orbital Coordinate System.

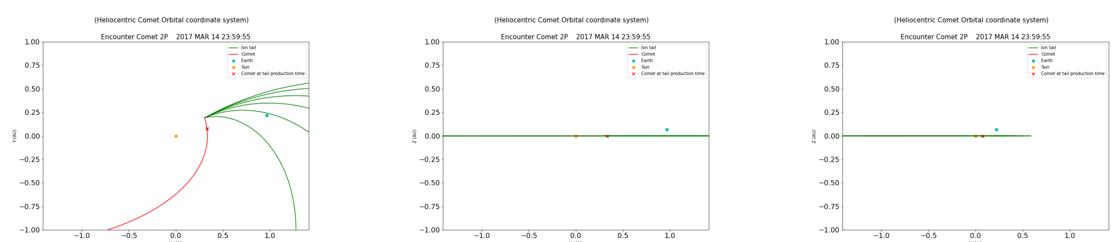
- Comet: **2P/Encke**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2017 MAR 12	2017 MAR 11 16:26	1.315	865	0.655	0.062	5.433	0.994	0.339
2017 MAR 13	2017 MAR 11 19:53	2.171	524	0.655	0.065	5.731	0.994	0.339
2017 MAR 14	2017 MAR 11 23:21	3.027	375	0.655	0.069	6.029	0.994	0.340
2017 MAR 15	2017 MAR 12 02:53	3.879	293	0.654	0.072	6.326	0.995	0.340
2017 MAR 16	2017 MAR 12 06:26	4.731	240	0.654	0.075	6.621	0.995	0.341
2017 MAR 17	2017 MAR 12 09:59	5.584	203	0.653	0.079	6.916	0.995	0.342
Crossing								
2018 FEB 23 11:58	2017 MAR 09 03:17		3					



(a) (b) (c)

Figure 126: Encounter with 2P/Encke at 2017 MAR 14 in the Ecliptic Coordinate System.

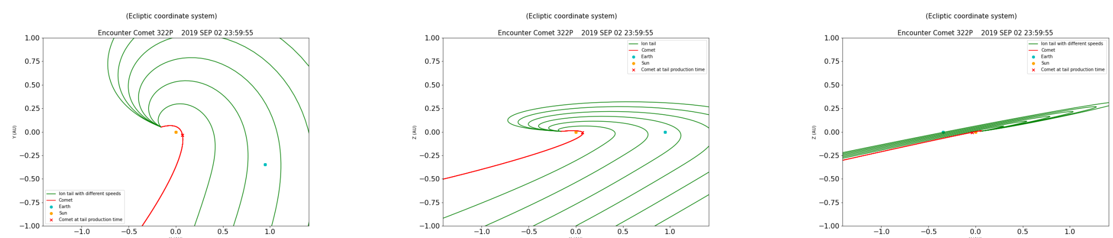


(a) (b) (c)

Figure 127: Encounter with 2P/Encke at 2017 MAR 14 in the Comet Orbital Coordinate System.

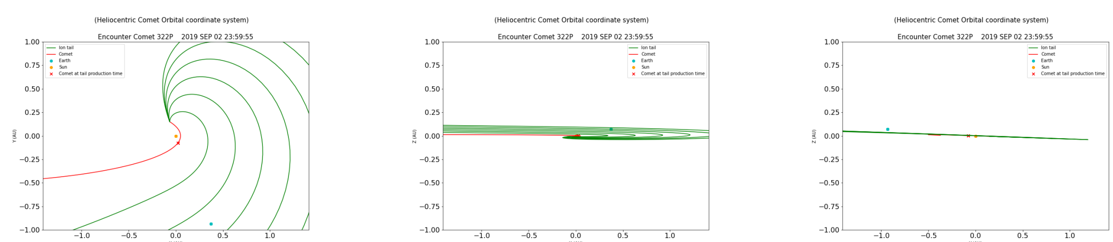
- Comet: **322P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2019 AUG 31	2019 AUG 30 14:57	1.377	1172	0.930	0.081	4.976	1.009	0.080
2019 SEP 01	2019 AUG 30 15:28	2.355	686	0.930	0.077	4.757	1.009	0.079
2019 SEP 02	2019 AUG 30 15:59	3.333	485	0.931	0.074	4.537	1.009	0.078
2019 SEP 03	2019 AUG 30 16:31	4.312	375	0.932	0.070	4.317	1.009	0.077
2019 SEP 04	2019 AUG 30 17:02	5.290	306	0.932	0.067	4.095	1.008	0.076
2019 SEP 05	2019 AUG 30 17:33	6.268	258	0.933	0.063	3.873	1.008	0.075
2019 SEP 06	2019 AUG 30 18:05	7.246	224	0.933	0.059	3.650	1.008	0.075
Crossing								
2019 SEP 23 02:39	2019 AUG 31 01:03		70					



(a) (b) (c)

Figure 128: Encounter with 322P at 2019 SEP 02 in the Ecliptic Coordinate System.

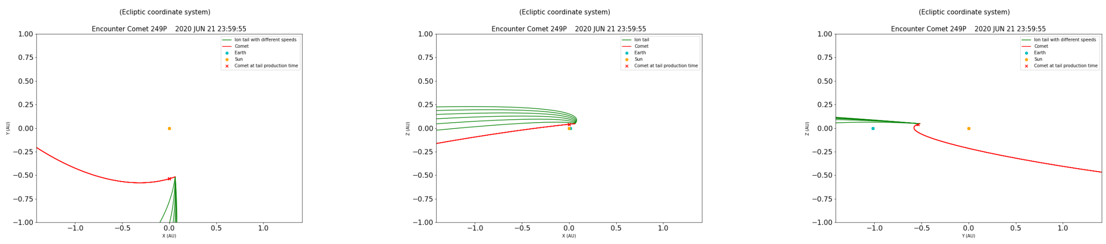


(a) (b) (c)

Figure 129: Encounter with 322P at 2019 SEP 02 in the Comet Orbital Coordinate System.

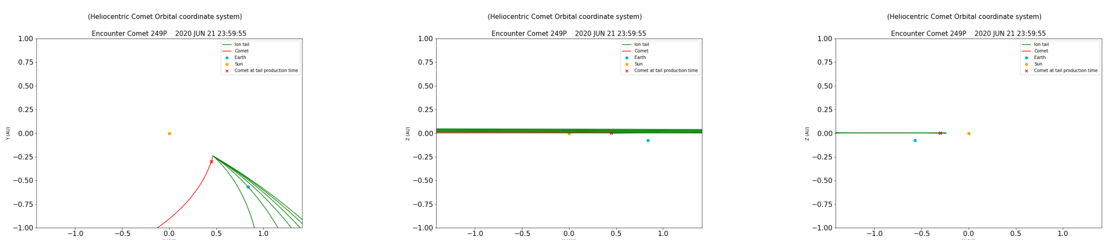
- Comet: **249P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2020 JUN 20	2020 JUN 19 15:42	1.345	604	0.468	0.074	-9.069	1.016	0.548
2020 JUN 21	2020 JUN 19 22:52	2.047	399	0.471	0.076	-9.283	1.016	0.546
2020 JUN 22	2020 JUN 20 05:51	2.756	298	0.473	0.078	-9.494	1.016	0.543
2020 JUN 23	2020 JUN 20 12:48	3.466	238	0.475	0.080	-9.702	1.016	0.541
Crossing								
2021 MAY 21 03:36	2020 JUN 08 09:37		2					



(a) (b) (c)

Figure 130: Encounter with 249P/ at 2020 JUN 21 in the Ecliptic Coordinate System.

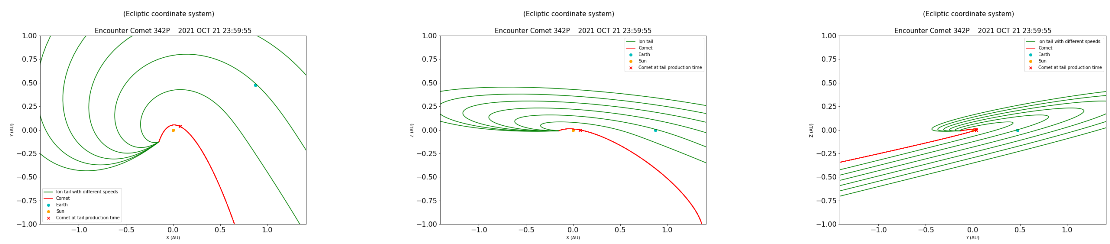


(a) (b) (c)

Figure 131: Encounter with 249P/ at 2020 JUN 21 in the Comet Orbital Coordinate System.

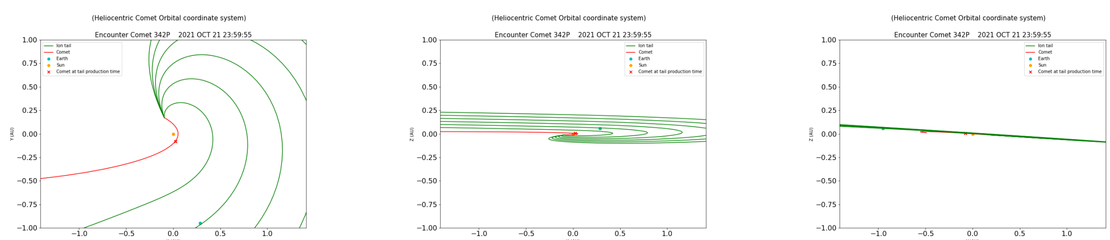
- Comet: **342P/**

Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2021 OCT 19	2021 OCT 17 21:15	2.114	749	0.912	0.066	4.174	0.996	0.084
2021 OCT 20	2021 OCT 17 22:01	3.082	514	0.913	0.063	3.929	0.996	0.083
2021 OCT 21	2021 OCT 17 22:46	4.051	391	0.913	0.059	3.685	0.995	0.082
2021 OCT 22	2021 OCT 17 23:31	5.019	316	0.914	0.055	3.439	0.995	0.081
2021 OCT 23	2021 OCT 18 00:05	5.996	265	0.915	0.051	3.194	0.995	0.080
2021 OCT 24	2021 OCT 18 00:21	6.985	228	0.916	0.047	2.947	0.994	0.079
Crossing								
2021 NOV 05 21:34	2021 OCT 18 03:23		85					



(a) (b) (c)

Figure 132: Encounter with 342P/ at 2021 OCT 21 in the Ecliptic Coordinate System.

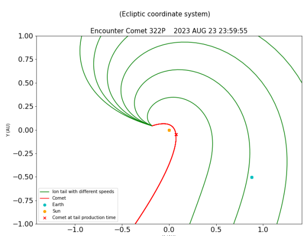


(a) (b) (c)

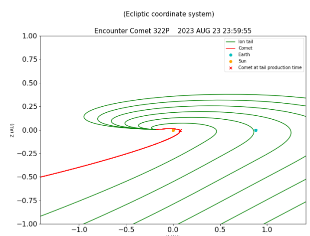
Figure 133: Encounter with 342P/ at 2021 OCT 21 in the Comet Orbital Coordinate System.

- Comet: **322P/**

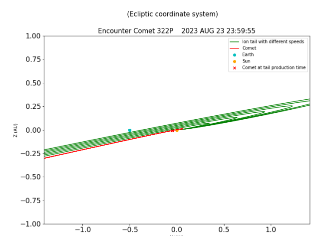
Date Earth	Date Comet	t delay (days)	SW Speed (km/s)	d_{E-C} (AU)	d_{E-T} (AU)	Angle (deg)	d_{E-S} (AU)	d_{C-S} (AU)
2023 AUG 21	2023 AUG 20 01:45	1.927	830	0.921	0.114	7.117	1.012	0.090
2023 AUG 22	2023 AUG 20 02:03	2.914	550	0.922	0.111	6.908	1.011	0.089
2023 AUG 23	2023 AUG 20 02:21	3.901	411	0.923	0.108	6.698	1.011	0.088
2023 AUG 24	2023 AUG 20 02:40	4.889	328	0.924	0.104	6.487	1.011	0.087
2023 AUG 25	2023 AUG 20 02:58	5.876	273	0.925	0.101	6.275	1.011	0.086
2023 AUG 26	2023 AUG 20 03:17	6.863	234	0.926	0.098	6.062	1.011	0.085
2023 AUG 27	2023 AUG 20 03:35	7.850	205	0.927	0.094	5.848	1.010	0.084
Crossing								
2023 SEP 23 03:05	2023 AUG 20 11:35		48					



(a)

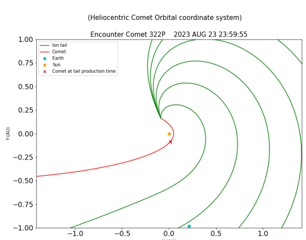


(b)

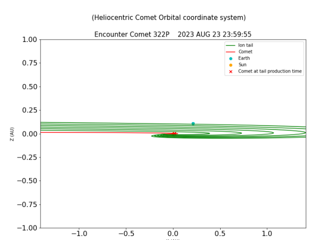


(c)

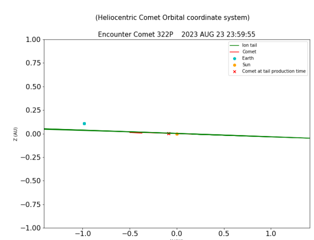
Figure 134: Encounter with in the Ecliptic Coordinate System.



(a)



(b)



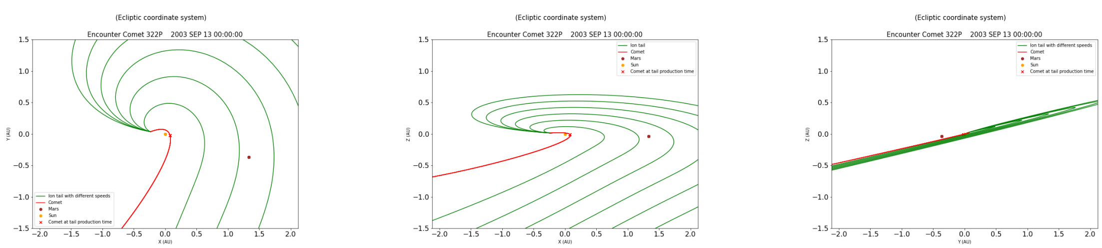
(c)

Figure 135: Encounter with in the Comet Orbital Coordinate System.

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2003 SEP 10	2003 SEP 07 23:40	2.013	1126	1.306	0.047	2.056	1.382	0.076
2003 SEP 11	2003 SEP 08 00:03	2.998	757	1.307	0.044	1.923	1.382	0.075
2003 SEP 12	2003 SEP 08 00:13	3.990	569	1.308	0.041	1.790	1.382	0.075
2003 SEP 13	2003 SEP 08 00:24	4.983	456	1.308	0.038	1.658	1.382	0.074
2003 SEP 14	2003 SEP 08 00:35	5.976	380	1.309	0.035	1.525	1.383	0.074
2003 SEP 15	2003 SEP 08 00:45	6.968	326	1.310	0.032	1.392	1.383	0.073
2003 SEP 16	2003 SEP 08 00:56	7.961	286	1.310	0.029	1.259	1.383	0.073
2003 SEP 17	2003 SEP 08 01:07	8.953	254	1.311	0.026	1.126	1.383	0.072
2003 SEP 18	2003 SEP 08 01:17	9.946	229	1.312	0.023	0.993	1.384	0.072
2003 SEP 19	2003 SEP 08 01:28	10.938	208	1.312	0.020	0.861	1.384	0.071
Crossing								
2003 SEP 25 11:51	2003 SEP 08 02:37		132					

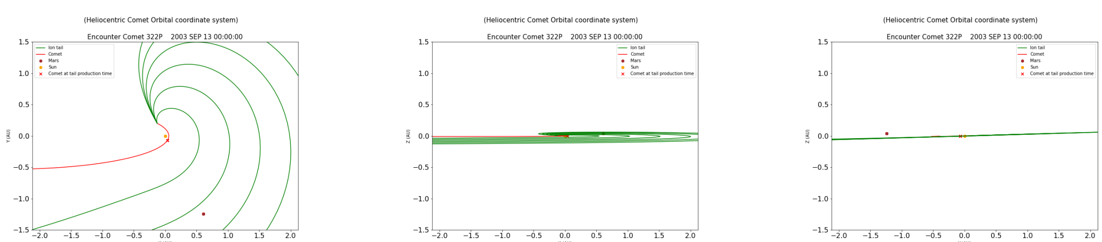
A.2.5 Mars Encounters

- Comet: **322P/**



(a) (b) (c)

Figure 136: Encounter with 322P/ at 2003 SEP 13 in the Ecliptic Coordinate System.

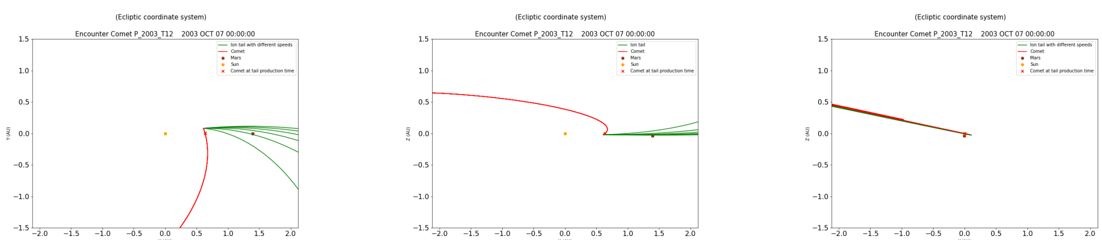


(a) (b) (c)

Figure 137: Encounter with 322P/ at 2003 SEP 13 in the Comet Orbital Coordinate System.

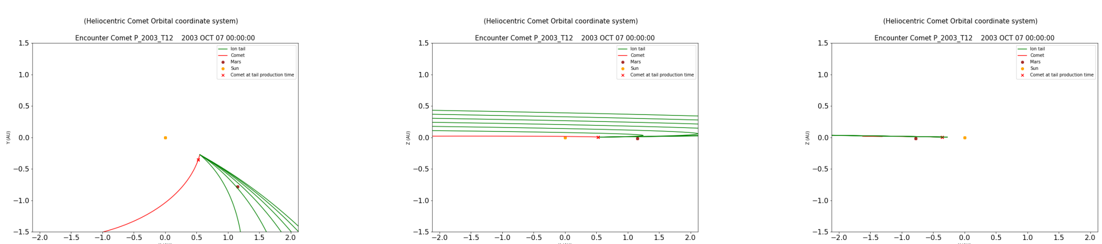
- Comet: **P_2003_T12/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2003 OCT 05	2003 OCT 03 12:46	1.468	905	0.765	0.024	-1.811	1.390	0.625
2003 OCT 06	2003 OCT 03 18:44	2.219	600	0.767	0.021	-1.557	1.391	0.623
2003 OCT 07	2003 OCT 04 00:40	2.972	450	0.770	0.018	-1.305	1.391	0.622
2003 OCT 08	2003 OCT 04 06:29	3.730	359	0.772	0.014	-1.055	1.392	0.620
2003 OCT 09	2003 OCT 04 12:18	4.487	300	0.774	0.011	-0.806	1.392	0.618
2003 OCT 10	2003 OCT 04 18:06	5.245	257	0.776	0.008	-0.558	1.393	0.616
2003 OCT 11	2003 OCT 04 23:54	6.004	225	0.779	0.004	-0.312	1.393	0.615
2003 OCT 12	2003 OCT 05 05:35	6.767	200	0.781	0.001	-0.067	1.394	0.613
Crossing								
2003 OCT 12 06:34	2003 OCT 05 07:08		194					



(a) (b) (c)

Figure 138: Encounter with P_2003_T12/ at 2003 OCT 07 in the Ecliptic Coordinate System.

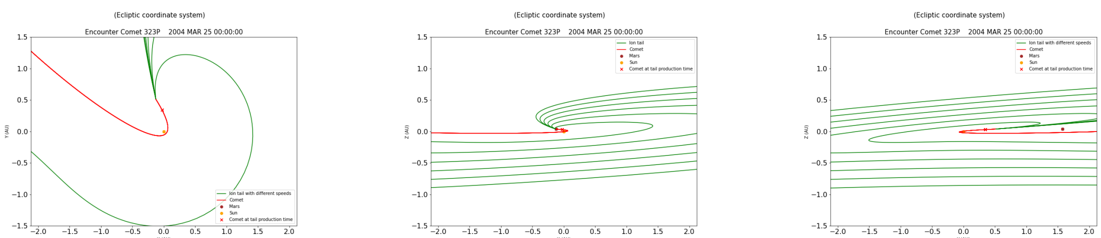


(a) (b) (c)

Figure 139: Encounter with P_2003_T12/ at 2003 OCT 07 in the Comet Orbital Coordinate System.

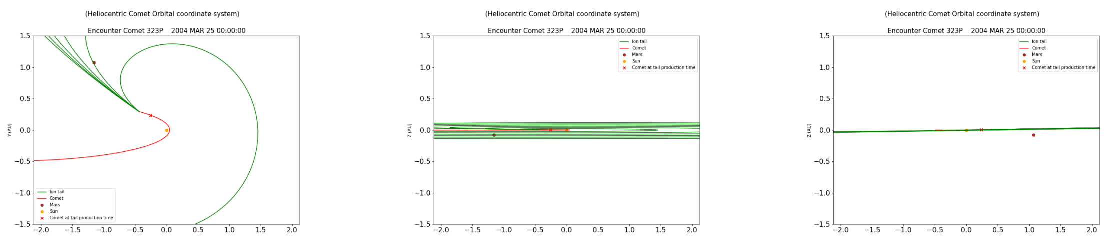
- Comet: **323P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2004 MAR 21	2004 MAR 18 20:16	2.155	1061	1.317	0.081	-3.527	1.576	0.259
2004 MAR 22	2004 MAR 18 23:49	3.007	758	1.314	0.080	-3.493	1.577	0.264
2004 MAR 23	2004 MAR 19 04:15	3.823	595	1.309	0.079	-3.458	1.579	0.269
2004 MAR 24	2004 MAR 19 08:43	4.637	489	1.305	0.078	-3.423	1.580	0.275
2004 MAR 25	2004 MAR 19 13:11	5.451	414	1.301	0.077	-3.388	1.581	0.280
2004 MAR 26	2004 MAR 19 17:38	6.265	359	1.296	0.076	-3.354	1.582	0.286
2004 MAR 27	2004 MAR 19 22:05	7.079	317	1.291	0.075	-3.319	1.583	0.292
2004 MAR 28	2004 MAR 20 03:06	7.871	284	1.286	0.074	-3.284	1.584	0.298
2004 MAR 29	2004 MAR 20 08:31	8.645	257	1.281	0.073	-3.249	1.585	0.304
2004 MAR 30	2004 MAR 20 13:56	9.419	235	1.276	0.072	-3.214	1.587	0.311
2004 MAR 31	2004 MAR 20 19:21	10.194	216	1.270	0.070	-3.179	1.588	0.318
2004 APR 01	2004 MAR 21 00:54	10.962	200	1.264	0.069	-3.144	1.589	0.325
Crossing								
2005 MAY 28 21:14								



(a) (b) (c)

Figure 140: Encounter with 323P/ at 2004 MAR 25 in the Ecliptic Coordinate System.

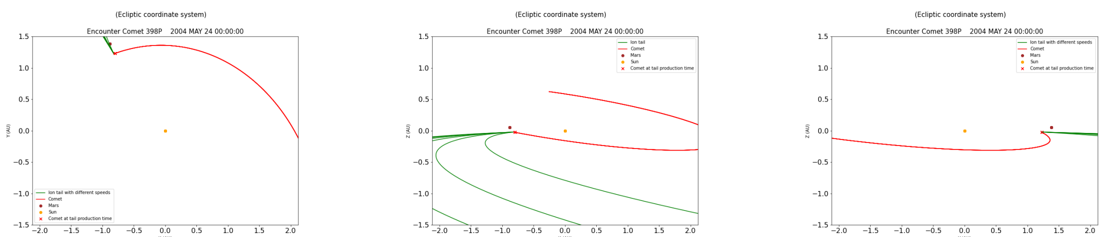


(a) (b) (c)

Figure 141: Encounter with 323P/ at 2004 MAR 25 in the Comet Orbital Coordinate System.

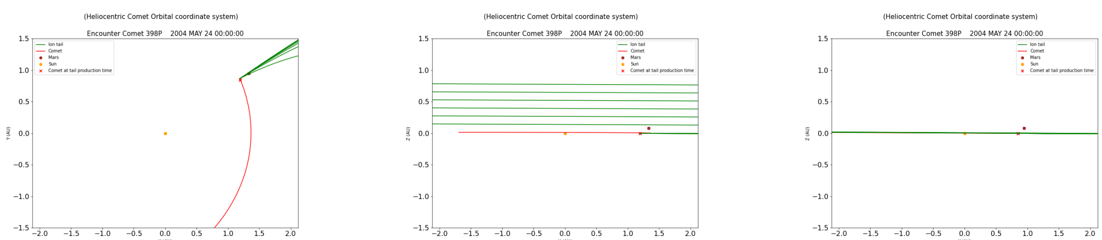
- Comet: **398P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2004 MAY 22	2004 MAY 21 14:24	0.400	1003	0.231	0.082	20.656	1.637	1.405
2004 MAY 23	2004 MAY 22 06:14	0.740	538	0.229	0.079	20.207	1.637	1.408
2004 MAY 24	2004 MAY 22 22:07	1.078	367	0.228	0.077	19.754	1.638	1.410
2004 MAY 25	2004 MAY 23 14:04	1.414	277	0.226	0.075	19.299	1.639	1.413
2004 MAY 26	2004 MAY 24 06:02	1.748	222	0.224	0.072	18.839	1.639	1.415
Crossing								
2004 JUN 25 17:13	2004 JUN 14 18:07		23					



(a) (b) (c)

Figure 142: Encounter with 398P/ at 2004 MAY 24 in the Ecliptic Coordinate System.

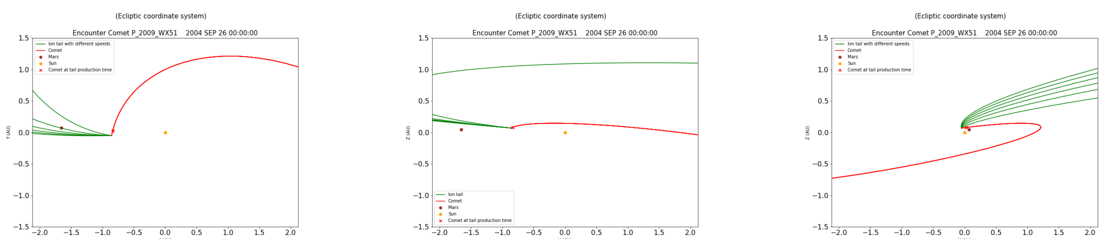


(a) (b) (c)

Figure 143: Encounter with 398P/ at 2004 MAY 24 in the Comet Orbital Coordinate System.

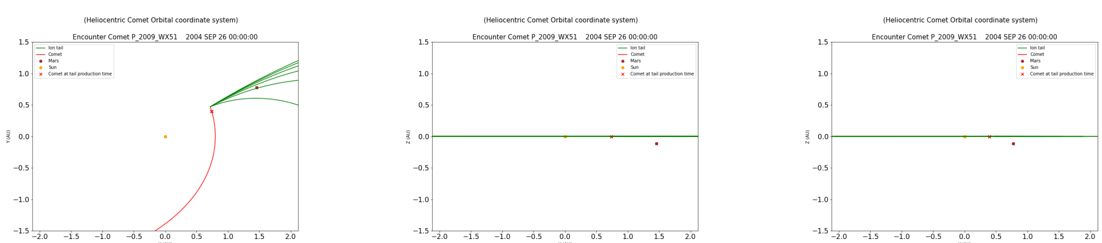
- Comet: **P_2009_WX51/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2004 SEP 24	2004 SEP 22 03:52	1.839	771	0.816	0.116	-8.201	1.655	0.839
2004 SEP 25	2004 SEP 22 10:16	2.572	550	0.814	0.115	-8.110	1.655	0.840
2004 SEP 26	2004 SEP 22 16:41	3.305	427	0.812	0.113	-8.019	1.654	0.842
2004 SEP 27	2004 SEP 22 23:05	4.038	349	0.811	0.112	-7.927	1.654	0.843
2004 SEP 28	2004 SEP 23 05:34	4.767	295	0.809	0.110	-7.834	1.653	0.845
2004 SEP 29	2004 SEP 23 12:04	5.497	255	0.807	0.109	-7.741	1.653	0.846
2004 SEP 30	2004 SEP 23 18:34	6.226	224	0.805	0.107	-7.647	1.652	0.847
2004 OCT 01	2004 SEP 24 01:05	6.954	200	0.803	0.106	-7.553	1.652	0.849
Crossing								
2004 DEC 01 03:57	2004 OCT 13 21:16		22					



(a) (b) (c)

Figure 144: Encounter with P_2009_WX51/ at 2004 SEP 26 in the Ecliptic Coordinate System.

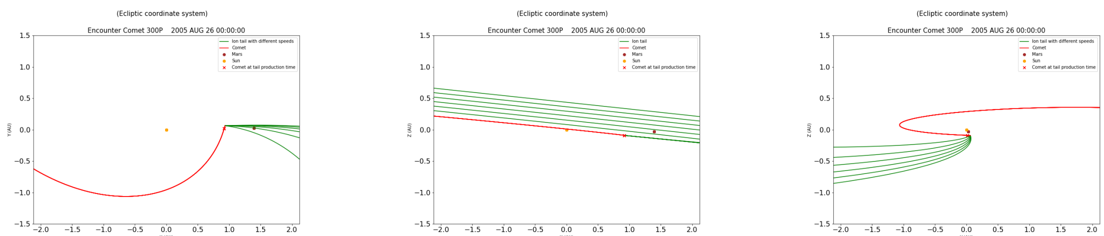


(a) (b) (c)

Figure 145: Encounter with P_2009_WX51/ at 2004 SEP 26 in the Comet Orbital Coordinate System.

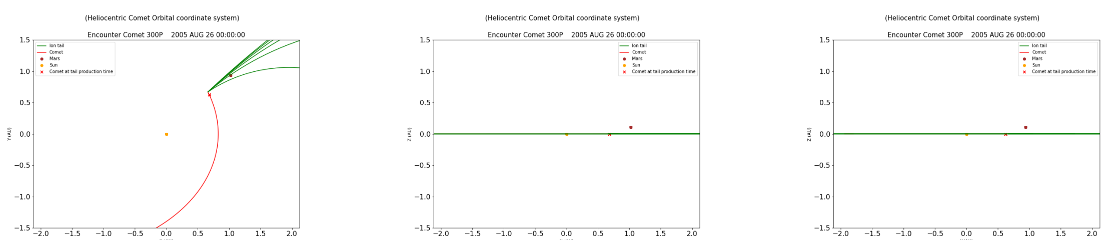
- Comet: **300P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2005 AUG 24	2005 AUG 22 23:09	1.035	794	0.473	0.103	12.593	1.391	0.918
2005 AUG 25	2005 AUG 23 10:08	1.578	518	0.471	0.104	12.725	1.392	0.921
2005 AUG 26	2005 AUG 23 21:06	2.120	383	0.468	0.104	12.858	1.392	0.924
2005 AUG 27	2005 AUG 24 08:12	2.658	304	0.465	0.105	12.993	1.393	0.927
2005 AUG 28	2005 AUG 24 19:19	3.195	252	0.463	0.105	13.129	1.393	0.931
2005 AUG 29	2005 AUG 25 06:32	3.727	214	0.460	0.106	13.266	1.394	0.934
Crossing								
2005 MAY 08 23:51								



(a) (b) (c)

Figure 146: Encounter with 300P/ at 2005 AUG 26 in the Ecliptic Coordinate System.

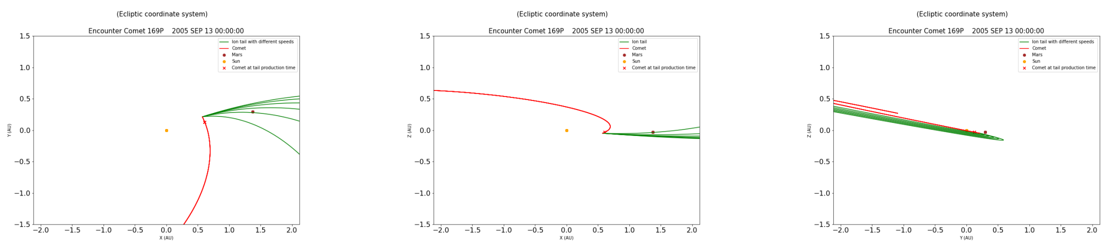


(a) (b) (c)

Figure 147: Encounter with 300P/ at 2005 AUG 26 in the Comet Orbital Coordinate System.

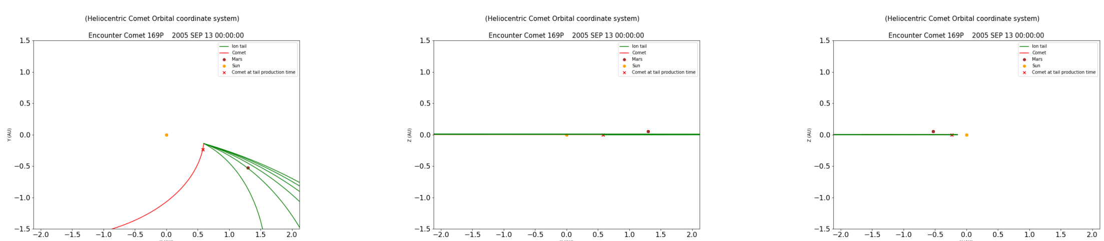
- Comet: **169P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2005 SEP 11	2005 SEP 09 06:51	1.714	783	0.773	0.042	3.130	1.403	0.629
2005 SEP 12	2005 SEP 09 12:24	2.483	542	0.775	0.045	3.363	1.403	0.628
2005 SEP 13	2005 SEP 09 17:57	3.252	415	0.777	0.049	3.595	1.404	0.627
2005 SEP 14	2005 SEP 09 23:30	4.021	336	0.779	0.052	3.825	1.405	0.626
2005 SEP 15	2005 SEP 10 04:58	4.793	283	0.781	0.055	4.054	1.406	0.625
2005 SEP 16	2005 SEP 10 10:25	5.566	244	0.783	0.058	4.281	1.407	0.624
2005 SEP 17	2005 SEP 10 15:52	6.339	215	0.784	0.062	4.507	1.407	0.623
Crossing								
2005 AUG 29 02:10								



(a) (b) (c)

Figure 148: Encounter with 169P/ at 2005 SEP 13 in the Ecliptic Coordinate System.

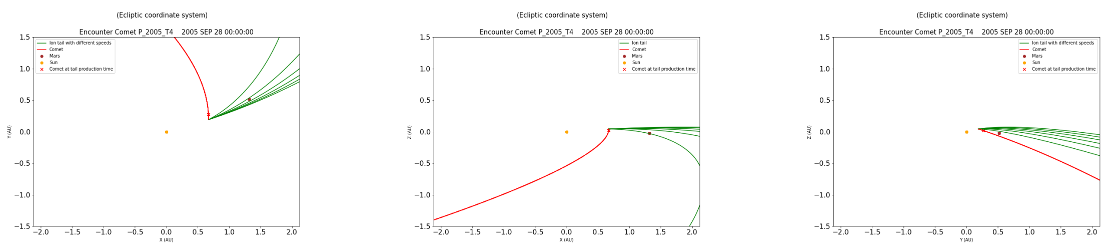


(a) (b) (c)

Figure 149: Encounter with 169P/ at 2005 SEP 13 in the Comet Orbital Coordinate System.

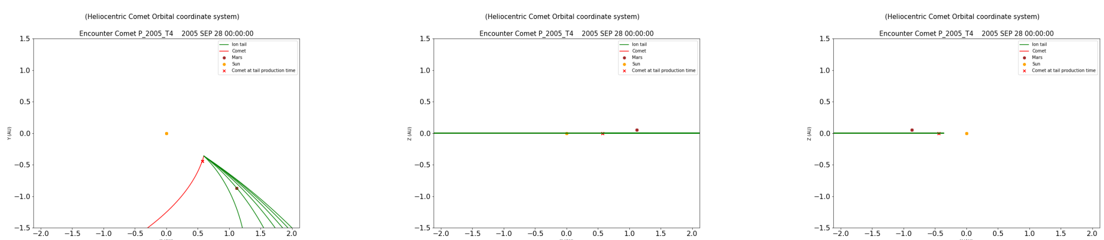
- Comet: **P_2005_T4/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2005 SEP 27	2005 SEP 25 05:28	1.772	682	0.696	0.060	4.985	1.416	0.720
2005 SEP 28	2005 SEP 24 23:09	3.035	397	0.694	0.055	4.545	1.417	0.723
2005 SEP 29	2005 SEP 24 16:42	4.304	279	0.693	0.050	4.103	1.418	0.725
2005 SEP 30	2005 SEP 24 10:16	5.572	215	0.691	0.044	3.659	1.419	0.728
Crossing								
2005 OCT 08 01:45	2005 SEP 22 05:07		74					



(a) (b) (c)

Figure 150: Encounter with P_2005_T4 at 2005 SEP 28 in the Ecliptic Coordinate System.

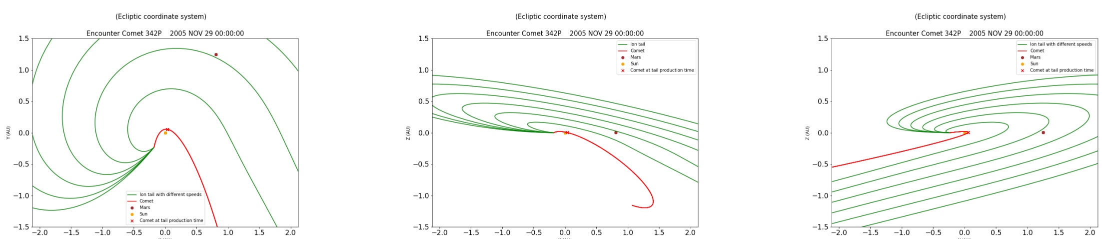


(a) (b) (c)

Figure 151: Encounter with P_2005_T4 at 2005 SEP 28 in the Comet Orbital Coordinate System.

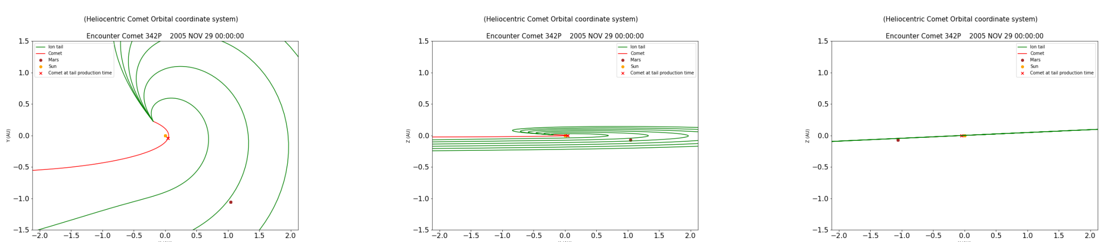
- Comet: **342P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2005 NOV 26	2005 NOV 23 00:08	2.994	824	1.422	0.066	-2.656	1.484	0.063
2005 NOV 27	2005 NOV 23 00:16	3.988	619	1.423	0.069	-2.767	1.486	0.063
2005 NOV 28	2005 NOV 23 00:24	4.983	496	1.425	0.071	-2.876	1.487	0.062
2005 NOV 29	2005 NOV 23 00:32	5.977	414	1.426	0.074	-2.986	1.488	0.062
2005 NOV 30	2005 NOV 23 00:40	6.972	356	1.428	0.077	-3.094	1.490	0.062
2005 DEC 01	2005 NOV 23 00:48	7.966	311	1.429	0.080	-3.203	1.491	0.062
2005 DEC 02	2005 NOV 23 00:56	8.961	277	1.431	0.083	-3.311	1.492	0.061
2005 DEC 03	2005 NOV 23 01:04	9.955	250	1.432	0.085	-3.418	1.493	0.061
2005 DEC 04	2005 NOV 23 01:12	10.950	227	1.434	0.088	-3.525	1.495	0.061
2005 DEC 05	2005 NOV 23 01:20	11.944	209	1.435	0.091	-3.631	1.496	0.061
Crossing								
2005 NOV 02 22:26								



(a) (b) (c)

Figure 152: Encounter with 342P/ at 2005 NOV 29 in the Ecliptic Coordinate System.

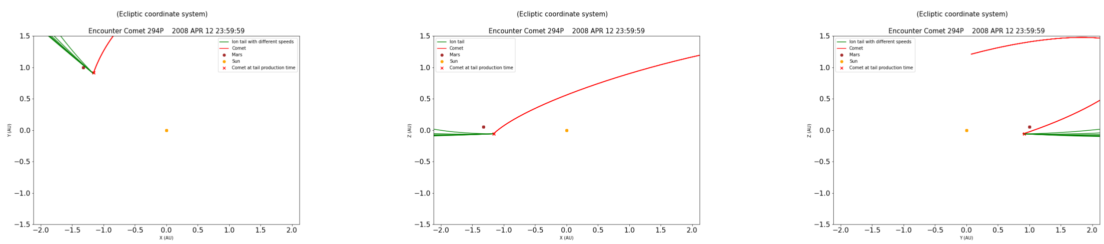


(a) (b) (c)

Figure 153: Encounter with 342P/ at 2005 NOV 29 in the Ecliptic Coordinate System.

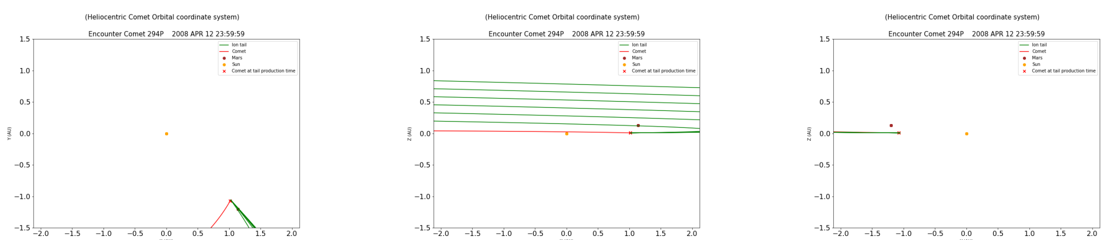
- Comet: **294P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2008 APR 11	2008 APR 11 10:22	0.568	630	0.206	0.126	37.777	1.661	1.455
2008 APR 12	2008 APR 12 01:50	0.923	394	0.210	0.130	38.406	1.661	1.452
2008 APR 13	2008 APR 12 17:13	1.282	288	0.213	0.134	39.027	1.662	1.449
2008 APR 14	2008 APR 13 08:32	1.644	229	0.217	0.138	39.640	1.662	1.445
Crossing								
2008 MAR 12 04:15								



(a) (b) (c)

Figure 154: Encounter with 294P/ at 2008 APR 12 in the Ecliptic Coordinate System.

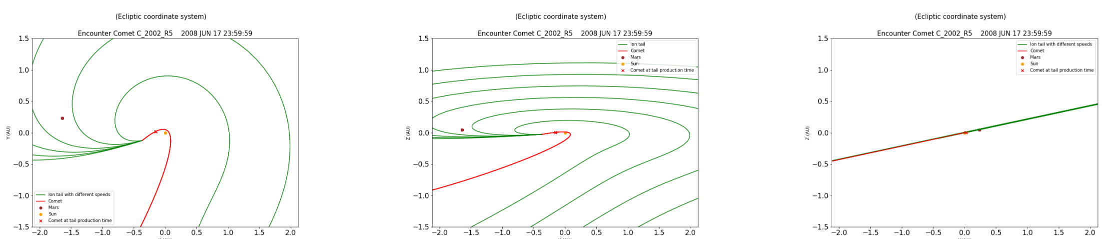


(a) (b) (c)

Figure 155: Encounter with 294P/ at 2008 APR 12 in the Comet Orbital Coordinate System.

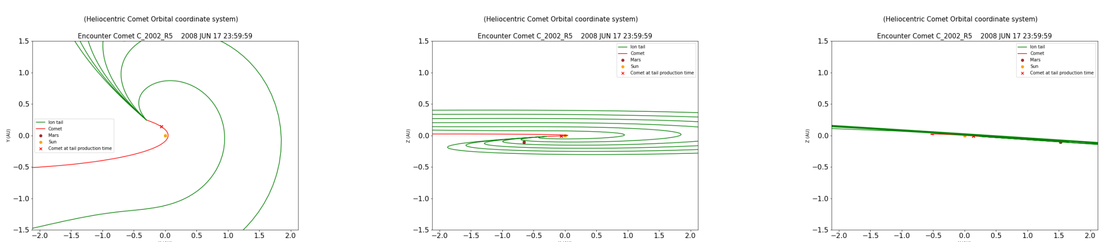
- Comet: **C_2002_R5/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2008 JUN 14	2008 JUN 12 07:16	2.697	973	1.512	0.112	-4.229	1.661	0.149
2008 JUN 15	2008 JUN 12 08:06	3.662	716	1.510	0.109	-4.133	1.660	0.150
2008 JUN 16	2008 JUN 12 08:57	4.627	566	1.508	0.106	-4.036	1.660	0.152
2008 JUN 17	2008 JUN 12 09:47	5.592	468	1.506	0.103	-3.938	1.660	0.154
2008 JUN 18	2008 JUN 12 10:38	6.557	398	1.504	0.101	-3.840	1.659	0.155
2008 JUN 19	2008 JUN 12 11:28	7.522	347	1.502	0.098	-3.742	1.659	0.157
2008 JUN 20	2008 JUN 12 12:18	8.487	307	1.500	0.095	-3.643	1.658	0.159
2008 JUN 21	2008 JUN 12 13:09	9.452	275	1.497	0.093	-3.544	1.658	0.161
2008 JUN 22	2008 JUN 12 13:59	10.417	249	1.495	0.090	-3.445	1.658	0.163
2008 JUN 23	2008 JUN 12 14:50	11.382	228	1.493	0.087	-3.345	1.657	0.165
2008 JUN 24	2008 JUN 12 15:40	12.347	210	1.490	0.084	-3.245	1.657	0.166
Crossing								
2008 JUL 25 02:47	2008 JUN 14 08:39		59					



(a) (b) (c)

Figure 156: Encounter with C_2002_R5/ at 2008 JUN 17 in the Ecliptic Coordinate System.

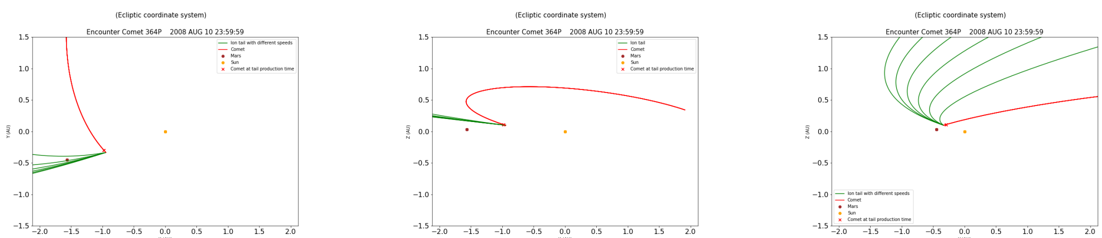


(a) (b) (c)

Figure 157: Encounter with C_2002_R5/ at 2008 JUN 17 in the Comet Orbital Coordinate System.

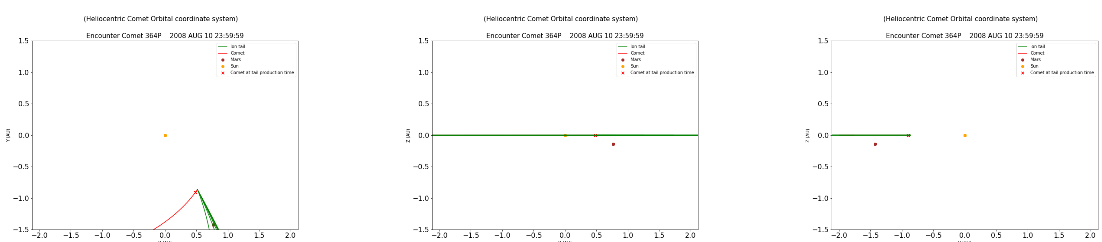
- Comet: **364P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2008 AUG 08	2008 AUG 07 20:52	1.130	916	0.596	0.148	-14.382	1.629	1.032
2008 AUG 09	2008 AUG 08 06:53	1.713	608	0.599	0.146	-14.102	1.628	1.028
2008 AUG 10	2008 AUG 08 16:52	2.297	455	0.602	0.144	-13.824	1.627	1.025
2008 AUG 11	2008 AUG 09 02:48	2.883	365	0.605	0.142	-13.550	1.626	1.021
2008 AUG 12	2008 AUG 09 12:37	3.474	304	0.608	0.140	-13.279	1.625	1.017
2008 AUG 13	2008 AUG 09 22:27	4.064	261	0.611	0.138	-13.011	1.624	1.013
2008 AUG 14	2008 AUG 10 08:08	4.661	229	0.614	0.135	-12.746	1.624	1.009
2008 AUG 15	2008 AUG 10 17:48	5.258	204	0.617	0.133	-12.484	1.623	1.006
Crossing								
2008 OCT 12 07:00	2008 AUG 30 15:36		29					



(a) (b) (c)

Figure 158: Encounter with 364P/ at 2008 AUG 10 in the Ecliptic Coordinate System.

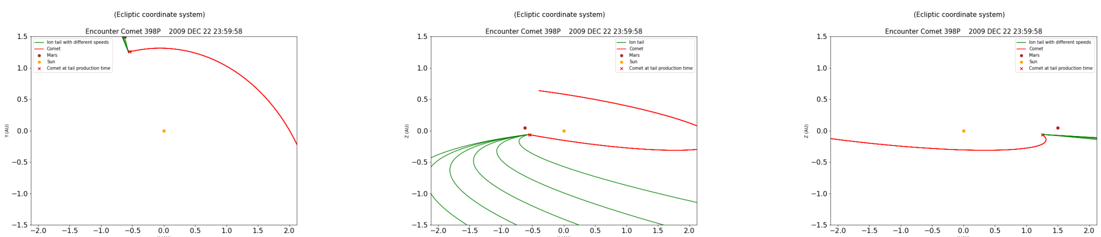


(a) (b) (c)

Figure 159: Encounter with 364P/ at 2008 AUG 10 in the Comet Orbital Coordinate System.

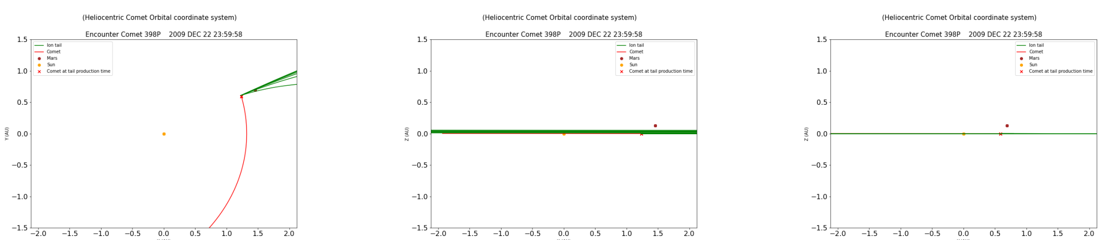
- Comet: **398P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2009 DEC 20	2009 DEC 20 14:41	0.388	1155	0.258	0.130	30.264	1.618	1.360
2009 DEC 21	2009 DEC 21 05:04	0.788	567	0.257	0.128	29.822	1.619	1.362
2009 DEC 22	2009 DEC 21 19:29	1.188	375	0.256	0.126	29.382	1.620	1.364
2009 DEC 23	2009 DEC 22 09:56	1.586	280	0.255	0.124	28.943	1.621	1.365
2009 DEC 24	2009 DEC 23 00:22	1.984	223	0.255	0.121	28.506	1.622	1.367
Crossing								
2010 FEB 15 15:49	2010 JAN 25 19:51		12					



(a) (b) (c)

Figure 160: Encounter with 398P/ at 2009 DEC 22 in the Ecliptic Coordinate System.

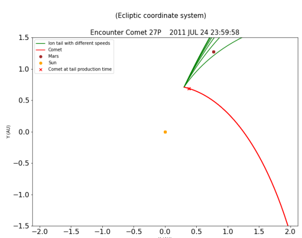


(a) (b) (c)

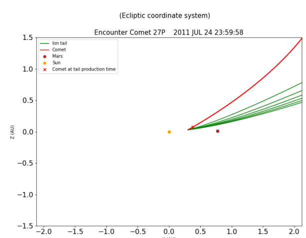
Figure 161: Encounter with 398P/ at 2009 DEC 22 in the Comet Orbital Coordinate System.

- Comet: **27P/**

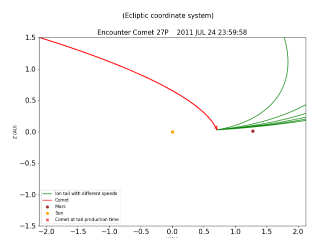
Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2011 JUL 23	2011 JUL 21 11:49	2.507	485	0.701	0.150	-12.351	1.491	0.790
2011 JUL 24	2011 JUL 21 17:48	3.258	375	0.704	0.143	-11.721	1.492	0.788
2011 JUL 25	2011 JUL 21 23:47	4.009	306	0.707	0.136	-11.097	1.494	0.787
2011 JUL 26	2011 JUL 22 05:39	4.764	258	0.709	0.129	-10.478	1.495	0.786
2011 JUL 27	2011 JUL 22 11:30	5.521	224	0.712	0.122	-9.865	1.496	0.784
Crossing								
2011 AUG 14 05:47	2011 JUL 26 11:49		70					



(a)

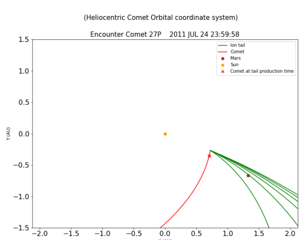


(b)

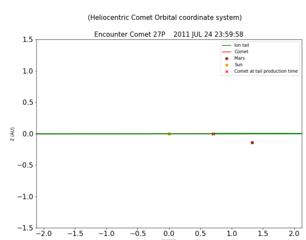


(c)

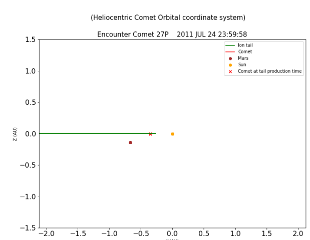
Figure 162: Encounter with 27P/ at 2011 JUL 24 in the Ecliptic Coordinate System.



(a)



(b)

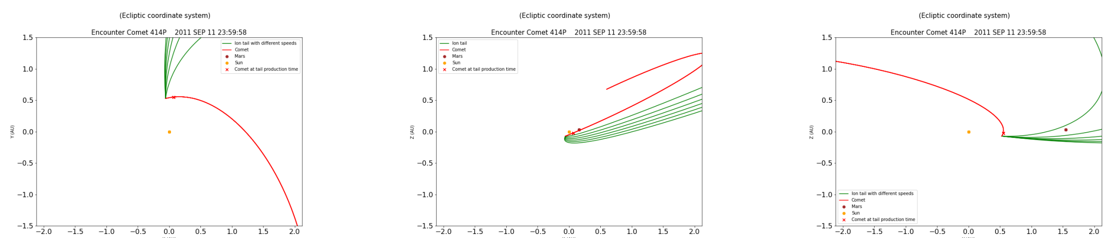


(c)

Figure 163: Encounter with 27P/ at 2011 JUL 24 in the Comet Orbital Coordinate System.

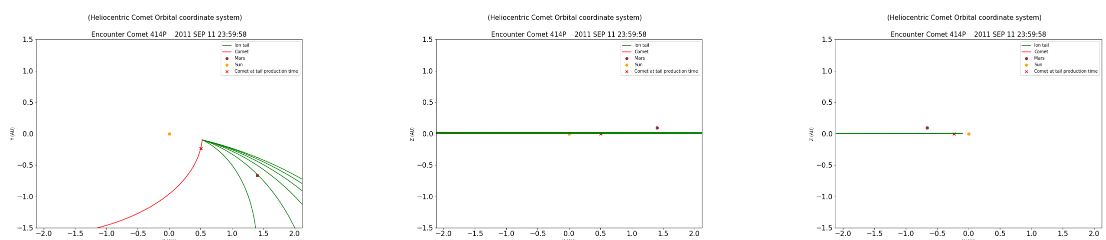
- Comet: **414P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2011 SEP 08	2011 SEP 07 03:00	1.875	925	0.999	0.078	4.482	1.552	0.553
2011 SEP 09	2011 SEP 07 06:30	2.729	637	1.001	0.084	4.804	1.553	0.552
2011 SEP 10	2011 SEP 07 09:59	3.583	486	1.004	0.090	5.125	1.554	0.551
2011 SEP 11	2011 SEP 07 13:29	4.438	393	1.006	0.095	5.444	1.556	0.550
2011 SEP 12	2011 SEP 07 16:58	5.293	331	1.008	0.101	5.762	1.557	0.549
2011 SEP 13	2011 SEP 07 20:26	6.148	285	1.010	0.107	6.078	1.558	0.548
2011 SEP 14	2011 SEP 07 23:55	7.003	251	1.012	0.113	6.393	1.559	0.547
2011 SEP 15	2011 SEP 08 03:19	7.861	224	1.014	0.118	6.706	1.561	0.547
2011 SEP 16	2011 SEP 08 06:43	8.720	202	1.016	0.124	7.018	1.562	0.546
Crossing								
2011 AUG 26 13:35								



(a) (b) (c)

Figure 164: Encounter with 414P/ at 2011 SEP 11 in the Ecliptic Coordinate System.

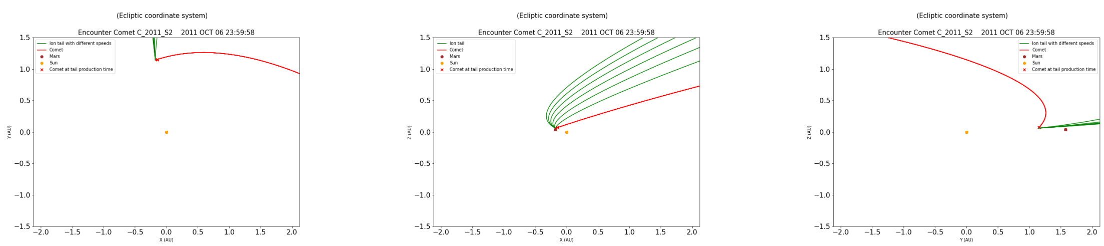


(a) (b) (c)

Figure 165: Encounter with 414P/ at 2011 SEP 11 in the Comet Orbital Coordinate System.

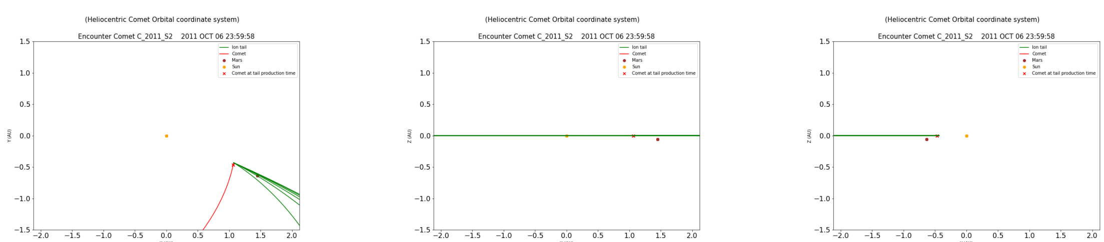
- Comet: **C_2011_S2/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2011 OCT 05	2011 OCT 05 00:38	0.973	750	0.420	0.065	-8.833	1.584	1.164
2011 OCT 06	2011 OCT 05 10:54	1.546	475	0.423	0.060	-8.197	1.585	1.162
2011 OCT 07	2011 OCT 05 21:08	2.119	349	0.426	0.056	-7.572	1.586	1.160
2011 OCT 08	2011 OCT 06 07:18	2.696	276	0.429	0.052	-6.957	1.588	1.158
2011 OCT 09	2011 OCT 06 17:26	3.273	229	0.432	0.048	-6.350	1.589	1.157
Crossing								
2011 OCT 21 08:39	2011 OCT 11 09:32		80					



(a) (b) (c)

Figure 166: Encounter with C_2011_S2 at 2011 OCT 06 in the Ecliptic Coordinate System.

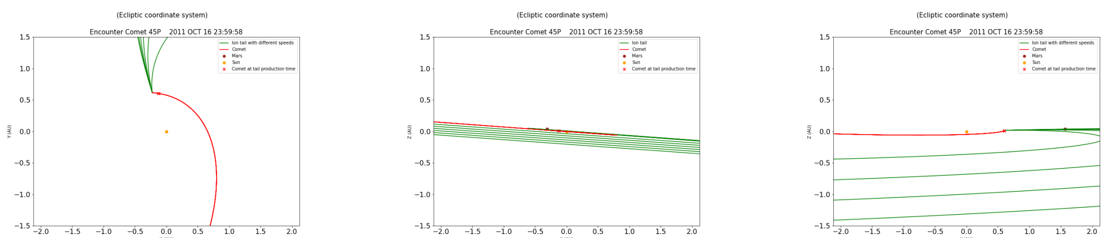


(a) (b) (c)

Figure 167: Encounter with C_2011_S2 at 2011 OCT 06 in the Comet Orbital Coordinate System.

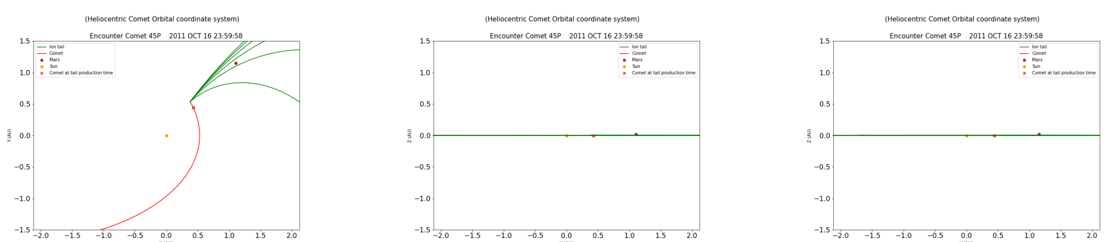
- Comet: **45P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2011 OCT 14	2011 OCT 13 00:08	1.994	853	0.980	0.017	0.966	1.594	0.614
2011 OCT 15	2011 OCT 13 04:36	2.808	605	0.979	0.016	0.927	1.595	0.616
2011 OCT 16	2011 OCT 13 09:04	3.622	469	0.978	0.015	0.888	1.596	0.618
2011 OCT 17	2011 OCT 13 13:32	4.436	383	0.977	0.014	0.849	1.597	0.620
2011 OCT 18	2011 OCT 13 17:59	5.250	323	0.976	0.014	0.809	1.598	0.622
2011 OCT 19	2011 OCT 13 22:26	6.065	279	0.976	0.013	0.770	1.600	0.624
2011 OCT 20	2011 OCT 14 02:59	6.875	246	0.975	0.012	0.730	1.601	0.626
2011 OCT 21	2011 OCT 14 07:34	7.684	220	0.974	0.012	0.690	1.602	0.628
Crossing								
2011 NOV 07 21:31	2011 OCT 17 16:26		78					



(a) (b) (c)

Figure 168: Encounter with 45P/ at 2011 OCT 16 in the Ecliptic Coordinate System.

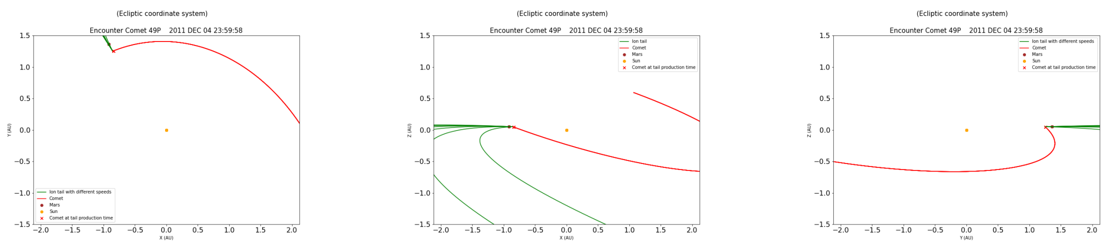


(a) (b) (c)

Figure 169: Encounter with 45P/ at 2011 OCT 16 in the Comet Orbital Coordinate System.

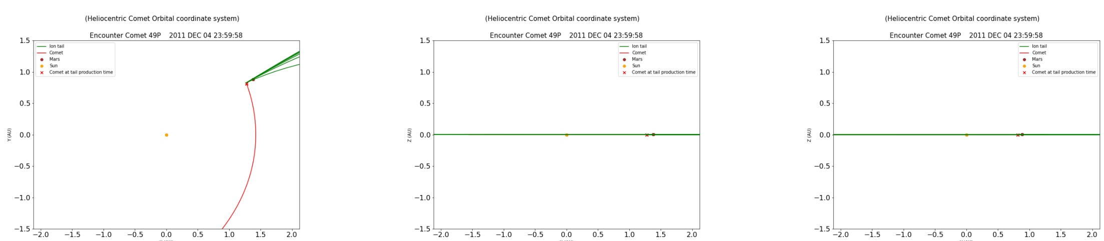
- Comet: **49P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2011 DEC 03	2011 DEC 03 15:26	0.357	627	0.129	0.005	2.342	1.639	1.511
2011 DEC 04	2011 DEC 04 07:11	0.700	315	0.127	0.001	0.530	1.640	1.513
2011 DEC 05	2011 DEC 04 22:58	1.043	209	0.125	0.003	-1.330	1.641	1.515
Crossing								
2011 DEC 05 06:54	2011 DEC 04 11:44		275					



(a) (b) (c)

Figure 170: Encounter with 49P at 2011 DEC 04 in the Ecliptic Coordinate System.

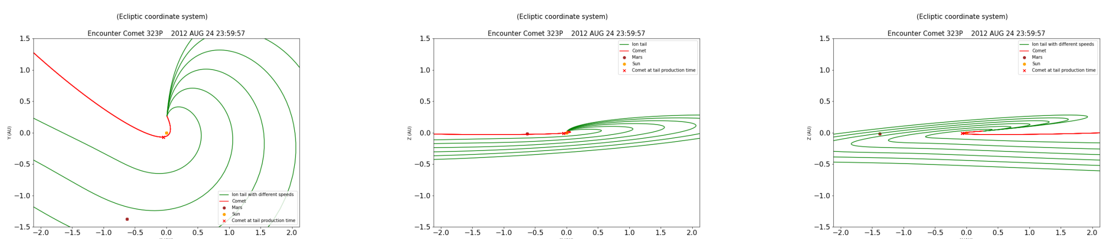


(a) (b) (c)

Figure 171: Encounter with 49P at 2011 DEC 04 in the Comet Orbital Coordinate System.

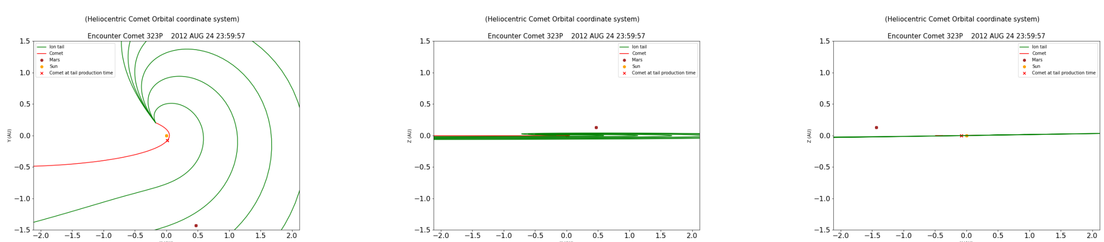
- Comet: **323P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2012 AUG 21	2012 AUG 19 08:43	2.636	958	1.455	0.128	5.035	1.516	0.061
2012 AUG 22	2012 AUG 19 08:56	3.627	696	1.454	0.127	5.008	1.514	0.060
2012 AUG 23	2012 AUG 19 09:10	4.618	546	1.453	0.126	4.980	1.513	0.060
2012 AUG 24	2012 AUG 19 09:23	5.609	450	1.452	0.125	4.952	1.512	0.060
2012 AUG 25	2012 AUG 19 09:36	6.599	382	1.451	0.125	4.923	1.510	0.059
2012 AUG 26	2012 AUG 19 09:50	7.590	332	1.450	0.124	4.894	1.509	0.059
2012 AUG 27	2012 AUG 19 10:03	8.581	293	1.449	0.123	4.864	1.508	0.058
2012 AUG 28	2012 AUG 19 10:17	9.571	263	1.448	0.122	4.834	1.506	0.058
2012 AUG 29	2012 AUG 19 10:30	10.562	238	1.448	0.121	4.804	1.505	0.058
2012 AUG 30	2012 AUG 19 10:44	11.553	217	1.447	0.120	4.773	1.504	0.057
2012 AUG 31	2012 AUG 19 10:57	12.543	200	1.446	0.120	4.742	1.503	0.057
Crossing								
2012 DEC 05 18:06	2012 AUG 20 05:31		22					



(a) (b) (c)

Figure 172: Encounter with 323P at 2012 AUG 24 in the Ecliptic Coordinate System.

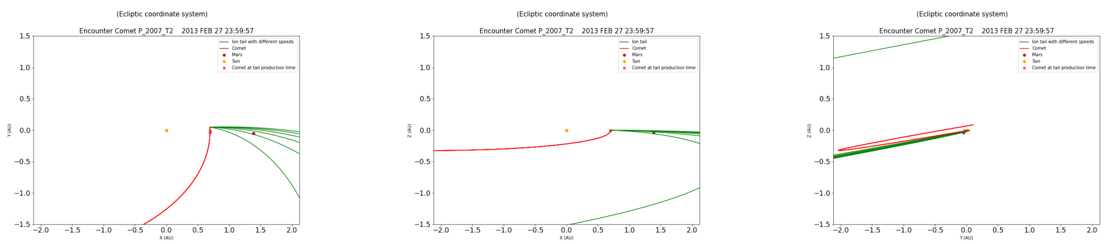


(a) (b) (c)

Figure 173: Encounter with 323P at 2012 AUG 24 in the Comet Orbital Coordinate System.

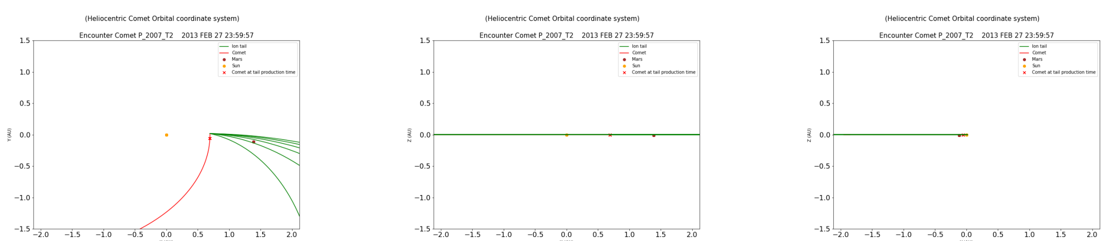
- Comet: **P_2007_T2/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2013 FEB 25	2013 FEB 24 17:54	1.254	958	0.692	0.005	-0.407	1.389	0.697
2013 FEB 26	2013 FEB 25 00:30	1.978	608	0.692	0.007	-0.597	1.390	0.697
2013 FEB 27	2013 FEB 25 07:05	2.704	445	0.693	0.010	-0.786	1.390	0.697
2013 FEB 28	2013 FEB 25 13:39	3.431	351	0.694	0.012	-0.976	1.391	0.697
2013 MAR 01	2013 FEB 25 20:13	4.157	290	0.695	0.014	-1.164	1.391	0.696
2013 MAR 02	2013 FEB 26 02:47	4.884	247	0.695	0.016	-1.353	1.392	0.696
2013 MAR 03	2013 FEB 26 09:20	5.611	215	0.696	0.019	-1.540	1.392	0.696
Crossing								
2013 FEB 23 20:51								



(a) (b) (c)

Figure 174: Encounter with P_2007_T2/ at 2013 FEB 27 in the Ecliptic Coordinate System.



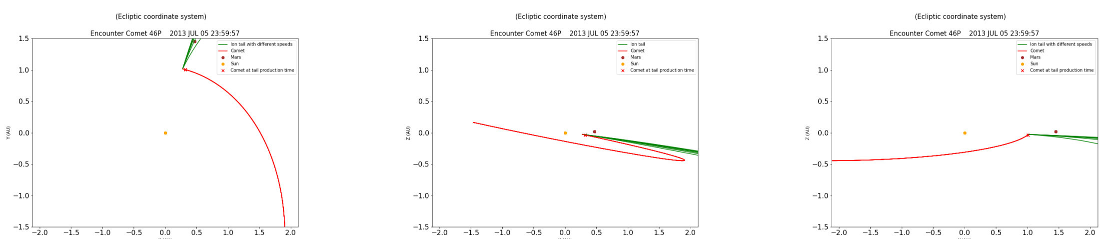
(a) (b) (c)

Figure 175: Encounter with P_2007_T2/ at 2013 FEB 27 in the Comet Orbital Coordinate System.

- Comet: **46P/**

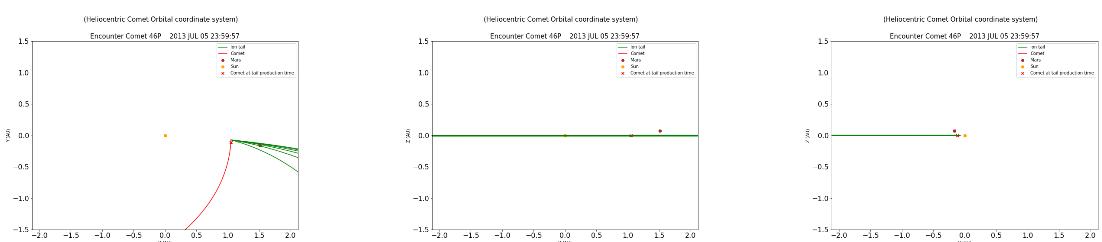
Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2013 JUL 03	2013 JUL 03 05:43	0.761	1057	0.464	0.078	9.667	1.522	1.059
2013 JUL 04	2013 JUL 03 16:17	1.321	612	0.466	0.076	9.343	1.524	1.058
2013 JUL 05	2013 JUL 04 02:50	1.882	431	0.467	0.073	9.022	1.525	1.058
2013 JUL 06	2013 JUL 04 13:21	2.444	333	0.469	0.071	8.703	1.526	1.057
2013 JUL 07	2013 JUL 04 23:50	3.006	272	0.471	0.069	8.387	1.528	1.057
2013 JUL 08	2013 JUL 05 10:18	3.571	230	0.472	0.066	8.073	1.529	1.057
Crossing								
2013 AUG 05 21:16	2013 JUL 17 06:43		45					

Table 6: Possible encounters.



(a) (b) (c)

Figure 176: Encounter with 46P/ at 2013 JUL 05 in the Ecliptic Coordinate System.

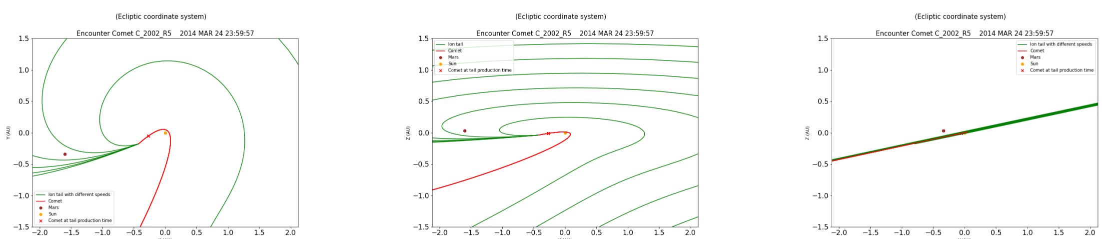


(a) (b) (c)

Figure 177: Encounter with 46P/ at 2013 JUL 05 in the Comet Orbital Coordinate System.

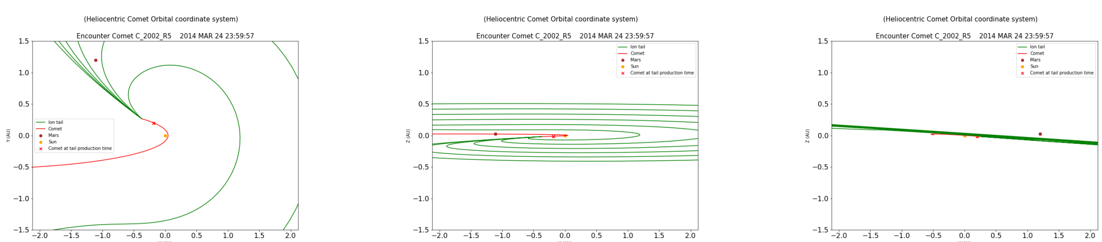
- Comet: **C_2002_R5/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2014 MAR 21	2014 MAR 19 13:35	2.434	974	1.366	0.014	0.584	1.636	0.271
2014 MAR 22	2014 MAR 19 15:56	3.336	708	1.361	0.017	0.705	1.636	0.275
2014 MAR 23	2014 MAR 19 18:18	4.237	555	1.355	0.020	0.827	1.635	0.280
2014 MAR 24	2014 MAR 19 20:39	5.139	456	1.350	0.022	0.951	1.634	0.284
2014 MAR 25	2014 MAR 19 23:01	6.041	386	1.344	0.025	1.075	1.633	0.289
2014 MAR 26	2014 MAR 20 01:52	6.922	336	1.338	0.028	1.200	1.633	0.294
2014 MAR 27	2014 MAR 20 05:03	7.789	297	1.332	0.031	1.327	1.632	0.299
2014 MAR 28	2014 MAR 20 08:15	8.656	266	1.326	0.034	1.455	1.631	0.305
2014 MAR 29	2014 MAR 20 11:27	9.523	241	1.320	0.036	1.584	1.630	0.310
2014 MAR 30	2014 MAR 20 14:39	10.389	220	1.314	0.039	1.714	1.629	0.316
2014 MAR 31	2014 MAR 20 17:52	11.255	202	1.307	0.042	1.846	1.629	0.322
Crossing								
2014 MAR 17 01:51								



(a) (b) (c)

Figure 178: Encounter with C_2002_R5/ at 2014 MAR 24 in the Ecliptic Coordinate System.

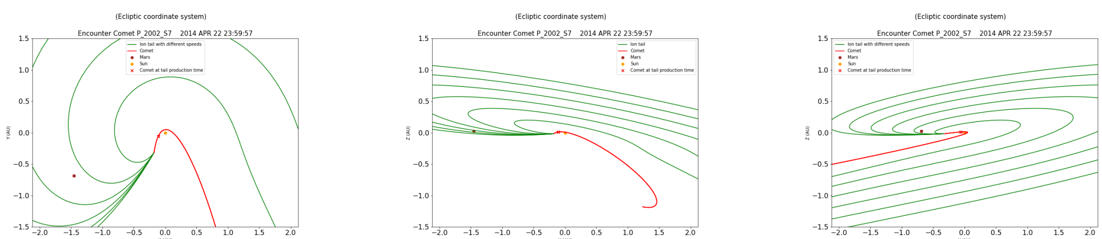


(a) (b) (c)

Figure 179: Encounter with C_2002_R5/ at 2014 MAR 24 in the Comet Orbital Coordinate System.

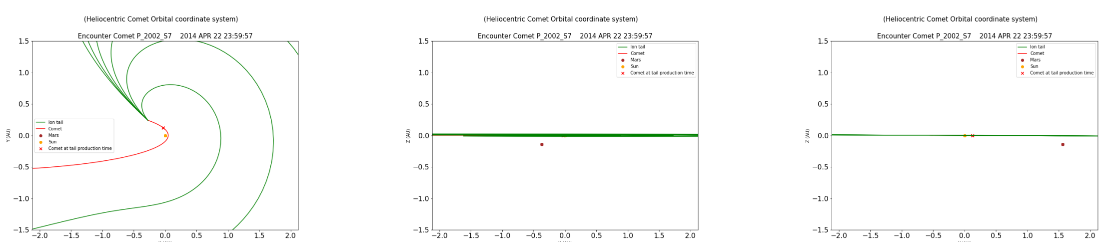
- Comet: **P_2002_S7/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2014 APR 19	2014 APR 17 09:41	2.596	996	1.490	0.146	-5.613	1.612	0.122
2014 APR 20	2014 APR 17 10:16	3.572	723	1.488	0.143	-5.525	1.611	0.123
2014 APR 21	2014 APR 17 10:51	4.548	567	1.485	0.141	-5.437	1.610	0.124
2014 APR 22	2014 APR 17 11:26	5.523	466	1.483	0.138	-5.348	1.609	0.126
2014 APR 23	2014 APR 17 12:00	6.499	396	1.481	0.136	-5.258	1.608	0.127
2014 APR 24	2014 APR 17 12:35	7.475	343	1.479	0.133	-5.168	1.607	0.128
2014 APR 25	2014 APR 17 13:10	8.451	303	1.476	0.131	-5.078	1.606	0.129
2014 APR 26	2014 APR 17 13:45	9.427	271	1.474	0.128	-4.987	1.605	0.131
2014 APR 27	2014 APR 17 14:20	10.402	246	1.471	0.126	-4.896	1.604	0.132
2014 APR 28	2014 APR 17 14:55	11.378	224	1.469	0.123	-4.804	1.603	0.133
2014 APR 29	2014 APR 17 15:30	12.354	206	1.467	0.120	-4.711	1.602	0.135
Crossing								
2014 JUN 13 13:15	2014 APR 19 19:50		41					



(a) (b) (c)

Figure 180: Encounter with P_2002_S7/ at 2014 APR 22 in the Ecliptic Coordinate System.

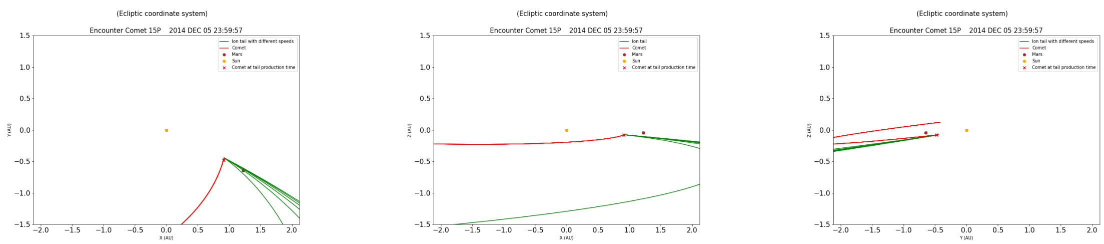


(a) (b) (c)

Figure 181: Encounter with P_2002_S7/ at 2014 APR 22 in the Comet Orbital Coordinate System.

- Comet: **15P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2014 DEC 03	2014 DEC 03 08:33	0.644	936	0.347	0.068	11.345	1.382	1.035
2014 DEC 04	2014 DEC 03 21:18	1.112	545	0.349	0.067	11.057	1.382	1.032
2014 DEC 05	2014 DEC 04 09:58	1.585	385	0.352	0.066	10.775	1.382	1.030
2014 DEC 06	2014 DEC 04 22:36	2.058	299	0.354	0.065	10.496	1.381	1.027
2014 DEC 07	2014 DEC 05 11:09	2.535	244	0.356	0.063	10.221	1.381	1.025
2014 DEC 08	2014 DEC 05 23:40	3.013	207	0.359	0.062	9.950	1.381	1.023
Crossing								
2015 JAN 22 23:50	2014 DEC 27 18:21		28					



(a) (b) (c)

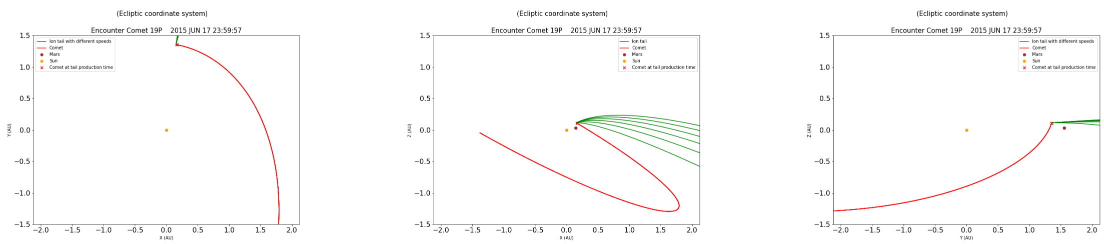
Figure 182: Encounter with 15P/ at 2014 DEC 05 in the Ecliptic Coordinate System.

(a) (b)

Figure 183: Encounter with 15P/ at 2014 DEC 05 in the Comet Orbital Coordinate System.

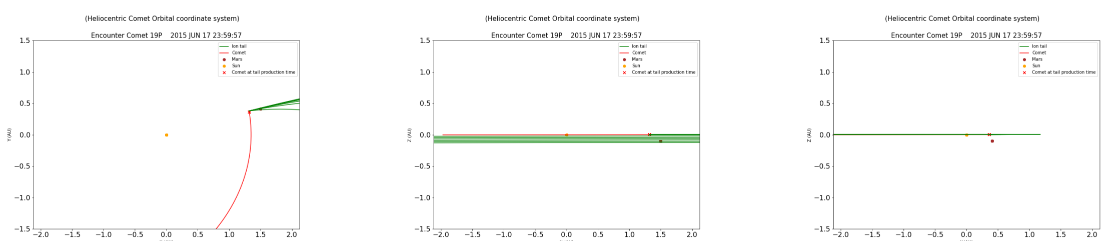
- Comet: **19P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2015 JUN 16	2015 JUN 16 11:06	0.537	577	0.178	0.096	-32.428	1.556	1.377
2015 JUN 17	2015 JUN 17 00:38	0.973	318	0.179	0.102	-34.913	1.557	1.378
2015 JUN 18	2015 JUN 17 14:11	1.409	220	0.179	0.109	-37.475	1.558	1.380
Crossing								
2015 JUN 02 10:54								



(a) (b) (c)

Figure 184: Encounter with 19P/ at 2015 JUN 17 in the Ecliptic Coordinate System.

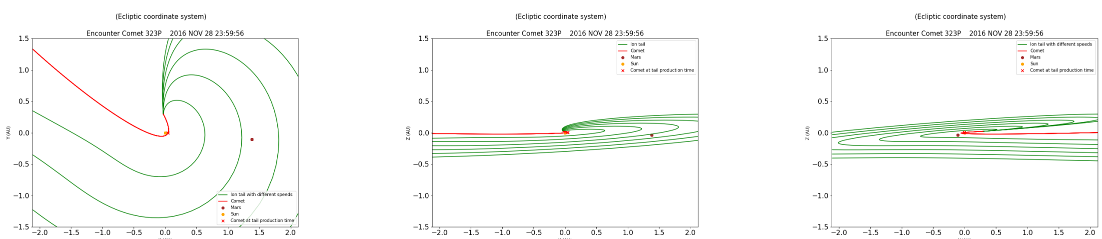


(a) (b) (c)

Figure 185: Encounter with 19P/ at 2015 JUN 17 in the Comet Orbital Coordinate System.

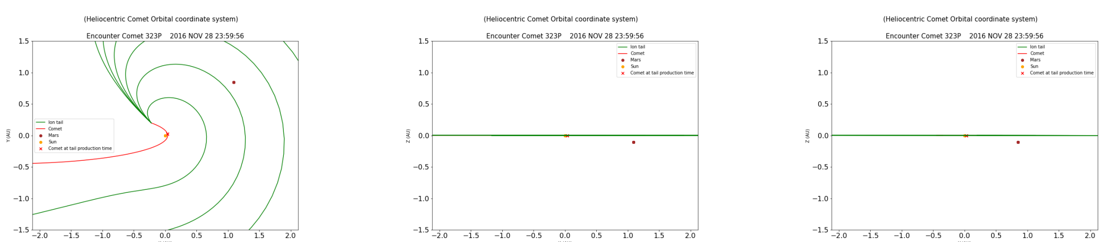
- Comet: **323P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2016 NOV 25	2016 NOV 23 20:36	2.141	1089	1.343	0.100	-4.289	1.387	0.043
2016 NOV 26	2016 NOV 23 20:43	3.136	744	1.344	0.101	-4.331	1.387	0.043
2016 NOV 27	2016 NOV 23 20:50	4.131	565	1.344	0.102	-4.372	1.387	0.044
2016 NOV 28	2016 NOV 23 20:57	5.127	455	1.344	0.103	-4.413	1.388	0.044
2016 NOV 29	2016 NOV 23 21:04	6.122	381	1.344	0.104	-4.453	1.388	0.044
2016 NOV 30	2016 NOV 23 21:11	7.117	328	1.345	0.105	-4.492	1.389	0.044
2016 DEC 01	2016 NOV 23 21:18	8.112	288	1.345	0.106	-4.531	1.389	0.044
2016 DEC 02	2016 NOV 23 21:24	9.108	256	1.345	0.107	-4.570	1.390	0.044
2016 DEC 03	2016 NOV 23 21:31	10.103	231	1.346	0.108	-4.608	1.390	0.045
2016 DEC 04	2016 NOV 23 21:38	11.098	211	1.346	0.109	-4.645	1.391	0.045
Crossing								
2016 SEP 09 18:20								



(a) (b) (c)

Figure 186: Encounter with 323P at 2016 NOV 28 in the Ecliptic Coordinate System.

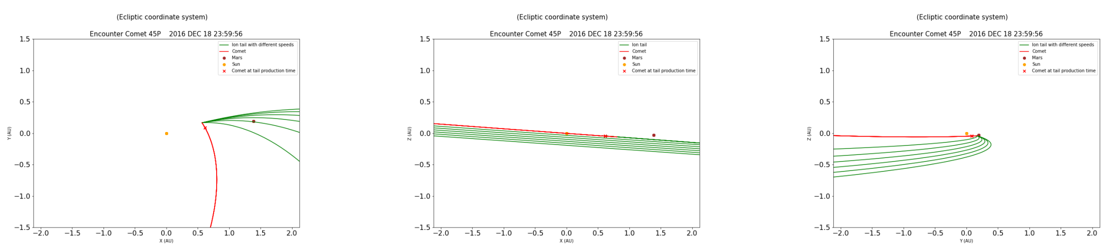


(a) (b) (c)

Figure 187: Encounter with 323P at 2016 NOV 28 in the Comet Orbital Coordinate System.

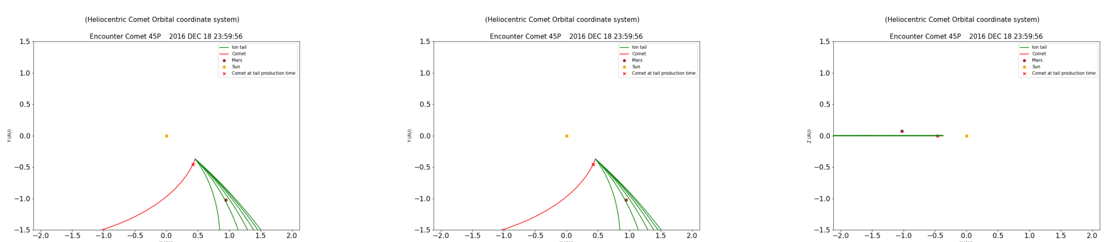
- Comet: **45P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2016 DEC 16	2016 DEC 15 08:50	1.632	819	0.769	0.072	5.372	1.398	0.628
2016 DEC 17	2016 DEC 15 14:51	2.381	564	0.773	0.072	5.366	1.398	0.626
2016 DEC 18	2016 DEC 15 20:53	3.130	430	0.776	0.072	5.360	1.399	0.623
2016 DEC 19	2016 DEC 16 02:48	3.883	348	0.779	0.073	5.354	1.400	0.621
2016 DEC 20	2016 DEC 16 08:37	4.641	293	0.783	0.073	5.347	1.401	0.618
2016 DEC 21	2016 DEC 16 14:25	5.399	253	0.786	0.073	5.340	1.401	0.615
2016 DEC 22	2016 DEC 16 20:13	6.157	222	0.789	0.073	5.333	1.402	0.613
Crossing								
2017 JUN 29 19:08	2017 JAN 19 12:27		10					



(a) (b) (c)

Figure 188: Encounter with 45P/ at 2016 DEC 18 in the Ecliptic Coordinate System.

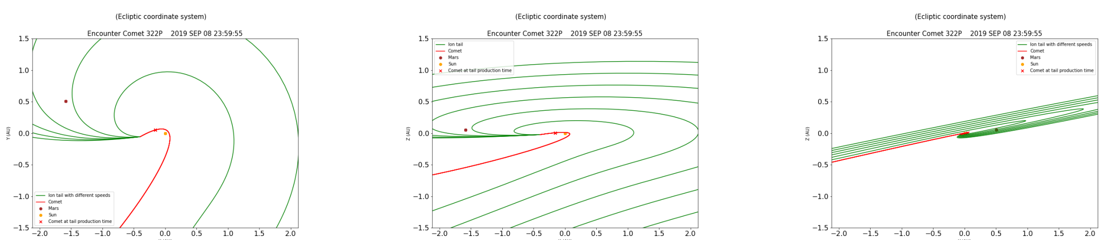


(a) (b) (c)

Figure 189: Encounter with 45P/ at 2016 DEC 18 in the Comet Orbital Coordinate System.

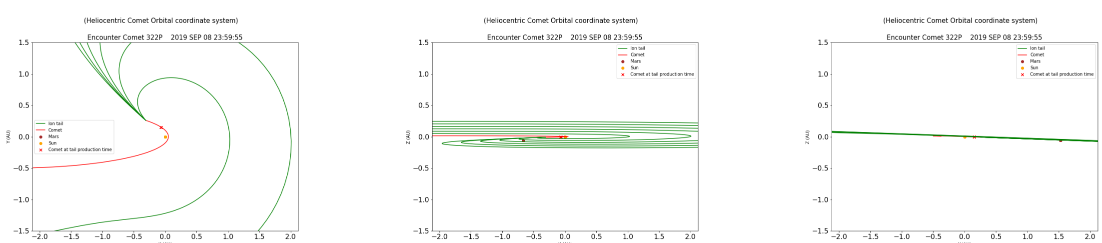
Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2019 SEP 05	2019 SEP 02 22:51	3.047	852	1.496	0.067	2.552	1.665	0.170
2019 SEP 06	2019 SEP 02 23:28	4.022	645	1.494	0.064	2.460	1.665	0.171
2019 SEP 07	2019 SEP 03 00:09	4.993	519	1.492	0.062	2.368	1.665	0.173
2019 SEP 08	2019 SEP 03 01:18	5.946	435	1.490	0.059	2.275	1.665	0.175
2019 SEP 09	2019 SEP 03 02:26	6.898	374	1.488	0.057	2.183	1.665	0.177
2019 SEP 10	2019 SEP 03 03:35	7.851	329	1.486	0.054	2.089	1.665	0.179
2019 SEP 11	2019 SEP 03 04:43	8.803	293	1.483	0.052	1.996	1.665	0.181
2019 SEP 12	2019 SEP 03 05:51	9.756	264	1.481	0.049	1.902	1.664	0.183
2019 SEP 13	2019 SEP 03 07:00	10.708	240	1.479	0.047	1.807	1.664	0.185
2019 SEP 14	2019 SEP 03 08:08	11.661	220	1.477	0.044	1.713	1.664	0.188
2019 SEP 15	2019 SEP 03 09:17	12.613	203	1.474	0.042	1.618	1.664	0.190
Crossing								
2019 OCT 02 10:47	2019 SEP 04 06:20		88					

- Comet: **322P/**



(a) (b) (c)

Figure 190: Encounter with 322P/ at 2019 SEP 08 in the Ecliptic Coordinate System.

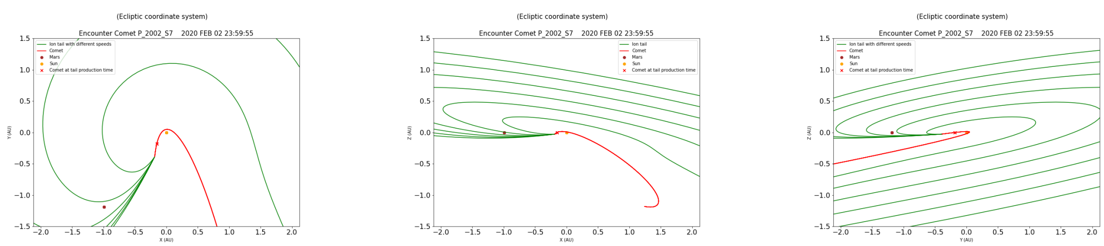


(a) (b) (c)

Figure 191: Encounter with 322P/ at 2019 SEP 08 in the Comet Orbital Coordinate System.

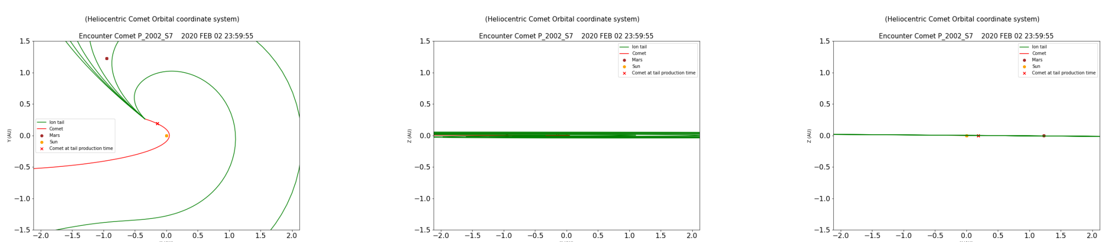
- Comet: **P_2002_S7/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2020 JAN 30	2020 JAN 28 15:52	2.339	982	1.322	0.010	-0.418	1.554	0.232
2020 JAN 31	2020 JAN 28 17:44	3.261	701	1.317	0.007	-0.299	1.553	0.236
2020 FEB 01	2020 JAN 28 19:36	4.183	545	1.312	0.004	-0.180	1.552	0.240
2020 FEB 02	2020 JAN 28 21:28	5.105	444	1.307	0.001	-0.059	1.551	0.244
2020 FEB 03	2020 JAN 28 23:20	6.027	375	1.301	0.001	0.063	1.549	0.248
2020 FEB 04	2020 JAN 29 01:45	6.927	325	1.296	0.004	0.186	1.548	0.252
2020 FEB 05	2020 JAN 29 04:27	7.814	287	1.290	0.007	0.310	1.547	0.257
2020 FEB 06	2020 JAN 29 07:09	8.701	256	1.284	0.010	0.435	1.546	0.261
2020 FEB 07	2020 JAN 29 09:52	9.588	231	1.278	0.013	0.561	1.544	0.266
2020 FEB 08	2020 JAN 29 12:35	10.475	211	1.272	0.015	0.688	1.543	0.271
Crossing								
2020 FEB 03 11:35	2020 JAN 28 22:22		408					



(a) (b) (c)

Figure 192: Encounter with P_2002_S7/ at 2020 FEB 02 in the Ecliptic Coordinate System.



(a) (b) (c)

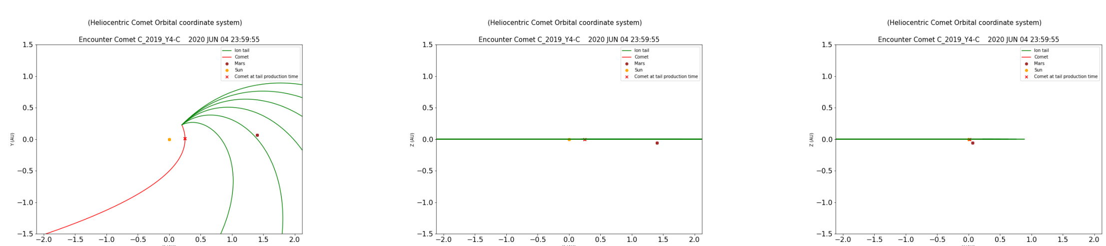
Figure 193: Encounter with P_2002_S7/ at 2020 FEB 02 in the Comet Orbital Coordinate System.

- Comet: **C_2019_Y4-C/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2020 JUN 01	2020 MAY 31 03:05	1.871	1072	1.156	0.093	-4.609	1.408	0.252
2020 JUN 02	2020 MAY 31 04:02	2.832	708	1.155	0.082	-4.083	1.407	0.252
2020 JUN 03	2020 MAY 31 04:59	3.792	528	1.154	0.072	-3.557	1.407	0.252
2020 JUN 04	2020 MAY 31 05:56	4.753	421	1.154	0.061	-3.030	1.406	0.252
2020 JUN 05	2020 MAY 31 06:53	5.713	350	1.153	0.050	-2.502	1.405	0.252
2020 JUN 06	2020 MAY 31 07:50	6.673	300	1.152	0.040	-1.974	1.404	0.252
2020 JUN 07	2020 MAY 31 08:47	7.633	262	1.151	0.029	-1.444	1.404	0.253
2020 JUN 08	2020 MAY 31 09:45	8.594	232	1.150	0.018	-0.914	1.403	0.253
2020 JUN 09	2020 MAY 31 10:42	9.554	209	1.149	0.008	-0.383	1.402	0.253
Crossing								
2020 JUN 10 17:16	2020 MAY 31 11:23		195					

(a) (b)

Figure 194: Encounter with C_2019_Y4-C at 2020 JUN 04 in the Ecliptic Coordinate System.



(a) (b) (c)

Figure 195: Encounter with C_2019_Y4-C at 2020 JUN 04 in the Comet Orbital Coordinate System.

- Comet: **141P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2021 JAN 05	2021 JAN 04 09:26	1.607	707	0.655	0.057	4.965	1.516	0.861
2021 JAN 06	2021 JAN 04 17:16	2.280	498	0.654	0.060	5.304	1.517	0.863
2021 JAN 07	2021 JAN 05 01:06	2.953	384	0.654	0.064	5.644	1.518	0.865
2021 JAN 08	2021 JAN 05 09:02	3.624	313	0.653	0.068	5.984	1.520	0.867
2021 JAN 09	2021 JAN 05 16:56	4.294	264	0.652	0.072	6.325	1.521	0.869
2021 JAN 10	2021 JAN 06 00:50	4.965	228	0.651	0.076	6.667	1.522	0.871
2021 JAN 11	2021 JAN 06 08:50	5.632	201	0.651	0.079	7.009	1.524	0.873
Crossing								
2020 DEC 22 05:04	2015 SEP 07 03:15		0.592					

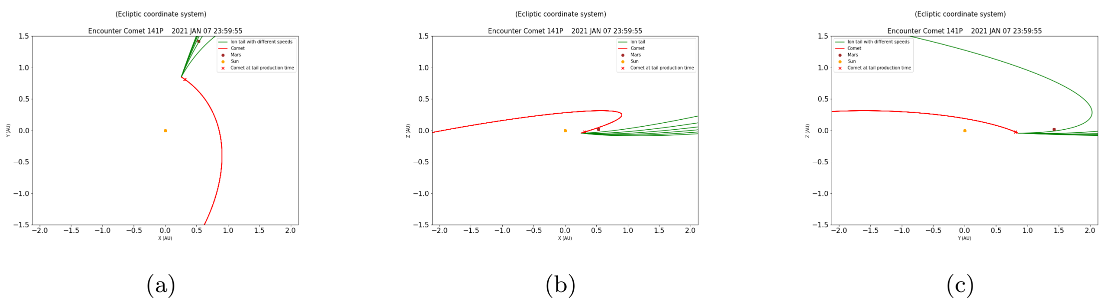


Figure 196: Encounter with 141P/ at 2021 JAN 07 in the Ecliptic Coordinate System.

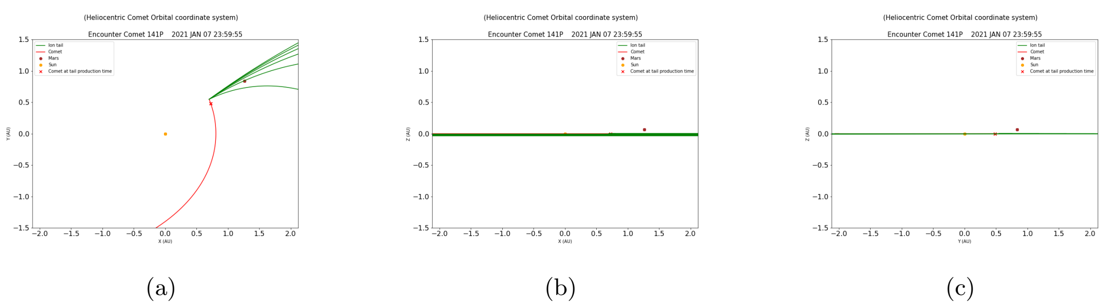
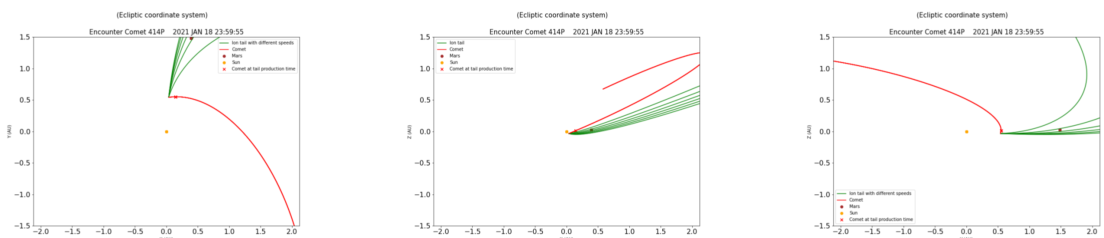


Figure 197: Encounter with 141P/ at 2021 JAN 07 in the Comet Orbital Coordinate System.

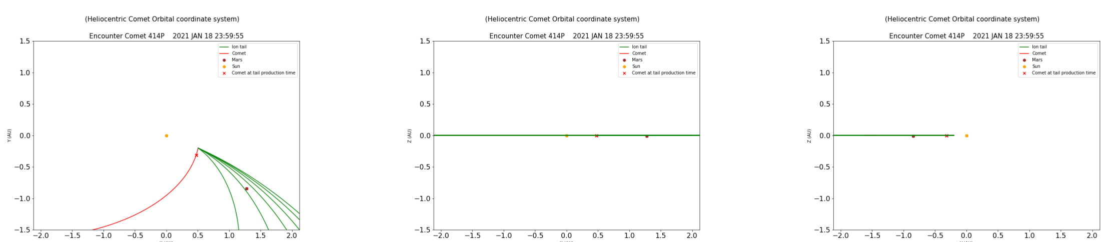
- Comet: **414P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2021 JAN 16	2021 JAN 14 21:47	2.092	796	0.959	0.020	-1.208	1.530	0.571
2021 JAN 17	2021 JAN 15 01:36	2.933	569	0.962	0.014	-0.858	1.531	0.570
2021 JAN 18	2021 JAN 15 05:20	3.777	443	0.964	0.009	-0.509	1.533	0.569
2021 JAN 19	2021 JAN 15 09:04	4.621	363	0.967	0.003	-0.163	1.534	0.567
2021 JAN 20	2021 JAN 15 12:48	5.466	308	0.969	0.003	0.182	1.535	0.566
2021 JAN 21	2021 JAN 15 16:32	6.311	267	0.972	0.009	0.525	1.537	0.565
2021 JAN 22	2021 JAN 15 20:15	7.156	236	0.974	0.015	0.867	1.538	0.564
2021 JAN 23	2021 JAN 15 23:57	8.001	212	0.976	0.021	1.207	1.539	0.563
Crossing								
2021 JAN 20 11:18	2021 JAN 15 10:50		335					



(a) (b) (c)

Figure 198: Encounter with 414P/ at 2021 JAN 18 in the Ecliptic Coordinate System.



(a) (b) (c)

Figure 199: Encounter with 414P/ at 2021 JAN 18 in the Comet Orbital Coordinate System.

- Comet: **323P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2021 JAN 21	2021 JAN 19 19:33	2.185	1102	1.386	0.110	-4.566	1.537	0.150
2021 JAN 22	2021 JAN 19 20:22	3.151	763	1.385	0.110	-4.536	1.538	0.153
2021 JAN 23	2021 JAN 19 21:10	4.118	584	1.384	0.109	-4.506	1.539	0.155
2021 JAN 24	2021 JAN 19 21:58	5.084	472	1.383	0.108	-4.476	1.540	0.157
2021 JAN 25	2021 JAN 19 22:46	6.051	397	1.382	0.107	-4.445	1.542	0.160
2021 JAN 26	2021 JAN 19 23:34	7.018	342	1.381	0.106	-4.414	1.543	0.162
2021 JAN 27	2021 JAN 20 00:42	7.970	301	1.380	0.105	-4.383	1.544	0.165
2021 JAN 28	2021 JAN 20 02:15	8.906	269	1.378	0.105	-4.352	1.546	0.167
2021 JAN 29	2021 JAN 20 03:48	9.841	243	1.377	0.104	-4.321	1.547	0.170
2021 JAN 30	2021 JAN 20 05:20	10.777	222	1.375	0.103	-4.289	1.548	0.173
2021 JAN 31	2021 JAN 20 06:52	11.713	204	1.374	0.102	-4.258	1.549	0.176
Crossing								
2022 MAY 02 17:13								

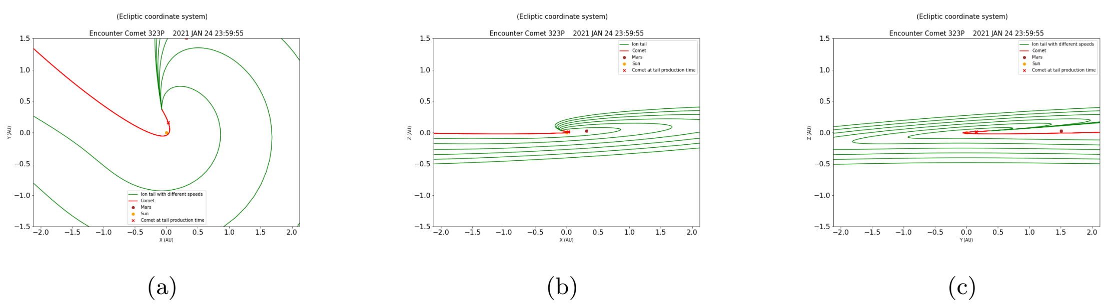


Figure 200: Encounter with 323P at 2021 JAN 24 in the Ecliptic Coordinate System.

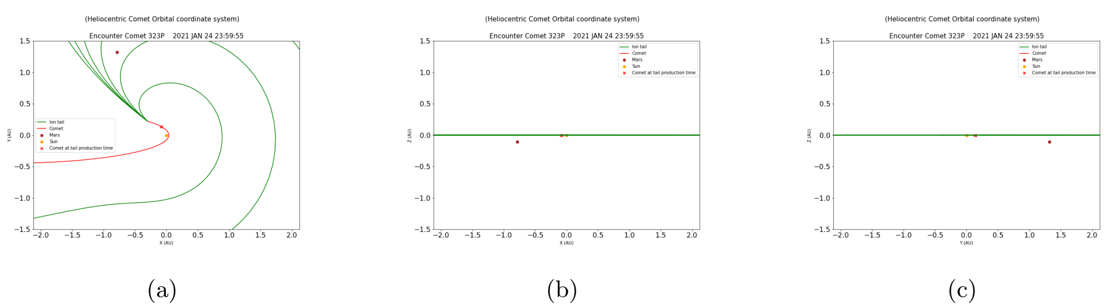
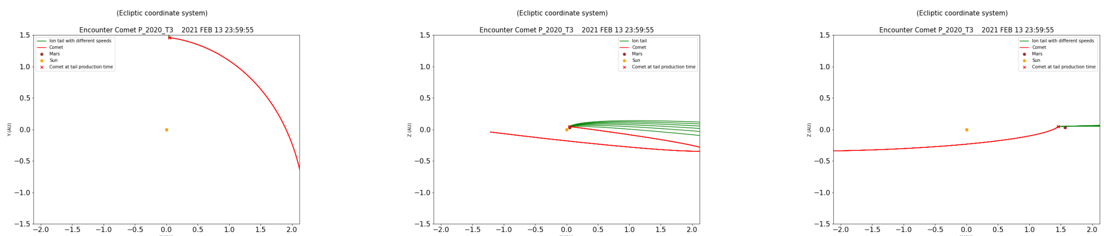


Figure 201: Encounter with 323P at 2021 JAN 24 in the Comet Orbital Coordinate System.

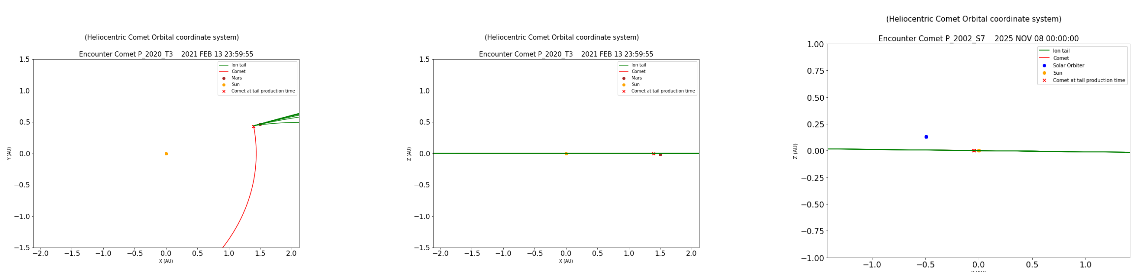
- Comet: **P_2020_T3/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2021 FEB 13	2021 FEB 13 14:02	0.415	437	0.104	0.017	-9.643	1.565	1.461
2021 FEB 14	2021 FEB 14 06:56	0.711	255	0.104	0.019	-10.410	1.567	1.462
Crossing								
2021 JAN 31 23:35								



(a) (b) (c)

Figure 202: Encounter with P_2020_T3/ at 2021 FEB 13 in the Ecliptic Coordinate System.

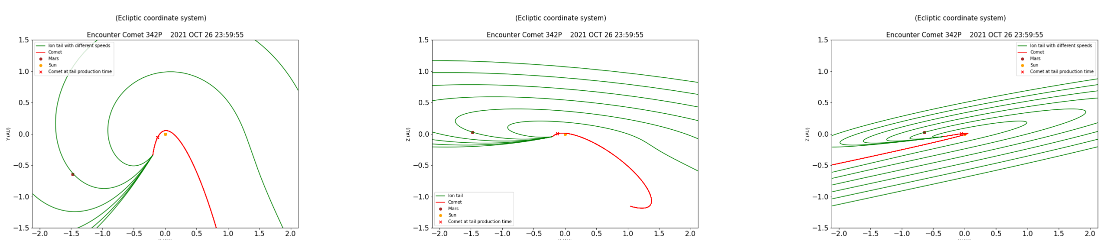


(a) (b) (c)

Figure 203: Encounter with P_2020_T3/ at 2021 FEB 13 in the Comet Orbital Coordinate System.

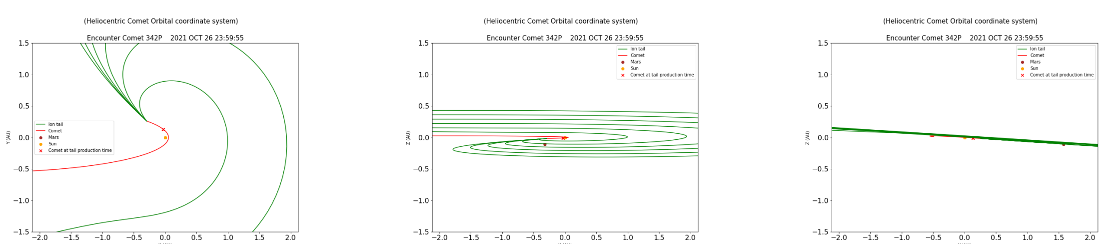
- Comet: **342P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2021 OCT 22	2021 OCT 20 15:13	2.365	1094	1.490	0.114	-4.385	1.616	0.126
2021 OCT 23	2021 OCT 20 15:43	3.345	772	1.488	0.111	-4.295	1.615	0.127
2021 OCT 24	2021 OCT 20 16:13	4.324	597	1.486	0.109	-4.204	1.614	0.129
2021 OCT 25	2021 OCT 20 16:43	5.303	486	1.484	0.106	-4.113	1.614	0.130
2021 OCT 26	2021 OCT 20 17:13	6.282	409	1.481	0.104	-4.022	1.613	0.131
2021 OCT 27	2021 OCT 20 17:43	7.262	354	1.479	0.101	-3.930	1.612	0.132
2021 OCT 28	2021 OCT 20 18:13	8.241	311	1.477	0.099	-3.837	1.611	0.134
2021 OCT 29	2021 OCT 20 18:42	9.220	278	1.475	0.096	-3.745	1.610	0.135
2021 OCT 30	2021 OCT 20 19:13	10.199	251	1.472	0.094	-3.651	1.609	0.136
2021 OCT 31	2021 OCT 20 19:43	11.178	228	1.470	0.091	-3.557	1.608	0.138
2021 NOV 01	2021 OCT 20 20:13	12.157	210	1.468	0.089	-3.463	1.607	0.139
Crossing								
2021 DEC 05 15:38	2021 OCT 22 05:27		53					



(a) (b) (c)

Figure 204: Encounter with 342P/ at 2021 OCT 26 in the Comet Orbital Coordinate System.

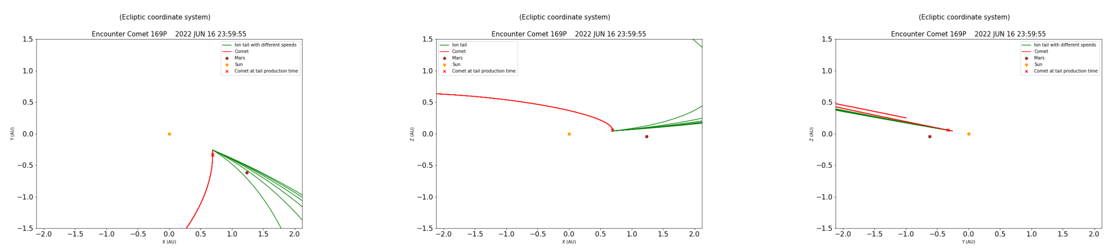


(a) (b) (c)

Figure 205: Encounter with 342P/ at 2021 OCT 26 in the Comet Orbital Coordinate System.

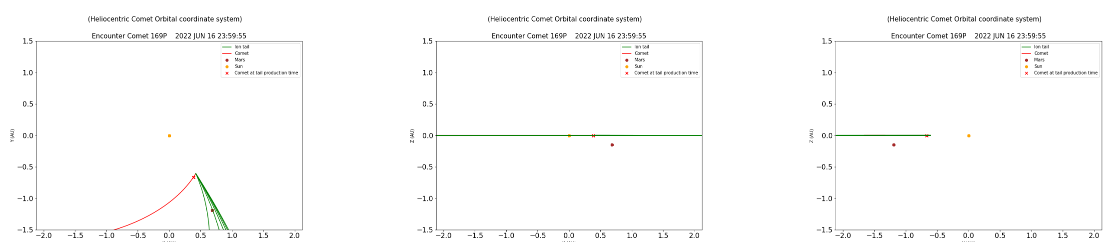
- Comet: **169P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2022 JUN 16	2022 JUN 14 03:59	2.834	371	0.605	0.148	-14.123	1.381	0.776
2022 JUN 17	2022 JUN 14 12:41	3.471	305	0.609	0.145	-13.748	1.381	0.772
2022 JUN 18	2022 JUN 14 21:22	4.109	259	0.613	0.142	-13.378	1.381	0.768
2022 JUN 19	2022 JUN 15 05:54	4.754	225	0.617	0.139	-13.013	1.381	0.764
Crossing								
2022 AUG 02 21:24	2022 JUN 28 02:09		36					



(a) (b) (c)

Figure 206: Encounter with 169P/ at 2022 JUN 16 in the Ecliptic Coordinate System.

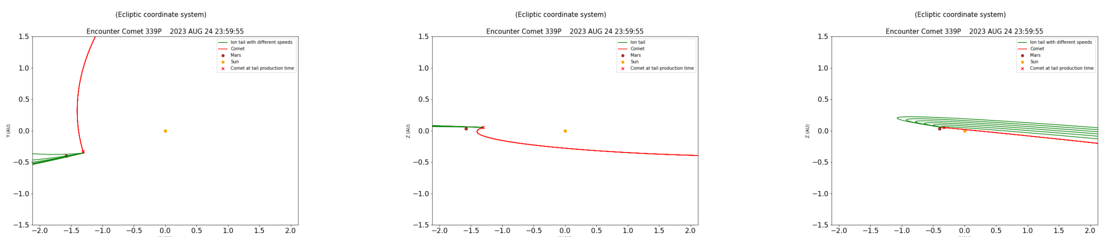


(a) (b) (c)

Figure 207: Encounter with 169P/ at 2022 JUN 16 in the Comet Orbital Coordinate System.

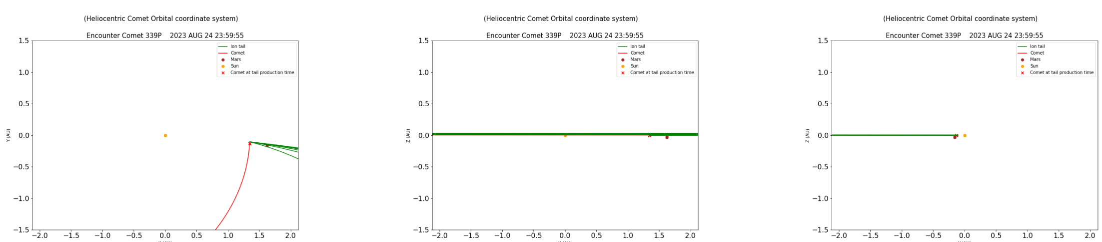
- Comet: **339P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2023 AUG 22	2023 AUG 22 11:38	0.515	1026	0.304	0.027	-5.022	1.632	1.327
2023 AUG 23	2023 AUG 23 01:11	0.950	555	0.304	0.028	-5.318	1.631	1.327
2023 AUG 24	2023 AUG 23 14:44	1.386	380	0.303	0.030	-5.616	1.630	1.327
2023 AUG 25	2023 AUG 24 04:17	1.821	289	0.303	0.031	-5.915	1.629	1.326
2023 AUG 26	2023 AUG 24 17:50	2.256	233	0.303	0.033	-6.216	1.628	1.326
Crossing								
2023 AUG 05 19:05								



(a) (b) (c)

Figure 208: Encounter with 339P/ at 2023 AUG 24 in the Ecliptic Coordinate System.

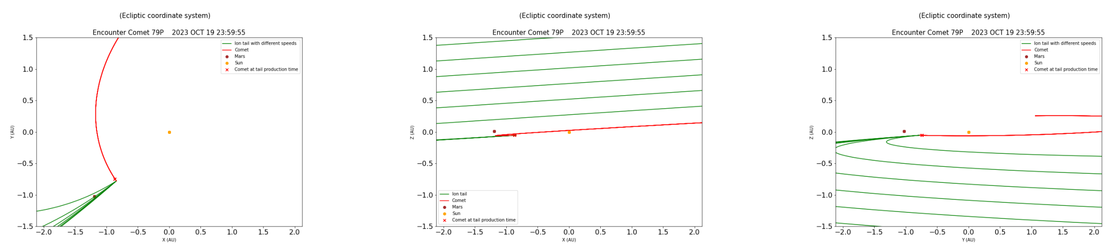


(a) (b) (c)

Figure 209: Encounter with 339P/ at 2023 AUG 24 in the Comet Orbital Coordinate System.

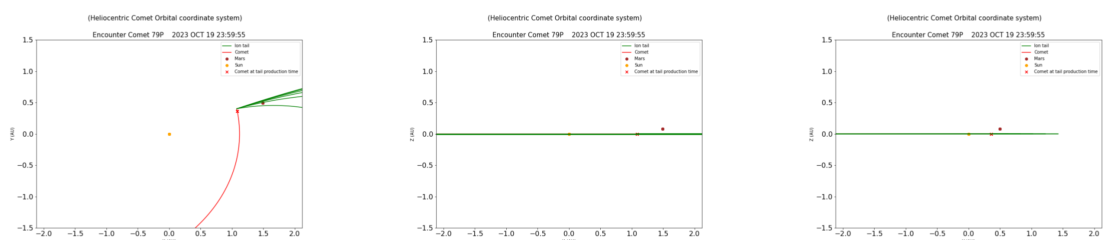
- Comet: **79P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2023 OCT 17	2023 OCT 17 00:29	0.980	766	0.432	0.084	11.241	1.576	1.144
2023 OCT 18	2023 OCT 17 11:59	1.500	497	0.430	0.083	11.188	1.575	1.145
2023 OCT 19	2023 OCT 17 23:30	2.020	367	0.427	0.083	11.133	1.574	1.146
2023 OCT 20	2023 OCT 18 11:06	2.537	291	0.425	0.082	11.079	1.572	1.147
2023 OCT 21	2023 OCT 18 22:42	3.054	240	0.423	0.081	11.024	1.571	1.149
2023 OCT 22	2023 OCT 19 10:22	3.568	204	0.420	0.080	10.968	1.570	1.150
Crossing								
2024 JAN 07 11:11	2023 DEC 04 23:54		4					



(a) (b) (c)

Figure 210: Encounter with 79P/ at 2023 OCT 19 in the Ecliptic Coordinate System.

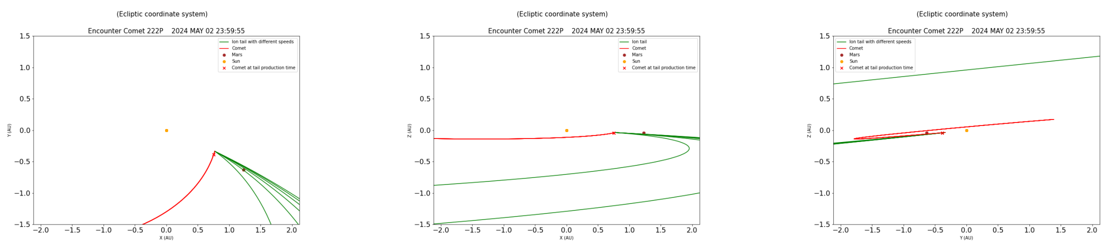


(a) (b) (c)

Figure 211: Encounter with 79P/ at 2023 OCT 19 in the Comet Orbital Coordinate System.

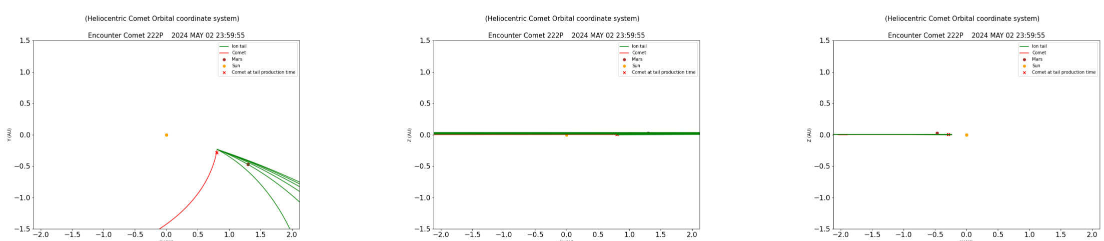
- Comet: **222P/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2024 APR 30	2024 APR 30 00:41	0.971	1034	0.579	0.029	2.858	1.382	0.803
2024 MAY 01	2024 APR 30 10:02	1.582	637	0.580	0.028	2.751	1.382	0.802
2024 MAY 02	2024 APR 30 19:23	2.192	460	0.581	0.027	2.645	1.382	0.801
2024 MAY 03	2024 MAY 01 04:42	2.804	361	0.582	0.026	2.539	1.382	0.799
2024 MAY 04	2024 MAY 01 13:59	3.417	296	0.583	0.025	2.433	1.382	0.798
2024 MAY 05	2024 MAY 01 23:16	4.030	252	0.585	0.024	2.327	1.382	0.797
2024 MAY 06	2024 MAY 02 08:29	4.646	219	0.586	0.023	2.222	1.382	0.796
Crossing								
2024 MAY 28 14:39	2024 MAY 10 10:52		58					



(a) (b) (c)

Figure 212: Encounter with 222P/ at 2024 MAY 02 in the Ecliptic Coordinate System.

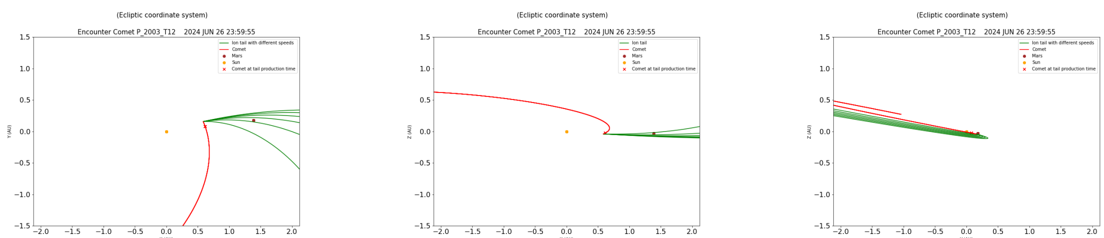


(a) (b) (c)

Figure 213: Encounter with 222P/ at 2024 MAY 02 in the Comet Orbital Coordinate System.

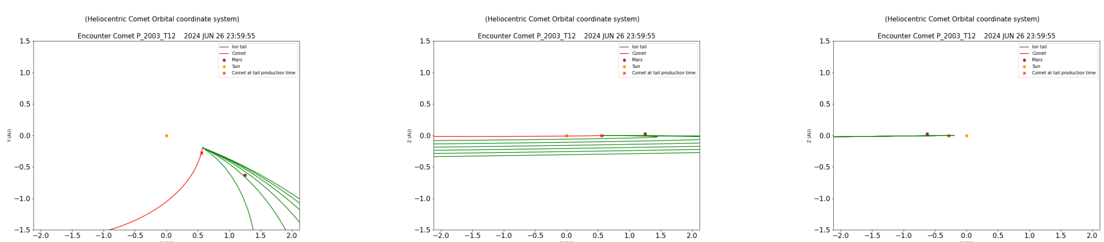
- Comet: **P_2003_T12/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2024 JUN 24	2024 JUN 23 13:20	1.444	952	0.792	0.016	1.183	1.397	0.606
2024 JUN 25	2024 JUN 23 18:59	2.209	624	0.794	0.020	1.420	1.398	0.604
2024 JUN 26	2024 JUN 24 00:36	2.975	464	0.796	0.023	1.655	1.399	0.603
2024 JUN 27	2024 JUN 24 06:08	3.744	370	0.798	0.026	1.890	1.399	0.602
2024 JUN 28	2024 JUN 24 11:39	4.514	308	0.800	0.030	2.122	1.400	0.600
2024 JUN 29	2024 JUN 24 17:09	5.285	263	0.802	0.033	2.354	1.401	0.599
2024 JUN 30	2024 JUN 24 22:40	6.055	230	0.804	0.036	2.584	1.402	0.598
2024 JUL 01	2024 JUN 25 04:06	6.829	205	0.805	0.040	2.814	1.402	0.597
Crossing								
2024 JUN 20 01:58	2020 APR 25 10:20		0.895					



(a) (b) (c)

Figure 214: Encounter with P_2003_T12/ at 2024 JUN 26 in the Ecliptic Coordinate System.

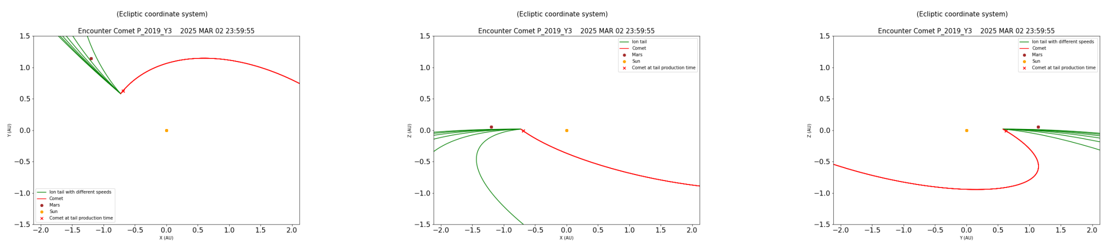


(a) (b) (c)

Figure 215: Encounter with P_2003_T12/ at 2024 JUN 26 in the Comet Orbital Coordinate System.

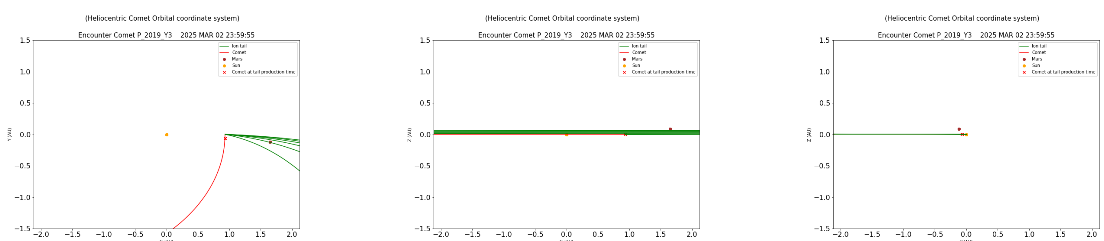
- Comet: **P_2019_Y3/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2025 FEB 28	2025 FEB 27 12:04	1.497	860	0.742	0.094	7.283	1.655	0.913
2025 MAR 01	2025 FEB 27 18:52	2.214	582	0.742	0.089	6.867	1.656	0.913
2025 MAR 02	2025 FEB 28 01:39	2.931	440	0.743	0.083	6.452	1.656	0.913
2025 MAR 03	2025 FEB 28 08:26	3.649	354	0.744	0.078	6.038	1.657	0.913
2025 MAR 04	2025 FEB 28 15:12	4.366	296	0.744	0.073	5.624	1.657	0.913
2025 MAR 05	2025 FEB 28 21:58	5.085	254	0.745	0.068	5.212	1.657	0.912
2025 MAR 06	2025 MAR 01 04:43	5.803	223	0.745	0.062	4.800	1.658	0.912
Crossing								
2025 MAR 18 18:02	2025 MAR 04 11:44		91					



(a) (b) (c)

Figure 216: Encounter with P_2019_Y3/ at 2025 MAR 02 in the Ecliptic Coordinate System.

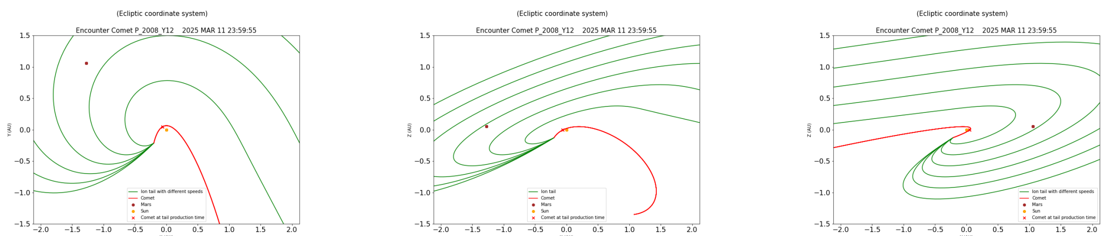


(a) (b) (c)

Figure 217: Encounter with P_2019_Y3/ at 2025 MAR 02 in the Comet Orbital Coordinate System.

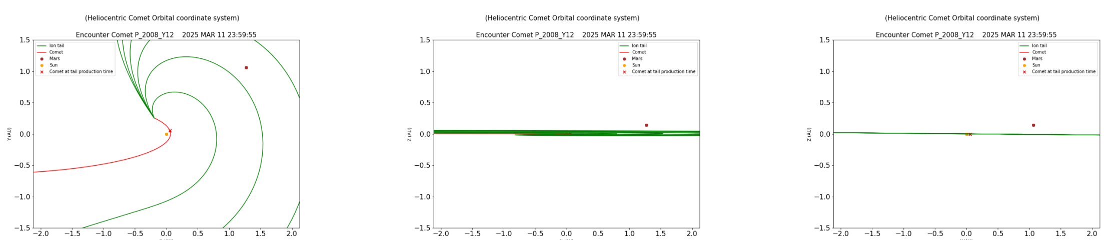
- Comet: **P_2008_Y12/**

Date Mars	Date Comet	t delay (days)	SW Speed (km/s)	d_{M-C} (AU)	d_{M-T} (AU)	Angle (deg)	d_{M-S} (AU)	d_{C-S} (AU)
2025 MAR 08	2025 MAR 06 05:17	2.780	990	1.585	0.124	4.494	1.659	0.073
2025 MAR 09	2025 MAR 06 05:28	3.771	730	1.585	0.129	4.677	1.659	0.074
2025 MAR 10	2025 MAR 06 05:40	4.763	578	1.586	0.134	4.859	1.659	0.074
2025 MAR 11	2025 MAR 06 05:52	5.755	478	1.586	0.139	5.041	1.660	0.074
2025 MAR 12	2025 MAR 06 06:04	6.747	408	1.586	0.144	5.222	1.660	0.074
2025 MAR 13	2025 MAR 06 06:15	7.739	356	1.586	0.149	5.404	1.660	0.074
Crossing								
2025 FEB 12 17:08								



(a) (b) (c)

Figure 218: Encounter with P_2008_Y12/ at 2025 MAR 11 in the Ecliptic Coordinate System.



(a) (b) (c)

Figure 219: Encounter with P_2008_Y12/ at 2025 MAR 11 in the Comet Orbital Coordinate System.