Search for Comet Ion Tail Encounters
- prediction and data analysis

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Without knowing that your destiny is destruction,
you move freely in the trajectory of yours.
Towards death, you have amazed people for centuries,
exploring space at new shores.

A comet so small,
consisting simply by ices and rocks.
But carrying a history,
the oldest solar system building blocks.

I turn to you,
when every noise has ceased in silence.
I turn to you,
when all I see is a world full of violence.

So great is your appearance,
so valuable the treasures you are bringing.
When the great stars have been looked upon,
I see you, the great home of my own beginning.

- Sofie

Abstract

Rosetta is an ESA (European Space Agency) spacecraft, launched towards a comet in March 2, 2004. She will not reach the target, comet Churyumov-Gerasimenko, until 2014, but under the journey Rosetta may possibly encounter the ion tails of other comets. The chance of crossing a tail close to a comet is small, but a comet ion tail can be identified at very large distances from its nucleus. The Ulysses spacecraft crossed the tail of comet Hyakutake at a distance of 3 AU from its nucleus. There are indeed a lot of conditions that all have to be fulfilled for the comet and spacecraft to be in exactly the right place at the right time. Here, by using two independent methods, it is shown that there were and will be several possible ion tail encounters with the Rosetta spacecraft. Possible ion tail encounters in the past have been found for other spacecrafts as well, and some of the possible corresponding signatures have been presented.

Contents

1 Introduction

There have been several cometary missions and there are missions in progress or in preparation. An armada of spacecraft (including the European Space Agency's Giotto probe and the former Soviet Union's Vega 1 and Vega 2) flew through the coma of Halley's comet in 1986 to photograph the nucleus and observed the jets of evaporating material. The Giotto mission also studied Comet P/Grigg-Skjellerup during its extended mission. The American probe Deep Space 1 flew past the nucleus of Comet Borrelly on September 21, 2001 and confirmed that the characteristics of Comet Halley are common on other comets as well. The Stardust spacecraft, launched in February 1999, has already collected particles from the coma of Comet Wild 2 in January 2004, and will return the samples to Earth in a capsule in 2006. In July 2005, the Deep Impact probe blasted a crater on Comet Tempel 1 to study its interior. Deep Space 1 may have its mission extended to allow it to visit a comet.

The most ambitious mission is the European Space Agency's Rosetta, which was launched in March 2004. The destination is a periodic comet known as Churyumov-Gerasimenko, which will be reached in 2014. The spacecraft will then follow the comet towards the sun and study its changes as it gets transformed by the heat of the Sun. Within 3.2 AU (1AU$\approx$150 millions kilometers), the comet is active, evaporating gas and dust from the icy nucleus and losing mass. About one year after arrival, both the comet and spacecraft will have reached perihelion and will thereafter be travelling outwards in the solar system. The mission will then be completed. Rosetta will be the first spacecraft to orbit a comet and fly alongside to see how it is transformed by the heat of the sun (Fig. 1). The Philae lander will be released onto the surface of this mysterious cosmic iceberg to take the first images from a comet's surface and find out about the composition. On its way, Rosettta will pass the asteroid belt that lies between the orbits of Mars and Jupiter. Two asteroids, Steins and Lutetia, are selected for close flybys and will provide us with information on the mass and density that will tell us more about their composition. Earlier results have shown that comets contain complex organic molecules that are rich in carbon, hydrogen, oxygen and nitrogen, i.e. the elements that make up nucleic acids and amino acids which are essential for life (as we know it). The Rosetta orbiter and its Philae lander will help us to learn more about the formation of our Solar System around 4600 million years ago and provide clues as to how comets may have contributed to the beginning of life on Earth. Rosetta may help finding out whether the occasional impacting comet provided Earth's oceans. If comets did not supply Earth's oceans then it implies something amazing about the comets themselves: if Rosetta finds that they are made of extremely different isotopes, it means that they may not have formed in our Solar System at all. Instead, they could be interstellar rovers captured by the Sun's gravity. No comets have yet been proven to come from interstellar space, but Rosetta will test if the relative abundances of several isotopes in the cometary matter are the same as in other bodies in our solar system. The scheduled trajectory (Fig. 2) last for 10 years, whereas most of the time she is put into hibernation.

Figure 1: Artist view of Rosetta's rendez-vous with Comet 67P/Churyumov-Gerasimenko. Copy from http://www.alfvenlab.kth.se/res/space/hw/rosetta/.

This mission is named after the Rosetta stone that was discovered in 1799. The carved inscriptions on the stone included hieroglyphics - the written language of ancient Egypt- and Greek, which was readily understood. By comparing the inscriptions on the stone, historians were able to begin deciphering the mysterious carved figures. As a result scholars were at last able to piece together the history of a long-lost culture. Similarly, it is hoped that the Rosetta spacecraft will be the key to unlock the mysteries of the oldest remaining building blocks in our solar system - comets. This means that scientists will look back 4600 million years, when only asteroids and comets surrounded the sun, together with gas and dust.

Sometimes in science, little surprises can have great impacts. Just ask the astronomers who stumbled across a small blip in the data collected from the ESA/NASA Ulysses spacecraft (Ulysses is a probe orbiting the Sun and aiming to study the solar wind) when it passes through supposedly empty space. The blip, it turned out, was the signature from an ion tail of comet Hyakutake that was more than 500 million kilometres long, i.e. almost double the longest comet tail previously known to exist. This was a complete surprise. It indicates that the comets, in particular those that are much larger and more active than Hyakutake, may influence the conditions in interplanetary space much more than earlier thought. Scientists thought it would break up, dissipate, and it would be so diluted, you would not be able to detect it at all. But now with this kind of *in situ* measurement, it is clear that these tails stay identifiable for longer distances.

The ion tails of comets are essentially formed due to the interaction of the solar wind with the cometary plasma. Many of the features seen in the ion tails of comets change on a short-time scale as well as on a long-time scale. Moreover, an ion tail is basically a plasma column of large spatial extent, thus providing a good opportunity to study physical phenomena covering a wide range of spatial and temporal variations. It can also help in distinguishing the phenomena connected with the processes taking place inside

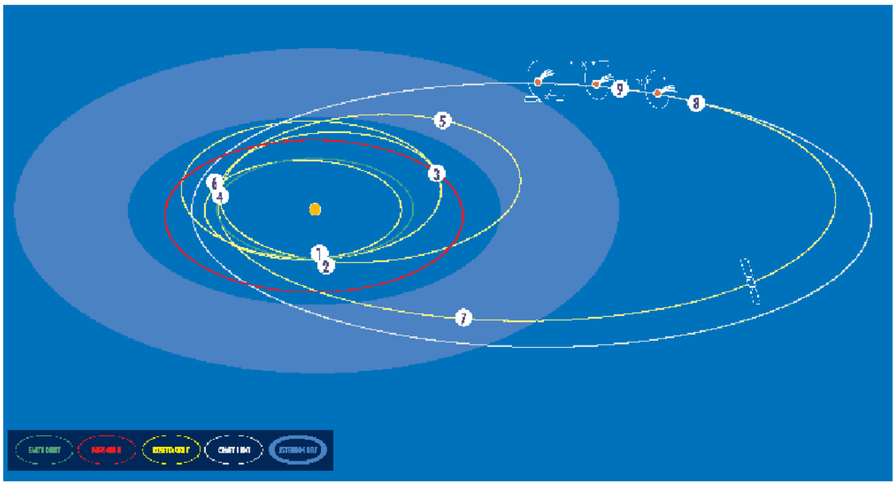

Figure 2: Rosetta interplanetary trajectory (Copyright: ESA.)

1. Launch, 2 March 2004
2. First Earth swing-by, 3 March 2005
3. Mars swing-by, 26 February 2007
4. Second Earth swing-by, 14 November 2007
5. Asteroid flyby
6. Third Earth flyby, 11 November 2009
7. Asteroid flyby
8. Arriving at the comet in 2014

the tail, such as the plasma instabilities, from those introduced by the fluctuations in the solar wind.

Can we find other encounters by prediction and not by chance? By developing software, it is possible to search for potential comet ion tail encounters with the *Rosetta spacecraft.* By calculating the shape and location of ion tails that could be produced, it is possible to predict whether Rosetta, or another spacecraft, will occupy a location where an ion tail is likely to be present. This would be a good opportunity to switch-on the scientific instruments on board Rosetta to record locally the fields, particle data and ion mass for further analyses. At the same time a check-out of the instrument can be performed before and after the possible event, to make sure they still are in a good shape. This report summarizes the results of an undergraduate thesis project performed at the Swedish Institute of Space Physics in Uppsala, initially intended for predicting times of likely ion tail encounters with Rosetta. The report gives a description of the procedures used to calculate the location and shape of the ion tails. This includes coordinate transformations and the theory involved to find the coordinates of the ion tail in the used reference system. Expected ion tail encounters with other spacecrafts are presented as well as the analysis of the recorded magnetic field signatures during that time. The validation of the software is discussed. Lastly, the calculated encounter results and the developed matlab source code are attached.

2 Comet Orbits

The theory of celestial mechanics and orbit determination was developed starting with Newton, and the progress has continued unabated until now.

2.1 Features of Comets

There are no distinct borders between different types of small bodies in the solar system. Some asteroids, and likely even Pluto, have the same features or origins as comets, and some NEAs (Near Earth Asteroids) are possibly cometary remnants where all volatile elements have disappeared. The classification as comet or asteroid is based largely on the visual appearance, and the relationship to real physical quantities is not always clear.

Comets are made of ice and dust. A typical diameter is of the order 10 km or less. The nucleus contains water ice and other frozen gases with embedded grains of rock and dust. At its centre, there can possibly be a small, rocky core. A comet is invisible when it is far from the Sun. When it gets closer to the Sun, the heat starts to melt the ice. The out-flowing gas and dust form an envelope, the *coma*, around the nucleus. The radiation pressure and the solar wind pressure push the ionised gas and dust away from the Sun, resulting in the typical long-tailed shape of a comet (Fig. 3).

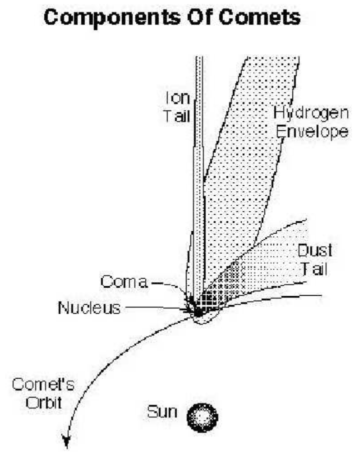

Figure 3: Components of comets. Copy from http://www.solarviews.com/eng/comet.htm.

2.2 The Two-Body Problem

Because of the dominance of the solar mass in the total mass of the solar system, in dealing with orbital motion, the model might be that of the problem of two bodies, where the parameters consist of a set of six Keplerian elements. But in more complicated cases (like comets passing close to a planet) the model might include masses of perturbing bodies.

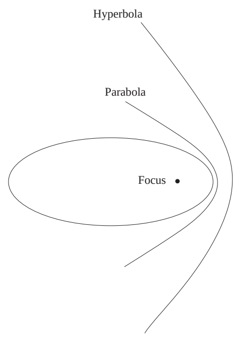

Figure 4: Comparison of elliptical, parabolic and hyperbolic orbits

The calculations carried out in this paper concerns the two-body problem, where the orbit of the comet is an ellipse (Fig. 4), with the Sun at one focus. These comets are periodic and complete several revolutions until they have been depleted by the heat of the Sun. The parabolic and hyperbolic orbits are not of interest in my search for ion tails, since the information on them comes from an observation from the single pass in the past and these comets will never enter the solar system again.

2.3 Orbital Elements

The elements of an orbit are the parameters needed to specify that orbit uniquely, given a model of two ideal masses obeying the Newtonian laws of motion and the inverse-square law of the gravitational attraction. Because there are multiple ways of defining a motion, depending on which set of variable you choose to measure, there are different ways of defining sets of orbital elements, each of which will define the same orbit. There are seven degrees of freedom in this model (time, positions in 3-D space at that time, velocity in 3-D space at that time) so all sets of orbital elements have seven parameters. For astronomical applications, a useful set of orbital parameters are those used to predict future positions (or ephemerides) of the comet. These Keplerian elements are [1]:

- Mean distance, a
- Eccentricity, e
- Perihelion distance, q
- Inclination of orbit, i
- Argument of perihelion, ω
- Longitude of ascending node, Ω
- Time of perihelion passage, τ

The longitude of ascending node and the argument of perihelion lie between 0° and 360°. The inclination lies between 0° and 180°. An inclination larger than 90° means a retrograde orbit, i.e. the comet moves around the Sun in a direction opposite to that of Earth's motion.

Due to perturbations from mainly the giant planets, like Jupiter and Saturn, the orbital elements of celestial bodies are constantly changing. The orbital elements for the Sun, the Moon and the major planets are valid for a long time period. However, orbital elements given for a comet or an asteroid are valid only for a limited time. A comet might travel in roughly the same orbit several orbital periods, experiencing only slight perturbations, but suddenly it might pass very close to Jupiter and get its orbit changed drastically. If one uses the orbital elements for a specific epoch, one or a few revolutions away from that moment will have an error in its computed position of at least one or a few arc minutes, and possibly more. The errors will accumulate with time [2]. To compute it in a reliable way is quite complicated and completely out of scope for this description.

3 Coordinate Systems

Observing or calculating the position and velocity of any celestial object requires a coordinate system. The origins of this search for suitable reference systems go back many thousands of years in astronomy. Originally, the Earth was the platform from which all measurements were taken. The coordinate system depends upon the particular problem involved. Initially, the position of Rosetta is defined in a heliocentric equatorial coordinate system and the cometary coordinates (calculated from their orbital elements) in a heliocentric plane-of-orbit coordinate system. It is thus necessary to transform the coordinates for Rosetta and the comets so they will be defined in the same coordinate system. The heliocentric ecliptic coordinate system has been used in method 1, and the cometary plane-of-orbit in method 2.

3.1 Heliocentric Ecliptic Coordinate System

When the Sun is observed over a long period of time, it is found to possess a second apparent motion in addition to its diurnal movement about the Earth. Its path is a great circle called the *ecliptic* which lies in the plane of the Earth's orbit about the Sun. This great circle is the fundamental reference plane in the ecliptic system of coordinates. It intersects the celestial equator in the vernal and autumnal equinoxes (First Point of Aries ϒ and Libra) at an angle equal to the Earth's inclination angle [1]. The heliocentric ecliptic coordinate system has the X-axis pointing from the Sun towards the first point of Aries, the Z-axis is directed perpendiculary to the ecliptic plane in the same direction as the rotation axis, and Y completes the right-handed orthogonal set ($Y = Z \times X$).

3.2 Heliocentric Equatorial Coordinate System

The X-axes in the heliocentric equatorial coordinate system and in the heliocentric ecliptic coordinate system pointing from the Sun towards the first point of Aries (i.e. the position of the sun at the vernal equinox) and thus coincides. This direction is the intersection of the Earth's equatorial plane and the ecliptic plane (Fig. 5). The Z-axis is parallel to the rotation axis of the Earth and Y completes the right-handed orthogonal set ($Y = Z \times X$).

3.3 Heliocentric Plane-of-Orbit Coordinate System

The heliocentric plane-of-orbit for comets is a Cartesian system centred at the Sun with the x-axis directed towards perihelion. The polar coordinates in the plane of orbit are the heliocentric distance r and the true anomaly f (denoted θ in Fig. 6). The z-component is necessarily zero. JPL (Jet Propulsion Laboratory) makes available a small-body orbital elements table generator where a list of cometary orbital elements are provided with options on the output [3].

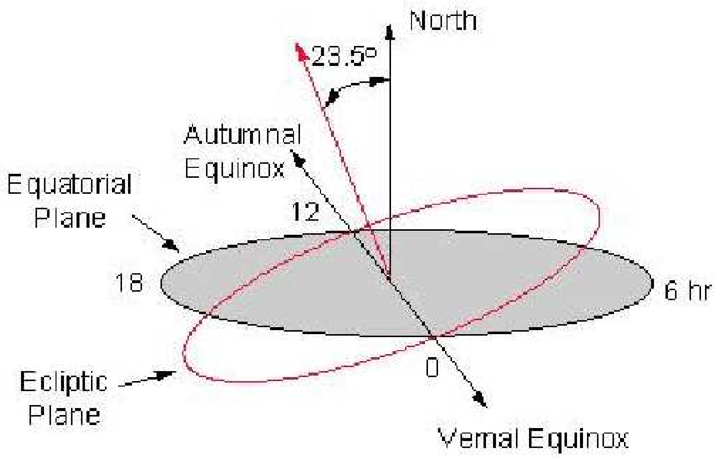

Figure 5: Equatorial system - Ecliptic system. Copy from coolcosmos.ipac.caltech.edu/.../coordsys.html.

3.4 Finding Positions

Provided the six orbital elements of a comet, one can calculate positions. The comet's mean motion, n, is defined by

$$n = \frac{2\pi}{P} \tag{1}$$

where P is the orbital period [days]. The mean anomaly, M, at time t is [4]

$$M = n\,(t - \tau). \tag{2}$$

From Kepler's equation

$$M = E - e\,\sin E \tag{3}$$

the eccentric anomaly, E, can be obtained. It is important because the rectangular coordinates of the comet in the plane-of-orbit are

$$\begin{aligned} x_{\text{com}} &= a(\cos E - e) \\ y_{\text{com}} &= a\sqrt{1-e^2}\sin E \\ z_{\text{com}} &= 0 \end{aligned} \tag{4}$$

The usual method allows us to obtain an approximate value of E that nearly satisfies Kepler's equation. The equation to solve is

$$f(E) = E - e\sin E - M = 0. \tag{5}$$

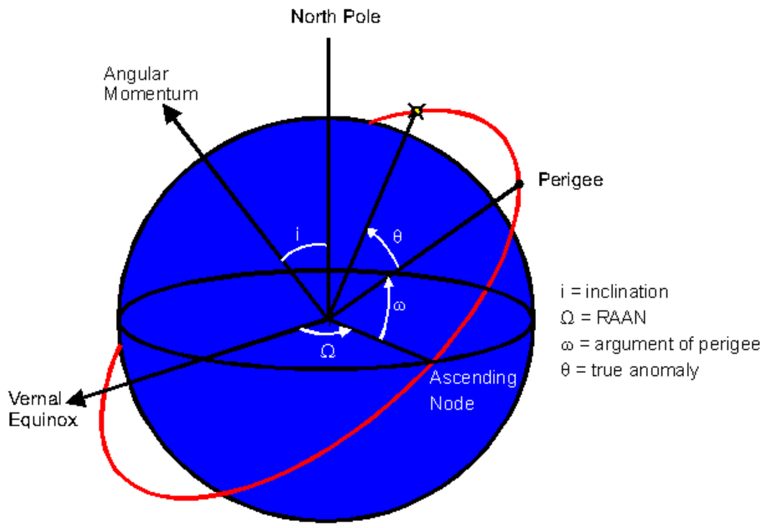

Figure 6: The plane of the orbital ellipse is defined by two angles: the inclination and the right ascension of the ascending node (RAAN). The argument of perigee is the angle measured in the direction of satellite motion from the ascending node to perigee. The true anomaly is the angle measured in the direction of motion from perigee to the satellite's position at some defined epoch time. Copy from http://www.mindspring.com/ n2wwd/html/body_orbital_description.html.

A suitable starting value is obtained by simply taking $E_0 = M$. The iterative method I started with was

$$E_{\mathrm{n}} = E - e \sin E \tag{6}$$

This method converges for elliptic orbits. But when I searched for the Ulysses encounter with Hyakutake's ion tail, there were no result at first. The reason was that the solution of the Kepler's equation are sensitive for comets with eccentricity close to one, i.e. for long period comets as Hyakutake. The problem tends to arise when $e > 0.99$ and $M \sim 0$. The method is not converging in those cases. The Kepler equation must then be solved with another iterative method. The alternative method is via Newton Raphson iteration [5]:

$$E_{\mathrm{n}} = E - \frac{f(E)}{f'(E)}, \tag{7}$$

where $f'(E) = 1 - e \cos E$.

The Halley's third order method is somewhat better behaved in the awkward cases of $e > 0.99$ and $M \sim 0$, and involves little extra effort for a considerable increase in robustness:

$$E_{\rm n} = E - \frac{f(E)}{f'(E)} - \frac{f(E)f^{"}(E)}{2f'(E)}, \tag{8}$$

where $f^{"}(E) = e\sin E$. This formulation converges slightly faster, and is much less inclined to bounce chaotically if started with an unsuitable initial guess. Hence, this is the method I have used throughout this work.

3.5 Transformation of Systems

3.5.1 Equatorial to Ecliptic

The angle between the z-axis' of the heliocentric equatorial coordinate system and the heliocentric ecliptic coordinate system is the Earth's inclination angle to the ecliptic. The transformation from geocentric coordinates to the ecliptic coordinates (Fig. 5), is carried out by

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{ecl} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\epsilon & \sin\epsilon \\ 0 & -\sin\epsilon & \cos\epsilon \end{pmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{eq} \tag{9}$$

where ecl represents the heliocentric ecliptic coordinate system, eq represents the heliocentric equatorial system and ϵ = Earth's inclination angle $\approx 23.452294°$

3.5.2 Ecliptic to Plane-of-Orbit

According to Euler's rotation theorem, any rotation may be described using three angles. The three angles giving the three rotation matrices are called the Euler angles [6], where (ϕ, θ, ψ) from Figure 7 corresponds to the orbital elements, (Ω, i, ω).

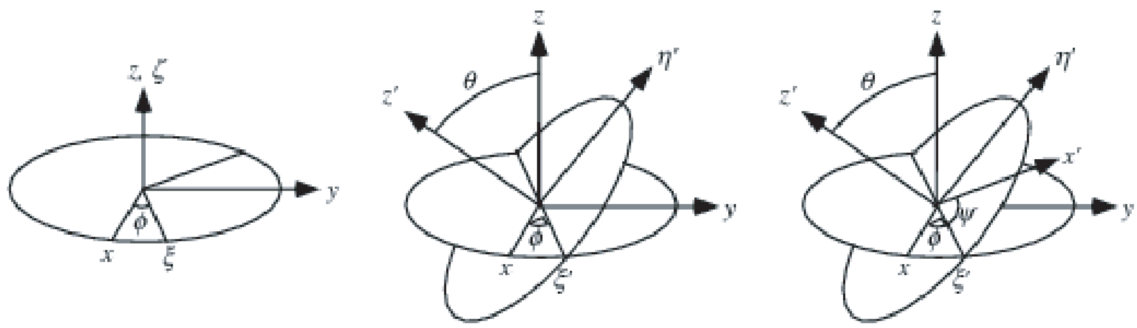

Figure 7: Euler Angles. Copy from http://mathworld.wolfram.com/EulerAngles.html.

If the rotations are written in terms of rotation matrices B, C, and D, then a general rotation A can be written as

$$A = BCD = \begin{bmatrix} P_\mathrm{x} & P_\mathrm{y} & P_\mathrm{z} \\ Q_\mathrm{x} & Q_\mathrm{y} & Q_\mathrm{z} \\ R_\mathrm{x} & R_\mathrm{y} & R_\mathrm{z} \end{bmatrix} \tag{10}$$

There are several conventions for Euler angles, depending on the axes about which the rotations are carried out. In our case we have

$$D = \begin{bmatrix} \cos\Omega & \sin\Omega & 0 \\ -\sin\Omega & \cos\Omega & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{11}$$

$$C = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos i & \sin i \\ 0 & -\sin i & \cos i \end{bmatrix} \tag{12}$$

$$B = \begin{bmatrix} \cos\omega & \sin\omega & 0 \\ -\sin\omega & \cos\omega & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{13}$$

The transformation to the plane-of-orbit system from the ecliptic system is

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{orb} = \begin{pmatrix} P_\mathrm{x} & P_\mathrm{y} & P_\mathrm{z} \\ Q_\mathrm{x} & Q_\mathrm{y} & Q_\mathrm{z} \\ R_\mathrm{x} & R_\mathrm{y} & R_\mathrm{z} \end{pmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{ecl} \tag{14}$$

where

$$P = \begin{bmatrix} \cos\omega\cos\Omega - \sin\omega\sin\Omega\cos i \\ \cos\omega\sin\Omega + \sin\omega\cos\Omega\cos i \\ \sin\omega\sin i \end{bmatrix} \tag{15}$$

$$Q = \begin{bmatrix} -\sin\omega\cos\Omega - \cos\omega\sin\Omega\cos i \\ -\cos\omega\sin\Omega + \cos\omega\cos\Omega\cos i \\ \cos\omega\sin i \end{bmatrix} \tag{16}$$

$$R = \begin{bmatrix} \sin\Omega\sin i \\ -\cos\Omega\sin i \\ \cos i \end{bmatrix} \tag{17}$$

3.5.3 Plane-of-Orbit to Ecliptic

A matrix maps one coordinate system to another. The mapping is directed and can be reversed by transposing a matrix. This is done by turning each row into a column in equation (14).

z_{orb} equals zero for the comet, so the transformation to the ecliptic system from the plane-of-orbit system becomes

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{ecl} = \begin{pmatrix} P_\mathrm{x} & Q_\mathrm{x} & R_\mathrm{x} \\ P_\mathrm{y} & Q_\mathrm{y} & R_\mathrm{y} \\ P_\mathrm{z} & Q_\mathrm{z} & R_\mathrm{z} \end{pmatrix} \begin{bmatrix} x \\ y \\ 0 \end{bmatrix}_{orb} \tag{18}$$

4 Comet Ion Tails

Here, I will give a brief description of the physical context of this study, which is the comet ion tail generation due to the interaction with the solar wind, as well as some of the underlying physical processes.

4.1 The Solar Wind

The solar wind is an outflow of plasma from the solar corona, particulary from coronal holes – regions of low density and temperature where the magnetic field is weak and the field lines are open to the interplanetary space. Its average physical properties (density, velocity, temperature, and magnetic field) vary depending on the solar cycle, heliographic latitude, heliocentric distance, and rotational period, they also vary in response to shocks waves and other turbulent phenomena arising in the interplanetary medium. The typical values of the solar wind velocity, proton density, and magnetic field strength near the Earth are, respectively, 450 km/s; 6.6 cm^{-3}, and 7 nT [7, pp. 92]. During the declining and minimum phases of the solar cycle, the solar wind is dominated by high-speed (500–800 km/s) flows emanating mostly from the polar coronal holes. Coronal holes occur both at low latitudes and at the poles; the polar holes are largest at solar minimum, extending equatorward and often merging with low-latitude holes of the same magnetic field polarity. In addition to the high-speed flow, the solar wind also has a dense low-speed component (400 km/s) associated with the equatorial coronal streamer belt. Understanding the physics behind the solar wind generation and its acceleration remains one of the major problems in solar physics. The future missions under preparation (NASA's Solar Probe, ESA's Solar Orbiter) are expected to bring key *in situ* measurements that would allow to solve these crucial problems.

When flowing in space, the solar wind interacts with the solar system planets causing all the known dynamical processes: magnetic substorms, auroras, . . . , but also with the various comets it encounters.

4.2 Comet - Solar Wind Interaction

The Interplanetary Magnetic Field (IMF) is a part of the Sun's magnetic field that is carried into the interplanetary space by the solar wind. In a fluid description of the solar wind, such as the MagnetoHydroDynamics (MHD), the interplanetary magnetic field lines are said to be *frozen in* the solar wind plasma.

A comet presents an interesting obstacle to the solar wind. The solar wind does not see the nucleus, and its interaction with the dust and neutral species is limited. The neutral molecules are released from the nucleus by sublimation and flow away from the comet at approximately 1 km/s, whereafter the ions are produced by photo-ionisation. The cometary plasma, consisting of these ionised molecules and electrons, constitutes a serious obstacle to the solar wind. The created ions are actually trapped into the magnetic field lines (this process is called *mass loading*), and because the ions are essentially at rest with respect to the solar wind, the flow is slowed. A first macroroscopic (*i.e.* fluid) description of these processes was provided by Alfven in 1957: The cometary ions follow the frozen-in magnetic field lines of the solar wind. These field lines wrap around the comet's ionosphere and are finally dragged into the tail (Fig. 8).

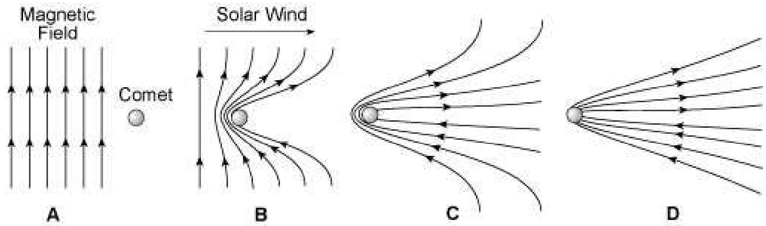

Figure 8: Magnetic field lines entrained within the solar wind (A) are unable to penetrate the sphere of ions that envelop a comet nucleus, and so they pile up in front of it and drape around it (B). An ion tail forms on the side of the comet facing away from the Sun (C and D). The ions flow away from the Sun between the oppositely directed magnetic field lines in the tail. When a comet enters a region where the original magnetic field lines in the solar wind (A) changes direction, the comet loses its ion tail and soon grows another. Copy from: http://ase.tufts.edu/cosmos/print_images.asp?id=14.

The solar wind deceleration, occuring at the comet, yields a velocity shear, giving entrained field lines hairpin-like configurations straddling an induced current sheet [8, pp. 574]. This deceleration of the supersonic solar wind flow leads the formation of a weak shock wave in front of the comet. Behind the shock, the flow is increasingly mass-loaded with the cometary ions. The interplanetary magnetic field, frozen in the flow, piles-up in front of a diamagnetic cavity which separates the mass-loaded solar wind from the purely cometary plasma (Fig. 9).

Basically, comets in the equatorial region are exposed to a slower, gustier solar wind while comets in the polar region are exposed to a faster, steadier solar wind. Hence, comets in the polar region should show a smoother, less disturbed appearance, while comets in the equatorial region should show a relatively structured, more disturbed appearance [4, pp. 218]. The solar wind from near the Heliospheric Current Sheet (HCS) is generally slow, 400 km/s, while that at high latitudes is fast, 700 km/s. If the solar wind flow was strictly radial, the percentage of fast and slow wind observed by a spacecraft would depend on the tilt of the HCS and the latitude of the spacecraft. The calculated ion tails, with the ion transportation strictly radial with the solar wind speed, thus has to be considered over a range of solar wind speeds.

4.3 Ion Tail Formation

The formation of ion tails is basically due to the interaction of the solar wind with the cometary plasma. In fact, it was observations of the varying orientations of comet tails that originally led to the suggestion of the existence of the solar wind. It is now well established that gas from comets is ionised by several processes and joins the solar wind,

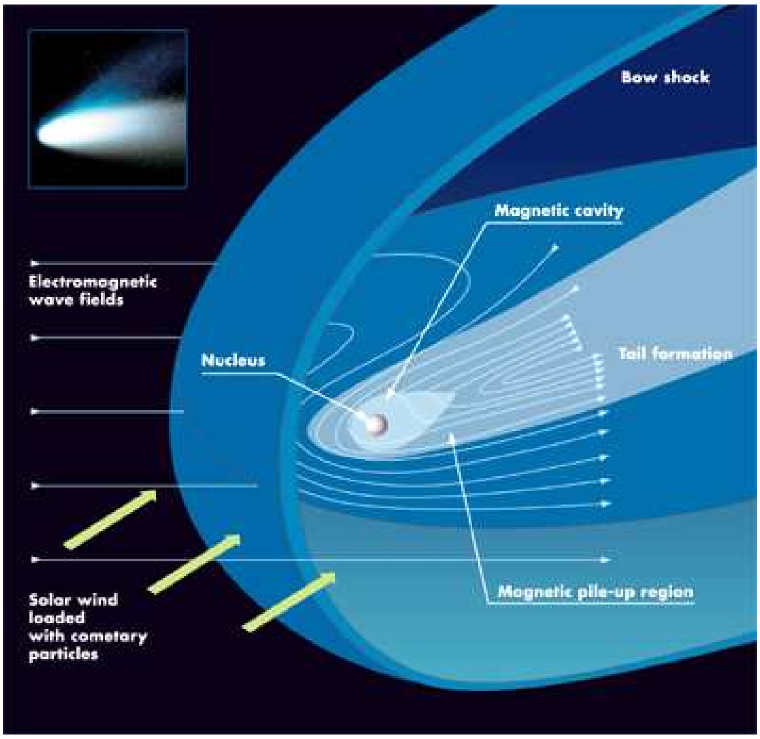

Figure 9: The ion tail formation. Copy from: http://www.esa.int/esaCP/SEMSLK1PGQD_index_0.html.

forming an ion (plasma) tail that points away from the Sun. The central axes of ion tails are found to lag behind by a few degrees with respect to the radius vector. The lag is due to the relative velocity of the solar wind with respect to the comet.

As the comet absorbs ultraviolet light, chemical processes release hydrogen, which escapes the comet's gravity, and forms a hydrogen envelope. Usually there are two tails, an *ion tail* (plasma tail) and a *dust tail* (neutral tail) (Fig. 3). The dust tail is whitish and the ion tail is bluish. The partly ionised gas and the very fine dust in the ion tail are driven by the solar wind and hence it points almost radially away from the Sun. Some of the light from the ion tail is reflected sunlight, but the brightness is mostly due to emission by the excited atoms. The dust tail is caused by the solar radiation pressure on the dust particles in the coma. Because the velocities of the dust tail are lower (the dust is much more massive than the constituents of the ion tail) than the velocities in the ion tail, the dust tail is often more curved due to the resultant velocity component between the radial velocity and the velocity of the comet. The probability of encounter a dust tail is small, since it remains close to the comet. A full description of the calculation of the dust tail is also more extensive and less straightforward compared to the ion tail that travels radially out from the Sun. Thus, the search for dust tail encounters are not treated here.

4.4 Ulysses' Observation of Ion Tail

The Ulysses spacecraft (the first to explore the out-of-ecliptic solar wind) recorded anomalously low solar wind proton density for several hours on 1 May 1996. An unusual magnetic field structure was detected by the spacecraft's magnetometer. Analysis of the magnetic field data revealed that this structure displayed draping patterns consistent with those expected within a cometary plasma tail. On the day of the proton density drop, Ulysses was radially aligned with the position that the comet Hyakutake had occupied approximately 8 days earlier. This time difference was in the range expected for cometary plasma to flow between the comet and the spacecraft (Fig. 10) [8]. This shows that it is possible to observe ion tails at least up to 3 AU, which were the distance between the Ulysses spacecraft and comet Hyakutake when the crossing of the tail occured.

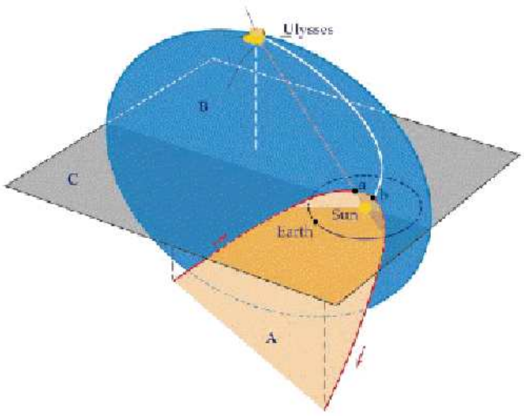

Figure 10: Relative positions of the Sun, the comet Hyakutake, Ulysses and Earth on 1 May 1996. The orbital planes of the last three objects are labelled A, B and C, respectively. Copy from [8].

5 Searching For Ion Tail Encounters

Some conditions are necessary and have to be met to have a chance to detect an ion tail, whereas other conditions, added to make the search easier, are here refered to as "easier-life conditions". Rosetta will reach the comet Churyumov-Gerasimenko at her maximum distance from the Sun, the mission aphelion beyond 5 AU. Ion tails are travelling radially out from the comet along a line connecting the Sun and the comet, i.e. Rosetta necessarily has to have a larger radial distance from the Sun than the comet if we should have a chance to observe the tail. This enable us to put another limitation on the output, a perihelion distance less than 5 AU.

Necessary conditions

- $q < 5$ AU (Section 3.3).
- Rosetta radially outside the comet from the Sun.
- Rosetta and the comet on the same side of the sun.

Easier-life conditions

- Elliptic orbits ($e < 1$) (Section 2.2).
- Two-body problem, stable orbits (no perturbations assumed) (Section 2.3).
- Dust tail - no (Section 4).
- Solar wind strictly radial (Section 4.2).
- Variation of solar wind speed (Section 4.2).
- Maximum distance to tail axis (to be classified as an encounter) chosen as 0.15 AU, i.e. assuming the tail has the shape of a bended cylinder with radius 0.15 AU.

5.1 Method 1

The calculation of ion tails in this method is iterative and is carried out in the heliocentric ecliptical system (Section 3.1). The method is shown as a flowchart in Figure 11, and a list of the programs with a short description is given in Table 1. A more extended description can be found in the source code attached as appendix.

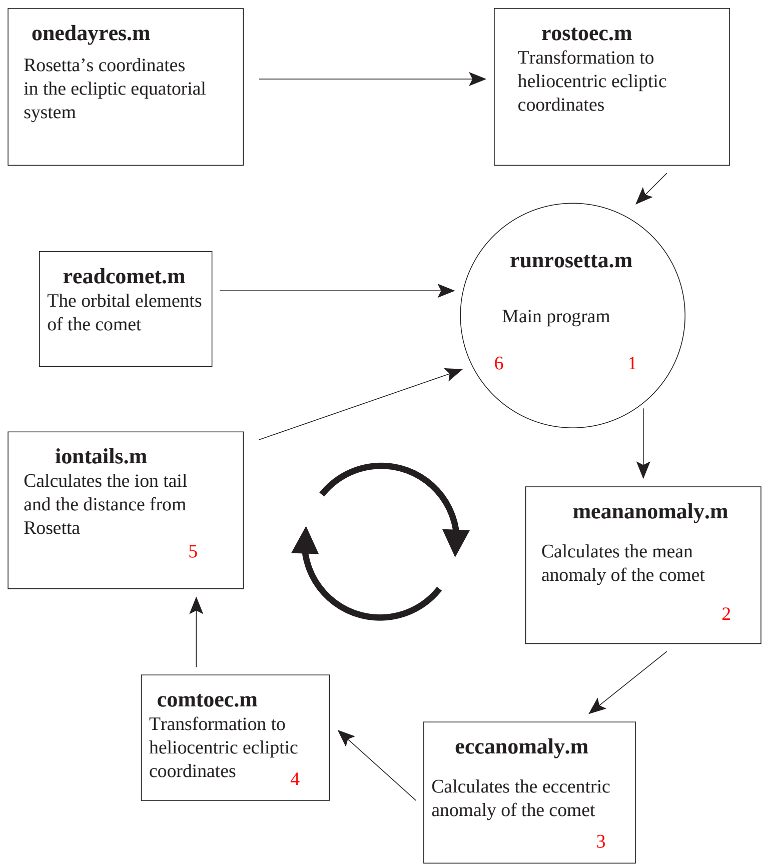

Figure 11: Flowchart of method 1.

5.1.1 Algorithm runrosetta.m

The algorithm of the main program:

1. The file with orbital elements of the first comet is opened.
2. The mean anomalies, M, in time steps of 24 hours over Rosetta's journey are calculated.
3. The corresponding eccentric anomalies, E, obtained from Kepler's equation, are calculated.
4. The cometary orbit in the heliocentric ecliptic coordinate system is calculated.
5. The ion tails of the comet and the distances from Rosetta are calculated. A more extensive description of this program is included in the next headline.
6. The orbital file for the next comet is opened, and the program starts over from step 2. This loop continues until all comets have been evaluated.

Filename	**Description**
onedayres.txt	Trajectory file
onedayres.m	Stores the equatorial coordinates
rostoec.m	Transforms to ecliptic coordinates for Rosetta
comets.txt	Orbital elements of the comets
readcomet.m	Stores the orbital elements
runrosetta.m	Main program
meananomaly.m	Calculates the mean anomaly
eccanomaly.m	Calculates the eccentric anomaly
comtoec.m	Transforms to ecliptic coordinates for the comets
iontails.m	Calculates the ion tails and the distances from Rosetta
timeres.m	Resolves with smaller time steps
plothit.m	Visualises the encounter

Table 1: Matlab files used in method 1.

5.1.2 Algorithm iontails.m

The algorithm of the ion tail calculations:

1. Iterations over 12 different values of the solar wind velocities, ranging from 200 to 800 km/s.
2. Iterations over the time span of Rosetta's journey are performed. Time step equals one day.
3. At the solar wind speed and time given in the loop, the program evaluates whether Rosetta is outside the cometary orbit and at the same side of the Sun. If it is true, the program proceeds to step 4, otherwise it jumps to step 2 again (one day is added).
4. Calculates the ion tail as it is located at time t.
5. Stores the minimum distance between the ion tail and Rosetta if it is less than 0.5 AU.
6. Returns to step 2. At time t+1, step 3 is processed again, and so on until end of mission.
7. A new value of the solar wind speed is selected (step 1).

Reduction of the calculation time is performed by adding the conditions presented on previous page and only calculating the extension of the ion tail out to 6 AU.

If the comet's positions in the heliocentric ecliptic coordinates are (x_{com}, y_{com}, z_{com}) from (18), the momentary ion tail extension is calculated component by component. If $\mathbf{v}$ is the solar wind velocity, t is the time since a certain ion was emitted from the comet,

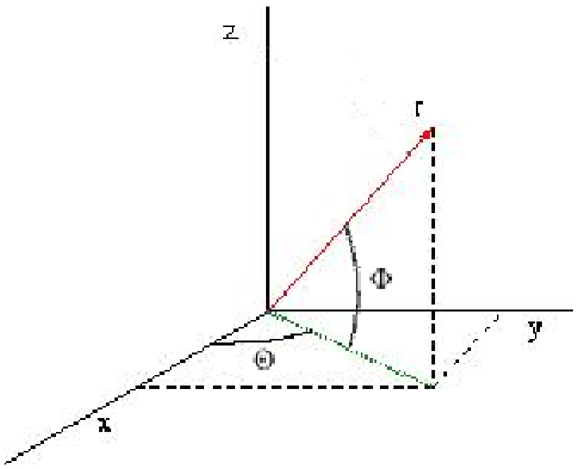

Figure 12: Angles between the axis' in the ecliptic system.

θ is the angle between the projected radial vector on the xy-plane and the x-axis and ϕ is the angle between the projected radial vector on the xy-plane and the radial vector (Fig. 12), the components of the ion tail at time T is given by

$$\begin{aligned} x_{\text{tail}}(T) &= x_{\text{com}}(T-t) + vt\cos\left(\phi_{\text{com}}(T-t)\right)\cos\left(\theta_{\text{com}}(T-t)\right) \\ y_{\text{tail}}(T) &= y_{\text{com}}(T-t) + vt\cos\left(\phi_{\text{com}}(T-t)\right)\sin\left(\theta_{\text{com}}(T-t)\right) \\ z_{\text{tail}}(T) &= z_{\text{com}}(T-t) + vt\sin\left(\phi_{\text{com}}(T-t)\right) \end{aligned} \tag{19}$$

where $t\epsilon[T - \frac{6AU}{v}, T]$ Why? We want to know the elongation of the ion tail out to 6 AU from the comet. The ions that have reached this distance were produced at time $T - \frac{6AU}{v}$. The minimum distance, R, from the ion tail at time T to the location of Rosetta can be achieved.

$$\begin{aligned} x(T) &= x_{\text{ros}}(T) - x_{\text{tail}}(T) \\ y(T) &= y_{\text{ros}}(T) - y_{\text{tail}}(T) \\ z(T) &= z_{\text{ros}}(T) - z_{\text{tail}}(T) \\ R(T) &= \sqrt{x(T)^2 + y(T)^2 + z(T)^2} \end{aligned} \tag{20}$$

5.2 Method 2

Searching for ion tails in the cometary plane-of-orbit, where the ion tails propagates, is the core of this independent method. Not only is it more accurate, the calculation time is reduced by a large factor. The calculation of ion tails in this method is analytical and carried out in the cometary plane-of-orbit system (see Section 3.3). Ion tails travel radially out from the Sun <u>in</u> the orbital plane of the comet. Possible ion tail encounters thus only occur when Rosetta crosses the orbital plane of the comet, or is close to it (since

Filename	Description
main.m	Main program
rosetta.d	Loads rosetta's coordinates in the ecliptic system
coordtransf.m	Transforms to plane-of-orbit coordinates
swvel.m	Calculates a solar wind speed necessary for encounter
hit.m	Stores the encounter
encounter.m	Stores the necessary conditions during plane encounter
plothit.m	Visualises the encounter

Table 2: Matlab files used in method 2.

the solar wind is not necessarily strictly radial). The method is shown as a flowchart in Figure 13 and a list of the used programs is given in Table 2. An more extended explanation can be found in the source code attached in appendix.

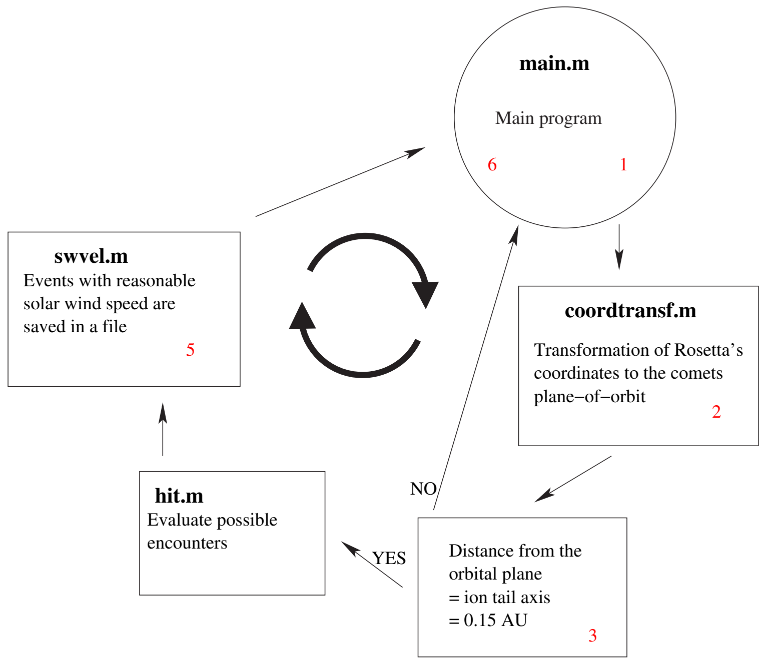

Figure 13: Flowchart of method 2.

The algorithm of the main program (main.m):

1. The file with orbital elements of the first comet is opened.
2. Transforms Rosetta's heliocentric ecliptic coordinates to the comets heliocentric reference system.
3. If Rosetta is within 0.15 AU from the orbital plane, the possible encounters are evaluated.

4. At the events, the solar wind speed necessary for an encounter with the ion tail is calculated (see next subsection).

5. If the solar wind speed is reasonable, the possible encounter is saved in a file.

6. The orbital file for the next comet is opened, and the program starts over from step 2. This loop continues until all comets have been evaluated.

5.2.1 Algorithm swvel.m

As pointed out, ion tails travel radially from the Sun in the comet's orbital plane. A radial line drawn from the position of Rosetta when she crosses the plane (or is at the most 0.15 AU from it) will cross the cometary orbit in one point. That point corresponds to the position that the comet had at the production of the ion tail that eventually ends up at the location of Rosetta. Rosetta can cross the orbital plane of a comet several times and thus has several chances to encounter an ion tail. The projected positions of Rosetta x- and y-coordinates onto the comets orbital plane gives us the desired true anomaly that the comet had at the production time. From the true anomaly, f, one can calculate the eccentric anomaly, E, at that time (21) and the radial position from the Sun (22) (see [1, pp. 83–85]):

$$E = 2\arctan\left(\tan\left(\frac{f}{2}\right)\sqrt{\frac{1-e}{1+e}}\right) \tag{21}$$

$$R = \frac{a(\cos E - e)}{\cos f} \tag{22}$$

This yields the Cartesian coordinates of the comet at the production time (23).

$$\begin{aligned} x &= R\cos f \\ y &= R\sin f \end{aligned} \tag{23}$$

This position was occupied by the comet at time t (24).

$$t = \frac{E - e\sin E}{n} + \tau \tag{24}$$

Where:
n = mean motion = $\frac{2\pi}{P}$
τ = time of perihelion passage

The difference in time between the plane encounter (or position near the plane), T, and the time of production of the tail, t, corresponds to the time delay of the ion tail, i.e. the time it takes for the ions to travel out to Rosetta's location (25).

$$t_{\text{delay}} = T - t \tag{25}$$

The solar wind speed necessary for this to occur can directly be calculated from the radial distance between the comet and Rosetta and the time delay (26).

$$v = \frac{R_{\text{ros}} - R_{\text{com}}}{t_{\text{delay}}} \tag{26}$$

If this speed turns out to be in a reasonable range for the solar wind, we have thus predicted an event for future measurements.

5.3 Resolution

The search for ion tails that Rosetta might encounter covers her outward journey which will last for 10 years from launch. This put limits on the time resolution that can be used in numerical calculations of the ion tails. In both methods, the calculations are made at every step of 24 hours. A higher resolution is needed to obtain a better accuracy and a more probable time of encounter. When an encounter within 0.15 AU has been identified, steps of half an hour are taken to calculate the 'missing' ion tails during that time span. This is because there is a gap of information 24 hours before and 24 hours after the encounter calculated with 24 hours resolution. A new set of distances to the ion tail produced by the comet are calculated, and the closest encounter most probable occurs in the interval between [1].

[1]This also means that the minimum distance to the tail for 00:00 UT, i.e. previously calculated time of encounter, changes due to that more points of the ion tail are produced to compare with, than there were before. So a closer distance are obtained even for that point.

5.4 Accessing Orbital Data

- The data file with **Rosetta** coordinates were obtained from ESOC (European Space Operations Center). These coordinates are in a *heliocentric equatorial coordinate system.*

- The JPL (Jet Propulsion Laboratory) HORIZONS On-Line Solar System Data and Ephemeris Computation Service provides access to the motions of the planets, comets and interplanetary spacecraft. HORIZONS is provided by the Solar System Dynamics Group of the JPL [9]. This provided me with a coordinate list of the Sun, Ulysses spacecraft and Cassini spacecraft in the *geocentric ecliptic coordinate system.* The orbits of **Earth, Ulysses and Cassini** around the Sun in the heliocentric ecliptic coordinate system are then obtained by transformations.

- The list of **comets** has been accessed from the Small-Body Orbital Elements Table Generator [3].

6 Rosetta encounters

As this report will show, there are a few possible ion tail encounters (see Table 4) which can be a reason to wake Rosetta up from hibernation. The first opportunity was discovered in the latest hour. The list of comets that has been used throughout my thesis work until the 13th of June, 2005, was downloaded during autumn 2004. New comets have been discovered since and the orbital element might have changed for others. So, I downloaded the latest updated list of comets and ran my programs again. It turned out that one possibility was going to take place during the weekend of 17-19 of June, 2005 (see Table 3), with a largest probability during the 18th concerning the solar wind speed. Luckily, instruments were going to be turned on the 16th for check-out and after some quick actions from my supervisor, Anders Eriksson, it was decided that the Rosetta magnetometer and Langmuir probe instruments were going to take measurements during the weekend. The signatures from the event were not convincing (see Section 9). The cross-section of an ion tail is wider at larger distances. Probably the distance between Rosetta and the comet were to small at the event (see Table 4), i.e. the cross-section of the tail was too thin and Rosetta never encountered it.

Date	Sign	$R_{\mathrm{R-i}}$ [AU]	SW-speed [km/s]	Time delay [days]	$R_{\mathrm{R-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
17-Jun-2005	-1	0.0731	1017	0.495	1.33	1.04
18-Jun-2005	-1	0.0719	565	0.920	1.34	1.04
19-Jun-2005	-1	0.0707	395	1.35	1.34	1.03
20-Jun-2005	-1	0.0696	307	1.80	1.34	1.03
21-Jun-2005	-1	0.0684	252	2.25	1.35	1.02
22-Jun-2005	-1	0.0671	215	2.71	1.35	1.02
encounter						
11-Aug-2005	-1	0.000448	35.1	32.8	1.54	0.877

Table 3: Encounter with **P/Catalina (2005 JQ5)** as calculated in method 2. R-Rosetta, i-ion tail, S-Sun, C-comet

Rosetta's trajectory in the heliocentric equatorial coordinate system (Fig. 14) has a large deviation from the equatorial plane compared to the trajectory in the heliocentric ecliptic coordinate system (Fig. 15) as expected.

Rosetta has an out of the ecliptic trajectory due to the fly-by of the asteroids Steins and Lutetia (Fig. 16). The predicted comet ion tail encounters, in the ecliptic reference system, under the best conditions are visualised in Figures 17, 18, 19, 20 and are produced by methods 1 with the 24 hours resolution. The more exact encounter time and distances (as calculated with timeres.m) are added to the figure together with the result from method 2. The blue ion tail corresponds to a solar wind velocity calculated for, i.e. 450 km/s. The yellow ion tails visualize how the ion tail look like at other solar wind velocities (ranging from 200 km/s to 800 km/s).

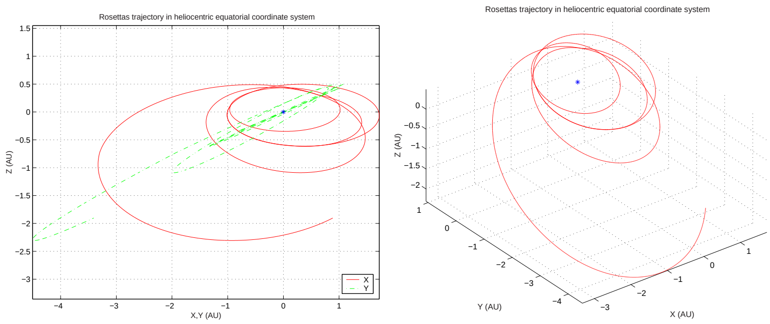

Figure 14: Rosetta's trajectory in the heliocentric equatorial system. Sun is located in origo.

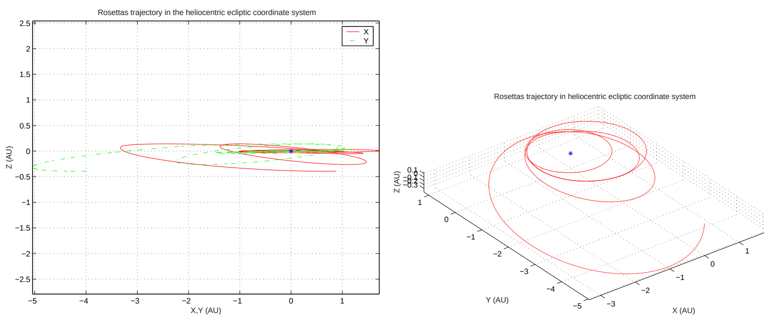

Figure 15: Rosetta's trajectory in the heliocentric ecliptic system. Sun is located in origo.

Figure 21 shows the encounter with an ion tail from 45P/Honda-Mrkos-Pajdusakova in the plane-of-orbit reference system.

The seven reasonable ion tail encounters with Rosetta are listed in Table 4. At a solar wind speed value of 450 km/s (for different solar wind speeds see the results in Section A) we obtain the *time delay* for the ions from their production at the comet until they reach the vicinity of Rosetta, the distance between Rosetta and the centre of the ion tail $R_{\mathrm{R-i}}$, the distance between Rosetta and the Sun at the time of encounter $R_{\mathrm{R-S}}$, and the distance between the comet and the Sun at the time of production $R_{\mathrm{C-S}}$. The column *'Sign'* indicates whether Rosetta is above the orbital plane of the comet (+) or below (-). The arrows indicate at what direction Rosetta is moving relative to the orbital plane of the comet. If Rosetta is located above the orbital plane, a down arrow indicates motion towards the plane. If Rosetta is located below the orbital plane, a down arrow indicates a movement away from the plane. The choice of a specific solar wind speed is performed in the program distance.m.

Encounters 5-7 are less likely due to the comets large distance from the Sun, i.e. the comets are probably inactive at that time. The most probable encounter is with an ion tail from 45P/Honda-Mrkos-Pajdusakova since the comet is close to the Sun and productive. The distance between the comet and Rosetta is also larger than nr 1-2, which is positive since ion tails broaden at larger distances.

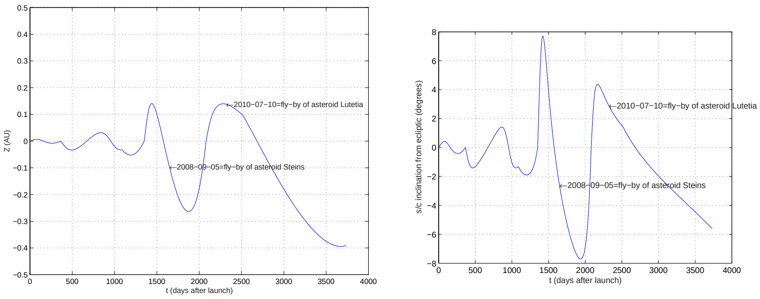

Figure 16: Left: z vs time. Right: Deviation angle vs time (heliocentric ecliptic system). Fly-by of Steins and Lutetia added.

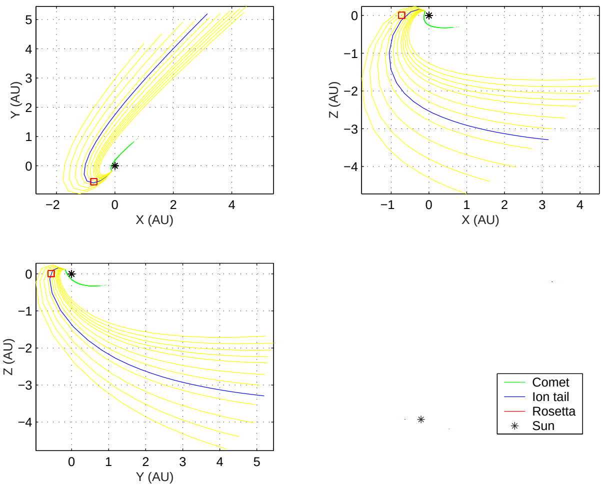

Figure 17: Ecliptic reference system - **C/Bradfield(2004F4)**:
Method 1: 21-Apr-2004 09:00:00, distance: 0.090777 AU, SW-speed: 450 km/s, Time delay: 2.5208 days
Method 2: 21-Apr-2004 04:30:00, Sw-speed: 450 km/s, Time delay: 2.8117 days, R_{RI}: 0.077073 AU, R_{RS}: 0.90737 AU, R_{CS}: 0.17662 AU.
R-Rosetta, I-Ion tail, S-Sun, C-Comet

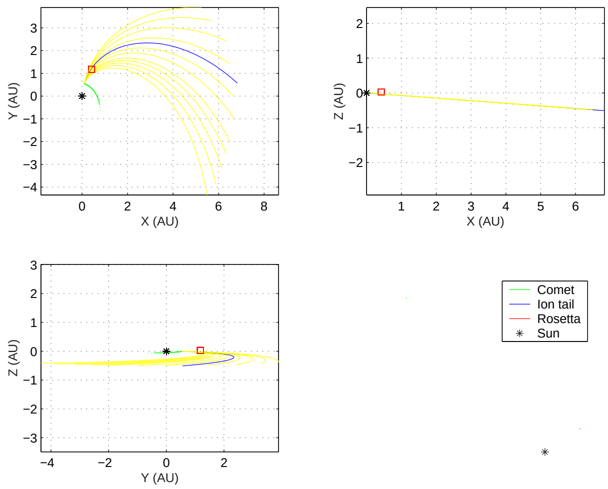

Figure 18: Ecliptic reference system - **45P/Honda-Mrkos-Pajdusakova**:
Method 1: 06-Jul-2006 15:00:00, distance: 0.061043 AU, SW-speed: 450 km/s, Time delay: 2.75 days
Method 2: 06-Jul-2006 16:00:00, Sw-speed: 450 km/s, Time delay: 2.7564 days, R_{RI}: 0.060986 AU, R_{RS}: 1.2533 AU, R_{CS}: 0.53671 AU.
R-Rosetta, I-Ion tail, S-Sun, C-Comet

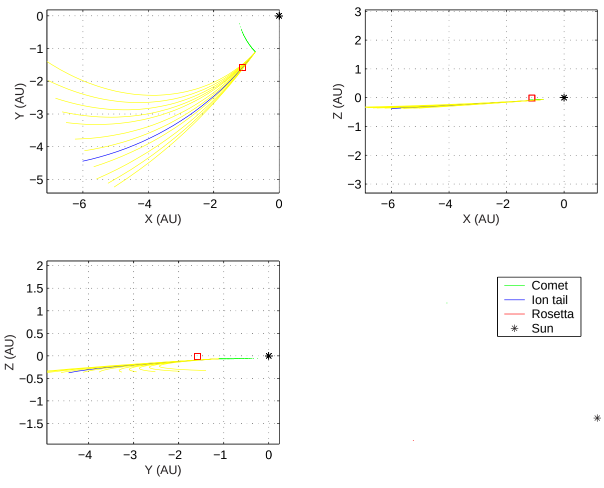

Figure 19: Ecliptic reference system - **79P/duToit-Hartley**:
Method 1: 08-Jul-2008 02:30:00, distance: 0.076838 AU, SW-speed: 450 km/s, Time delay: 2.4167 days
Method 2: 07-Jul-2008 23:15:00, Sw-speed: 450 km/s, Time delay: 2.4246 days, R_{RI}: 0.07679 AU, R_{RS}: 1.9424 AU, R_{CS}: 1.3121 AU.
R-Rosetta, I-Ion tail, S-Sun, C-Comet

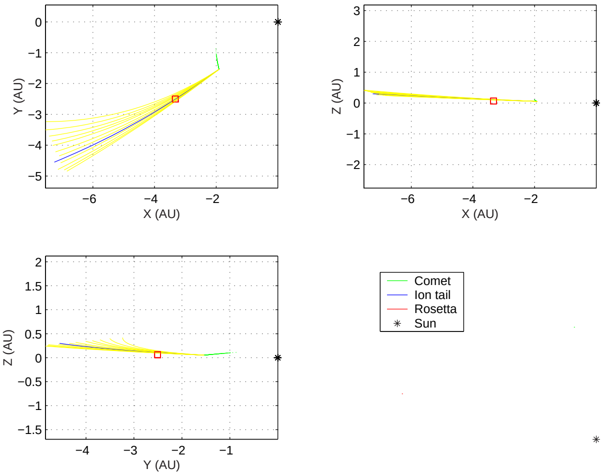

Figure 20: Ecliptic reference system - **P/Catalina-LINEAR(2004EW38)**:
Method 1: 2011-3-23 8:0, distance: 0.044113 AU, SW-speed: 450 km/s, Time delay: 6.7292 days
Method 2: 23-Mar-2011 03:15:00, Sw-speed: 450 km/s, Time delay: 6.7362 days, $R_{\rm RI}$: 0.044038 AU, $R_{\rm RS}$: 4.1666 AU, $R_{\rm CS}$: 2.4157 AU.
R-Rosetta, I-Ion tail, S-Sun, C-Comet

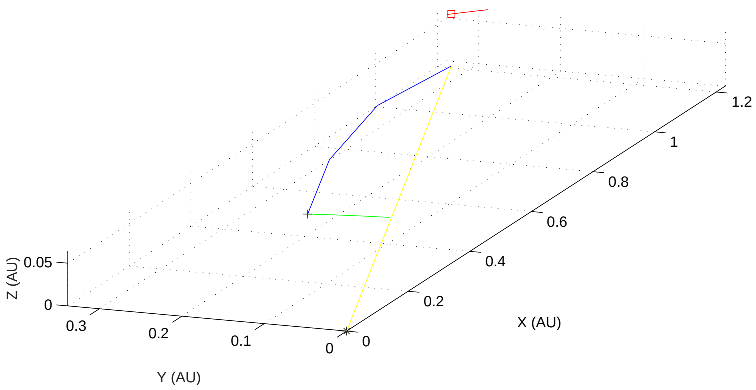

Figure 21: Plane-of-orbit reference system - **45P/Honda-Mrkos-Pajdusakova**: 06-Jul-2006 16:00:00, Sw-speed: 450 km/s, Time delay: 2.7564 days, $R_{\rm RI}$: 0.060986 AU, $R_{\rm RS}$: 1.2533 AU, $R_{\rm CS}$: 0.53671 AU.
R-Rosetta, I-Ion tail, S-Sun, C-Comet.
+ - Comet's location at encounter, □ - Rosetta's location at encounter, green line - the comet's movement, read line - Rosetta's trajectory, blue line - ion tail in 07-Jul-2006.

R-Rosetta, i-ion tail, S-Sun, C-comet

Nr	Date	Sign	SW-speed [km/s]	Time delay [days]	$R_{\mathrm{R-i}}$ [AU]	$R_{\mathrm{R-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
1	21-Apr-2004	+ ↓	450	2.81	0.0771	0.907	0.177
2	18-Jun-2005	- ↑	450	1.18	0.0712	1.34	1.03
3	06-Jul-2006	+ ↓	450	2.76	0.0610	1.25	0.537
4	07-Jul-2008	+ ↓	450	2.42	0.0768	1.94	1.31
5	23-Mar-2011	- ↓	450	6.74	0.0440	4.17	2.42
6	24-Dec-2013	+ ↑	450	5.06	0.0425	4.58	3.27
7	04-Mar-2014	+ ↑	450	4.98	0.0111	4.33	3.04

1 - C/Bradfield (2004 F4)
2 - P/Catalina (2005 JQ5)
3 - 45P/Honda-Mrkos-Pajdusakova
4 - 79P/duToit-Hartley
5 - P/Catalina-LINEAR (2004 EW38)
6 - P/LINEAR (2003 HT15)
7 - 117P/Helin-Roman-Alu

Table 4: Possible ion tail encounters with Rosetta. The source comets are numbered beneath the table.

7 Other Spacecraft Encounters

7.1 Ulysses Encounters

Ulysses is a joint NASA and ESA mission to study the Sun at all latitudes. After 15 years in flight, Ulysses has returned a wealth of data that have led to a much broader understanding of the global structure of the Sun's environment - the heliosphere [10]. The encounter of comet Hyakutake's ion tail on 1 May 1996 (Fig. 22) was described in Section 4.4 and will be mentioned again in Section 8.

Figure 22: Ulysses' Hyakutake Encounter. Copy from http://www.sciencenews.org/articles/20000408/fob1.asp.

In the ecliptic plane, the solar wind is quite dynamic which means that the magnetic field signatures of an ion tail detected by Rosetta, Cassini or the spacecrafts around the Earth could be mashed by the variations in the solar wind and hence difficult to discern.

In addition to the known Hyakutake encounter in May 1996, the program resulted in several other encounters with the Ulysses spacecraft that might have occured in the past. The data from some of them have been surveyed (Section 9). The reasonable ion tail encounters with Ulysses, during the period 07-Oct-1990 to 01-Jan-2006, are listed in Table 5 at a solar wind speed of 700 km/s (for different solar wind speeds see the results in Section A). All of them has a large $R_{\mathrm{C-S}}$ distance at production, which lower the probability of detection (since the comet is weakly productive), except for the famous event of the encounter with comet Hyakutake's tail (see Table 5). Thus, the possible signatures presented in Section 9 are not clear nor convincing.

U-Ulysses, i-ion tail, S-Sun, C-comet

Nr	Date	Sign	SW-speed [km/s]	Time delay [days]	$R_{\mathrm{U-i}}$ [AU]	$R_{\mathrm{U-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
1	06-Sep-1991	- ↓	700	3.17	0.0391	4.11	2.83
2	30-Sep-1991	+ ↑	700	6.07	0.0134	4.33	1.87
3	14-Mar-1992	- ↓	700	4.86	0.0153	5.40	3.43
4	18-Jul-1992	- ↓	700	3.14	0.0823	5.32	4.05
5	01-Oct-1992	+ ↓	700	0.716	0.0159	5.23	4.94
6	01-May-1996	- ↑	700	8.36	0.100	3.74	0.353
7	27-Apr-1998	+ ↓	700	4.83	0.0974	5.41	3.45
8	11-Aug-1998	+ ↓	700	6.62	0.0460	5.37	2.69
9	07-May-2002	+ ↓	700	3.44	0.0612	3.38	1.99
10	23-May-2002	- ↓	700	2.90	0.0189	3.46	2.29
11	28-Jun-2003	+ ↓	700	1.01	0.0528	4.99	4.58
12	15-Mar-2004	+ ↓	700	1.80	0.0454	5.37	4.64
13	29-Apr-2004	+ ↓	700	0.813	0.0630	5.39	5.06
14	12-Jun-2004	- ↓	700	2.51	0.0285	5.40	4.39
15	18-Jul-2004	+ ↓	700	1.12	0.0144	5.40	4.95

1 - 149P/Mueller 4
2 - 52P/Harrington-Abell
3 - 37P/Forbes
4 - 131P/Mueller 2
5 - P/LINEAR (2002 LZ11)
6 - C/Hyakutake(1996B2)
7 - 37P/Forbes
8 - 105P/SingerBrewster
9 - C/LINEAR(2002Q2)
10 - C/LINEAR(2002B1)
11 - P/NEAT(2001T3)
12 - P/Skiff(2002S1)
13 - C/Larsen(2004C1)
14 - 154P/Brewington
15 - P/LINEAR-NEAT(2001Q5)

Table 5: Possible ion tail encounters with Ulysses. The source comets are numbered beneath the table.

7.2 Earth Satellite Encounters

Earth encounters is another opportunity of detecting ion tails, since several spacecrafts orbit the Earth. The probability of encounter an ion tail with the spacecrafts orbiting around the Earth is much less due to that the comet has to be less than 1 AU from the Sun and in the right position relative to the Earth for the spacecrafts around us to observe the ion tail. Also, the widths of the ion tails at the Earth are small, i.e. Earth must be very close to the orbital plane of the comet. A positive view though is that IF an ion tail is crossed it will probably be easier to detect it with satellites around Earth than with spacecrafts further out since the structure has larger probability to remain intact at such a small distance. Even so, possible encounters between 1980 and 2020 have been found in my programs [2]. Encounter with comet 2P/Encke has been visualised in the ecliptic system (Fig. 23) and in the plane-of-orbit system (Fig. 24).

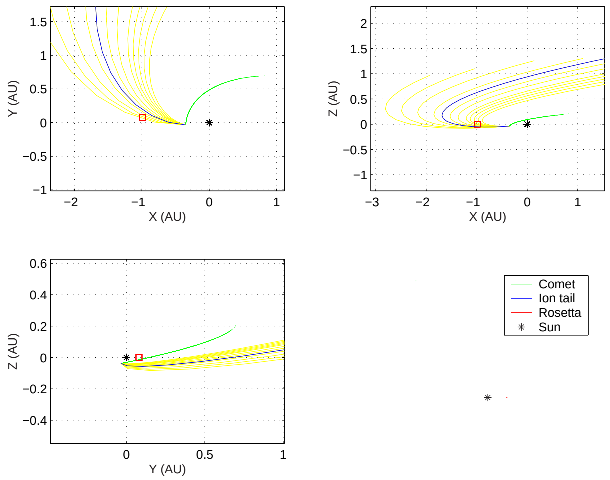

Figure 23: Ecliptic reference system - **2P/Encke**:
Method 1: 16-Mar-2017 20:00:00, distance: 0.07473 AU, SW-speed: 450 km/s, Time delay: 2.5 days
Method 2: 16-Mar-2017 23:15:00, Sw-speed: 450 km/s, Time delay: 2.5057 days, R_{EI}: 0.075131 AU, R_{ES}: 0.99495 AU, R_{CS}: 0.34379 AU.
E-Earth, I-Ion tail, S-Sun, C-Comet

The newly discovered comet P/Catalina (2005 JQ5) that returned a result with Rosetta in my program, also have an event with the Earth this summer (2005) (see Table 6).

Date	Sign	$R_{\mathrm{E-i}}$ [AU]	SW-speed [km/s]	Time delay [days]	$R_{\mathrm{E-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
09-Jul-2005	1	0.0192	645	0.368	1.02	0.880
10-Jul-2005	1	0.0208	329	0.740	1.02	0.876
11-Jul-2005	1	0.0225	223	1.12	1.02	0.873
encounter						
27-Jun-2005	-1	0.000833	0.0947	1610	1.02	0.928

Table 6: E-Earth, i-ion tail, S-Sun, C-comet

[2]Several encounters occur with a couple of comets at the same date at different years, due to the Earth's one year orbital period, i.e. when the encounter of the comet's orbital plane occur, the Earth has completed one orbit and crosses the plane again.

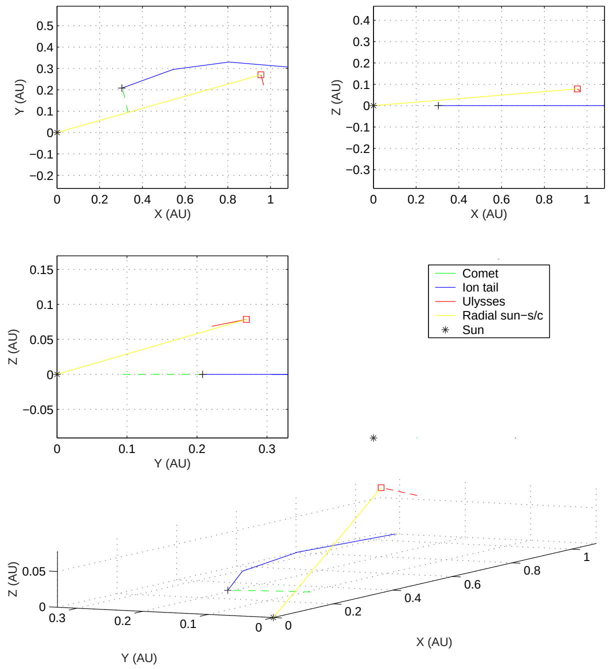

Figure 24: Plane-of-orbit reference system - **2P/Encke**: 16-Mar-2017 23:15:00, Sw-speed: 450 km/s, Time delay: 2.5057 days, R_{EI}: 0.075131 AU, R_{ES}: 0.99495 AU, R_{CS}: 0.34379 AU.
E-Earth, I-Ion tail, S-Sun, C-Comet.
+ - Comet's location at encounter, □ - Earth's location at encounter, green line - the comet's movement, read line - Earth's trajectory, blue line - ion tail in 16-Mar-2017.

The reasonable ion tail encounters with spacecrafts around Earth are listed in Table 7 at a solar wind speed of 450 km/s (for different solar wind speeds see the results in Section A). The distances between the spacecrafts and all of the comets are small, i.e. the spacecrafts need to be close to the center of the tail to be able to detect it. The most probable encounters are nr 1, 5 and 12 when the comets are closest to the Sun.

E-Earth, i-ion tail, S-Sun, C-comet

Nr	Date	Sign	SW-speed [km/s]	Time delay [days]	$R_{\mathrm{E-i}}$ [AU]	$R_{\mathrm{E-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
1	16-Mar-1984	+ ↑	450	2.51	0.0752	0.995	0.344
2	19-Dec-1985	+ ↓	450	1.66	0.0186	0.984	0.552
3	04-Oct-1987	+ ↓	450	0.844	0.0765	1.00	0.781
4	24-Aug-1990	+ ↑	450	0.464	0.0662	1.01	0.890
5	02-Feb-1994	- ↑	450	2.42	0.0738	0.986	0.357
6	11-Oct-1996	+ ↓	450	0.840	0.0592	0.998	0.780
7	09-Jul-2005	+ ↑	450	0.533	0.0199	1.02	0.878
8	19-Oct-2005	+ ↓	450	0.812	0.0410	0.996	0.785
9	25-Aug-2009	+ ↓	450	0.800	0.0515	1.01	0.803
10	24-Aug-2011	+ ↑	450	0.463	0.0662	1.01	0.891
11	26-Oct-2014	+ ↓	450	0.762	0.0217	0.994	0.796
12	16-Mar-2017	- ↓	450	2.51	0.0751	0.995	0.344
13	23-Jan-2017	- ↓	450	0.939	0.0416	0.984	0.740
14	25-May-2019	- ↑	450	0.211	0.0146	1.01	0.958

1 - 2P/Encke
2 - P/Christensen(2003K2)
3 - 72P/Denning-Fujikawa
4 - 45P/Honda-Mrkos-Pajdusakova
5 - 2P/Encke
6 - 72P/Denning-Fujikawa
7 - P/Catalina (2005 JQ5)
8 - 72P/Denning-Fujikawa
9 - P/LINEAR (2004 X1)
10 - 45P/Honda-Mrkos-Pajdusakova
11 - 72P/Denning-Fujikawa
12 - 2P/Encke
13 - 45P/Honda-Mrkos-Pajdusakova
14 - P/LINEAR(2004CB)

Table 7: Possible ion tail encounters with Earth. The source comets are numbered beneath the table.

7.3 Cassini Encounters

The Cassini-Huygens mission to Saturn is the most ambitious effort in planetary space exploration ever mounted. A joint endeavour of ESA and NASA, Cassini-Huygens is a sophisticated spacecraft being sent to the ringed planet to study the Saturnian system in detail over a four-year period [11].

There were only a couple possible encounters of interest with the Cassini spacecraft, for which I investigated the period 16-Oct-1997 to 01-Jan-2005. In addition, data were missing for the one and only encounter when Cassini were going to cross the central tail. The calculated values of the other interesting possible encounter are shown in Table 8. The result was produced with the ephemerides observed 20 January 2001, i.e. close to the calculated encounter dates. The ephemerids are thus as accurate as they can be.

Date	Sign	$R_{\mathrm{CA-i}}$ [AU]	SW-speed [km/s]	Time delay [days]	$R_{\mathrm{CA-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
22-Apr-2001	1	0.0421	506	17.4	5.64	0.542
23-Apr-2001	1	0.0418	479	18.4	5.65	0.542

Table 8: CA-Cassini, i-ion tail, S-Sun, C-comet

The reasonable ion tail encounters with Cassini are listed in Table 9 at a solar wind speed of 450 km/s (for different solar wind speeds see the results in Section A). Nr 1 is the only encounter where the spacecraft actually crosses the center of the ion tail (due to my calculations). The distances is probably too large for all of the others to produce visible ion tails, except for nr 4 (see signature in Section 9).

CA-Cassini, i-ion tail, S-Sun, C-comet

Nr	Date	Sign	SW-speed [km/s]	Time delay [days]	$R_{\mathrm{CA-i}}$ [AU]	$R_{\mathrm{CA-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
1	22-Apr-2000	CROSS	450	6.44	0.0001	3.39	1.71
2	24-Apr-2000	- ↑	450	5.43	0.0607	3.41	1.99
3	22-Feb-2001	+ ↓	450	14.3	0.0980	5.33	1.60
4	24-Apr-2001	+ ↓	450	19.7	0.0415	5.65	0.542
5	09-Jun-2001	+ ↑	450	16.9	0.0161	5.89	1.48
6	09-Apr-2001	+ ↓	450	10.9	0.0147	5.58	2.76
7	04-Apr-2001	+ ↓	450	14.6	0.0361	5.55	1.74
8	04-Dec-2002	- ↓	450	23.4	0.0166	7.93	1.85

1 - 108P/Ciffreo
2 - 137P/Shoemaker-Levy2
3 - 24P/Schaumasse
4 - 45P/Honda-Mrkos-Pajdusakova
5 - 144P/Kushida
6 - 147P/Kushida-Muramatsu
7 - 148P/Anderson-LINEAR
8 - 155P/Shoemaker3

Table 9: Possible ion tail encounters with Cassini. The source comets are numbered beneath the table.

8 Validation

That the cometary orbits, Rosetta's orbit and Earth's orbit are calculated correctly is clear from the comparison of my plot and the plot produced by ESOC (Fig. 25, Tab. 10) of the event when Rosetta closes in to comet Tempel 1 on July 4, 2005. By using a ruler (as accurate as it can be) to measure the coordinates in the ecliptic plane from the plot produced by ESOC it fits well with my calculated coordinates.

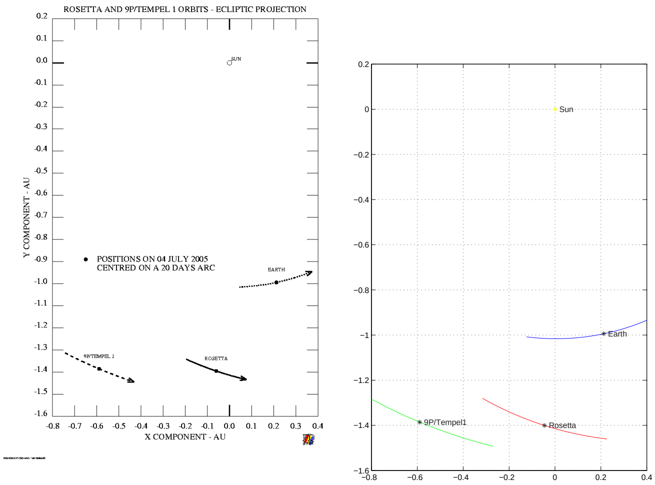

Figure 25: Encounter with **9P/Tempel**. Left: plot from ESOC. Right: my plot.

	X_{com} [AU]	Y_{com} [AU]	X_{ros} [AU]	Y_{ros} [AU]	X_{earth} [AU]	Y_{earth} [AU]
ESOC	-0.5885	-1.3846	-0.0577	-1.4008	0.2115	-0.9923
METHOD 2	-0.5896	-1.3858	-0.0460	-1.4004	0.2124	-0.9943

Table 10: X- and Y coordinates of the comet, Rosetta and Earth in the heliocentric ecliptic system on 04-Jul-2005.

The calculations of the ion tails and the time of encounter is essential to validate. My program found Ulysses' encounter of comet Hyakutake's ion tail on 1 May 1996 (see Figure 26 and 27) with 2-3 hours deviation from the true value.

Table 11 shows the comparison of the data presented in the report by Jones et al [8] to the values calculated by method 2.

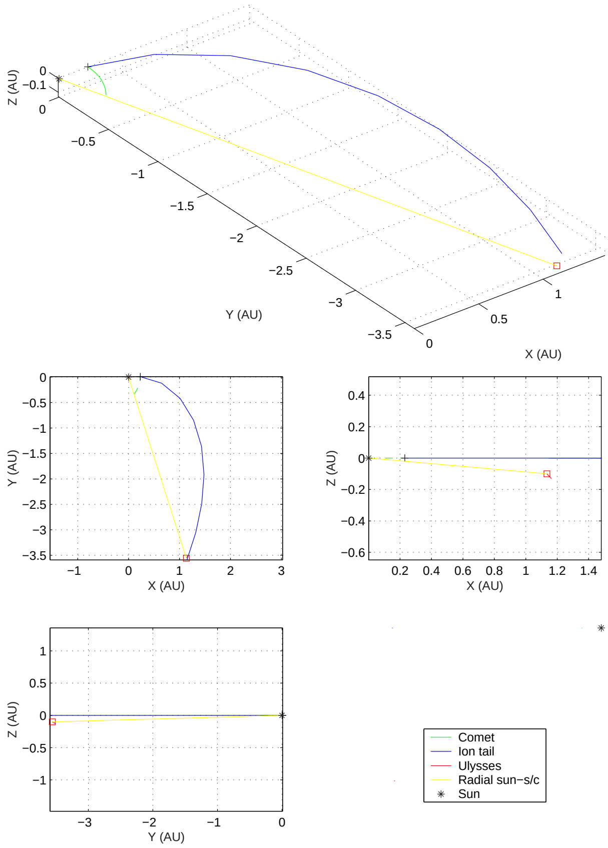

Figure 26: Ulysses encounter with Hyakutake's ion tail in the plane-of orbit reference system.

	Encounter date	Production date	SW [km/s]	Delay [days]
JONES	01-May-1996	23-Apr-1996	740	7.92
METHOD 2	01-May-1996	23-Apr-1996	740	7.909
	$R_{\mathrm{C-S}}$-production [AU]	$R_{\mathrm{C-S}}$-encounter [AU]	$R_{\mathrm{U-C}}$ [AU]	$R_{\mathrm{U-S}}$ [AU]
JONES	0.35	0.23	3.39	3.73
METHOD 2	0.35291	0.230619	3.3802	3.7305

Table 11: encounter with **Hyakutake's** ion tail. U-Ulysses, S-Sun, C-comet

Rosetta's first scientific activity: observation of Comet C/2002 T7 (LINEAR) on 30 April 2004 at a distance of 0.635 AU, is not in my list of comets since it is currently travelling for the first and only time through the inner Solar System (i.e. the eccentricity is larger than 1). Otherwise this would have been a good validation of my programs. The event offered though Rosetta an excellent opportunity to make its first scientific observation [12]. Rosetta successfully measured the presence of water molecules in the tenuous atmosphere around the comet. Images shows a pronounced nucleus and a section of the tenuous tail extending over about 2 million kilometers was obtained.

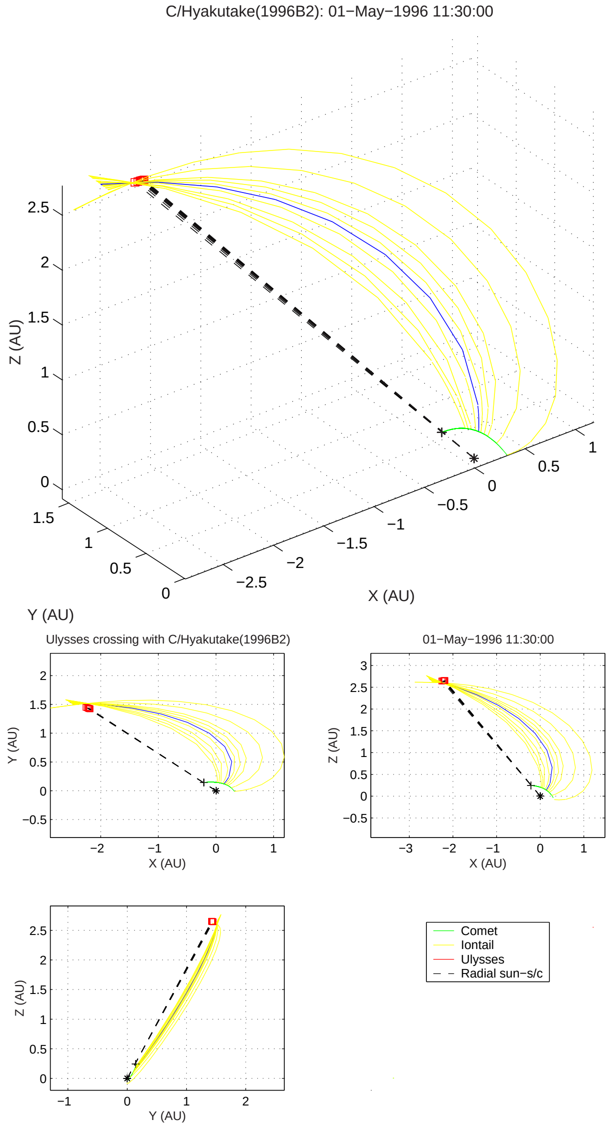

Figure 27: Ulysses encounter with Hyakutake's ion tail in the ecliptic reference system. The blue ion tail corresponds to solar wind velocity 740 km/s, the yellow ion tails visualise how the ion tail would have looked at solar wind velocities ranging from 200 km/s to 800 km/s.

9 Signatures of Ion Tail Encounters

Having established a number of possible ion tail encounters for the Ulysses and Cassini s/c in Section 7, it was an obvious extension of this work to look at data for some of these events to see if any trace of a comet tail could be seen. In order to do so, I have used data for magnetic field, proton number density, temperature, velocity and number density of heavy ions (if available).

There are sporadic disturbances that involve true time variations. The most striking of these are interplanetary shock waves that propagate outward from the Sun. An interplanetary observer detects the passage of such a shock wave by abrupt changes in the plasma speed, density, temperature and magnetic field strength, with unusual values of these parameters persisting on a time scale of a day or more after these initial changes [7, pp. 124]. The features observed from an ion tail range on a timescale of a couple of hours. For the comet, the extended mass-loading region plays the major role in defining the features of the solar-wind interaction. On the other hand, the magnetic field of an induced planetary magnetotail inferred from observations very much resembles the physical processes responsible for both structures [7, pp. 224].

9.1 What To Look For

In the last part of Jones article [8] it sais: *This event was unique, only one other unexpected encounter with a comet has been reported, but that comet remained unidentified.* The reference goes back to a paper by Russell and Luhmann [13]. In that article one can see a sharp rotation of the magnetic field detected by the spacecraft Pioneer Venus Orbiter. Over 20 years have passed and more comets have been detected since. So I decided to see if I could identify the comet. However the source comet was not detected by my program for this event that occurred in 1982. One possibility is that, if there truly was an ion tail encounter, the comet that produced the ion tail has ended his history at some point during this passed 20 years by running in to the Sun and have remained undetected or it may be an still undetected periodic comet. Another less likely possibility is that it was a hyperbolic or parabolic comet. The unsuccessfully try to identify the comet presumably responsible for the unusual magnetic event can also be due to that the orbital elements have changed a lot since 1982 and the program is sensitive to small variations (especially at small distances from the Sun).

Comets varies in activity due to their different ratios of composition. Hyakutake was less active than Halley (their water production rates at 0.9 AU from the Sun being $1.8 * 10^{29}$ and $5.5 * 10^{29}$ molecules s^{-1} respectively), but Hyakutake's small heliocentric distance on 23 April 1996 resulted in a higher production rate, making it the most productive comet encountered by a spacecraft. The images of ion tails show fine structure that strongly implies the existence of induced magnetic fields in comet tails. Ulysses' detection of magnetic signatures of the comet Hyakutake's ion tail suggest that the structure of the ion tail may extend far beyond the visible tail. At the event, on May 1, 1996, Gloeckler et al found that the proton density seen at Ulysses dropped dramatically for several hours. Other instruments on board the spacecraft had also detected this event. One of those instruments was the magnetometer (VHM), which measures the strength and direction of the magnetic field of the solar wind. Looking at the magnetometer data from May 1 (Fig. 28), Jones et al noticed that they seemed reminiscent of a 'wake', and were broadly symmetrical. Further analysis revealed that the magnetic field direction remained broadly constant for several minutes at a time during this period. Looking at the event as a whole, they came to the conclusion that the field lines were hairpin-shaped. This is exactly what is expected in comets' ion tails. Evidence of velocity shear at Ulysses was a radial velocity decrease from 750 to 740 kms^{-1}. This small decrease is consistent with re-acceleration of plasma in the tail. An anomalously low solar wind proton density was recorded at the spacecraft for several hours during the encounter with the cometary plasma. At the same time, Ulysses detected large densities of singly and doubly charged heavy ion species, well above the ubiquitous, steady, low-level pickup ion fluxes [8]. The expected signatures vary depending on composition, distance to the Sun, the spacecraft's path through it and surrounding disturbances. Even so, in summary, what we can say about the characteristic signatures an ion tail encounter leaves behind is a symmetric rotation in the magnetic field vectors, proton density drop, velocity drop, increase of heavy ions and a temperature increase. This opened a new adventure to this thesis work, to look at data from the expected ion tail encounters found in my program.

The magnetic field structure that characterize an ion tail encounter is nested regions of near-constant field orientation (s/c located in interplanetary magnetic field), separated by discontinuities (s/c encounter the magnetic field in the ion tail). The solar wind consist largely of protons and electrons in nearly equal numbers, whereas the density of material in the coma and tails is very low, lower than the best vacuum that can be produced in most laboratories, although the density of cometary heavy ion species is larger than the density of solar wind ions. A drop in proton density and an increase in heavy ion density is thus to be expected when entering an ion tail. When ionization occur (from photoionization of the neutral molecules released from the nucleus by sublimation), the ions are trapped on the field lines. This is called *mass loading* and, because the ions are essentially at rest with respect to the solar wind speed, the flow is slowed. A velocity decrease is expected and consistent with re-acceleration of plasma in the tail. The temperature within the tail is higher than the surroundings from the interaction between the solar wind plasma with the cometary plasma. In the regime (near the ecliptic plane), where Rosetta, Earth and Cassini are situated, alternating slow and fast streams velocity shears make the recognition of a tail's magnetic field signature less likely (as discussed in Section 7). Ulysses is thus the highest priority to start the analyses of the magnetic field signatures with.

9.2 Procedure

- Compare the daily mean solar wind speed with the program results. This yields the dates when the ion tail encounter were possible.
- The program *distance.m* returns a more accurate value of time of encounter at the speed that was present that dates.
- Look for discontinuities in the magnetic field.
- Look for a decrease in proton- and alpha number.
- Look for a increase in temperature.
- Look for a decrease in velocity.

It is possible that this procedure can leave out events of interest, since I am only looking at daily mean values of the solar wind. But the procedure is good as a first search for encounters. Afterwards, one can look at all data within the time-span of hits, and if there seem to be any of interest, one can look if the solar wind speed is the desired.

9.3 Ulysses Data

The RTN coordinate system is centered at the spacecraft and oriented with respect to the line connecting the Sun and spacecraft. The R (radial) axis is directed radially away from the Sun through the spacecraft. The T (tangential) axis is the cross product of the Sun's spin vector (North directed) and the R axis, i.e. the T axis is parallel to the solar equatorial plane and is positive in the direction of planetary rotation around the Sun. The N (north) axis completes the right handed set. The magnetometer data from Ulysses is accessed in the RTN coordinate system. In Figure 29, the angle arctan $\frac{N}{T}$ is plotted against time to obtain the rotation of the magnetic field and one clearly sees the encounter with Hyakutake's ion tail. The time span for the encounter is between 08:30 until 09:30, i.e. Method 2 ended up with an accuracy of 2-3 hours deviation from the true value, which I regard as a satisfying result. The distance to the tail axis was lower than the 0.1 AU predicted by Method 2 (unless the tail was very wide), which can be due to variations in solar wind speed and/or deviations from strictly radial flow, as also suggested by Gloeckler et al [14]. However, produced plots are available on the web for Ulysses and Earth orbiting spacecrafts [15] [16]. The rest of the analyses for my encounters have been done there.

Concerning the magnetic field vectors, they vary naturally due to the change in activity at the Sun. Other disturbances than comets (heliospheric current sheet for example) cause variations. To an untrained eye it is thus useful to do a blind test. Four months of data were scanned through (1993-01-01 until 1993-04-30) to investigate if the signatures interpreted as possible ion tail encounters were unique or if they were a common pattern.

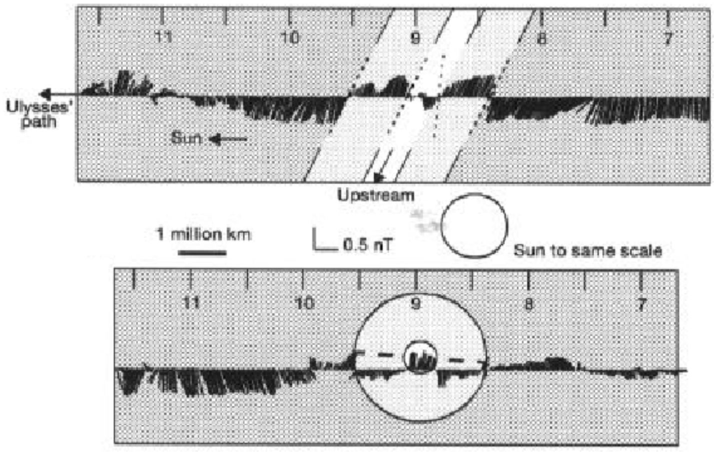

Figure 28: Magnetic field vectors obtained during the tail encounter (from [8]).

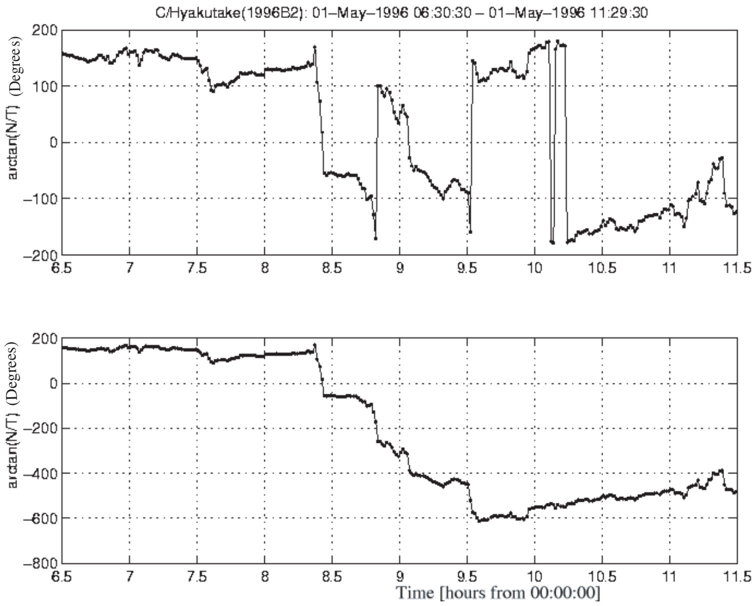

Figure 29: Top: The Hyakutake ion tail encounter, with Ulysses passing the centre of the tail around 09:00. Bottom: Unwrapped figure. My program in Method 2 results in encounter at 1996-05-01 11:30, distance: 0.102 AU, SW-speed 740 km/s, time delay 7.90 days. Calculated distances for 1996-05-01 9:00 - distance to sun: 3.73 AU, distance to comet: 3.66 AU, comet distance to Sun: 0.23 AU.

Signatures I have been searching for in the magnetic field vectors in the blind test is structures with a sharp rotation in the magnetic field direction from an nearly uniform field which rotates back after a couple of hours or less. One signature from the blind test fulfilled the conditions. There was no result of the event in my program. Either the signatures are caused by an event that does not have its origin in a comet. If it was a comet, it has not yet been discovered or has been taken by the Sun as could be the case for the event with Pioneer Venus as well. Whatever the case might be, the signatures need to be analysed closer. Nevertheless, possible signatures have been found and are visualized in Figures 31, 32, 33 and 34. Some of the events have been unanalysed since the comet is too far from the Sun, i.e. it is likely to be inactive.

The search have concerned the calculated encounters presented Table 5 in Section 7 except number 11-15, where the distances between the comet and the Sun is large. Velocity data has been retrieved from COHOWeb [16]. That velocity yields a date of encounter for that specific velocity in my calculations. The signatures has been analyzed at that date, as well as one day before and one day after. Only if the magnetic field vectors shows probable signatures, the outcome of the search are presented in the figures. The analyze of data has been performed at CDAWeb [15].

The reference signature, comet Hyakutake, is shown in Figure 30.

9.4 Earth Data

Since the calculated possible encounters dates far back in time (or in the future), the orbital elements have changed and the signatures from spacecrafts around Earth are poor [15]. Thus, there are no signatures to be reported.

9.5 Cassini Data

There is not yet any access to direct plots of Cassini data at the web. There were access of data from the magnetic field in the heliocentric ecliptic coordinate system for one of the two most interesting events in the Table 9 which I could produce a figure from (Fig. 35). Still, additional data are necessary to confirm that an encounter took place.

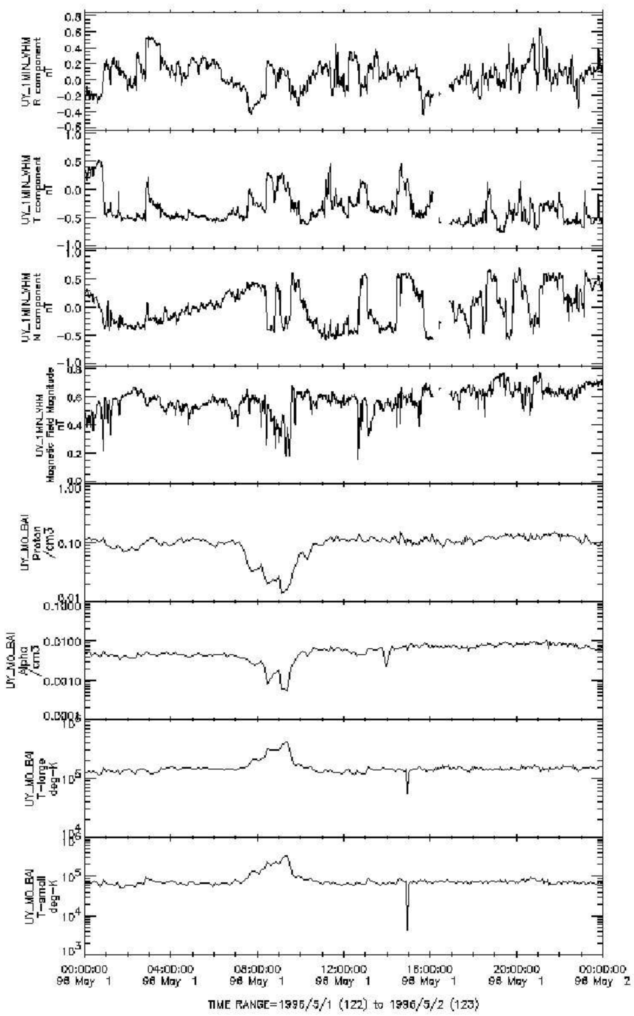

Figure 30: Ulysses' encounter with Hyakutake's ion tail between 08-10 am. A velocity decrease of 10 km/s were detected.

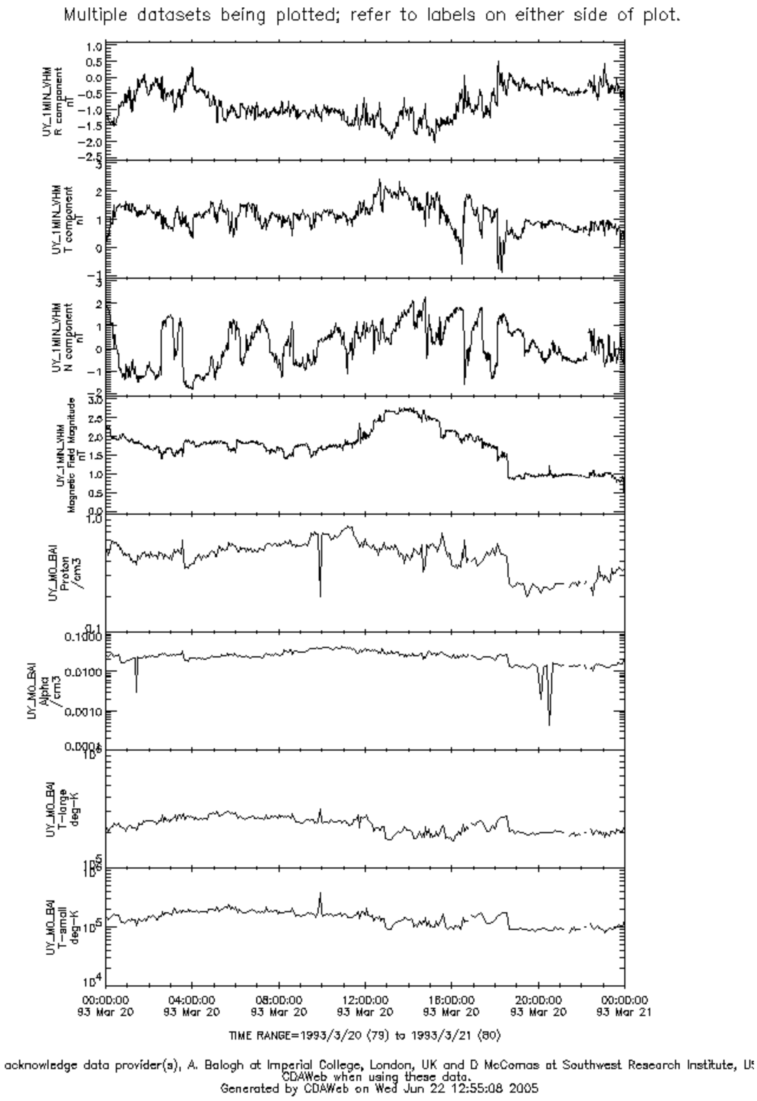

Figure 31: BLIND-TEST. Signatures between 04-06 pm. Negative is a velocity increase of 13 km/s

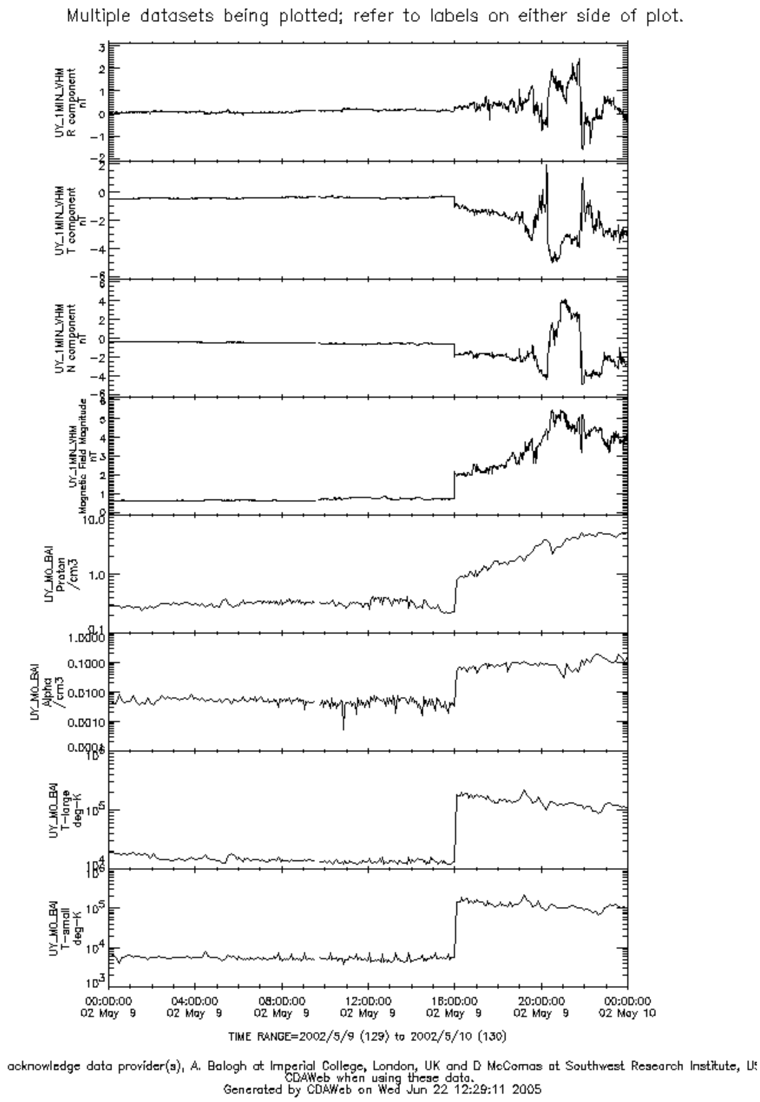

Figure 32: Source comet to the possible signatures is C/LINEAR (2002Q2). Signatures between 08-10 pm. Negative is a velocity increase of 15 km/s

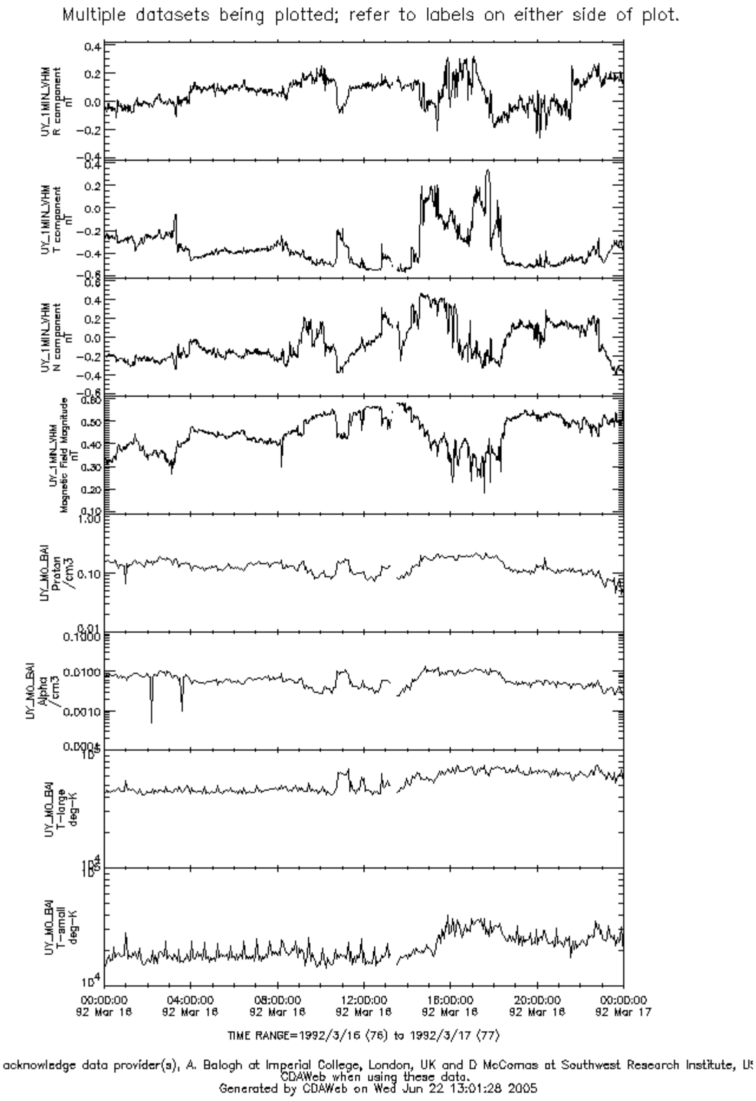

Figure 33: Source comet to the possible signatures is 37P/Forbes around 11 am. Velocity stable.

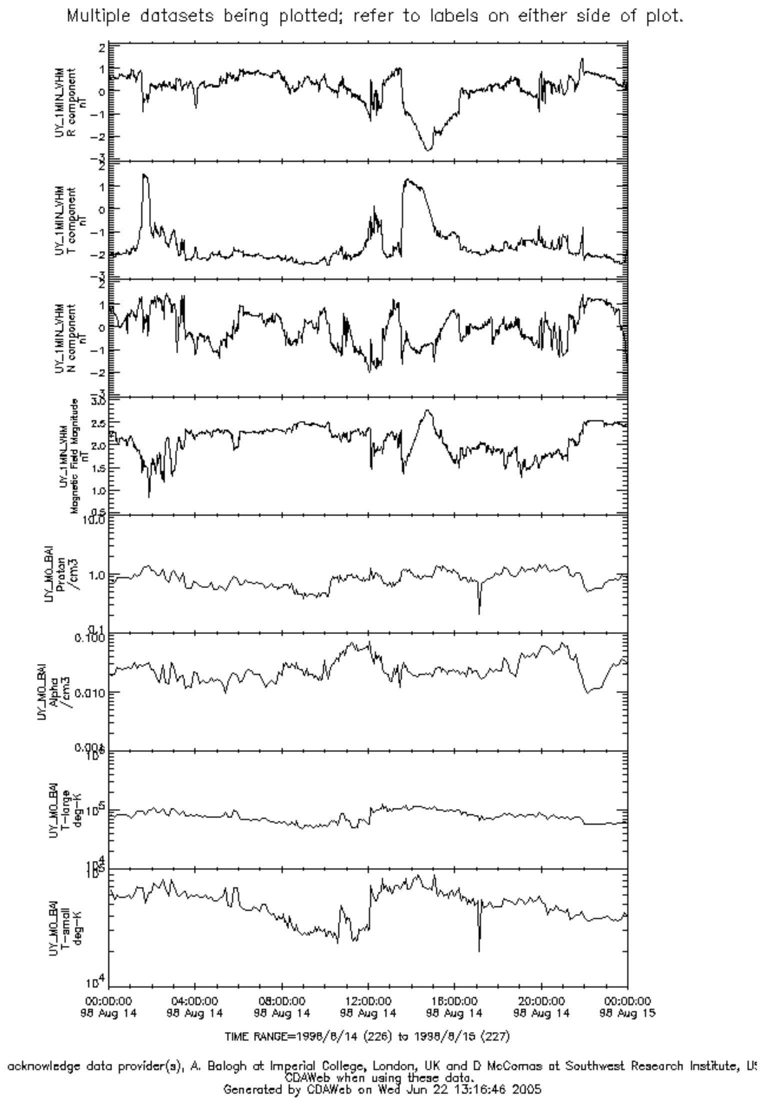

Figure 34: Source comet to the possible signatures is 105P/SingerBrewster. Signatures between 12:30-13:30. Positive is a velocity decrease of 8 km/s.

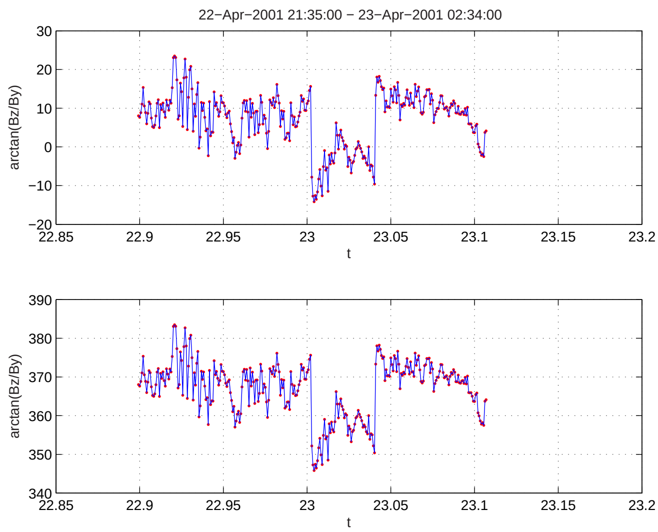

Figure 35: Top: Possible Cassini encounter with 45P/Honda-Mrkos-Pajudsakova. Bottom: Unwrapped figure. Method 2 return a velocity of 479 km/s for encounter at 23-Apr-2001 00:00.

10 Conclusion and Discussion

The aim of this work was to calculate possible ion tail encounters with the Rosetta spacecraft in order to plan operations of the Rosetta plasma instruments. Eight interesting encounters were found with the Rosetta spacecraft, where one had already occured. Three of the comets will be far from the Sun at production time of the ions, i.e. the tail will be faint if it will be possible to detect it at all. This end up in four encounters that are of special interest, P/Catalina (2005 JQ5) in June 2005, 45P/Honda-Mrkos-Pajdusakova in July 2006, 79P/duToit-Hartley in July 2008 and P/LINEAR(2000G1) in December 2010. However, the perihelion distance, q, is larger than comet Hyakutake's at the published event for all of the comets. 45P/Honda-Mrkos-Pajdusakova will be around 0.5 AU from the Sun and 79P/duToit-Hartley will be around 1.3 AU from the Sun at production, compared to comet Hyakutake's distance of 0.35 AU. They will thus be less productive and from my predictions, the ion tail encounters will not occur through the center of the tail, though the actual distance to the tail centre will depend on detailed solar wind properties. Comet Hyakutake were indeed of a larger size (2.4 km across) than average and more ions could probably join the solar wind. Honda-Mrkos-Pajdusakova as well as duToit-Hartley have sizes of around 1.3 km across. In addition, Rosetta is traveling close to the ecliptic plane. Under these conditions one can expect the signatures to be harder to trace, when analyzing data. Possibly the ion tails will not stay intact at large distances and the disadvantage at smaller distances is that the tail width will be smaller. Ulysses' crossing with Hyakutake's ion tail was indeed an event with lucky circumstances, it was an highly productive comet which was exposed to a steady solar wind that resulted in an intact tail at such a large distance where it also was broad enough to be easily detectable. Assuming the ion tails are more likely to be diluted in the ecliptic plane, the comet needs to be highly productive to produce a tail that Rosetta can detect at a larger distance. If the comet is not highly productive, the distance between Rosetta and the comet needs to be reasonable small and Rosetta's distance to the tail axis needs to be small. This return the predicted encounter with 45P/Honda-Mrkos-Pajdusakova as the most probable one and the predicted encounter with 79P/duToit-Hartley earns the second most probable encounter.

Orbital elements of comets change with time and will produce errors in the calculations if the encounter date differs several years from the previous perihelion passage. New comets are continuously discovered as well, which also implies that updates of the comet list are indeed necessary. An improvement to my work would be to save orbital elements (from JPL) from different years in files and to automatize the code to search for encounters by using orbital elements nearest the date of calculation. The newly discovered comets can also be automatically added.

A search for ion tail encounters with other spacecrafts were performed to survey magnetic field data as well as heavy ion spectra, velocity, temperature and proton density (if available) in order to find out whether signatures from ion tails are easy to detect.

The data survey has been limited to visual inspection of survey plots available on the web [15]. What to expect in magnetic field signatures of comet ion tails is not fully understood. A further means to understand whether the signatures are due to ion tail encounters as calculated, is to deeper analyze the magnetic data during the predicted encounter days.

An improvement to the data analysis could be performed as following: Since we know what comet is the source of the tail in the predicted ion tail encounter, we can use information about the size and perhaps other physical properties available for some of the comets. The distance at production is known as well, and the variation in the solar wind speed can at least for sufficiently well-instrumented spacecraft be known after the event, i.e. in the data analysis phase. We thus know how the spacecraft is approaching the expected ion tail. We could make an estimate of where the bow shock is located and the time span when the spacecraft is expected to be inside the cometary plasma and compare it with the time span of the magnetic signatures. A method that takes into account the important input parameters about the comet, geometrical circumstances, solar wind variations etc. and calculate what is expected as an output as magnetic field signatures, velocity change at the spacecraft, heavy ions (i.e. parameters that get affected by an expected encounter with the known comet) would be of great assistance for data analysis, though it would require a good model of an ion tail and its responses to solar wind variations. If it is possible to do such a method, one could also find undiscovered comets by looking at the signatures.

Of the two methods I have used to predict ion tail encounters, method 2 has an obvious reduced calculation time compared to method 1 since the calculations have to be done only when the spacecraft is close to the orbital plane of the comet, whereas method 1 perform calculation at all times when the comet is closer to the Sun than the spacecraft. The reduced calculation time with method 2 is true for Earth as well, but not comparable to the relative difference obtained with the other spacecrafts. Short period comets have their orbit close to the ecliptic plane with low inclination and they orbit the Sun in the same direction as Earth. This means that the cometary plane and the plane of the Earth will be close to each other over a long period of time, i.e. both methods require about the same amount of calculation time with Earth as a spacecraft. Concerning Rosetta, Ulysses and Cassini, method 2 is significantly quicker. In any case, method 2 is preferable.

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A Results

In the following tables, the possible encounters calculated seperatly by method 1 and method 2 are shown. No result is presented for the encounter of the plane for a couple of the comets. This comes from the fact that they are calculated in the program cases.m (a subprogram of main.m) which means that the encounter occurs before the iterations started or after Rosetta has encountered 67P/Churyumov-Gerasimenko and the iterations have stopped. The length of the tables varies since it depends on what angle and velocity Rosetta is moving towards the plane. A smaller angle and velocity result in a larger time span of when she has a chance of encounter an ion tail. The distance from the ion tail equals the distance to the comet's orbital plane. A positive sign (+) appears if Rosetta is located above the orbital plane and negative (-) if she is below. $R_{\mathrm{C-S}}$ is the distance between the comet and the Sun when it produced the ions that reaches Rosetta at the encounter time. Time delay is the time it takes for the ions to traverse the space between the comet at production time and Rosetta at encounter time. encounters of greatest interest have been collected in Tables, the other encounters calculated are attached as they appear when the results are saved in files from the running of the program. Run date for the following tables is 13-May-2005, i.e. before the updated list. I leave the new runlist out, except of those of interest, since the past encounters corresponds better to the older orbital elements. The list needs to be updated for the later encounters with new ephemerides if possible. For example, the orbital elements for 117P/Helin-Roman-Alu has been updated on the web and the new results from 14-Jun-2005 produce another date of encounter in 2014. Cassini has not been evaluated with the new comets. Ion tails are normally found only in comets with heliocentric distances less than 1.5 to 2.0 AU. There are exceptions to this rule. In addition, a comet that pass too close to the Sun does not show ion tails. The reason is not understood [4, pp. 151].

A.1 Rosetta

Comet: **C/Bradfield(2004F4)**
Method 2

Date	Sign	$R_{\mathrm{R-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]	$R_{\mathrm{R-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
20-Apr-2004	+	0.096913	764.5272	1.6593	0.90883	0.17618
21-Apr-2004	+	0.080211	481.3425	2.6298	0.90762	0.17655
22-Apr-2004	+	0.063477	350.8499	3.6002	0.90643	0.17692
23-Apr-2004	+	0.046717	275.7832	4.5704	0.90528	0.17731
24-Apr-2004	+	0.02994	227.0196	5.5405	0.90415	0.1777
CROSSING						
25-Apr-2004	+	0.01315	192.7983	6.5105	0.90305	0.17811

Table 12: R-Rosetta, i-ion tail, S-Sun, C-comet

Method 1

Date	Time	$R_{\mathrm{R-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]
2004-4-20	8:30	0.1223	700	1.5833
2004-4-20	8:30	0.091	623	1.8125
2004-4-20	11:0	0.089259	593	2.2292
2004-4-21	9:0	0.090777	450	2.5208
2004-4-21	9:0	0.073958	417	2.8125
2004-4-21	13:0	0.071216	398	3.3333
2004-4-22	9:30	0.056886	315	3.6042
2004-4-22	15:0	0.053011	298	4.4583
2004-4-23	10:0	0.039749	252	4.5833
2004-4-23	11:30	0.03871	248	5.125
2004-4-24	11:0	0.022474	209	5.6042
2004-4-24	18:0	0.017445	200	6.2917

Table 13: R-Rosetta, i-ion tail

Comet: **45P/Honda-Mrkos-Pajdusakova**
Method 2

Date	Sign	$R_{\mathrm{R-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]	$R_{\mathrm{R-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
05-Jul-2006	+	0.063084	873.6458	1.4368	1.2604	0.53546
06-Jul-2006	+	0.061829	559.2164	2.2292	1.2562	0.53619
07-Jul-2006	+	0.060565	409.9481	3.0196	1.2519	0.53697
08-Jul-2006	+	0.059292	322.7671	3.808	1.2477	0.5378
09-Jul-2006	+	0.05801	265.5983	4.5942	1.2434	0.53867
10-Jul-2006	+	0.056718	225.2147	5.3783	1.2392	0.53958
CROSSING						
18-Aug-2006	+	0.0010739	23.7222	33.3219	1.0851	0.62859

Table 14: R-Rosetta, i-ion tail, S-Sun, C-comet

Method 1

Date	Time	$R_{\mathrm{R-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]
2006-7-5	3:0	0.062929	800	1.5625
2006-7-5	10:0	0.062638	700	1.7917
2006-7-5	18:30	0.062152	600	2.0833
2006-7-6	7:0	0.061482	500	2.4792
2006-7-6	15:0	0.061043	450	2.75
2006-7-7	1:0	0.060514	400	3.0833
2006-7-7	14:30	0.059818	350	3.5208
2006-7-8	7:30	0.058896	300	4.0833
2006-7-8	18:30	0.058319	275	4.4375
2006-7-9	7:30	0.057642	250	4.875
2006-7-9	23:0	0.056778	225	5.375
2006-7-10	18:30	0.055723	200	6.0208

Table 15: R-Rosetta, i-ion tail

Comet: **79P/duToit-Hartley**
Method 2

Date	Sign	$R_{\mathrm{R-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]	$R_{\mathrm{R-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
06-Jul-2008	+	0.079412	916.2053	1.1816	1.9344	1.3092
07-Jul-2008	+	0.078082	599.7395	1.8126	1.9385	1.3106
08-Jul-2008	+	0.076748	446.5573	2.4443	1.9425	1.3121
09-Jul-2008	+	0.075411	356.1917	3.0768	1.9466	1.3136
10-Jul-2008	+	0.074072	296.5706	3.7099	1.9506	1.3151
11-Jul-2008	+	0.072729	254.2798	4.3438	1.9545	1.3166
12-Jul-2008	+	0.071383	222.7178	4.9783	1.9585	1.3181
CROSSING						
01-Sep-2008	+	0.00039245	32.9351	37.845	2.1259	1.406

Table 16: R-Rosetta, i-ion tail, S-Sun, C-comet

Method 1

Date	Time	$R_{\mathrm{R-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]
2008-7-6	10:30	0.079087	800	1.3542
2008-7-7	11:0	0.07778	700	2.4583
2008-7-7	11:0	0.077727	600	2.1875
2008-7-7	17:0	0.077378	500	1.8333
2008-7-8	2:30	0.076838	450	2.4167
2008-7-9	0:30	0.075613	400	2.7292
2008-7-9	5:0	0.075352	350	3.125
2008-7-10	14:0	0.073512	300	4.3333
2008-7-10	14:0	0.073512	275	4
2008-7-11	5:30	0.072646	250	4.4167
2008-7-12	3:30	0.071403	225	4.9167
2008-7-13	17:0	0.069292	200	6.4375

Table 17: R-Rosetta, i-ion tail

Comet: **P/LINEAR(2000G1)**
Method 2

Date	Sign	$R_{\mathrm{R-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]	$R_{\mathrm{R-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
25-Dec-2010	-	0.11353	999.9087	4.6297	3.7565	1.0829
26-Dec-2010	-	0.11509	835.5733	5.5498	3.7616	1.0833
27-Dec-2010	-	0.11665	717.961	6.4702	3.7666	1.0837
28-Dec-2010	-	0.11822	629.625	7.3906	3.7716	1.0841
29-Dec-2010	-	0.11978	560.843	8.3112	3.7767	1.0845
30-Dec-2010	-	0.12134	505.7688	9.232	3.7817	1.0849
31-Dec-2010	-	0.1229	460.6754	10.1529	3.7867	1.0854
01-Jan-2011	-	0.12446	423.0745	11.074	3.7916	1.0858
02-Jan-2011	-	0.12602	391.2417	11.9952	3.7966	1.0862
03-Jan-2011	-	0.12757	363.9438	12.9165	3.8016	1.0866
04-Jan-2011	-	0.12913	340.2761	13.838	3.8065	1.087
05-Jan-2011	-	0.13069	319.5592	14.7596	3.8115	1.0874
06-Jan-2011	-	0.13224	301.2735	15.6814	3.8164	1.0878
07-Jan-2011	-	0.1338	285.0146	16.6033	3.8213	1.0882
08-Jan-2011	-	0.13535	270.4629	17.5253	3.8262	1.0887
09-Jan-2011	-	0.13691	257.3629	18.4475	3.8311	1.0891
10-Jan-2011	-	0.13846	245.5075	19.3699	3.836	1.0895
11-Jan-2011	-	0.14001	234.7272	20.2923	3.8409	1.0899
CROSSING						
14-Oct-2010	+	0.00024301	2.1099	1892.9812	3.3603	1.0536

Table 18: R-Rosetta, i-ion tail, S-Sun, C-comet

Method 1

Date	Time	$R_{\mathrm{R-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]
2010-12-26	5:30	0.11549	800	5.7917
2010-12-27	7:30	0.11724	700	6.6458
2010-12-28	9:30	0.11888	600	8.25
2010-12-29	20:0	0.12112	500	8.6667
2010-12-30	23:0	0.12292	450	9.625
2011-1-1	17:30	0.12565	400	12.2708
2011-1-3	6:30	0.12804	350	13.4167
2011-1-6	1:30	0.13239	300	15.7292
2011-1-7	8:30	0.13441	275	17.1875
2011-1-9	7:30	0.13743	250	18.9792
2011-1-11	16:0	0.14108	225	20.8333
2011-1-14	17:30	0.14583	200	24.0625

Table 19: R-Rosetta, i-ion tail

Comet: **P/Catalina-LINEAR(2004EW38)**
Method 2

Date	Sign	$R_{\mathrm{R-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]	$R_{\mathrm{R-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
18-Mar-2011	-	0.043721	987.6967	3.0438	4.1447	2.4084
19-Mar-2011	-	0.043783	800.3857	3.7623	4.149	2.4098
20-Mar-2011	-	0.043845	673.1037	4.481	4.1532	2.4113
21-Mar-2011	-	0.043907	580.9808	5.2	4.1575	2.4127
22-Mar-2011	-	0.043969	511.2147	5.9193	4.1618	2.4141
23-Mar-2011	-	0.04403	456.5471	6.6388	4.166	2.4156
24-Mar-2011	-	0.044091	412.5557	7.3585	4.1703	2.417
25-Mar-2011	-	0.044153	376.3894	8.0784	4.1745	2.4184
26-Mar-2011	-	0.044213	346.1315	8.7986	4.1788	2.4198
27-Mar-2011	-	0.044274	320.4422	9.5191	4.183	2.4213
28-Mar-2011	-	0.044335	298.3598	10.2398	4.1872	2.4227
29-Mar-2011	-	0.044395	279.1743	10.9606	4.1914	2.4241
30-Mar-2011	-	0.044455	262.3501	11.6818	4.1956	2.4256
31-Mar-2011	-	0.044515	247.4765	12.4031	4.1998	2.427
01-Apr-2011	-	0.044575	234.2328	13.1247	4.2039	2.4284
02-Apr-2011	-	0.044635	222.3648	13.8465	4.2081	2.4298
03-Apr-2011	-	0.044694	211.6686	14.5686	4.2123	2.4313
04-Apr-2011	-	0.044754	201.9786	15.2908	4.2164	2.4327

Table 20: R-Rosetta, i-ion tail, S-Sun, C-comet

Method 1

Date	Time	$R_{\mathrm{R-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]
2011-3-19	3:30	0.043887	800	3.7708
2011-3-19	14:0	0.043912	700	3.6875
2011-3-20	14:0	0.044026	600	4.9792
2011-3-22	0:0	0.044057	500	6
2011-3-23	8:0	0.044113	450	6.7292
2011-3-24	14:30	0.044193	400	7.6042
2011-3-26	2:30	0.044239	350	8.7083
2011-3-27	18:0	0.044346	300	9.8125
2011-3-29	1:30	0.044401	275	11.125
2011-3-30	16:0	0.044495	250	11.7292
2011-4-2	1:30	0.044641	225	13.6875
2011-4-4	1:30	0.04476	200	15.4375

Table 21: R-Rosetta, i-ion tail

Comet: **P/LINEAR(2003HT15)**
Method 2

Date	Sign	$R_{\mathrm{R-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]	$R_{\mathrm{R-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
20-Dec-2013	+	0.034652	976.8714	2.3643	4.5977	3.2638
21-Dec-2013	+	0.036604	757.7926	3.0378	4.5944	3.2649
22-Dec-2013	+	0.038557	618.3415	3.7107	4.5912	3.266
23-Dec-2013	+	0.040509	521.7797	4.3829	4.5879	3.2672
24-Dec-2013	+	0.042461	450.9562	5.0544	4.5847	3.2683
25-Dec-2013	+	0.044413	396.7891	5.7251	4.5814	3.2694
26-Dec-2013	+	0.046365	354.0194	6.3952	4.5781	3.2705
27-Dec-2013	+	0.048317	319.3919	7.0646	4.5748	3.2717
28-Dec-2013	+	0.050268	290.7824	7.7333	4.5715	3.2728
29-Dec-2013	+	0.052219	266.747	8.4012	4.5682	3.274
30-Dec-2013	+	0.054171	246.2693	9.0685	4.5649	3.2751
31-Dec-2013	+	0.056122	228.6134	9.735	4.5616	3.2762
01-Jan-2014	+	0.058073	213.2332	10.4008	4.5583	3.2774
CROSSING						
02-Dec-2013	-	0.00050381	0.67857	3598.8595	4.6546	3.2442

Table 22: R-Rosetta, i-ion tail, S-Sun, C-comet

Method 1

Date	Time	$R_{\mathrm{R-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]
2013-12-18	22:0	0.037215	800	2.9167
2013-12-25	5:0	0.060459	700	2.7917
2013-12-19	21:0	0.04121	600	3.875
2013-12-18	16:30	0.058381	500	4.6875
2013-12-23	2:0	0.041252	450	4.9167
2013-12-21	18:30	0.050325	400	5.7708
2013-12-28	9:0	0.056966	350	5.625
2013-12-23	16:0	0.060179	300	7.6667
2013-12-28	4:0	0.050655	275	7.8333
2013-12-28	12:0	0.052404	250	9
2013-12-30	0:30	0.055264	225	9.9375
2013-12-31	16:30	0.058463	200	10.8958

Table 23: R-Rosetta, i-ion tail

Comet: **117P/Helin-Roman-Alu 1**
Method 2

Date	Sign	$R_{\mathrm{R-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]	$R_{\mathrm{R-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
28-Feb-2014	+	0.0099562	1089.5547	2.0836	4.3505	3.0393
01-Mar-2014	+	0.010217	825.5657	2.7419	4.3466	3.0393
02-Mar-2014	+	0.010478	663.9116	3.3997	4.3428	3.0392
03-Mar-2014	+	0.010739	554.7459	4.0568	4.3389	3.0392
04-Mar-2014	+	0.011	476.0738	4.7134	4.3351	3.0391
05-Mar-2014	+	0.01126	416.6827	5.3694	4.3312	3.039
06-Mar-2014	+	0.011521	370.2574	6.0247	4.3273	3.039
07-Mar-2014	+	0.011782	332.9692	6.6795	4.3234	3.0389
08-Mar-2014	+	1 0.012042	302.3613	7.3336	4.3195	3.0389
09-Mar-2014	+	0.012303	276.7858	7.9871	4.3156	3.0388
10-Mar-2014	+	0.012564	255.0952	8.64	4.3117	3.0387
11-Mar-2014	+	0.012824	236.4665	9.2923	4.3077	3.0387
12-Mar-2014	+	0.013085	220.2937	9.944	4.3038	3.0386
13-Mar-2014	+	0.013345	206.1208	10.595	4.2999	3.0386
CROSSING:						
20-Jan-2014	-	0.00023709	0.84039	2989.344	4.4934	3.0425

Table 24: R-Rosetta, i-ion tail, S-Sun, C-comet

Method 1

Date	Time	$R_{\mathrm{R-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]
2014-3-23	13:0	0.019015	200	10.5417
2014-3-22	10:0	0.01534	225	8.5833
2014-3-19	13:30	0.024792	250	8.5625
2014-3-19	18:30	0.014692	275	7.7708
2014-3-18	15:0	0.014168	300	6.8542
2014-3-17	3:30	0.01378	350	5.8542
2014-3-18	8:30	0.02835	400	4.6458
2014-3-14	19:30	0.014409	450	4.8125
2014-3-16	7:30	0.024365	500	3.6875
2014-3-10	16:0	0.034584	600	3.6667
2014-3-13	3:0	0.014897	700	2.875
2014-3-8	18:30	0.038215	800	2.7708

Table 25: R-Rosetta, i-ion tail

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***************************
       METHOD 2
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%-----------------------------------------------------------------------------------------
% C/McNaught (2005 E2):    (Run date: 14-June-2005)
%-----------------------------------------------------------------------------------------
Date:            Sign:        Distance [AU]:     SW-speed [km/s]:        Timedelay [days]:    s/c-sun [AU]:    comet-sun [AU]:
27-Nov-2005        1           0.14154            729.3597                 2.1195              1.7508            0.85797
28-Nov-2005        1           0.13875            663.1117                 2.34                1.7513            0.85516
29-Nov-2005        1           0.13595            606.8757                 2.5662              1.7518            0.85238
30-Nov-2005        1           0.13314            558.5892                 2.798               1.7523            0.84964
01-Dec-2005        1           0.13033            516.7196                 3.0352              1.7527            0.84693
02-Dec-2005        1           0.12751            480.0996                 3.2779              1.7532            0.84424
03-Dec-2005        1           0.12468            447.8266                 3.5259              1.7535            0.84159
04-Dec-2005        1           0.12184            419.1925                 3.7791              1.7539            0.83897
05-Dec-2005        1           0.119              393.6321                 4.0374              1.7542            0.83637
06-Dec-2005        1           0.11615            370.6923                 4.3007              1.7546            0.83381
07-Dec-2005        1           0.11329            350.0025                 4.5688              1.7548            0.83127
08-Dec-2005        1           0.11043            331.2578                 4.8418              1.7551            0.82876
09-Dec-2005        1           0.10756            314.2063                 5.1195              1.7553            0.82628
10-Dec-2005        1           0.10469            298.6363                 5.4018              1.7555            0.82383
11-Dec-2005        1           0.10181            284.3699                 5.6887              1.7557            0.82141
12-Dec-2005        1           0.098926           271.2556                 5.98                1.7558            0.81901
13-Dec-2005        1           0.096036           259.1652                 6.2756              1.756             0.81663
14-Dec-2005        1           0.09314            247.9875                 6.5755              1.7561            0.81429
15-Dec-2005        1           0.090239           237.627                  6.8796              1.7561            0.81197
16-Dec-2005        1           0.087334           228.0008                 7.1878              1.7562            0.80967
17-Dec-2005        1           0.084424           219.0366                 7.5001              1.7562            0.8074
18-Dec-2005        1           0.081509           210.6711                 7.8163              1.7562            0.80515
19-Dec-2005        1           0.078589           202.8486                 8.1363              1.7561            0.80293

%-----------------------------------------------------------------------------------------
% P/LINEAR (2004 X1):    (Run date: 14-June-2005)
%-----------------------------------------------------------------------------------------
Comet:       Date:              Distance [AU]:       SW-speed [km/s]:       Timedelay [days]:   s/c-sun [AU]:    comet-sun [AU]:
08-Sep-2009         -1           0.12741            690.2334                 1.4909              1.3773            0.78297
09-Sep-2009         -1           0.12697            468.6905                 2.1712              1.3709            0.78319
10-Sep-2009         -1           0.12651            353.2299                 2.8484              1.3645            0.78344
11-Sep-2009         -1           0.12603            282.362                  3.5223              1.3581            0.78373
12-Sep-2009         -1           0.12555            234.4243                 4.1929              1.3517            0.78406

%-----------------------------------------------------------------------------------------
% P/LINEAR(2003KV2):    (Run date: 13-May-2005)
%-----------------------------------------------------------------------------------------
Date:            Sign:       Distance [AU]:     SW-speed [km/s]:        Timedelay [days]:    s/c-sun [AU]:    comet-sun [AU]:
08-Apr-2013        1           0.13396            1107.5519                6.421               5.1708            1.0635
09-Apr-2013        1           0.13544            963.3839                 7.3795              5.1695            1.0635
10-Apr-2013        1           0.13693            852.3632                 8.338               5.1682            1.0635
11-Apr-2013        1           0.13841            764.2359                 9.2965              5.1669            1.0636
12-Apr-2013        1           0.1399             692.5827                 10.255              5.1656            1.0636
13-Apr-2013        1           0.14138            633.1786                 11.2134             5.1642            1.0636
14-Apr-2013        1           0.14287            583.1297                 12.1718             5.1629            1.0636
15-Apr-2013        1           0.14435            540.3871                 13.1302             5.1616            1.0636
16-Apr-2013        1           0.14584            503.4598                 14.0886             5.1602            1.0636
17-Apr-2013        1           0.14732            471.2362                 15.0469             5.1589            1.0637
18-Apr-2013        1           0.1488             442.8714                 16.0052             5.1575            1.0637
CROSSING OF THE PLANE:
08-Jan-2013       -1           0.00055834         4.2856                   1695.2254           5.2591            1.0631

%-----------------------------------------------------------------------------------------
% P/LINEAR(2003O3):    (Run date: 13-May-2005)
%-----------------------------------------------------------------------------------------
Date:             Sign:    Distance [AU]:       SW-speed [km/s]:        Timedelay [days]:    s/c-sun [AU]:    comet-sun [AU]:
10-May-2014        1           0.11847            979.2041                 4.4484              4.0551            1.5393
11-May-2014        1           0.11756            819.1365                 5.31                4.0506            1.5385
12-May-2014        1           0.11665            703.7765                 6.1714              4.046             1.5376
13-May-2014        1           0.11573            616.6881                 7.0327              4.0415            1.5367
14-May-2014        1           0.11482            548.6122                 7.8939              4.037             1.5358
15-May-2014        1           0.1139             493.935                  8.7549              4.0325            1.5349
16-May-2014        1           0.11299            449.0547                 9.6157              4.0279            1.5341
17-May-2014        1           0.11207            411.5545                 10.4764             4.0233            1.5332
18-May-2014        1           0.11115            379.7518                 11.3369             4.0188            1.5323
19-May-2014        1           0.11024            352.4397                 12.1973             4.0142            1.5314
20-May-2014        1           0.10932            328.7295                 13.0575             4.0096            1.5305
21-May-2014        1           0.1084             307.9526                 13.9176             4.005             1.5297
22-May-2014        1           0.10746            289.6068                 14.7767             4.0004            1.5288

%-----------------------------------------------------------------------------------------
% P/NEAT(2003U3):    (Run date: 13-May-2005)
%-----------------------------------------------------------------------------------------
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Date:	Sign:	Distance [AU]:	SW-speed [km/s]:	Timedelay [days]:	s/c-sun [AU]:	comet-sun [AU]:	
18-Jan-2014	1	0.14219	1070.3949	2.052	4.5004	3.2318	
19-Jan-2014	1	0.14153	815.5533	2.6891	4.4969	3.2303	
20-Jan-2014	1	0.14086	658.3727	3.326	4.4934	3.2287	
21-Jan-2014	1	0.14019	551.7395	3.9627	4.4899	3.2272	
22-Jan-2014	1	0.13952	474.6473	4.5991	4.4864	3.2256	
23-Jan-2014	1	0.13885	416.3127	5.2353	4.4829	3.2241	
24-Jan-2014	1	0.13818	370.6315	5.8713	4.4793	3.2225	
25-Jan-2014	1	0.1375	333.889	6.5071	4.4758	3.221	
26-Jan-2014	1	0.13683	303.695	7.1427	4.4723	3.2195	
27-Jan-2014	1	0.13616	278.4413	7.778	4.4687	3.2179	
28-Jan-2014	1	0.13549	257.0071	8.4131	4.4652	3.2164	
29-Jan-2014	1	0.13482	238.5862	9.048	4.4616	3.2148	
30-Jan-2014	1	0.13414	222.5848	9.6826	4.458	3.2133	
31-Jan-2014	1	0.13347	208.5553	10.317	4.4544	3.2117	3.0425

A.2 Ulysses

Comet: **C/Hyakutake(1996B2)**
Method 2

Date	Sign	$R_{\mathrm{U-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]	$R_{\mathrm{U-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
29-Apr-1996	-	0.11167	1081.135	5.3946	3.7204	0.35198
30-Apr-1996	-	0.10782	911.104	6.4103	3.7255	0.35235
01-May-1996	-	0.10397	787.5813	7.4259	3.7305	0.35273
02-May-1996	-	0.10011	693.78	8.4415	3.7355	0.3531
03-May-1996	-	0.096258	620.1244	9.4571	3.7405	0.35348
04-May-1996	-	0.092402	560.7534	10.4726	3.7455	0.35386
05-May-1996	-	0.088546	511.8785	11.4882	3.7505	0.35423
06-May-1996	-	0.08469	470.942	12.5038	3.7555	0.35461
07-May-1996	-	0.080833	436.1549	13.5193	3.7605	0.35498
08-May-1996	-	0.076976	406.2281	14.5349	3.7655	0.35536
09-May-1996	-	0.073118	380.2094	15.5504	3.7704	0.35573
10-May-1996	-	0.06926	357.38	16.5659	3.7754	0.35611
11-May-1996	-	0.065402	337.1872	17.5814	3.7803	0.35649
12-May-1996	-	0.061543	319.199	18.5969	3.7853	0.35686
13-May-1996	-	0.057684	303.0729	19.6124	3.7902	0.35724
14-May-1996	-	0.053824	288.534	20.6279	3.7951	0.35761
15-May-1996	-	0.049964	275.3588	21.6434	3.8	0.35799
16-May-1996	-	0.046104	263.3639	22.6589	3.8049	0.35836
17-May-1996	-	0.042244	252.3974	23.6744	3.8098	0.35874
18-May-1996	-	0.038383	242.3325	24.6898	3.8147	0.35911
19-May-1996	-	0.034522	233.0623	25.7053	3.8195	0.35949
20-May-1996	-	0.030661	224.4961	26.7207	3.8244	0.35986
21-May-1996	-	0.0268	216.5567	27.7362	3.8293	0.36024
22-May-1996	-	0.022939	209.1776	28.7516	3.8341	0.36061
23-May-1996	-	0.019078	202.3014	29.767	3.8389	0.36099
CROSSING						
27-May-1996	-	0.0036308	178.9207	33.8286	3.8582	0.36249

Table 26: U-Ulysses, i-ion tail, S-Sun, C-comet

Method 1

Date	Time	$R_{\mathrm{U-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]
1996-5-1	11:30	0.10225	740	7.904
1996-5-1	22:30	0.10048	700	8.389
1996-5-2	14:0	0.097995	650	9.0198
1996-5-3	7:30	0.095072	600	9.7633
1996-5-5	7:0	0.087573	500	11.7483
1996-5-8	5:30	0.076128	400	14.742
1996-5-13	5:30	0.057001	300	19.7981
1996-5-23	8:30	0.017719	200	30.15

Table 27: U-Ulysses, i-ion tail

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***************************
        METHOD 2
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%----------------------------------------------------------------------------------------------
% 52P/Harrington-Abell:   (Run date: May-2005)
%----------------------------------------------------------------------------------------------
Date:               Sign:        Distance [AU]:      SW-speed [km/s]:        Timedelay [days]:     s/c-sun [AU]:  comet-sun [AU]:
  28-Sep-1991          1           0.010897           1163.2255               3.6178               4.3005          1.87
  29-Sep-1991          1           0.011747           946.2196                4.4624               4.3092          1.8705
  30-Sep-1991          1           0.012596           798.2036                5.3076               4.3178          1.871
  01-Oct-1991          1           0.013445           690.7896                6.1533               4.3264          1.8715
  02-Oct-1991          1           0.014294           609.2854                6.9995               4.3351          1.872
  03-Oct-1991          1           0.015143           545.3246                7.8463               4.3437          1.8725
  04-Oct-1991          1           0.015992           493.7928                8.6936               4.3523          1.873
  05-Oct-1991          1           0.016841           451.3876                9.5415               4.3609          1.8735
  06-Oct-1991          1           0.017689           415.8812                10.3898              4.3695          1.874
  07-Oct-1991          1           0.018538           385.7166                11.2387              4.3781          1.8744
  08-Oct-1991          1           0.019387           359.7723                12.0881              4.3867          1.8749
  09-Oct-1991          1           0.020235           337.2203                12.9379              4.3952          1.8754
  10-Oct-1991          1           0.021083           317.4359                13.7883              4.4038          1.8759
  11-Oct-1991          1           0.021932           299.9388                14.6393              4.4123          1.8764
  12-Oct-1991          1           0.02278            284.3541                15.4907              4.4209          1.8769
  13-Oct-1991          1           0.023628           270.3841                16.3426              4.4294          1.8774
  14-Oct-1991          1           0.024476           257.7903                17.195               4.4379          1.8779
  15-Oct-1991          1           0.025324           246.3786                18.0478              4.4465          1.8783
  16-Oct-1991          1           0.026172           235.9901                18.9012              4.455           1.8788
  17-Oct-1991          1           0.027019           226.4929                19.7551              4.4635          1.8793
  18-Oct-1991          1           0.027867           217.777                 20.6094              4.472           1.8798
  19-Oct-1991          1           0.028714           209.7496                21.4643              4.4805          1.8803
  20-Oct-1991          1           0.029562           202.3322                22.3196              4.4889          1.8807
CROSSING OF THE PLANE:
  15-Sep-1991         -1           0.00014644         -550.2874               -7.3114              4.1872          1.8635

%----------------------------------------------------------------------------------------------
% 149P/Mueller 4:   (Run date: May-2005)
%----------------------------------------------------------------------------------------------
Date:               Sign:        Distance [AU]:       SW-speed [km/s]:        Timedelay [days]:     s/c-sun [AU]:  comet-sun [AU]:
 05-Sep-1991          -1           0.034606           1034.6212               2.1209               4.099           2.8316
 06-Sep-1991          -1           0.037655           781.3879                2.8294               4.1078          2.831
 07-Sep-1991          -1           0.040704           629.3201                3.5392               4.1167          2.8303
 08-Sep-1991          -1           0.043752           527.8838                4.2504               4.1255          2.8297
 09-Sep-1991          -1           0.046801           455.398                 4.9629               4.1344          2.829
 10-Sep-1991          -1           0.049849           401.0139                5.6769               4.1432          2.8284
 11-Sep-1991          -1           0.052897           358.7016                6.3921               4.152           2.8278
 12-Sep-1991          -1           0.055945           324.8414                7.1087               4.1608          2.8271
 13-Sep-1991          -1           0.058992           297.1299                7.8266               4.1696          2.8265
 14-Sep-1991          -1           0.06204            274.0303                8.5458               4.1784          2.8259
 15-Sep-1991          -1           0.065087           254.479                 9.2663               4.1872          2.8253
 16-Sep-1991          -1           0.068134           237.7159                9.9881               4.1959          2.8246
 17-Sep-1991          -1           0.07118            223.1836                10.7112              4.2047          2.824
 18-Sep-1991          -1           0.074226           210.4641                11.4355              4.2135          2.8234
CROSSING OF THE PLANE:
 24-Aug-1991           1           0.0019914          -318.2579               -6.2678              3.9918          2.8398
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%-----------------------------------------------------------------------------------------
% 37P/Forbes:   (Run date: May-2005)
%-----------------------------------------------------------------------------------------
Date:               Sign:          Distance [AU]:      SW-speed [km/s]:        Timedelay [days]:     s/c-sun [AU]:  comet-sun [AU]:
  12-Mar-1992          -1            0.0051217            1188.0374               2.8638              5.3997          3.4347
  13-Mar-1992          -1            0.0096438            907.617                 3.7494              5.3995          3.4341
  14-Mar-1992          -1            0.014163             734.3803                4.6347              5.3992          3.4335
  15-Mar-1992          -1            0.018681             616.7314                5.5199              5.399           3.4329
  16-Mar-1992          -1            0.023196             531.6136                6.4049              5.3988          3.4323
  17-Mar-1992          -1            0.027709             467.1715                7.2897              5.3985          3.4317
  18-Mar-1992          -1            0.03222              416.6866                8.1744              5.3983          3.4311
  19-Mar-1992          -1            0.036729             376.0674                9.059               5.3981          3.4305
  20-Mar-1992          -1            0.041236             342.6783                9.9434              5.3978          3.4299
  21-Mar-1992          -1            0.045741             314.7466                10.8277             5.3975          3.4293
  22-Mar-1992          -1            0.050244             291.035                 11.7119             5.3973          3.4287
  23-Mar-1992          -1            0.054746             270.6538                12.596              5.397           3.4281
  24-Mar-1992          -1            0.059247             252.9475                13.4799             5.3967          3.4274
  25-Mar-1992          -1            0.063745             237.4214                14.3638             5.3964          3.4268
  26-Mar-1992          -1            0.068243             223.696                 15.2475             5.3961          3.4262
  27-Mar-1992          -1            0.072739             211.4752                16.1312             5.3958          3.4256
  28-Mar-1992          -1            0.077233             200.5242                17.0148             5.3955          3.425
CROSSING OF THE PLANE:
  10-Mar-1992           1            0.0039306            3114.1615                1.0921             5.4001          3.4359

%-----------------------------------------------------------------------------------------
% 131P/Mueller2:   (Run date: May-2005)
%-----------------------------------------------------------------------------------------
 Date:              Sign:         Distance [AU]:      SW-speed [km/s]:        Timedelay [days]:     s/c-sun [AU]:  comet-sun [AU]:
  17-Jul-1992          -1            0.077375             1026.3045               2.1446              5.3238          4.0526
  18-Jul-1992          -1            0.082074             711.434                 3.091               5.3228          4.0527
  19-Jul-1992          -1            0.086772             544.1823                4.0374              5.3218          4.0529
  20-Jul-1992          -1            0.091471             440.4517                4.9838              5.3208          4.053
  21-Jul-1992          -1            0.096169             369.8285                5.9301              5.3198          4.0531
  22-Jul-1992          -1            0.10087              318.6438                6.8763              5.3188          4.0533
  23-Jul-1992          -1            0.10556              279.842                 7.8226              5.3177          4.0534
  24-Jul-1992          -1            0.11026              249.4141                8.7688              5.3167          4.0536
  25-Jul-1992          -1            0.11496              224.9132                9.7149              5.3157          4.0537
  26-Jul-1992          -1            0.11966              204.7609                10.661              5.3146          4.0539
CROSSING OF THE PLANE:
  30-Jun-1992           1            0.0025379            -160.0491               -13.9506            5.3397          4.0502

%-----------------------------------------------------------------------------------------
% P/Lagerkvist(1996R2):   (Run date: May-2005)
%-----------------------------------------------------------------------------------------
 Date:              Sign:        Distance [AU]:      SW-speed [km/s]:        Timedelay [days]:     s/c-sun [AU]:  comet-sun [AU]:
 12-Feb-1992          -1            0.13191             1121.9305               1.2998              5.4031          4.5608
 13-Feb-1992          -1            0.13699             643.5545                2.2659              5.4031          4.5609
 14-Feb-1992          -1            0.14198             453.2656                3.2168              5.4031          4.561
 15-Feb-1992          -1            0.1469              350.6773                4.1572              5.403           4.5611
 16-Feb-1992          -1            0.15178             286.3634                5.0899              5.403           4.5612
 17-Feb-1992          -1            0.15662             242.202                 6.0167              5.4029          4.5613
 18-Feb-1992          -1            0.16143             209.9673                6.9387              5.4029          4.5614

%-----------------------------------------------------------------------------------------
%  P/LINEAR(2002LZ11):   (Run date: May-2005)
%-----------------------------------------------------------------------------------------
 Date:              Sign:          Distance [AU]:      SW-speed [km/s]:        Timedelay [days]:     s/c-sun [AU]:  comet-sun [AU]:
 01-Oct-1992          1            0.016555            845.8412                0.5926              5.2305          4.941
 02-Oct-1992          1            0.011764            332.2968                1.5008              5.229           4.941
 03-Oct-1992          1            0.0069718           205.9664                2.4089              5.2275          4.941
CROSSING OF THE PLANE:
 04-Oct-1992          1            0.00218             148.8084                3.317               5.2261          4.941

%-----------------------------------------------------------------------------------------
%  10P/Tempel2:   (Run date: May-2005)
%-----------------------------------------------------------------------------------------
 Date:              Sign:          Distance [AU]:      SW-speed [km/s]:        Timedelay [days]:     s/c-sun [AU]:  comet-sun [AU]:
 31-Dec-1997          -1            0.12571             940.2567                1.9949              5.3728          4.2895
 01-Jan-1998          -1            0.13041             630.4256                2.9773              5.3734          4.2894
 02-Jan-1998          -1            0.13512             474.3246                3.9596              5.3741          4.2894
 03-Jan-1998          -1            0.13982             380.2799                4.942               5.3747          4.2893
 04-Jan-1998          -1            0.14452             317.4213                5.9243              5.3754          4.2893
CROSSING OF THE PLANE:
 04-Dec-1997          1             0.0013581           -74.9801                -24.5267            5.3528          4.2907

%-----------------------------------------------------------------------------------------
% 37P/Forbes:  (Run date: May-2005)
%-----------------------------------------------------------------------------------------
 Date:              Sign:         Distance [AU]:      SW-speed [km/s]:        Timedelay [days]:     s/c-sun [AU]:  comet-sun [AU]:
  26-Apr-1998          1            0.10327              920.3611                3.6747              5.4079          3.4546
  27-Apr-1998          1            0.098839             743.1723                4.5522              5.4078          3.4539
  28-Apr-1998          1            0.094405             623.2478                5.4297              5.4078          3.4533
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  29-Apr-1998        1         0.08997          536.6878          6.3073          5.4077          3.4527
  30-Apr-1998        1         0.085536         471.268           7.1849          5.4076          3.452
  01-May-1998        1         0.081101         420.0869          8.0626          5.4075          3.4514
  02-May-1998        1         0.076666         378.9512          8.9403          5.4075          3.4508
  03-May-1998        1         0.072231         345.1679          9.818           5.4074          3.4501
  04-May-1998        1         0.067796         316.9273          10.6958         5.4073          3.4495
  05-May-1998        1         0.063361         292.9685          11.5736         5.4072          3.4489
  06-May-1998        1         0.058926         272.386           12.4515         5.4071          3.4482
  07-May-1998        1         0.054489         254.514           13.3294         5.4069          3.4476
  08-May-1998        1         0.050054         238.8483          14.2073         5.4068          3.447
  09-May-1998        1         0.045618         225.0049          15.0853         5.4067          3.4463
  10-May-1998        1         0.041182         212.683           15.9634         5.4066          3.4457
  11-May-1998        1         0.036747         201.6448          16.8415         5.4064          3.4451
CROSSING OF THE PLANE:
  19-May-1998        1         0.0012587        142.5553          23.8675         5.4051          3.44

%------------------------------------------------------------------------------------------
%  105P/SingerBrewster:  (Run date: May-2005)
%------------------------------------------------------------------------------------------
Date:              Sign:      Distance [AU]:     SW-speed [km/s]:     Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
 09-Aug-1998         1          0.058085          1136.8232           4.0807           5.3688          2.6896
 10-Aug-1998         1          0.05339           915.049             5.0685           5.3681          2.6895
 11-Aug-1998         1          0.048695          765.6172            6.0563           5.3674          2.6895
 12-Aug-1998         1          0.043999          658.0939            7.0441           5.3667          2.6894
 13-Aug-1998         1          0.039304          577.0163            8.0319           5.366           2.6894
 14-Aug-1998         1          0.034608          513.6961            9.0196           5.3653          2.6893
 15-Aug-1998         1          0.029913          462.8749            10.0074          5.3646          2.6893
 16-Aug-1998         1          0.025217          421.1843            10.9952          5.3638          2.6892
 17-Aug-1998         1          0.020522          386.3659            11.983           5.3631          2.6892
 18-Aug-1998         1          0.015826          356.8499            12.9707          5.3623          2.6891
 19-Aug-1998         1          0.01113           331.5107            13.9585          5.3616          2.6891
 20-Aug-1998         1          0.0064344         309.5201            14.9462          5.3608          2.689
 21-Aug-1998         1          0.0017386         290.2553            15.934           5.3601          2.689
 22-Aug-1998        -1          0.0029571         273.2389            16.9218          5.3593          2.6889
 23-Aug-1998        -1          0.0076529         258.0989            17.9095          5.3585          2.6889
 24-Aug-1998        -1          0.012349          244.5412            18.8973          5.3577          2.6888
 25-Aug-1998        -1          0.017044          232.3299            19.885           5.357           2.6888
 26-Aug-1998        -1          0.02174           221.2738            20.8727          5.3562          2.6887
 27-Aug-1998        -1          0.026436          211.2164            21.8605          5.3554          2.6887
 28-Aug-1998        -1          0.031131          202.0281            22.8482          5.3546          2.6886
CROSSING OF THE PLANE:
 21-Aug-1998         1          0.0017386         290.2553            15.934           5.3601          2.689

%------------------------------------------------------------------------------------------
% C/LINEAR(1998G1):  (Run date: May-2005)
%------------------------------------------------------------------------------------------
 Date:              Sign:      Distance [AU]:     SW-speed [km/s]:     Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
  09-Jul-1998        -1          0.14086           452.8385            10.6807          5.3874           2.594
  10-Jul-1998        -1          0.13846           419.4453            11.5324          5.3869           2.5931
  11-Jul-1998        -1          0.13606           390.6421            12.3842          5.3864           2.5923
  12-Jul-1998        -1          0.13365           365.5433            13.2361          5.3858           2.5915
  13-Jul-1998        -1          0.13125           343.4771            14.088           5.3853           2.5906
  14-Jul-1998        -1          0.12885           323.9253            14.94            5.3848           2.5898
  15-Jul-1998        -1          0.12645           306.481             15.7921          5.3842           2.5889
  16-Jul-1998        -1          0.12405           290.8208            16.6442          5.3837           2.5881
  17-Jul-1998        -1          0.12165           276.6843            17.4965          5.3832           2.5872
  18-Jul-1998        -1          0.11924           263.8593            18.3487          5.3826           2.5864
  19-Jul-1998        -1          0.11684           252.1713            19.2011          5.382            2.5856
  20-Jul-1998        -1          0.11444           241.4755            20.0535          5.3815           2.5847
  21-Jul-1998        -1          0.11204           231.6505            20.906           5.3809           2.5839
  22-Jul-1998        -1          0.10963           222.5942            21.7586          5.3803           2.5831
  23-Jul-1998        -1          0.10723           214.2197            22.6112          5.3797           2.5822
  24-Jul-1998        -1          0.10483           206.4527            23.4639          5.3791           2.5814
CROSSING OF THE PLANE:
  05-Sep-1998        -1          0.0013451          80.598             60.1845          5.3479           2.5463

%------------------------------------------------------------------------------------------
% P/NEAT(2001T3):   (Run date: May-2005)
%------------------------------------------------------------------------------------------
  Date:              Sign:      Distance [AU]:     SW-speed [km/s]:     Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
  29-Jun-2003         1          0.051064          536.3614            1.3188           4.9914           4.5829
  30-Jun-2003         1          0.046182          327.1655            2.1701           4.9937           4.5837
  01-Jul-2003         1          0.0413            235.8479            3.0215           4.996            4.5844
CROSSING OF THE PLANE:
  09-Jul-2003         1          0.0022365          74.555             9.8362           5.0141           4.5906

%------------------------------------------------------------------------------------------
%  C/LINEAR(2002B1):   (Run date: May-2005)
%------------------------------------------------------------------------------------------
  Date:              Sign:      Distance [AU]:     SW-speed [km/s]:     Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
  22-May-2002        -1          0.01036           1125.6028           1.7907           3.4554           2.2912
  23-May-2002        -1          0.017437           747.1075           2.7105           3.4609           2.2913
  24-May-2002        -1          0.024515           560.3556           3.6304           3.4664           2.2914
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  25-May-2002      -1      0.031592      449.0892      4.5506       3.4719      2.2916
  26-May-2002      -1      0.038669      375.2333      5.4711       3.4773      2.2917
  27-May-2002      -1      0.045746      322.6351      6.3918       3.4828      2.2918
  28-May-2002      -1      0.052823      283.2704      7.3127       3.4882      2.2919
  29-May-2002      -1      0.059899      252.7024      8.2339       3.4937      2.292
  30-May-2002      -1      0.066974      228.2783      9.1553       3.4991      2.2921
  31-May-2002      -1      0.07405       208.3143      10.0769      3.5046      2.2922
CROSSING OF THE PLANE:
  20-May-2002       1      0.0037955     0.17523       11395.9508   3.4443      2.291

%-----------------------------------------------------------------------------------------
% C/LINEAR(2002Q2):   (Run date: May-2005)
%-----------------------------------------------------------------------------------------
 Date:           Sign:   Distance [AU]:  SW-speed [km/s]:  Timedelay [days]:  s/c-sun [AU]:  comet-sun [AU]:
  07-May-2002       1      0.061824      1095.4783     2.1943       3.3717      1.9834
  08-May-2002       1      0.06121       686.3569      3.5086       3.3774      1.9866
  09-May-2002       1      0.060597      500.2188      4.8228       3.383       1.9897
  10-May-2002       1      0.059983      393.8028      6.1369       3.3886      1.9928
  11-May-2002       1      0.059368      324.9241      7.4511       3.3942      1.996
  12-May-2002       1      0.058753      276.698       8.7651       3.3998      1.9991
  13-May-2002       1      0.058138      241.046       10.0791      3.4054      2.0023
  14-May-2002       1      0.057522      213.617       11.3931      3.411       2.0054
CROSSING OF THE PLANE:
  13-Aug-2002       1      0.00040355    20.8947       131.0542     3.8807      2.2991

%-----------------------------------------------------------------------------------------
% P/LINEAR(2003KV2):   (Run date: May-2005)
%-----------------------------------------------------------------------------------------
  Date:           Sign:   Distance [AU]:  SW-speed [km/s]:  Timedelay [days]:  s/c-sun [AU]:  comet-sun [AU]:
  24-Feb-2003       1      0.14031       496.4123      9.2452       4.6495      1.9989
  25-Feb-2003       1      0.13507       450.1997      10.2076      4.6527      1.9986
  26-Feb-2003       1      0.12984       411.9467      11.1701      4.6559      1.9983
  27-Feb-2003       1      0.1246        379.7597      12.1326      4.6591      1.998
  28-Feb-2003       1      0.11937       352.3017      13.0952      4.6622      1.9977
  01-Mar-2003       1      0.11413       328.6014      14.0579      4.6654      1.9974
  02-Mar-2003       1      0.1089        307.9368      15.0206      4.6685      1.9971
  03-Mar-2003       1      0.10366       289.7596      15.9834      4.6716      1.9968
  04-Mar-2003       1      0.098426      273.646       16.9463      4.6748      1.9965
  05-Mar-2003       1      0.09319       259.2634      17.9092      4.6779      1.9962
  06-Mar-2003       1      0.087953      246.3469      18.8722      4.681       1.9959
  07-Mar-2003       1      0.082716      234.6832      19.8352      4.6841      1.9956
  08-Mar-2003       1      0.077478      224.0983      20.7983      4.6872      1.9953
  09-Mar-2003       1      0.072241      214.4491      21.7615      4.6903      1.995
  10-Mar-2003       1      0.067003      205.6167      22.7247      4.6934      1.9947
CROSSING OF THE PLANE:
  22-Mar-2003       1      0.0041355     138.2909      34.2881      4.7298      1.9912

%-----------------------------------------------------------------------------------------
%  37P/Forbes:  (Run date: May-2005)
%-----------------------------------------------------------------------------------------
  Date:           Sign:   Distance [AU]:  SW-speed [km/s]:  Timedelay [days]:  s/c-sun [AU]:  comet-sun [AU]:
  22-Jun-2004       1      0.14401       220.1829      15.2741      5.4053      3.4629
  23-Jun-2004       1      0.13952       208.3572      16.1469      5.4054      3.4623
CROSSING OF THE PLANE:
  24-Jul-2004       1      6.2504e-05    78.5925       43.2226      5.4039      3.442

%-----------------------------------------------------------------------------------------
%  154P/Brewington:   (Run date: May-2005)
%-----------------------------------------------------------------------------------------
  Date:           Sign:   Distance [AU]:  SW-speed [km/s]:  Timedelay [days]:  s/c-sun [AU]:  comet-sun [AU]:
  11-Jun-2004      -1      0.024194      993.4032      1.7733       5.4044      4.387
  12-Jun-2004      -1      0.028335      709.3255      2.4797       5.4045      4.3886
  13-Jun-2004      -1      0.032477      551.2517      3.1858       5.4046      4.3903
  14-Jun-2004      -1      0.036618      450.5598      3.8917       5.4047      4.392
  15-Jun-2004      -1      0.04076       380.8057      4.5974       5.4048      4.3937
  16-Jun-2004      -1      0.044901      329.6281      5.3028       5.4049      4.3954
  17-Jun-2004      -1      0.049042      290.4775      6.008        5.405       4.397
  18-Jun-2004      -1      0.053183      259.5594      6.7129       5.405       4.3987
  19-Jun-2004      -1      0.057324      234.5241      7.4176       5.4051      4.4004
  20-Jun-2004      -1      0.061464      213.8377      8.1221       5.4052      4.4021
CROSSING OF THE PLANE:
  05-Jun-2004       1      0.00065781    0.45512       3905.7734    5.4036      4.3769

%-----------------------------------------------------------------------------------------
%  P/LINEAR-NEAT(2001Q5):   (Run date: May-2005)
%-----------------------------------------------------------------------------------------
  Date:           Sign:   Distance [AU]:  SW-speed [km/s]:  Timedelay [days]:  s/c-sun [AU]:  comet-sun [AU]:
  18-Jul-2004       1      0.01636       985.0471      0.79696      5.4046      4.9512
  19-Jul-2004       1      0.011969      516.1495      1.5203       5.4045      4.9513
  20-Jul-2004       1      0.0075779     349.5926      2.2436       5.4044      4.9514
  21-Jul-2004       1      0.0031871     264.2464      2.9668       5.4043      4.9515
  22-Jul-2004      -1      0.0012037     212.3554      3.69         5.4041      4.9516
CROSSING OF THE PLANE:
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  21-Jul-2004          1          0.0031871            264.2464                2.9668              5.4043             4.9515

%-------------------------------------------------------------------------------------------
%  P/Skiff(2002S1):   (Run date: May-2005)
%-------------------------------------------------------------------------------------------
   Date:              Sign:     Distance [AU]:     SW-speed [km/s]:       Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
  15-Mar-2004          1          0.046593          786.8452              1.6031              5.3707            4.6422
  16-Mar-2004          1          0.042856          566.3956              2.2255              5.3714            4.6434
  17-Mar-2004          1          0.039119          442.3264              2.8479              5.372             4.6445
  18-Mar-2004          1          0.035382          362.7678              3.47                5.3727            4.6456
  19-Mar-2004          1          0.031644          307.4101              4.0921              5.3733            4.6468
  20-Mar-2004          1          0.027907          266.6674              4.714               5.3739            4.6479
  21-Mar-2004          1          0.024169          235.4259              5.3357              5.3745            4.649
  22-Mar-2004          1          0.020432          210.7088              5.9574              5.3751            4.6502
CROSSING OF THE PLANE:
  27-Mar-2004          1          0.001743          137.9851              9.0633              5.3781            4.6558

%-------------------------------------------------------------------------------------------
% C/Larsen(2004C1):   (Run date: May-2005)
%-------------------------------------------------------------------------------------------
Date:               Sign:       Distance [AU]:     SW-speed [km/s]:       Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
  29-Apr-2004          1          0.063865          947.4058              0.60144             5.3938            5.0647
  30-Apr-2004          1          0.059351          326.084               1.7519              5.3941            5.0642
CROSSING OF THE PLANE:
  13-May-2004          1          0.00063932         35.2758             16.7016              5.3984            5.0582
```

A.3 Earth

Comet: **2P/Encke**
Method 2

Date	Sign	$R_{\mathrm{E-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]	$R_{\mathrm{E-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
01-Feb-1994	-	0.077263	703.3589	1.5425	0.98535	0.35876
02-Feb-1994	-	0.073977	457.3333	2.3782	0.9855	0.35732
03-Feb-1994	-	0.070669	339.0832	3.2154	0.98565	0.35595
04-Feb-1994	-	0.067338	269.5767	4.0539	0.98581	0.35464
05-Feb-1994	-	0.063986	223.8183	4.8937	0.98597	0.35338
CROSSING						
23-Feb-1994	-	0.0012801	55.7775	20.1689	0.98939	0.33967

Table 28: E-Earth, i-ion tail, S-Sun, C-comet

Method 1

Date	$R_{\mathrm{E-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]
1994-1-31	0.17891	800	1
1994-2-2	0.19846	700	2
1994-2-2	0.10432	600	2
1994-2-2	0.095221	500	2
1994-2-2	0.13478	450	2
1994-2-3	0.097221	400	3
1994-2-3	0.075706	350	3
1994-2-4	0.093089	300	4
1994-2-4	0.067659	275	4
1994-2-4	0.084624	250	4
1994-2-5	0.069657	225	5
1994-2-5	0.084087	200	5

Table 29: E-Earth, i-ion tail

Comet: **2P/Encke**

Method 2

Date	Sign	$R_{\mathrm{E-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]	$R_{\mathrm{E-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
16-Mar-2017	+	0.071929	671.2967	1.6805	0.99468	0.34314
17-Mar-2017	+	0.075235	445.2224	2.5323	0.99496	0.34382
18-Mar-2017	+	0.078519	332.9912	3.3835	0.99524	0.34454
19-Mar-2017	+	0.08178	265.8994	4.234	0.99553	0.34532
20-Mar-2017	+	0.085017	221.2677	5.0838	0.99581	0.34614
CROSSING						
23-Feb-2017	-	0.0009494	0.94619	1189.0782	0.98944	0.33964

Table 30: E-Earth, i-ion tail, S-Sun, C-comet

Method 1

Date	Time	$R_{\mathrm{E-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]
2017-3-16	6:0	0.072783	700	1.6042
2017-3-16	6:0	0.072788	600	1.875
2017-3-16	13:0	0.073759	500	2.25
2017-3-16	20:0	0.07473	450	2.5
2017-3-17	10:0	0.076665	400	2.8125
2017-3-17	16:0	0.077454	350	3.2083
2017-3-18	14:0	0.080495	300	4.2708
2017-3-18	16:0	0.080748	275	3.9375
2017-3-19	3:0	0.082295	250	4.4583
2017-3-19	18:30	0.084301	225	5.0208
2017-3-20	22:30	0.088072	200	6.4167

Table 31: E-Earth, i-ion tail

Comet: **45P/Honda-Mrkos-Pajdusakova**
Method 2

Date	Sign	$R_{\mathrm{E-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]	$R_{\mathrm{E-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
24-Jan-1996	-	0.0411	566.9062	0.75526	0.98429	0.73701
25-Jan-1996	-	0.042169	351.958	1.1789	0.98439	0.74476
26-Jan-1996	-	0.043225	252.3367	1.5903	0.98449	0.75273
CROSSING						
21-Dec-1995	+	0.00050676	0.37612	1899.0798	0.98378	0.57124

Table 32: E-Earth, i-ion tail, S-Sun, C-comet

Method 1

Date	$R_{\mathrm{E-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]
1996-2-9	0.12345	800	0
1996-2-9	0.12345	700	0
1996-1-21	0.08842	600	1
1996-1-23	0.052624	500	1
1996-1-24	0.043105	450	1
1996-1-25	0.042778	400	1
1996-1-26	0.05068	350	1
1996-1-28	0.062272	300	1
1996-1-29	0.068633	275	1
1996-1-25	0.062995	250	2
1996-1-25	0.050545	225	2
1996-1-27	0.044957	200	2

Table 33: E-Earth, i-ion tail

Comet: **45P/Honda-Mrkos-Pajdusakova**

Method 2

Date	Sign	$R_{\mathrm{E-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]	$R_{\mathrm{E-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
23-Jan-2017	-	0.040717	730.2211	0.59339	0.98429	0.73404
24-Jan-2017	-	0.041791	411.2871	1.0217	0.9844	0.74171
25-Jan-2017	-	0.042853	282.8704	1.4379	0.98451	0.74959
26-Jan-2017	-	0.043901	213.3473	1.8416	0.98462	0.7577
CROSSING						
20-Dec-2016	+	0.00096326	0.37716	1898.828	0.98381	0.5702

Table 34: E-Earth, i-ion tail, S-Sun, C-comet

Method 1

Date	$R_{\mathrm{E-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]
2017-2-8	0.12555	800	0
2017-2-8	0.12555	700	0
2017-1-21	0.087229	600	1
2017-1-22	0.051368	500	1
2017-1-23	0.042303	450	1
2017-1-24	0.042936	400	1
2017-1-25	0.051769	350	1
2017-1-27	0.063382	300	1
2017-1-28	0.069814	275	1
2017-1-24	0.061143	250	2
2017-1-25	0.04916	225	2
2017-1-26	0.044142	200	2

Table 35: E-Earth, i-ion tail

Comet: **72P/Denning-Fujikawa**
Method 2

Date	Sign	$R_{\mathrm{E-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]	$R_{\mathrm{E-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
18-Oct-2005	+	0.043511	1157.7053	0.31743	0.99629	0.78404
19-Oct-2005	+	0.04101	455.5954	0.80175	0.99601	0.78505
20-Oct-2005	+	0.038498	282.5062	1.2845	0.99573	0.78616
21-Oct-2005	+	0.035973	204.0775	1.7655	0.99546	0.78737
CROSSING						
03-Nov-2005	+	0.0024443	39.725	7.7866	0.99204	0.81339

Table 36: E-Earth, i-ion tail, S-Sun, C-comet

Method 1

Date	Time	$R_{\mathrm{E-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]
2005-10-18	12:30	0.043043	700	0.52083
2005-10-18	14:30	0.042621	600	0.60417
2005-10-19	10:0	0.040437	500	0.72917
2005-10-19	10:0	0.040463	450	0.8125
2005-10-19	11:0	0.040468	400	0.89583
2005-10-19	12:0	0.040228	350	0.95833
2005-10-19	20:30	0.039351	300	0.79167
2005-10-20	1:30	0.038807	275	1.3125
2005-10-20	8:0	0.038147	250	1.4583
2005-10-21	11:0	0.035251	225	1.5833
2005-10-21	11:0	0.035254	200	1.7917

Table 37: E-Earth, i-ion tail

Comet: **P/Christensen(2003K2)**

Method 2

Date	Sign	$R_{\mathrm{E-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]	$R_{\mathrm{E-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
02-Feb-2009	-	0.1098	597.7299	0.90887	0.98548	0.67172
03-Feb-2009	-	0.11218	370.139	1.4434	0.98562	0.67706
04-Feb-2009	-	0.11452	266.4472	1.9703	0.98576	0.68256
05-Feb-2009	-	0.11683	207.0587	2.4894	0.98591	0.68822
CROSSING						
25-Dec-2008	+	0.0013606	0.35444	2083.8329	0.98352	0.55695

Table 38: E-Earth, i-ion tail, S-Sun, C-comet

Method 1

Date	Time	$R_{\mathrm{E-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]
2009-1-30	17:0	0.10986	800	0.70833
2009-1-31	15:30	0.10716	700	0.79167
2009-1-31	16:0	0.10714	600	1.0833
2009-2-1	2:0	0.10769	500	0.91667
2009-2-2	4:0	0.11154	450	0.83333
2009-2-2	7:30	0.11152	400	0.6875
2009-2-2	10:0	0.1113	350	1.5208
2009-2-2	8:30	0.1113	300	1.7917
2009-2-2	9:30	0.1113	275	2.0625
2009-2-3	2:0	0.11238	250	1.9167
2009-2-3	7:0	0.11294	225	1.7083
2009-2-4	3:30	0.11542	200	2.5833

Table 39: E-Earth, i-ion tail

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***************************
        METHOD 2
***************************

%-----------------------------------------------------------------------------------------------
% 2P/Encke:
%-----------------------------------------------------------------------------------------------
 Date:               Sign:          Distance [AU]:      SW-speed [km/s]:         Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
 15-Mar-1984           1            0.07017             925.8068                 1.2189               0.99455            0.3428
 16-Mar-1984           1            0.073486            544.576                  2.071                0.99482            0.34345
 17-Mar-1984           1            0.07678             385.6536                 2.9225               0.9951             0.34415
 18-Mar-1984           1            0.080051            298.4732                 3.7735               0.99538            0.3449
 19-Mar-1984           1            0.083298            243.3941                 4.6237               0.99566            0.3457
 20-Mar-1984           1            0.086521            205.4376                 5.4732               0.99594            0.34654
CROSSING OF THE PLANE:
 23-Feb-1984          -1            0.0028077           0.94608                  1188.616             0.98928            0.33981

%-----------------------------------------------------------------------------------------------
% 45P/Honda-Mrkos-Pajdusakova:
%-----------------------------------------------------------------------------------------------
 Date:                Sign:         Distance [AU]:      SW-speed [km/s]:         Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
 23-Aug-1990           1            0.065421            904.8996                 0.20148              1.0113             0.90601
 24-Aug-1990           1            0.066017            514.0912                 0.39311              1.0111             0.89437
 25-Aug-1990           1            0.066594            365.9085                 0.6049               1.0109             0.88304
 26-Aug-1990           1            0.067151            287.1267                 0.83605              1.0106             0.87201
 27-Aug-1990           1            0.067689            237.8434                 1.0858               1.0104             0.86126
 28-Aug-1990           1            0.068207            203.888                  1.3535               1.0102             0.85081
CROSSING OF THE PLANE:
 20-Jun-1990          -1            0.0007095            0                        0                   1.0162             3.1027

%-----------------------------------------------------------------------------------------------
% 45P/Honda-Mrkos-Pajdusakova:
%-----------------------------------------------------------------------------------------------
 Date:                Sign:         Distance [AU]:      SW-speed [km/s]:         Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
 24-Aug-2011           1            0.065808            605.7651                 0.32111              1.0112             0.89885
 25-Aug-2011           1            0.066392            407.3631                 0.52528              1.011              0.88741
 26-Aug-2011           1            0.066957            310.9605                 0.74901              1.0108             0.87626
 27-Aug-2011           1            0.067503            253.4712                 0.99156              1.0106             0.86541
 28-Aug-2011           1            0.068029            215.0191                 1.2522               1.0103             0.85484
CROSSING OF THE PLANE:
 20-Jun-2011          -1            0.0011357            0                        0                   1.0161             3.1314

%-----------------------------------------------------------------------------------------------
% 72P/Denning-Fujikawa:
%-----------------------------------------------------------------------------------------------
 Date:                Sign:         Distance [AU]:       SW-speed [km/s]:         Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
 04-Oct-1987           1            0.077714             665.1213                 0.57088              1.0004             0.78115
 05-Oct-1987           1            0.075469             357.8257                 1.0621               1.0002             0.78066
 06-Oct-1987           1            0.073202             244.6995                 1.5538               0.99986            0.78027
CROSSING OF THE PLANE:
 04-Nov-1987           1            0.00087565           19.9172                  15.3642              0.99184            0.81511

%-----------------------------------------------------------------------------------------------
% 72P/Denning-Fujikawa:
%-----------------------------------------------------------------------------------------------
 Date:                Sign:         Distance [AU]:       SW-speed [km/s]:         Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
 11-Oct-1996           1            0.0599               538.629                  0.70153              0.99827            0.78003
 12-Oct-1996           1            0.057499             316.0679                 1.1923               0.99798            0.78034
 13-Oct-1996           1            0.05508              223.275                  1.6824               0.9977             0.78074
CROSSING OF THE PLANE:
 03-Nov-1996           1            0.0016723             26.5751                 11.5775              0.99193            0.81423

%-----------------------------------------------------------------------------------------------
% 72P/Denning-Fujikawa:
%-----------------------------------------------------------------------------------------------
 Date:                Sign:         Distance [AU]:       SW-speed [km/s]:         Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
 26-Oct-2014           1            0.023979             1014.7288                0.34082              0.99428            0.79454
 27-Oct-2014           1            0.021402             423.0627                 0.80879              0.99401            0.79639
 28-Oct-2014           1            0.018818             265.5434                 1.274                0.99374            0.79835
CROSSING OF THE PLANE:
 04-Nov-2014           1            0.00062436            68.8488                 4.4396               0.99187            0.81533

%-----------------------------------------------------------------------------------------------
% P/Christensen(2003K2):
%-----------------------------------------------------------------------------------------------
 Date:                Sign:         Distance [AU]:       SW-speed [km/s]:         Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
 18-Dec-1985           1            0.023197             1191.2239                0.62895              0.98398            0.55127
 19-Dec-1985           1            0.020141             566.5777                 1.3204               0.98389            0.55183
 20-Dec-1985           1            0.017079             371.3539                 2.0111               0.98381            0.55247
 21-Dec-1985           1            0.014012             275.9816                 2.7012               0.98373            0.55319
 22-Dec-1985           1            0.01094              219.4384                 3.3903               0.98366            0.55399
```

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CROSSING OF THE PLANE:
 25-Dec-1985          1          0.0017108            135.4964              5.4518             0.98348            0.55685

%-------------------------------------------------------------------------------------------
%  P/LINEAR(2004CB):
%-------------------------------------------------------------------------------------------
 Date:              Sign:        Distance [AU]:       SW-speed [km/s]:       Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
 26-May-2019         -1           0.013076             316.7495               0.29674             1.0129            0.95863
CROSSING OF THE PLANE:
 28-May-2019         -1           0.0019442             90.2803               0.92586             1.0133            0.96501

%-------------------------------------------------------------------------------------------
% C/Bradfield(2004F4):
%-------------------------------------------------------------------------------------------
 Date:              Sign:        Distance [AU]:      SW-speed [km/s]:       Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
 24-Apr-2004          1          0.1354              251.1633              5.7247              1.0058            0.1754
 25-Apr-2004          1          0.12033             214.577               6.7006              1.0061            0.17568
CROSSING OF THE PLANE:
 02-May-2004          1          0.014137            106.2066              13.5319             1.0079            0.17782

%-------------------------------------------------------------------------------------------
%  P/LINEAR(2004CB):
%-------------------------------------------------------------------------------------------
 Date:             Sign:         Distance [AU]:       SW-speed [km/s]:       Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
 25-Apr-2014         -1           0.17466             336.9252              0.4816              1.0059            0.91218

%-------------------------------------------------------------------------------------------
%  P/LINEAR(2004CB):
%-------------------------------------------------------------------------------------------
 Date:             Sign:          Distance [AU]:       SW-speed [km/s]:      Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
  26-May-2019         -1           0.013076             316.7495              0.29674             1.0129            0.95863
CROSSING OF THE PLANE:
  28-May-2019         -1           0.0019442             90.2803              0.92586             1.0133            0.96501

%-------------------------------------------------------------------------------------------
%  P/LINEAR (2004 X1):
%-------------------------------------------------------------------------------------------
 Date:             Sign:         Distance [AU]:       SW-speed [km/s]:       Timedelay [days]:    s/c-sun [AU]:  comet-sun [AU]:
 25-Aug-2009          1          0.052397            749.5862               0.47723             1.0108            0.80423
 26-Aug-2009          1          0.051134            385.9769               0.93484             1.0106            0.80222
 27-Aug-2009          1          0.049855            260.7543               1.395               1.0104            0.80031
CROSSING OF THE PLANE:
 30-Sep-2009          1          0.00046481           20.598                17.5505             1.0015            0.79271

%-------------------------------------------------------------------------------------------
%  P/Catalina (2005 JQ5):
%-------------------------------------------------------------------------------------------
Comet:        Date:              Distance [AU]:        SW-speed [km/s]:        Timedelay [days]:    s/c-sun [AU]:    comet-sun [AU]:
411: 09-Jul-2005         1           0.019196             645.4364               0.36788            1.0167            0.87956
411: 10-Jul-2005         1           0.020841             328.5794               0.73984            1.0167            0.87627
411: 11-Jul-2005         1           0.022481             222.6347               1.1164             1.0166            0.87309
CROSSING OF THE PLANE:
14-Jun-2005 411: 27-Jun-2005          -1           0.00083319            0.094677             1610.7648             1.0166            0.92847
```

A.4 Cassini

Comet: **108P/Ciffreo**
Method 2

Date	Sign	$R_{\mathrm{CA-i}}$ [AU]	SW-speed [km/s]	Timedelay [days]	$R_{\mathrm{CA-S}}$ [AU]	$R_{\mathrm{C-S}}$ [AU]
18-Apr-2000	+	0.0065625	1056.5738	2.6831	3.3509	1.7136
19-Apr-2000	+	0.0051298	816.4425	3.489	3.3588	1.7136
20-Apr-2000	+	0.0036971	666.2822	4.2959	3.3667	1.7136
21-Apr-2000	+	0.0022643	563.5042	5.1037	3.3745	1.7135
22-Apr-2000	+	0.00083152	488.735	5.9123	3.3824	1.7135
23-Apr-2000	-	0.00060126	431.897	6.7219	3.3902	1.7135
24-Apr-2000	-	0.002034	387.2289	7.5323	3.398	1.7135
25-Apr-2000	-	0.0034668	351.1992	8.3437	3.4058	1.7134
26-Apr-2000	-	0.0048995	321.5219	9.1558	3.4136	1.7134
27-Apr-2000	-	0.0063322	296.6525	9.9689	3.4214	1.7134
28-Apr-2000	-	0.0077648	275.5096	10.7828	3.4292	1.7134
29-Apr-2000	-	0.0091974	257.3133	11.5975	3.4369	1.7134
30-Apr-2000	-	0.01063	241.4874	12.4131	3.4446	1.7134
01-May-2000	-	0.012062	227.5966	13.2295	3.4524	1.7134
02-May-2000	-	0.013495	215.3061	14.0467	3.4601	1.7134
03-May-2000	-	0.014927	204.3542	14.8647	3.4678	1.7134
CROSSING						
22-Apr-2000	+	0.00083152	488.735	5.9123	3.3824	1.7135

Table 40: CA-Cassini, i-ion tail, S-Sun, C-comet

```
***************************
       METHOD 2
***************************

%********************************************************************************
% 137P/Shoemaker-Levy2: (Run date: May-2005)
%********************************************************************************
Date:                Sign:         Distance [AU]:       SW-speed [km/s]:       Timedelay [days]:  s/c-sun [AU]:  comet-sun [AU]:
 21-Apr-2000          -1            0.062157             972.7957               2.4616            3.3745          1.9915
 22-Apr-2000          -1            0.061795             749.5756               3.2109            3.3824          1.9923
 23-Apr-2000          -1            0.061432             610.6723               3.9611            3.3902          1.9931
 24-Apr-2000          -1            0.061069             515.8986               4.7123            3.398           1.994
 25-Apr-2000          -1            0.060705             447.1055               5.4644            3.4058          1.9948
 26-Apr-2000          -1            0.060341             394.8958               6.2175            3.4136          1.9956
 27-Apr-2000          -1            0.059976             353.9168               6.9715            3.4214          1.9964
 28-Apr-2000          -1            0.059611             320.8959               7.7264            3.4292          1.9972
 29-Apr-2000          -1            0.059245             293.7191               8.4823            3.4369          1.998
 30-Apr-2000          -1            0.058879             270.9604               9.239             3.4446          1.9988
 01-May-2000          -1            0.058513             251.6228               9.9966            3.4524          1.9996
 02-May-2000          -1            0.058146             234.9884               10.7551           3.4601          2.0004
 03-May-2000          -1            0.057779             220.527                11.5145           3.4678          2.0012
 04-May-2000          -1            0.057411             207.8385               12.2748           3.4754          2.002
CROSSING OF THE PLANE:
 30-Sep-2000          -1            0.00026404            31.0337               132.5398           4.4871          2.1115

%********************************************************************************
% P/Lovas2(1986W1):  (Run date: May-2005)
%********************************************************************************
Date:                Sign:         Distance [AU]:      SW-speed [km/s]:       Timedelay [days]:     s/c-sun [AU]:  comet-sun [AU]:
 05-Jun-2000          -1            0.12089             978.2565               3.4095              3.7143          1.788
 06-Jun-2000          -1            0.12102             792.7862               4.2205              3.7216          1.7891
 07-Jun-2000          -1            0.12116             667.04                 5.0321              3.7288          1.7902
 08-Jun-2000          -1            0.12129             576.1692               5.8442              3.736           1.7913
 09-Jun-2000          -1            0.12142             507.4308               6.6569              3.7433          1.7924
 10-Jun-2000          -1            0.12156             453.6161               7.4699              3.7505          1.7934
 11-Jun-2000          -1            0.12169             410.34                 8.2835              3.7576          1.7945
 12-Jun-2000          -1            0.12182             374.7826               9.0976              3.7648          1.7956
 13-Jun-2000          -1            0.12195             345.0473               9.9122              3.772           1.7967
 14-Jun-2000          -1            0.12208             319.812                10.7272             3.7792          1.7978
 15-Jun-2000          -1            0.12221             298.1268               11.5428             3.7863          1.7988
 16-Jun-2000          -1            0.12234             279.2913               12.3588             3.7934          1.7999
 17-Jun-2000          -1            0.12247             262.7783               13.1753             3.8006          1.801
 18-Jun-2000          -1            0.12259             248.1829               13.9922             3.8077          1.802
 19-Jun-2000          -1            0.12272             235.1893               14.8096             3.8148          1.8031
 20-Jun-2000          -1            0.12284             223.5472               15.6275             3.8218          1.8042
 21-Jun-2000          -1            0.12297             213.0561               16.4459             3.8289          1.8052
 22-Jun-2000          -1            0.12309             203.5531               17.2647             3.836           1.8063
    CROSSING OF THE PLANE:
 29-Jul-1999           1            0.00054251            0                      0                  0.84419         1.7319

%********************************************************************************
% 82P/Gehrels3:  (Run date: May-2005)
%********************************************************************************
Date:                Sign:         Distance [AU]:      SW-speed [km/s]:       Timedelay [days]:     s/c-sun [AU]:  comet-sun [AU]:
 07-Dec-2000          -1            0.046912            986.4045               2.0293              4.8786          3.7226
 08-Dec-2000          -1            0.046875            751.3871               2.6775              4.8842          3.7223
 09-Dec-2000          -1            0.046837            607.805                3.3266              4.8898          3.7221
 10-Dec-2000          -1            0.0468              510.9884               3.9767              4.8954          3.7218
 11-Dec-2000          -1            0.046762            441.2898               4.6277              4.9011          3.7216
 12-Dec-2000          -1            0.046725            388.717                5.2797              4.9067          3.7214
 13-Dec-2000          -1            0.046688            347.6509               5.9325              4.9123          3.7211
 14-Dec-2000          -1            0.046652            314.6878               6.5862              4.9179          3.7209
 15-Dec-2000          -1            0.046615            287.6472               7.2407              4.9236          3.7207
 16-Dec-2000          -1            0.046579            265.0663               7.896               4.9292          3.7204
 17-Dec-2000          -1            0.046543            245.9288               8.552               4.9349          3.7202
 18-Dec-2000          -1            0.046507            229.5055               9.2086              4.9406          3.72
 19-Dec-2000          -1            0.046472            215.2604               9.8657              4.9463          3.7197
 20-Dec-2000          -1            0.046436            202.7904               10.5231             4.952           3.7195

%********************************************************************************
% 24P/Schaumasse:  (Run date: May-2005)
%********************************************************************************
Date:                Sign:        Distance [AU]:       SW-speed [km/s]:       Timedelay [days]:     s/c-sun [AU]:  comet-sun [AU]:
 13-Feb-2001           1           0.10638             1109.4828              5.7227              5.2751          1.6081
 14-Feb-2001           1           0.1055              960.2689               6.6234              5.2807          1.6073
 15-Feb-2001           1           0.10463             846.7489               7.5244              5.2863          1.6065
 16-Feb-2001           1           0.10375             757.4823               8.4257              5.2919          1.6058
 17-Feb-2001           1           0.10288             685.4463               9.3273              5.2975          1.605
 18-Feb-2001           1           0.102               626.0905               10.2291             5.3031          1.6042
 19-Feb-2001           1           0.10112             576.3367               11.1312             5.3086          1.6035
 20-Feb-2001           1           0.10025             534.0298               12.0335             5.3142          1.6027
```

21-Feb-2001	1	0.099368	497.6136	12.9361	5.3198	1.602
22-Feb-2001	1	0.098489	465.9376	13.839	5.3253	1.6012
23-Feb-2001	1	0.09761	438.1326	14.7422	5.3309	1.6005
24-Feb-2001	1	0.096731	413.5296	15.6456	5.3364	1.5997
25-Feb-2001	1	0.095851	391.6056	16.5492	5.3419	1.599
26-Feb-2001	1	0.09497	371.9453	17.4532	5.3475	1.5982
27-Feb-2001	1	0.09409	354.2152	18.3574	5.353	1.5975
28-Feb-2001	1	0.093208	338.1443	19.2618	5.3585	1.5968
01-Mar-2001	1	0.092327	323.5099	20.1665	5.364	1.596
02-Mar-2001	1	0.091445	310.1275	21.0715	5.3695	1.5953
03-Mar-2001	1	0.090562	297.843	21.9768	5.375	1.5946
04-Mar-2001	1	0.089679	286.5266	22.8823	5.3804	1.5938
05-Mar-2001	1	0.088796	276.068	23.788	5.3859	1.5931
06-Mar-2001	1	0.087912	266.3732	24.6941	5.3914	1.5924
07-Mar-2001	1	0.087028	257.3615	25.6003	5.3968	1.5916
08-Mar-2001	1	0.086144	248.9629	26.5069	5.4023	1.5909
09-Mar-2001	1	0.085259	241.1171	27.4137	5.4077	1.5902
10-Mar-2001	1	0.084374	233.7709	28.3207	5.4132	1.5895
11-Mar-2001	1	0.083489	226.8783	29.228	5.4186	1.5888
12-Mar-2001	1	0.082603	220.3983	30.1356	5.424	1.5881
13-Mar-2001	1	0.081717	214.295	31.0434	5.4295	1.5874
14-Mar-2001	1	0.080831	208.5364	31.9514	5.4349	1.5867
15-Mar-2001	1	0.079944	203.094	32.8597	5.4403	1.586
CROSSING OF THE PLANE:						
12-Jun-2001	1	0.00035758	65.9853	114.5871	5.898	1.5311

%**
% 45P/Honda-Mrkos-Pajdusakova: (Run date: May-2005)
%**

Date:	Sign:	Distance [AU]:	SW-speed [km/s]:	Timedelay [days]:	s/c-sun [AU]:	comet-sun [AU]:
12-Apr-2001	1	0.044714	1150.6106	7.5961	5.5891	0.54128
13-Apr-2001	1	0.044449	1019.5805	8.5811	5.5944	0.54135
14-Apr-2001	1	0.044183	915.5301	9.5661	5.5996	0.54142
15-Apr-2001	1	0.043917	830.9041	10.5511	5.6048	0.54149
16-Apr-2001	1	0.043651	760.7274	11.5361	5.61	0.54156
17-Apr-2001	1	0.043385	701.5901	12.5212	5.6152	0.54163
18-Apr-2001	1	0.043119	651.0772	13.5062	5.6204	0.5417
19-Apr-2001	1	0.042853	607.4301	14.4913	5.6256	0.54177
20-Apr-2001	1	0.042587	569.3379	15.4765	5.6308	0.54184
21-Apr-2001	1	0.042321	535.8036	16.4616	5.636	0.54191
22-Apr-2001	1	0.042054	506.0552	17.4468	5.6412	0.54198
23-Apr-2001	1	0.041788	479.4856	18.432	5.6463	0.54205
24-Apr-2001	1	0.041521	455.6113	19.4172	5.6515	0.54212
25-Apr-2001	1	0.041255	434.0417	20.4024	5.6567	0.54219
26-Apr-2001	1	0.040988	414.4584	21.3877	5.6618	0.54226
27-Apr-2001	1	0.040721	396.5992	22.373	5.667	0.54233
28-Apr-2001	1	0.040454	380.2458	23.3583	5.6721	0.5424
29-Apr-2001	1	0.040187	365.2155	24.3436	5.6773	0.54247
30-Apr-2001	1	0.03992	351.3539	25.329	5.6824	0.54254
01-May-2001	1	0.039653	338.5297	26.3143	5.6875	0.54261
02-May-2001	1	0.039386	326.6307	27.2997	5.6926	0.54268
03-May-2001	1	0.039119	315.5602	28.2851	5.6978	0.54275
04-May-2001	1	0.038852	305.2345	29.2706	5.7029	0.54282
05-May-2001	1	0.038584	295.5809	30.256	5.708	0.5429
06-May-2001	1	0.038317	286.5358	31.2415	5.7131	0.54297
07-May-2001	1	0.038049	278.0435	32.227	5.7182	0.54304
08-May-2001	1	0.037782	270.0546	33.2125	5.7233	0.54311
09-May-2001	1	0.037514	262.5257	34.1981	5.7283	0.54318
10-May-2001	1	0.037246	255.4182	35.1836	5.7334	0.54325
11-May-2001	1	0.036978	248.6977	36.1692	5.7385	0.54332
12-May-2001	1	0.03671	242.3332	37.1548	5.7435	0.54339
13-May-2001	1	0.036442	236.2974	38.1404	5.7486	0.54347
14-May-2001	1	0.036174	230.5653	39.1261	5.7537	0.54354
15-May-2001	1	0.035906	225.1145	40.1117	5.7587	0.54361
16-May-2001	1	0.035638	219.9248	41.0974	5.7638	0.54368
17-May-2001	1	0.03537	214.978	42.0831	5.7688	0.54375
18-May-2001	1	0.035102	210.2572	43.0689	5.7738	0.54382
19-May-2001	1	0.034833	205.7474	44.0546	5.7789	0.5439
20-May-2001	1	0.034565	201.4347	45.0404	5.7839	0.54397
CROSSING OF THE PLANE:						
24-Sep-2001	1	0.00016166	59.2256	170.3766	6.3813	0.55343

%**
% 144P/Kushida: (Run date: May-2005)
%**

Date:	Sign:	Distance [AU]:	SW-speed [km/s]:	Timedelay [days]:	s/c-sun [AU]:	comet-sun [AU]:
30-May-2001	1	0.012	1103.484	6.8206	5.8338	1.4869
31-May-2001	1	0.012381	971.8624	7.7536	5.8388	1.4867
01-Jun-2001	1	0.012762	868.4995	8.6867	5.8438	1.4865
02-Jun-2001	1	0.013143	785.1765	9.6199	5.8487	1.4863
03-Jun-2001	1	0.013524	716.5802	10.5532	5.8537	1.4861
04-Jun-2001	1	0.013905	659.1232	11.4867	5.8586	1.4859
05-Jun-2001	1	0.014286	610.2957	12.4202	5.8635	1.4857

06-Jun-2001	1	0.014668	568.2892	13.354	5.8685	1.4855
07-Jun-2001	1	0.015049	531.7676	14.2878	5.8734	1.4853
08-Jun-2001	1	0.01543	499.7224	15.2218	5.8783	1.4851
09-Jun-2001	1	0.015811	471.378	16.1559	5.8833	1.4849
10-Jun-2001	1	0.016192	446.1282	17.0901	5.8882	1.4847
11-Jun-2001	1	0.016573	423.4923	18.0244	5.8931	1.4845
12-Jun-2001	1	0.016954	403.0844	18.9589	5.898	1.4843
13-Jun-2001	1	0.017335	384.5909	19.8935	5.9029	1.4841
14-Jun-2001	1	0.017716	367.7544	20.8282	5.9078	1.4839
15-Jun-2001	1	0.018097	352.3616	21.763	5.9127	1.4838
16-Jun-2001	1	0.018478	338.2346	22.698	5.9175	1.4836
17-Jun-2001	1	0.018859	325.2232	23.6331	5.9224	1.4834
18-Jun-2001	1	0.01924	313.2003	24.5683	5.9273	1.4832
19-Jun-2001	1	0.019621	302.0574	25.5036	5.9322	1.483
20-Jun-2001	1	0.020002	291.7011	26.4391	5.937	1.4828
21-Jun-2001	1	0.020383	282.0511	27.3746	5.9419	1.4826
22-Jun-2001	1	0.020764	273.0373	28.3103	5.9467	1.4824
23-Jun-2001	1	0.021145	264.5989	29.2461	5.9516	1.4822
24-Jun-2001	1	0.021525	256.6824	30.182	5.9564	1.482
25-Jun-2001	1	0.021906	249.2409	31.1181	5.9613	1.4819
26-Jun-2001	1	0.022287	242.2328	32.0542	5.9661	1.4817
27-Jun-2001	1	0.022668	235.6213	32.9905	5.9709	1.4815
28-Jun-2001	1	0.023049	229.3736	33.9269	5.9757	1.4813
29-Jun-2001	1	0.02343	223.4605	34.8634	5.9806	1.4811
30-Jun-2001	1	0.02381	217.8558	35.8	5.9854	1.4809
01-Jul-2001	1	0.024191	212.5359	36.7368	5.9902	1.4808
02-Jul-2001	1	0.024572	207.4797	37.6736	5.995	1.4806
03-Jul-2001	1	0.024953	202.668	38.6106	5.9998	1.4804
CROSSING OF THE PLANE:						
28-Apr-2001	-1	0.00018968	-315.0617	-22.962	5.6721	1.4939

%**
% 147P/Kushida-Muramatsu: (Run date: May-2005)
%**

Date:	Sign:	Distance [AU]:	SW-speed [km/s]:	Timedelay [days]:	s/c-sun [AU]:	comet-sun [AU]:
01-Apr-2001	1	0.015807	1183.5428	4.059	5.5312	2.7567
02-Apr-2001	1	0.015673	992.3842	4.8502	5.5365	2.7566
03-Apr-2001	1	0.015538	854.7854	5.6418	5.5418	2.7566
04-Apr-2001	1	0.015403	751.0018	6.4338	5.5471	2.7565
05-Apr-2001	1	0.015269	669.9318	7.2262	5.5524	2.7564
06-Apr-2001	1	0.015134	604.8536	8.0189	5.5576	2.7564
07-Apr-2001	1	0.015	551.46	8.8121	5.5629	2.7563
08-Apr-2001	1	0.014865	506.8629	9.6056	5.5682	2.7562
09-Apr-2001	1	0.01473	469.0539	10.3996	5.5734	2.7562
10-Apr-2001	1	0.014596	436.5923	11.1939	5.5787	2.7561
11-Apr-2001	1	0.014461	408.4185	11.9885	5.5839	2.756
12-Apr-2001	1	0.014326	383.7353	12.7836	5.5891	2.756
13-Apr-2001	1	0.014191	361.9319	13.579	5.5944	2.7559
14-Apr-2001	1	0.014056	342.5318	14.3748	5.5996	2.7558
15-Apr-2001	1	0.013922	325.1582	15.171	5.6048	2.7558
16-Apr-2001	1	0.013787	309.5094	15.9676	5.61	2.7557
17-Apr-2001	1	0.013652	295.3405	16.7645	5.6152	2.7557
18-Apr-2001	1	0.013517	282.4509	17.5618	5.6204	2.7556
19-Apr-2001	1	0.013382	270.6749	18.3594	5.6256	2.7555
20-Apr-2001	1	0.013247	259.8739	19.1575	5.6308	2.7555
21-Apr-2001	1	0.013112	249.9318	19.9559	5.636	2.7554
22-Apr-2001	1	0.012977	240.7498	20.7546	5.6412	2.7554
23-Apr-2001	1	0.012842	232.2439	21.5538	5.6463	2.7553
24-Apr-2001	1	0.012707	224.3421	22.3532	5.6515	2.7552
25-Apr-2001	1	0.012572	216.9821	23.1531	5.6567	2.7552
26-Apr-2001	1	0.012437	210.1101	23.9533	5.6618	2.7551
27-Apr-2001	1	0.012302	203.679	24.7539	5.667	2.7551
CROSSING OF THE PLANE:						
26-Jul-2001	1	8.3561e-05	59.2316	98.1293	6.1088	2.7519

%**
% 148P/Anderson-LINEAR: (Run date: May-2005)
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Date:	Sign:	Distance [AU]:	SW-speed [km/s]:	Timedelay [days]:	s/c-sun [AU]:	comet-sun [AU]:
26-Mar-2001	1	0.038253	1044.5874	6.2241	5.4993	1.7443
27-Mar-2001	1	0.038027	913.7024	7.1262	5.5047	1.7441
28-Mar-2001	1	0.0378	812.2092	8.0285	5.51	1.7439
29-Mar-2001	1	0.037574	731.2066	8.931	5.5153	1.7437
30-Mar-2001	1	0.037348	665.0577	9.8338	5.5206	1.7435
31-Mar-2001	1	0.037122	610.0199	10.7367	5.5259	1.7432
01-Apr-2001	1	0.036895	563.5101	11.6398	5.5312	1.743
02-Apr-2001	1	0.036669	523.6887	12.5431	5.5365	1.7428
03-Apr-2001	1	0.036442	489.2095	13.4466	5.5418	1.7426
04-Apr-2001	1	0.036215	459.0648	14.3504	5.5471	1.7424
05-Apr-2001	1	0.035989	432.4857	15.2543	5.5524	1.7421
06-Apr-2001	1	0.035762	408.8745	16.1584	5.5576	1.7419
07-Apr-2001	1	0.035535	387.7604	17.0627	5.5629	1.7417
08-Apr-2001	1	0.035308	368.767	17.9672	5.5682	1.7415

09-Apr-2001	1	0.035081	351.5901	18.8719	5.5734	1.7413
10-Apr-2001	1	0.034854	335.9808	19.7768	5.5787	1.7411
11-Apr-2001	1	0.034627	321.7339	20.6819	5.5839	1.7409
12-Apr-2001	1	0.034399	308.6783	21.5872	5.5891	1.7407
13-Apr-2001	1	0.034172	296.6707	22.4927	5.5944	1.7404
14-Apr-2001	1	0.033945	285.5895	23.3983	5.5996	1.7402
15-Apr-2001	1	0.033717	275.3316	24.3042	5.6048	1.74
16-Apr-2001	1	0.03349	265.8084	25.2102	5.61	1.7398
17-Apr-2001	1	0.033262	256.9436	26.1165	5.6152	1.7396
18-Apr-2001	1	0.033034	248.6713	27.0229	5.6204	1.7394
19-Apr-2001	1	0.032806	240.9339	27.9295	5.6256	1.7392
20-Apr-2001	1	0.032579	233.6811	28.8363	5.6308	1.739
21-Apr-2001	1	0.032351	226.8688	29.7433	5.636	1.7388
22-Apr-2001	1	0.032123	220.4579	30.6505	5.6412	1.7386
23-Apr-2001	1	0.031895	214.414	31.5578	5.6463	1.7384
24-Apr-2001	1	0.031667	208.7064	32.4654	5.6515	1.7382
25-Apr-2001	1	0.031439	203.3078	33.3731	5.6567	1.738
CROSSING OF THE PLANE:						
08-Sep-2001	1	6.3421e-05	50.2452	158.2776	6.3102	1.7172

%**
% C/LINEAR(2002A1): (Run date: May-2005)
%**

Date:	Sign:	Distance [AU]:	SW-speed [km/s]:	Timedelay [days]:	s/c-sun [AU]:	comet-sun [AU]:
04-May-2001	1	0.10056	917.4958	1.4897	5.7029	4.9135
05-May-2001	1	0.09954	658.977	2.0896	5.708	4.9127
06-May-2001	1	0.098521	515.6142	2.6902	5.7131	4.9119
07-May-2001	1	0.097501	424.4747	3.2917	5.7182	4.9112
08-May-2001	1	0.096482	361.4167	3.894	5.7233	4.9104
09-May-2001	1	0.095462	315.1924	4.497	5.7283	4.9097
10-May-2001	1	0.094442	279.8526	5.1009	5.7334	4.909
11-May-2001	1	0.093422	251.9569	5.7056	5.7385	4.9082
12-May-2001	1	0.092402	229.3762	6.3111	5.7435	4.9075
13-May-2001	1	0.091381	210.7226	6.9174	5.7486	4.9067
CROSSING OF THE PLANE:						
10-Aug-2001	1	4.533e-05	36.0707	63.7188	6.1785	4.851

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% C/LINEAR(2002A2): (Run date: May-2005)
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Date:	Sign:	Distance [AU]:	SW-speed [km/s]:	Timedelay [days]:	s/c-sun [AU]:	comet-sun [AU]:
11-May-2001	1	0.096853	1058.1916	1.3515	5.7385	4.9125
12-May-2001	1	0.095836	736.2526	1.9562	5.7435	4.9117
13-May-2001	1	0.094819	566.1617	2.5617	5.7486	4.911
14-May-2001	1	0.093802	460.9833	3.1679	5.7537	4.9102
15-May-2001	1	0.092784	389.51	3.775	5.7587	4.9095
16-May-2001	1	0.091767	337.7758	4.3829	5.7638	4.9087
17-May-2001	1	0.090749	298.5931	4.9915	5.7688	4.908
18-May-2001	1	0.089731	267.8877	5.6009	5.7738	4.9073
19-May-2001	1	0.088712	243.1759	6.2111	5.7789	4.9065
20-May-2001	1	0.087694	222.8576	6.8221	5.7839	4.9058
21-May-2001	1	0.086675	205.8562	7.4339	5.7889	4.9051
CROSSING OF THE PLANE:						
13-Aug-2001	1	0.00068854	37.8436	61.3053	6.1923	4.8524

%**
% 155P/Shoemaker3: (Run date: May-2005)
%**

Date:	Sign:	Distance [AU]:	SW-speed [km/s]:	Timedelay [days]:	s/c-sun [AU]:	comet-sun [AU]:
19-Nov-2002	-1	0.011334	1154.4068	9.0459	7.8836	1.8524
20-Nov-2002	-1	0.011681	1045.1295	9.9965	7.8864	1.8523
21-Nov-2002	-1	0.012029	954.8275	10.9473	7.8892	1.8522
22-Nov-2002	-1	0.012377	878.9532	11.898	7.892	1.8521
23-Nov-2002	-1	0.012724	814.3046	12.8488	7.8948	1.852
24-Nov-2002	-1	0.013072	758.562	13.7996	7.8976	1.8519
25-Nov-2002	-1	0.013419	710.0034	14.7505	7.9004	1.8518
26-Nov-2002	-1	0.013767	667.3242	15.7014	7.9032	1.8517
27-Nov-2002	-1	0.014114	629.5173	16.6524	7.906	1.8516
28-Nov-2002	-1	0.014462	595.7936	17.6034	7.9088	1.8515
29-Nov-2002	-1	0.014809	565.5252	18.5544	7.9116	1.8514
30-Nov-2002	-1	0.015157	538.2071	19.5055	7.9144	1.8513
01-Dec-2002	-1	0.015504	513.4278	20.4566	7.9171	1.8511
02-Dec-2002	-1	0.015852	490.8492	21.4078	7.9199	1.851
03-Dec-2002	-1	0.016199	470.1904	22.359	7.9227	1.8509
04-Dec-2002	-1	0.016547	451.2167	23.3102	7.9255	1.8508
05-Dec-2002	-1	0.016894	433.7298	24.2615	7.9282	1.8507
06-Dec-2002	-1	0.017242	417.5616	25.2128	7.931	1.8506
07-Dec-2002	-1	0.017589	402.5683	26.1642	7.9338	1.8505
08-Dec-2002	-1	0.017936	388.6262	27.1156	7.9365	1.8504
09-Dec-2002	-1	0.018284	375.6287	28.067	7.9393	1.8503
10-Dec-2002	-1	0.018631	363.4828	29.0185	7.942	1.8502
11-Dec-2002	-1	0.018979	352.1074	29.97	7.9448	1.8501

12-Dec-2002	-1	0.019326	341.4314	30.9216	7.9475	1.85	
13-Dec-2002	-1	0.019673	331.3924	31.8732	7.9503	1.8499	
14-Dec-2002	-1	0.020021	321.9348	32.8248	7.953	1.8498	
15-Dec-2002	-1	0.020368	313.0096	33.7765	7.9557	1.8497	
16-Dec-2002	-1	0.020715	304.5731	34.7282	7.9585	1.8496	
17-Dec-2002	-1	0.021063	296.5861	35.6799	7.9612	1.8495	
18-Dec-2002	-1	0.02141	289.0138	36.6317	7.9639	1.8494	
19-Dec-2002	-1	0.021757	281.8244	37.5836	7.9666	1.8493	
20-Dec-2002	-1	0.022104	274.9899	38.5354	7.9694	1.8492	
21-Dec-2002	-1	0.022452	268.4844	39.4873	7.9721	1.8491	
22-Dec-2002	-1	0.022799	262.2848	40.4393	7.9748	1.849	
23-Dec-2002	-1	0.023146	256.37	41.3913	7.9775	1.8489	
24-Dec-2002	-1	0.023493	250.7207	42.3433	7.9802	1.8488	
25-Dec-2002	-1	0.02384	245.3196	43.2953	7.9829	1.8487	
26-Dec-2002	-1	0.024188	240.1505	44.2474	7.9856	1.8486	
27-Dec-2002	-1	0.024535	235.1989	45.1996	7.9883	1.8485	
28-Dec-2002	-1	0.024882	230.4513	46.1517	7.991	1.8484	
29-Dec-2002	-1	0.025229	225.8953	47.104	7.9937	1.8483	
30-Dec-2002	-1	0.025576	221.5196	48.0562	7.9964	1.8482	
31-Dec-2002	-1	0.025923	217.3136	49.0085	7.9991	1.8481	
01-Jan-2003	-1	0.02627	213.2677	49.9608	8.0018	1.848	
02-Jan-2003	-1	0.026618	209.3729	50.9132	8.0044	1.8479	
03-Jan-2003	-1	0.026965	205.6208	51.8656	8.0071	1.8478	
04-Jan-2003	-1	0.027312	202.0038	52.818	8.0098	1.8477	1.8477
CROSSING OF THE PLANE:							
17-Oct-2002	1	0.00013884	-460.5792	-22.3025	7.7888	1.8562	

%**
% C/LINEAR(2002X1): (Run date: May-2005)
%**

Date:	Sign:	Distance [AU]:	SW-speed [km/s]:	Timedelay [days]:	s/c-sun [AU]:	comet-sun [AU]:
14-May-2003	-1	0.092421	1152.2613	8.6183	8.3308	2.5955
15-May-2003	-1	0.09159	1025.7257	9.6849	8.3331	2.5957
16-May-2003	-1	0.090759	924.2989	10.7516	8.3354	2.5959
17-May-2003	-1	0.089928	841.1816	11.8182	8.3376	2.5961
18-May-2003	-1	0.089097	771.8265	12.8848	8.3399	2.5963
19-May-2003	-1	0.088265	713.0768	13.9513	8.3422	2.5965
20-May-2003	-1	0.087434	662.6724	15.0178	8.3444	2.5967
21-May-2003	-1	0.086603	618.9533	16.0843	8.3467	2.5969
22-May-2003	-1	0.085771	580.672	17.1508	8.3489	2.5971
23-May-2003	-1	0.08494	546.8732	18.2173	8.3512	2.5973
24-May-2003	-1	0.084108	516.8133	19.2837	8.3534	2.5975
25-May-2003	-1	0.083277	489.9042	20.3501	8.3557	2.5977
26-May-2003	-1	0.082445	465.6752	21.4164	8.3579	2.598
27-May-2003	-1	0.081614	443.7448	22.4828	8.3601	2.5982
28-May-2003	-1	0.080782	423.8008	23.5491	8.3624	2.5984
29-May-2003	-1	0.079951	405.5849	24.6154	8.3646	2.5986
30-May-2003	-1	0.079119	388.8819	25.6816	8.3668	2.5988
31-May-2003	-1	0.078287	373.5107	26.7479	8.369	2.599
01-Jun-2003	-1	0.077456	359.318	27.8141	8.3713	2.5992
02-Jun-2003	-1	0.076624	346.1735	28.8803	8.3735	2.5994
03-Jun-2003	-1	0.075792	333.9651	29.9464	8.3757	2.5996
04-Jun-2003	-1	0.07496	322.5961	31.0126	8.3779	2.5998
05-Jun-2003	-1	0.074129	311.983	32.0787	8.3801	2.6
06-Jun-2003	-1	0.073297	302.0526	33.1447	8.3823	2.6002
07-Jun-2003	-1	0.072465	292.7412	34.2108	8.3845	2.6004
08-Jun-2003	-1	0.071633	283.9927	35.2768	8.3867	2.6006
09-Jun-2003	-1	0.070801	275.7574	36.3428	8.3889	2.6009
10-Jun-2003	-1	0.069969	267.9915	37.4088	8.3911	2.6011
11-Jun-2003	-1	0.069137	260.656	38.4748	8.3933	2.6013
12-Jun-2003	-1	0.068305	253.716	39.5407	8.3955	2.6015
13-Jun-2003	-1	0.067473	247.1404	40.6066	8.3977	2.6017
14-Jun-2003	-1	0.066641	240.9012	41.6725	8.3999	2.6019
15-Jun-2003	-1	0.065809	234.9732	42.7384	8.4021	2.6021
16-Jun-2003	-1	0.064977	229.3337	43.8042	8.4042	2.6023
17-Jun-2003	-1	0.064145	223.9621	44.87	8.4064	2.6025
18-Jun-2003	-1	0.063313	218.8398	45.9358	8.4086	2.6027
19-Jun-2003	-1	0.062481	213.9498	47.0015	8.4108	2.6029
20-Jun-2003	-1	0.061649	209.2767	48.0673	8.4129	2.6032
21-Jun-2003	-1	0.060816	204.8062	49.133	8.4151	2.6034
22-Jun-2003	-1	0.059984	200.5256	50.1987	8.4172	2.6036
CROSSING OF THE PLANE:						
02-Sep-2003	-1	4.7629e-05	81.1533	126.8676	8.5652	2.6189

%**
% P/Christensen(2003K2): (Run date: May-2005)
%**

Date:	Sign:	Distance [AU]:	SW-speed [km/s]:	Timedelay [days]:	s/c-sun [AU]:	comet-sun [AU]:
25-Apr-2003	-1	0.1553	1161.4587	11.5161	8.2871	0.56214
26-Apr-2003	-1	0.15588	1069.5926	12.5089	8.2894	0.56217
27-Apr-2003	-1	0.15646	991.2362	13.5017	8.2918	0.5622
28-Apr-2003	-1	0.15704	923.6135	14.4946	8.2941	0.56223
29-Apr-2003	-1	0.15762	864.6602	15.4874	8.2964	0.56226

30-Apr-2003	-1	0.1582	812.8096	16.4802	8.2987	0.5623
01-May-2003	-1	0.15879	766.851	17.4731	8.301	0.56233
02-May-2003	-1	0.15937	725.834	18.4659	8.3033	0.56236
03-May-2003	-1	0.15995	689.0022	19.4587	8.3056	0.56239
04-May-2003	-1	0.16053	655.7461	20.4516	8.308	0.56242
05-May-2003	-1	0.16111	625.5691	21.4444	8.3103	0.56246
06-May-2003	-1	0.16169	598.0624	22.4373	8.3126	0.56249
07-May-2003	-1	0.16227	572.8867	23.4302	8.3148	0.56252
08-May-2003	-1	0.16285	549.7575	24.423	8.3171	0.56255
09-May-2003	-1	0.16343	528.4352	25.4159	8.3194	0.56258
10-May-2003	-1	0.16401	508.7159	26.4087	8.3217	0.56262
11-May-2003	-1	0.16459	490.4253	27.4016	8.324	0.56265
12-May-2003	-1	0.16517	473.4136	28.3945	8.3263	0.56268
13-May-2003	-1	0.16575	457.5513	29.3874	8.3286	0.56271
14-May-2003	-1	0.16633	442.7255	30.3802	8.3308	0.56274
15-May-2003	-1	0.16691	428.8379	31.3731	8.3331	0.56278
16-May-2003	-1	0.16749	415.8022	32.366	8.3354	0.56281
17-May-2003	-1	0.16807	403.5422	33.3589	8.3376	0.56284
18-May-2003	-1	0.16865	391.9908	34.3518	8.3399	0.56287
19-May-2003	-1	0.16923	381.0882	35.3447	8.3422	0.56291
20-May-2003	-1	0.16981	370.7812	36.3376	8.3444	0.56294
21-May-2003	-1	0.17039	361.0224	37.3305	8.3467	0.56297
22-May-2003	-1	0.17097	351.769	38.3234	8.3489	0.563
23-May-2003	-1	0.17155	342.9829	39.3163	8.3512	0.56304
24-May-2003	-1	0.17213	334.6295	40.3092	8.3534	0.56307
25-May-2003	-1	0.17271	326.6775	41.3021	8.3557	0.5631
26-May-2003	-1	0.17329	319.0988	42.295	8.3579	0.56313
27-May-2003	-1	0.17387	311.8676	43.288	8.3601	0.56317
28-May-2003	-1	0.17445	304.9605	44.2809	8.3624	0.5632
29-May-2003	-1	0.17502	298.3563	45.2738	8.3646	0.56323
30-May-2003	-1	0.1756	292.0354	46.2667	8.3668	0.56326
31-May-2003	-1	0.17618	285.98	47.2597	8.369	0.5633
01-Jun-2003	-1	0.17676	280.1737	48.2526	8.3713	0.56333
02-Jun-2003	-1	0.17734	274.6014	49.2456	8.3735	0.56336
03-Jun-2003	-1	0.17792	269.2493	50.2385	8.3757	0.56339
04-Jun-2003	-1	0.17849	264.1045	51.2314	8.3779	0.56343
05-Jun-2003	-1	0.17907	259.1552	52.2244	8.3801	0.56346
06-Jun-2003	-1	0.17965	254.3905	53.2173	8.3823	0.56349
07-Jun-2003	-1	0.18023	249.8003	54.2103	8.3845	0.56352
08-Jun-2003	-1	0.18081	245.375	55.2032	8.3867	0.56356
09-Jun-2003	-1	0.18138	241.1061	56.1962	8.3889	0.56359
10-Jun-2003	-1	0.18196	236.9853	57.1892	8.3911	0.56362
11-Jun-2003	-1	0.18254	233.005	58.1821	8.3933	0.56366
12-Jun-2003	-1	0.18312	229.1583	59.1751	8.3955	0.56369
13-Jun-2003	-1	0.18369	225.4384	60.1681	8.3977	0.56372
14-Jun-2003	-1	0.18427	221.8392	61.1611	8.3999	0.56375
15-Jun-2003	-1	0.18485	218.3549	62.154	8.4021	0.56379
16-Jun-2003	-1	0.18543	214.9801	63.147	8.4042	0.56382
17-Jun-2003	-1	0.186	211.7097	64.14	8.4064	0.56385
18-Jun-2003	-1	0.18658	208.5389	65.133	8.4086	0.56389
19-Jun-2003	-1	0.18716	205.4633	66.126	8.4108	0.56392
20-Jun-2003	-1	0.18773	202.4785	67.119	8.4129	0.56395

B Matlab-programs: source code

The code presented is for Rosetta, but the same code has been used for Earth, Ulysses and Cassini only with the change of positional vectors and time span.

B.1 M1

B.1.1 onedayres.m

```
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Method: Reads the data from Rosettas trajectory file with one day resolution
%         and put it into vectors as year, month, day & coordinates.
%         Also creates a datavector (time) which are used later when I want
%         to know the comets positions for comparison with Rosettas positions.
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------

clear
global rosetta data;

fp = fopen(’onedayres.txt’,’r’);   % Open Rosettas trajectory file
format long e
AU = 1.49597870*10^(8);            % [km]

i = 1;
stop = 0;
 while stop == 0
   test = fscanf(fp,’%*3c %2c’,1);

     if isempty(test)           % If end of file
         stop = 1;
     elseif test == ’20’        % If the line begins with 20 it is usable data

         % Read the intigers (year, month, day)
         [A] = fscanf(fp,’%2u %*1c %2u %*1c %2u’,3);
         YYYY(i) = double(2000+A(1));                     % Year
         MM(i) = double(A(2));                            % Month
         DD(i) = double(A(3));                            % Day

         % read the float variables (coordinate vectors)
         [B] = fscanf(fp,’%*46c %f %f %f’,3);
         X(i) = B(1)/AU;
         Y(i) = B(2)/AU;                                  % Equatorial coordinates
         Z(i) = B(3)/AU;

         data(i) = datenum(YYYY(i),MM(i),DD(i));          % Datavector
         fgetl(fp);
         i = i+1;
     end
 end

 fclose(fp);
 save(’data.d’,’data’,’-ascii’)

 number = i-1;

 t = data-data(1);
 N1 = datenum(2008,09,05);   % Fly-by of asteroid Steins
 ind1 = find(N1 == data);

 N2 = datenum(2010,07,10);   % Fly-by of asteroid Lutetia
 ind2 = find(N2 == data);

%-----------------------------------------------------------------------
% Plots Rosettas trajectory in the heliocentric equatorial coordinate
% system and the variation of z-component with time,
% to compare it with the transformation to heliocentric ecliptic
% coordinate system.
% Fly-by of asteroids Steins and Lutetia are also shown.
%-----------------------------------------------------------------------

figure(1)
     plot(X,Z,’r’,Y,Z,’g-.’,0,0,’*’)
     title(’Rosettas trajectory in heliocentric equatorial coordinate system’)
     xlabel(’X,Y (AU)’)
     ylabel(’Z (AU)’)
     legend(’X’,’Y’,0)
     grid on
     axis equal

figure(2)
     plot3(X,Y,Z,’r’,0,0,0,’*’)
     title(’Rosettas trajectory in heliocentric equatorial coordinate system’)
     xlabel(’X (AU)’)
     ylabel(’Y (AU)’)
     zlabel(’Z (AU)’)
     grid on
     axis equal
```

```
figure(3)
     plot(t,Z,'b')
     title('Deviation from the equatorial plane')
     xlabel('t (days after launch)')
     ylabel('Z (AU)')
     text(N1-data(1),Z(ind1),'\leftarrow2008-09-05=fly-by of asteroid Steins')
     text(N2-data(1),Z(ind2),'\leftarrow2010-07-10=fly-by of asteroid Lutetia')
     grid on


clear fp i ind1 ind2 stop t number A B AU N1 N2
```

B.1.2 rostoec.m

```
function rostoec(X,Y,Z,YYYY,MM,DD)
%------------------------------------------------------------------------
%------------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Input:  X    - Rosettas x-coordinate in the equatorial system
%         Y    - Rosettas y-coordinate in the equatorial system
%         Z    - Rosettas z-coordinate in the equatorial system
%         YYYY - Year corresponding to the position
%         MM   - Month corresponding to the position
%         DD   - Day corresponding to the position
%
% Method: Transformation from the heliocentric equatorial coordinate system
%         to the heliocentric ecliptic coordinate system of Rosettas coordinates.
%         Requires you to run onedayres.m before running this program.
%------------------------------------------------------------------------
%------------------------------------------------------------------------

global rosetta data;

% Earths inclination angle (from Physic Handbook)
   v = (23.452294-0.013011*1.05)*pi/180;


% Transformation to ecliptic coordinates
   X_sun = X;                         % [AU]
   Y_sun = cos(v)*Y+sin(v)*Z;         % [AU]
   Z_sun = cos(v)*Z-sin(v)*Y;         % [AU]

%------------------------------------------------------------------------
% Rosettas positional components in the ecliptic coord. syst.
%------------------------------------------------------------------------
   rosetta = [X_sun; Y_sun; Z_sun];
   save('rosetta.d','rosetta','-ascii');

%------------------------------------------------------------------------
% Rosettas inclination angle (degrees) from the ecliptic plane
%------------------------------------------------------------------------
   angle = atan(Z_sun./sqrt(X_sun.^2+Y_sun.^2))*180/pi;


             t = data-data(1);
             N1 = datenum(2008,09,05);   % Fly-by of asteroid Steins
             ind1 = find(N1 == data);

             N2 = datenum(2010,07,10);   % Fly-by of asteroid Lutetia
             ind2 = find(N2 == data);

%------------------------------------------------------------------------
% Plots Rosettas trajectory in the heliocentric ecliptic coordinate system,
% the variation of z-component with time and Rosettas inclination angle
% from the ecliptic with time.
% Fly-by of asteroids Steins and Lutetia also shown.
%------------------------------------------------------------------------

figure(1)
     plot(X_sun,Z_sun,'r',Y_sun,Z_sun,'g-.',0,0,'*')
```

```
     axis equal
     xlabel('X,Y (AU)')
     ylabel('Z (AU)')
     title('Rosettas trajectory in the heliocentric ecliptic coordinate system')
     legend('X','Y',0)
     grid on

figure(2)
     plot3(X_sun, Y_sun, Z_sun, 'r' ,0,0,0, '*')
     grid on
     axis equal
     xlabel('X (AU)')
     ylabel('Y (AU)')
     zlabel('Z (AU)')
     title('Rosettas trajectory in heliocentric ecliptic coordinate system')
     grid on

figure(3)
     plot(t,Z_sun,'b')
     xlabel('t (days after launch)')
     ylabel('Z (AU)')
     text(N1-data(1),Z_sun(ind1),'\leftarrow2008-09-05=fly-by of asteroid Steins')
     text(N2-data(1),Z_sun(ind2),'\leftarrow2010-07-10=fly-by of asteroid Lutetia')
     grid on

figure(4)
     plot(t,angle,'b')
     xlabel('t (days after launch)')
     ylabel('s/c inclination from ecliptic (degrees)')
     text(N1-data(1),angle(ind1),'\leftarrow2008-09-05=fly-by of asteroid Steins')
     text(N2-data(1),angle(ind2),'\leftarrow2010-07-10=fly-by of asteroid Lutetia')
     grid on


clear t ind1 ind2 N1 N2;
```

B.1.3 readcomet.m

```
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Method: Read from the comets orbitalfile and put it into vectors as
%         mean distance (a), eccentricity (e), inclination of orbit (inc),
%         longitude of ascending node (W), argument of perihelion (w),
%         time of perihelion passage (Tper) in year, month, day
%         and orbital period (P).
%         Saves the variables in a separate file for each comet.
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------

global M E e a Tper w W inc X_ecl Y_ecl Z_ecl t_int start;
format long e

fp = fopen('comets.txt','r');    % Opens the file with comet data

      for i = 1:2
        fgetl(fp);
      end

%-----------------------------------------------------------------------
% Number of comets in comets.txt (downloaded from
% http://ssd.jpl.nasa.gov/et_form.html)
% is 381, i.e. all the comets which has the possibility to produce
% ion tails that ends up at Rosettas location
%-----------------------------------------------------------------------
j = 1;
while j <= 381
      [A] = fscanf(fp,'%*59c %f %*f %f %f %f %f %4u %2u %f %f',9);
      fil = sprintf('fil%0d.d',j);
      a(j) = A(1);    % Mean distance [AU]
      e(j) = A(2);    % Eccentricity [rad]
```

```
      inc(j) = A(3);  % Inclination  [deg]
      W(j) = A(4);    % Longitude of ascending node [deg]
      w(j) = A(5);    % Argument of perihelion [deg]

      YYYY_com(j) = A(6);
      MM_com(j) = A(7);
      DD_com(j) = A(8);

      P(j) = A(9);    % Orbital period [years]

      % Time of perihelion passage [days after year 0]
      Tper(j) = datenum(YYYY_com(j),MM_com(j),DD_com(j));

   str = [a; e; inc; W; w; Tper; P];
   save(fil,'str','-ascii');

      j = j+1;
end

 fclose(fp);
```

B.1.4 runrosetta.m

```
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Method: The main program for Rosetta.
%         Runs through one comet at a time to evaluate possible
%         ion tail crossings at different solar wind speeds.
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------

load rosetta.d
load data.d
load('-mat','name.d')

% Launch date, 2004-03-02, starts the iterations
 Tstart = data(1);

% Iterations end in 2014-05-22
 Tend = data(3734);

% Integration time
 t_int = Tend-Tstart+1;          % [days]



 j = input('Comet number: ');

% Open the file for comet j
 file = ['/home/sosp/thesis/Documents/exjobb/method1/Rosetta/comets/fil' num2str(j)];
 filed = [file '.d'];
 load(filed)
     filen = ['fil' num2str(j)];
     value = eval(filen);
     a = value(1);
     e = value(2);
     inc = value(3);
     W = value(4);
     w = value(5);
     Tper = value(6);
     P = value(7);


ques = input('Time resolution? 0-no, 1-yes ');
n = 0;
while n == 0
```

```

meananomaly
eccanomaly
comtoec
iontails

 clear(['fil' num2str(j)])

 j = j+1;

 file = ['comets/fil' num2str(j)];
 filed = [file '.d'];
 load(filed)
     filen = ['fil' num2str(j)];
     value = eval(filen);
     a = value(1);
     e = value(2);
     inc = value(3);
     W = value(4);
     w = value(5);
     Tper = value(6);
     P = value(7);
end


```

B.1.5 meananomaly.m

```
%---------------------------------------------------------------------
%---------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Method: Calculates the mean anomaly, M, of the comet
%         during Rosettas journey.
%---------------------------------------------------------------------
%---------------------------------------------------------------------

G = 6.67259*10^(-11);          % The gravitational constant [Nm^2/kg^2]
M_sun = 1.989*10^(30);         % Mass of the Sun [kg]

%---------------------------------------------------------------------
% Iteration start time, i.e. Rosettas launch date
%---------------------------------------------------------------------
Tnu = Tstart;

for k = 1:t_int
       t(k) = Tnu-Tper;              % In mean solar days
       M(k) = 2*pi*t(k)/(P*365.25);  % Mean anomaly [rad]


 %---------------------------------------------------------------------
 % If M results in a negative value, an addition of multiple 2*pi
 % are needed to get M between zero and 2*pi
 %---------------------------------------------------------------------
       while sign(M(k)) == -1
         M(k) = M(k)+2*pi;
       end

 %---------------------------------------------------------------------
 % If M results is larger than 2*pi, an subtraction of multiple 2*pi
 % are needed to retrieve the right angle between zero and 2*pi
 %---------------------------------------------------------------------
       while M(k) >= 2*pi
         M(k) = M(k)-2*pi;
       end

 %---------------------------------------------------------------------
 % Add one day until end of iteration, i.e. the end of Rosettas journey
 %---------------------------------------------------------------------
       Tnu = Tnu+1;
end

```

B.1.6 eccanomaly.m

```
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
%
% Method: Calculates the eccentric anomaly, E, of the comet
%         during Rosettas journey, from Keplers equation using
%         Newton Raphson iteration improved by Halleys third order method.
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------

 for k = 1:t_int
    if M(k) == 0
      E(k) = 0;

    else
      E_start(k) = M(k);
      f(k) = E_start(k)-e*sin(E_start(k))-M(k);
      fprim(k) = 1-e*cos(E_start(k));
      fbis(k) = e*sin(E_start(k));
      E(k) = E_start(k)-(f(k)/fprim(k))-(f(k)*fbis(k)/(2*fprim(k)));

    %-----------------------------------------------------------------------
    % improvement of E until it the error is small enough
    %-----------------------------------------------------------------------
        while abs(E(k)-E_start(k)) > 10^(-4)
           E_start(k) = E(k);
           f(k) = E_start(k)-e*sin(E_start(k))-M(k);
           fprim(k) = 1-e*cos(E_start(k));
           fbis(k) = e*sin(E_start(k));
           E(k) = E_start(k)-(f(k)/fprim(k))-(f(k)*fbis(k)/(2*fprim(k)));
        end
    end
 end


clear E_start;
```

B.1.7 comtoec.m

```
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Method: Calculates the cometary orbits in the heliocentric
%         ecliptic coordinate system through transformation
%         of the coordinates from the comets plane-of-orbit.
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------

AU=1.49597870*10^(11);         % [m]

%-----------------------------------------------------------------------
% The cometary coordinates in plane-of-orbit [AU]
%-----------------------------------------------------------------------
```

```
    X_com=a*(cos(E)-e);
    Y_com=a*sqrt(1-e^2)*sin(E);

%----------------------------------------------------------------------
% Gauss vector transformation
%----------------------------------------------------------------------
    Cw=cos(w*pi/180);
    CW=cos(W*pi/180);
    Sw=sin(w*pi/180);
    SW=sin(W*pi/180);
    Ci=cos(inc*pi/180);
    Si=sin(inc*pi/180);

    PX=Cw.*CW-Sw.*SW.*Ci;
    PY=Cw.*SW+Sw.*CW.*Ci;
    PZ=Sw.*Si;

    QX=-Sw.*CW-Cw.*SW.*Ci;
    QY=-Sw.*SW+Cw.*CW.*Ci;
    QZ=Cw.*Si;

%----------------------------------------------------------------------
% Coordinates in the heliocentric ecliptic system [AU]
%----------------------------------------------------------------------
    X_ecl=X_com.*PX+Y_com.*QX;
    Y_ecl=X_com.*PY+Y_com.*QY;
    Z_ecl=X_com.*PZ+Y_com.*QZ;


clear X_com Y_com Cw CW Sw SW Ci Si PX PY PZ QX QY QZ f r_com r_ecl;
```

B.1.8 iontails.m

```
%----------------------------------------------------------------------
%----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Method: Calculates the ion tails from the comet and the distances
%         from Rosetta.
%----------------------------------------------------------------------
%----------------------------------------------------------------------

AU = 1.49597870*10^(11);       % [m]

%----------------------------------------------------------------------
% Produces matrices that will be filled up with new values later
%----------------------------------------------------------------------
   time = zeros(1,t_int);
   iontail = zeros(3,t_int);
   dist = 50*ones(3,t_int);
   distance = 50*ones(1,t_int);

%----------------------------------------------------------------------
% Solar wind speed [m/s]
%----------------------------------------------------------------------
   sw = 1000*[200 225 250 275 300 350 400 450 500 600 700 800];

%----------------------------------------------------------------------
% Maximum value of Rosettas z-coordinate
%----------------------------------------------------------------------
   mx = max(rosetta(3,:));

%----------------------------------------------------------------------
% Minimum value of Rosettas z-coordinate
%----------------------------------------------------------------------
   mn = min(rosetta(3,:));

%----------------------------------------------------------------------
% Transformation to spherical coordinates for the comet and Rosetta position
%----------------------------------------------------------------------
[theta_com,phi_com,radcomet] = cart2sph(X_ecl,Y_ecl,Z_ecl);
[theta_ros,phi_ros,radrosetta] = cart2sph(rosetta(1,:),rosetta(2,:),rosetta(3,:));
```

```

%---------------------------------------------------------------------
% Iteration over the different values of the solar wind speed
%---------------------------------------------------------------------
for g = 1:12
   v_sw = sw(g);

%---------------------------------------------------------------------
% Time [days] it takes for the iontail to travel out to 6 AU,
% i.e. outside Rosettas location at all times
%---------------------------------------------------------------------
   t_travel = ceil(6*AU/(v_sw*86400));

%---------------------------------------------------------------------
% Iteration over time
%---------------------------------------------------------------------
   for k = 1:t_int

   %------------------------------------------------------------------
   % Rosetta outside the cometary orbit and within the same region
   % in space are necessary conditions for the comet to be able to
   % produce ion tails that ends up at Rosettas location
   %------------------------------------------------------------------
     if (radrosetta(k)>radcomet(k) & ...
       (abs(theta_ros(k)-theta_com(k))<(pi/2) | (abs(theta_ros(k)-theta_com(k))>(3*pi/2))))

       avst = 50*ones(1,t_int);

       %---------------------------------------------------------------------
       % p returns the time when the iontail were created
       % and k represent the time of this iteration when it has reached 6 AU
       %---------------------------------------------------------------------
       p = k-t_travel;

       %---------------------------------------------------------------------
       % If it is less then zero, p starts at the beginning of our time-interval
       %---------------------------------------------------------------------
       if p <= 0
        p = 1;
       end


       for i = p:k
         %---------------------------------------------------------------------
         % How the whole iontail looks at different locations, in x,y,z-coord., at time k
         %---------------------------------------------------------------------
         iontail(1,i) = X_ecl(i)+(v_sw*(k-i)*86400/AU)*cos(phi_com(i))*cos(theta_com(i));
         iontail(2,i) = Y_ecl(i)+(v_sw*(k-i)*86400/AU)*cos(phi_com(i))*sin(theta_com(i));
         iontail(3,i) = Z_ecl(i)+(v_sw*(k-i)*86400/AU)*sin(phi_com(i));

         %---------------------------------------------------------------------
         % The distance between each point on the ion tail and Rosetta, in x,y,z-coord
         %---------------------------------------------------------------------
         dist(1,i) = rosetta(1,k)-iontail(1,i);
         dist(2,i) = rosetta(2,k)-iontail(2,i);
         dist(3,i) = rosetta(3,k)-iontail(3,i);

         %---------------------------------------------------------------------
         % The radial distance between ion tail and Rosetta
         %---------------------------------------------------------------------
         avst(i)=sqrt(dist(1,i)^2+dist(2,i)^2+dist(3,i)^2);
       end

     %---------------------------------------------------------------------
     % Time of the current iteration
     %---------------------------------------------------------------------
     time(k) = data(1)+k-1;

     %------------------------------------------------------------------
     % The closest distance between the whole ion tail and Rosetta
     %------------------------------------------------------------------
     distance(k) = min(avst);

     clear avst
     end
   end

  %---------------------------------------------------------------------
  % Evaluate if there will be more than one close approach with the
  % ion tails produced by the comet during Rosettas journey
  %---------------------------------------------------------------------
  step = round(length(data)/300);
  for test = 1:300:step*300
```

```

   %----------------------------------------------------------------------
   % The smallest distance to all tails from comet j over the whole journey
   % divided in 'step' iterations
   %----------------------------------------------------------------------
   minidistance = min(distance(test:(test+300)));

   %-------------------------------------------------------------------
   % If the distance turn out to be less than 0.5 AU, it is considered
   % as an encounter
   %-------------------------------------------------------------------
   if minidistance < 0.5
     % Time of encounter
     t_hit = find(distance == min(distance(test:(test+300))));

     clear iontail avst

     p = t_hit-t_travel;
     if p <= 0
      p = 1;
     end

    %----------------------------------------------------------------------
    % Reproduces the ion tail for the encounter to see when it was produced
    % (since the iteration has got erased)
    %----------------------------------------------------------------------
    iontail = zeros(3,t_int);
    avst = 50*ones(1,t_int);
    s = 0;

    for i = p:t_hit

         iontail(1,i) = X_ecl(i)+(v_sw*(t_hit-i)*86400/AU)*cos(phi_com(i))*cos(theta_com(i));
         iontail(2,i) = Y_ecl(i)+(v_sw*(t_hit-i)*86400/AU)*cos(phi_com(i))*sin(theta_com(i));
         iontail(3,i) = Z_ecl(i)+(v_sw*(t_hit-i)*86400/AU)*sin(phi_com(i));

         dist(1,i) = rosetta(1,t_hit)-iontail(1,i);
         dist(2,i) = rosetta(2,t_hit)-iontail(2,i);
         dist(3,i) = rosetta(3,t_hit)-iontail(3,i);

         avst(i) = sqrt(dist(1,i)^2+dist(2,i)^2+dist(3,i)^2);

         % s returns the lenght of the number of iterations
         s = s+1;
     end

     t_prod = find(avst == min(avst));

     %----------------------------------------------------------------------
     % Time it takes for the tail from production until it encounter Rosetta
     %----------------------------------------------------------------------
     delay = t_hit-t_prod;

             day = datevec(time(t_hit));
             str1 = char(name(j));
             str2 = num2str(day(1));
             str3 = num2str(day(2));
             str4 = num2str(day(3));
             str5 = num2str(day(4));
             str6 = num2str(round(day(5)));
             str7 = num2str(minidistance);
             str8 = num2str(v_sw/1000);
                 str9 = num2str(delay);
             nu = date;

        str = [str1 ': ' str2 '-' str3 '-' str4 ' ' str5 ':' str6 ' distance: ' str7 'AU'];
        strny = [' SW-speed: ' str8 'km/s' ' Timedelay: ' str9 ' days'];

       % Prints out on screen
       [str1 ': ' str2 '-' str3 '-' str4 ' ' str5 ':' str6...
         ' distance: ' str7 'AU' ' SW-speed: ' str8 'km/s' ' Timedelay: ' str9 ' days']

%----------------------------------------------------------------------
% From runrosetta.m - timeresolution or not
%----------------------------------------------------------------------
if ques == 1
    timeres
elseif ques == 0
     if g == 7
        %---------------------------------------------------------------
        % Plot of the result
        %---------------------------------------------------------------
        hit(rosetta(1,t_hit),rosetta(2,t_hit),rosetta(3,t_hit),...
```

```
          86400,t_hit,t_prod,t_travel,X_ecl,Y_ecl,Z_ecl,v_sw,sw,...
          phi_com,theta_com,time,t_int,name(j),minidistance,str,strny)
          break
       end

       %------------------------------------------------------------------
       % Saves the encounters in files depending on what year it happens
       %------------------------------------------------------------------
      spara = [nu ' ' str ' ' strny];
      if day(1) == 2004
          fid = fopen('hits/2004.txt','a');
          fprintf(fid,'%s\n',spara);
          fclose(fid);

      elseif day(1) == 2005
          fid = fopen('hits/2005.txt','a');
          fprintf(fid,'%s\n',spara);
          fclose(fid);

          elseif day(1) == 2006
          fid = fopen('hits/2006.txt','a');
          fprintf(fid,'%s\n',spara);
          fclose(fid);

          elseif day(1) == 2007
          fid = fopen('hits/2007.txt','a');
          fprintf(fid,'%s\n',spara);
          fclose(fid);

          elseif day(1) == 2008
          fid = fopen('hits/2008.txt','a');
          fprintf(fid,'%s\n',spara);
          fclose(fid);

          elseif day(1) == 2009
          fid = fopen('hits/2009.txt','a');
          fprintf(fid,'%s\n',spara);
          fclose(fid);

          elseif day(1) == 2010
          fid = fopen('hits/2010.txt','a');
          fprintf(fid,'%s\n',spara);
          fclose(fid);

          elseif day(1) == 2011
          fid = fopen('hits/2011.txt','a');
          fprintf(fid,'%s\n',spara);
          fclose(fid);

      elseif day(1) == 2012
          fid = fopen('hits/2012.txt','a');
          fprintf(fid,'%s\n',spara);
          fclose(fid);

      else
          fid=fopen('hits/2013.txt','a');
          fprintf(fid,'%s\n',spara);
          fclose(fid);
      end

      end
     end    % Terminates for test = 1:300:step*300
  end    % Terminates if minidistance < 0.5
 end   % Terminates for g = 1:12

 j

   clear DD E M MM W w X Y YYYY Z a e f inc q;

```

B.1.9 hit.m

```
function hit(xros, yros, zros,sec,t_hit,t_prod,t_travel,X_ecl,Y_ecl,Z_ecl,v_sw,sw,...
             phi_com,theta_com,time,t_int,name,minidistance,str,strny)
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Method: Plot of ion tail encounter
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
clear avst iontail
AU = 1.49597870*10^(11);       % [m]

 v_hit = v_sw;

for g = 1:12
      v_sw = sw(g);
      t_travel = ceil(6*AU/(v_sw*sec));
      p = t_hit-t_travel;

    if p <= 0
      p = 1;
    end

    %-----------------------------------------------------------------------
    % produce the iontail for the encounter to see when it was produced,
    % since the iteration has got erased
    %-----------------------------------------------------------------------
    avst = 50*ones(1,t_int);
    for i = p:t_hit
         iontail(1,i) = X_ecl(i)+(v_sw*(t_hit-i)*sec/AU)*cos(phi_com(i))*cos(theta_com(i));
         iontail(2,i) = Y_ecl(i)+(v_sw*(t_hit-i)*sec/AU)*cos(phi_com(i))*sin(theta_com(i));
         iontail(3,i) = Z_ecl(i)+(v_sw*(t_hit-i)*sec/AU)*sin(phi_com(i));
     end


   if v_sw == v_hit
        % XY projection
        subplot(2,2,1)
        plot(X_ecl(p:t_hit),Y_ecl(p:t_hit),'g-.',iontail(1,p:t_hit),iontail(2,p:t_hit),'b',...
             xros,yros,'rs',0,0,'k*')
        xlabel('X (AU)')
        ylabel('Y (AU)')
        grid on
        axis equal
        hold on

        % XZ projection
        subplot(2,2,2)
        plot(X_ecl(p:t_hit),Z_ecl(p:t_hit),'g-.',iontail(1,p:t_hit),iontail(3,p:t_hit),'b',...
             xros,zros,'rs',0,0,'k*')
        xlabel('X (AU)')
        ylabel('Z (AU)')
        grid on
        axis equal
        hold on

        % YZ projection
        subplot(2,2,3)
        plot(Y_ecl(p:t_hit),Z_ecl(p:t_hit),'g-.',iontail(2,p:t_hit),iontail(3,p:t_hit),'b',...
             yros,zros,'rs',0,0,'k*')
        xlabel('Y (AU)')
        ylabel('Z (AU)')
        grid on
        axis equal
        hold on

        subplot(2,2,4)
        plot(Y_ecl(1), Z_ecl(1), 'g', iontail(1), iontail(1), 'b',...
           yros, zros, 'r', 0, 0, 'k*')
        legend('Comet','Ion tail','Rosetta','Sun',0)
        axis off

   else
        % XY projection
        subplot(2,2,1)
        plot(X_ecl(p:t_hit),Y_ecl(p:t_hit),'g-.',iontail(1,p:t_hit),iontail(2,p:t_hit),'y',...
             xros,yros,'rs',0,0,'k*')
        xlabel('X (AU)')
        ylabel('Y (AU)')
        grid on
        axis equal
        hold on
```

```

        % XZ projection
        subplot(2,2,2)
        plot(X_ecl(p:t_hit),Z_ecl(p:t_hit),'g-.',iontail(1,p:t_hit),iontail(3,p:t_hit),'y',...
             xros,zros,'rs',0,0,'k*')
        xlabel('X (AU)')
        ylabel('Z (AU)')
        grid on
        axis equal
        hold on

        % YZ projection
        subplot(2,2,3)
        plot(Y_ecl(p:t_hit),Z_ecl(p:t_hit),'g-.',iontail(2,p:t_hit),iontail(3,p:t_hit),'y',...
             yros,zros,'rs',0,0,'k*')
        xlabel('Y (AU)')
        ylabel('Z (AU)')
        grid on
        axis equal
        hold on

    end
end

hold off

```

B.1.10 timeres.m

```
%----------------------------------------------------------------------
%----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Method: Calculates the iontails of comets and the distances from Rosetta
%         with half an hour resolution.
%----------------------------------------------------------------------
%----------------------------------------------------------------------

clear Tstart M E
clear dist minidistance p t_travel

        t_old=time(t_hit);
        sec = 1800;

        t_resol = time(t_hit-1):(sec/86400):time(t_hit+1);
        t_it = length(t_resol);
        Tstart = time(t_prod-1);

        d=delay*(86400/sec);


        td = time((t_hit-1):(t_hit+1));
        rosx = rosetta(1,(t_hit-1):(t_hit+1));
        rosy = rosetta(2,(t_hit-1):(t_hit+1));
        rosz = rosetta(3,(t_hit-1):(t_hit+1));

%----------------------------------------------------------------------
% Interpolate the coordinates for Rosetta during the interval with
% gap of data, t_hit-1 to t_hit+1
%----------------------------------------------------------------------
        xr = interp1(td,rosx,t_resol);
        yr = interp1(td,rosy,t_resol);
        zr = interp1(td,rosz,t_resol);

        clear iontail time

%----------------------------------------------------------------------
% Interpolate the coordinates for the comet over the interval with
% gap of data, t_prod-1 to t_prod+1
%----------------------------------------------------------------------
 meananres;
 eccanres;
```

```
 comtoecres;

% Transformation to spherical coordinates for the comet
 [th_com_res,phi_com_res,radcom_res] = cart2sph(X_ecl_res,Y_ecl_res,Z_ecl_res);

%-----------------------------------------------------------------------
% Iteration over the timeinterval with gap of data for the new resolution
%-----------------------------------------------------------------------
for k = 1:t_it
   avst = 50*ones(1,t_it);

  for i = 1:t_it
     if i >= k
       n = k;
     else
       n = i;
     end

       % Calculated in astronomical units
         iontail(1,i) = X_ecl_res(n)+(v_sw*(d+k-i)*sec/AU)*cos(phi_com_res(n))*cos(th_com_res(n));
         iontail(2,i) = Y_ecl_res(n)+(v_sw*(d+k-i)*sec/AU)*cos(phi_com_res(n))*sin(th_com_res(n));
         iontail(3,i) = Z_ecl_res(n)+(v_sw*(d+k-i)*sec/AU)*sin(phi_com_res(n));

         dist(1,i) = xr(k)-iontail(1,i);
         dist(2,i) = yr(k)-iontail(2,i);
         dist(3,i) = zr(k)-iontail(3,i);

         avst(i) = sqrt(dist(1,i)^2+dist(2,i)^2+dist(3,i)^2);
  end

     % Time of the current iteration in days
     time(k) = t_resol(1)+(k-1)*sec/86400;

     % The closest distance from the whole iontail
     dist_res(k) = min(avst);
end


   t_hit = find(dist_res == min(dist_res));
   minsta = min(dist_res);

    % Produce the iontail for the encounter to see when it was produced,
    % since the iteration has got erased
    iontail = zeros(3,t_it);
    dist = 50*ones(1,t_it);
    avst = 50*ones(1,t_it);

for i = 1:t_it

  if i >= t_hit
    n = t_hit;
  else
    n = i;
  end

         iontail(1,i)=X_ecl_res(n)+(v_sw*(d+t_hit-i)*sec/AU)*cos(phi_com_res(n))*cos(th_com_res(n));
         iontail(2,i)=Y_ecl_res(n)+(v_sw*(d+t_hit-i)*sec/AU)*cos(phi_com_res(n))*sin(th_com_res(n));
         iontail(3,i)=Z_ecl_res(n)+(v_sw*(d+t_hit-i)*sec/AU)*sin(phi_com_res(n));

         dist(1,i)=xr(t_hit)-iontail(1,i);
         dist(2,i)=yr(t_hit)-iontail(2,i);
         dist(3,i)=zr(t_hit)-iontail(3,i);

         avst(i)=sqrt(dist(1,i)^2+dist(2,i)^2+dist(3,i)^2);
end

     t_prod=find(avst==min(avst));


   % New delay time
   if t_old<time(t_hit)
      delay=(d+t_hit-t_prod)*sec/86400;
   elseif t_old>time(t_hit)
      delay=(d-(t_hit-t_prod))*sec/86400;
   else
      delay=delay;
   end
   format long

             day=datevec(time(t_hit));
             str1=char(name(j));
             str2=num2str(day(1));
             str3=num2str(day(2));
```

```
            str4=num2str(day(3));
            str5=num2str(day(4));
            str6=num2str(round(day(5)));
            str7=num2str(minsta);
            str8=num2str(v_sw/1000);
                str9=num2str(delay);
            nu = date;


         str=[str1 ': ' str2 '-' str3 '-' str4 ' ' str5 ':' str6 ' distance: ' str7 'AU'];
         strny=[' SW-speed: ' str8 'km/s' ' Timedelay: ' str9 ' days'];

            [str1 ': ' str2 '-' str3 '-' str4 ' ' str5 ':' str6...
                  ' distance: ' str7 'AU' ' SW-speed: ' str8 'km/s' ' Timedelay: ' str9 ' days']

    %-----------------------------------------------------------------
    % Saves the encounters in files depending on what year it happens
    %-----------------------------------------------------------------
       spara = [nu ' ' str ' ' strny];
       if day(1) == 2004
       fid = fopen('hits/2004.txt','a');
       fprintf(fid,'%s\n',spara);
       fclose(fid);

       elseif day(1) == 2005
       fid = fopen('hits/2005.txt','a');
       fprintf(fid,'%s\n',spara);
       fclose(fid);

       elseif day(1) == 2006
       fid = fopen('hits/2006.txt','a');
       fprintf(fid,'%s\n',spara);
       fclose(fid);

       elseif day(1) == 2007
       fid = fopen('hits/2007.txt','a');
       fprintf(fid,'%s\n',spara);
       fclose(fid);

       elseif day(1) == 2008
       fid = fopen('hits/2008.txt','a');
       fprintf(fid,'%s\n',spara);
       fclose(fid);

       elseif day(1) == 2009
       fid = fopen('hits/2009.txt','a');
       fprintf(fid,'%s\n',spara);
       fclose(fid);

       elseif day(1) == 2010
       fid = fopen('hits/2010.txt','a');
       fprintf(fid,'%s\n',spara);
       fclose(fid);

       elseif day(1) == 2011
       fid = fopen('hits/2011.txt','a');
       fprintf(fid,'%s\n',spara);
       fclose(fid);

   elseif day(1) == 2012
       fid = fopen('hits/2012.txt','a');
       fprintf(fid,'%s\n',spara);
       fclose(fid);

   else
       fid=fopen('hits/2013.txt','a');
       fprintf(fid,'%s\n',spara);
       fclose(fid);
   end


```

B.1.11 tempel.m

```
%----------------------------------------------------------------------
%----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Method: Validation of the event when Rosetta closes in to comet
%         9P/Tempel1
%----------------------------------------------------------------------
%----------------------------------------------------------------------

load rosetta.d
load earth.d
load data.d
load data_e.d
load('-mat','name.d')

% Launch date, 2004-03-02, starts the iterations
 Tstart = data(1);

% Iterations end in 2014-05-22
 Tend = data(3734);

% Integration time
 t_int = Tend-Tstart+1;          % [days]

%----------------------------------------------------------------------
% Open the file for comet 9P/Tempel
%----------------------------------------------------------------------
 j = 7;
 file = ['/home/sosp/thesis/Documents/exjobb/method1/Rosetta/comets/fil' num2str(j)];
 filed = [file '.d'];
 load(filed)
     filen = ['fil' num2str(j)];
     value = eval(filen);
     a = value(1);
     e = value(2);
     inc = value(3);
     W = value(4);
     w = value(5);
     Tper = value(6);
     P = value(7);


meananomaly
eccanomaly
comtoec

   t_close = datenum(2005,07,04);
   t_ros = find(data == t_close);
   t_earth = find(data_e == t_close);

     plot(X_ecl((t_ros-20):(t_ros+20)), Y_ecl((t_ros-20):(t_ros+20)), 'g', ...
          X_ecl(t_ros), Y_ecl(t_ros), 'k*',...
          rosetta(1,(t_ros-20):(t_ros+20)), rosetta(2,(t_ros-20):(t_ros+20)), 'r', ...
         rosetta(1,(t_ros)), rosetta(2,(t_ros)), 'k*', ...
         earth(1,(t_earth-20):(t_earth+20)), earth(2,(t_earth-20):(t_earth+20)), 'b', ...
         earth(1,(t_earth)), earth(2,(t_earth)), 'k*', 0, 0, 'y*')

         text(X_ecl(t_ros), Y_ecl(t_ros), '  9P/Tempel1')
         text(rosetta(1,t_ros), rosetta(2,t_ros), '  Rosetta')
         text(earth(1,t_earth), earth(2,t_earth), '  Earth')
         text(0, 0, '  Sun')

         grid on
         axis([-0.8 0.4 -1.6 0.2])


        x_com = num2str(X_ecl(t_ros));
        y_com = num2str(Y_ecl(t_ros));

        x_ros = num2str(rosetta(1,t_ros));
        y_ros = num2str(rosetta(2,t_ros));

        x_e = num2str(earth(1,t_earth));
        y_e = num2str(earth(2,t_earth));

        spara = [x_com ' ' y_com ' ' x_ros ' ' y_ros ' ' x_e ' ' y_e];
        fid = fopen('tempel.txt','a');
        fprintf(fid,'%s\n',spara);
        fclose(fid);


```

B.2 M2

B.2.1 main.m

```
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Method: The main program for Rosetta.
%         Runs through one comet at a time to evaluate possible
%         ion tail crossings analytically.
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------

load rosetta.d
load data.d
load('-mat','name.d')
format long e

% Launch date, 2004-03-02, starts the iterations
 Tstart = data(1);

% Iterations end in 2014-05-22
 Tend = data(length(data));

% Integration time
 t_int = Tend-Tstart+1;          % [days]

 j = input('Comet number: ');

% Open the file for comet j
 file = ['/home/sosp/thesis/Documents/exjobb/method2/ros/newcomets/fil' num2str(j)];
 filed = [file '.d'];
 load(filed)
     filen = ['fil' num2str(j)];
     value = eval(filen);
     a = value(1);     % Mean distance [AU]
     e = value(2);     % Eccentricity [rad]
     inc = value(3);   % Inclination [deg]
     W = value(4);     % Longitude of ascending node [deg]
     w = value(5);     % Argument of perihelion [deg]
     Tper = value(6);  % Time of perihelion passage [days after year 0]
     P = value(7);     % Orbital period [years]

  n = 0;
  while n == 0

%-----------------------------------------------------------------------
% Transformation of Rosettas heliocentric ecliptic coordinates
% to the comets heliocentric reference system.
%-----------------------------------------------------------------------
   [xsc,ysc,zsc] = coordtransf(rosetta(1,:), rosetta(2,:), rosetta(3,:), ...
                   (W*pi/180), (w*pi/180), (inc*pi/180));

   if n == 1
     % Put n == 1 to see a plot of Rosettas trajectory in the comet coordinate system
     [x_com,y_com] = orbcom(Tstart, t_int, Tper, P, e, a);
     plottraj
     break
   end

%-----------------------------------------------------------------------
% Since Rosetta can cross the orbital plane of the comet several times,
% each one of these occations are of interest.
%-----------------------------------------------------------------------

   cross = [];

   m = 1;
   for jj = 1:(t_int-1)
      if sign(zsc(jj)) ~= sign(zsc(jj+1))
         cross(m) = jj;
         m = m+1;
```

```
      end
   end

%-----------------------------------------------------------------------
% The smallest value of Rosettas z-coordinate at each occation is
% desired which is not equal to zero due to that coordinates are
% given in an interval of 24 hours.
%-----------------------------------------------------------------------

   aa = 1;

   for u = 1:length(cross)
        int = zsc(cross(u):(cross(u)+1));
        ind = find(min(abs(int)));
        if ind == 1
          ii = cross(u);
        else
          ii = cross(u)+1;
        end

        if u == 1
           B = 1;
           T = ii + round((cross(u+1)-ii)/2);
        elseif u == length(cross)
           B = ii - round((ii-cross(u-1))/2);
           T = length(data);
        else
           B = ii - round((ii-cross(u-1))/2);
           T = ii + round((cross(u+1)-ii)/2);
        end

%-----------------------------------------------------------------------
% Search for events when Rosetta z-coordinate lies between +0.15 and -0.15
% from the orbital plane of the comet where the ion tails travels.
% I.e the z-coordinate equal the distance from the possible ion tails.
%-----------------------------------------------------------------------
        jt = 0.15;
        jb = 0.14;
        [g1] = find(zsc(B:T) < jt & zsc(B:T) > jb);
           while isempty(g1)
              jt = jt-0.01;
              jb = jb-0.01;

              [g1] = find(zsc(B:T) < jt & zsc(B:T) > jb);
           end

        jt = -0.15;
        jb = -0.14;
        [g2] = find(zsc(B:T) < jb & zsc(B:T) > jt);

          while isempty(g2)
              jt = jt+0.01;
              jb = jb+0.01;

              [g2] = find(zsc(B:T) < jb & zsc(B:T) > jt);
          end


                 l1 = find(abs(g1+B-1-ii)==min(abs(g1+B-1-ii)));
                 l2 = find(abs(g2+B-1-ii)==min(abs(g2+B-1-ii)));

                 ilow = min([g1(l1) g2(l2)])+B-1;
                 itop = max([g1(l1) g2(l2)])+B-1;

%-----------------------------------------------------------------------
% Calculation of possible encounter
%-----------------------------------------------------------------------
  jk = hit(ilow, itop, e, a, P, Tper, xsc, ysc, zsc, name(j), Tstart, t_int);

           if jk ~= 1
              crossing(ii, e, a, P, Tper, xsc, ysc, zsc, name(j))
           end

%-----------------------------------------------------------------------
% Evaluate the cases in the beginning or the end of the iteration interval
%-----------------------------------------------------------------------
          if u == 1
             icb = 1;
             ict = find(zsc(1:ii) == max(zsc(1:ii)));
             cases(icb, ict, e, a, P, Tper, xsc, ysc, zsc, name(j))
          elseif u == length(cross)
             icb = find(zsc(ii:length(data)) == max(zsc(ii:length(data))));
             ict = length(data);
```

```
            cases(icb, ict, e, a, P, Tper, xsc, ysc, zsc, name(j))
         end

   end  % Terminates  for u = 1:length(cross)

j


 clear(['fil' num2str(j)])

 j = j+1;

 file = ['/home/sosp/thesis/Documents/exjobb/method2/ros/newcomets/fil' num2str(j)];
 filed = [file '.d'];
 load(filed)
     filen = ['fil' num2str(j)];
     value = eval(filen);
     a = value(1);
     e = value(2);
     inc = value(3);
     W = value(4);
     w = value(5);
     Tper = value(6);
     P = value(7);

end  %  Terminates while n == 0

```

B.2.2 coordtransf.m

```
function  [xsc,ysc,zsc] = coordtransf(rx, ry, rz, W, w, inc)
%----------------------------------------------------------------------
%----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Input:  rx  - Rosettas x-coordinates in the eclipic system
%         ry  - Rosettas y-coordinates in the eclipic system
%         rz  - Rosettas z-coordinates in the eclipic system
%         W   - The comets longitude of ascending node
%         w   - The comets argument of perihelion
%         inc - The comets inclination
%
% Output: xsc - Rosettas x-coordinates in the comets system
%         ysc - Rosettas y-coordinates in the comets system
%         zsc - Rosettas z-coordinates in the comets system
%
% Method: Calculates Rosettas orbit in the comets heliocentric system
%         (plane-of-orbit) through transformation from the coordinates
%         in the heliocentric ecliptic system.
%----------------------------------------------------------------------
%----------------------------------------------------------------------

    Cw=cos(w);
    CW=cos(W);
    Sw=sin(w);
    SW=sin(W);
    Ci=cos(inc);
    Si=sin(inc);


    PX=Cw.*CW-Sw.*SW.*Ci;
    PY=Cw.*SW+Sw.*CW.*Ci;
    PZ=Sw.*Si;

    QX=-Sw.*CW-Cw.*SW.*Ci;
    QY=-Sw.*SW+Cw.*CW.*Ci;
    QZ=Cw.*Si;

    RX=SW.*Si;
    RY=-CW.*Si;
    RZ=Ci;

```

```
    xsc=rx.*PX+ry.*PY+rz.*PZ;
    ysc=rx.*QX+ry.*QY+rz.*QZ;
    zsc=rx.*RX+ry.*RY+rz.*RZ;
```

B.2.3 hit.m

```
function jk = hit(ilow, itop, e, a, P, Tper, xsc, ysc, zsc, name, Tstart, t_int)
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Input:  ilow   - Iteration number corresponding to maximal z-coord. for
%                  Rosetta to obtain an ion tail, when she is moving towards
%                  the comets orbital plane
%         itop   - Iteration number corresponding to maximal z-coord. for
%                  Rosetta to obtain an ion tail, when she is moving away
%                  from the comets orbital plane
%         e      - The comets eccentricity
%         a      - The comets mean distance
%         P      - The comets orbital period
%         Tper   - The comets time of perihelion passage
%         xsc    - Rosettas x-coordinates in the comets system
%         ysc    - Rosettas y-coordinates in the comets system
%         zsc    - Rosettas z-coordinates in the comets system
%         name   - Name of the comet
%         Tstart - Launch date, start of iterations
%         t_int  - Length of integration interval
%
% Output: jk     - 1 if NO encounter were detected
%
% Method: Evaluates possible encounter(s) and if there is one (or several)
%         it is (they are) saved in file.
%         The data saved are: Comet, date of encounter, distance to ion tail,
%         SW-speed, timedelay, s/c-sun distance and comet-sun distance.
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
load data.d
jk = 1;

    for i=ilow:itop

     time = data(i);

     xrr = xsc(i);
     yrr = ysc(i);
     zrr = zsc(i);


% Rosettas radial position from the Sun
        rr = sqrt(xrr^2+yrr^2+zrr^2);

%-----------------------------------------------------------------------
% Calculates the solar wind speed necessary for encounter with an ion tail
%-----------------------------------------------------------------------

[dt, v_sw, xcr, ycr] = swvel(xrr, yrr, zrr, rr, time, e, a, P, Tper);

        if (v_sw > 200000 & v_sw < 1200000)

             RU = sqrt(xrr^2+yrr^2+zrr^2);
             Rc = sqrt(xcr^2+ycr^2);

             day = datevec(time);
             str1 = char(name);
             str2 = datestr(time);
             str3 = num2str(sign(zrr));
             str7 = num2str(abs(zrr));
             str8 = num2str(v_sw/1000);
                 str9 = num2str(dt);
             str10 = num2str(RU);
             str11 = num2str(Rc);
```

```
            nu = date;

            s = [str1 ': ' str2  '        ' str3 '       ' str7 '  '];
            s1 = ['        ' str8 '         ' str9 '     '];
            s2 = ['      ' str10 '        ' str11];

            str = [nu ' ' s ' ' s1 ' ' s2];


      stjk = ['Comet:        Date:               Distance [AU]:        '...
             'SW-speed [km/s]:        Timedelay [days]:    s/c-sun [AU]:    comet-sun [AU]:'];

      sti = ['     '];


        jk = jk+1;
        if (day(1) == 2006  &  day(2) == 07  &  day(3) == 06)
             str
                  plothitnew(time, dt, xsc, ysc, zsc, v_sw, e, a, P);
              break
        end

%-------------------------------------------------------------------------
% saves the encounter in different files depending on what year it happens
%-------------------------------------------------------------------------

         if day(1) == 2004
         fid = fopen('hits/2004.txt','a');
         if jk == 1
         fprintf(fid,'%s\n',sti);
         fprintf(fid,'%s\n',stjk);
         end
         fprintf(fid,'%s\n',str);
         fclose(fid);

         elseif day(1) == 2005
         fid = fopen('hits/2005.txt','a');
         if jk == 1
         fprintf(fid,'%s\n',sti);
         fprintf(fid,'%s\n',stjk);
         end
         fprintf(fid,'%s\n',str);
         fclose(fid);

             elseif day(1) == 2006
         fid = fopen('hits/2006.txt','a');
         if jk == 1
         fprintf(fid,'%s\n',sti);
         fprintf(fid,'%s\n',stjk);
         end
         fprintf(fid,'%s\n',str);
         fclose(fid);

             elseif day(1) == 2007
         fid = fopen('hits/2007.txt','a');
         if jk == 1
         fprintf(fid,'%s\n',sti);
         fprintf(fid,'%s\n',stjk);
         end
         fprintf(fid,'%s\n',str);
         fclose(fid);

             elseif day(1) == 2008
         fid = fopen('hits/2008.txt','a');
         if jk == 1
         fprintf(fid,'%s\n',sti);
         fprintf(fid,'%s\n',stjk);
         end
         fprintf(fid,'%s\n',str);
         fclose(fid);

             elseif day(1) == 2009
         fid = fopen('hits/2009.txt','a');
         if jk == 1
         fprintf(fid,'%s\n',sti);
         fprintf(fid,'%s\n',stjk);
         end
         fprintf(fid,'%s\n',str);
         fclose(fid);

             elseif day(1) == 2010
         fid = fopen('hits/2010.txt','a');
         if jk == 1
```

```
        fprintf(fid,'%s\n',sti);
        fprintf(fid,'%s\n',stjk);
        end
        fprintf(fid,'%s\n',str);
        fclose(fid);

            elseif day(1) == 2011
        fid = fopen('hits/2011.txt','a');
        if jk == 1
        fprintf(fid,'%s\n',sti);
        fprintf(fid,'%s\n',stjk);
        end
        fprintf(fid,'%s\n',str);
        fclose(fid);

        elseif day(1) == 2012
        fid = fopen('hits/2012.txt','a');
        if jk == 1
        fprintf(fid,'%s\n',sti);
        fprintf(fid,'%s\n',stjk);
        end
        fprintf(fid,'%s\n',str);
        fclose(fid);

        else
        fid = fopen('hits/2013.txt','a');
        if jk == 1
        fprintf(fid,'%s\n',sti);
        fprintf(fid,'%s\n',stjk);
        end
        fprintf(fid,'%s\n',str);
        fclose(fid);
        end


      end
    end

```

B.2.4 swvel.m

```
function [dt, v_sw, xcr, ycr] = swvel(xrr, yrr, zrr, rr, time, e, a, P, Tper)
%------------------------------------------------------------------------
%------------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Input:  xrr  - Rosettas x-coordinate at the current iteration
%         yrr  - Rosettas y-coordinate at the current iteration
%         zrr  - Rosettas z-coordinate at the current iteration
%         rr   - Rosettas radial position from the Sun
%         time - Time of current iteration
%         e    - The comets eccentricity
%         a    - The comets mean distance
%         P    - The comets orbital period
%         Tper - The comets time of perihelion passage
%
% Output: dt   - Delaytime, i.e the time it takes for the ion tail to
%                reach Rosettas location (xrr,yrr,zrr)
%         v_sw - Solar wind speed necessary for encounter
%         xcr  - x-coordinate of the comet at production time
%         ycr  - y-coordinate of the comet at production time
%
% Method: Finds the position of the comet in its orbit which complete
%           a radial line drawn between Sun-comet-Rosetta. The position of the
%           comet in its orbit at that line corresponds to the position at
%         production since the ion tail has move radially outwards.
%         The elapsed time between this location and the location the comet
%         has at the current iteration corresponds to the delaytime of the
%         ion tail to move out to Rosetta with a solar wind speed derived.
%------------------------------------------------------------------------
%------------------------------------------------------------------------
AU = 1.49597870*10^(11);       % [m]
```

```
%----------------------------------------------------------------------
% xrr, yrr is the projected position of Rosetta on the comets
% orbital plane which gives us the desired true anomaly the
% comet have to have at production time
%----------------------------------------------------------------------
         f0 = atan(abs(yrr/xrr));
         if (sign(xrr) == 1 & sign(yrr) == 1)
           f0 = f0;
         elseif (sign(xrr) == -1 & sign(yrr) == 1)
           f0 = pi-f0;
         elseif (sign(xrr) == -1 & sign(yrr) == -1)
           f0 = pi+f0;
         elseif (sign(xrr) == 1 & sign(yrr) == -1)
           f0 = 2*pi-f0;
         end


% True anomaly and eccentric anomaly are positive

    while sign(f0) == -1
       f0 = f0+2*pi;
    end

    E0 = 2*atan(sqrt((1-e)/(1+e))*tan(f0/2));
    while sign(E0) == -1
       E0 = E0+2*pi;
    end

    r = a*(cos(E0)-e)/cos(f0);

%----------------------------------------------------------------------
% Position of the comet at production time
%----------------------------------------------------------------------

    xcr = r*cos(f0);
    ycr = r*sin(f0);

%----------------------------------------------------------------------
% Distance the ion tail travel equals the distance between Rosetta
% and the distance of the comet at production time, i.e. the radiall
% distance from the Sun. The solar wind speed necessary can be calculated
% directly
%----------------------------------------------------------------------
   d = rr-r;

if d > 0
   bb = Tper;
   if time > (bb+P*365.25637)
      while time > (bb+P*365.25637)
        bb = bb+P*365.25637;
      end

   elseif time < bb
      while time < bb
        bb = bb-P*365.25637;
      end
   end

   tt = bb+P*365.25637*(E0-e*sin(E0))/(2*pi);

%----------------------------------------------------------------------
% Time that has passed between the radial distance of the comet and
% the time of iteration can be calculated from celestial mechanics
% and equals the time it takes for the ion tail to reach Rosetta.
% If it is less than zero it means that the comet is close to
% perihelion at production time and has passed it at the time
% of encounter, i.e. an addition of 2pi has been added to the
% eccentric anomaly. So in that case we need to subtract 2pi.
%----------------------------------------------------------------------

    dt = time-tt;
    if dt < 0
       dt = time-(bb+P*365.25637*(E0-e*sin(E0)-2*pi)/(2*pi));
    end
    v_sw = d*AU/(dt*86400);

else
    tt = 0;
    dt = 0;
    v_sw = 0;
end
```

B.2.5 crossing.m

```
function crossing(ii, e, a, P, Tper, xsc, ysc, zsc, name)
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Input:  ii   - Iteration number when Rosetta crosses orbital plane
%         e    - The comets eccentricity
%         a    - The comets mean distance
%         P    - The comets orbital period
%         Tper - The comets time of perihelion passage
%         xsc  - Rosettas x-coordinates in the comets system
%         ysc  - Rosettas y-coordinates in the comets system
%         zsc  - Rosettas z-coordinates in the comets system
%         name - Name of the comet
%
% Method: Evaluates the conditions when Rosetta crosses the orbital plane
%         of the comet. Saves the data in files.
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
load data.d

     time = data(ii);

     xrr = xsc(ii);
     yrr = ysc(ii);
     zrr = zsc(ii);


% Rosettas radial position from the Sun
        rr = sqrt(xrr^2+yrr^2+zrr^2);

%-----------------------------------------------------------------------
% Calculates the solar wind speed necessary for encounter with the ion tail
%-----------------------------------------------------------------------

[dt, v_sw, xcr, ycr] = swvel(xrr, yrr, zrr, rr, time, e, a, P, Tper);


             RU = sqrt(xrr^2+yrr^2+zrr^2);
             Rc = sqrt(xcr^2+ycr^2);

             day = datevec(time);
             str1 = char(name);
             str2 = datestr(time);
             str3 = num2str(sign(zrr));
             str7 = num2str(abs(zrr));
             str8 = num2str(v_sw/1000);
                 str9 = num2str(dt);
             str10 = num2str(RU);
             str11 = num2str(Rc);
             nu = date;

             s = [str1 ': ' str2  '        ' str3 '          ' str7 '  '];
             s1 = ['         ' str8 '         ' str9 '     '];
             s2 = ['        ' str10 '          ' str11];

            str = [nu ' ' s ' ' s1 ' ' s2];


%------------------------------------------------------------------------
% saves the encounter in different files depending on what year it happens
%------------------------------------------------------------------------

        if (day(1)==2004)
        fid=fopen('hits/2004.txt','a');
        fprintf(fid,'%s\n','CROSSING OF THE PLANE:');
        fprintf(fid,'%s\n',str);
        fclose(fid);

        elseif (day(1)==2005)
        fid=fopen('hits/2005.txt','a');
        fprintf(fid,'%s\n','CROSSING OF THE PLANE:');
        fprintf(fid,'%s\n',str);
```

```
        fclose(fid);

             elseif (day(1)==2006)
        fid=fopen('hits/2006.txt','a');
        fprintf(fid,'%s\n','CROSSING OF THE PLANE:');
        fprintf(fid,'%s\n',str);
        fclose(fid);

            elseif (day(1)==2007)
        fid=fopen('hits/2007.txt','a');
        fprintf(fid,'%s\n','CROSSING OF THE PLANE:');
        fprintf(fid,'%s\n',str);
        fclose(fid);

            elseif (day(1)==2008)
        fid=fopen('hits/2008.txt','a');
        fprintf(fid,'%s\n','CROSSING OF THE PLANE:');
        fprintf(fid,'%s\n',str);
        fclose(fid);

            elseif (day(1)==2009)
        fid=fopen('hits/2009.txt','a');
        fprintf(fid,'%s\n','CROSSING OF THE PLANE:');
        fprintf(fid,'%s\n',str);
        fclose(fid);

            elseif (day(1)==2010)
        fid=fopen('hits/2010.txt','a');
        fprintf(fid,'%s\n','CROSSING OF THE PLANE:');
        fprintf(fid,'%s\n',str);
        fclose(fid);

            elseif (day(1)==2011)
        fid=fopen('hits/2011.txt','a');
        fprintf(fid,'%s\n','CROSSING OF THE PLANE:');
        fprintf(fid,'%s\n',str);
        fclose(fid);

        elseif (day(1)==2012)
        fid=fopen('hits/2012.txt','a');
        fprintf(fid,'%s\n','CROSSING OF THE PLANE:');
        fprintf(fid,'%s\n',str);
        fclose(fid);

        else
        fid=fopen('hits/2013.txt','a');
        fprintf(fid,'%s\n','CROSSING OF THE PLANE:');
        fprintf(fid,'%s\n',str);
        fclose(fid);
        end
```

B.2.6 orbcom.m

```
function  [x_com,y_com] = orbcom(Tstart, t_int, Tper, P, e, a)
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
%
% Input:  Tstart - Rosettas launch date
%         t_int  - Integration time
%         Tper   - The comets time of perihelion passage
%         P      - The comets orbital period
%         e      - The comets eccentricity
%         a      - The comets mean distance
%
% Output: x_com  - Comets x-coordinates in the plane-of-orbit
%         y_com  - Comets y-coordinates in the plane-of-orbit
%
% Method: Calculates the cartesian coordinates of the comet in the
```

```
%         plane-of-orbit from the orbital elements.
%         This program is only used when I want to create a plot with
%         the movement of the comet in its orbit included.
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------


%-----------------------------------------------------------------------
% Calculates the mean anomaly, M, of the comet during Rosettas journey.
%-----------------------------------------------------------------------

G = 6.67259*10^(-11);            % The gravitational constant [Nm^2/kg^2]
M_sun = 1.989*10^(30);           % Mass of the Sun [kg]

% Iteration start time, i.e. Rosettas launch date
Tnu = Tstart;

for k = 1:t_int
       t(k) = Tnu-Tper;                 % In mean solar days
       M(k) = 2*pi*t(k)/(P*365.25637);  % Mean anomaly [rad]


 % If M results in a negative value, an addition of multiple 2*pi
 % are needed to get M between zero and 2*pi
       while sign(M(k)) == -1
         M(k) = M(k)+2*pi;
       end

 % If M results is larger than 2*pi, an subtraction of multiple 2*pi
 % are needed to retrieve the right angle between zero and 2*pi
       while M(k) >= 2*pi
         M(k) = M(k)-2*pi;
       end

 % Add one day until end of iteration, i.e. the end of Rosettas journey
       Tnu = Tnu+1;
end


%-----------------------------------------------------------------------
% Calculates the eccentric anomaly, E, of the comet during Rosettas
% journey, from Keplers equation using Newton Raphson iteration improved
% by Halleys third order method.
%-----------------------------------------------------------------------

 for k = 1:t_int
    if M(k) == 0
      E(k) = 0;

    else
      E_start(k) = M(k);
      f(k) = E_start(k)-e*sin(E_start(k))-M(k);
      fprim(k) = 1-e*cos(E_start(k));
      fbis(k) = e*sin(E_start(k));
      E(k) = E_start(k)-(f(k)/fprim(k))-(f(k)*fbis(k)/(2*fprim(k)));

    % improvement of E until it the error is small enough
        while abs(E(k)-E_start(k)) > 10^(-4)
           E_start(k) = E(k);
           f(k) = E_start(k)-e*sin(E_start(k))-M(k);
           fprim(k) = 1-e*cos(E_start(k));
           fbis(k) = e*sin(E_start(k));
           E(k) = E_start(k)-(f(k)/fprim(k))-(f(k)*fbis(k)/(2*fprim(k)));
        end
    end
 end


%-----------------------------------------------------------------------
% The cometary coordinates in plane-of-orbit [AU]
%-----------------------------------------------------------------------

    x_com = a*(cos(E)-e);
    y_com = a*sqrt(1-e^2)*sin(E);

```

B.2.7 plothit.m

```
function plothit(time, dt, xsc, ysc, zsc, v_sw, e, a, P)
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Method: Plot the occation(s) when the solar wind speed is reasonable.
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
load data.d
AU=1.49597870*10^(11);       % [m]
aa = 1;

     th = time-data(1)+1;
     tpr = th-round(dt);
     istop = th-tpr+1;
     for i = 1:istop

       xrr(i) = xsc(tpr+i-1);
       yrr(i) = ysc(tpr+i-1);
       zrr(i) = zsc(tpr+i-1);
     end

%-----------------------------------------------------------------------
% xrr, yrr is the projected position of Rosetta on the comets
% orbital plane which gives us the desired true anomaly the
% comet have to have at production time
%-----------------------------------------------------------------------
       f0 = atan(abs(yrr(i)/xrr(i)));

       if (sign(xrr) == 1 & sign(yrr) == 1)
          f0 = f0;
       elseif (sign(xrr) == -1 & sign(yrr) == 1)
          f0 = pi-f0;
       elseif (sign(xrr) == -1 & sign(yrr) == -1)
          f0 = pi+f0;
       elseif (sign(xrr) == 1 & sign(yrr) == -1)
          f0 = 2*pi-f0;
       end

% True anomaly and eccentric anomaly are positive

       while sign(f0) == -1
          f0 = f0+2*pi;
       end

       E0 = 2*atan(sqrt((1-e)/(1+e))*tan(f0/2));
       while sign(E0) == -1
          E0 = E0+2*pi;
       end


       r = a*(cos(E0)-e)/cos(f0);

%-----------------------------------------------------------------------
% Position of the comet from production time to time of encounter
%-----------------------------------------------------------------------

       xc1 = r*cos(f0);
       yc1 = r*sin(f0);

%---------------------------------------------------------
% Calculates E, from Keplers equation, by using Newton Raphson
% iteration improved by Halleys third order method
%---------------------------------------------------------
  Mstart = E0-e*sin(E0);
  for k = 1:(istop-1)
    M(k) = k*2*pi/(P*365.25637)+Mstart;

 % If M results in a negative value, an addition of multiple 2*pi
 % are needed to get M between zero and 2*pi
       while sign(M(k)) == -1
         M(k) = M(k)+2*pi;
       end

 % If M results is larger than 2*pi, an subtraction of multiple 2*pi
 % are needed to retrieve the right angle between zero and 2*pi
       while M(k) >= 2*pi
```

```
        M(k) = M(k)-2*pi;
      end

    if M(k) == 0
      E(k) = 0;
    else
      E_start(k) = M(k);
      f(k) = E_start(k)-e*sin(E_start(k))-M(k);
      fprim(k) = 1-e*cos(E_start(k));
      fbis(k) = e*sin(E_start(k));
      E(k) = E_start(k)-(f(k)/fprim(k))-(f(k)*fbis(k)/(2*fprim(k)));

    % improvement of E until it the error is small enough
        while abs(E(k)-E_start(k)) > 10^(-4)
           E_start(k) = E(k);
           f(k) = E_start(k)-e*sin(E_start(k))-M(k);
           fprim(k) = 1-e*cos(E_start(k));
           fbis(k) = e*sin(E_start(k));
           E(k) = E_start(k)-(f(k)/fprim(k))-(f(k)*fbis(k)/(2*fprim(k)));
        end
    end

 end

   fan = 2*atan(sqrt((1+e)/(1-e))*tan(E./2));

    r = a*(cos(E)-e)./cos(fan);
    xc2 = r.*cos(fan);
    yc2 = r.*sin(fan);

    xc = [xc1 xc2];
    yc = [yc1 yc2];
    [the, rad] = cart2pol(xc, yc);


         ve = [(istop-1):-1:0];
         ionx = xc+(v_sw*ve*86400/AU).*cos(the);
         iony = yc+(v_sw*ve*86400/AU).*sin(the);


         zc = [0*(tpr:th)];
         ionz = [0*(tpr:th)];

               arrx = [0 xsc(th)];
               arry = [0 ysc(th)];
               arrz = [0 0];

figure(aa)
subplot(2,2,1)
% XY projection
      plot(xc, yc, 'g', ionx, iony, 'b', xrr, yrr, 'r',...
          xrr(istop), yrr(istop), 'rs', xc(istop), yc(istop), 'k+', arrx, arry, ...
           'y-', 0, 0, 'k*')
      xlabel('X (AU)')
      ylabel('Y (AU)')
      grid on
      axis equal

subplot(2,2,2)
% XZ projection
      plot(xc, zc, 'g', ionx, ionz, 'b', xrr, zrr, 'r',...
           xrr(istop), zrr(istop), 'rs', xc(istop), zc(istop), 'k+', arrx, arrz, ...
           'y-', 0, 0, 'k*')
      xlabel('X (AU)')
      ylabel('Z (AU)')
      grid on
      axis equal

subplot(2,2,3)
% YZ projection
      plot(yc, zc, 'g', iony, ionz, 'b', yrr, zrr, 'r',...
           yrr(istop), zrr(istop), 'rs', yc(istop), zc(istop), 'k+', arry, arrz, ...
           'y-', 0, 0, 'k*')
      xlabel('Y (AU)')
      ylabel('Z (AU)')
      grid on
      axis equal

subplot(2,2,4)
      plot(yc(1), zc(1), 'g', iony(1), ionz(1), 'b',...
           yrr(istop), zrr(istop), 'r', arry(1), arrz(1), ...
           'y', 0, 0, 'k*')
      legend('Comet','Ion tail','Rosetta','Radial sun-s/c','Sun',0)
```

```
      axis off


figure(aa+1)
% 3D
      plot3(xc(istop), yc(istop), zc(istop), 'k+',xc, yc, zc, 'g', ...
           ionx, iony, ionz, 'b', xrr, yrr, zsc(tpr:th), 'r',  xrr(istop), yrr(istop), ...
           zsc(th), 'rs', arrx, arry, arrz, 'y-', 0, 0, 0, 'k*')
      xlabel('X (AU)')
      ylabel('Y (AU)')
      zlabel('Z (AU)')
      grid on
      axis equal
```

B.2.8 cases.m

```
function cases(icb, ict, e, a, P, Tper, xsc, ysc, zsc, name)
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Input:  icb - Iteration start time for the cases
%         ict - Iteration stop time for the cases
%         e    - The comets eccentricity
%         a    - The comets mean distance
%         P    - The comets orbital period
%         Tper - The comets time of perihelion passage
%         xsc  - Rosettas x-coordinates in the comets system
%         ysc  - Rosettas y-coordinates in the comets system
%         zsc  - Rosettas z-coordinates in the comets system
%         name - Name of the comet
%
% Method:  Evaluate the cases in the beginning or the end of the iteration
%          interval when Rosetta might be close to the orbital plane,
%          but with the crossing time before or after iteration interval.
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
load data.d
var = 1;

    for i = icb:ict

     if zsc(i) < 0.15

     time = data(i);

     xrr = xsc(i);
     yrr = ysc(i);
     zrr = zsc(i);

% Rosettas radial position from the Sun
        rr = sqrt(xrr^2+yrr^2+zrr^2);

%-----------------------------------------------------------------------
% Calculates the solar wind speed necessary for encounter with an ion tail
%-----------------------------------------------------------------------

[dt, v_sw, xcr, ycr] = swvel(xrr, yrr, zrr, rr, time, e, a, P, Tper);


        if (v_sw > 200000 & v_sw < 1200000)


             RU = sqrt(xrr^2+yrr^2+zrr^2);
             Rc = sqrt(xcr^2+ycr^2);

             day = datevec(time);
```

```
               str1 = char(name);
               str2 = datestr(time);
               str3 = num2str(sign(zrr));
               str7 = num2str(abs(zrr));
               str8 = num2str(v_sw/1000);
                   str9 = num2str(dt);
               str10 = num2str(RU);
               str11 = num2str(Rc);
               nu = date;

               s = [str1 ': ' str2  '         ' str3 '        ' str7 '  '];
               s1 = ['        ' str8 '         ' str9 '     '];
               s2 = ['        ' str10 '          ' str11];

               str = [nu ' ' s ' ' s1 ' ' s2];


        stjk = ['Comet:        Date:              Distance [AU]:        '...
                'SW-speed [km/s]:        Timedelay [days]:    s/c-sun [AU]:    comet-sun [AU]:'];

        sti = ['     '];

%----------------------------------------------------------------------
% saves the encounter in different files depending on what year it happens
%----------------------------------------------------------------------
          if day(1) == 2004
          fid = fopen('hits/2004.txt','a');
          if var == 1
          fprintf(fid,'%s\n',sti);
          fprintf(fid,'%s\n',stjk);
          end
          fprintf(fid,'%s\n',str);
          fclose(fid);

          elseif day(1) == 2005
          fid = fopen('hits/2005.txt','a');
          if var == 1
          fprintf(fid,'%s\n',sti);
          fprintf(fid,'%s\n',stjk);
          end
          fprintf(fid,'%s\n',str);
          fclose(fid);

              elseif day(1) == 2006
          fid = fopen('hits/2006.txt','a');
          if var == 1
          fprintf(fid,'%s\n',sti);
          fprintf(fid,'%s\n',stjk);
          end
          fprintf(fid,'%s\n',str);
          fclose(fid);

              elseif day(1) == 2007
          fid = fopen('hits/2007.txt','a');
          if var == 1
          fprintf(fid,'%s\n',sti);
          fprintf(fid,'%s\n',stjk);
          end
          fprintf(fid,'%s\n',str);
          fclose(fid);

              elseif day(1) == 2008
          fid = fopen('hits/2008.txt','a');
          if var == 1
          fprintf(fid,'%s\n',sti);
          fprintf(fid,'%s\n',stjk);
          end
          fprintf(fid,'%s\n',str);
          fclose(fid);

              elseif day(1) == 2009
          fid = fopen('hits/2009.txt','a');
          if var == 1
          fprintf(fid,'%s\n',sti);
          fprintf(fid,'%s\n',stjk);
          end
          fprintf(fid,'%s\n',str);
          fclose(fid);

               elseif day(1) == 2010
          fid = fopen('hits/2010.txt','a');
          if var == 1
          fprintf(fid,'%s\n',sti);
```

```
        fprintf(fid,'%s\n',stjk);
        end
        fprintf(fid,'%s\n',str);
        fclose(fid);

            elseif day(1) == 2011
        fid = fopen('hits/2011.txt','a');
        if var == 1
        fprintf(fid,'%s\n',sti);
        fprintf(fid,'%s\n',stjk);
        end
        fprintf(fid,'%s\n',str);
        fclose(fid);

        elseif day(1) == 2012
        fid = fopen('hits/2012.txt','a');
        if var == 1
        fprintf(fid,'%s\n',sti);
        fprintf(fid,'%s\n',stjk);
        end
        fprintf(fid,'%s\n',str);
        fclose(fid);

        else
        fid = fopen('hits/2013.txt','a');
        if var == 1
        fprintf(fid,'%s\n',sti);
        fprintf(fid,'%s\n',stjk);
        end
        fprintf(fid,'%s\n',str);
        fclose(fid);
        end


        var = var+1;
      end
   end
end

```

B.2.9 distance.m

```
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Method: For all encounters at different solar wind velocity obtained
%         in the tables, the time of production is the same. This means
%         that we will know what solar wind velocity it is at production
%         date, and through this program get the exact time
%         (only 5 minutes error) that an possible encounter can occur.
%         On line 45 and 46 you need to change ilow and itop to the time-
%         interval you have the encounter within from your run of the main
%         program.
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
load rosetta.d
load data.d
load('-mat','name.d')
format long e
AU=1.49597870*10^(11);            % [m]

 j = input('Comet number: ');

% Open the file for comet j
 file = ['newcomets/fil' num2str(j)];
 filed = [file '.d'];
 load(filed)
     filen = ['fil' num2str(j)];
     value = eval(filen);
     a = value(1);
     e = value(2);
```

```
     inc = value(3);
     W = value(4);
     w = value(5);
     Tper = value(6);
     P = value(7);


%-----------------------------------------------------------------------
% Transformation of Rosetta heliocentric ecliptic coordinates
% to the comets heliocentric reference system.
%-----------------------------------------------------------------------
   [xsc,ysc,zsc] = coordtransf(rosetta(1,:), rosetta(2,:), rosetta(3,:), (W*pi/180), (w*pi/180), (inc*pi/180));

%-----------------------------------------------------------------------
% Solar wind velocity and time span you want to evaluate
%-----------------------------------------------------------------------
v_sw = 450000;
ilow = datenum(2014,03,01)-data(1)+1;
itop = datenum(2014,03,13)-data(1)+1;


            ind = 1;
            aa = 1;

                       for i = ilow:itop

                       time = data(i);

                       xrr = xsc(i);
                       yrr = ysc(i);
                       zrr = zsc(i);

                       % Rosettas radial position from the Sun
                       rr = sqrt(xrr^2+yrr^2+zrr^2);

                       arrx = [0 xrr];
                       arry = [0 yrr];

                       x0 = interp1(1:2,arrx,1:5000);
                       y0 = interp1(1:2,arry,1:5000);


%-----------------------------------------------------------------------
% xrr, yrr is the projected position of Rosetta on the comets
% orbital plane which gives us the desired true anomaly the
% comet have to have at production time
%-----------------------------------------------------------------------

                 f0 = atan(abs(yrr/xrr));
                 if (sign(xrr) == 1 & sign(yrr) == 1)
                     f0 = f0;
                 elseif (sign(xrr) == -1 & sign(yrr) == 1)
                     f0 = pi-f0;
                 elseif (sign(xrr) == -1 & sign(yrr) == -1)
                     f0 = pi+f0;
                 elseif (sign(xrr) == 1 & sign(yrr) == -1)
                     f0 = 2*pi-f0;
                 end

% True anomaly and eccentric anomaly are positive

    while sign(f0) == -1
       f0 = f0+2*pi;
    end

       E0 = 2*atan(sqrt((1-e)/(1+e))*tan(f0/2));
    while sign(E0) == -1
       E0 = E0+2*pi;
    end


    r = a*(cos(E0)-e)/cos(f0);

%-----------------------------------------------------------------------
% Position of the comet at production time
%-----------------------------------------------------------------------

    xcr = r*cos(f0);
    ycr = r*sin(f0);

%-----------------------------------------------------------------------
% Distance the ion tail travel equals the distance between Rosetta
% and the distance of the comet at production time, i.e. the radial distance
```

```
% from the Sun.
%----------------------------------------------------------------------
            d = rr-r;


%----------------------------------------------------------------------
% Time that has passed between the radial distance of the comet and
% the time of iteration can be calculated from celestial mechanics
%----------------------------------------------------------------------

      tt = Tper+P*365.25637*(E0-e*sin(E0))/(2*pi);


      bb = Tper;
        if time > (bb+P*365.25637)
           while time > (bb+P*365.25637)
               bb = bb+P*365.25637;
           end
        elseif time < (bb-P*365.25637)
           while time < (bb-P*365.25637)
               bb = bb-P*365.25637;
           end
        end

      tt = bb+P*365.25637*(E0-e*sin(E0))/(2*pi);

%----------------------------------------------------------------------
% Time it takes for the ion tail to reach Rosetta.
% If it is less than zero it means that the comet is close to
% perihelion at production time and has passed it at the time
% of encounter, i.e. an addition of 2pi has been added to the
% eccentric anomaly. So in that case we need to subtract 2pi.
%----------------------------------------------------------------------

       dt = time-tt;
       if dt < 0
         dt = time-(Tper+P*365.25637*(E0-e*sin(E0)-2*pi)/(2*pi));
       end

%----------------------------------------------------------------------
% The distance necessary can be calculated
% directly
%----------------------------------------------------------------------
                       dhit = v_sw*dt*86400/AU;

%----------------------------------------------------------------------
% If this turnes out to be the true distance, an observation at
% that time is of interest
%----------------------------------------------------------------------

                       rhit(ind) = abs(dhit-d);
                       ind = ind+1;
                    end    %  Terminates  for i = ilow:itop

                      ind = find(rhit == min(rhit));

%----------------------------------------------------------------------
% Interpolate the coordinates to be exact on 5 minutes
%----------------------------------------------------------------------

                    thit = ind+ilow-1;

                    sec = 300;

     xtemp = xsc((thit-1):(thit+1));
     ytemp = ysc((thit-1):(thit+1));
     ztemp = zsc((thit-1):(thit+1));


     ttemp = data((thit-1):(thit+1));
     tres = data((thit-1)):(sec/86400):data((thit+1));

     x1 = interp1(ttemp,xtemp,tres);
     y1 = interp1(ttemp,ytemp,tres);
     z1 = interp1(ttemp,ztemp,tres);

     ind = 1;

              for i = 1:length(tres)
                       time = data(thit-1)+(i-1)*sec/86400;

                       xrr = x1(i);
                       yrr = y1(i);
```

```
                       zrr = z1(i);

                       % The radial position of Rosetta
                       rr(i) = sqrt(xrr^2+yrr^2+zrr^2);

                       arrx = [0 xrr];
                       arry = [0 yrr];

                       x0 = interp1(1:2,arrx,1:5000);
                       y0 = interp1(1:2,arry,1:5000);


%---------------------------------------------------------------------
% xrr, yrr is the projected position of Rosetta on the comets
% orbital plane which gives us the desired true anomaly the
% comet have to have at production time
%---------------------------------------------------------------------

               f0 = atan(abs(yrr/xrr));

               if (sign(xrr) == 1 & sign(yrr) == 1)
                   f0 = f0;
               elseif (sign(xrr) == -1 & sign(yrr) == 1)
                   f0 = pi-f0;
               elseif (sign(xrr) == -1 & sign(yrr) == -1)
                   f0 = pi+f0;
               elseif (sign(xrr) == 1 & sign(yrr) == -1)
                   f0 = 2*pi-f0;
               end

% True anomaly and eccentric anomaly are positive

    while sign(f0) == -1
       f0 = f0+2*pi;
    end

       E0 = 2*atan(sqrt((1-e)/(1+e))*tan(f0/2));
    while sign(E0) == -1
       E0 = E0+2*pi;
    end


    r(i) = a*(cos(E0)-e)/cos(f0);

%---------------------------------------------------------------------
% Position of the comet at production time
%---------------------------------------------------------------------

    xcr = r*cos(f0);
    ycr = r*sin(f0);

%---------------------------------------------------------------------
% Distance the ion tail travel equals the distance between Rosetta
% and the distance of the comet at production time, i.e. the radial distance
% from the Sun.
%---------------------------------------------------------------------
            d(i) = rr(i)-r(i);


%---------------------------------------------------------------------
% Time that has passed between the radial distance of the comet and
% the time of iteration can be calculated from celestial mechanics
%---------------------------------------------------------------------

     tt = Tper+P*365.25637*(E0-e*sin(E0))/(2*pi);

     bb = Tper;
     if time > (bb+P*365.25637)
        while time > (bb+P*365.25637)
            bb = bb+P*365.25637;
        end
     elseif time < (bb-P*365.25637)
        while time < (bb-P*365.25637)
             bb = bb-P*365.25637;
        end
     end

     tt = bb+P*365.25637*(E0-e*sin(E0))/(2*pi);

%---------------------------------------------------------------------
% Time it takes for the ion tail to reach Rosetta.
% If it is less than zero it means that the comet is close to
% perihelion at production time and has passed it at the time
```

```
% of encounter, i.e. an addition of 2pi has been added to the
% eccentric anomaly. So in that case we need to subtract 2pi.
%-----------------------------------------------------------------------

        dt = time-tt;
      if dt < 0
        dt = time-(Tper+P*365.25637*(E0-e*sin(E0)-2*pi)/(2*pi));
      end

      t(ind) = dt;

%-----------------------------------------------------------------------
% The distance necessary can be calculated
% directly
%-----------------------------------------------------------------------
                       dhit(ind) = v_sw*t(ind)*86400/AU;

%-----------------------------------------------------------------------
% If this turnes out to be the true distance, an observation at
% that time is of interest
%-----------------------------------------------------------------------

                       rhit(ind) = abs(dhit(ind)-d(i));
                       ind = ind+1;
                    end   % Terminates  for i = 1:length(tres)

                      ti = find(rhit == min(rhit));


             str1 = char(name(j));
             str2 = datestr(data(thit-1)+(ti-1)*sec/86400);
             str3 = num2str(t(ti));
                  str4 = datestr(data(thit-1)+(ti-1)*sec/86400-t(ti));
             str5 = num2str(rr(ti));
             str6 = num2str(r(ti));
             str7 = num2str(v_sw/1000);
                 str8 = num2str(abs(z1(ti)));

   disp(['Encounter time: ' str2])
   disp(['Production time: ' str4])

            s = [str1 ': ' str2  '           ' str4 '              ' str7 '           ' ...
                 str3 '           ' str8 '          ' str5 '          ' str6];



      stjk = ['        Comet:               Encounter:             Production:        '...
               'SW-speed [km/s]:     Timedelay [days]           R-RI              R-RS               R-CS'];

      sti = ['     '];

%-----------------------------------------------------------
% saves the encounter in a file
%-----------------------------------------------------------


        fid=fopen('lookmag.txt','a');
        fprintf(fid,'%s\n',sti);
        fprintf(fid,'%s\n',stjk);
        fprintf(fid,'%s\n',s);
        fclose(fid);
```

B.2.10 readcassini.m

```
%-----------------------------------------------------------------------
%-----------------------------------------------------------------------
% Created by: Sofie Spjuth, IRF-Uppsala, 2005, thesis-work
%
% Method: Reads from Cassinis trajectory file with one day resolution and
%         transform from geocentric ecliptic coordinates to heliocentric
%         ecliptic coordinates by adding the coordinate of Earth.
%         Puts the data into vectors as year, month, day & coordinates.
```

```
%         Also creates a datavector which are used later when I want to know
%         the comets positions for comparison with Ulysses positions.
%----------------------------------------------------------------------
clear
global cassini data_c;

fp = fopen('cassini.txt','r');   % Open Cassinis trajectory file
format long e

for a = 1:28
     fgetl(fp);
end

i=1;
stop=0;
 while (stop==0)
     test=fscanf(fp,'%1c',1);

     if test=='$'            % If end of file
         stop=1;
     else

         % Read the intigers (year, month, day)
         [A]=fscanf(fp,'%*24c %4u %*1c %2u %*1c %2u',3);
         YYYY(i)=double(A(1));                    % Year
         MM(i)=double(A(2));                      % Month
         DD(i)=double(A(3));                      % Day

         fgetl(fp);

         % Read the float variables (coordinate vectors)
         [B]=fscanf(fp,'%*2c %f %f %f',3);
         X_temp(i)=B(1);
         Y_temp(i)=B(2);                    % Geocentric ecliptic coordinates
         Z_temp(i)=B(3);

         data_c(i)=datenum(YYYY(i),MM(i),DD(i));         % Datavector/time
         fgetl(fp);
         i=i+1;
     end
 end

 fclose(fp);


load earth.d
load data_e.d

%----------------------------------------------------------------------
% Finds the launch date for Cassini
%----------------------------------------------------------------------
estart=find(data_e == data_c(1))-1;

%----------------------------------------------------------------------
% Translates Ulysses coordinates
%----------------------------------------------------------------------
for q=1:length(data_c)
     X_c(q)=earth(1,estart+q)+X_temp(q);
     Y_c(q)=earth(2,estart+q)+Y_temp(q);
     Z_c(q)=earth(3,estart+q)+Z_temp(q);
end

%----------------------------------------------------------------------
% Ulysses positional components in the ecliptic coord. syst.
%----------------------------------------------------------------------
cassini = [X_c; Y_c; Z_c];


save('data_c.d','data_c','-ascii');
save('cassini.d','cassini','-ascii');
```

C Comet List

Object Designation	Epoch	Ref.	a (AU)	e	i (deg)	W (deg)	w (deg)	TP	P (yr)
1P/Halley	19940217	J863/77	17.8341443	0.96714291	162.26269	58.42008	111.33249	19860205.89532	7.53e+01
2P/Encke	20040823	K033/15	2.2174097	0.84731968	11.76865	334.58842	186.50482	20031229.87651	3.30e+00
4P/Faye	20000516	J993/10	3.8380798	0.56814362	9.04886	199.34013	204.99704	19990506.12673	7.52e+00
6P/d'Arrest	20010620	K024/45	3.4937680	0.61285312	19.49723	138.94945	178.12211	20020203.59955	6.53e+00
7P/Pons-Winnecke	20040205	K027/23	3.4363148	0.63412259	22.28809	93.43668	172.26324	20020515.70935	6.37e+00
8P/Tuttle	19920806	J943/10	5.6712663	0.82415040	54.70519	270.59170	206.69069	19940625.24504	1.35e+01
9P/Tempel 1	20050311	K052/7	3.1219372	0.51756755	10.52960	68.94088	178.83838	20050705.31618	5.52e+00
10P/Tempel 2	20041002	K0512/15	3.0709367	0.53535948	12.01774	117.84930	195.55628	20050215.03659	5.38e+00
11P/Tempel-Swift-LINEAR	20020215	K0116/15	3.4373964	0.53916516	13.46043	240.71050	163.63395	20011230.75628	6.37e+00
12P/Pons-Brooks	19540915	JPL#15	17.1212232	0.95481239	74.17689	255.89114	199.02847	19540522.88085	7.08e+01
13P/Olbers	19561014	JPL#10	16.9067774	0.93029715	44.60989	86.10313	64.64121	19560619.13533	6.95e+01
14P/Wolf	20040205	K007/18	4.0671095	0.40838829	27.65530	203.52542	162.64307	20001120.21250	8.20e+00
15P/Finlay	20020506	K024/10	3.5726041	0.71055148	3.67428	41.96083	323.64510	20020207.20510	6.75e+00
16P/Brooks 2	20020327	K013/4	3.6150504	0.49243600	5.54816	176.87788	198.17124	20010719.93540	6.87e+00
17P/Holmes	20010401	K006/9	3.6867592	0.41272851	19.18878	327.93810	23.43539	20000511.95402	7.08e+00
19P/Borrelly	20020615	K012/142	3.6098966	0.62377941	30.32383	75.42208	353.35896	20010914.69681	6.86e+00
21P/Giacobini-Zinner	20050530	K054/9	3.5264938	0.70567858	31.81105	195.42981	172.54311	20050702.76097	6.62e+00
22P/Kopff	20031227	K023/85	3.4669167	0.54332250	4.71879	120.91929	162.73717	20021212.05979	6.46e+00
23P/Brorsen-Metcalf	19891001	JPL#13	17.0692068	0.97195226	19.33394	311.58546	129.61068	19890911.93743	7.05e+01
24P/Schaumasse	20010730	K014/19	4.0820173	0.70480036	11.75153	79.83104	57.87449	20010502.66093	8.25e+00
26P/Grigg-Skjellerup	19971108	J978/18	2.9649241	0.66379625	21.08674	213.30872	359.33380	19970830.30467	5.11e+00
27P/Crommelin	19840629	J843/16	9.0872244	0.91916891	29.10126	250.90026	195.84083	19840220.16897	2.74e+01
28P/Neujmin 1	20040316	JPL#23	6.9111705	0.77541331	14.18564	347.02892	346.91625	20021227.33432	1.82e+01
30P/Reinmuth 1	20030720	K027/19	3.7688839	0.50187000	8.13039	119.75675	13.26299	20021224.33909	7.32e+00
31P/Schwassmann-Wachmann 2	20030610	K023/8	4.2286994	0.19386657	4.55009	114.19633	18.34216	20020118.03343	8.70e+00
32P/Comas Sola	20050530	K053/16	4.2554459	0.56925133	12.92690	60.79574	45.82615	20050401.34056	8.78e+00
33P/Daniel	20010220	K004/3	4.0199487	0.46333049	22.41018	66.58304	18.99197	20000623.46595	8.06e+00
35P/Herschel-Rigollet	19390805	IAUCAT03	28.8435453	0.97405000	64.20700	355.98000	29.29800	19390809.46400	1.55e+02
36P/Whipple	20040316	K037/37	4.1666265	0.25880575	9.93325	182.40143	202.20244	20030706.59601	8.51e+00
37P/Forbes	20050420	K055/8	3.4286755	0.54139219	8.95812	315.10111	329.25042	20050801.74185	6.35e+00
38P/Stephan-Oterma	19810426	JPL#10	11.2476697	0.86002249	17.98142	79.18838	358.19104	19801205.17613	3.77e+01
40P/Vaisala 1	20040823	K045/7	4.8924949	0.63291236	11.53846	134.73252	47.18940	20040122.88601	1.08e+01
41P/Tuttle-Giacobini-Kresak	20010511	K013/19	3.0889067	0.65935850	9.22552	141.10537	62.17514	20010106.97667	5.43e+00
42P/Neujmin 3	20041111	K044/16	4.8565623	0.58515624	3.98546	150.38392	147.16042	20040715.94444	1.07e+01
43P/Wolf-Harrington	20050420	K043/32	3.4688218	0.54508789	18.53222	254.61370	187.36019	20040318.00044	6.46e+00
44P/Reinmuth 2	20030210	K014/2	3.5647453	0.46603475	6.91492	295.96212	47.28913	20010223.90356	6.73e+00
45P/Honda-Mrkos-Pajdusakova	20010620	K013/6	3.0206379	0.82507079	4.25559	89.08165	326.12943	20010329.92621	5.25e+00
46P/Wirtanen	20030501	K023/22	3.0937377	0.65782220	11.73837	82.16801	356.38663	20020826.72990	5.44e+00
47P/Ashbrook-Jackson	20020327	JPL#40	3.8262345	0.39702587	12.50740	2.48302	349.20574	20010107.20812	7.48e+00
48P/Johnson	20050130	JPL#41	3.6466806	0.36656077	13.65786	117.32762	207.68953	20041011.94911	6.96e+00
49P/Arend-Rigaux	20050709	JPL#56	3.5240383	0.61164042	18.30130	121.64622	330.71043	20050224.56732	6.62e+00
50P/Arend	20000516	JPL#31	4.0790534	0.53007409	19.17860	355.37983	48.99705	19990803.75086	8.24e+00
51P/Harrington	19950212	J943/5	3.5836379	0.56138213	8.65580	119.26014	233.45608	19940823.23428	6.78e+00
51P/Harrington-A	20020215	K013/32	3.5822882	0.56220236	8.65735	119.17192	233.64697	20010605.83424	6.78e+00
52P/Harrington-Abell	19990701	J994/2	3.8427336	0.54303772	10.21798	337.28799	138.90326	19990127.88618	7.53e+00
53P/Van Biesbroeck	20050130	JPL#52	5.3938288	0.55229060	6.60999	149.00229	134.08314	20031009.44479	1.25e+01
54P/de Vico-Swift-NEAT	20030210	JPL#18	3.7669883	0.43057063	6.08507	358.96538	2.05730	20020730.94162	7.31e+00
55P/Tempel-Tuttle	19980815	J985/69	10.3383382	0.90555272	162.48658	235.27099	172.50027	19980228.09773	3.32e+01
56P/Slaughter-Burnham	20050420	K053/28	5.1094850	0.50382561	8.15541	346.27084	44.09300	20050115.01025	1.15e+01
57P/duToit-Neujmin-Delporte	19830526	J964/1	3.4359788	0.50285001	2.84633	189.15077	115.16413	19830601.32769	6.37e+00
57P/duToit-Neujmin-Delporte-A	20030101	K023/3	3.4521536	0.49904012	2.84481	188.92568	115.23253	20020731.15124	6.41e+00
58P/Jackson-Neujmin	19960318	JPL#6	4.0803572	0.66150673	13.47841	160.71487	200.35826	19951006.61418	8.24e+00
59P/Kearns-Kwee	20000406	J993/27	4.4682091	0.47645561	9.35202	313.03484	127.46725	19990916.39625	9.45e+00
60P/Tsuchinshan 2	19990522	J995/7	3.5868121	0.50642442	6.71631	288.19902	203.18924	19990308.18878	6.79e+00
61P/Shajn-Schaldach	20020106	K015/12	3.8215649	0.39027755	6.08424	166.83992	216.70401	20010509.18532	7.47e+00
62P/Tsuchinshan 1	20050420	K044/13	3.5282912	0.57792141	10.50141	96.75996	22.85913	20041207.92572	6.63e+00
63P/Wild 1	20000516	JPL#25	5.5996033	0.64982138	19.93313	358.52376	167.98819	19991227.07721	1.33e+01
64P/Swift-Gehrels	20010401	JPL#14	4.3820644	0.69443283	8.43801	306.13405	92.41195	20000421.76148	9.17e+00
65P/Gunn	20050130	K034/21	3.5909153	0.31907397	10.38482	68.39599	196.37751	20030511.93215	6.80e+00
66P/du Toit	20031008	JPL#48	6.0022407	0.78770149	18.70074	22.21536	257.24972	20030827.99192	1.47e+01
67P/Churyumov-Gerasimenko	20040823	K023/22	3.5029497	0.63193560	7.12723	50.92302	11.36788	20020818.23754	6.56e+00
68P/Klemola	19990122	JPL#19	4.8875668	0.64109193	11.08945	175.54337	154.50165	19980501.58054	1.08e+01
69P/Taylor	20050530	K043/15	3.6440029	0.46709033	20.56267	108.79523	355.54677	20041130.64995	6.96e+00
70P/Kojima	20010620	JPL#16	3.6732105	0.45455070	6.60046	119.29536	1.99472	20000914.89993	7.04e+00
71P/Clark	20011127	K002/6	3.1209561	0.50038649	9.49519	59.69277	208.83162	20001201.98258	5.51e+00
72P/Denning-Fujikawa	19790107	JPL#17	4.3284463	0.81985972	8.64319	41.53343	334.31710	19781002.14222	9.01e+00
73P/Schwassmann-Wachmann 3	19951229	J954/19	3.0565303	0.69482691	11.42349	69.94634	198.76998	19950922.88986	5.34e+00
73P/Schwassmann-Wachmann 3-B	20010730	JPL#9	3.0638416	0.69401060	11.40605	69.92112	198.78365	20010127.97736	5.36e+00
73P/Schwassmann-Wachmann 3-C	20011127	K012/12	3.0617745	0.69373522	11.40530	69.92491	198.78105	20010127.68930	5.36e+00
73P/Schwassmann-Wachmann 3-E	20010111	K013/11	3.0622933	0.69387746	11.40562	69.91710	198.77324	20010128.45340	5.36e+00
74P/Smirnova-Chernykh	20041221	K012/5	4.1717086	0.14887248	6.64833	77.13797	87.29803	20010119.63340	8.52e+00
75P/Kohoutek	19940617	J873/16	3.5431470	0.49630740	5.90721	269.68609	175.80172	19940629.89848	6.67e+00
76P/West-Kohoutek-Ikemura	20010511	JPL#15	3.4682584	0.53974502	30.49888	84.12396	0.10250	20000601.27175	6.46e+00
77P/Longmore	20020615	JPL#11	3.5985024	0.35818984	24.40314	14.97706	196.43873	20020904.70137	6.83e+00
78P/Gehrels 2	20050530	K043/36	3.7355174	0.46241795	6.25287	210.54821	192.95228	20041027.03756	7.22e+00

79P/du Toit-Hartley	20030322	K035/3	3.0303079	0.59410787	2.89447	307.97028	253.07607	20030215.37973	5.28e+00
80P/Peters-Hartley	19980527	JPL#15	4.0403600	0.59807504	29.85433	260.00816	338.40141	19980811.63354	8.12e+00
81P/Wild 2	20040823	K033/47	3.4482103	0.53869913	3.23984	136.14129	41.76646	20030925.93703	6.40e+00
82P/Gehrels 3	20020327	JPL#11	4.1388674	0.12387464	1.12653	239.62884	227.65070	20010831.62834	8.42e+00
83P/Russell 1	19850624	JPL#7	3.3379758	0.51720991	22.65946	230.84201	0.37623	19850705.22914	6.10e+00
84P/Giclas	20000516	JPL#29	3.6426275	0.49329493	7.28268	112.47909	276.39324	19990825.04166	6.95e+00
85P/Boethin	19860331	JPL#12	5.0137807	0.77774599	5.75637	26.48124	11.67646	19860116.42607	1.12e+01
86P/Wild 3	20010620	JPL#12	3.6352420	0.36447645	15.43861	72.61301	179.16137	20010618.59194	6.93e+00
87P/Bus	20000516	JPL#8	3.4882941	0.37480091	2.57426	182.20705	24.16211	20001229.81088	6.52e+00
88P/Howell	20050311	K043/12	3.1162078	0.56124367	4.38281	56.81719	235.83590	20040412.56379	5.50e+00
89P/Russell 2	20030101	JPL#12	3.8024388	0.39779499	12.02846	42.47686	249.19241	20020322.81482	7.41e+00
90P/Gehrels 1	20030210	JPL#20	6.0422351	0.50913673	9.61527	13.51663	28.23751	20020623.11474	1.49e+01
91P/Russell 3	20050530	JPL#18	3.8884850	0.33086811	14.09186	247.89741	354.69827	20050626.80898	7.67e+00
92P/Sanguin	20040205	JPL#24	5.3664161	0.66308226	18.76465	182.33999	163.07043	20020922.99755	1.24e+01
93P/Lovas 1	20000516	JPL#36	4.3771807	0.61326433	12.23139	340.01543	74.55861	19981014.25658	9.16e+00
94P/Russell 4	20040714	JPL#23	3.5106488	0.36445100	6.18542	70.92869	92.92293	20030829.12725	6.58e+00
96P/Machholz 1	20020725	JPL#41	3.0138019	0.95881324	60.18131	94.60901	14.58389	20020108.62807	5.23e+00
97P/Metcalf-Brewington	20010111	JPL#26	4.8012895	0.45620917	17.98854	186.44419	229.72030	20010415.04204	1.05e+01
98P/Takamizawa	19980706	JPL#13	3.7321122	0.57524677	9.48967	124.84739	147.79689	19981107.98568	7.21e+00
99P/Kowal 1	20050420	K072/2	6.0970389	0.22588929	4.34625	28.39845	172.69631	20070114.68644	1.51e+01
100P/Hartley 1	20030720	K033/11	3.4083284	0.41915379	25.66351	37.89222	181.52895	20030818.00867	6.29e+00
101P/Chernykh	19930513	JPL#16	5.7938889	0.59321658	5.07815	130.39692	263.24654	19920125.40067	1.39e+01
102P/Shoemaker 1	19921204	JPL#20	3.7477004	0.47015250	26.24287	339.95020	18.75061	19911218.15523	7.26e+00
103P/Hartley 2	20050420	JPL#48	3.4523038	0.69956647	13.60743	219.86457	180.89998	20040517.97203	6.41e+00
104P/Kowal 2	20040316	K043/16	3.3667377	0.58532468	15.48938	246.08374	192.03541	20040509.17930	6.18e+00
105P/Singer Brewster	20050709	JPL#27	3.4659884	0.41105179	9.17950	192.47131	46.65617	20050911.33674	6.45e+00
106P/Schuster	20000406	JPL#13	3.7593238	0.58777572	20.13904	50.58942	355.84768	19991216.20756	7.29e+00
108P/Ciffreo	20010111	JPL#15	3.7439240	0.54236246	13.09275	53.72049	358.02517	20000418.34415	7.24e+00
109P/Swift-Tuttle	19951010	JPL#32	26.0920695	0.96322576	113.45382	139.38119	152.98217	19921211.99978	1.33e+02
110P/Hartley 3	20020506	JPL#30	3.6128366	0.31398179	11.69070	287.75389	167.89492	20010321.20061	6.87e+00
111P/Helin-Roman-Crockett	20011018	JPL#6	4.0459558	0.14048021	4.23264	91.95557	10.01662	20041223.99119	8.14e+00
112P/Urata-Niijima	19991208	JPL#14	3.5363294	0.58776040	24.20494	31.94395	21.46697	20000304.40486	6.65e+00
113P/Spitaler	20010220	JPL#25	3.6902578	0.42354904	5.77655	14.52548	50.06300	20010225.87171	7.09e+00
114P/Wiseman-Skiff	20000516	JPL#26	3.5383715	0.55644468	18.29104	271.06970	172.82407	20000111.73825	6.66e+00
115P/Maury	20031117	JPL#11	4.2599100	0.52079387	11.68371	176.75533	119.85216	20021223.79927	8.79e+00
116P/Wild 4	20041022	JPL#87	3.4766299	0.37567697	3.61555	21.05679	173.50806	20030121.82213	6.48e+00
117P/Helin-Roman-Alu 1	20050530	K052/9	4.0813971	0.25585299	8.70747	58.93747	222.62189	20051219.65864	8.25e+00
118P/Shoemaker-Levy 4	20040714	JPL#38	3.4814948	0.42279028	8.48135	152.03316	302.02536	20030716.72975	6.50e+00
119P/Parker-Hartley	20050311	K052/6	4.2928462	0.29079929	5.18765	244.09426	181.41233	20050524.34711	8.89e+00
120P/Mueller 1	20041221	JPL#13	4.1409798	0.33667688	8.78702	4.46017	30.16501	20040930.09520	8.43e+00
121P/Shoemaker-Holt 2	20050530	JPL#33	4.0054431	0.33878869	17.71463	99.65652	6.30046	20040901.94792	8.02e+00
122P/de Vico	19960716	JPL#27	17.6808167	0.96270889	85.38275	79.62450	12.99609	19951006.00017	7.43e+01
123P/West-Hartley	20040823	JPL#56	3.8576249	0.44826919	15.35036	46.61037	102.88322	20031209.00203	7.58e+00
124P/Mrkos	20020506	JPL#17	3.2081197	0.54270322	31.35115	1.39136	181.23883	20020727.00757	5.75e+00
125P/Spacewatch	20021013	JPL#10	3.1294669	0.51159372	9.98212	153.23527	87.29159	20020128.04393	5.54e+00
126P/IRAS	19970313	JPL#9	5.6116618	0.69657553	45.96135	357.70014	356.89050	19961029.99940	1.33e+01
127P/Holt-Olmstead	20031217	JPL#8	3.4243980	0.36948481	14.39652	14.00801	6.50035	20030612.46859	6.34e+00
128P/Shoemaker-Holt 1-A	19961223	JPL#10	4.4881574	0.32104005	4.36157	214.52920	210.19222	19971120.20418	9.51e+00
128P/Shoemaker-Holt 1-B	19990522	JPL#17	4.4944293	0.32189408	4.36149	214.50745	210.33548	19971120.80676	9.53e+00
129P/Shoemaker-Levy 3	20050420	K052/10	3.7394747	0.24937202	5.01202	303.63215	181.66853	20050604.66896	7.23e+00
130P/McNaught-Hughes	20041221	JPL#29	3.5419774	0.40591321	7.30694	89.88565	224.11825	20041023.27804	6.67e+00
131P/Mueller 2	20041221	JPL#26	3.6852314	0.34222181	7.34921	214.22893	179.84684	20041217.57126	7.07e+00
132P/Helin-Roman-Alu 2	19980527	JPL#15	4.0788722	0.53171295	5.77569	178.47785	220.97320	19971110.12241	8.24e+00
134P/Kowal-Vavrova	19990810	JPL#12	6.2330998	0.58684094	4.34545	202.28914	18.69080	19981118.78316	1.56e+01
135P/Shoemaker-Levy 8	19990701	JPL#11	3.8302088	0.28956774	6.05011	213.31757	22.60841	19991210.59430	7.50e+00
136P/Mueller 3	20000117	JPL#16	4.2263123	0.28820561	9.40619	137.80113	225.12721	19990318.22784	8.69e+00
137P/Shoemaker-Levy 2	20010401	JPL#11	4.4410207	0.57951640	4.65785	234.75276	141.91615	20000205.59953	9.36e+00
138P/Shoemaker-Levy 7	19990303	JPL#7	3.6197112	0.53109225	10.08854	309.51772	95.53605	19980824.58765	6.89e+00
139P/Vaisala-Oterma	19990412	JPL#20	4.4972680	0.24806512	2.33291	242.46753	165.58795	19980929.02046	9.54e+00
140P/Bowell-Skiff	19990522	JPL#25	6.3972483	0.69176166	3.83583	343.45646	173.08677	19990514.81193	1.62e+01
141P/Machholz 2-A	20050420	JPL#75	3.0128934	0.75012396	12.79506	246.16159	149.28443	20050228.24850	5.23e+00
141P/Machholz 2-D	19991208	JPL#11	3.0088091	0.75106241	12.81184	246.13363	149.29181	19991209.95528	5.22e+00
142P/Ge-Wang	19991029	JPL#9	5.0003570	0.50070951	12.17188	177.13828	177.35971	19990621.36782	1.12e+01
143P/Kowal-Mrkos	20041111	JPL#21	4.3069203	0.41037417	4.68655	245.41206	320.58522	20000703.27636	8.94e+00
144P/Kushida	20000804	JPL#3	3.8556547	0.62882352	4.11878	245.62509	216.04937	20010627.75320	7.57e+00
145P/Shoemaker-Levy 5	20010220	JPL#13	4.2251247	0.52942391	11.76767	29.67674	6.20663	20000816.99990	8.68e+00
146P/Shoemaker-LINEAR	20010220	JPL#15	3.9585756	0.66681152	21.61536	55.35528	317.74639	20000714.28581	7.88e+00
147P/Kushida-Muramatsu	20020327	JPL#7	3.8033533	0.27659804	2.36782	93.74163	347.26837	20010428.47670	7.42e+00
148P/Anderson-LINEAR	20010220	JPL#12	3.6781787	0.53955615	3.68230	89.80217	6.72999	20010501.97487	7.05e+00
149P/Mueller 4	20010730	JPL#7	4.3299490	0.38874612	29.74807	145.36474	43.61475	20010207.87030	9.01e+00
150P/LONEOS	20010620	JPL#18	3.8857856	0.54662122	18.51996	272.55213	245.50353	20010323.33163	7.66e+00
151P/Helin	20011018	JPL#16	5.8253740	0.56554383	4.71711	143.53821	215.43097	20010923.75607	1.41e+01
152P/Helin-Lawrence	19990427	JPL#28	4.4825970	0.30715738	9.87540	92.02309	163.97626	20021223.96438	9.49e+00
153P/Ikeya-Zhang	20021013	JPL#73	51.2135811	0.99009752	28.11988	93.37027	34.67317	20020318.98078	3.67e+02
154P/Brewington	20030501	JPL#20	4.8433935	0.67164300	18.05971	343.64353	48.00747	20030219.37086	1.07e+01
155P/Shoemaker 3	20030610	JPL#31	6.6343243	0.72667267	6.38589	97.26450	14.91091	20021214.82944	1.71e+01
156P/Russell-LINEAR	20010220	JPL#12	3.6042426	0.55700385	20.74789	39.04243	357.71954	20000817.57450	6.84e+00
157P/Tritton	20040425	JPL#17	3.4657166	0.58993084	7.11624	300.72151	147.41019	20030924.27991	6.45e+00
158P/Kowal-LINEAR	20050311	JPL#8	4.7261650	0.02793209	7.90467	137.30218	234.61879	20020715.92731	1.03e+01
159P/LONEOS	20040212	JPL#20	5.8951990	0.38071268	23.42139	55.16111	4.99512	20040303.05099	1.43e+01
160P/LINEAR	20040618	JPL#14	3.9815274	0.47690602	17.25660	337.06186	18.00594	20041013.05213	7.94e+00
161P/Hartley-IRAS	20050709	JPL#38	7.7319514	0.83508153	95.69812	1.39728	47.07550	20050620.84431	2.15e+01
162P/Siding Spring	20041020	JPL#42	3.0485172	0.59730099	27.84477	31.25263	356.36213	20041110.28300	5.32e+00

163P/NEAT	20050311	JPL#28	3.6630262	0.47586876	12.46464	103.74733	347.17825	20050131.30545	7.01e+00
164P/Christensen	20041209	JPL#19	3.6284740	0.54641376	16.24181	88.68861	325.46072	20040621.90515	6.91e+00
C/Dubiago (1921 H1)	19210421	IAUCAT03	15.7234037	0.92908800	22.32650	67.20650	97.44880	19210505.34680	6.23e+01
C/Tago-Honda-Yamamoto (1968 H1)	19680517	JPL#1	174.3155675	0.99609686	102.16980	233.10788	50.44713	19680516.27136	2.30e+03
C/Tago-Sato-Kosaka (1969 T1)	19700122	JPL#1	6419.6880115	0.99992638	75.81774	101.65980	267.83434	19691221.26781	5.14e+05
C/Mori-Sato-Fujikawa (1975 T1)	19751220	JPL#1	631.6729521	0.99746081	91.60767	278.67849	246.24136	19751225.87791	1.59e+04
C/Kohler (1977 R1)	19771101	JPL#1	2185.7795102	0.99954681	48.71185	182.52270	163.48658	19771110.56999	1.02e+05
C/Seargent (1978 T1)	19790107	JPL#2	212.7745943	0.99826175	67.82781	41.77587	207.75265	19780914.84761	3.10e+03
C/Bradfield (1979 Y1)	19800124	JPL#5	45.0169706	0.98788780	148.60237	103.21654	257.60120	19791221.60604	3.02e+02
C/Meier (1980 V1)	19810605	JPL#3	296.9184061	0.99488197	100.98980	25.43527	87.97674	19801209.66939	5.12e+03
C/Panther (1980 Y2)	19811222	JPL#7	1590.4574005	0.99895798	82.63462	331.99614	105.60150	19810127.31306	6.34e+04
C/Austin (1982 M1)	19830416	JPL#2	995.5484458	0.99934928	84.49809	326.26123	33.82165	19820824.72407	3.14e+04
C/IRAS-Araki-Alcock (1983 H1)	19830512	JPL#9	97.5315423	0.98983570	73.25215	49.10249	192.85153	19830521.25525	9.63e+02
C/Bradfield 1 (1984 A1)	19840629	JPL#2	28.4757026	0.95232793	51.80206	356.85512	219.16649	19831227.79336	1.52e+02
C/Levy-Rudenko (1984 V1)	19850624	JPL#3	1161.1110926	0.99920947	65.71740	331.16823	82.73501	19841214.25837	3.96e+04
C/Hartley-Good (1985 R1)	19851101	JPL#2	5773.1628810	0.99987969	79.92940	358.39587	87.03298	19851209.11637	4.39e+05
C/Nishikawa-Takamizawa-Ta (1987 B1)	19870614	JPL#1	206.5932998	0.99579067	172.22986	176.01271	200.40693	19870317.34675	2.97e+03
C/Bradfield (1987 P1)	19880429	JPL#6	163.1016789	0.99467304	34.09229	268.09155	73.89164	19871107.26977	2.08e+03
C/McNaught (1987 U3)	19880608	JPL#1	708.4614286	0.99881245	97.12552	261.34159	17.41978	19871211.93905	1.89e+04
C/Yanaka (1989 A1)	19890713	JPL#2	1507.8345156	0.99874345	52.40769	157.08385	351.56819	19881031.81429	5.86e+04
P/Shoemaker-Levy 1 (1990 V1)	19910124	JPL#3	6.6778823	0.77177519	24.33167	52.04477	310.62445	19900918.59396	1.73e+01
C/Levy (1991 L3)	19930222	JPL#6	13.8530846	0.92878096	19.15757	329.44354	41.58820	19910707.93546	5.16e+01
C/Shoemaker-Levy (1991 T2)	19920915	JPL#16	5640.9352766	0.99985175	113.49808	49.05061	145.24078	19920724.50730	4.24e+05
P/Shoemaker-Levy 6 (1991 V1)	19920119	JPL#10	3.8463906	0.70560145	16.85440	37.93282	333.13154	19911013.86094	7.54e+00
P/Mueller 5 (1993 W1)	19940130	JPL#23	5.7504583	0.26094745	16.46378	100.66078	29.99565	19940911.92040	1.38e+01
C/McNaught-Russell (1993 Y1)	19940422	JPL#12	134.5693829	0.99355250	51.58658	166.35910	353.46785	19940331.09604	1.56e+03
P/Shoemaker 4 (1994 J3)	19941015	JPL#2	5.9548654	0.50555851	24.80423	92.94265	192.13082	19941014.59845	1.45e+01
P/McNaught-Hartley (1994 N2)	19960207	JPL#3	7.5681183	0.67170676	17.64563	36.00781	312.20086	19941208.22969	2.08e+01
P/McNaught-Russell (1994 X1)	19950503	JPL#4	6.9252669	0.81564123	29.07411	218.00723	171.13919	19940907.93644	1.82e+01
P/Jedicke (1995 A1)	19960207	JPL#3	5.8916258	0.30763353	19.88524	116.00990	295.71767	19930815.88050	1.43e+01
C/Hale-Bopp (1995 O1)	19970105	JPL#212	186.2199051	0.99509107	89.43026	282.47097	130.58885	19970401.13683	2.54e+03
P/Jedicke (1996 A1)	19980706	JPL#13	7.1792411	0.43593771	6.62395	249.17407	223.93416	19950814.53928	1.92e+01
C/Szczepanski (1996 B1)	19960610	JPL#13	155.2330306	0.99066695	51.91909	345.44232	151.28378	19960206.91346	1.93e+03
C/Hyakutake (1996 B2)	19961113	JPL#68	2347.9878030	0.99990196	124.92271	188.05770	130.17293	19960501.39253	1.14e+05
C/Tabur (1996 Q1)	19961130	JPL#12	664.8541599	0.99873685	73.35695	31.40054	57.41120	19961103.53023	1.71e+04
C/Hergenrother-Spahr (1996 R1)	19960927	JPL#10	131.8995967	0.98560117	145.81446	149.74499	139.45686	19960828.73966	1.51e+03
P/Lagerkvist (1996 R2)	19961008	JPL#17	3.7820178	0.30999203	2.60532	40.24084	334.04513	19970119.20014	7.36e+00
P/Kobayashi (1997 B1)	19970601	JPL#11	8.5855096	0.76069686	12.34957	329.06421	183.33755	19970302.34088	2.52e+01
C/Spacewatch (1997 BA6)	19990929	JPL#86	3408.1087145	0.99899169	72.71448	317.66636	285.93421	19991127.56190	1.99e+05
P/Gehrels (1997 C1)	19980308	JPL#23	6.7136698	0.46925701	2.86829	225.87566	211.31756	19960129.01381	1.74e+01
P/Montani (1997 G1)	19980706	JPL#18	7.2240852	0.41674960	3.98897	267.84883	213.45412	19970406.33389	1.94e+01
C/Montani (1997 G2)	19970724	JPL#25	529.1608555	0.99417007	69.83547	55.80253	239.84284	19980416.30111	1.22e+04
C/Mueller (1997 J1)	19970806	JPL#18	255.5409226	0.99099114	122.96833	277.07602	98.95464	19970503.80336	4.09e+03
C/Zhu-Balam (1997 L1)	19980924	JPL#22	1844.8837113	0.99734438	73.00768	233.31347	346.34876	19961122.70532	7.92e+04
C/Tilbrook (1997 O1)	19980417	JPL#18	86.9988240	0.98423212	115.80472	231.25187	336.19067	19970713.42109	8.11e+02
C/Utsunomiya (1997 T1)	19971122	JPL#29	920.4303430	0.99852340	127.99262	53.70276	95.96525	19971210.14489	2.79e+04
P/Lagerkvist-Carsenty (1997 T3)	19990303	JPL#21	6.6818528	0.36531970	4.83519	63.19843	334.27740	19980311.78089	1.73e+01
P/Larsen (1997 V1)	19980308	JPL#11	4.9301144	0.33199024	12.09081	234.83795	132.86593	19970915.11225	1.09e+01
C/LINEAR (1998 G1)	19980706	JPL#15	12.0946699	0.82361472	109.71414	341.38402	236.32507	19981116.63006	4.21e+01
C/Stonehouse (1998 H1)	19980815	JPL#13	703.2326776	0.99788510	104.69371	222.11031	1.32371	19980414.42328	1.86e+04
C/Mueller (1998 K1)	19980605	JPL#14	62.3657691	0.94521621	35.63587	18.25633	165.25015	19980901.03861	4.93e+02
C/LINEAR (1998 K2)	20000406	JPL#34	2002.3298083	0.99883832	64.47970	68.75392	221.48297	19980901.11820	8.96e+04
C/LINEAR (1998 K3)	19980815	JPL#14	1833.3818583	0.99806568	160.20579	307.94922	47.83366	19980307.21216	7.85e+04
C/LINEAR (1998 K5)	19980726	JPL#29	72.4089346	0.98669298	9.92714	211.11769	99.46028	19980717.44622	6.16e+02
C/LINEAR (1998 M1)	19991208	JPL#23	422.1116439	0.99261044	20.38427	256.05847	19.45424	19981028.22694	8.67e+03
C/LINEAR (1998 M2)	19980819	JPL#17	1216.7387786	0.99776013	60.18235	260.88021	37.24309	19980813.17265	4.24e+04
C/LINEAR (1998 M4)	19980924	JPL#7	1095.4441199	0.99762626	154.57228	92.92186	106.29731	19971210.15060	3.63e+04
C/LINEAR (1998 M5)	19981117	JPL#42	438.4266619	0.99602603	82.22890	333.37677	101.28254	19990124.56830	9.18e+03
C/Williams (1998 P1)	19990522	JPL#64	3144.1945595	0.99963557	145.72669	156.37162	294.43777	19981017.84284	1.76e+05
C/LINEAR (1998 Q1)	19981213	JPL#17	369.1878912	0.99572671	32.30269	159.78224	134.72458	19980629.50793	7.09e+03
P/LONEOS-Tucker (1998 QP54)	19990303	JPL#20	4.1974776	0.55167462	17.74273	341.92538	30.09087	19981006.36946	8.60e+00
P/LINEAR-Mueller (1998 S1)	20010401	JPL#25	4.3659202	0.41556462	10.55588	359.19263	26.41489	19981102.51096	9.12e+00
C/LINEAR (1998 T1)	19990510	JPL#76	1647.0496993	0.99910888	170.15992	153.35749	226.35153	19990625.24916	6.68e+04
P/Mueller (1998 U2)	19990303	JPL#13	4.2312080	0.52134700	2.19322	336.21993	49.53145	19981020.73492	8.70e+00
P/Jager (1998 U3)	19990522	JPL#30	6.0671146	0.64828495	19.14077	303.54228	180.89729	19990310.07566	1.49e+01
P/Spahr (1998 U4)	19990302	JPL#24	5.5702267	0.31001983	31.51909	181.71686	251.74981	19990226.51080	1.31e+01
C/LINEAR (1998 U5)	19981129	JPL#39	102.8684845	0.98798026	131.76471	66.65059	51.13424	19981221.75996	1.04e+03
P/LINEAR (1998 VS24)	19990122	JPL#9	4.5032938	0.24378766	5.03103	159.19876	244.60998	19981103.34129	9.56e+00
P/Spahr (1998 W1)	19990102	JPL#18	3.5225574	0.51007965	21.96185	101.97326	346.67687	19990117.95128	6.61e+00
P/Hergenrother (1998 W2)	19990522	JPL#24	3.6251340	0.60824022	21.92916	356.50214	13.88122	19981205.93119	6.90e+00
P/ODAS (1998 X1)	19990522	JPL#20	3.5782762	0.44814371	1.35198	358.84388	68.82717	19980721.01721	6.77e+00
C/LINEAR (1998 Y1)	19990522	JPL#11	22.9882557	0.92400197	28.10712	98.85690	339.85130	19981121.59308	1.10e+02
P/Li (1998 Y2)	19990118	JPL#13	6.1208083	0.58848341	24.32405	91.83139	318.98178	19981217.80729	1.51e+01
C/Tilbrook (1999 A1)	19990303	JPL#10	176.0061255	0.99584820	89.48109	259.12221	232.67130	19990129.65813	2.34e+03
P/Hermann (1999 D1)	19990522	JPL#10	5.7607358	0.71277929	21.52166	349.37501	173.09837	19990218.02814	1.38e+01
P/Korlevic-Juric (1999 DN3)	19990427	JPL#10	4.5191860	0.13516762	18.71950	5.95448	161.30187	19980930.82226	9.61e+00
C/Li (1999 E1)	19990910	JPL#19	16.3401638	0.76009902	46.88133	127.83435	329.76788	19990131.77805	6.61e+01
C/Dalcanton (1999 F2)	19990929	JPL#16	2629.6358182	0.99820581	56.42738	210.29773	352.35241	19980823.68837	1.35e+05
C/LINEAR (1999 G1)	19990522	JPL#3	26.1703797	0.84563054	76.31914	23.48364	135.98948	19980731.82831	1.34e+02
C/Lee (1999 H1)	20000117	JPL#38	2966.7105362	0.99976137	149.34438	162.65946	40.70165	19990711.17718	1.62e+05
C/LINEAR (1999 J3)	19990902	JPL#40	1616.3912157	0.99939569	101.65608	228.97899	161.98104	19990920.16717	6.50e+04
P/LINEAR (1999 J5)	19990615	JPL#12	4.4708599	0.16952501	13.71793	112.01336	132.21298	19990512.31806	9.45e+00
C/LINEAR (1999 K3)	19990810	JPL#17	232.9995904	0.99172192	92.27492	266.91416	341.14958	19990227.53183	3.56e+03

C/LINEAR (1999 K4)	19990701	JPL#6	28.8610532	0.94993942	120.99251	241.54300	8.80026	19990516.39538	1.55e+02
C/LINEAR (1999 K6)	20000117	JPL#20	347.2354789	0.99352856	46.34448	245.37033	56.77471	19990724.69624	6.47e+03
C/LINEAR (1999 K7)	19990810	JPL#5	690.9842293	0.99663845	135.15956	50.33012	104.66380	19990224.79033	1.82e+04
C/LINEAR (1999 L2)	19990810	JPL#13	391.2410770	0.99513152	43.94214	94.28979	178.71866	19990804.89046	7.74e+03
C/LINEAR (1999 L3)	19991222	JPL#23	77.5850430	0.97436468	166.09929	140.16131	353.29781	20000104.90823	6.83e+02
C/Lynn (1999 N2)	19991029	JPL#8	296.1557645	0.99742950	111.65623	254.67692	357.83285	19990723.04968	5.10e+03
P/LONEOS (1999 RO28)	19991208	JPL#12	3.5275907	0.65082116	8.19079	148.44423	219.86469	19991002.34302	6.63e+00
C/LINEAR (1999 S3)	20000406	JPL#32	18.9120227	0.89979987	70.56043	11.87782	44.13146	19991109.01927	8.22e+01
C/LINEAR (1999 S4)	20000724	JPL#87	1471.0598387	0.99947987	149.39055	83.19093	151.05663	20000726.17774	5.64e+04
C/McNaught-Hartley (1999 T1)	20001112	JPL#77	8502.0409336	0.99986219	79.97525	182.48298	344.75829	20001213.47222	7.84e+05
P/LINEAR (1999 U3)	20000406	JPL#17	4.8458480	0.61898617	20.39570	306.97590	111.31558	19991118.45771	1.07e+01
P/Catalina (1999 V1)	19991223	JPL#32	6.5513602	0.55058205	15.58671	294.31115	186.69791	19991025.07349	1.68e+01
P/Korlevic (1999 WJ7)	20000905	JPL#42	4.6315135	0.31609732	2.97992	290.53059	154.55356	20000215.88732	9.97e+00
P/Hug-Bell (1999 X1)	20000226	JPL#8	3.6718450	0.47251535	10.96980	103.64769	296.91329	19990620.80558	7.04e+00
P/LINEAR (1999 XB69)	20000516	JPL#9	4.4546040	0.63200406	11.33638	256.16596	220.18488	20000217.04473	9.40e+00
C/LINEAR (1999 XS87)	20000406	JPL#11	17.3736979	0.84045403	14.84659	266.72959	151.35556	19990806.59966	7.24e+01
P/Catalina (1999 XN120)	20000115	JPL#29	4.1803503	0.21387451	5.02844	285.46914	161.78628	20000501.39397	8.55e+00
C/LINEAR (2000 B2)	20000406	JPL#13	6025.1263892	0.99937325	93.64865	284.99112	154.60264	19991110.10158	4.68e+05
P/LINEAR (2000 B3)	20000308	JPL#44	4.0025154	0.57520546	11.12616	352.14772	130.50623	20000214.15953	8.01e+00
P/Hergenrother (2000 C1)	20000308	JPL#15	3.5302758	0.40640735	6.10538	127.04468	51.16295	20000319.85852	6.63e+00
C/LINEAR (2000 CT54)	20011120	JPL#58	2159.9454228	0.99853881	49.20834	18.96061	272.64902	20010619.48440	1.00e+05
C/LINEAR (2000 D2)	20000406	JPL#10	17.2791616	0.86703022	156.99195	235.88718	117.68461	20000308.61897	7.18e+01
P/LINEAR (2000 G1)	20000804	JPL#20	3.0581408	0.67207283	10.37686	191.02297	343.29290	20000309.80631	5.35e+00
C/LINEAR (2000 G2)	20000516	JPL#8	14.3069557	0.81008902	170.47909	328.38354	101.76734	20000206.23396	5.41e+01
C/Ferris (2000 J1)	20000625	JPL#14	56.0776289	0.95465869	98.79548	28.43916	147.22181	20000511.30882	4.20e+02
C/LINEAR (2000 K2)	20010103	JPL#43	529.2603152	0.99539533	25.63352	195.26136	106.82675	20001011.37064	1.22e+04
P/LINEAR (2000 R2)	20001202	JPL#8	3.3390103	0.58371147	3.21627	187.49934	147.06969	20000912.66629	6.10e+00
P/Skiff (2000 S1)	20001016	JPL#22	6.5887411	0.61845258	21.00761	29.13834	308.45324	20000714.70460	1.69e+01
C/LONEOS (2000 S3)	20010111	JPL#7	11.7006410	0.77245880	25.16305	41.15440	298.28334	20000716.35236	4.00e+01
P/LINEAR-Spacewatch (2000 S4)	20001202	JPL#7	7.1211271	0.68187268	28.32612	174.64482	172.32247	20001019.09421	1.90e+01
P/Tichy (2000 U6)	20010220	JPL#18	3.7902894	0.43151015	19.36530	24.42341	11.83964	20001004.54823	7.38e+00
C/Utsunomiya-Jones (2000 W1)	20001210	JPL#19	1017244.1165620	0.99999968	160.16544	10.76589	51.50885	20001226.55928	1.03e+09
C/Skiff (2000 Y2)	20010216	JPL#44	491.7351811	0.99436948	12.08755	185.84802	326.81965	20010321.81165	1.09e+04
P/Scotti (2000 Y3)	20010806	JPL#43	5.0399453	0.19701914	2.24952	354.98367	88.57632	20001030.92298	1.13e+01
C/LINEAR (2001 A1)	20010203	JPL#39	266.3830255	0.99096618	59.94127	339.59426	107.88909	20000917.61994	4.35e+03
C/LINEAR (2001 A2-A)	20010520	JPL#2	2530.5300244	0.99969214	36.48661	295.12772	295.32273	20010524.52366	1.27e+05
C/LINEAR (2001 A2-B)	20011205	JPL#59	1025.2588044	0.99924030	36.47703	295.12590	295.31671	20010524.51746	3.28e+04
P/LINEAR-NEAT (2001 BB50)	20010410	JPL#32	5.6816719	0.58694573	10.61722	355.81579	189.34314	20010130.42364	1.35e+01
P/LINEAR (2001 CV8)	20010620	JPL#21	3.8786733	0.44515291	9.04208	359.95362	151.45542	20010212.35819	7.64e+00
P/NEAT (2001 F1)	20010526	JPL#25	6.4493255	0.35601300	19.08743	92.83185	80.80617	20001122.57566	1.64e+01
P/NEAT (2001 H5)	20010730	JPL#9	5.9953406	0.60025212	8.39927	329.56000	224.88071	20010128.70296	1.47e+01
C/LINEAR-NEAT (2001 HT50)	20030824	JPL#102	1170.3059521	0.99761424	163.21190	42.91285	324.06922	20030709.01607	4.00e+04
P/NEAT (2001 J1)	20010507	JPL#43	3.8772367	0.75831457	10.15920	200.79616	271.02522	20010314.10595	7.63e+00
P/NEAT (2001 K1)	20010730	JPL#17	3.8457582	0.35759935	16.91282	84.83717	94.65525	20001106.93085	7.54e+00
C/Skiff (2001 K3)	20010718	JPL#53	2878.5298739	0.99893691	52.02660	289.85013	3.45256	20010422.87751	1.54e+05
P/LINEAR (2001 MD7)	20011021	JPL#46	3.9705741	0.68410582	13.52393	129.16878	244.84669	20011130.13207	7.91e+00
C/NEAT (2001 O2)	20011018	JPL#31	2898.2225113	0.99833278	91.01223	328.69922	281.07532	19991017.65382	1.56e+05
C/LONEOS (2001 OG108)	20011215	JPL#31	13.3003613	0.92526170	80.24502	10.55531	116.41960	20020315.20597	4.85e+01
P/Petriew (2001 Q2)	20020327	JPL#28	3.1127221	0.69624339	13.94486	214.09787	181.89546	20010901.91637	5.49e+00
P/LINEAR-NEAT (2001 Q5)	20020106	JPL#17	3.5027391	0.41668292	10.94481	336.26419	6.41468	20010611.65906	6.56e+00
P/NEAT (2001 Q6)	20011025	JPL#44	7.9946763	0.82386047	56.85527	22.13591	43.32926	20011109.46604	2.26e+01
P/LONEOS (2001 R1)	20020106	JPL#23	3.4758148	0.60859864	7.04158	35.48588	24.75582	20020217.59380	6.48e+00
P/LINEAR-Skiff (2001 R6)	20020106	JPL#16	4.1146491	0.48596327	17.34459	70.32342	306.19172	20011027.09403	8.35e+00
C/Skiff (2001 S1)	20011127	JPL#8	54.9638840	0.93177356	139.13598	330.11229	285.19080	20010602.54034	4.07e+02
P/NEAT (2001 T3)	20011117	JPL#18	6.5060298	0.61485808	19.19863	56.53873	356.23302	20020201.09384	1.66e+01
P/LINEAR-NEAT (2001 TU80)	20020506	JPL#14	3.6587896	0.47182982	6.58723	109.10274	355.12284	20011209.96726	7.00e+00
C/LINEAR (2001 U6)	20020325	JPL#45	1152.2982645	0.99617597	107.25547	115.23053	85.71510	20020808.65942	3.91e+04
C/LINEAR (2001 W1)	20020110	JPL#28	225734.1320214	0.99998937	118.65291	91.94069	6.15797	20011224.88927	1.07e+08
C/BATTERS (2001 W2)	20011205	JPL#19	17.9294235	0.94137761	115.91307	113.35591	142.08585	20011223.91835	7.59e+01
P/LONEOS (2001 WF2)	20011227	JPL#43	2.9292772	0.66669330	16.92424	75.13685	51.35012	20020129.84970	5.01e+00
C/LINEAR (2001 X1)	20020106	JPL#45	593.8804970	0.99714093	115.62715	336.07098	202.20144	20020108.09232	1.45e+04
P/Scotti (2001 X2)	20020108	JPL#38	3.7769940	0.33181237	2.18425	194.63808	255.89703	20011014.57390	7.34e+00
P/LINEAR (2001 YX127)	20030211	JPL#18	4.1761513	0.17959424	7.90565	31.15327	115.93109	20030307.46583	8.53e+00
C/LINEAR (2002 A1)	20020725	JPL#31	17.0493697	0.72372469	14.04075	81.73752	18.91051	20011126.90722	7.04e+01
C/LINEAR (2002 A2)	20020516	JPL#14	17.1108228	0.72493255	14.03974	81.88013	19.26015	20011205.19621	7.08e+01
P/LINEAR (2002 AR2)	20020410	JPL#2	5.3737496	0.61582861	21.10924	7.83622	73.67720	20020116.52211	1.25e+01
P/Yeung (2002 BV)	20020320	JPL#8	3.5132610	0.36114609	11.51511	40.14109	178.77088	20020311.05871	6.59e+00
C/LINEAR (2002 B1)	20020208	JPL#29	9.9180063	0.77100928	51.02136	58.18546	76.15813	20020420.00465	3.12e+01
C/LINEAR (2002 B2)	20020506	JPL#6	1611.3490193	0.99761551	152.87257	54.31862	257.07754	20020406.85986	6.47e+04
C/LINEAR (2002 C2)	20020518	JPL#17	8897.6099216	0.99963431	104.88161	242.95594	159.93395	20020410.81633	8.39e+05
C/LINEAR (2002 CE10)	20030708	JPL#26	9.8165710	0.79149951	145.45867	147.44390	126.18823	20030622.09912	3.08e+01
P/LINEAR (2002 CW134)	20020322	JPL#10	3.6026532	0.48939073	15.22625	348.31684	190.11105	20020228.94434	6.84e+00
P/LINEAR (2002 EJ57)	20020516	JPL#4	6.4885892	0.59380709	4.96953	330.38382	166.90577	20011219.16677	1.65e+01
C/Utsunomiya (2002 F1)	20020516	JPL#10	969.8228397	0.99954807	80.87653	289.02933	125.89956	20020422.89837	3.02e+04
C/LINEAR (2002 H2)	20020521	JPL#17	275.7649163	0.99407162	110.50109	269.00206	20.41941	20020323.40865	4.58e+03
C/NEAT (2002 J4)	20030301	JPL#32	23504.6013977	0.99984540	46.52607	70.88460	230.71069	20031003.19150	3.60e+06
P/LINEAR (2002 JN16)	20020607	JPL#31	3.4843330	0.48610488	11.41278	230.07751	39.62876	20020727.59860	6.50e+00
C/NEAT (2002 K1)	20020624	JPL#6	9816.8346316	0.99967095	89.72172	280.54835	4.45896	20020616.44660	9.73e+05
C/NEAT (2002 K4)	20020713	JPL#16	17.5281964	0.84228181	94.06266	308.09899	24.43178	20020712.97382	7.34e+01
P/LINEAR (2002 LZ11)	20030811	JPL#16	3.6558610	0.35160372	11.51979	231.13989	107.96444	20030315.62010	6.99e+00
P/NEAT (2002 O5)	20020811	JPL#30	2.9171548	0.59746762	20.39996	282.20894	15.30683	20020803.10213	4.98e+00
C/SWAN (2002 O6)	20020810	JPL#5	352.9461745	0.99859852	58.62438	330.95193	78.74835	20020909.44932	6.63e+03
P/NEAT (2002 O8)	20021007	JPL#11	4.0329977	0.19927125	12.78517	75.49859	222.25784	20020508.47574	8.10e+00

P/Van Ness (2002 Q1)	20020903	JPL#5	3.5357013	0.56970481	36.36879	174.10366	184.75216	20020715.99145	6.65e+00
C/LINEAR (2002 Q2)	20020903	JPL#7	59.6844182	0.97816746	96.76694	154.28328	125.47531	20020817.78808	4.61e+02
P/Skiff (2002 S1)	20021015	JPL#18	4.0394136	0.42923065	27.68754	347.37971	35.45109	20020325.28025	8.12e+00
P/LINEAR (2002 T1)	20021019	JPL#28	3.5449242	0.66374926	20.71015	15.50372	1.31255	20021008.08623	6.67e+00
P/LINEAR (2002 T5)	20031022	JPL#49	6.9885442	0.43705865	30.90355	123.33228	326.78084	20030628.01096	1.85e+01
P/NEAT-LINEAR (2002 T6)	20030728	JPL#34	7.6518114	0.55734706	11.00930	209.04613	217.57590	20030627.03165	2.12e+01
C/NEAT (2002 V1)	20021226	JPL#33	1010.4581580	0.99990177	81.70600	64.08843	152.16964	20030218.29578	3.21e+04
C/LINEAR (2002 X1)	20030412	JPL#42	1397.9952329	0.99822124	164.08957	281.88697	207.32455	20030712.88660	5.23e+04
P/NEAT (2002 X2)	20030212	JPL#11	4.0349193	0.37328737	25.35449	78.15434	356.03624	20030329.60384	8.11e+00
C/Kudo-Fujikawa (2002 X5)	20030120	JPL#33	1175.1270382	0.99983837	94.15235	119.06506	187.58470	20030129.00228	4.03e+04
C/Juels-Holvorcem (2002 Y1)	20030212	JPL#23	250.6037908	0.99715164	103.78165	166.22019	128.81563	20030413.24810	3.97e+03
P/LINEAR (2003 A1)	20030201	JPL#11	3.6914456	0.48101412	46.26197	55.19253	357.07664	20030201.23797	7.09e+00
P/LINEAR-NEAT (2003 CP7)	20030401	JPL#10	4.0158769	0.24875430	12.33935	133.12593	42.62510	20030429.37183	8.05e+00
C/NEAT (2003 E1)	20031008	JPL#27	13.7256080	0.76358306	33.53789	137.07004	103.85858	20040213.60220	5.09e+01
C/LINEAR (2003 F1)	20030528	JPL#28	20.6639570	0.80604776	70.22162	87.48755	121.18695	20030628.45325	9.39e+01
P/NEAT (2003 F2)	20030406	JPL#4	6.5041185	0.54226675	11.60389	359.02854	191.61321	20030414.86777	1.66e+01
C/LINEAR (2003 G2)	20030503	JPL#3	178.9034810	0.99132076	96.11562	24.56779	190.70693	20030429.98335	2.39e+03
C/LINEAR (2003 H1)	20030815	JPL#42	2680.4482469	0.99916445	138.66725	19.00030	196.13870	20040222.62225	1.39e+05
C/LINEAR (2003 H2)	20030523	JPL#12	38.1724731	0.94292949	74.21781	79.83799	155.08231	20030517.96935	2.36e+02
C/NEAT (2003 H3)	20030728	JPL#30	12913.2485336	0.99977531	42.81176	269.41727	6.47750	20030424.23098	1.47e+06
P/LINEAR (2003 H4)	20030526	JPL#10	3.3394058	0.48999642	18.14809	226.79346	10.44777	20030514.30522	6.10e+00
P/LINEAR (2003 HT15)	20030429	JPL#14	4.6051014	0.41988311	27.67021	81.47277	124.04561	20030417.70602	9.88e+00
C/Spacewatch (2003 K1)	20030530	JPL#5	44.0381674	0.95257752	129.85382	250.06367	314.56398	20021221.36978	2.92e+02
P/Christensen (2003 K2)	20030602	JPL#9	3.2174764	0.82921916	10.14063	93.89492	345.57952	20030407.85849	5.77e+00
P/LINEAR (2003 KV2)	20030605	JPL#21	2.8672238	0.62925331	25.53910	66.40964	188.74152	20030710.84818	4.86e+00
C/LINEAR (2003 L2)	20030917	JPL#29	154.4900155	0.98145643	82.05108	273.55929	119.84138	20040119.19213	1.92e+03
P/LINEAR (2003 O2)	20030910	JPL#23	4.2530962	0.64603572	14.69110	344.71091	32.72085	20030905.80924	8.77e+00
P/LINEAR (2003 O3)	20030830	JPL#17	3.1046597	0.59854526	8.36448	341.50079	0.76328	20030814.06399	5.47e+00
P/NEAT (2003 QX29)	20030828	JPL#8	8.0242788	0.47167951	11.39605	264.57850	37.27465	20021026.58131	2.27e+01
C/LINEAR (2003 R1)	20031012	JPL#11	19.6979897	0.89329498	149.19562	356.68916	302.68944	20030629.61508	8.74e+01
P/NEAT (2003 S1)	20031115	JPL#19	4.5582284	0.43055749	5.94489	241.06827	175.81395	20040327.61134	9.73e+00
P/NEAT (2003 S2)	20031101	JPL#17	3.8328827	0.35882488	7.63747	87.77411	284.22918	20030907.31546	7.50e+00
C/LINEAR (2003 S4-A)	20041018	JPL#4	39.3031069	0.90181603	40.60734	224.55066	154.44564	20040526.58899	2.46e+02
C/LINEAR (2003 S4-B)	20041018	JPL#4	39.3035722	0.90181915	40.60711	224.55126	154.44737	20040526.59660	2.46e+02
P/NEAT-LONEOS (2003 SQ215)	20031217	JPL#12	5.5078131	0.58163577	5.54592	257.63790	137.30257	20040324.21680	1.29e+01
C/LINEAR (2003 T2)	20031129	JPL#16	7813.1868405	0.99977137	87.53194	238.53249	152.23332	20031114.02812	6.91e+05
C/Tabur (2003 T3)	20040801	JPL#61	5664.5053592	0.99973853	50.44448	347.05761	43.77367	20040429.00158	4.26e+05
C/LINEAR (2003 T4)	20050530	JPL#99	7301.0627840	0.99988362	86.76469	93.90258	181.62367	20050403.63979	6.24e+05
C/LINEAR (2003 U1)	20031104	JPL#11	22.8884978	0.92154523	164.47460	322.76296	278.38358	20031103.39773	1.10e+02
P/LINEAR (2003 U2)	20031029	JPL#7	4.5175364	0.62136752	24.49144	186.45718	177.32079	20031204.87786	9.60e+00
P/NEAT (2003 U3)	20031105	JPL#10	5.0811379	0.50881372	7.04679	348.36942	356.24713	20030423.05114	1.15e+01
P/LINEAR (2003 UY275)	20031201	JPL#6	3.7286981	0.50879754	16.33026	245.75129	119.37709	20030702.08194	7.20e+00
C/LINEAR (2003 V1)	20040112	JPL#26	620.3876191	0.99712588	28.67515	25.83356	8.63143	20030311.19692	1.55e+04
C/LINEAR (2003 W1)	20031205	JPL#9	25.1728697	0.93435694	78.07604	256.74256	113.28868	20031109.46298	1.26e+02
P/LINEAR-Catalina (2003 WC7)	20040213	JPL#6	5.1864449	0.68092123	21.21993	89.88811	341.05808	20040205.74685	1.18e+01
P/LINEAR-NEAT (2003 XD10)	20031220	JPL#5	3.3388052	0.43667953	14.72716	43.55522	9.14286	20030916.84618	6.10e+00
P/LINEAR (2004 CB)	20040304	JPL#29	2.9367605	0.68939195	19.14693	66.48766	149.65524	20040402.16318	5.03e+00
C/Larsen (2004 C1)	20040226	JPL#6	11.5696370	0.62320471	28.91860	151.95393	316.14468	20030319.60108	3.94e+01
P/Spacewatch-LINEAR (2004 DO29)	20040312	JPL#9	7.4585105	0.45094412	14.54727	147.87212	41.87920	20041011.96421	2.04e+01
C/Catalina-LINEAR (2004 DZ61)	20040323	JPL#28	45.7835084	0.95602498	66.80930	172.79184	44.46207	20040526.85782	3.10e+02
P/Catalina-LINEAR (2004 EW38)	20040401	JPL#6	3.5885367	0.50028276	6.52368	49.89498	90.22341	20031119.86141	6.80e+00
P/NEAT (2004 F1)	20040318	JPL#5	4.4691820	0.45169456	18.26771	111.89533	26.33881	20031019.64279	9.45e+00
C/LINEAR (2004 F2)	20040429	JPL#11	151.6483463	0.99056738	104.96007	248.27358	317.14343	20031226.64601	1.87e+03
P/NEAT (2004 F3)	20040610	JPL#25	4.0163550	0.28685079	15.98581	78.83703	176.07406	20050104.09106	8.05e+00
C/Bradfield (2004 F4)	20040601	JPL#29	238.3557688	0.99929406	63.16464	222.77820	332.78604	20040417.08996	3.68e+03
C/LINEAR (2004 G1)	20040415	JPL#7	247.6798750	0.99515279	114.48523	228.33580	110.64486	20040604.98266	3.90e+03
P/Larsen (2004 H2)	20040512	JPL#8	4.5029340	0.41876191	11.78673	131.55199	104.56631	20040510.98225	9.56e+00
P/Larsen (2004 H3)	20040505	JPL#6	3.8939638	0.37409348	25.15601	220.97363	346.49688	20040312.94750	7.68e+00
P/LINEAR (2004 HC18)	20040620	JPL#19	3.4897633	0.50956539	23.50713	219.56096	30.84057	20040618.67830	6.52e+00
C/Spacewatch (2004 HV60)	20040509	JPL#2	30.8548696	0.90141471	91.92917	44.80085	146.93300	20031212.62569	1.71e+02
C/Catalina (2004 K1)	20050101	JPL#30	1743.5668423	0.99805039	153.74743	326.92240	97.74393	20050705.07554	7.28e+04
P/McNaught (2004 K2)	20040826	JPL#17	3.1169880	0.50129606	8.12283	150.12389	180.77259	20040616.81367	5.50e+00
C/LINEAR (2004 K3)	20040611	JPL#7	57.7919019	0.98090830	111.92795	275.53668	60.49224	20040630.45820	4.39e+02
C/LINEAR (2004 L1)	20041218	JPL#23	854.8298076	0.99760489	159.36020	66.17326	243.57942	20050330.11124	2.50e+04
C/LINEAR (2004 L2)	20040901	JPL#9	734.9791454	0.99485858	62.52747	99.18794	257.30584	20051115.11888	1.99e+04
C/Tucker (2004 Q1)	20041122	JPL#42	186.9855350	0.98905411	56.08753	22.13008	32.96889	20041206.86583	2.56e+03
C/Machholz (2004 Q2)	20050114	JPL#55	2104.4421937	0.99942738	38.58891	93.62421	19.50471	20050124.91180	9.65e+04
P/McNaught (2004 R1)	20040915	JPL#10	3.1113023	0.68229270	4.89054	296.00592	0.60310	20040830.21000	5.49e+00
P/LINEAR-NEAT (2004 R3)	20040929	JPL#10	3.8371263	0.44190869	7.97288	318.80991	5.28427	20040524.46856	7.52e+00
C/LINEAR (2004 RG113)	20050131	JPL#26	699.3997185	0.99722282	21.61826	8.77308	125.30509	20050303.71698	1.85e+04
P/LINEAR-NEAT (2004 T1)	20041107	JPL#19	3.4722385	0.50764463	11.03801	51.45996	336.52387	20041107.77019	6.47e+00
C/LINEAR (2004 U1)	20041224	JPL#23	3099.9161487	0.99914212	130.62314	112.54610	20.12519	20041208.74950	1.73e+05
P/Skiff (2004 V1)	20041212	JPL#14	4.6348267	0.69395807	11.46707	242.23773	144.76148	20041208.86358	9.98e+00
P/Siding Spring (2004 V3)	20041219	JPL#9	7.1166026	0.44660623	50.45019	356.09553	322.44451	20041111.87671	1.90e+01
P/LINEAR-Hill (2004 V5-A)	20050125	JPL#32	7.9502398	0.44519090	19.35822	47.86035	87.66568	20050228.56229	2.24e+01
P/LINEAR-Hill (2004 V5-B)	20050126	JPL#25	7.9506372	0.44521351	19.35825	47.86017	87.66082	20050228.75683	2.24e+01
P/LONEOS (2004 VR8)	20050107	JPL#22	4.8481874	0.50995548	20.11548	71.21606	63.08596	20050902.46828	1.07e+01
P/LINEAR (2004 WR9)	20041227	JPL#14	6.0622344	0.68374598	5.04839	25.44877	70.64295	20050111.51038	1.49e+01
P/LINEAR (2004 X1)	20041219	JPL#9	2.8621060	0.72662024	5.14157	7.13946	345.45040	20041101.92704	4.84e+00
C/LINEAR (2004 X2)	20050114	JPL#16	1484.5224955	0.99744491	72.11871	307.34135	162.21360	20040824.32602	5.72e+04
P/Tubbiolo (2005 E1)	20050326	JPL#9	7.2240036	0.38455308	5.15444	4.41404	170.62796	20050316.90271	1.94e+01
C/McNaught (2005 E2)	20050427	JPL#10	17793.0169688	0.99991459	16.98853	347.85052	39.97022	20060223.52700	2.37e+06
P/LONEOS (2005 GF8)	20050424	JPL#6	5.8606886	0.51715471	1.18944	315.22559	285.25052	20050817.42725	1.42e+01

C/LINEAR (2005 H1)	20050511	JPL#12	45.9515817	0.89635385	81.49353	71.52085	94.94756	20041026.65247	3.12e+02
P/Spacewatch (2005 JN)	20050503	JPL#4	3.4983627	0.34953881	8.85588	70.80378	153.64945	20050620.36832	6.54e+00
P/McNaught (2005 J1)	20050510	JPL#4	3.5643323	0.57074747	31.76101	268.83806	338.91158	20050417.29073	6.73e+00
P/Catalina (2005 JQ5)	20050520	JPL#6	2.6928654	0.69343124	5.69531	95.86361	222.69488	20050728.04340	4.42e+00
P/Catalina (2005 JY126)	20050524	JPL#1	3.7525359	0.43346128	20.22550	207.97038	117.56347	20060221.14199	7.27e+00
P/McNaught (2005 K3)	20050528	JPL#2	4.6624562	0.66926116	15.65434	352.84430	12.55916	20050807.16363	1.01e+01
P/McNaught (2005 L1)	20050602	JPL#2	3.9734481	0.20775608	7.74521	138.30189	149.87445	20051215.25559	7.92e+00

Description of Table Columns

"Object Designation"
Name and/or designation of the asteroid or comet

"Epoch"
Epoch of the osculating orbital elements (YYYYMMDD)

"Ref."
Orbit solution reference: "JPL..." = Jet Propulsion Laboratory, "MPC..." = Minor Planet Center, "IHW..." = International Halley Watch, "BM..." = Brian G. Marsden, and "BGMCAT..." = Brian G. Marsden Catalog

"a (AU)"
Semi-major axis (AU)

"e"
Eccentricity

"i (deg)"
Inclination (degrees, J2000 ecliptic)

"W (deg)"
Longitude of the ascending node (degrees, J2000 ecliptic)

"w (deg)"
Argument of perihelion (degrees, J2000 ecliptic)

"TP"
Time of perihelion passage (YYYYMMDD.DDDDD)

"P (yr)"
Orbital period (years)