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rosetta

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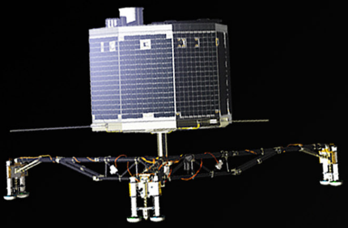
OCTOBER 2014

‘GO’ FOR PRIMARY LANDING SITE



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European Space Agency

Rosetta is one of the most complex and ambitious missions ever undertaken.

It will perform unique science. No other mission has Rosetta's potential to look back to the infant Solar System when our planet was forming, and investigate the role comets may have played in seeding Earth with water, perhaps even the ingredients for life.

To do this, Rosetta will be the first mission to orbit and land on a comet. To get there, scientists had to plan in advance, in the greatest possible detail, a ten-year trip through the Solar System.

Approaching, orbiting, and landing on a comet require delicate and spectacular manoeuvres. Rosetta's target, comet 67P/Churyumov-Gerasimenko, is a relatively small object, about 4 kilometres along its longest side, moving at a speed as great as 120,000 kilometres per hour with respect to the Sun.

Prior to arriving at the comet, very little was known about its surface properties or the close environment. Only after arrival were we able to explore the comet in such detail that we can safely orbit it and deploy the lander.

Rosetta's lander will obtain the first images from a comet's surface and make the first in-situ analysis of a comet's composition.

Rosetta will also be the first mission to investigate a comet's nucleus and environment over an extended period of time. It will witness, at close proximity, how a comet changes as it approaches the increasing intensity of the Sun's radiation and then returns to the outer Solar System.

Rosetta is an ESA mission with contributions from its member states and NASA. Rosetta's Philae lander is provided by a consortium led by DLR, MPS, CNES and ASI.

Cover image: Artist's impression of Rosetta and Philae with comet 67P/ Churyumov-Gerasimenko
Credit: ESA/Rosetta/NAVCAM - C. Carreau

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Press briefing schedule for Rosetta

7 November, Google Hangout [TBC]
A Google Hangout to brief media about Rosetta mission events during the week of 10-14 November is planned for 7 November. Details of the Hangout will be announced on the ESA Portal (www.esa.int).

10 November, ESOC, Germany – Press briefing
Members of the Rosetta team will brief the media about the latest status of the spacecraft and the preparations during the coming days leading to the deployment of the lander. The briefing is foreseen for the afternoon – time to be confirmed. Details of the timing of the briefing and how to attend will be published on the ESA Portal (www.esa.int).

11 November, ESOC, Germany – Press briefings
During a morning briefing (time to be confirmed), members of the Rosetta team will provide updates on the status of the spacecraft and the preparations leading to the deployment of the lander.
During an evening briefing, foreseen to start at 20:30 CET (time to be confirmed), members of the Rosetta team will give an update on the outcome of the first of 5 Go/No Go decisions leading up to the deployment of Rosetta's lander.
Details of the timing of the briefing and how to attend will be published on the ESA Portal (www.esa.int).

12 November, ESOC, Germany – Landing on comet
Members of the media are invited to cover Rosetta's delivery of the lander Philae to the surface of the comet. Several press briefings will be held during the day to update on the Go/No Go decisions; report on the spacecraft and lander status; provide first images from the orbiter and lander. Details will be published on the ESA Portal (www.esa.int).

Press briefing schedule for Rosetta - continued

13 November, ESOC, Germany – Press briefing on first surface operations
A status update on the first surface operations is foreseen for the afternoon of 13 November – to be confirmed. Details of the timing of the briefing and how to attend will be published on the ESA Portal (www.esa.int).

Accreditation to press events

Members of the media wishing to attend Rosetta press events must register using the link provided in the related Call for Media published on the ESA Portal (www.esa.int).

For the landing event, the Call for Media will be published on 15 October with a deadline for receipt of applications of 26 October at 23:59 UTC.

Online transmission of press events

ESA press events covering the deployment of Rosetta's lander, Philae, the landing and first science results from the lander will be streamed live on: www.esa.int

ESA TV productions

ESA TV productions are made available via: television.esa.int

Rosetta online

Information about the mission and the role of the partners can be found on the following websites:

European Space Agency
www.esa.int/rosetta - the entry point for all ESA web pages covering the Rosetta mission.
sci.esa.int/rosetta – detailed information about the Rosetta mission
blogs.esa.int/rosetta – regular updates, behind-the-scenes reports, contributions from guest writers.

The Rosetta pages on our partners' websites are at:
NASA rosetta.jpl.nasa.gov/
DLR www.dlr.de/rosetta and www.dlr.de/en/rosetta
CNES www.cnes.fr/rosetta and www.cnes.fr/rosetta-blog
ASI www.asi.it/it/attivita/sistema_solare/rosetta

Rosetta is also present on social media platforms:

Twitter: @ESA_Rosetta
FaceBook: www.facebook.com/RosettaMission
YouTube: bit.ly/rosettaYT
Flickr: bit.ly/rosettaFlickr
Instagram: http://instagram.com/rosettamission

Pictures, illustrations and animations

A variety of photographs, illustrations and animations are available for non-commercial use. They cover a broad range of topics including: images of comet 67P/Churyumov-Gerasimenko taken with the cameras on Rosetta; pictures and animations to illustrate the science of Rosetta; and photographs documenting the different phases of the mission.

An extensive collection of illustrations can be found online, in particular:

All Rosetta images and videos: www.esa.int/spaceinimages/Missions/Rosetta/

Images of 67P/C-G from Rosetta: sci.esa.int/rosetta_comet_67P_images
Images of asteroid Lutetia: sci.esa.int/rosetta_lutetia_images
Images of asteroid Šteins: sci.esa.int/rosetta_steins_images

QUICK REFERENCE MISSION FACTS

Fast facts

Launch: 07:17 GMT on 2 March 2004, on an Ariane 5 G+ from ESA's spaceport at Kourou, French Guiana

Launch mass: 3000 kg (fully fuelled) of which the Orbiter accounted for 2900 kg (including 1670 kg propellant and 165 kg science payload), and the Lander 100kg (with 26.7 kg of science payload).

Orbiter dimensions: 2.8m x 2.1m x 2.0m with two 14m long solar wings

Orbiter payload: 11 experiments (ALICE, CONSERT, COSIMA, GIADA, MIDAS, MIRO, OSIRIS, ROSINA, RPC [ICA, IES, LAP, MAG, MIP, PIU], RSI and VIRTIS) to study the comet's global and local environment, surface, and sub-surface.

Lander dimensions: 1 m x 1 m x 1 m (before deployment of landing gear)

Lander payload: 10 experiments (APXS, CIVA, CONSERT, COSAC, PTOLEMY, MUPUS, ROLIS, ROMAP, SD2, SESAME) to investigate the local comet environment, surface and sub-surface.

Distance travelled (by 12 November*): 6550 million km

One-way signal travel time (on 12 November*): 1700 seconds

Ground communications: ESA's New Norcia (01:46–14:27 UTC) and Malargüe (13:55–02:59 UTC) ground stations, with support from NASA ground stations.

Distance of Rosetta from Sun (on 12 November*): 448 million km

Distance of Rosetta from Earth (on 12 November*): 510 million km

Speed of spacecraft and comet with respect to Sun: 18.3 km/s

** See Appendix A for equivalent numbers for other key periods of the mission*

Cost: The total cost of the mission is 1.3 thousand million Euro. This includes the launch, the spacecraft, the science payload (instruments and lander), and mission and science operations.

Industrial contributions: The Rosetta spacecraft was built by an industrial team led by prime contractor Astrium GmbH, Friedrichshafen, Germany, and involving more than 50 contractors from 14 European countries and the USA. Major subcontractors were Astrium Ltd. who built the spacecraft platform, Astrium France who supplied the spacecraft avionics and Alenia Spazio, Turin, Italy, for assembly, integration and verification. Canada participated in the construction of ESA's first 35 m-diameter Deep Space Antenna in Australia, which was built for Rosetta. Scientific consortia from institutes across Europe and the United States provided the 11 experiments for the orbiter.

Rosetta's Philae lander is provided by a consortium led by DLR, MPS, CNES and ASI. Other members of the consortium are ESA and institutes from Austria, Finland, France, Hungary, Ireland, Italy and the UK.

What’s in a name?

For the people charged with naming one of the most ambitious missions in planetary science this decade there was one name that seemed to have been destined for it: Rosetta.

The Rosetta Stone, an ancient Egyptian stone tablet from the second century BC was unearthed near Rashid (Rosetta) on the Nile delta in 1799. Famous for carrying the same text inscribed in three different languages – ancient Egyptian hieroglyphics, Demotic script (an everyday form of Egyptian) and ancient Greek - the stone allowed archeologists to decipher hieroglyphics for the first time. This in turn provided the key to understanding an ancient civilisation. In a similar manner, ESA’s Rosetta mission will allow scientists to unlock the mysteries of the oldest building blocks of our Solar System: comets.

Rosetta's lander Philae is named after an island in the Nile river, where archeologists found an inscription on an obelisk that confirmed their interpretation of the Rosetta Stone texts.

Mission milestones

Date	Event	Comment
2 March 2004	Launch	
4 March 2005	1st Earth flyby	Distance from Earth: 1950 km. Purpose: Gravity assist from Earth
25 February 2007	Mars flyby	Distance from Mars: 250 km. Purpose: Gravity assist from Mars
13 November 2007	2nd Earth flyby	Distance from Earth: 5300 km. Purpose: Gravity assist from Earth
5 September 2008	Asteroid Šteins flyby	Distance from Steins: 803 km. Purpose: Scientific investigation of asteroid (2867) Šteins
13 November 2009	3rd Earth flyby	Distance from Earth: 2480 km. Purpose: Gravity assist from Earth
10 July 2010	Asteroid Lutetia flyby	Distance from Lutetia: 3162 km. Purpose: Scientific investigation of asteroid (21) Lutetia
8 June 2011	Enter deep space hibernation	Distance from Sun: 667 million km. Purpose: To conserve energy while far from the Sun
20 January 2014	Exit deep space hibernation	Distance from Sun: 672 million km. Purpose: To prepare for comet rendezvous.
May to August 2014	Comet rendezvous manoeuvres – see Appendix D	Distance from comet: 230,000 km to 100 km. Purpose: To approach the comet for scientific investigations
6 August 2014	Arrival at comet	Distance from comet: 100 km. Purpose: To enter close orbit around comet
12 November 2014	Delivery of Philae lander to comet and start of First Scientific Sequence of Lander	Distance from comet: 22.5 km at time of deployment Distance from Earth: 509 million km Distance from Sun: 448 million km. Purpose: To deliver the lander on the comet surface.
November 2014 – December 2015	Accompany comet through perihelion (August 2015) and back towards outer Solar System	Distance from Sun at perihelion: 186 million km. Purpose: To study how a comet changes as it approaches and recedes from the Sun.

HIGHLIGHTS FROM THE ROSETTA MISSION THUS FAR

There are many highlights from the Rosetta mission because there is nothing routine about the endeavour. It is a daring mission that demanded world-class ambition and technological development to match.

When Rosetta deploys the lander, Philae, to the surface of comet 67P/Churyumov-Gerasimenko on 12 November 2014, the mission will already have accumulated a significant number of successes.

The idea that became Rosetta was conceived in the early 1980's even before ESA's Giotto mission flew by comet 1P/Halley, returning the first detailed picture of a comet's nucleus ever seen. The success of Giotto meant that plans for a follow-on mission were enthusiastically considered.

Almost 20 years later, Rosetta was built, tested and ready to launch. But disaster struck just one month before the planned liftoff. In December 2002, an Ariane 5, similar to the one designated to launch Rosetta, failed while lifting a communications satellite into orbit. With one billion Euros of tax-payers money and the hopes of the world's comet scientists resting on the successful launch of Rosetta, the difficult decision was made to postpone the attempt until the launcher failure was understood.

This robbed the mission of its original target, comet 46P/Wirtanen. While the engineers worked to understand and prevent the loss of another Ariane 5, scientists and engineers searched for a replacement target. Eventually they settled on comet 67P/Churyumov-Gerasimenko, a somewhat more massive comet than Wirtanen. This led to the strengthening of the legs on Rosetta's lander Philae, to cope with the slightly faster landing speed now expected.

With all this drama behind it, the first highlight of the mission was simply to leave the surface of the Earth behind and begin its interplanetary journey. The launch took place on 2 March 2004.

A complex journey

Rosetta could not head straight for the comet. Instead it began a series of looping orbits around the Sun that brought it back for three Earth fly-bys and one Mars fly-by. Each time, the spacecraft changed its velocity and trajectory as it extracted energy from the gravitational field of Earth or Mars. During these planetary fly-bys, the science teams checked out their instruments and, in some cases, took the opportunity to carry out science observations coordinated with other ESA spacecraft such as Mars Express, ENVISAT and Cluster.

Each of the fly-bys required months of intense preparation. In particular the fly-by of Mars in February 2007 was a critical operation: the new mission trajectory to 67P/Churyumov-Gerasimenko required that Rosetta fly past Mars at just 250 km from the surface, and spend 24 minutes in its shadow.

The spacecraft had been designed for the mission to Wirtanen, which did not include a period in Mars's shadow. The flight team had to re-programme the spacecraft completely in the months preceding the Mars fly-by, teaching Rosetta “not to worry” and to avoid potentially catastrophic autonomous reactions to the absence of sunlight on the solar panels and Sun sensors.

When the Rosetta signal reappeared after the passage behind Mars, shortly after the end of the “shadow” period, there was a collective sigh of relief.

Getting to know Rosetta

A decade has passed since Rosetta was launched. This meant that by the time it arrived at the comet, it was an old-timer in terms of starting its main mission phase. Nevertheless, it must work at peak efficiency to make the most use of the months it will have at the comet.

One advantage of the mission’s 10-year cruise phase is that the flight team has had plenty of opportunities to become familiar with many aspects of the spacecraft’s personality. No matter how precisely designed and constructed, all complex machinery takes on a life of its own once it starts working. Spacecraft are no different.

In the case of Rosetta, the flight team has learned to use the thrusters at slightly reduced efficiency to compensate for the fact that the fuel tanks cannot be re-pressurized. This is due to a leak in the Reaction Control System that manifested itself in 2006.

They have also learned to operate the reaction wheels at lower speeds than originally designed. The reaction wheels are critical to the mission. They are used to orient the spacecraft such that the instruments can point to the comet, the solar arrays to the Sun, and the main antenna to the Earth. Well into the mission, two out of the four reaction wheels started showing signs of vibrations when operated at their normal operating speed. An alternative software has been devised that uses only two wheels; this is ready to be uploaded and used in case the two reaction wheels completely fail.

The cruise phase has not been all quiet. Even in the periods of low activity, during the long arcs between fly-bys, the spacecraft had to be monitored once a week, and its flight plan continuously updated.

Science along the way

En-route to the comet, Rosetta encountered two asteroids. These allowed the scientists and flight team to practise with the instruments and to gain more valuable experience about how to navigate the spacecraft. A highlight from the first encounter was Rosetta executing a manoeuvre that had originally been termed too risky.

Asteroid Steins is tiny, just 5 kilometres across; about the size of a large village. On 5 September 2008, Rosetta was to fly past at a distance of 800 kilometres, roughly the distance between Paris and Munich, and keep everything in the sharpest focus possible. To do this throughout the fly-by would have meant exposing one face of the spacecraft to the Sun for longer than allowed.

The original strategy defined by the spacecraft manufacturer, taking into account Rosetta's thermal and mechanical constraints, involved stopping before the closest approach to turn the spacecraft back to its nominal attitude. This would have led to significant loss of data. Naturally, the data-hungry scientists wanted to take observations all the way through.

So the flight control team invented and tested a new strategy, such that Rosetta tracked the asteroid autonomously all the way through the encounter, boosting confidence in the spacecraft enormously.

However, not everything went according to plan. The OSIRIS science camera and the navigation cameras did not work exactly as expected during the fly-by revealing another quirk of the spacecraft's personality. The team worked out how to ensure this did not happen again so that the next fly-by would be a success.

This paved the way for the mission's most celebrated science highlight prior to arriving at comet 67P/Churyumov-Gerasimenko: the fly-by of asteroid Lutetia in July 2010.

Whereas Steins was a small jumble of rocky debris that resembled a solid object, Lutetia was a miniature world, with a diameter of 130 kilometres. At the time, it was the largest asteroid ever seen in close-up.

Rosetta was going to fly past at a greater distance, 3162 kilometres this time in order to allow the full asteroid to appear in the field of view of the scientific cameras. Nevertheless, the spacecraft would be out of communications with Earth for about 40 minutes as it turned its attention to Lutetia.

The vigil was worth it. Rosetta began streaming back its data, revealing a mini-world of the most complex geology. Its pulverised surface appeared to be poor in metals but showed the presence of hydrated minerals. There were rockslides and giant craters covering this battered relic from the formation of the Solar System.

In terms of aesthetics, the beauty-shot was an image that Rosetta had snapped on approach, showing the looming bulk of the asteroid in the foreground. In the distance, more than ten thousand times further away from the spacecraft, was the unmistakable shape of Saturn and her rings.

Rosetta sped on. It had charged past the asteroid at a relative speed of 54,000 kilometres per hour and was heading for the comet. Even at that great speed, there were still four more years to go. This meant that the moment many of the mission team dreaded was almost upon them: hibernation.

Hibernation and then …

Putting Rosetta to sleep for two years, seven months and twelve days was forced on the mission because it had to go so far out into the Solar System. Rosetta carries large solar panels based on completely new technology that makes them exceptionally efficient. But so far from the Sun, where no solar-powered spacecraft has gone before, there would not be enough power to keep all the spacecraft's systems operating. So everything was shut down, except for the on-board computer, some internal heaters and a few clocks to count down until 10:00 UTC on 20 January 2014. Then it was time for Rosetta to wake up, reactivate its communications system and phone home.

It did so, after a tense 18 minute delay, caused by the on-board computer rebooting. A memorable moment for the assembled scientists, flight team, officials and press, and a significant highlight ticked off the list. The mission was alive and ready for business. Next stop: the comet itself. Not that the flight team could relax. There was still a lot to do.

Destination in sight

Between wake-up and rendezvous, all twenty-one instruments had to be brought online and checked out. Software was updated and the spacecraft had to perform a series of 10 manoeuvres to reduce its speed sufficiently to rendezvous with the comet rather than fly by it.

The final arrival manoeuvre took place on 6 August 2014. During the preceding few weeks, as Rosetta approached the comet, it became increasingly obvious that the mission to orbit and land on the comet was going to be more difficult than anyone had imagined because of the comet's unexpected shape.

Instead of the expected 'potato' form, 67P/C-G was revealed to be a double-lobed structure with a 'head' and a 'body' separated by a narrow neck – some people have even likened the shape to that of a rubber duck.

The rendezvous with the comet took place with Rosetta at a distance of about 100 kilometres. This was too far away for the comet to hold the spacecraft with its weak gravitational field. The flight team executed a series of manoeuvres, known as pyramid trajectories, to steer Rosetta towards the comet. During this time, they studied how Rosetta responded to the weak but complex gravitational field generated by the comet's odd shape, while at the same time scientists gathered data to characterise the comet.

Gradually the distance between Rosetta and the comet was reduced until the spacecraft was captured by the comet's gravitational field on 10 September. At this point it was just 30 kilometres from the surface. Since then, Rosetta has edged even closer and is currently at a distance of about 10 kilometres from the surface.

Preparing for landing

In tandem, the Rosetta team was searching for a place to set down Philae. This too was complicated by the comet's shape. By 24 August, using data collected when Rosetta was still about 100 km from the comet, five candidate regions had been identified for further analysis; three were on the head and two were on the body.

All were more difficult terrains than hoped. Cliffs, craters, and boulders populate each of the sites. A detailed analysis of Philae's capabilities and the opportunities offered by each site revealed that the best choice was a location currently referred to as Site J.

The landing attempt will take place on 12 November. Philae will be released at 08:35 GMT/09:35 CET, landing about seven hours later. Confirmation of the landing will arrive at Earth around 16:00 GMT/17:00 CET.

Beyond the landing, everything is now set for Rosetta to follow the comet through its closest approach to the Sun in August 2015. Already, more data have been collected by Rosetta than any previous mission to a comet. Scientists are beginning to understand the behaviour of comet 67P/Churyumov-Gerasimenko, and they will test these ideas watching its activity build as it nears the Sun.

In contrast to previous missions to comets, this is not a quick fly by, but a chance to study a comet in detail, to monitor its transformation over the course of more than a year, and to learn its secrets. Rosetta will allow scientists to put all other comet observations into context. It will show us how comets 'work'.

As comet 67P/Churyumov-Gerasimenko is accelerating towards its encounter with the Sun its surface will become more active, more challenging to the spacecraft. The rewards to be reaped are every bit as great as the challenges to be faced.

Rosetta will be there every step of the way.

It has already been a wild ride for this spacecraft, and it is set to get even wilder….

SELECTING SITE J - A LANDING SITE FOR PHILAE

Rosetta's lander Philae will target Site J, an intriguing region on comet 67P/Churyumov-Gerasimenko that offers unique scientific potential, with hints of activity nearby, and minimum risk to the lander compared to the other candidate sites.

This was the decision of the Landing Site Selection Group (LSSG) following a relatively short – 6 weeks – but intense period of investigation and assessment of the comet surface.

The LSSG is composed of engineers and scientists from Philae’s Science, Operations and Navigation Centre (SONC/CNES), the Lander Control Centre (LCC/DLR), scientists representing the Philae Lander instruments, and the ESA Rosetta team.

So how did the choice of Site J as the landing site for Philae come about? Since comet 67P/Churyumov-Gerasimenko had never been seen up close, a meaningful selection could only be made once the spacecraft was close enough to be able to characterise it.

In this context, characterising the comet meant determining the shape, rotation rate and orientation, gravity field, albedo (reflectivity), surface features and surface temperature of the nucleus. It also meant measuring outgassing and quantifying the density and velocity distribution of particles in the coma, the envelope of gas and dust surrounding the comet nucleus.

The selection of the landing site was a race against time in a brief window of opportunity, and a balance had to be found between competing needs. The comet’s activity is driven by the increase in heat as it heads closer to the Sun every day. The lander must be deployed before this activity rises to levels that could jeopardise a safe landing.

On the other hand, the landing cannot take place too early because there must be sufficient sunlight for Philae’s solar cells to generate enough power to operate the lander in the weeks after landing. Also, the surface temperature should be suitable for the lander to operate: not to cold or too hot.

Combined, these factors dictate that the landing should take place when the comet and Rosetta are about 3 Astronomical Units (450 million km) from the Sun – this is where the comet will be by mid-November.

Those involved in the selection process made the best use of the limited time following the rendezvous on 6 August to gather critical data and to make informed decisions.

As the distance between Rosetta and the comet decreased rapidly between May and August, the onboard scientific and navigation cameras began to resolve the comet and identify features on its surface. Rosetta’s other instruments also began to ‘sense’ the comet’s environment in more and more detail as the spacecraft drew close.

In July 2014, images from the OSIRIS cameras began to reveal the shape of comet 67P/C-G. By the time the spacecraft arrived at the comet in August, it was clear that the comet is a complex double-lobed structure with a ‘head’ and a ‘body’ separated by a neck – a distinctive shape that has added to the challenges involved in selecting a safe landing site.

The first step in the selection process was to gather the crucial technical information needed by the LSSG to identify suitable candidate landing sites.

At this stage, the primary driver was whether or not landing on a given site would be technically feasible, independent of scientific desirability.

‘Feasibility’ is based on many factors relating to where a site is on the comet. Some of these are specific to the descent phase after Rosetta has deployed the lander: its duration and the illumination conditions and radio communications with Rosetta during descent.

Others relate to the conditions at touchdown, such as the speed at which the lander reaches the site, the slope of the surface and the orientation of the lander.

The physical nature of the site was also an important factor: aspects such as the presence of large boulders or deep crevasses on the surface, and the suitability of the topography of the landing site for the science experiments were taken into account.

Periodic communications between the lander and the orbiter must be maintained as much as possible during the lander’s First Science Sequence (FSS; the first intensive phase, lasting about 3 days) and its Long Term Science Sequence (LTS; up to about March 2015).

There must also be a balance between comet day and comet night to cater for the scientific needs of the instruments, as well as ensuring that the solar cells can recharge the battery to power the lander instruments, while not overheating the lander.

Finally, sites should allow for operations of the CONSERT experiment, which requires radio signals to be transmitted between the orbiter and lander through the body of the comet.

The scientific value of the potential sites was also taken into account. To help judge this, essential observations were made with Rosetta’s scientific instruments, in particular OSIRIS, MIRO, and VIRTIS, with additional contributions from ALICE and ROSINA, and from the navigation camera, NAVCAM.

NAVCAM and OSIRIS images were used not only to model the shape and rotation of the comet. They also allowed the flight team to compute the spacecraft's trajectory and so deduce the comet's gravitational field. MIRO and VIRTIS measurements of the comet's surface temperature were used to predict the temperature at the comet during lander operations. Measurements from MIRO, VIRTIS, ROSINA and ALICE of the pressure and density of gas surrounding the nucleus have been used to indicate the environment in which the spacecraft will be operating.

Scientific measurements of the comet surface and environment were also gathered by other orbiter experiments. These were used in assessing the scientific merit of the candidate sites.

A preliminary selection of 10 landing sites, referred to by the letters A to J, was made by a subset of the LSSG, meeting on 20 August, just two weeks after rendezvous. For each of these sites, the LCC and the SONC carried out a technical analysis that was presented at the first full meeting of the LSSG, on 22-24 August.

At this meeting, participants reviewed the results from the technical analysis and discussed the scientific merits of the candidate sites. By the end of the meeting, the group selected five of the sites (A, B, C, I, and J) for detailed investigation.

Between 25 August and 13 September, the ESA Rosetta Mission Operations Centre (RMOC) at ESOC carried out a comprehensive analysis to identify possible trajectories to deliver the lander, and to confirm that the proposed landing sites could be reached with the required accuracy.

During this period, more detailed measurements were taken from the orbiter, as it approached to within 30km of the comet's centre.

At this stage a shape model of the comet was generated with a resolution of 3.6m on the surface of the comet and 0.5m in elevation. This was used to simulate a view of the horizon as seen from Philae's panoramic cameras, which was also factored into the selection of the primary site.

At the second meeting of the LSSG, on 13-14 September, the latest data were scrutinised. Technical aspects, such as flight dynamics analyses for the orbiter and the lander, and scientific aspects, for example, new measurements from orbiter instruments, were considered. The possible landing scenarios and their implications on the science programme of the lander were discussed.

Finally, the remaining candidate sites were ranked. Site J, situated on the smaller lobe, was selected as the primary landing site, and Site C, on the larger lobe, as the backup site.

From 16 September to 9 October, detailed analysis and operational preparation for the landing took place. During this period the spacecraft was close enough to the comet to allow the OSIRIS Narrow Angle Camera to map the boulder distribution at the primary and backup landing sites.

On 10 October the LSSG met to make the crucial Go/No Go decision for Philae to land on the primary site.

While the primary site coordinates define the location where the lander is envisaged to land, the actual landing can take place within a landing ellipse measuring some hundreds of metres across. The precise dimensions of the actual landing area will depend on a number of factors, including the precision with which the orbiter's location is known at the time the lander is released and on where along the delivery trajectory the lander is released. In preparation for this Go/No Go meeting, OSIRIS delivered its high resolution images and information about the distribution of boulders on the primary and backup landing sites which were used as an input to the risk analysis. This information served to support slight adjustments to be made to the target coordinates within the landing area with the aim to reduce the overall risk of landing in a section which has a higher fraction of boulders.

Final scientific measurements from orbiter instruments were also used to support the risk analysis, although these were not considered as an essential part for the Go/No Go decision.

Two days later, on 14 October, the formal Lander Operations Readiness Review took place, to give the official go-ahead for the landing.

Then from 13 October to 3 November the SONC and LCC prepare the final operational sequences for the Separation, Descent and Landing (SDL) and First Scientific Sequence (FSS) operations of Philae.

In parallel, the spacecraft operators at ESOC prepare the command sequences for the deployment of Philae onto the surface of comet 67P/Churyumov-Gerasimenko. Due to the extremely high precision required for this manoeuvre, the spacecraft’s trajectory and commands will be continually updated as the days count down. The final separation and landing sequence will only be transmitted to Rosetta a few hours before separation.

Then, the world waits. The landing, planned for 12 November, will take place entirely automatically.

Key dates

19 August: Due date for all data needed for the Landing Site Selection Group (LSSG) meeting of 20 August
20 August: LSSG pre-select 10 candidate sites: Lander Control Centre (LCC) and Science Operations and Navigation Centre (SONC) carry out technical analysis
22-24 August: LSSG meet and select five candidate landing sites; Coordinates of sites are sent to Rosetta Mission Operations Centre (RMOC)
25 August: Delivery of OSIRIS Digital Terrain Models of the candidate sites
5 September: RMOC experts report on first analysis of landing sites
13-14 September: LSSG meet and select Site J as the primary landing site and Site C as the backup landing site; Landing Site coordinates are sent to RMOC
23 September: Delivery of OSIRIS high-resolution images and boulder distribution file for primary and backup landing sites
26 September: RMOC report on final analyses and operational scenario of primary landing site
10 October: LSSG meet for final Go/No Go decision for Site J as the primary landing site
14 October: Lander Operations Readiness Review
7 November: Final landing sequences are sent from LCC to RMOC
9 November: Final landing sequences are uploaded to the Lander
12 November: Date of landing

More about Site J

Site J was selected by Rosetta mission scientists and engineers over four other candidates as Philae’s primary landing site. The site is located close to a distinctive large depression on the smaller lobe of the comet.

Site J is considered to pose minimum risk to the lander compared to the other candidate sites, while also offering the opportunity to conduct unique science – regions of activity have been identified nearby. The majority of the terrain within a square kilometre area has slopes of less than 30^o relative to the local vertical and there are relatively few large boulders, although, as close-up images show, the site is not completely free of such hazards. The area also receives sufficient daily illumination to recharge Philae and hopefully continue surface science operations beyond the initial 64-hour battery-powered phase.

LANDING ON A COMET

Beyond the significant achievements of the first rendezvous with a comet and accompanying a comet as it makes its closest approach to the Sun, Rosetta will attempt another first: landing on a comet.

The Rosetta orbiter will release the Philae lander at 08:35 GMT/09:35 CET on 12 November at a distance of approximately 22.5 km from the centre of comet 67P/Churyumov-Gerasimenko. About seven hours later Philae should touch down on the landing site, currently known as Site J. With a one-way signal travel time between Rosetta and Earth on 12 November of 28 minutes 20 seconds, that means that confirmation of separation will arrive on Earth ground stations at 09:03 GMT/10:03 CET and of touchdown at around 16:00 GMT/17:00 CET.

On 6 August, Rosetta arrived at a distance of 100 km from the comet. Between then and mid-October, the spacecraft edged closer to the comet approaching to within 10 km of the centre.

By the end of October, a series of small manoeuvres will place the spacecraft into the pre-delivery orbit. The delivery manoeuvre requires extremely high precision, so Rosetta will remain in this orbit for a few days to give the spacecraft operators time to verify the position and velocity of the spacecraft with great accuracy.

The first in a series of Go/No-Go decisions will be taken on 11 November, prior to separation, with a confirmation from the flight dynamics team that Rosetta is on the right trajectory ahead of lander delivery. Further Go/No-Go decisions will be made during the night of 11–12 November concerning readiness of the orbiter and uplink of commands, and confirmation of the lander readiness for separation. Once this is done, the landing attempt can begin.

From the pre-delivery orbit, Rosetta will manoeuvre to a hyperbolic trajectory flying in front of the comet, on the Sun side. At this point there is another Go/No-Go decision based on the outcome of this pre-delivery manoeuvre. In the event of a No-Go decision at this point, the orbiter continues along the delivery trajectory but the lander is not released. However, all being well, a Go decision means that two hours later, the lander will be automatically released, at a speed of about 0.18 m/s.

Once released, Philae is on its own, since a signal will take far too long to cross the distance between Earth and the comet to allow any kind of manual intervention.

The descent to Site J will take about 7 hours. The lander will touch down somewhere inside a “landing ellipse”, roughly a few hundred metres across. The landing ellipse was selected to be as free as possible of hazards such as large boulders and to avoid, as much as possible, slopes exceeding 30 degrees, but there will nevertheless be a degree of risk involved.

As Philae descends it will fall slowly without propulsion or guidance, gradually gathering speed in the comet's weak gravitational field, with its attitude will be stabilised via an internal flywheel.

During the descent, images will be recorded with the downward looking camera and some of the science experiments on the lander will be active too. Meanwhile, the orbiter will continue on its trajectory away from the comet's nucleus. A small manoeuvre will allow it to look back and monitor Philae's descent using cameras. This manoeuvre also ensures that there can be communication between the orbiter and lander during the descent and up to 90 minutes after landing.

Philae will reach the surface at roughly walking pace, around 1 m/s. That may not sound like much, but as the comet's surface gravity is roughly one hundred thousand times weaker than Earth's, a sophisticated system must be used to prevent it from rebounding into space. The three-legged landing gear will absorb the momentum and use it to drive an ice screw in each foot into the surface. At the same time, two harpoons will fire to lock the probe onto the surface, and a small thruster on top may be used to counteract the recoil of the harpoon.

Once anchored to the nucleus, Philae's primary science mission will begin and must happen quickly. Its initial battery life is only 64 hours, and while it also has solar cells with which to recharge the batteries and extend its lifetime, this will depend on the landing site location and illumination, and how much dust collects on the panels.

Philae will take panoramic images of its surroundings, with a section in 3D, and high-resolution images of the surface immediately underneath it. It will perform on-the-spot analysis of the composition of the comet's ices and organic material, and a drill will take samples from a depth of 23 cm and feed them to the on-board laboratory for analysis. The lander will also make measurements of the electrical and mechanical characteristics of the nucleus surface.

The data will be relayed to the orbiter, ready for transmission back to Earth at the next period of contact with a ground station. For the first five Earth days, there will be regular contact between the orbiter and lander when the two can see each other as the comet rotates with its 12.4 hour period. In addition, low-frequency radio signals will be beamed between Philae and the orbiter through the nucleus, to probe its internal structure.

The detailed in-situ surface measurements that Philae makes at its landing site will be used to complement and calibrate the extensive remote observations made by the orbiter covering the whole comet. Once the primary science mission has been completed, the lander will continue to monitor the physical and chemical properties of the comet's surface as it continues on its journey towards the Sun and for as long as the batteries are able to recharge.

In the meantime, Rosetta will begin the next major part of its mission, the escort phase. The orbiter will continue to manoeuvre around the comet at walking pace, collecting dust and gas samples and making remote sensing observations as the comet warms up and the nucleus and its environment evolve. The comet will reach its closest point to the Sun (perihelion) in August 2015, at a distance of 186 million kilometres. Rosetta will then track the waning of activity as the comet heads back towards the outer Solar System, at least until the end of 2015.

COMETS – AN INTRODUCTION

What is so special about comets that ESA has spent ten years flying a spacecraft towards one?

These small icy bodies are the most primitive objects in our cosmic neighbourhood, preserving pristine material left over from the formation of the Solar System, 4.5 billion years ago. For this reason, studying the chemical composition of comets may help scientists to answer some of the open questions about the Solar System's formation, including the way Earth came together.

Comets may have played an important role in delivering water to the young Earth, as well as bringing carbon-based molecules that may have been key to the development of life. Locked up in their rock-ice interiors are frozen water and other volatiles, including carbon monoxide, carbon dioxide, methane, and ammonia.

When comets approach the Sun these frozen worlds are gently heated, releasing these ices into space to produce a vast envelope of dust and gas around the nucleus. This 'coma' results from ices on the nucleus sublimating – changing directly from a solid to a gas – and carrying tiny dust particles into space. Sunlight reflecting off these particles makes the coma visible.

For observers on Earth, the result of this process can be spectacular: the coma can grow to millions of kilometres in diameter and, eventually, pressure from solar radiation and the solar wind is enough to cause some of the material to stream out in the opposite direction to the Sun to form two tails. One tail is made of gas and plasma and points in a direction directly opposite to the Sun, and the other is made primarily of dust, following a slightly curved path that points back along the comet's orbit.

Humans have observed comets since ancient times, but only in the past few centuries have scientists started to grasp the nature of these fascinating bodies. And it wasn't until the second half of the twentieth century that a clear picture began to emerge.

The most famous of all comets is undoubtedly Halley, a so-called periodic comet that returns to our skies once every 76 years. In general, short-period comets have periods up to two hundred years; their orbits are elliptical and occupy a very similar region in the Solar System to the one where the giant planets are found.

But the majority of comets have longer periods, spend most of their time in the far reaches of the Solar System and have highly eccentric elliptical orbits that only bring them to our skies once every few hundreds of thousands of years or so. There are also non-periodic comets. As these fall towards the inner Solar System, the gravitational pull of the giant planets places them on 'open orbits'. This means that they only pass by the Sun once.

Two reservoirs supply the Solar System with comets: the Kuiper belt a flattened, ring-like distribution that begins just outside Neptune's orbit, and the Oort cloud, a huge spherical cloud that extends over a thousand times farther than the orbits of Neptune and Pluto. These two reservoirs are named after Dutch astronomers Gerard Kuiper and Jan Oort, respectively, who predicted their existence in the 1950s.

Comets in the Kuiper belt and Oort cloud are gravitationally bound to the Solar System. They originated from the same primordial nebula that gave birth to the Sun and the planets. It is likely that these comets formed closer to the Sun and were later expelled outwards as a consequence of repeated interactions with the giant planets.

As the Sun moves through the Galaxy, stars or gas clouds passing near the outer boundaries of the Oort cloud may perturb the motion of some of these ‘dormant’ comets just enough to modify their orbits. This can kick them into the inner Solar System, where they eventually develop the characteristic coma and tails. Then, as a comet leaves the inner Solar System, the rate of sublimation decreases significantly and the coma and tails disappear. But the comet’s activity does not die down, and occasional outbursts may occur also at larger distances from the Sun.

In some cases, the comet plunges back along its highly eccentric orbit into the far reaches of our planetary system (for long period comets) or even beyond (for non-periodic comets). In other cases, it may be affected by the gravitational pull of one or more of the giant planets and remain trapped in a more regular, less eccentric orbit that keeps it closer to the Sun on a short-period orbit. For example, Rosetta’s comet 67P/Churyumov-Gerasimenko is trapped on a 6.5 year commute around the Sun between the orbits of Jupiter and Earth.

Sometimes a comet meets a dramatic fate. If the comet comes too close to the Sun, the gravity of our parent star may tear it apart. This can happen either at a comet's first passing by the Sun (as in the case of comet ISON, a ‘sungrazer’ that disintegrated in late 2013) or after many orbits (as for the short-period comet known as Biela's Comet, which was seen to split in two pieces in 1852). Other Solar System bodies can also cause a comet's demise, as witnessed by the collision of comet Shoemaker-Levy 9 with Jupiter in 1994. Or a comet can simply ‘fade away’, having exhausted its ices or developed a thick layer of dust.

Scientists have been observing comets remotely using ground-based telescopes for the past four centuries, but the advent of the space age revolutionised the field. Now, spacecraft can fly past comets and study them up close. Five comets have been visited by spacecraft since Giotto flew past comet 1P/Halley in 1986, setting the stage for ESA's Rosetta mission, the first spacecraft to rendezvous with a comet, attempt a landing on its nucleus, and accompany it as it moves closer to the Sun.

ROSETTA'S COMET - AT A GLANCE

After a journey lasting ten years and covering a distance of 6.5 billion km, ESA's Rosetta mission is on the brink of deploying a lander to touch down on the surface of comet 67P/Churyumov–Gerasimenko, or 67P/C-G for short.

The name acknowledges the Ukrainian astronomers Klim Churyumov and Svetlana Gerasimenko, who first spotted the comet in 1969. The '67P' refers to it being the 67th short-period comet discovered.

Comet 67P/C-G is on an elliptical 6.5-year orbit. Its closest approach to the Sun (perihelion) is in the region between the orbits of Earth and Mars, while its farthest point from the Sun (aphelion) is slightly beyond the orbit of Jupiter. It belongs to the Jupiter Family of comets, whose motion is strongly affected by Jupiter's gravity. Close encounters with Jupiter in 1840 and 1959 reduced the perihelion from a distance of almost 600 million to 186 million kilometres.

Prior to 2014 very little was known about this comet. That is all set to change now that Rosetta has arrived at 67P/C-G.

First measurements from Rosetta

Although Rosetta is just at the start of its scientific mission at 67P/C-G it has already begun to tease out some of the secrets stored in this remnant from the formation of the Solar System.

In July, when the comet was still a distant blur at a distance of 583 million km, the MIRO team detected the first traces of water vapour, at that time a modest 300 millilitres per second (equivalent to two small glasses of water). By mid-September, the team were reporting an average rate of 1 litre of water per second coming from the comet. As well as water vapour, they have also detected ammonia and methanol.

The ROSINA team have also been busy studying gases in the coma surrounding the comet and have revealed a rather diverse and chemically rich environment, varying significantly in local time around the comet. They have detected water, carbon monoxide and carbon dioxide, as well as trace amounts of ammonia, methane, and methanol, with some material coming from the subsurface and other material being produced by the interaction of the solar wind with the nucleus surface.

As the spacecraft approached the comet in August, what had until then been a distant blur of light was revealed by the scientific and navigation cameras to be a remarkable landscape, rich with features and showing signs of activity.

Physical properties such as the dimensions of the two comet lobes, the rotation period, spin axis, mass, volume and density of the comet have been reported by the RSI and OSIRIS teams.

The average surface temperature of the comet, reported by the VIRTIS team, is -70 °C (205 K), which although rather cold could already, when first measured in July, rule out the possibility of the comet being covered exclusively in ice – as was borne out when comet nucleus was resolved with the cameras. The team have also shown how the surface temperature varies during the comet day, and have recorded temperatures up to 230 K. Complementing these results are the measurements of subsurface temperatures obtained by the MIRO team.

The COSIMA and GIADA teams have reported the detection of dust grains of different shapes and sizes (from a few microns to a few hundred microns). Each of these experiments looks at different aspects of dust grains: COSIMA will study the composition of the grains it has captured, while GIADA investigates the optical and physical properties of the grains it detects.

These early measurements tell us that 67P/C-G has a dark, dry, and dusty surface with a rich and complex chemistry. But there is still much more to learn about this curiously-shaped comet. When Rosetta's Philae lander touches down on the surface of the comet on 12 November it will begin a series of *in situ* measurements at the landing site, providing 'ground truth' for the orbiter measurements that are being made now and into 2015 as the comet becomes more active.

Complementing Rosetta's measurements

Using ground-based telescopes comet 67P/C-G has been observed from Earth on seven approaches to the Sun: 1969 (discovery), 1976, 1982, 1989, 1996, 2002 and 2009. This time around astronomers are paying particular attention. More than 70 professional astronomers are observing 67P/C-G using telescopes at major observatories all over the world. These ground-based observations complement the unique results that will come from Rosetta. While Rosetta investigates the nucleus and inner core of the coma, observations from Earth get a wider view, taking in the entire coma and tails of the comet. This provides valuable context information for scientists and for mission planners.

As 67P/C-G approaches the Sun, it will brighten, bringing it within reach of amateur astronomers and their telescopes. A ProAm collaboration to monitor activity on the comet is already underway and will continue for the duration of the mission.

FAST FACTS ABOUT ROSETTA’S COMET

Year of discovery	1969
Discoverers	Klim Churyumov & Svetlana Gerasimenko
Size*:	
Small lobe	2.5 km x 2.5 km x 2.0 km
Large lobe	4.1 km x 3.2 km x 1.3 km
Mass*	10^{13} kg
Volume*	25 km^3
Density*	0.4 g/cm^3
Rotation period	12.4043 hours
Spin axis*	Right ascension: 69 degrees; Declination: 64 degrees
Orbital period	6.5 years
Perihelion	186 million km (1.243 AU)
Aphelion	849.7 million km (5.68 AU)
Orbital eccentricity	0.640
Orbital inclination	7.04 degrees
Water vapour production rate*	300 ml/s (June 2014); 1–5 l/s (July - August 2014)
Surface temperature*	205–230 K (July - August 2014)
Subsurface temperature*	30–160 K (August 2014)
Gases detected*	Water, carbon monoxide, carbon dioxide, ammonia, methane, methanol
Dust grains*	A few tens of microns to a few hundreds of microns

* Preliminary values

MISSIONS TO COMETS – ROSETTA IN CONTEXT

For much of history, humans have been fascinated by comets. Evidence for this can be found in Scottish rock carvings dating back to the second millennium BC, on clay tablets from ancient Babylon, and on an 11th century BC Chinese almanac transcribed on silk.

Comets were seen as omens of portent, and thought by many to be atmospheric phenomena rather than celestial. Gradually, astronomers realised that these apparitions were visitors from the distant reaches of outer space. In doing so, mere curiosity evolved over the centuries into scientific study.

Where did comets come from? How did they move through space? What were they made from? All of these became key drivers in the astronomers' pursuit of knowledge throughout the 18th century Age of Enlightenment.

Towards the end of the twentieth century, advances in space technology provided exciting new possibilities for comet scientists. Before they had relied solely on naked-eye observations or ground-based telescopes to study these ghostly messengers. Now it was possible to approach them with spacecraft, catching them as they journeyed towards the inner regions of the Solar System, relatively close to Earth.

In 1985, NASA's International Cometary Explorer (ICE) became the first space mission to pass through the tail of a comet. It flew past at a distance of 7800 kilometres from the nucleus of comet 21P/Giacobini-Zinner.

Just one year later, when Halley's Comet returned to our skies, an armada of spacecraft was sent to study the comet up close: these included two probes from Russia (Vega-1 and Vega-2), two from Japan (Sakigake and Suisei), and ESA's Giotto spacecraft.

Giotto flew within 600 kilometres of comet 1P/Halley, closer than any other spacecraft, and sent back detailed images of the icy nucleus at the heart of the comet. This was a world-leading first. Giotto's unique data showed, among other things, that comets contain complex organic molecules. Studying these may help us understand if comets helped to 'seed' life on Earth.

After Halley, the spacecraft continued its journey. It was revived in 1992 to fly past comet 26P/Grigg-Skjellerup. Giotto's camera had been blinded by dust particles during its encounter with Halley, but nonetheless its other instruments could sense 26P's nucleus as it flew within 200 km of it. It confirmed the picture from Halley that comets were solid objects rather than mere rubble piles or conglomerates of small fragments.

Other missions to comets followed. These include a trio of NASA probes: Deep Space 1, which flew by comet 19P/Borelly in 2001; Stardust, which flew past comet 81P/Wild in 2004 collecting samples from the comet's coma, the envelope of gases that surrounds the nucleus, that it returned to Earth two years later; and Deep Impact, which in 2005 shot a block of copper onto the nucleus of comet 9P/Tempel to investigate the subsurface.

The Stardust mission was extended and as Stardust-NExT it flew by comet 9P/Tempel in 2011 and imaged the crater created six years earlier by Deep Impact. The latter mission was also extended and as the EPOXI mission flew by comet 103P/Hartley in 2010 and imaged comet C/2009 P1 (Garradd) in April 2012 and comet C/2012 S1 (ISON) in January 2013. Another NASA mission, Contour, launched in Summer 2002, failed when it was incorrectly inserted into its interplanetary trajectory.

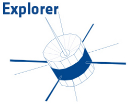
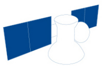
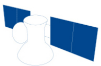
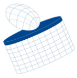
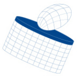
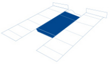
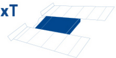
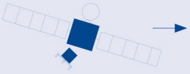
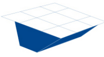
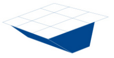
Rosetta is much more ambitious and advanced than Giotto or any of the previous comet explorers. Its observation phase will last much longer and will not be limited to 'snap-shots' from flybys.

Unlike all previous missions, Rosetta is capable of investigating the nucleus and the coma over an extended period of time. The mission includes an orbiter and a lander, so observations made from orbit can be correlated with in-situ measurements made on the surface.

Rosetta carries a much more advanced payload than any of its predecessors. The suite of eleven experiments on the orbiter will observe all aspects of the comet from close range over more than a year as it moves along its orbit towards the inner Solar System. The ten experiments on the lander, including spectrometers, high-resolution cameras and drill, will provide ground-truth measurements of the nucleus.

Rosetta is unique. It will be the first mission to rendezvous with a comet, deploy a lander and then accompany the comet as it reaches its closest approach to the Sun.

TIMELINE OF MISSIONS TO COMETS

LAUNCH DATE	MISSION NAME	COMET
12 August **1978**	**International Cometary Explorer** 	**Comet 21P/Giacobini-Zinner** Flew past the comet at a distance of 7,860 km on 11 September 1985. First spacecraft to fly in the vicinity of a comet. **Comet 1P/Halley** Flew through the coma at a distance of 31 million km from comet nucleus on 28 March 1986.
15 December **1984**	**Vega-1** 	**Comet 1P/Halley** Flew past the comet at a distance of 8,890 km on 6 March 1986. Part of international fleet to study 1P/Halley.
21 December **1984**	**Vega-2** 	**Comet 1P/Halley** Flew past the comet at a distance of 8,030 km from comet on 9 March 1986. Part of international fleet to study 1P/Halley.
7 January **1985**	**Sakigake** 	**Comet 1P/Halley** Flew past the comet at a distance of 151,000 km on 8 March 1986. Part of international fleet to study 1P/Halley.
2 July **1985**	**Giotto** 	**Comet 1P/Halley** Flew within 600 km of comet on 13 March 1986. Closest approach to 1P/Halley. First resolved image of comet nucleus. Part of international fleet to study 1P/Halley.
18 August **1985**	**Suisei** 	**Comet 26P/Grigg-Skjellerup** Flew within 200 km of comet on 10 July 1992. **Comet 1P/Halley** Flew 7 million km past the comet on 11 March 1986. Part of international fleet to study 1P/Halley.
24 October **1998**	**Deep Space 1** 	**Comet 19P/Borrelly** Flew past the comet at a distance of 2,200 km on 22 September 2001. Main mission was technology demonstrator of ion engines, main target was asteroid Braille. Extended to go to 19P/Borelly.
7 February **1999**	**Stardust** 	**Comet 81P/Wild** Flew within 240 km on 2 January 2004. Mission to collect samples of comet atmosphere and to sample comet grains. Samples returned to Earth on 15 January 2006.
7 February **1999**	**Stardust-NExT** 	**Comet 9P/Tempel** Flew within 181 km of the comet on 14 February 2011.
3 September **2002**	**Contour** 	**Comet 2P/Encke & Comet 73P/Schwassmann-Wachmann** Contact lost shortly after launch.
2 March **2004**	**Rosetta** 	**Comet 67P/Churyumov-Gerasimenko** Orbit comet, deploy lander to surface and escort comet though perihelion. Asteroids Steins and Lutetia were studied along the way.
12 January **2005**	**Deep Impact** 	**Comet 9P/Tempel** Flew within 500 km of the comet on 4 July 2005 before releasing impactor to study comet's interior.
12 January **2005**	**EPOXI** 	**Comet 103P/Hartley** Flew past the comet at a distance of 700 km on 4 September 2010. Mission to study a hyper-active comet. Deep Impact was reassigned as EPOXI, a combination of two missions: DIXI, Deep Impact Extended Investigation, and EPOCh, Extrasolar Planet Observation and Characterisation. **Comet C/2009 P1 (Garradd)** Imaged from a distance of 210 million km between February and April 2012. **Comet C/2012 S1 (ISON)** Imaged from a distance of 793 million km in January 2013.

Appendix A: MISSION MILESTONES -DISTANCES, DATES, TIMES

Date	Event	Distance Rosetta – Earth	Distance Rosetta – Sun	Distance Rosetta –comet	Distance travelled by Rosetta	One-way signal travel time
2 March 2004	Launch	—	148 million km	585 million km	—	1 s
4 March 2005	Earth swingby	1950 km (at closest approach)	148 million km	777 million km	941 million km	1 s
25 February 2007	Mars swingby	316 million km (250 km from Mars)	216 million km	553 million km	2.5 billion km	1053 s
13 November 2007	Earth swingby	5300 km (at closest approach)	148 million km	721 million km	3 billion km	1 s
5 September 2008	Steins flyby	359 million km	319 million km	393 million km	3.7 billion km	1197 s
13 November 2009	Earth swingby	2480 km (at closest approach)	148 million km	537 million km	4.5 billion km	1 s
10 July 2010	Lutetia flyby	454 million km	406 million km	276 million km	5 billion km	1514 s
8 June 2011	Enter deep space hibernation	549 million km	667 million km	141 million km	5.5 billion km	1831 s
20 January 2014	Exit deep space hibernation	807 million km	672 million km	9.2 million km	6.2 billion km	2693 s
7 May 2014	Start of manoeuvres towards comet	538 million km	609 million km	1.9 million km	6.3 billion km	1796 s
6 August 2014	Arrival at comet	404 million km	539 million km	100 km	6.5 billion km	1349 s
12 November 2014	Deploy lander	510 million km	448 million km	—	6.6 billion km	1700 s
13 August 2015	Closest approach to the Sun (Perihelion)	265 million km	186 million km	—	7.2 billion km	884
December 2015	End of nominal	244 million km	301 million km	—	7.5 billion km	813 s

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Corrections and updates to this media kit can be found at: sci.esa.int/rosetta/54767