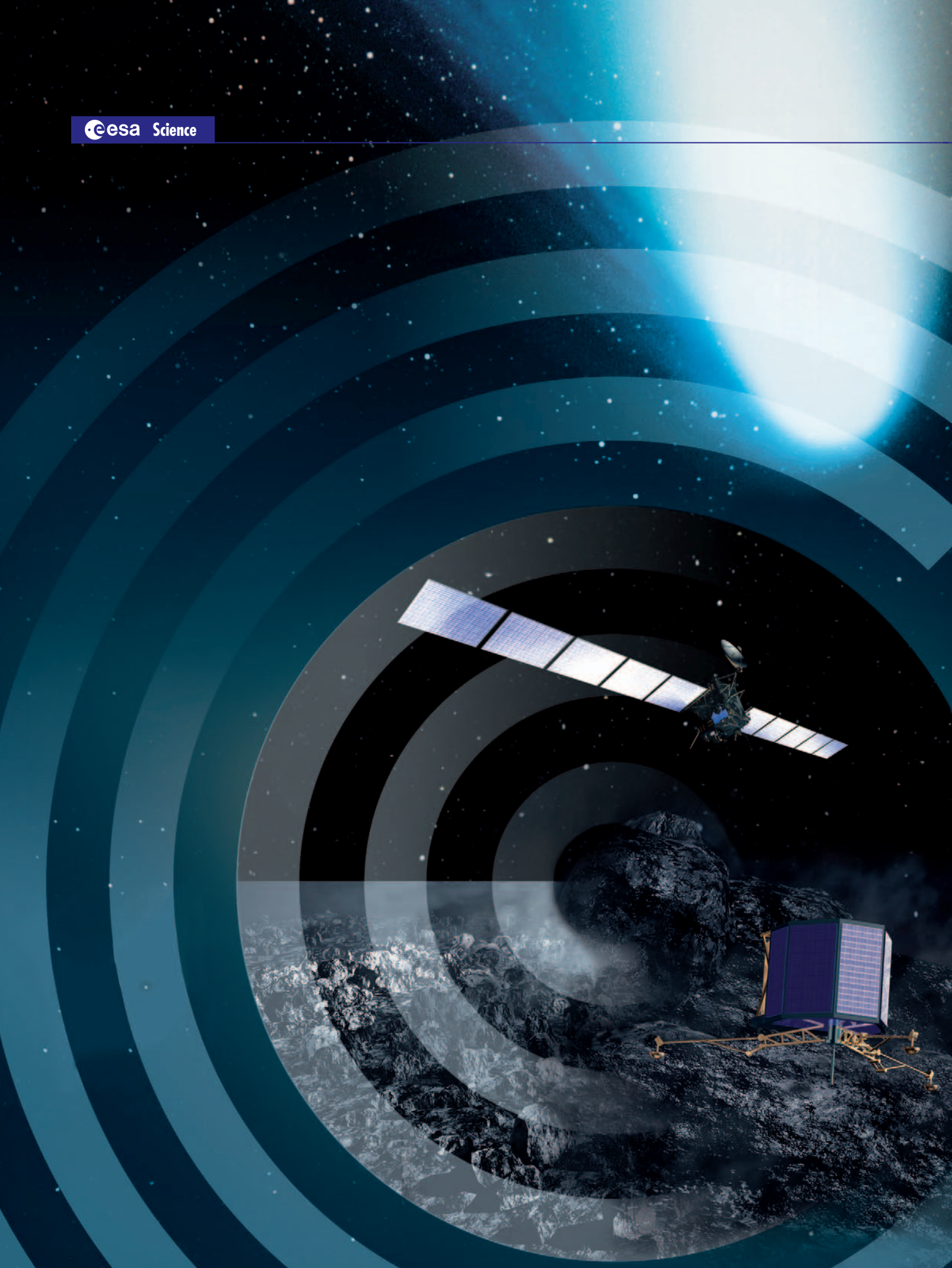


Rosetta's New Target Awaits

John Ellwood, Gerhard Schwehm & the Rosetta Project Team
ESA Directorate of Scientific Programmes, ESTEC, Noordwijk, The Netherlands

Peter Bond
Space Consultant, Cranleigh, United Kingdom

The countdown is under way once more for Europe's ambitious comet chaser. After the disappointment of a prolonged launch postponement in January 2003, engineers and scientists from all over the world are eagerly awaiting the February 2004 lift-off of ESA's Rosetta spacecraft and the start of its historic mission to orbit and land on a comet.

However, the lengthy delay has meant that Rosetta will no longer be heading for comet 46P/Wirtanen. Following careful analysis of the available comets and associated launch constraints for each mission scenario, the ESA Science Programme Committee accepted the recommendation to change the target comet, but not the scientific objectives. The new target is a cosmic iceberg known as 67P/Churyumov-Gerasimenko, a fairly large, active comet which sweeps through the inner Solar System once every six and a half years.

The revised mission scenario is even more challenging than the original one. In order to rendezvous with comet Churyumov-Gerasimenko, the spacecraft will now have to complete no fewer than four planetary flybys. During its circuitous 10-year odyssey around the inner Solar System, it will also have to endure long periods of hibernation, dramatic variations in sunlight and temperature, and two excursions through the main asteroid belt.

SEE PAGE 88 FOR LATEST INFORMATION

The Story So Far

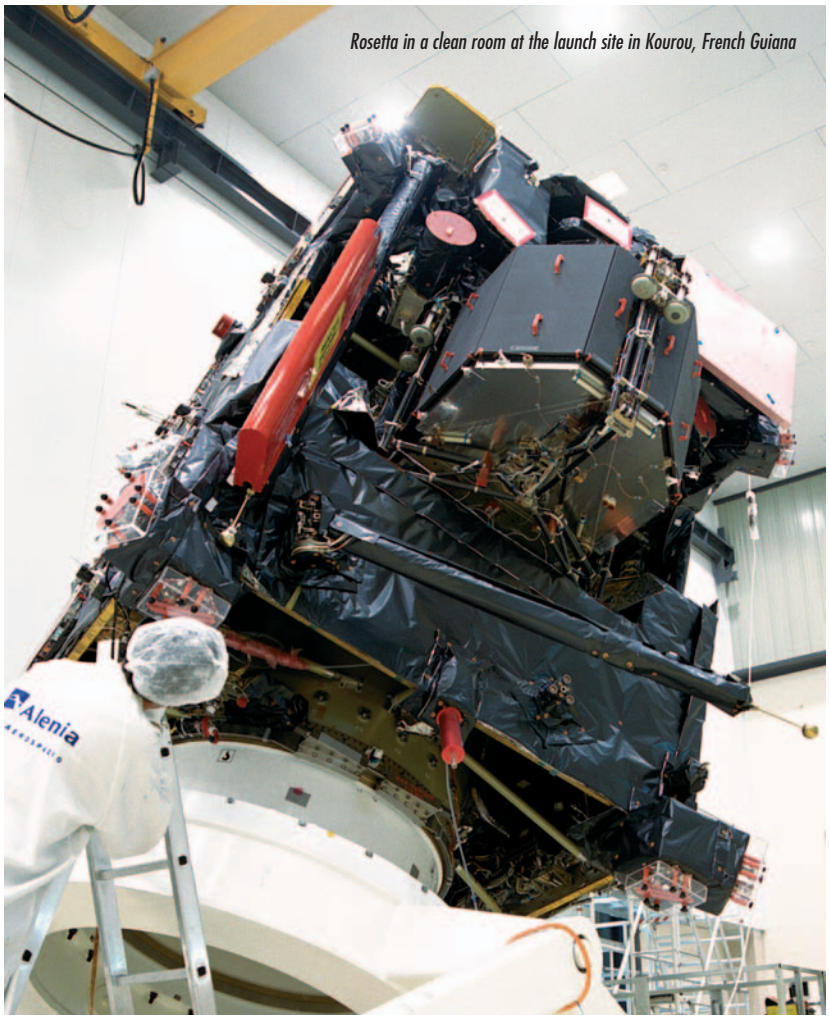
After more than a decade of careful mission analysis and intensive hardware preparation, Rosetta was shipped to Europe's Kourou spaceport in French Guiana in September 2002, prior to its scheduled launch aboard an Ariane-5. After completion of spacecraft fuelling and testing, Rosetta was only weeks from lift-off when tragedy struck, with the launch failure of Ariane flight 157 on 11 December 2002.

Although Rosetta would not be using the same version of Ariane-5 that was involved in the accident, ESA and Arianespace immediately set up a Review Board to consider the options for the billion Euro comet mission. After careful consideration of all factors, they took the joint decision not to launch Rosetta during its January 2003 window, despite the fact that this would jeopardise its mission to rendezvous with comet Wirtanen.

While ESA waited for Arianespace to provide the necessary guarantees regarding the Ariane-5 system qualification procedures and review process, the Rosetta team was asked to identify comets that their spacecraft could reach if launched within the next two-and-a-half years. The targets were to be selected on the basis of three main criteria: the scientific return, the technical risks to the spacecraft, and the extra funding needed.

After careful scrutiny of more than 150 periodic comets, the team presented nine mission scenarios to the Rosetta Science Working Team. The three most favoured options were then considered by the ESA Science Programme Committee (SPC) on 25-26 February 2003.

One option was to prepare Rosetta for a January 2004 launch towards its original target, comet Wirtanen. Under this scenario, no modifications would have to be made to the Rosetta spacecraft, although a more powerful Proton launch vehicle would have to be used in order to reach the comet. The other two options (with possible launches in February 2004 or 2005, respectively) would take Rosetta to a different periodic comet, 67P/Churyumov-Gerasimenko. Since Churyumov-Gerasimenko was thought to be larger than Wirtanen, this would be likely to involve certain modifications to the Lander.



Rosetta in a clean room at the launch site in Kourou, French Guiana

The 2004 opportunity was favoured since it would mean that Rosetta would have to spend less time in storage and it would require only a standard Ariane-5 G+ launcher. The 2005 alternative would need a larger launch vehicle – either an Ariane-5 ECA (not yet available) or a Russian Proton – in order to provide sufficient energy for a rendezvous with the fast-moving comet.

After a favorable response from the SPC, the mission team continued to study the technical and scientific implications of the three options in more detail. In order to assist their deliberations, a campaign of observations to study comet Churyumov-Gerasimenko was conducted with both the NASA-ESA Hubble Space Telescope and facilities of the European Southern Observatory. The intention was to determine the main physical characteristics of the comet - especially its size - as inputs to a detailed mission analysis that would identify landing scenarios and make a thorough assessment of any hardware modifications that would be necessary.

Finally, during its meeting on 13-14 May 2003, the SPC decided to give the green light for a mission to explore comet Churyumov-Gerasimenko. Although a February 2004 launch was anticipated, the date could not be finalised until the ESA Council found a solution to a shortage of funds in the Science Programme's immediate budget, partly the result of an estimated 80 million Euro additional cost caused by the grounding of Ariane-5. A February 2005 launch to the same comet was to be investigated as a back-up plan.

"If the extra funding required for Rosetta was the only tab on the table, the ESA Science Directorate could have absorbed the cost," said Professor David Southwood, ESA's Director of Science, at that time. *"Unfortunately, we have to face a number of other financial challenges."*

Fortunately the financial conundrum was resolved at the end of May when the ESA Ministerial Council agreed to approve a redistribution of funds. The way was clear for Rosetta to be launched in February 2004 aboard an Ariane-5 G+ vehicle, the same rocket selected for the original 2003 launch to comet Wirtanen.

Landing on a Larger Comet

One of the major concerns arising from the change of target involved the ability of the small Rosetta Lander to touch down safely on a much larger object than originally planned.

"Comet Churyumov-Gerasimenko has three to four times the diameter of comet Wirtanen and its gravity could be at least 30 times greater," says Philippe Kletzkine, ESA manager for the Rosetta Lander. *"This means that the maximum landing speed will increase from 0.2 – 0.5 metres per second for Wirtanen to 0.7 – 1.5 metres per second for Churyumov-Gerasimenko."*

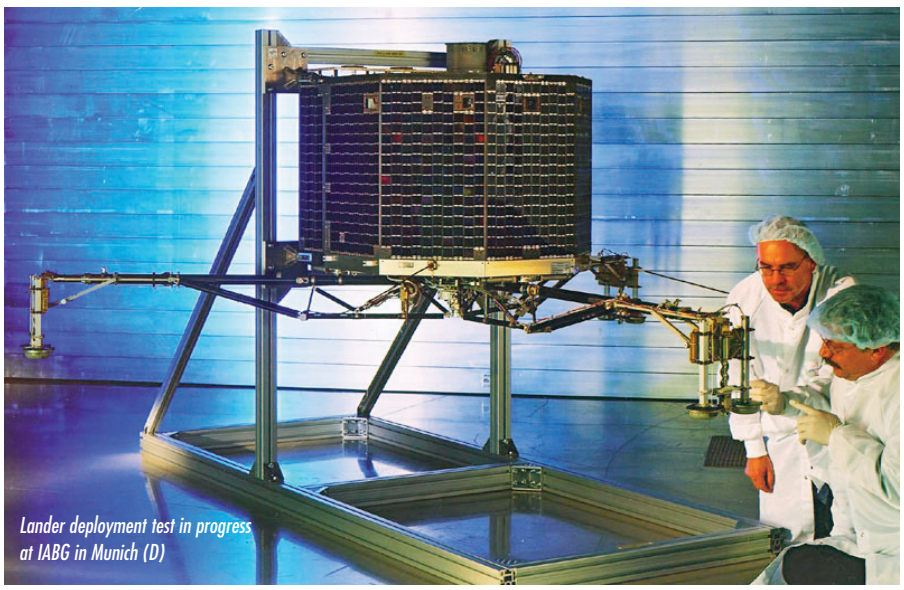
In the case of Wirtanen, the biggest problem was avoiding a rebound – the spacecraft only had to bounce slightly and its momentum would overcome the weak gravitational hold of the comet's nucleus. For Churyumov-Gerasimenko, there were also concerns about a faster landing, which would produce a greater shock on impact, and about the stability of the Lander upon touchdown. In the worst-case scenario of a 'hard' comet surface, rough terrain and relatively high gravity, it was possible that the Lander could topple over.

Hoping to avoid the necessity of removing either the landing gear or the entire Lander from the Rosetta Orbiter, the design team carefully analysed the descent profile and decided that it would be possible to achieve a successful touchdown by making a fairly simple modification to the landing gear. The solution came in the form of a small bracket, known as a 'tilt limiter', that could be attached to the bottom of the Lander.

The limiter was designed by Astrium GmbH in collaboration with ESA and the Max-Planck-Institute in Lindau, Germany. By carrying out pendulum tests with a model of the landing gear, it was possible to simulate landing on a wall at different angles of approach, and to verify that the spacecraft could successfully touch down at speeds of up to 1.5 metres per second on a 10 degree slope, or up to 1.2 metres per second on a 30 degree slope. Computer simulations of landings were run in parallel by the Max-Planck-Institute in order to determine more accurately the landing performances for various surface characteristics, impact velocities and Lander attitudes. The tilt limiter was delivered to Kourou and mounted on the spacecraft landing gear on 30 September 2003.

"By restricting the angle at which the landing gear can flex on touchdown to only 3 to 5 degrees, we improve the damping effect and reduce the possibility of a rebound," explains Philippe Kletzkine. *"This excellent collaboration between ESA, industry and MPAe enabled us to adapt to the new mission very quickly and efficiently."*

No major changes are envisaged in the Lander's descent profile. Under the new mission scenario, the rendezvous will take place at 4 AU – further from the Sun than planned for Wirtanen. As a result, there will be more time available for the Orbiter's instruments to map the nucleus at high resolution and find a safe haven for the 100 kg Lander before its historic touchdown on the comet's pristine surface in November 2014. Another advantage over the original scenario will be the ability to send data back to Earth at a much higher rate, since the Rosetta Orbiter will be nearer to Earth during the close encounter.



Lander deployment test in progress at IABG in Munich (D)

The Race Against Time – Part 2

Once the decision was made to ground Rosetta only weeks before completion of its launch campaign, engineers had to ensure that the spacecraft could be stored safely and cleanly until a new launch date was agreed. It was carefully moved to the empty S3B clean room in Kourou and a number of safety precautions were undertaken, including removal of the needle-sharp explosive harpoons on the Lander, the high-gain antenna and the huge pair of solar arrays. The mission team also decided to remove and refurbish five of the instruments on the Orbiter.

One of the main concerns was how to deal with the fully fuelled spacecraft. Eventually, it was decided to offload the 660 kg of monomethyl hydrazine (MMH) fuel, but leave the nitrogen tetroxide oxidiser on board in order to avoid potential corrosion of the titanium tanks.

With the new target comet now confirmed, the team also had to revalidate all flight system software in order to meet the requirements of the revised mission, and also to revalidate all flight system testing.

Fuel being offloaded from the Rosetta Orbiter after the first launch's postponement

"We had already prepared some software for uplinking to Rosetta in May, four months after its planned launch, so we decided to take advantage of the delay to include additional functionality and put the new software onboard the spacecraft while it was still on the ground," explains Jan van Casteren, Rosetta System Engineering Manager.

Other modifications had to be made to allow for the fact that during its monumental trek Rosetta would at various times be closer to the Sun or further away from it than originally planned.

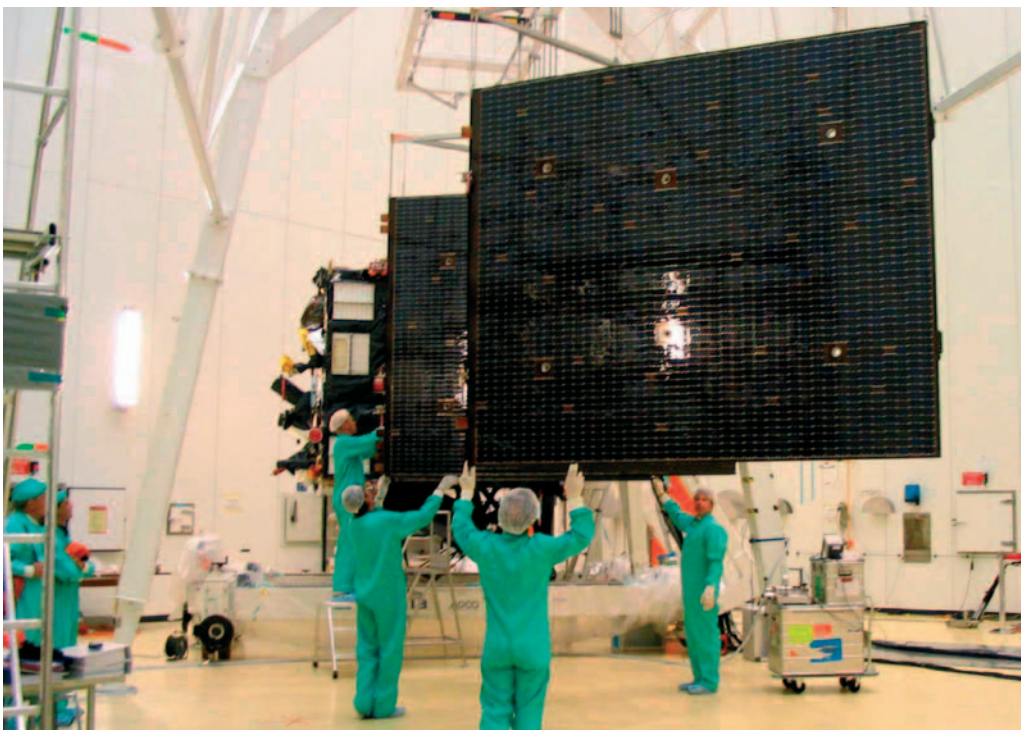
"We put reflective surfaces on the exterior of some thermal blankets to prevent overheating," explains Jan van Casteren. *"We also had to analyse the potential impact of spending longer in space during a period of maximum solar activity. By accumulating a larger overall dose of radiation, there was a likelihood that the solar arrays would be degraded more quickly, so we carefully studied the power situation to ensure that we would have a sufficient margin throughout the mission. This gave us confidence that Rosetta will have enough power even when it is beyond the orbit of Jupiter."*

Finally, the Launch Preparation Readiness Review Board gave the go-ahead for the start of the launch campaign on 24 October 2003. Over the next few weeks, the Orbiter took on a more familiar appearance as the high-gain antenna and the solar wings were reinstalled, and the thermal blankets were carefully sewn back into place.

The most critical milestones were scheduled for after the Christmas break. In late January, the Orbiter's tanks were to be loaded once again with MMH fuel and re-pressurised. Two weeks later, Rosetta is scheduled to be moved to the Final Assembly Building (BAF) for mating with the Ariane-5 booster.

Installation of the protective fairing on 18 February is to be followed by the launch countdown rehearsal and transfer of the launch vehicle to the ELA-3 pad on 24 February. The launch window lasts from 26 February until 17 March but, if all goes according to plan, Rosetta should begin its monumental trek to comet Churyumov-Gerasimenko at 08:16 CET on 26 February.

"The delay presented us with our second race against time to meet a launch deadline," says Claude Berner, Rosetta Payload and Operations Manager. *"This meant that we were faced with some unexpected challenges and risks, particularly in dismantling a flight-worthy spacecraft, but the ESA-Industry team has successfully overcome all of the obstacles and we are on track for a February launch."*



Remounting of the solar arrays in Kourou

Great Expectations

Despite the modifications mentioned above, most aspects of Rosetta's expedition to explore one of the most primitive objects in the Solar System have changed little over the past 12 months. After its launch from Kourou in February 2004, the 3 tonne spacecraft will be inserted into an elliptical, 4000 km x 200 km trajectory around the Earth. After about two hours, the Ariane-5 upper stage will be ignited to send the unique comet chaser on its way.

In order to gain enough orbital energy to reach its target, one gravity assist from Mars and three from Earth will be required. The first planetary encounter will take place in March 2005, when Rosetta returns to Earth's vicinity for its initial orbital slingshot. Three years after launch, the spacecraft will fly past Mars, before completing its second Earth encounter in November 2007.

With its orbit now substantially more elongated, Rosetta will enter the asteroid belt prior to its third and final visit home in November 2009. Only then will it have picked up sufficient velocity to leave the inner Solar System behind and set course for the distant comet.

At present, the amount of science that can be conducted during the 10-year trek to comet Churyumov-Gerasimenko remains uncertain. The previous flight plan en route to comet Wirtanen included observations of Mars and two very unusual main-belt asteroids. Under the revised mission scenario, Rosetta will experience an eclipse during the Mars flyby, so limiting the scientific observations that can be made. However, there is likely to be at least one opportunity to study an asteroid at close quarters, and a number of possible candidates have already been identified. The final selection will be made after launch, once the mission team has determined how much surplus fuel is available.

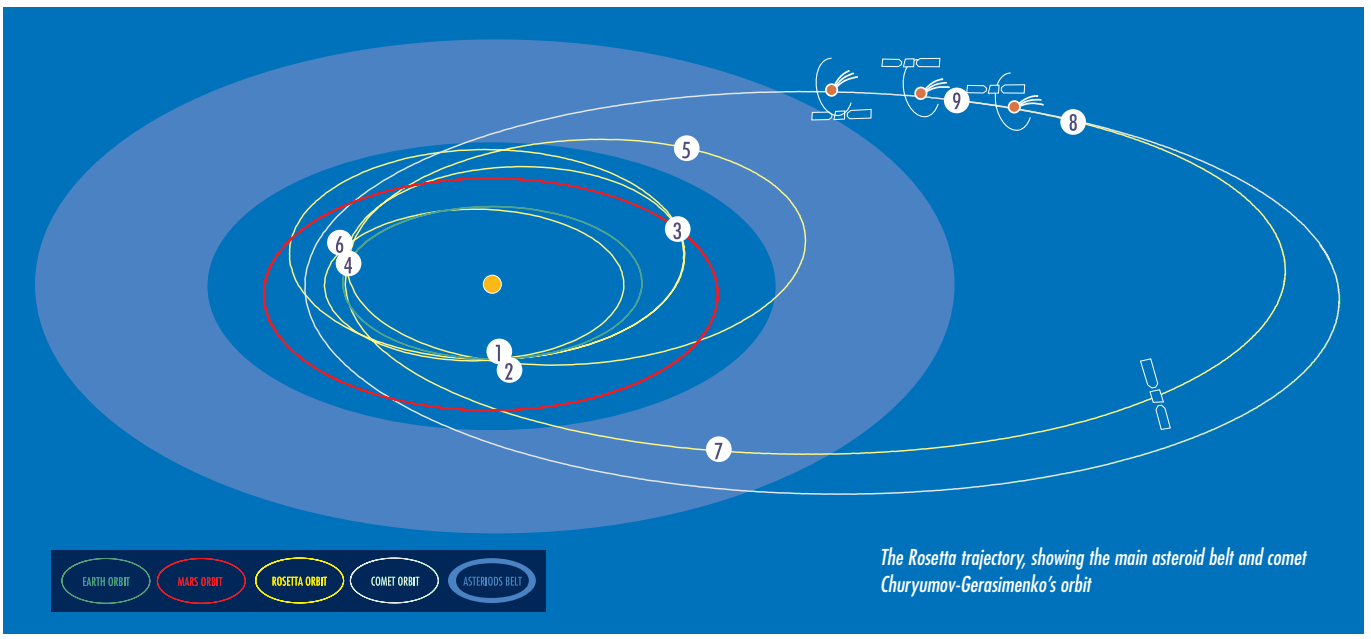
Since Rosetta will be launching to Churyumov-Gerasimenko with the same amount of oxidiser and fuel that it was carrying to Wirtanen, the mission team had to examine the spacecraft's propellant margins very carefully. Of particular concern was the extended thruster firing that will be required to rendezvous with the comet.

"We do not have too much fuel to spare," explains John Ellwood, the Rosetta Project Manager. *"Our capability to target one or more asteroids will depend on the efficiency of the launch and how much fuel we will need to conduct orbital manoeuvres and course corrections, so no decision will be made until after lift-off."*

Finally, after more than seven years of interplanetary travel, Rosetta will fire its thrusters to alter course towards comet Churyumov-Gerasimenko and then cross the orbit of Jupiter, some 800 million kilometres from the Sun. Handicapped by the low levels of sunlight – 25 times less than on Earth – Rosetta will be operating on minimal electrical power and relying heavily on its huge solar wings to capture every photon. However, as it begins to head sunwards and close in on the dormant nucleus, power levels will gradually rise. By the time the second rendezvous manoeuvre burn takes place in May 2014, the electricity supply will be adequate for operation of the suite of 11 scientific instruments.

Once its target's position is pinpointed, Rosetta will edge towards the speeding comet, eventually braking into orbit around the coal-black nucleus in August 2014. From an altitude of just a few kilometres, its cameras will map the pockmarked surface at high resolution and search for suitable landing sites.

Once the surface of the comet's nucleus has been surveyed in unprecedented detail and a safe landing site has been selected, the Lander will separate from the Orbiter and slowly descend to the comet's surface.



The Rosetta trajectory, showing the main asteroid belt and comet Churyumov-Gerasimenko's orbit

Comet 67P/Churyumov-Gerasimenko

Comet 67P/Churyumov-Gerasimenko photographed by the European Southern Observatory (ESO)

Rosetta's new target, comet 67P/Churyumov-Gerasimenko, is one of more than 150 comets that follow fairly predictable, short-period paths around the Sun. It was discovered as recently as 1969, when several astronomers from Kiev visited the Alma-Ata Astrophysical Institute to conduct a comet survey.

On 20 September, Klim Churyumov was examining photographs of comet 32P/Comas Solá, taken by Svetlana Gerasimenko, when he found a fuzzy feature near the edge of the plate. At first, he assumed that the faint object was the expected periodic comet, but upon returning to Kiev, he studied the plates very carefully and eventually realised that a previously unknown comet had been found, less than two degrees from comet Comas Solá.

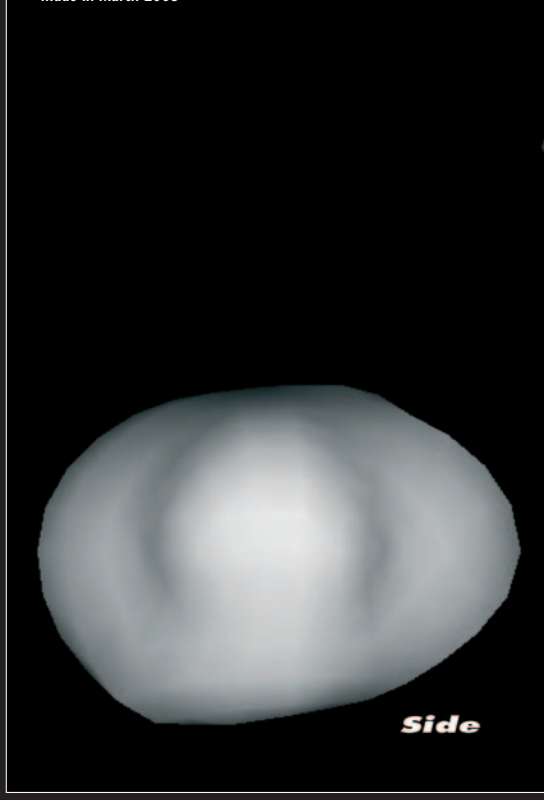
Comet Churyumov-Gerasimenko has a particularly unusual history. Up to 1840, its perihelion distance was 4.0 AU (four Sun-Earth distances or about 600 million km) and the comet was completely unobservable from Earth. Then a fairly close encounter with Jupiter caused the comet's orbit to move inwards to a perihelion distance of 3.0 AU (450 million km). Over the next century, the perihelion gradually decreased further to 2.77 AU. Then, in 1959, a further Jupiter encounter reduced it to just 1.28 AU.

The comet's orbit is still evolving and, after another perturbation from Jupiter in 2007, the perihelion at the time of Rosetta's encounter in 2014 is expected to be only 1.24 AU (186 million km). It currently completes one orbit of the Sun in approximately 6.6 years.

The comet has now been observed from Earth on six approaches to the Sun - 1969 (year of discovery), 1976, 1982, 1989, 1996 and 2002. Unusually active for a short-period object, it displays a coma (a diffuse cloud of dust and gas surrounding the solid nucleus) and often a tail at perihelion. During the 2002-2003 apparition, the tail was up to 10 arcminutes long, with a bright central condensation in a faint extended coma. Even 7 months after perihelion the tail continued to be very well developed, although it subsequently faded rapidly. The comet typically reaches a maximum magnitude of around 12, usually as the result of marked bursts of activity at perihelion, observed during three of its last four returns.

Despite being a relatively active object, even at the peak of outburst the dust production rate is some 40 times lower than for 1P/Halley. The peak dust production rate in 2002-03 was estimated at approximately 60 kg/s, although values as high as 220 kg/s were reported in 1982-83. The ratio of gas/dust emission is thought to be approximately 2.

A model of comet Churyumov-Gerasimenko's nucleus derived from the Hubble Space Telescope observations made in March 2003



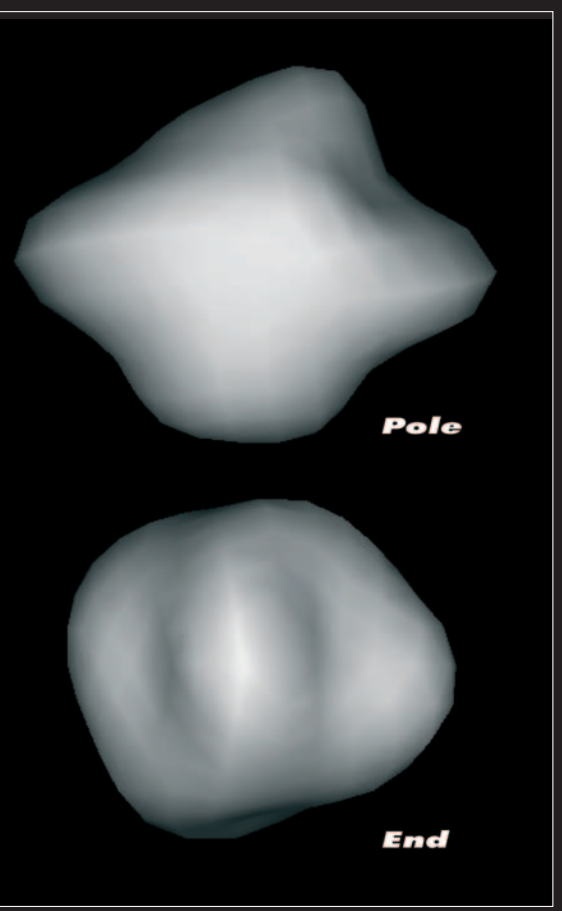
Facts about Comet 67P/Churyumov-Gerasimenko

Diameter of nucleus (km)	5 x 3
Orbital period (years)	6.57
Perihelion distance from Sun in 2014	186 million km (1.24 AU)
Aphelion distance from Sun	858 million km (5.74 AU)
Orbital eccentricity	0.632
Orbital inclination (degrees)	7.12
Year of discovery	1969
Discoverers	Klim Churyumov, Svetlana Gerasimenko


Klim Churyumov

In an effort to improve our knowledge of the nucleus, 61 images of comet Churyumov-Gerasimenko were taken with the Wide Field Planetary Camera 2 on the Hubble Space Telescope between 11 and 12 March 2003. The HST's sharp vision enabled astronomers to isolate the nucleus from the coma and to discover that the comet's icy heart is ellipsoidal in shape, measuring about five by three kilometres. It rotates once in approximately 12 hours.

"Although 67P/Churyumov-Gerasimenko is roughly three times larger than the original Rosetta target, its elongated shape should make landing on its nucleus feasible, now that measures have been taken to adapt the Lander package to the new configuration," says Philippe Lamy of France's Laboratoire d'Astronomie Spatiale.

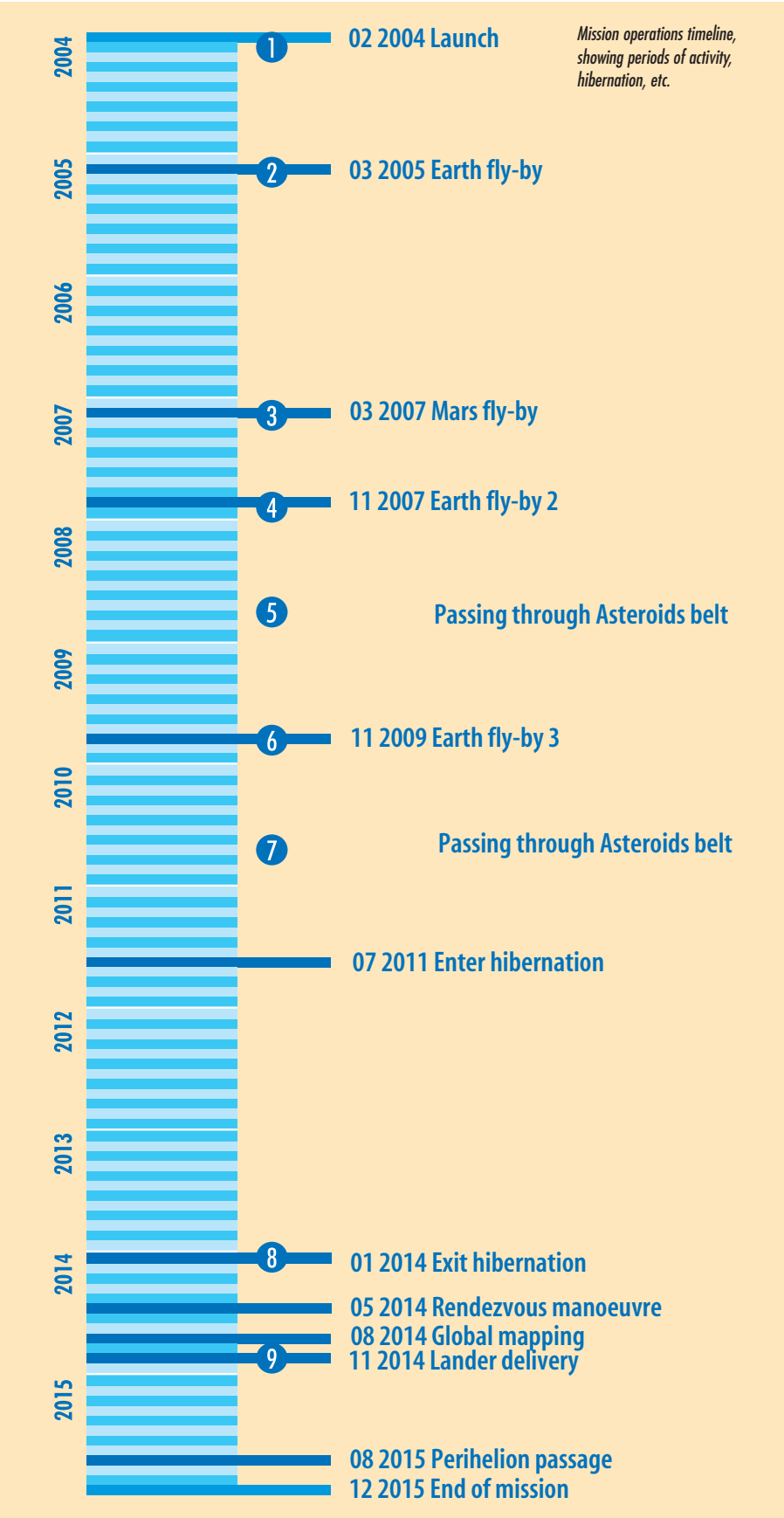


If all goes according to plan in November 2014, the Lander will anchor itself to the icy crust and begin a detailed survey of its surroundings. Over the next few months, it will provide a unique opportunity to conduct in-situ studies of a comet's nucleus – its temperature, composition, density and other properties. Even the internal structure of the dirty snowball will be probed as radio waves are passed through the comet nucleus from the Orbiter to the Lander and back again.

For the scientists, this 'ground truth' data will provide invaluable validation of the remote observations sent back by the Orbiter as its sweeps to within a few kilometres of the pockmarked nucleus. Over a period of about 18 months, the 11 experiments on the Rosetta Orbiter will examine every aspect of comet Churyumov-Gerasimenko during its high-speed journey towards the Sun.

According to the Rosetta Project Scientist, Gerhard Schwehm, it should be an exciting time for all concerned: *"Ground observations have shown that the comet becomes active at around 3 AU (about 450 million km from the Sun)," he says. "We see a lot of jets and surface activity with considerable structure in the coma. Since Churyumov-Gerasimenko has only made a few passes through the inner Solar System, it is still a fairly fresh, active comet, which produces a lot of gas and dust. By flying alongside it for more than a year, we will be able to observe the dramatic transformation that takes place as it is warmed by the Sun. It will also be intriguing to see how the activity dies down after it passes perihelion and begins the outward leg of its orbit. Working in unison, the Lander and the Orbiter will revolutionise our understanding of comets, leading to amazing discoveries about the most primitive building blocks of the Solar System."*

In particular, the enormous flood of data returned during Rosetta's remarkable voyage will provide new insights into such fundamental mysteries as the formation of Earth's oceans and the origin of life. It may even help the human race to survive in the long term. By transforming our understanding of the Solar System's icy wanderers, Rosetta will tell us more about how to deal with the threat from one of these unpredictable intruders that might one day head our way.



Mission operations timeline, showing periods of activity, hibernation, etc.

"We may separate at a lower altitude, since this means less acceleration," says Philippe Kletzkine. *"We anticipate a maximum separation speed of just 0.5 metres per second, so the overall descent time is likely to be between 30 minutes and 1 hour. We anticipate a landing on the 'summer' side of the nucleus, where there is maximum illumination."*

Over a period of several weeks, a treasure trove of data from the nine instruments on the Lander will be sent back to Earth via the Orbiter. For the first time, scientists will be able to study close-up pictures, drill into the dark organic crust, sample the primordial ices and gases, and probe the internal structure of the 4.5 billion-year-old celestial snowball.

Meanwhile, the Orbiter will continue to survey the dramatic changes in the nucleus during its headlong plunge towards the inner Solar System. Since Churyumov-Gerasimenko typically becomes much more active than Wirtanen, scientists expect to observe at close quarters for the first time the remarkable transformation of a comet from a tranquil iceberg into a world of turmoil. In particular, as its ices sublimate, bright jets will appear, ejecting gas and dust into space to create a coma

The New Norcia ground station in Western Australia. Rosetta operations will be controlled from ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany. Signals from the Orbiter will be relayed to ESOC via the 35 metre antenna at New Norcia and a similar one that is currently under construction at Cerebros in Spain

and a distinctive, diaphanous tail that stretches for vast distances in the anti-sunward direction.

Despite Churyumov-Gerasimenko's generally more active nature, the dust environment close to the comet is probably little more hazardous for the spacecraft than it would have been in the vicinity of comet Wirtanen. Churyumov-Gerasimenko's larger perihelion distance means that its nucleus is heated less strongly by the Sun, so limiting the output of gas-laden dust that could threaten the Orbiter.

Rosetta's unique odyssey of exploration will terminate in December 2015, six months after the comet passes perihelion – its closest point to the Sun – and begins its retreat to the more frigid regions of Jupiter's realm. After a dramatic saga lasting almost 12 years, the curtain will fall on the most ambitious scientific mission ever launched by Europe. But, for the scientists, the work will only just be beginning !

The Rosetta Lander